# Distribution and Status of Acroporid Coral (Scleractinia) Populations in Puerto Rico

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## ABSTRACT

Acroporid corals were important components of shallow fore reef and lagoonal habitats in coral reefs of the tropical western Atlantic and the Caribbean. An epizootic event of white-band disease (WBD) in the early 80's, produced extensive mass mortality of both species throughout their distribution range in the wider Caribbean. As a result, there were significant changes in community structure, loss of habitat and biodiversity. In the late 70's, extensive thickets of elkhorn coral *Acropora palmata* were present in 40 % of 35 reef localities surveyed around the island of Puerto Rico. Another 20 % of these reefs had dense patches and abundant colonies of staghorn coral *A. cervicornis*. The hybrid *A. prolifera* was present in many localities but it rarely formed dense thickets. Surveys of more than 100 coastal and offshore localities around the island during the last 20 years indicate a significant decline in populations of both species in most localities and recovery in others. Most of the high profile, dense thickets that formed the *Acropora* zones have disappeared, and only a few reefs localities, mostly in the southwest coast, have healthy, high density populations of *A. palmata*, *A. cervicornis* and *A. prolifera*. The primary cause of this significant decline in distribution and density of populations was the widespread white band disease (WBD) epizootic event of the early 80's. In following years however, surviving populations and colonies where hit by hurricanes, storms, bleaching, more disease, and an increasing deterioration of the environmental conditions around coastal coral reefs due to anthropogenic activities. Other, long-term natural factors, such as snail and fireworm predation, and damselfish territorial behavior, have caused increasing tissue mortality and the pre-emptive competition of corals by filamentous algae. In recent years, patchy necrosis and substrate monopolization by an aggressive, endolytic sponge, *Cliona langae*, have become important factors in the loss of live tissue in *A. palmata* along the southwest and west coasts, and the offshore islands. Deterioration of local environmental conditions (high sedimentation and turbidity), the occasional hurricane, persistent disease, and predation by snails and fireworms cause significant mortality in *A. cervicornis* and *A. prolifera*. Today however, signs of recovery can be observed in few localities for *A. palmata* and *A. cervicornis* mostly. Few extensive fields, abundant thickets, high densities of small colonies, and most importantly, many sexually produced recruits can be observed in many localities of the southwest coast and offshore islands. New protective legislation by the Department of Natural Resources in combination with the presence of healthy populations, the high growth rates of these species, and new sexual recruitment may provide a chance for some recovery in many localities.

[1]Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

## 1. Historical perspective

Acroporid corals (*A. palmata* and *A. cervicornis*, and to a lesser degree, *A. prolifera*) were important components of shallow fore reef and lagoonal habitats in coral reefs of the tropical western Atlantic until the late 70's and early 80's. These species formed the famous *Acropora* zones, dense stands of high profile, spatially complex, monospecific thickets in shallow and intermediate depths in most Caribbean coral reefs (Vaugham, 1919; Goreau, 1959; Lewis, JB, 1960, 1965; Scatterday, JW, 1974; Ross, PJ, 1964, 1971; Glynn, 1973; Colin, 1978). In the late 70's and early 80's, a white-band disease (WBD) epizootic event caused extensive mass mortality of these species throughout their range with losses up to 95% (Gladfelter, 1982). The demise of *Acropora* spp. has resulted in significant changes in community structure, loss of habitat and biodiversity (Aronson and Precht, 2001). In many localities, acroporids have disappeared as a consequence of regional disease outbreaks, compounded locally by hurricanes, bleaching events, and a overall deterioration of local environmental conditions.

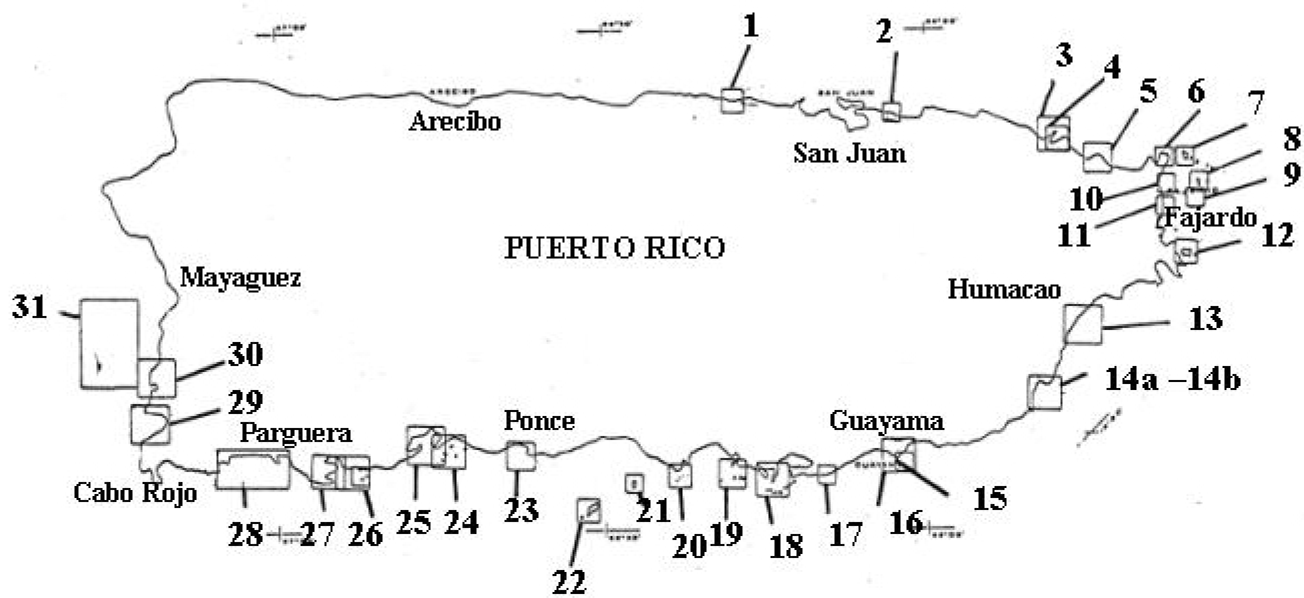
In Puerto Rico, Acroporid coral populations have declined significantly over the last two decades in almost all reef localities where they were formerly abundant. Dense and well developed thickets of both *A. palmata* and *A. cervicornis* were present on many reefs, patch reefs and shelf edge localities off the north-east, east, south, west and north west coast, and also the offshore islands of Mona, Vieques and Culebra (Fig. 1) (Almy and Carrión-Torres, 1963; McKenzie and Benton, 1972; Rogers, 1977; Goenaga and Cintrón, 1979; Boulon, 1980). Goenaga and Cintrón (1979) conducted island-wide surveys of 35 localities in 1978-79 (Fig. 1) and found 88% of all locations colonized by *A. palmata* and 52% by *A. cervicornis* colonies. Many reefs (40%) had high profile thickets with high colony densities, while 20-28% of the locations only had isolated colonies (Table 1).

**Table 1. Abundance of acroporids in 35 coastal locations of Puerto Rico in 1978-79. Adapted from Goenaga and Cintrón (1979).**

| Condition | *A.palmata* | *A.cervicornis* |
|---|---|---|
| High profile thickets/dense patches | 40% | 20% |
| High colony density and few patches | 20% | 6% |
| Isolated colonies | 20% | 28% |
| Absence of Acropora spp. | 12% | 48% |
| Live cover | 5-100% | |

Some reefs however, were already showing signs of anthropogenic impacts such as high siltation and turbidity (Goenaga and Cintrón, 1979). Today, evidence of these species remains in many locations where standing dead skeletons of *A. palmata* and rubble piles of *A. cervicornis* can be seen. With the exception of few reefs in the southwest and isolated offshore locations, the dense, high profile, monospecific thickets of both species have disappeared from Puerto Rico coral reefs (unpublished data).

Although few long term data are available, the primary cause of the significant decline in population densities and distribution is thought to be an island wide outbreak of white-band disease in the early 1980's. In addition to disease, surviving colonies were hit by hurricanes and tropical storms, other types of disease, a concentration of predators, bleaching, and an increasing deterioration of the environment around coastal coral reefs due to anthropogenic activities (Table 2). For example, large stands of *A. palmata* on east coast reefs near Fajardo were decimated by WBD in the mid 1980's, and subsequently, hurricane Hugo (1989), caused almost total destruction to the remaining *A .palmata* thickets (Goenaga and Boulon, 1992). Hurricane David (1979) had devastating effects to *A. palmata* thickets on fore reef habitats throughout the south and west coast, with a high proportion of colonies being dislodged from the reef substrate and deposited onto the reef flat followed by high mortality (Vicente, 1993).




**<u>Figure 1</u>. Map of Puerto Rico showing major coral reef areas surveyed (lines) by Goenaga and Cintrón (1979).**

Then WBD hit in the early 80's and up to 30% of the colonies were reported to be affected in many reefs (Davis et al., 1986). During the 1990's a number of other coral reef areas (i.e., Islote Palominitos, Los Corchos Reef, Cayo Dákity, Playa Larga, Culebra) showed severe physical destruction of the *A. palmata* framework and *A. cervicornis* thickets as a result of several hurricanes [Louis (1995), Marilyn (1995), and George's (1998)] (Goenaga, 1990; Hernandez-Delgado, 2000). In the nineties WBD continues to affect *Acropora* populations throughout Puerto Rico, but disease prevalence is generally low (Bruckner et al., 1997; Bruckner and Bruckner, 1997, 2001; Williams et al., 1999; Weil et al., 2000; Weil, 2002). For instance, in one of the outer reefs studied by Davies (1986), remaining Acroporid populations were reported to have WBD on 8.5% of the living colonies by 1993 (Williams et al., 1999). In the absence of compounding impacts from disease and other factors, like those observed in the 1960's and 1970's, *Acropora* populations in Puerto Rico generally recovered from hurricane damage. Coral fragments produced by hurricane Edith in the early 1960's were observed to reattach and recover in many localities in the southwest (Glynn et al., 1964).

Other natural factors, such as damselfish (Pomacentridae) territorial behavior, are causing increasing tissue mortality and the pre-emptive competition of corals by filamentous algae (Hernández-Delgado, unpublished data). In addition, coral bleaching was documented in *Acropora* spp. in 1987, 1989, 1990, 1995 and 1998 (Williams et al., 1987; Goenaga et al., 1989; Goenaga and Canals, 1990; Winter et al., 1999; Weil, 2000), but associated mortality was not reported. Localized anthropogenic impacts (i.e., historic coral collection for souvenirs, reef trampling, snorkeling, SCUBA diving, anchoring, some fishing methods) have also caused some destruction of corals around Fajardo (Mckenzie and Benton, 1972; Torres, 1975; Hernández-Delgado, 1992). Ship groundings have caused significant mechanical destruction of *Acropora* assemblages in Los Corchos, Culebrita Island, Islote Palominitos, off Fajardo (Hernandez-Delgado, 2000), Guánica and Mona island (Bruckner and Bruckner, 2001). Military activities have caused some damage also in Culebra and Viéques (Antonious and Weiner, 1982; Hernández-Delgado, pers. obs.).

With few exceptions, most of these impacts have never been quantified. For example, quantitative information on the impact the Fortuna Reefer ship grounding in Mona island has been collected for over two years (Bruckner and Bruckner, 2001), the fates of storm generated fragments following Tropical storm Debbie and Hurricane Hortense in La Parguera were evaluated (Bruckner, unpublished data), and an ongoing project is evaluating the impact of Hurricane George's on *A. palmata* populations off La Parguera and Guánica (Ortiz, unpublished data). The impact of predation by the snail *Coralliophilla abbreviata* was assessed by Bruckner (2000). Ongoing anthropogenic degradation of coastal (urban development) and inland areas (deforestation) continue to affect the quality of the coastal reef environments (i.e. higher turbidity, high nutrient input, pesticides and herbicides, solid suspended material, high sedimentation rates, etc.), and may contribute to the decline of acroporids and coral reefs in general (Goenaga and Boulon, 1992; Hernandez-Delgado, 1992, 2000; Morelock, 2001).

## 2. Current status

Although there is very limited quantitative data regarding the current ecological status of Acroporids in Puerto Rico, a wealth of qualitative observations and information on their distribution and relative abundances have been collected over the years for many coral reefs in the east, southwest and west coasts, and some of the offshore islands. These data are good baseline information and provides a picture of the current status of Acroporid populations. Recent surveys of over 100 reefs along the coast and islands, indicate that Acroporid populations have continued to decline in some areas from persistent disease, storms, and sedimentation coupled with the poor coastal environmental conditions (high turbidity, sub-optimal water quality, etc.) and algal overgrowth (Appendices 1 and 2 ).

Many environmentally-degraded fringing coral reefs along the shoreline of Puerto Rico (i.e., Punta Picúa, Punta Miquillo; Río Grande, Guánica, La Parguera, Mayagüez) show large stands of dead *A. palmata* in their upright, growth position, suggesting mortality resulted from factors such as disease outbreaks, bleaching, siltation, algae competition, or a combination of any of these (Table 2), and not from physical damage associated with storms or hurricanes. Most frequently, total colony mortality does not occur from these factors, and high growth rates, capacity for tissue regeneration, asexual reproduction, and high survivorship of storm-generated fragments, seem to be playing an important role in maintaining some populations. A recent event of patchy necrosis in southwest reefs produced moderate levels of partial tissue mortality in a high proportion of colonies in a relatively short period of time (November 13-18, 2002). On average, between 35 and 74 % of all colonies of *A. palmata* in six reef areas were affected by this syndrome (Fig. 2). Average tissue loss varied between 14 and 17% of the colony surface area (Fig. 3) (Weil and Ruiz, unpublished data). This event happened after a period of extreme calm weather and seas

Table 2. Historical and current causes of tissue mortality (partial and/or total) of acroporid corals in Puerto Rico. Question mark indicates that factor needs to be verified.

| Natural factors | Species | Anthropogenic Factors | Species |
|---|---|---|---|
| | | | |
| **Disease** | | **Siltation** | Ap, Ac |
| White band-I and II | Ap, Ac | **Pollution** | Ap, Ac |
| White plague ? | Ap, Ac | **Ship and boat groundings** | Ap, Ac |
| Black band | Ac | **Eutrophication** | Ap, Ac |
| **Bleaching** | Ap, Ac | **Floating debris** | Ap, Ac |
| **Patchy necrosis** | Ap | **Divers** | Ap, Ac |
| **Predation** | | **Anchors** | Ap, Ac |
| Snails | Ap, Ac | | |
| Fireworm | Ac | | |
| Parrotfish | Ap | | |
| Damselfish | Ap, Ac | | |
| **Storms** | Ap, Ac | | |
| **Clionid sponges** | Ap | | |
| **Algae competition** | Ap, Ac | | |

that lasted for approximately 15 days. Tissue mortality could also be associated with high residence time of fish and sea turtle feces on the surface of *A. palmata* colonies. Almost all colonies affected by patchy necrosis showed rapid regeneration of the lost tissue a week after the mortality. Follow-up surveys up to August of 2002 of the tagged colonies that suffered mortality in November of 2001 show total (100% new tissue cover) recovery of tissue in 98 - 100% of the injuries in all tagged colonies. Injuries that have not completely recovered show active growth margins but, a layer of turf algae and sediment seem to slow down the advance of the new growth (Weil & Ruiz, unpublished data).

## 2.a. Eastern coast

Over 90 localities have been surveyed in the last decade by various authors along the northeastern and eastern region of Puerto Rico. Hernnadez-Delgado surveyed 86 sites and compared the information with previous reports from the same sites (Table 3) (Appendix 1). Data were geographically sub-divided into four main areas: northern inshore, eastern inshore, eastern offshore close (<6 km), and eastern offshore remote (>6 km). This classification was originally based on a Bray-Curtis ordination analysis for coral species presence/absence data sets to classify coral reefs (Hernández-Delgado, 2000). *A. palmata* was an important component of coral reefs and coral communities in most of the sites (93%) of four major localities surveyed prior to 1980 (Almy and Carrión-Torres, 1963; Pressick ,1970; Mckenzie and Benton, 1972; Goenaga and Cintrón, 1979; Goenaga and Vicente, 1990; Goenaga and Boulon, 1992; Hernández-Delgado, 1992; and unpublished data). Today, however, *A. palmata* has been observed only in 36.7 % of these sites, as one moves across an anthropogenic stress gradient of water transparency, sedimentation and concentration of suspended solid material (Hernández-Delgado, 2000). The northern inshore localities showed the highest decline (68.4 %) and the offshore remote reefs (>6 km) the lowest *A. palmata* has but disappeared from 62 % of the sites in northern and eastern Puerto Rico where it used to be found in high densities many years ago. Surveys conducted in 1998 in the southwest coast of Culebra and northwest coast of Vieques islands showed scattered colonies of *A. palmata* in good health in these localities (Weil et al., 1998). *A. palmata* was more abundant in Vieques and showed higher colony densities than in Culebra.

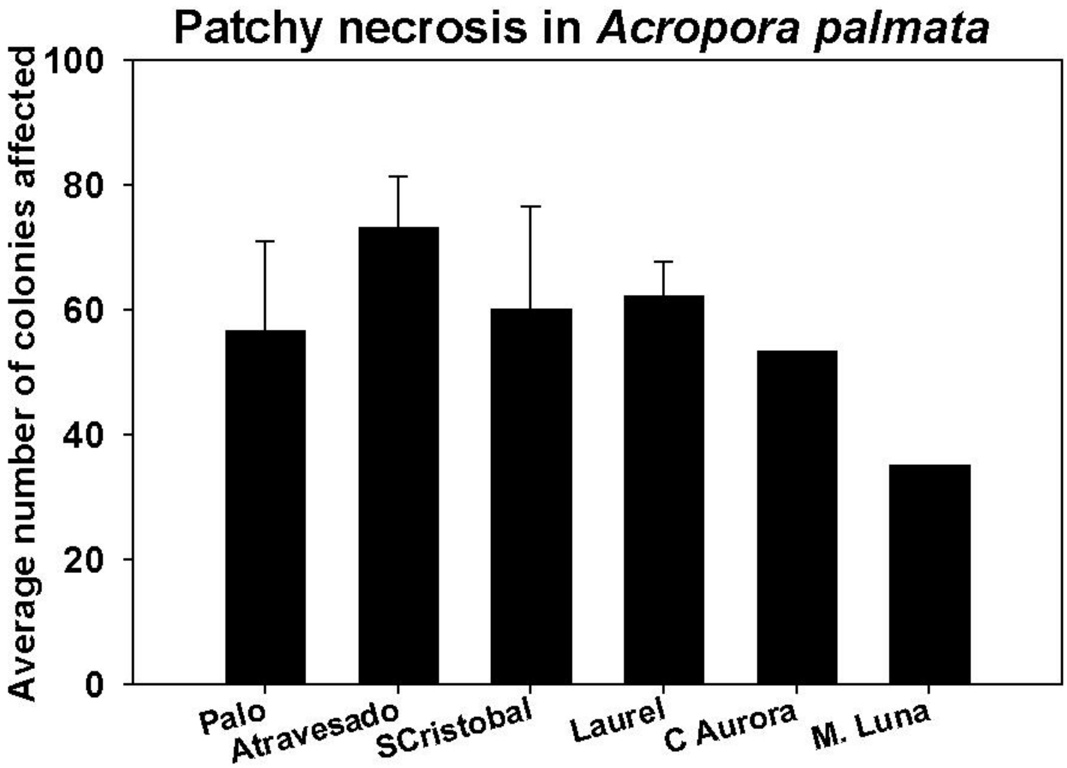



Figure 2. Average number of colonies of *A. palmata* affected by patchy necrosis in six coral reefs off La Parguera and Guánica. (Weil & Ruiz, unpublished data).

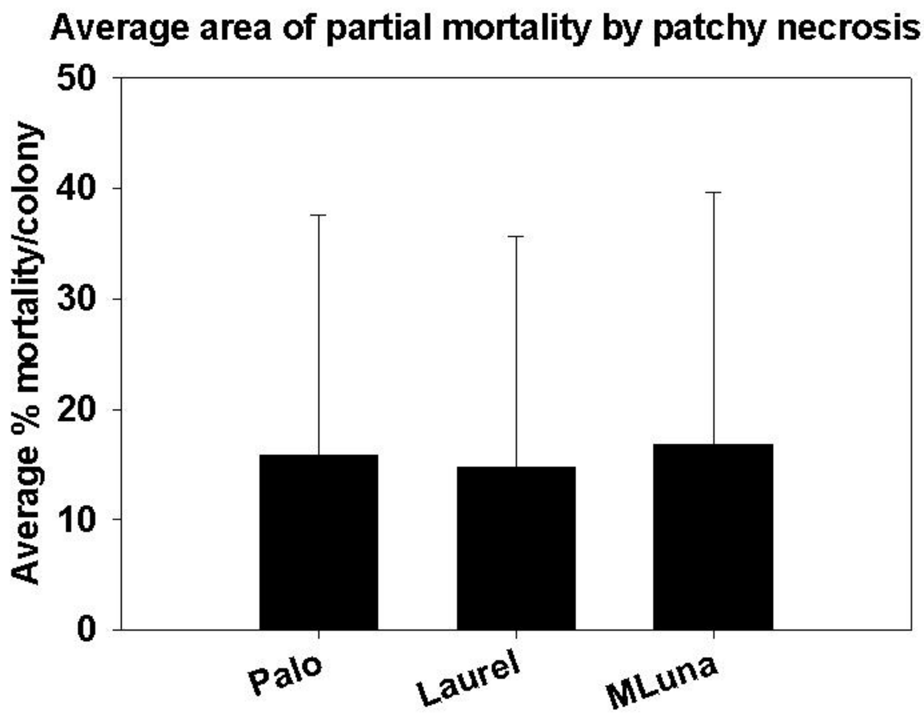
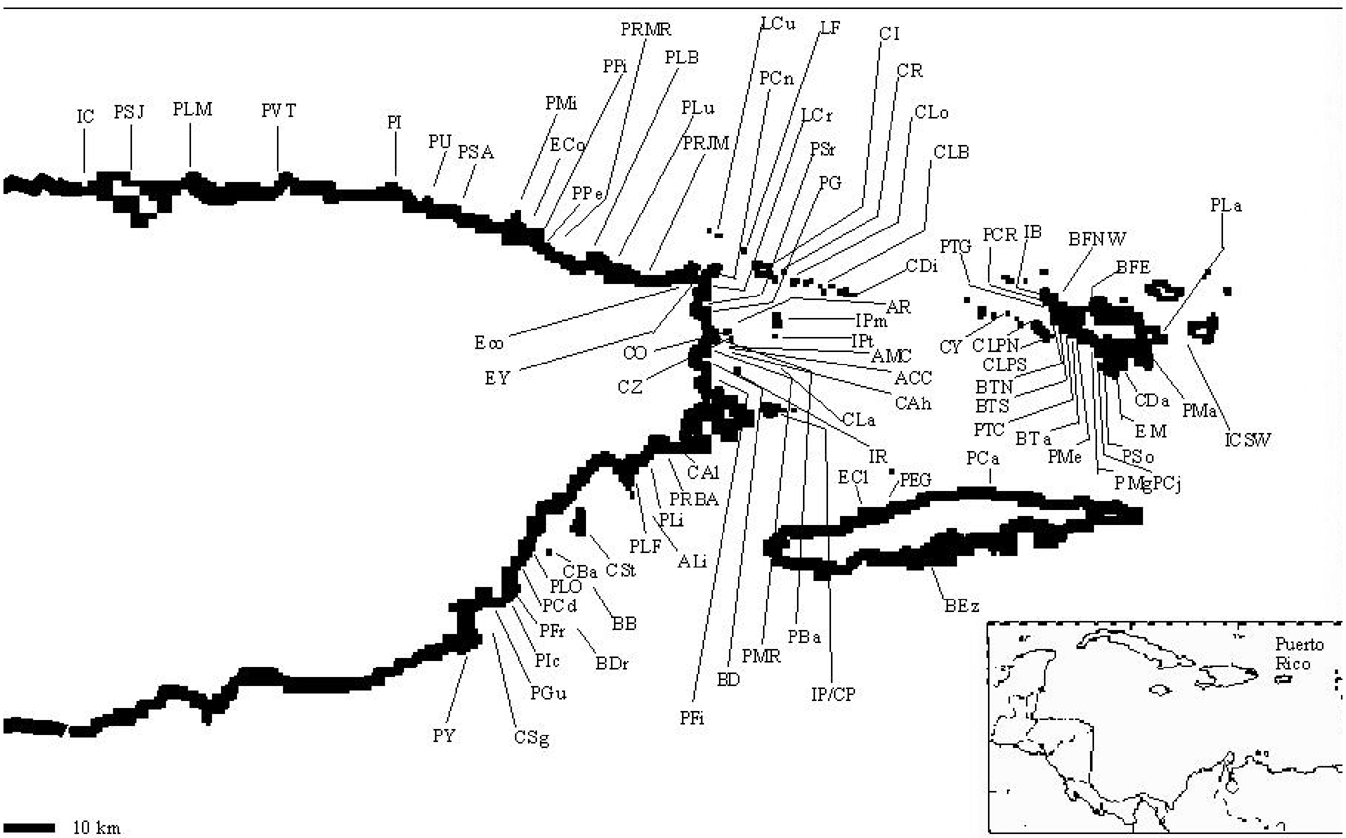



Figure 3. Average tissue loss in *A. palmata* by patchy necrosis in three coral reef areas with dense populations of the coral in La Parguera (Weil & Ruiz, unpublished data).

*A .cervicornis*, was documented from the northern and eastern reefs in past reports. It was present in 52.9% of the sites surveyed in the 1970's, but today, it is only found in 24% of these sites. It has disappeared from 43% of the eastern close offshore reefs, and from all the northern and eastern inshore sites. It is present in 100 % of the eastern offshore remote reefs, but it has decline in abundance. The hybrid *A. prolifera*, was rare in all of the four geographic localities. It disappeared from 100% of the northern reefs and from 60% of the eastern offshore close reefs. It disappeared also from 27% of the eastern offshore remote reefs. No colonies were ever documented in eastern inshore reefs. Recent surveys of two reefs in Culebra and northwest coats of Vieques islands, showed presence of isolated colonies and thickets of *A. cervicornis* (Weil et al., 1998) (Appendix 2). There were many small-sized thickets (10 x 5 m or less) of *A. cervicornis* in the southwestern side of Culebrita Island, but most of these where destroyed by recent hurricanes and disease outbreaks. Several isolated patches of *A. cervicornis* growing on Los Corchos Reef south of Culebrita Island are doing well (Hernández-Delgado, unpublished data). A WBD outbreak in August, 2001 caused partial to total colony mortality in 51% of the surveyed *A. cervicornis* colonies (n=118) within the Luis Peña Channel Marine Fishery Reserve, at Culebra (Hernández-Delgado, unpublished data). No current information is available for other localities in the the east coast of Puerto Rico or offshore islands. Low abundance of large mature colonies and low abundance or lack of juveniles, sexual recruits or reattached fragments is a clear indication that recovery is not occurring. Moreover, many recently dead colonies, and colonies showing partial tissue mortality are common sights in many of these localities. Despite the ability of Acroporid corals to regenerate tissue lesions (Matos-Caraballo, 1988) and grow fast, the combination of natural and anthropogenic factors may be preventing recovery in eastern reefs.

Figure 4. Map of the eastern section of Puerto Rico showing the location of 88 reef localities surveyed in the last 10 years. Many of these localities were surveyed in 1978-79 by Goenaga & Cintrón. List of localities can be found in Appendix 1. From Hernandez-Delgado (2000).



## 2.b. Southwest and western coasts

### *Acropora palmata*

With few exceptions, *A. palmata* occurs at low densities from 0.5-5 m depth throughout the south and southwest coast of Puerto Rico. Colonies continue to experience partial mortality in many localities, however. This species is now rare below 5 m, but it can still be found in few, deep patch reefs and some locations on the shelf edge. High densities of medium to large colonies are common in at least two exposed reefs in La Parguera (Laurel and San Cristobal), and dense, high profile thickets pave the exposed fore reef of Atravesado (Appendix 2) (Bruckner et al., 1997; Weil, pers. obs.). No *A palmata* thickets were observed in extensive surveys from La Parguera to Ponce between 1995-1997, but medium size and few large colonies are common in some locations. Colonies were widely scattered (<1 colony every 5 m), or corals occurred in aggregates of less than 4 colonies (Bruckner and Morelock, unpublished data). Prevalence of corallivores and disease was high (Bruckner, unpublished data). High mortality was associated with Hurricane Georges (1998), and over 90% of coral was removed from Laurel, Pinnacles, Media Luna and Turrumote reefs off La Parguera (Bruckner, unpublished data, Ortiz, unpublished data). In 1999, disease affected an average 1.3% of all colonies of *A .palmata* in Turrumote, Media Luna and Laurel reefs off La Parguera (Weil, 2002), an apparent decline from previous years. Average live cover of this species on most reefs near La Parguera is now low or less than 1% (Williams, et al., 1999; Weil, unpublished data; Bruckner, unpublished data).

A recent problem is the mortality of *A. palmata* colonies by the intrusive colonization and fast advance of a brown, endolytic, clionid sponge (*Cliona langae*) (Fig 5). This sponge monopolizes much of the exposed reef substrate that was formerly occupied by live *A .palmata,* and it rapidly overgrows standing colonies and fragments. In 1999, an average 16 % of all colonies of *A. palmata* from three reefs in La Parguera, were attacked by the sponge. Average coral tissue mortality rate was 9 cm/year, which is faster than the coral's growth rate (Weil, 1999a,b and unpublished data). The sponge is resilient and in almost all cases, it kills the colony within a short period of time.

Small elkhorn coral thickets still occur on the west coast of Puerto Rico near Rincón (Steps Reef) and the northwest coast near Isabela (Shacks Reef) in 1-2 m depth. These populations were largely unaffected by disease or predation between 1994-1997 (Bruckner, pers. obs.). Unpublished data from August 1999 indicate that elkhorn thickets on fringing reef near Rincón (Tres Palmas and Steps) were still in excellent condition (EarthWatch report, 1999).

*A. palmata* has been virtually eliminated from other reefs near shore reefs of the west coast, especially near Mayagüez, possibly from anthropogenic disturbances (Morelock & Bruckner, unpublished data). One of the largest remaining healthy stands of elkhorn coral is located in 3-5 m deep in Bajo Gallardo reef, 13 km off the west coast. Coral disease outbreaks were observed during 1996 and 1997, however live coral cover remained high (30-90%), with corals in good shape with low incidence of recent mortality. Like many other shallow populations, this one was hit hard by Hurricane Georges, but remaining colonies and fragments recovered and/or reattached to the reef and were actively growing in 1999 (Earthwatch report, 1999).

Shallow areas of La Parguera were also hit hard by Georges, and in some areas nearly all *A. palmata* colonies were removed (Bruckner, pers. obs.). However, several reefs including Laurel and San Cristobal had a high number of remaining fragments which exhibited substantial growth by February of 1999 (Fig. 6) (Weil, pers. obs., Ortiz, unpublished data). Most colonies damaged by the Hurricane are now recovering

(Bruckner unpublished data, Earthwatch report, 1999; Ortiz, unpublished data). However, the survival of the fragments is being hampered by partial tissue mortality on the average of 46 % of the total live tissue in one year (Ortiz, unpublished data). Elkhorn coral thickets on fringing reefs near Rincón (Tres Palmas and Steps) were still in excellent condition in 1999, one year after Georges (Earthwatch report, 1999; Appendix 2). Populations of *A. palmata* on the southeast and west coast Mona island have been monitored in recent years. Two surveys in 1998 and two in 1999 indicate that in general, populations are in poor shape, with significant recent mortality, moderate-to-high incidence of disease, predation, algae and cyanobacteria overgrowth, and tissue loss caused by *Cliona* moving in (Bruckner, Earthwatch data, 1999; Bruckner and Bruckner, 2001; Weil, 1999a,b, unpublished data). Small thickets of *A. palmata* in fairly good shape exist to the north and south of the Fortuna Reefer restoration site in Mona island, although *Cliona*, patchy necrosis, white-band disease and neoplasia are affecting many of these colonies.

A recent study of the impact of snail predation on populations of acroporids indicate that they are playing an important role in the decline of acroporids in some reefs (Bruckner, 2000). Surveys of 12 reefs around La Parguera and the west coast found that snails were on 18 % of all colonies of *A. palmata* and that the average snail density on those colonies was 3.7 snails per colony. A larger proportion of colonies supported more snails in inshore reef habitats compared to exposed habitats. In some areas, up to 32 snails have been observed on a single colony. Also, larger snails have been recorded (which adds to more injury per snail) on *A. palmata* (Fig. 7) where they caused conspicuous feeding lesions and in several occasions, consumed entire colonies (Bruckner, 2000).

### *Acropora cervicornis* and *A. prolifera*

Populations of *A. cervicornis* off the southwest coast of Puerto Rico are continuing to be impacted by WBD, predation, and other factors such as the occasional storm, which can be devastating. In 1996, white-band disease affected 0.5-10% of the colonies in four locations in La Parguera (Bruckner and Bruckner, 1997; Bruckner, unpublished data); disease prevalence varied seasonally, with a peak infection in August and September. In 1999, average disease incidence for *A. cervicornis* was 1.15 % in three reefs off La Parguera (Weil, 2002), an apparent decline from previous years.

Although there has been a substantial decline of *A. cervicornis* populations near la Parguera, abundant isolated colonies or small thickets can be found in several fringing and patch reefs in the area. High growth rates and some recruitment appear to exceed mortality in some localities, and dense and extensive fields have been able to reestablish (San Cristobal, Turrumote, Atravesado). The largest thickets of *A. cervicornis* (50 x 100 m) and *A. prolifera* (approximately 10 x 10 m) in the area are located on a shallow (1-3 m) sandy platform fringing the back lagoonal area on the northwest side of San Cristobal. Isolated colonies occur in western Puerto Rico, but no extensive thickets are known to remain. Small and healthy colonies were recently observed in several localities on the western platform (El Ron, Cabo Rojo, El Negro, Turmaline, Buyé). No current information is available for other localities.

Mujeres reef is a deep fringing reef in the southwest coast of Mona island. An extensive and healthy field of *A. cervicornis* (approximately 3,500 $m^2$ located between 12 and 15 m deep) was first observed in 1996 (R. Bruckner and E. Weil, pers. obs.). This population had no disease, few damselfish algal lawns, and few corallivores. It remained in good health during three subsequent surveys (Weil, unpublished data) until Hurricane Georges hit the island. Surveys during 1999-2001 revealed few remaining live colonies (Earthwatch report, 2001). Isolated colonies and small thickets can still be found along the southwest coast of Mona and around Mujeres reef. Some recovery has been noted (Bruckner, pers. obs.). Several small

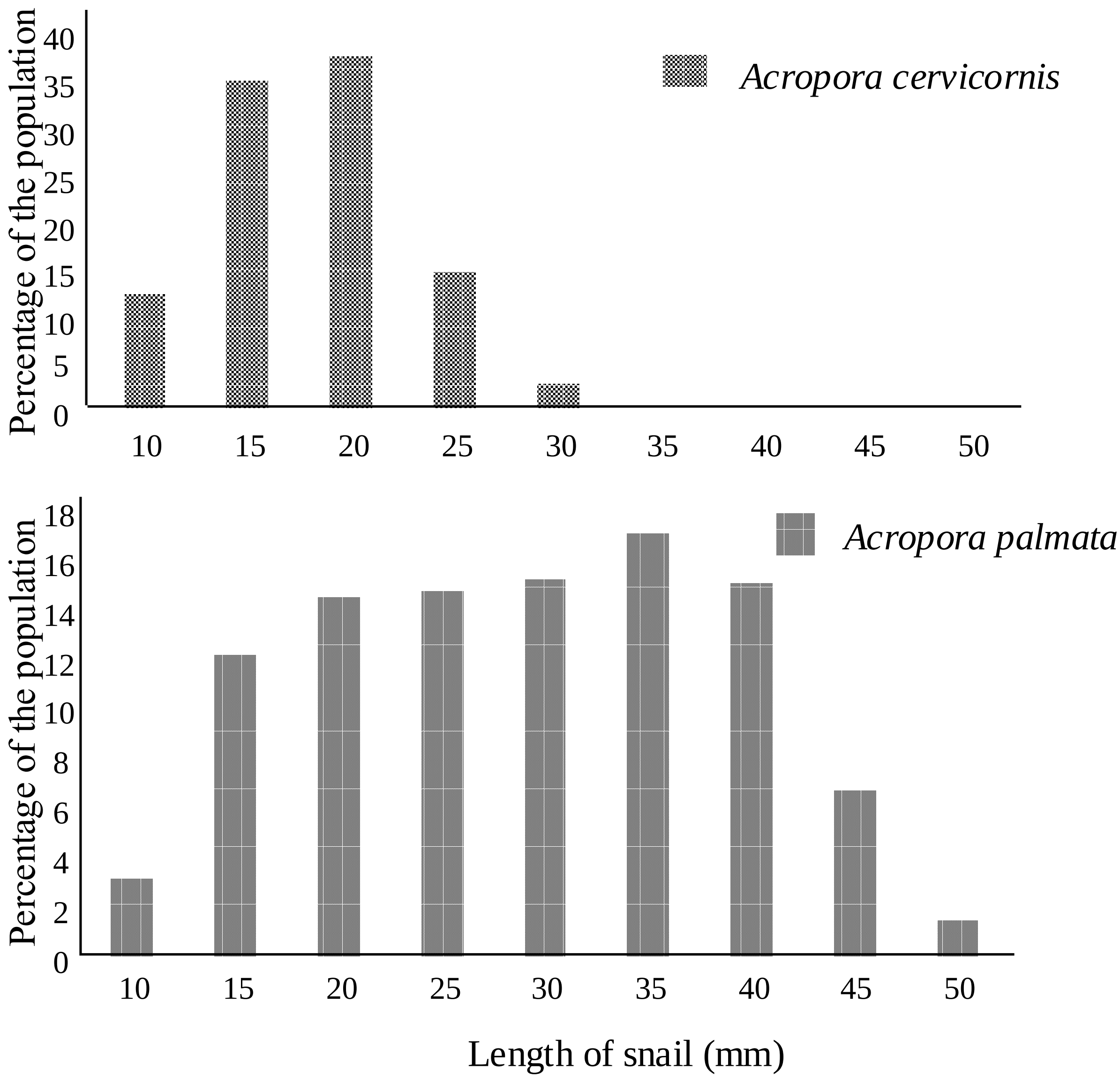



Figure 7. Shell length frequency distribution of *C. abbreviata* in acroporids from reefs off the southwest coast of Puerto Rico (from Bruckner, 2000).

colonies and few large colonies and small isolated thickets have been observed in surveys (1999-2002) conducted in the southwest coast of Desecheo island (3-22 m deep). Few of these were affected by WBD and no corallivores were observed. Significant accumulations of bioeroded and fouled *A .cervicornis* rubble in the area indicates that the species was abundant in the past (Weil, unpublished data).

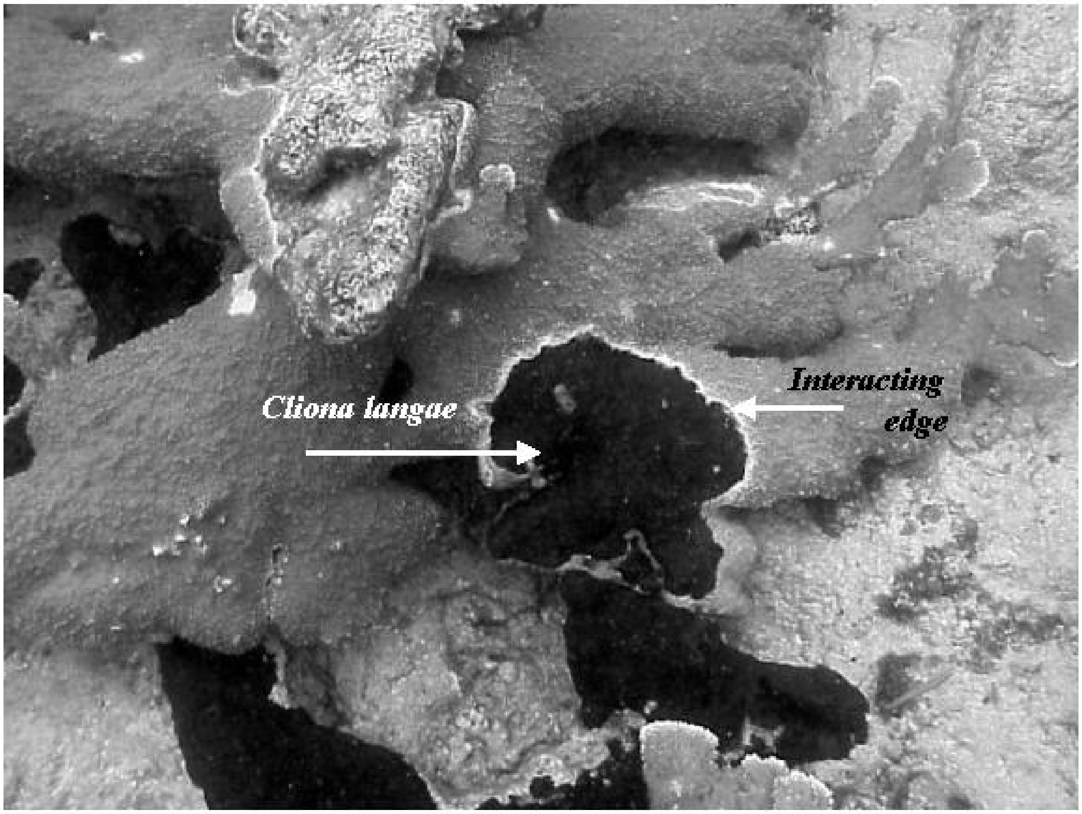
The Department of Natural Resources has conducted monitoring surveys in several reefs around Puerto Rico in the last three years. In 16 reefs surveyed in 2001, most of the transects sampled did not contain colonies of *A. cervicornis or A. palmata*. A total of 3 colonies were observed in 80 transects. The colonies ranged in size from 10 to 85 centimeters measured as the distance intercepted by the chain transect. The mean percent cover of *A. cervicornis* for the Canoas, Botes, and Media Luna reef sites was 1.7%, 0.5%, and 0.2% respectively. The overall mean percent cover for the 80 transects of the study is 0.15%. Additionally one of the colonies in Desecheo (21 kilometers west of Puerto Rico and frequently flushed by oceanic waters) was observed with white-band disease.

Table 3. Percent decline in the number of northeastern and eastern reef sites with *Acropora* spp. populations in the last 20 years.

| Geographic province | Reefs Surveyed | Reefs with Acroporids old survey | Reefs with Acroporids today | Percent Change |
|---|---|---|---|---|
| ***Acropora palmata*** | | | | |
| Northern inshore | 19 | 19 | 6 | 68.4 |
| Eastern inshore | 18 | 15 | 7 | 53.3 |
| Eastern offshore close | 24 | 22 | 15 | 31.8 |
| Eastern offshore remote | 27 | 23 | 22 | 4.3 |
| Total number of localities | 85 | 79 (93 %) | 50 | 36.7 |
| ***Acropora cervicornis*** | | | | |
| Northern inshore | 19 | 2 | 0 | 100 |
| Eastern inshore | 18 | 3 | 0 | 100 |
| Eastern offshore close | 24 | 14 | 8 | 42.9 |
| Eastern offshore remote | 27 | 26 | 26 | 0 |
| Total number of localities | 85 | 45 (52.9 %) | 34 | 24.4 |
| ***Acropora prolifera*** | | | | |
| Northern inshore | 19 | 1 | 0 | 100 |
| Eastern inshore | 18 | 0 | 0 | N.P.* |
| Eastern offshore close | 24 | 5 | 2 | 60.1 |
| Eastern offshore remote | 27 | 11 | 8 | 27.3 |
| Total number of localities | 85 | 17 (20 %) | 10 | 41.1 |

*N.P.= Not present in any survey.

Figure 5. Colony of *Acropora palmata* being killed by the endolytic sponge *Cliona langae* in Laurel reef, La Parguera, PR. (photo E.Weil)



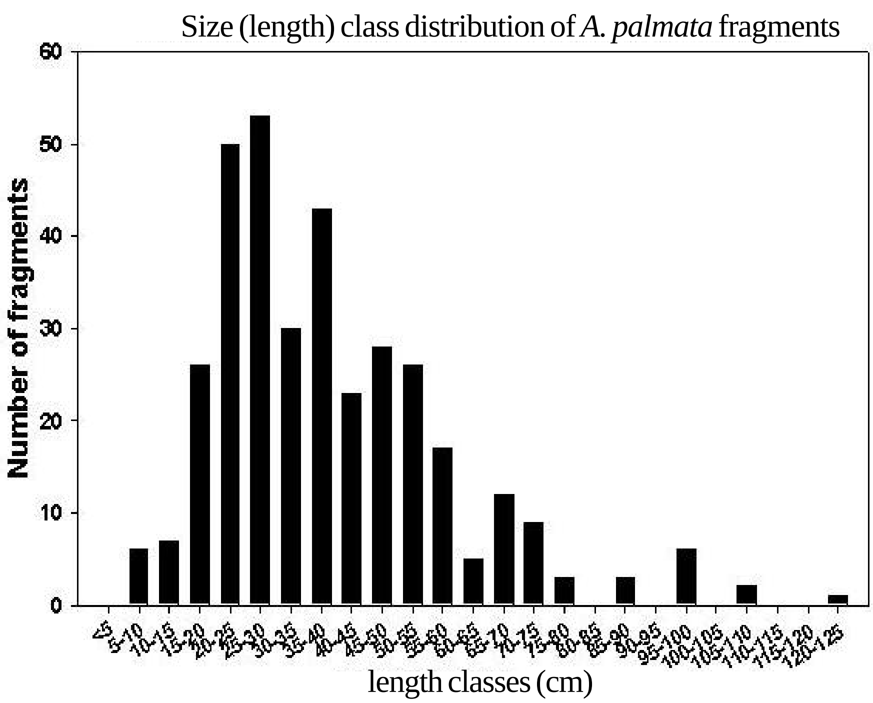




Figure 6. Size frequency distribution of *A. palmata* fragments one year after Hurricane Georges hit Puerto Rico in 1998 (Ortiz, unpublished data).

## 3. Management approaches in Puerto Rico DNER pertinent to conservation

### 3a. Existing and proposed regulations

#### Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico (Law 147)

In Puerto Rico there exist several laws and proposed regulations that may aid in the conservation of corals. The most pertinent statute is the Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico, is Law 147. This law explicitly mandates the conservation and management of coral reefs in order to protect their functions and values. The Department of Natural and Environmental Resources (DNER), the agency in charge of implementing the law, will do so through a regulation that is currently being prepared. Law 147 provides for the creation of zoned areas in order to mitigate impacts from human activities. These zones include (1) Reef Recuperation Areas and (2) Ecologically Sensitive Areas. Although the specifics are being worked out, these zones will facilitate the DNER in controlling human activity that can directly impact *Acropora* spp. such as anchoring. Law 147 also directs the DNER to identify and mitigate threats to coral reefs from degraded water quality due to pollution, a measure that can also be used to protect reefs with *Acropora* spp. In this regard, the law requires Environmental Impact Statements (EIS) for projects or activities that can negatively affect coral reefs. An interagency committee will be convened to coordinate government activities that may affect coral reefs.

#### Marine Reserves Law

Law 137 from 2000 directs the DNER to designate priority areas as marine reserves. Marine reserves are defined as areas where all extractive activities are prohibited in order to help recover depleted fishery resources and protect biodiversity. The law states that that 3 percent of the insular platform must be designated within 3 years (2003). This mechanism could be helpful in the conservation of *Acropora* spp. if it is determined that overfishing of coral reefs that is affecting survivorship of these corals. It has been hypothesized that overfishing of reef fish, octopus, and lobster may lead to an increased abundance of *Acropora* spp. predators. Currently there are two marine reserves in Puerto Rico, Reserva Natural Canal Luis Peña in Culebra, and Desecheo Island.

### 3b. Existing conservation strategies

#### Natural Reserves

There are currently 13 natural reserves in Puerto Rico that have coral reefs within their boundaries. The natural reserves are a logical setting to adopt the zoning measures mentioned above because of the available infrastructure and experience. Zoning strategies that regulate direct human impacts, such as no anchor zones, may be more easily applied due to the existing jurisdiction, although this remains to be seen. It should be noted that natural reserves probably have minimal success in preventing impacts to coral reefs and *Acropora* spp. from degraded water quality because these impacts are not excluded by reserve boundaries. More information is needed on the location and status of *Acropora* spp. populations within the natural reserves in order to apply the conservation strategies, particularly those pertaining to direct impacts.

### Mooring buoys

Another existing strategy that may assist in the conservation of these species is the use of mooring buoys. The DNER has been utilizing this strategy since 1990 principally in Fajardo, Culebra, Guánica, and La Parguera. It is apparent that *Acropora* spp. are very vulnerable to anchor damage because of their branching growth form and their presence in shallow reef zones where anchoring is common. This strategy can be applied in cases where heavy anchoring is occurring on reefs with high abundance of these species. As mentioned above it is necessary to obtain more information on the location of reefs with existing *Acropora* spp. populations that may be important to their conservation.

### Restoration projects

Currently there is a restoration project being conducted with *Acropora* spp. in southwest Puerto Rico. The restoration includes reefs on the southwest and west coast in its first stage. This project involves a coral nursery that uses fragments to propagate colonies for restoring populations. Specially designed structures to growth the fragments and transport them without major manipulations have been designed along to facilitate transport and placement once the fragments reach a certain size. One important aspect of this project is that it includes considerations and methods to preserve sufficient levels of natural genetic variation in the cultured fragments to increase genetic variability in the restored populations so it can respond to both short- and long-term changes in the environment. Fragments collected from different populations (well separated) in different areas of the southwest are cultured in the farm for future propagation to impacted areas in Puerto Rico or even, in other places within the Caribbean. As soon as the transplanted fragments reach sexual reproductive sizes in their final restoration site, the chances of increasing genetic combinations during the reproductive season of the population in the area also increases.

This project is now on its second phase. Preliminary results indicate that the overall survival of coral fragments, 10 months after transplanted, was 86.6% (n= 367), however, differences in the survival of different clones was observed. This could imply that some clones may be better adapted to survive and grow in a wild range of environmental conditions while other may be restricted to specific environmental conditions (light regime, sedimentation rates, water movement, etc.). Survival of fragments had also been affected by their manipulation and transportation, and by algae (*Ceramium nitens*) overgrowth. New methods were developed after the first movement of fragments and mortality during transportation has been reduced significantly. In the second phase, over 2,000 coral fragments have been transported with an overall survival rate of 99.6% one month after the fragments were transplanted into the reef area. Maintenance of the culturing devices every two weeks is needed to prevent algae overgrowth.

The overall linear growth (accumulate length of all branches), 10 months after transplantation, was 52.2 ± 4.6 cm (n= 318 initial fragments). High growth rates account for the fast linear extension of most fragments in the culturing devices with an overall net linear growth of 38.4 ± 4.5 cm. Other useful parameter in coral farming is the branchiness (number of branches produced over time). These measurements provide information to decide the number of fragments that will be harvested after one or two years. The overall number of branches produced, was 7.3 ± 1.8 branches per year. To calculate the expected number of corals to be harvested and propagated to restoration places, the number of initial fragments to be transplanted is multiplied by 7. However, after 10 months of coral growth, the branch lengths of those corals were too small to be harvest. From this previous work, we expect that 1.5 to 2 years of coral growth are needed to harvest the cultured coral fragments (branches).

## 4. Needs for Improving Conservation

### Water quality

In order to improve the current conservation efforts there are some gaps in knowledge that need to be addressed. One important question is understanding how water quality impacts are affecting the persistence of *Acropora* spp. in Puerto Rico. Previous research has highlighted the degraded condition of many near-shore reefs in Puerto Rico (Goenaga and Cintron 1979; Goenaga and Boulon 1992; Hernandez-Delgado, 2000; Velazco et al., 1985). It is evident that there are multiple factors causing this degradation but there seems to be a general consensus that water quality impacts are a major force involved in this decline. Two major threats to water quality on coral reefs in Puerto Rico are high loads of suspended sediments and nutrient contamination, although direct evidence is only available implicating sediment impacts. Since it is probable that impacts from degraded water quality play a role in the health of these species, a logical step in conservation may be to determine thresholds in the important parameters in order to establish adequate standards.

### Information on location and status

More information is needed on the location and condition of these species, particularly information on areas that may be important to conservation because of high abundance. Management efforts should compile all of the available information for Puerto Rico to determine where there are information gaps. Habitat maps are currently available from the NOAA/NOS biogeography program[1]. These could be useful for mapping and quantifying the existing *Acropora* spp. A methodology should be developed to aid in this quantification and it should provide for comparing abundances among reefs such that spatial priorities can be established.

### Case study- Proposed Natural Reserve in Rincon

A situation that can be used to examine conservation strategies for *A. palmata* in Puerto Rico involves a fringing reef in Rincon with a high abundance of healthy colonies. Several years of monitoring has showed that the colonies at this site are some of the healthiest in the northwest (A. Bruckner, letter to DNER; Appendix III, this report). The adjacent coastal zone exhibits low levels of development although the reef experiences increases in turbidity from storm runoff (A. Bruckner, unpublished data. Letter to DNER). There are currently several large resort development projects proposed for the adjacent terrestrial areas. Possible threats from this type of development to the *A. palmata* include water quality degradation from increased run-off, and direct impacts from increased recreational activities. Several local NGO's have proposed the creation of a natural reserve encompassing the reef, adjacent marine habitats and available land areas, as mechanism to mitigate impacts. The strategy aims to use the natural reserve designation to prevent or minimize the development, although there is no evidence that this has been successful elsewhere. Any effort should strive to prevent the creation of a Paper Park by providing effective solutions. The best case scenario for this reef would be the avoidance of impacts by not doing the development projects. If this is not successful then the impacts should be minimized and mitigation should include monitoring programs to insure the *A. palmata* is not affected. Impacts from recreational activities could be managed with the use of zoned areas as provided by the Coral Reef Conservation Law. The question arises as to the role of ESA designation for this case in Rincon.

[1]NOAA/NOS NCCOS/Biogeography Program. 1305 East West Highway, Silver Spring, MD. 20910. 301-713-3028 x 144

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**Appendix 1a**. Distribution of *Acropora* spp. in northern inshore Puerto Rican coral reefs (based on presence/absence data).

| Location | Historic (1970s) | | | Present (1999-2002) | | |
|---|---|---|---|---|---|---|
| | *A. pal* | *A.cer* | *A.pro* | *A. pal* | *A.cer* | *A.pro* |
| Playa de Vega Baja | * | | | * | | |
| Cerro Gordo, Vega Alta | * | | | | | |
| Isla de Cabras, Cataño | * | | | | | |
| Punta San Jorge, San Juan | * | | | | | |
| Punta Las Marías, Carolina | * | | | * | | |
| Punta Vacía Talega, Loíza | * | | | | | |
| Punta Iglesias, Loíza | * | | | | | |
| Punta Uvero, Río Grande | * | | | | | |
| Punta San Agustín, Río Grande | * | | | | | |
| Punta Miquillo, Río Grande | * | | | | | |
| Ensenada Comezón, Río Grande | * | | | | | |
| Punta Picúa, Río Grande | * | | | | | |
| Punta Percha, Río Grande | * | | | | | |
| Patch reef off Río Grande | * | | | | | |
| Punta La Bandera, Luquillo | * | | | * | | |
| Playa de Luquillo | * | | | * | | |
| La Selva, Luquillo | * | | | | | |
| Playa El Convento, Fajardo | * | * | | * | | |
| Ensenada Yegua, Fajardo | * | * | * | * | | |
| *n=19* | *19* | *2* | *1* | *6* | *0* | *0* |

**Appendix 1b**. Distribution of *Acropora* spp. in eastern inshore Puerto Rican coral reefs (based on presence/absence data).

| Location | Historic (1970s) | | | Present (1999-2002) | | |
|---|---|---|---|---|---|---|
| | *A. pal* | *A.cer* | *A.pro* | *A. pal* | *A.cer* | *A.pro* |
| Playa Canalejo, Fajardo | * | | | * | | |
| Playa Las Croabas, Fajardo | * | | | | | |
| Playa Sardinera, Fajardo | * | | | | | |
| Punta Gorda, Fajardo | | | | | | |
| Punta Barrancas, Fajardo | * | | | | | |
| Punta Mata Redonda, Fajardo | * | | | | | |
| Bahía Demajagua, Fajardo | * | | | | | |
| Punta Figueras, Ceiba | | | | | | |
| Cayo Algodones, Naguabo | * | * | | * | | |
| Patch reef off Bahía Algodones, Naguabo | * | | | * | | |
| Punta Lima, Naguabo | * | | | * | | |
| Playa Fanduca, Naguabo | * | | | * | | |
| Playa Las Ochenta, Humacao | | | | | | |
| Punta Candelero, Humacao | * | * | | * | | |
| Punta Fraile, Humacao | * | * | | * | | |
| Punta Icacos, Humacao | * | | | | | |
| Punta Guayanés, Yabucoa | * | | | | | |
| Punta Yegua, Yabucoa | * | | | | | |
| *n=18* | *15* | *3* | *0* | *7* | *0* | *0* |

**Appendix 1c**. Distribution of *Acropora* spp. in eastern offshore close (<6 km) Puerto Rican coral reefs (based on presence/absence data).

| Location | Historic (1970s) | | | Present (1999-2002) | | |
|---|---|---|---|---|---|---|
| | *A. pal* | *A.cer* | *A.pro* | *A. pal* | *A.cer* | *A.pro* |
| Cayo Obispo, Fajardo | * | * | | | | |
| Cayo Zancudo, Fajardo | * | | | | | |
| Arrecife Mata Caballos, Fajardo | * | | | | | |
| Arrecife Roncador, Fajardo | * | * | * | * | | * |
| Arrecife Corona Carrillo, Fajardo | * | | | | | |
| Cayo Ahogado, Fajardo | * | * | | | | |
| Isla de Ramos, Fajardo | * | * | | * | | |
| Isla Piñero/Cabeza de Perro, Ceiba | * | * | | * | | |
| Arrecife Lima, Naguabo | * | | | * | | |
| Cayo Santiago, Humacao | * | | | * | | |
| Cayo Batata, Humacao | * | | | | | |
| Bajo Blake, Humacao | | | | | | |
| Bajo Drift, Humacao | | | | | | |
| Cayo Sargento, Yabucoa | * | * | | | | |
| Cayo Largo, Fajardo | * | * | | * | * | |
| Las Cucarachas, Fajardo | * | | | * | | |
| Los Farallones, Fajardo | * | | | * | | |
| Cayo Icacos, Fajardo | * | * | * | * | * | |
| Cayo Ratones, Fajardo | * | * | | * | * | |
| Cayo Lobo, Fajardo | * | * | | * | * | |
| Islote Palominitos, Fajardo | * | * | * | * | * | |
| Isla Palominos, Fajardo | * | * | * | * | * | |
| Cayo La Blanquilla, Fajardo | * | * | | * | * | |
| Cayo Diablo, Fajardo | * | * | * | * | * | * |
| *n=24* | *22* | *14* | *5* | *15* | *8* | *2* |

**Appendix 2**. Relative abundances of acroporid corals and sexual recruits in several reef localities along the south and west of the main island and few offshore islands. (*** = abundant, ** =few patches and isolated colonies, * = isolated colonies).

| Locality | Reef | Depth m | Latitude | Longitude | *A. palmata* | *A. cervicornis* | Sexual recruits |
|---|---|---|---|---|---|---|---|
| Guanica | Aurora | 0.5 - 15 | 17° 56.652 | | ** | * | * |
| | Coral | 0.5 - 15 | | | * | *** | |
| Parguera | Corral | 0.5 - 15 | | | ** | * | * |
| | Pinnacles W | 1.5 - 20 | 17$^{3}$ 55.973 | 67$^{3}$ 00.726 | * | * | * |
| | Pinnacles E | 2 - 20 | 17$^{3}$ 55.973 | 67$^{3}$ 00.720 | * | * | * |
| | Turrumote | 0.5 - 20 | 17$^{3}$ 56.061 | 67$^{3}$ 01.066 | ** | ** | * |
| | Mata la Gata | 0.5 - 12 | 17$^{3}$ 57.664 | 67$^{3}$ 02.253 | ** | | * |
| | Caracoles | 0.5 - 12 | 17$^{3}$ 57.65 | 67$^{3}$ 02.175 | | | |
| | Enrique | 0.5 - 18 | 17$^{3}$ 57.223 | 67$^{3}$ 03.119 | * | * | * |
| | Media Luna | 0.5 - 20 | 17$^{3}$ 56.092 | 67$^{3}$ 02.952 | * | * | * |
| | Laurel | 0.5 - 18 | 17$^{3}$ 56.581 | 67$^{3}$ 03.296 | ** | ** | * |
| | Mario | 0.5 - 18 | 17$^{3}$ 57.157 | 67$^{3}$ 03.380 | * | * | * |
| | Conserva | 0.5 - 14 | 17$^{3}$ 57.442 | 67$^{3}$ 03.397 | * | * | |
| | Long Reef | 4 - 20 | 17$^{3}$55.439 | 67$^{3}$ 00.962 | * | * | * |
| | San Cristobal | 0.5 - 18 | 17$^{3}$ 56.581 | 67$^{3}$ 04.673 | ** | ** | * |
| | Atravesado | 0.5 - 15 | 17$^{3}$ 56.521 | 67$^{3}$ 05.094 | *** | *** | * |
| | El Palo | 0.5 - 12 | 17$^{3}$ 56.006 | 67$^{3}$ 05.702 | ** | * | * |
| | Margarita | 0.5 - 12 | 17$^{3}$ 36.006 | 67$^{3}$ 05.702 | * | * | * |
| | Acuario | 15 - 20 | | | * | * | * |
| | Black Wall | 17 - 30 | 17$^{3}$ 58.569 | 67$^{3}$ 04.175 | | * | |
| | Buoy site | 17 - 30 | 17$^{3}$ 53.304 | 66$^{3}$ 59.074 | | * | * |
| | Shelf edge | 17 - 30 | 17$^{3}$ 52.104 | 66$^{3}$ 61.104 | | * | |
| Cabo Rojo | El Ron | 0.5-18 | | | * | * | |
| | Buye | 0.5-10 | 18° 08.068 | 67° 11.210 | * | | |
| Joyuda | El Negro | 0.5-20 | 18$^{3}$ 09.162 | 67$^{3}$ 14.758 | ** | * | * |
| Mayaguez | Gallardo | 1.5-18 | | | *** | | |
| Rincon | Tres Palmas | 1-3 | | | ** | | |
| | Steps | 1-3 | 18$^{3}$ 21 | 67$^{3}$ 15 | ** | | |
| Aguadilla | El Natural | 5-20 | | | * | | |
| Desecheo Is. | South Gardens | 1-22 | 18$^{3}$ 22.69 | 67$^{3}$ 29.044 | * | ** | * |
| | West | 1.5-18 | 18$^{3}$ 22.740 | 67$^{3}$29.120 | * | | |
| Isabela | Shacks Reef | 1-14 | | | ** | | |
| Mona Island | Fortuna Reefer | 1-12 | 18° 02 | 67° 51 | ** | | * |
| | Pajaro | 4-15 | 18° 03.930 | 67° 51.938 | * | * | * |
| | Mujeres | 10-20 | 18° 04.503 | 67° 56.278 | | * | * |
| | Sardinera | 0.5-10 | 18° 05.410 | 67° 56.420 | * | | |
| | Carmelita | 0.5-3 | 18° 05.650 | 67° 56.502 | ** | | |
| Culebra | Culebra s-w | 0.5-18 | 18° 29.330 | 65° 29.910 | * | * | * |
| Vieques | Viequez n-w | 0.5-18 | 18° 16.300 | 65° 42.200 | * | * | * |

## Appendix 3: Letter to DNER on *Acropora palmata* populations at Steps Reef, Rincon

Vicente Quevedo
Natural Heritage Division
DNER
P.O. Box 9066600
Pta. De Tierra Station
San Juan, P.R. 00906-6600

Dear Mr. Quevedo,

I was recently informed that Puerto Rico’s Department of Natural and Environmental Resources (DNER) is considering the establishment of a marine natural reserve for Steps Beach and surrounding reefs off the west coast to offer protection for the benefit of the elkhorn reef system in Rincon. I would recommend implementing additional conservation measures for the coastal habitats near Steps and Tres Palmas, particularly because these areas support endangered and threatened wildlife, and also contains one of the few remaining healthy stands of elkhorn coral (*Acropora palmata*) left in the Caribbean. A large-scale development project in the cattle field immediately fronting Steps Reef is likely to cause substantial run-off during construction, and elevated nutrients and pollutants once the establishment is operational (as a result of increased sewage production and pesticides and fertilizers used on the surrounding grounds). Coral reefs are negatively affected by sediments, excessive nutrients and pollutants, and elkhorn corals are particularly sensitive to these types of stressors. A development project in this area may accelerate the decline in the health and productivity of the nearshore reefs, and possibly threaten the survival of elkhorn coral populations due to their limited tolerance to sedimentation and nutrient loading.

In support of further protection for Steps and Tres Palmas as a marine natural reserve, I am providing this information on the diversity, health and importance of two coral reefs located off the west coast of Puerto Rico near Rincon, Steps Reef and Tres Palmas. I conducted monthly surveys on Steps and Tres Palmas between 1994-1997, and annual surveys in 1998-2000. I am coral reef ecologist with the National Marine Fisheries Service. I received my Ph.D. from the University of Puerto Rico, Department of Marine Sciences in La Parguera, where I lived from 1994-1998. During the five years I lived in Puerto Rico, I spent 4-5 days per week diving on reefs off the northwest, west and south coast of Puerto Rico, and have continued to revisit these sites two times each year. For my research and dissertation I examined the effect of coral diseases and predators on important reef building corals. I collected information on different measures of coral reef health from the west and south coast near Aguadilla, Rincon, Desecheo, Mayaguez, Boqueron, La Parguera, Guayanilla, Guanica, and Ponce. I also established permanent study sites on the northwest coast (Aguadilla), southwest coast (off Parguera), the west coast at Steps and Tres Palmas (Rincon), and Mona Island, to conduct a detailed study of coral disease processes, long-term impacts, and synergistic effects of human activities. I have continued my research in Puerto Rico over the last three years under a study sponsored by Earthwatch “Saving Puerto Rico’s Reefs”. My studies focus on the effects of disease, predation and storm damage on the dominant and most important corals, including elkhorn coral, star coral and brain coral. I take a holistic approach to my research to obtain a snapshot of the health of the reef ecosystem using a modification of the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol (I examine corals as well as other indicators of reef health like fish abundance and size, type and biomass of algae, and present of key indicator organisms including commercially important species and keystone species). I also examine the long-term effect of these processes on coral survival, growth and new recruitment.

In the following document, I have provided a summary of the importance and role of elkhorn corals, their status throughout the region including Puerto Rico, threats that are impacting elkhorn coral populations, and measures that are needed to protect these corals. I am providing specific information on the elkhorn coral reef at Steps and Tres Palmas, based on my study between 1994-2000. I was unable to reexamine these sites in 2001 due to weather. It is important that these sites continue to be monitored to detect change in reef health. A detailed synoptic examination of the site in 2002 is recommended to quantify the extent, abundance and condition of the elkhorn population. I would be interested in conducting these studies but would need minimal support to conduct the work. If you have any questions about the following document, please contact me at andy.bruckner@noaa.gov.

**Rincon's unusual elkhorn coral *Acropora palmata* thickets**

Steps and Tres Palmas reefs are some of the best developed fringing coral reefs found off the west coast of Puerto Rico. The coastline at Rincon is fringed by a narrow sandy beach, with beach rock at the waters edge. Tres Palmas and Steps Reefs are two hardground areas, separated by a channel 50-150 m wide. The reefs start immediately seaward of the beach rock and slope from 0.5m to 8-10 m depth. The reef extends out for less than 200 m before terminating in a shallow sand flat (8-10 m depth). In shallow water (0.5-3 m depth) the reef is dominated by *Acropora palmata* with isolated brain, star and mustard hill corals. Elkhorn colonies form a dense stand that begins about 5 m offshore and extends seaward 20-30 m. The densest areas of elkhorn growth are near Steps and Tres Palmas, and colonies also occur at a lower density from just north of the marina to the dome. The deeper portion of the reefs (from 2-8 m) is dominated by *Diploria strigosa*, but many other massive and branching corals, sea fans, soft corals, and other invertebrates also occur here.[1]

A second reef begins from 250-400 m offshore. This reef is completely submerged, and slopes gradually seaward to about 70 feet. It is shallowest at the landward edge (0.5-2m ) where the reef is colonized by isolated *A. palmata* colonies, and massive and plating corals dispersed over the remainder of the hardground areas. There is relatively high cover (25-40%) in moderate depths (15-20 m) and several large massive boulder corals and plating corals.

**Background information on *Acropora palmata***

**Life history:** *Acropora palmata* is a fast-growing (5-10 cm/year linear branch extension) branching coral that forms dense thickets (stands) from 0.5-6 m depth in exposed fore reef environments. Colonies are also found in exposed back reef and deeper fore reef zones (to 18 m depth) at a lower abundance**,** provided that there is good circulation, high light, and low levels of sedimentation. Colonies are large and tree-like with exceptionally thick and sturdy branches up to 3 m in diameter. Elkhorn coral is an annual broadcast spawner (individual colonies release eggs and sperm bundles in August/ September) that produces millions of gametes, but this species exhibits very low rates of sexual recruitment. The main mode reproduction is believed to be asexual - colonies produce long branches that become very fragile and are easily dislodged during storms. These detached branches reattach to substrate and continue to grow, and damaged adult colonies regenerate injuries.

At Steps, Tres Palmas and other surrounding fringing reefs, sea conditions are generally calm from April through September, with periods of high wave action in winter. Colonies are often fragmented, and the reef substrate may be littered with branches, but these rapidly fuse to the substrate and begin sending up new branches (protobranches). This has allowed elkhorn populations to rapidly recover from storms; elkhorn coral populations have remained very dense, with colonies slowly expanding into deeper water and to neighboring areas.

**Distribution and abundance**: This species was formerly the dominant species on the shallow fore reef in the Florida Reef Tract, the Bahamas and throughout the Caribbean[2] , forming extensive, densely aggregated, monospecific thickets between low water level and 5-6 m depth, in wave-exposed and high surge reef zones.

Colonies of *A. palmata* occur throughout shallow nearshore reef environments of Puerto Rico, except for 1) locations on much of the north coast; 2) reef environments adjacent to major cities; and 3) reefs affected by discharge from large rivers. Elkhorn populations were formerly most abundant on the northwest coast near Jobos and Isabela; on the west coast near Rincon; south of Mayaguez to Boqueron; on reefs near La Parguera; fringing reefs near Guayanilla, Guanica, Ponce; isolated reefs near Punta Tuna; Fajardo and offshore emergent reefs, and the islands of Mona, Culebra and Vieques. Possibly the largest remaining stand of elkhorn coral in Puerto Rico is located at depths of 3-5 m on a submerged reef 15-20 km off Boqueron (Bajo Gullardo). During the 1970s and 1980s Goenaga conducted island-wide surveys of reefs; and his reports provide extensive information on known locations of *A. palmata* throughout Puerto Rico.

**Success and limitations of life history and population recovery:** The success this species has achieved is a result of its fast rate of growth, persistence of injured adults by rapid wound healing, and high rate of asexual recruitment of fragments (Gladfelter et al., 1978; Bak and Criens, 1981; Highsmith, 1982). *A. palmata* has adaptations for survival in shallow, high energy reef environments occupied by few other stony corals, but colonies are susceptible to breakage from physical forces associated with storms and high wave action. Branches that break off standing colonies fuse to the substrate and continue growing. This has allowed *A. palmata* to rapidly recolonize an area after a major disturbance and spread into new areas, especially habitats not suitable for settlement by sexually-produced larvae (Fong and Lirman, 1997). However, this mode of reproduction also limits the extent of spread of populations. Unlike *A. palmata*, colonies that reproduce sexually and have a high success of settlement and recruitment of planula larvae benefit from the ability to disperse to surrounding and distant reefs, as the larvae are carried by water currents. Because *A. palmata* exhibits limited ability to recruit sexually, damaged populations are unlikely to recover unless a local source of branches remains following the disturbance.

While storms may enhance the spread of *A. palmata* populations, recent observations indicate that initial mortality to colonies and fragments may be quite high, injured colonies and fragments exhibit reduced growth rates and declines in reproductive output, and damaged populations are susceptible to subsequent disturbances (Bruckner, unpubl. Data; Lirman, 1998). If populations of *A. palmata* were seriously damaged near Rincon, there is no other site within close proximity that could serve as a site for new recruits. Populations of elkhorn coral formerly existed on reefs surrounding the Mayaguez Bay, but these have largely disappeared as a result of poor water quality.

**Importance of *Acropora palmata***

**A. Storm damage:** Elkhorn coral thickets reduce incoming wave energy, offering critical protection to coastlines. Loss of this species may negatively affect shorelines with mangrove and grass bed habitats which rely on calm water provided by these effective reef barriers. Fringing reefs with elkhorn thickets, like those found in Rincon, are also particularly important to coastal communities and the beach as they form a buffer that protects shorelines from erosion during storms. The loss of elkhorn thickets results in higher wave action reaching coastal environments, and this can lead to erosion and loss of nearshore grassbeds and mangroves. In Rincon, the elkhorn thickets front a narrow sandy beach. There is high wave action during winter. This is associated with offshore transport of sand, which accumulates among the corals on fringing reefs and in the surrounding area. Without the presence of a large stand of elkhorn coral, it is likely that much more sand will be carried offshore during periods of high wave action, and the beaches may eventually disappear.

**B. Fisheries habitat:** The high structural complexity produced by the interdigitated branches of *A. palmata* colonies provide essential fish habitat. Studies from Florida and the Virgin islands have shown that a higher number of lobsters, snappers, grunts, parrotfish and other large reef fish occur in areas with live stands of elkhorn coral. In many locations elkhorn populations have died, but erect skeletons (standing in place) may remain for 10-20 years. Dead colonies continue to provide high relief habitat utilized by a number of organisms. The skeletons are rapidly overgrown with algae and benthic invertebrates, and fish communities become dominated by schools of herbivorous fish like surgeonfish due to increased biomass of algae. Over time, however, the skeletons eventually collapse, eliminating high-relief topography and habitat for predatory fish and motile invertebrates.

**C. Reef growth:** Coral reefs were formerly dominated (prior to 1980s) by three species of coral - elkhorn coral (*A. palmata*), staghorn coral (*Acropora cervicornis*) and star coral (*Montastrea annularis* complex). *A. palmata* formed characteristic thickets in the shallowest, exposed areas, on fringing reefs and the outer portions of offshore reefs. These often extended along the coastline or the crest of the reef for several kilometers. *A. cervicornis* also forms thickets, but it occurs in intermediate depths (5-25 m) on the fore reef in areas with moderate to low amounts of wave action, and shallow calm back reef environments. *M. annularis* is a complex of three species of massive corals that occurs throughout most reef environments (it is uncommon in areas dominated by elkhorn coral). *M. annularis* grows very slowly and colonies may live for hundreds of years forming immense structures several meters tall.

The genus *Acropora* include the fastest growing scleractinian corals in the Indo-Pacific and Caribbean. Branch extension rates of 10-12 cm per year are common for the Caribbean species, which is approximately 10 times greater than massive reef-building corals. Gladfelter (1982) estimated a rate of reef accretion by elkhorn coral of 10.3 kg $CaCO_3/m^2/yr$; over 1000 years, shallow windward *A. palmata* reefs have grown upward close to 15 meters, keeping pace with rising sea level (Adey, 1975).

This growth results in a large accumulation of branches and rubble as a result of wave action that periodically prunes colonies. Some of these branches are carried to deep reef or soft bottom communities, where they accumulate and are cemented together. This creates additional habitat for fish, hard substrate for colonization by other corals, and also contributes to reef growth. In offshore populations of elkhorn coral, hurricanes will also break branches and carry these from the front of the reef to the back side, depositing them in a lower energy environment. These accumulate and slowly build new islands. Recently Dr. Ernest Williams and colleagues excavated several of the outer islands off La Parguera (Turrumote; Media Luna) and found that the entire island consists of elkhorn coral.

**Threats:** *A. palmata* once was the dominant scleractinian coral on high-energy, windward reefs of the tropical western Atlantic (Goreau, 1959; Almy and Carrion-Torres, 1963). Over the past two decades the density of this species has been greatly reduced throughout its range as a result of various anthropogenic and natural disturbances[3], especially white-band disease (WBD) epizootics and storm damage (Gladfelter, 1982; Peters, *et al*.,1983; Rogers, *et al*., 1982; Peters, 1993). A number of studies have shown that elkhorn reefs rapidly recovered from periodic storms and other short-term disturbances through regrowth of colony stumps and branch fragments. However, in many cases elkhorn populations are being impacted by a number of different stresses at the same time which have may a synergistic effect, compounding losses or preventing recovery.

*Acropora palmata* populations on the southwest coast of Puerto Rico have suffered similar losses to that reported from other parts of the Caribbean. These reefs have been impacted by relatively few hurricanes since the 1960's, the most severe of which were Hurricanes Edith (1963), David and Frederick (1979), Hortense (1996) and Georges (1998). While Hurricane Edith caused extensive destruction to *A. palmata* thickets, Glynn et al. (1964) observed high survivorship and continued growth among damaged colonies and fragments. Hurricanes David and Frederick also damaged *A. palmata* populations (Armstrong, 1983), however information on patterns of recovery is unavailable. I followed the fates of hurricane generated fragments on reefs near La Parguera after Tropical Storm Debbie ( 1994), Hurricane Hortense and Hurricane Georges (Bruckner, unpubl. Data). In my study area a high incidence of disease affected fragments after Debbie with mortality that exceeded 50% of the branches, and Hortense dislodged and overturned many of the remaining fragments. However, new fragments produced during Hortense exhibited fairly good survival until Hurricane Georges, which removed most remaining standing colonies and fragments generated by Hortense. Some sites in La Parguera have shown little recovery after 3 years. Although La Parguera has some of the best deep reef environments (e.g., shelf edge reefs) found in Puerto Rico (and these rival reefs found throughout the Caribbean), there is only one reef in the entire Parguera reef system that still has an extensive thicket of *A. palmata* (Morelock, pers. Comm.Bruckner, unpubl. data). in areas off La Parguera where this species once formed large thickets (shallow reef crest/ fore reef), only isolated colonies or small groups of colonies remain and many of these are affected by disease, *Cliona* overgrowth, and snail predation.

In Rincon, a number of broken colonies were observed after Hurricane Georges. Unlike La Parguera, most fragments remained near mother colonies and these did not die. One year later the fragments were firmly attached to the reef and had produced numerous small protobranches.

Like other Caribbean locations, observations from Puerto Rico suggest that coral disease has impacted this species in the past. On one reef near La Parguera, C. Goenaga observed an incidence of WBD which affected 20-33% of the *A. palmata* colonies in 1984 (Davis, *et al*.,1986). During the 1990's I have documented a slow, steady decline of remaining *A. palmata* thickets in La Parguera due to a combination of factors including disease and predation (Bruckner *et al*., 1997, unpubl. data). On the east coast of Puerto Rico, vast stretches of living *A. palmata* colonies were observed in 1979 in Fajardo, Culebra and Vieques. Populations near Fajardo were decimated by WBD in the 1980s, and Hurricane Hugo in 1989 caused almost total destruction to *A. palmata* thickets in eastern Culebro (Goenaga and Boulon, 1992). On 85 reefs off the east coast and associated islands, populations of elkhorn coral have continued to decline from disease, sedimentation, and algal overgrowth (Hernandez-Degado, pers. Comm).

**Tolerance to terrestrial impacts:** Elkhorn coral is an environmentally sensitive species that requires clear, high saline, well circulated water with moderate temperatures (25-29°C). *A. palmata* is intolerant of prolonged periods of high sedimentation; this species lacks a well developed ciliary mucus system found in sediment-tolerant species like *Porites astreoides* and *Montastraea cavernosa*. It can only tolerate short periods of increased water turbidity if the site is exposed regularly to moderate to high levels of wave action. Rogers (1983) found that even low doses of sediment accumulate on the flattened branch surfaces, resulting in rapid tissue necrosis; in addition, injuries regenerate more slowly at elevated sedimentation levels (Meesters and Bak, 1995). Rincon's reefs are affected by poor water quality conditions during the rainy season in summer due to run-off, but murky conditions generally persist for short periods and water clarity improving after a few days. In winter high wave action prevents accumulation of sediment on branches. Clearing of the land adjacent to Steps reef would cause a significant increase in run-off, which is likely to have a significant impact on nearshore elkhorn coral populations.

**Natural disturbances:** Coral disease is a major factor that has impacted this species since the 1970s (first reported in 1977 from St. Croix, USVI). White-band disease (WBD) spread throughout the Caribbean, with concurrent losses of 90-95% reported during the 1980s and early 1990s. White-band disease still affects *A. palmata* throughout its range and other new, white-type diseases (white pox; patchy necrosis) have been reported on this species in the 1990s. Elkhorn coral is one of only two coral species (other species is *A. cervicornis*) known to have experienced mass mortalities from disease.

Throughout its range, Caribbean-wide losses of *A. palmata* have been attributed primarily to WBD, with compounding (localized) effects from hurricanes, increased predation pressure, hypothermic stress, bleaching events, physical damage from ship groundings, and problems associated with increased nutrient and sediment loading**.** Two predators in particular, include the fireworm, *Hermodice carunculata* and the corallivorous gastropod, *Coralliophila abbreviata*, are a significant threat to elkhorn populations. While worms generally consume parts of individual branches, the gastropods are capable of denuding entire colonies of *A. palmata*. The pressure on remaining populations from coral predators may be increasing in many locations, because, even if snail and fireworm densities have not increased, they may occur at higher densities on individual corals because there are fewer corals remaining. However, recent work suggests that coral eating gastropods have become more prevalent and more voracious on reefs in Puerto Rico and the Florida Keys possibly as a result of overfishing of their predators, the octopus and spiny lobster (Bruckner et al., 1996; Szmant, pers. comm). Work by Bruckner et al. (1997) examined the population dynamics of snails on reefs in La Parguera, and the relative affect of snails on remaining populations. This study showed that individual snails will consume 5-25 square centimeters of tissue in one day and aggregates of snails eat entire colonies in as little as one month. It is interesting to note that the snails were much larger (30-50 mm) than those found on massive corals, and these were predominantly female (the snails change sex from male to female once they reach a certain size) suggesting that populations may continue to increase in abundance (larger females producea higher number of offspring) and contribute to the loss of remaining coral thickets near la Parguera.

Fortunately, Rincon populations of elkhorn coral currently do not face a substantial threat from coral diseases or predators at this time. Snails have been observed at high densities (2-25 snails per coral) on massive brain and star corals on these reefs, but the snails are very small (less than 1 cm). Over the duration of the study (1994-1997), only six standing elkhorn colonies have been affected by groups of snails and associated predation was minimal.

A low incidence of disease has been observed at Steps and Tres Palmas. Isolated colonies are periodically observed with white band, and patchy necrosis may be relatively common after extended periods of terrestrial runoff (May-July, during the rainy season water visibility may drop below 1 m and remain this way for several days). However, patchy necrosis most frequently affects fragments, colonies are not entirely killed, and branches begin to regenerate tissue off areas that were formerly affected by disease.

An outbreak of disease (patchy necrosis) was recorded on *Acropora palmata* at **Steps Reef** during 1996. The occurrence of the disease may be associated with high sediment loads that affected corals at the time of construction of a residential structure across the street from Steps. The construction project involved removal of all trees, and the land was bulldozed, exposing the underlying sediment. Unfortunately, this occurred during the rainy period in summer, and run-off was exacerbated. Fortunately, the amount of sediment run-off declined within a few weeks, and the disease outbreak subsided. However, this indicates that coral populations are very vulnerable in this location, and development of the land immediately in front of Steps may seriously compromise elkhorn coral populations, especially if construction coincides with the rainy season.

**Conservation Measures:** *A. palmata* is offered limited **protection by existing legislation** in U.S. waters: The Fishery Management Plan for Coral and Coral Reefs, developed in 1982 by the Gulf of Mexico and the South Atlantic Fisheries Management Councils provides direct protection in federal waters for acroporid corals (and other species). The FMP 1) prohibits the taking of stony coral or destruction of coral; 2) establishes a permit system for taking corals for scientific or educational purposes; 3) requires the return of stony corals taken incidently in other fisheries; and 4) prohibits the use of toxic chemicals in taking fish or other marine organisms. Other protected areas include National Parks (Florida: Dry Tortugas; Biscayne National Park and the U.S. Virgin Islands: Buck Island; St. John) and in the Florida Keys National Marine Sanctuary. It is illegal to damage, remove, collect, or sell *Acropora palmata* and other stony corals In State waters of Florida (State statute, in effect since the mid 1970s).

The Fishery Management Plan for Corals and Reef Associated Plants and Invertebrates of Puerto Rico and the USVI, July 1994, Caribbean Fishery Management Council regulates take of stony corals in federal waters around Puerto Rico: Harvest and possession of stony corals, octocorals, and live rock, whether dead or alive, are prohibited, except for the purpose of scientific research, education, and restoration. In territorial waters of Puerto Rico, DNER prohibits the harvest or take of corals (Law No. 83) for commercial purposes except under permit.

**Potential impacts associated with a loss of elkhorn coral populations in Rincon:** The disappearance of these coral thickets may ultimately affect the diversity and abundance of reef organisms, the rate of carbonate deposition and reef growth, and the skeletal contribution to coral cayes and boulder ramparts (Hernandez-Avila *et al*., 1977; Gladfelter *et al*., 1978; Williams, pers. comm.).
*Reduced Diversity*. In addition to the loss of one of the most important reef builders in the Caribbean, many organisms that rely on *A. palmata* for habitat, feeding areas, and refuge will disappear.
*Tourism.* Steps reef is a very popular site for snorkeling, due to the shallow water and close proximity to land. Steps is one of the few reefs in Puerto Rico accessible immediately off the shore.
*Beach erosion*. Loss of elkhorn coral would result in stronger waves reaching the shoreline, which will subsequently cause substantial increase in erosion of sand. Increased erosion of sediments will ultimately affect other benthic reefs invertebrates found slightly deeper than elkhorn coral and also those found on the outer reefs. In addition, increased erosion is likely to result in decreased water clarity which will affect the amount of light reaching photosynthetic reef organisms.

**The U.S. Endangered Species Act**: In the U.S. Federal Register Notice (FR Doc. 99-1011, 1/15/99; Vol. 64, no. 10) the National Marine Fishery Service (NMFS) has proposed to add two coral species, elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) as candidates for possible addition to the List of Endangered and Threatened species under the Endangered Species Act. These species are fast-growing, branching corals that form dense, high profile, monospecific stands at shallow and intermediate depths. Formerly, these were two of the three most important corals in the tropical western Atlantic, contributing significantly to reef growth and providing essential fishery habitat. During the last two decades, disease outbreaks and compounding (localized) factors such as hurricane damage, increased predation, hypothermia, boat groundings, sedimentation, and bleaching have resulted in widespread mortalities. Losses are well documented at several sites in the U.S. and throughout the Caribbean, where populations declined during the 1980s by up to 96%. To date, acroporid corals have not recovered to their former abundance. Low remaining population densities, a strong dependence on asexual recruitment by coral fragments, and limited potential for larval recruitment may hinder recovery of these species, given continuing losses from coral diseases, storms, and human impacts.

In this notice, NMFS is not proposing to list these corals as Threatened or Endangered species under the U.S. Endangered Species Act. The goals of the candidate species program are 1) to identify species that may qualify as candidates for possible addition to the List of Endangered and Threatened Species, 2) to assist in acquiring information needed to determine the status and trends of a species, and 3) to encourage voluntary efforts to help prevent listings. NMFS is seeking additional information on these species that would support or argue against inclusion on the candidate species list. This includes historic and current population abundances and distribution, assessments of threats, and existing and future protective measures that may assist in recovering these species.

Using information collected from an initial analysis of published information indicating that populations of *A. palmata* were in serious decline, and public comments generated from the Federal Register Notice proposing the candidate listing, NMFS added two coral species, elkhorn coral (*Acropora palmata*) and staghorn coral *(Acropora cervicornis*) to the candidate species list of the Endangered Species Act (Federal Register Vol. 64, No. 120, June 23, 1999 pp. 33466-33467).

[1]Stony corals recorded in study area at Steps and Tres Palmas reefs: *Acropora cervicornis, A. palmata, Montastraea faveolata, M. cavernosa, Porites astreoides, P. porites, Favia fragum, Agaricia agaricites, Diploria strigosa, D. clivosa, D. labyrinthiformis, Siderastrea siderea, Dendrogyra cylindricus, Colpophyllia natans*, *Dichocoenia stokesi, Meandrina meandrites*

[2]These species occur in Florida and throughout the Caribbean including the Antilles, the West Indies, Central and South America, including Mexico, Belize, Honduras, Nicaragua, Costa Rica, Panama and Columbia. Isolated populations occur in the southern portion of the Gulf of Mexico, near Veracruz, Mexico; the northern limit in 1992 was the Tuxpan Reef System, approx 29°N latitude; northern limit off the east coast of Florida is Biscayne National Park; the species is absent from Bermuda, the east coast of Florida, Florida Middle Grounds and Flower Garden Banks; the southern limit is Venezuela, in areas without freshwater runoff.

[3]White-band disease is the most significant source of mortality to *Acropora palmata* populations throughout the range over which this coral occurs, and populations have declined by as much as 90-95% as a result of disease. However, localized losses of *A. palmata* populations have also been associated with storm damage, ship groundings, predation, cold water events, flooding, bleaching, siltation, and algal and invertebrate overgrowth.