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Baseline Characterization of Coral Reefs and Fish Communities Within the Proposed Culebra Island Marine Fishery Reserve, Puerto Rico.

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ABSTRACT

Our objective was to provide a baseline data bank of the ecological conditions of the proposed Culebra Island's Marine Fishery Reserve (MFR). Aerial photographs were analyzed using dot grids to determine the percent coverage of bottom communities. We used line intercept transects to quantitatively describe coral reef epibenthic communities and stationary visual censuses to quantitatively describe fish communities. With these data we calculated the following community parameters: species richness, abundance, Shannon-Weaver Index (H'n), evenness (J'n), % of coral cover, total biomass and standing stock biomass. Bootstrapping analysis was used to test for significant differences in the average values of these parameters between sampling stations and years. Seagrass beds were the most abundant community type (35%), followed by coral reefs (34%), sandy bottoms (11%) and hard grounds (10%). A total of 69 coral species were identified, including 4 hydrocorals, 25 octocorals and 40 scleractinians. Epibenthic surveys showed that there were no significant changes in species richness, H'n, and J'n between 1997 and 1998 in sampling stations CR1 and CR2. There was a non-significant increase in colony abundance between 1997 and 1998 mostly due to partial coral tissue mortality and its consequent colony fragmentation. Only 29% of the hard corals were considered to be healthy, 46% were overgrown by filamentous algae, 37% by macroalgae and 20% were bioeroded. Coral mortality was estimated to be 32.9±5.6% at CR1 and 28.3±9.8% in CR2 for the 1998 data. A total of 221 fish species were identified, including 113 genera and 59 families. Fish surveys demonstrated no significant changes in the fish community of the Carlos Rosario Beach between 1996 and 1998. But, there were significant differences between Carlos Rosario Beach and Cayo de Luis Peña. The latter showed significantly higher average values in fish abundance, total biomass, standing stock biomass, and biomass and density of fishery target species. Our data indicate that the proposed MFR has a high coverage of critical habitats, high diversity of corals and fishes, and that fish populations are very healthy in parts of the proposed reserve. Cayo de Luis Peña is less accessible to spearfishermen than Carlos Rosario Beach, which suggest that there is a severe overfishing problem in the latter locality. We recommend to the government of Puerto Rico to take action as soon as possible and establish a "no take" MFR in Culebra Island to prevent further depletion of fish stocks.

KEY WORDS: Bootstrapping analysis, Coral reefs, Marine Fishery Reserve.

INTRODUCTION

Marine Fishery Reserves (MFRs) have been recognized as one of the most effective tools to restore depleted reef fishery stocks (Plan Development Team, 1990; Bohnsack, 1994; Roberts, 1994, 1995, Wantiez et al., 1997; Jennings, 1998). Since 1980, in a time were MFRs were not a frequently used management tool and were also largely unknown to the fishermen community, fishermen from Culebra Island, Puerto Rico, were proposing to the government of Puerto Rico the closure of an area for the propagation of target reef fish species (=no take zone). In spite of their unanimous support, and after a 18 year time span, no action has been taken. Vicente (1995) formally proposed the designation of a MFR in the western coast of Culebra Island. In spite of the very well known ecological significance of this zone and its touristic potential, there is a lack of qualitative and quantitative descriptions of its coral reefs and fish communities. Our objective was to provide a preliminary baseline data bank regarding the ecological conditions of the proposed MFR.

METHODS

Study sites

Culebra Island is located 27 km off northeastern Puerto Rico (Figure 1). The proposed MFR is located in the western coast of Culebra Island, between Punta Melones and the southeastern coast of Cayo de Luis Peña, in the south, and the northwestern coast of Cayo de Luis Peña and parallel 18˚20'N, 65˚20'W, just north of Carlos Rosario Beach, in the north. This area was part of a former U.S. Navy practice bombing site (see IDEA, 1970; Rogers et al., 1978). Unexploded ordnance are frequently found in the area.

Qualitative Description

A preliminary qualitative characterization of marine communities within the proposed MFR was based on field data obtained between 1994 and 1998, and on an analysis of 21 low altitude (152 m) oblique photos. The western coast of Culebra Island was subdivided in three different zones: Zone 1 (Punta Noroeste to Punta Tamarindo Grande), Zone 2 (Punta Tamarindo Grande to Punta Tamarindo Chico), and Zone 3 (Punta Tamarindo Chico to Punta Melones). Each aerial photo was analyzed with a 200 point dot grid (n=3,098 points). We estimated the percent cover of rocky reefs, reef flats, coral reefs, hard grounds, seagrass beds and sandy bottoms within approximately 200 m of the coastline.

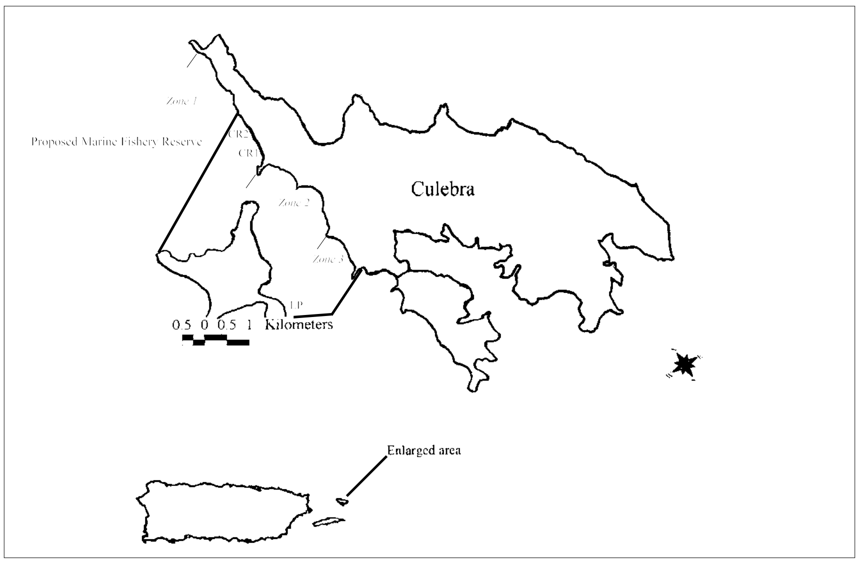


FIGURE 1. Study sites and proposed Marine Fishery Reserve (MFR).

Quantitative Description

The quantitative studies of epibenthic communities were carried out in Carlos Rosario Beach (18˚19'36"N, 65˚19'56"W). We used the line-intercept transect method (Loya and Slobodkin, 1971) to describe coral reef epibenthic communities. Briefly, two monitoring stations (Figure 1) were permanently established (CR1, CR2). Five 10-m long transect systems were placed in duplicates at each station (n=10 transects/station) at depths ranging from 4 to 8 m in CR1 and from 3 to 11 m in CR2. This method allowed us to determine the percentage of cover of all major epibenthic components (i.e., corals, algae, sponges, other macroinvertebrates), corals species diversity index, H'n (Shannon and Weaver, 1948) and evenness (Pielou, 1966a,b). In addition, we assessed coral vitality conditions (sensu=Dustan, 1977) and estimated the percentage of partial colony mortality of the scleractinian corals with diameters larger than 25 cm following the Atlantic & Gulf Reef Assessment Protocol (AGRA-RAP).

Reef fish communities were described by means of the stationary visual census method of Bohnsack and Bannerot (1986). Each sampling station covered an imaginary cylinder with a radius of 7.5 m, a surface area of 176.7 m^2. Data was obtained within a period of 15 min. Fish fork lengths were estimated in cm by direct comparison of fishes to a 0.5 m cm-calibrated ruler attached at a perpendicular angle to the end of a 1.0 m PVC pipe carried out by each observer. Size data was used to calculate fish biomass according to Bohnsack and Harper (1988), and Bohnsack (unpublished manuscript). Weight-length relationships were calculated by fitting a regression line to the equation: log W= log a + b log L, which is equivalent to the equation $W= aL^b$, where W is weight in grams, L is length in mm, and a and b are constants Data was obtained from Carlos Rosario Beach (26 sampling stations in 1996, 31 sampling stations in 1998) and from the southeastern coast of Cayo de Luis Peña, located at 18˚17.931'N, 65˚19.663'W (9 sampling stations in 1998). Data was compared between both years.

Data was analyzed by means of bootstrapping analysis (Efron, 1982; Efron and Tibshirani, 1986). Each data set (individual replicate samples) was re-sampled 1000 times to generate a sampling distribution of the means of each parameter. The 0.025 and 0.975 percentile values of these distributions were calculated to test for significant differences ($\propto$=0.05) between 1997 and 1998 for epibenthic communities and between 1996 and 1998 for fish communities at Carlos Rosario Beach. We also tested for significant differences between Carlos Rosario Beach and Cayo de Luis Peña for the 1998 data.

RESULTS

Qualitative Description

A preliminary characterization of the marine communities located in the western coast of Culebra Island (Figure 2) showed that seagrass beds were the most abundant community type (35%), followed by coral reefs (34%), sandy bottoms (11%) and hard grounds (10%). Coral reefs were the dominant community type in Zone 1 (51%), followed by hard ground communities (14%). Seagrass beds were dominant in Zones 2 (62%) and 3 (51%), followed by coral reefs. Other deeper areas (15-22 m) of the Luis Peña Channel are mostly covered by seagrasses. In addition, most of the Cayo de Luis Peña coast (not included in this analysis) is covered by hard ground, rocky reefs and coral reef communities. The above data suggest that a significant portion of the proposed MFR is characterized by the presence of highly developed biogenic coral reefs (Zone 1), seagrass beds and fringing reefs (Zones 2 and 3).

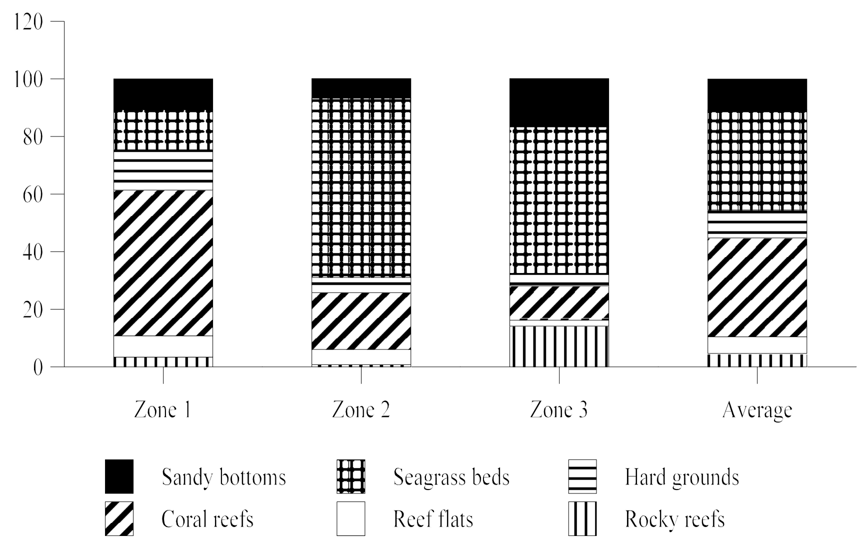


FIGURE 2. Qualitative characterization of epibenthic communities within the proposed MFR of Culebra Island (data was obtained from the first 200 m offshore of the western coast of Culebra.

Biological Characterization

A total of 69 coral species (4 hydrocorals, 25 octocorals, 40 scleractinians) were identified (Table 1). Thirty nine scleractinian coral species were identified in Carlos Rosario Beach, followed by Cayo de Luis Peña (34), Punta Tamarindo Chico (30) and Tarja Bay (29). The latter two were also characterized by a significant presence of juvenile stages (=recruits) of important reef building coral species such as *Montastrea* spp., *Diploria* spp., *Colpophyllia natans*, *Siderastrea siderea* and *Meandrina meandrites*. This is a characteristic which is indicative of good reef health. In addition, 221 species, 113 genera and 59 fish families were listed (Table 2). There are also unusually high aggregations of several important species: juvenile stages of commercially important fish species, recovering populations of the long-spined sea urchin, *Diadema antillarum*, an species which almost disappeared from the entire Caribbean after a massive die-off, and a high aggregation of queen conch, *Strombus gigas*.

TABLE 1. Coral species inventory of the candidate Culebra Island's MFR.

Hydrocorals (n=4)

Millepora complanata
Millepora alcicornis
Millepora squarrosa
Stylaster roseus

Octocorals (n=25)

Erythropodium caribbaeorum
Briareum asbestinum
Gorgonia ventalina
Gorgonia flabellum
Gorgonia mariae
Pseudopterogorgia bipinnata
Pseudopterogorgia spp.
Pterogorgia americana
Pterogorgia citrina
Pterogorgia anceps
Pterogorgia guadalupensis
Plexaura flexuosa
Plexaura homomalla
Plexaura grisea
Eunicea spp.
Eunicea mammosa
Pseudoplexaura porosa
Pseudoplexaura spp.
Muricea muricata
Muricea spp.
Muriceopsis flavida
Plexaurella dichotoma
Plexaurella nutans
Iciligorgia schrammi
Carijoa riisei

Scleractinians (n=40)

Stephanocoenia michelini
Madracis decactis
Madracis formosa?
Madracis sp.
Acropora cervicornis
Acropora palmata
Acropora prolifera
Agaricia agaricites f. *agaricites*
Agaricia agaricites f. *carinata*
Agaricia agaricites f. *purpurea*
Agaricia agaricites f. *danai*
Agaricia fragilis
Agaricia fragilis f. *contracta*
Agaricia lamarcki
Agaricia tenuifolia
Agaricia humilis
Leptoseris cucullata
Siderastrea radians
Siderastrea siderea
Porites astreoides
Porites porites f. *porites*
Porites porites f. *divaricata*
Porites porites f. *furcata*
Favia fragum
Oculina diffusa
Diploria clivosa
Diploria labyrinthiformis (2 morphs)
Diploria strigosa
Manicina areolata
Colpophyllia natans
Colpophyllia natans f. *breviserialis*
Montastraea annularis (3 morphs)
Montastraea cavernosa
Meandrina meandrites f. *meandrites*
Meandrina meandrites f. *braziliensis*
Meandrina meandrites f. *danae*
Dichocoenia stokesii
Dendrogyra cylindrus
Mussa angulosa
Scolymia lacera
Isophyllia sinuosa
Isophillastrea rigida
Mycetophyllia lamarckiana
Mycetophyllia danaana
Mycetophyllia aliciae
Mycetophyllia ferox
Eusmilia fastigiata
Tubastrea aurea
Astrangia solitaria

TABLE 2. Reef fish species inventory of the candidate Culebra Island's MFR.

Family	Species	Common name
Class Chondrichthyes		
Orectolobidae	*Ginglymostoma cirratum*	Nurse shark
Carcharhinidae	*Negaprion brevirostris*	Lemon shark
	Carcharhinus spp.	Requiem sharks
Dasyatididae	*Dasyatis americana*	Southern stingray
Mobulidae	*Manta birostris*	Atlantic manta
Myliobatidae	*Aetobatis narinari*	Spotted eagle ray
Class Osteichthyes		
Elopidae	*Megalops atlanticus*	Tarpon
Albulidae	*Albula vulpes*	Bonefish
Clupeidae	*Harengula* spp.	Sardines
	Opisthonema oglinum	Thread herring
	Jenkinsia lamprotaenia	Dwarf herring
Synodontidae	*Synodus intermedius*	Sand diver
	Synodus synodus	Rockspear
Ophichthidae	*Myrichthys ocellatus*	Goldspotted snake eel
Muraenidae	*Gymnothorax moringa*	Spotted moray
	Gymnothorax funebris	Green moray
	Gymnothorax miliaris	Golden tail moray
	Gymnothorax vicinus	Purplemouth moray
	Echidna catenata	Chain moray
Atennariidae	*Attenarius multiocellatus*	Longlure frogfish
Gobiesocidae	*Arcos* spp.	Clingfishes
	Gobiesox punctulatus	Stippled clingfish
Exocoetidae	*Hirundichthys* sp.	Flying fishes
Belonidae	*Tylosurus crocodilus*	Houndfish
Hemiramphidae	*Hemiramphus brasiliensis*	Ballyhoo
	Hemiramphus balao	Balao
Atherinidae	*Allanetta harringtonensis*	Reef silverside
	Atherinomorus stipes?	Hardhead silverside
Fistularidae	*Fistularia tabacaria*	Cornetfish
Aulostomidae	*Aulostomus maculatus*	Trumpetfish
Holocentridae	*Holocentrus ascensionis*	Longjaw squirrelfish
	Holocentrus rufus	Squirrelfish
	Neoniphon marianus	Longspine squirrelfish
	Sargocentron vexillarium	Dusky squirrelfish
	Sargocentron coruscum	Reef squirrelfish
	Myripristis jacobus	Blackbar soldierfish
Scorpaenidae	*Scorpaena plumieri*	Spotted scorpionfish
	Scorpaena inermis	Mushroom scorpionfish
	Scorpaenodes sp.?	Reef scorpionfisDactylopteridae
	Dactylopterus volitans	Flying gurnard
Serranidae	*Cephalopholis cruentata*	Graysby
	Cephalopholis fulva	Coney
	Epinephelus adscensionis	Rock hind
	Epinephelus guttatus	Red hind
	Epinephelus itajara	Jewfish
	Epinephelus morio	Red grouper
	Epinephelus striatus	Nassau grouper

	Hypoplectrus aberrans	Yellowbellied hamlet
	Hypoplectrus chlorurus	Yellowtail hamlet
	Hypoplectrus indigo	Indigo hamlet
	Hypoplectrus nigricans	Black hamlet
	Hypoplectrus puella	Barred hamlet
	Hypoplectrus unicolor	Butter hamlet
	Hypoplectrus guttavarius	Shy hamlet
	Hypoplectrus gummigutta	Golden hamlet
	Hypoplectrus sp.?	Tan hamlet
	Alphestes afer	Mutton hamlet
	Liopropoma spp.	Basslets
	Serranus tigrinus	Harlequin bass
	Serranus baldwini	Lantern bass
	Serranus annularis	Orangeback bass
	Serranus tabacarius	Tobaccofish
	Serranus tortugarum	Chalk bass
	Serranus sp.	Basslet
	Paranthias furcifer	Creole fish
	Rypticus saponaceus	Soapfish
Grammatidae	*Gramma loreto*	Fairy basslet
Priacanthidae	*Priacanthus cruentatus*	Glasseye
	Priacanthus arenatus	Bigeye
Apogonidae	*Apogon townsendi*	Belted cardinalfish
	Apogon binotatus	Barred cardinalfish
	Apogon planifrons	Pale cardinalfish
	Apogon lachneri	Whitestar cardinalfish
	Apogon aurolineatus	Bridle cardinalfish
	Apogon quadrisquamatus	Sawcheek cardinalfish
	Apogon spp.	Cardinalfishes
	Astrapogon stellatus	Conchfish
Malacanthidae	*Malacanthus plumieri*	Sand tilefish
Cirrhitidae	*Amblycirrhitus pinos*	Redspotted hawkfish
Mugilidae	*Mugil curema*	White mullet
Sphyraenidae	*Sphyraena barracuda*	Great barracuda
	Sphyraena picudilla	Southern sennet
Echeneididae	*Echeneis naucrates*	Sharksucker
	Echeneis neucratoides	Whitefin sharksucker
	Remorina albescens	Sharksucker
	Remora remora	Remora
Carangidae	*Carangoides bartholomaei*	Yellow jack
	Carangoides crysos	Blue runner
	Carangoides ruber	Bar jack
	Caranx hippos	Crevalle jack
	Caranx latus	Horse-eye jack
	Caranx lugubris	Black jack
	Decapterus sp.	Scad
	Elegatis bipinnulatus	Rainbow runner
	Selar crumenophthalmus	Bigeye scad
	Trachinotus falcatus	Permit
	Trachinotus goodei	Palometa
	Allectis ciliaris	African pompano
Scombridae	*Scomberomorus regalis*	Cero
Lutjanidae	*Lutjanus analis*	Mutton snapper
	Lutjanus apodus	Schoolmaster
	Lutjanus cyanopterus	Cubera snapper

	Lutjanus griseus	Gray snapper
	Lutjanus jocu	Dog snapper
	Lutjanus mahogoni	Mahogany snapper
	Lutjanus synagris	Lane snapper
	Ocyurus chrysurus	Yellowtail snapper
Haemulidae (=Pomadasyidae)	*Anisotremus surinamensis*	Black margate
	Anisotremus virginicus	Porkfish
	Haemulon album	Margate
	Haemulon aurolineatum	Tomtate
	Haemulon bonariense	Black grunt
	Haemulon carbonarium	Caesar grunt
	Haemulon chrysargyreum	Smallmouth grunt
	Haemulon flavolineatum	French grunt
	Haemulon macrostonum	Spanish grunt
	Haemulon melanurum	Cottonwick
	Haemulon parrai	Sailor's choice
	Haemulon plumieri	White grunt
	Haemulon sciurus	Bluestriped grunt
	Haemulon striatum	Striped grunt
Sparidae	*Calamus calamus*	Saucereye porgy
Sciaenidae	*Equetus lanceolatus*	Jacknife fish
	Equetus punctatus	Spotted drum
	Odontoscion dentex	Reef croaker
	Pareques acuminatus	Cubbyu
Mullidae	*Mulloidichthys martinicus*	Yellow goatfish
	Pseudupeneus maculatus	Spotted goatfish
Pempheridae	*Pempheris schomburgki*	Copper sweeper
Gerreidae	*Gerres cinereus*	Yellowfin mojarra
	Eucinostomus sp.	Mojarra
Kyphosidae	*Kyphosus sectatrix*	Bermuda chub
Ephippidae	*Chaetodipterus faber*	Spadefish
Bothidae	*Bothus lunatus*	Peacock flounder
	Bothus ocellatus	Eyed flounder
Chaetodontidae	*Chaetodon capistratus*	Foureye butterflyfish
	Chaetodon ocellatus	Spotfin butterflyfish
	Chaetodon striatus	Banded butterflyfish
Pomacanthidae	*Centropyge argi*	Cherubfish
	Holacanthus ciliaris	Queen angelfish
	Holacanthus tricolor	Rock beauty
	Pomacanthus arcuatus	Gray angelfish
	Pomacanthus paru	French angelfish
Pomacentridae	*Abudefduf saxatilis*	Sergeant major
	Abudefduf taurus	Night sergeant
	Chromis cyanea	Blue chromis
	Chromis multilineata	Yellow-edge chromis
	Chromis scotti	Purple reef fish
	Microspathodon chrysurus	Yellowtail damselfish
	Stegastes diencaeus	Longfin damselfish
	Stegastes dorsopunicans	Dusky damselfish
	Stegastes leucostictus	Beau gregory
	Stegastes partitus	Bicolor damselfish
	Stegastes planifrons	3-spot damselfish
	Stegastes variabilis	Cocoa damselfish
Labridae	*Bodianus pulchellus*	Spotfin hogfish
	Bodianus rufus	Spanish hogfish

	Clepticus parrae	Creaole wrasse
	Halichoeres bivittatus	Slippery dick
	Halichoeres garnoti	Yellowhead wrasse
	Halichoeres maculipinna	Clown wrasse
	Halichoeres pictus	Painted wrasse
	Halichoeres poeyi	Black-ear wrasse
	Halichoeres radiatus	Pudding wife
	Lachnolaimus maximus	Hogfish
	Thalassoma bifasciatum	Bluehead
	Xyrichthys sp.	Razorfish
Scaridae	*Cryptotomus roseus*	Slender parrotfish
	Sparisoma atomarium	Green blotch parrotfish
	Sparisoma aurofrenatum	Red band parrotfish
	Sparisoma chrysopterum	Redtail parrotfish
	Sparisoma radians	Bucktooth parrotfish
	Sparisoma rubripinne	Yellowtail parrotfish
	Sparisoma viride	Stoplight parrotfish
	Scarus coeruleus	Blue parrotfish
	Scarus iserti (=*S. croicensis*)	Striped parrotfish
	Scarus taeniopterus	Princess parrotfish
	Scarus vetula	Queen parrotfish
Opistognathidae	*Opistognathus whitehursti*	Dusky jawfish
	Opistognathus spp.	Jawfish
Bleniidae	*Ophioblennius atlanticus*	Redlip blenny
	Bleniidae spp.	Blennies
Labrisomidae	*Labrisomus gobio*	Palehead blenny
	Labrisomus spp.	Blennies
	Malacoctenus triangulatus	Saddled blenny
	Malacoctenus versicolor	Barfin blenny
	Malacoctenus macropus	Rosy blenny
Chaenopsidae	*Acanthemblemaria spinosa*	Spinyhead blenny
	Acanthemblemaria sp.	Flag blenny
	Chaenopsidae spp.	Flag blennies
Gobiidae	*Bathygobius soporator*	Frillfin goby
	Coryphopterus glaucofraenum	Bridled goby
	Coryphopterus personatus	Masked goby
	Coryphopterus punctipectophorus	Spotted goby
	Gobiosoma oceanops	Neon goby
	Gobiosoma horsti	Yellowline goby
	Gobiosoma evelynae	Sharknose goby
	Gobiosoma genie	Cleaning goby
	Gobiosoma multifasciatum	Greenbanded goby
	Gobiosoma sp.	Goby
	Gobiidae spp	Gobies
Acanthuridae	*Acanthurus bahianus*	Ocean surgeon
	Acanthurus chirurgus	Doctorfish
	Acanthurus coeruleus	Blue tang
Balistidae	*Balistes vetula*	Queen triggerfish
	Melichthys niger	Black durgon
Monacanthidae	*Aluterus scriptus*	Scrawled filefish
	Cantherhines pullus	Orangespotted filefish
	Cantherines macrocerus	Whitespotted filefish
	Monacanthus tuckeri	Slender filefish
	Monacanthus setifer	Speckled filefish
	Monacanthus ciliatus	Fringed filefish

Ostraciidae	*Acanthostracion polygonius*	Honeycomb cowfish
	Acanthostracion quadricornis	Scrawled cowfish
	Lactophrys bicaudalis	Spotted trunkfish
	Lactophrys trigonus	Buffalo trunkfish
	Lactophrys triqueter	Smooth trunkfish
Tetraodontidae	*Canthigaster rostrata*	Sharpnose puffer
	Sphoeroides spengleri	Bandtail puffer
Diodontidae	*Diodon holocanthus*	Spiny puffer
	Diodon hystrix	Porcupine fish
Family richness =	59	
Genera richness =	113	
Species richness =	221	

QUANTITATIVE DESCRIPTION

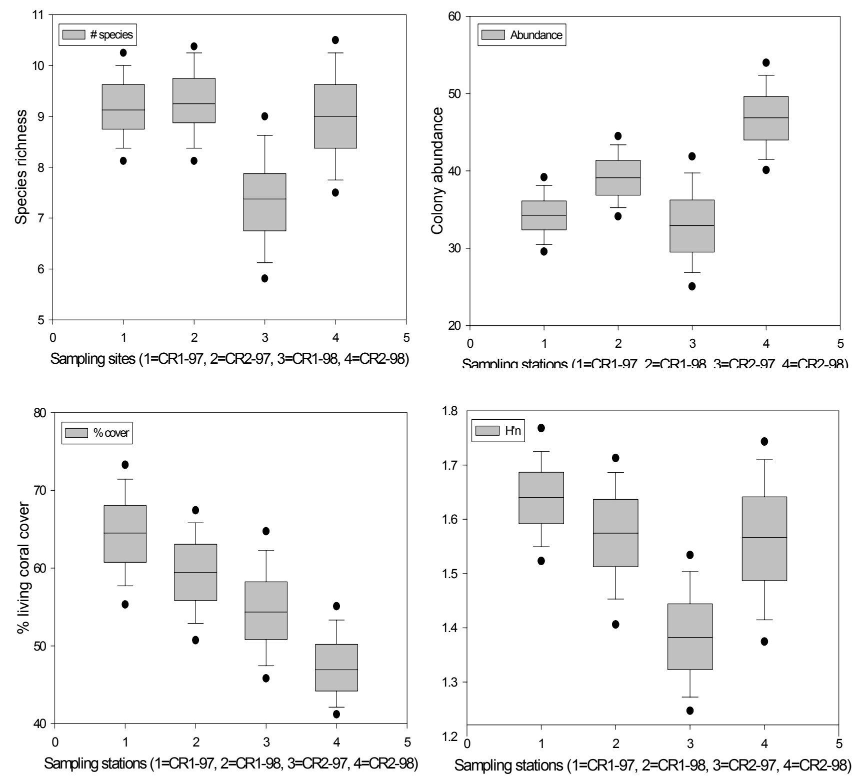
Coral Reef Epibenthic Communities

Average species richness increased in CR1 from 9.2±0.7 to 9.3±0.7, and in CR2 from 7.4±0.9 to 8.9±0.9. However, these increases between years were not significant (Figure 3a). There was also a non-significant increase in colony abundance in sampling station CR2 between 1997 and 1998, from 33.1±5.0 to 46.9 colonies (Figure 3b). However, in most cases, this increase was actually the result of colony fragmentation instead of coral recruitment. Fragmentation was caused by partial colony mortality associated to algal overgrowth, damselfish (Pomacentridae) activities, lethal diseases (i.e., white plague, black band disease) or bioerosion.

In both sampling stations there was a non-significant decrease in living coral cover between years from 64.5±5.4% to 59.4±5.1% in CR1, and from 54.7±5.7% to 47.4±4.3% in CR2 (Figure 3c). Diversity decreased in CR1 from 1.6405±0.0718 to 1.5711±0.0918, and increased in CR2, from 1.3860±0.0877 to 1.5645±0.1137 (Figure 3d). But, these changes were not significant. Evenness decreased from 0.7443±0.0205 to 0.7069±0.0244 in CR1, and from 0.7193±0.0220 to 0.7185±0.0242 in CR2. These changes were also not significant. The analysis of coral vitality conditions showed that only 29% of the hard corals were considered to be healthy or unblemished, 46% were overgrown by filamentous algae, 37% by macroalgae and 20% were bioeroded. Percentage of mortality in corals with maximum diameter larger than 25 cm was estimated to be 32.9±5.6% at CR1 and 28.3±9.8% in CR2 for the 1998 data.

Reef Fish Communities

Average species richness decreased from 18.0±1.1 to 17.9±2.3 (Figure 4a) in Carlos Rosario Beach between 1996 (CR96) and 1998 (CR98). Species richness in Cayo de Luis Peña (LP98), 22.5±1.5, is not significantly different from CR98.



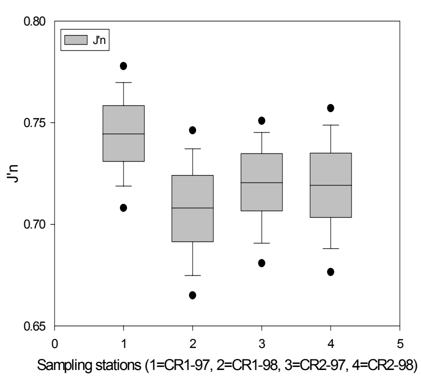


FIGURE 3. Box and whisker plots after bootstrapping analysis (n=1000 replicates) for the coral reef epibenthic community data (from top left to bottom right): a) coral species richness per 10-m long transect; b) coral colony abundance; c) % living coral cover; d) coral H'n; e) coral J'n. Data based on 10 transects per sampling station (CR1, CR2), per year (1997, 1998). The horizontal line within each box represents the mean value, boxes represent the 75% percentile, error bars represent the 90% percentile, dots represent the 95% percentile.

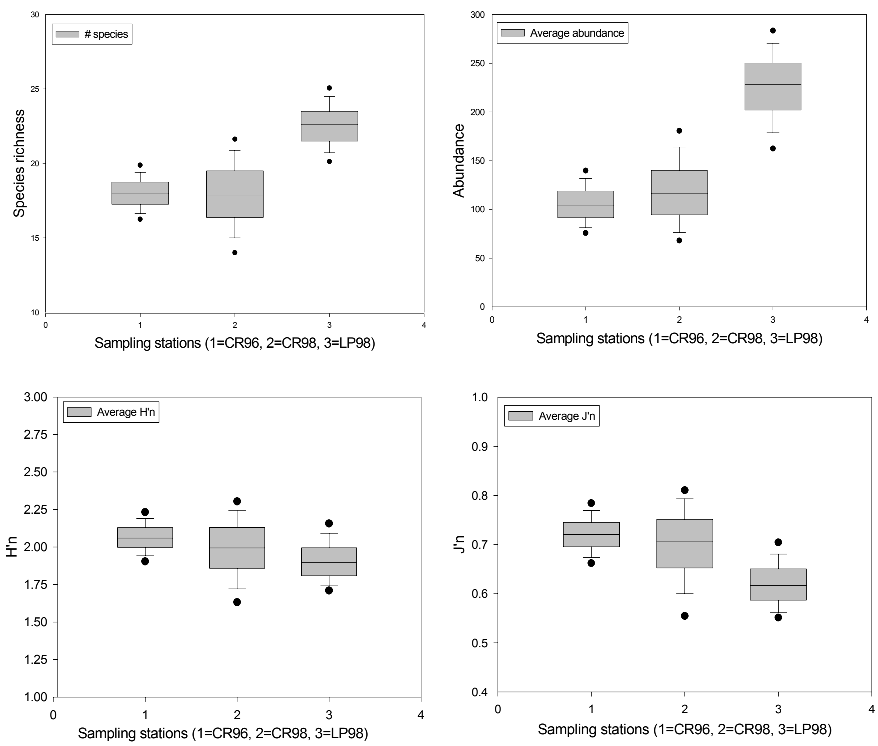


FIGURE 4. Box and whisker plots after bootstrapping analysis (n=1000 replicates) for reef fish community data (from top left to bottom right): a) species richness per station; b) fish abundance; c) H'n; d) J'n. The horizontal line within each box represents the mean value, boxes represent the 75% percentile, error bars represent the 90% percentile, dots represent the 95% percentile.

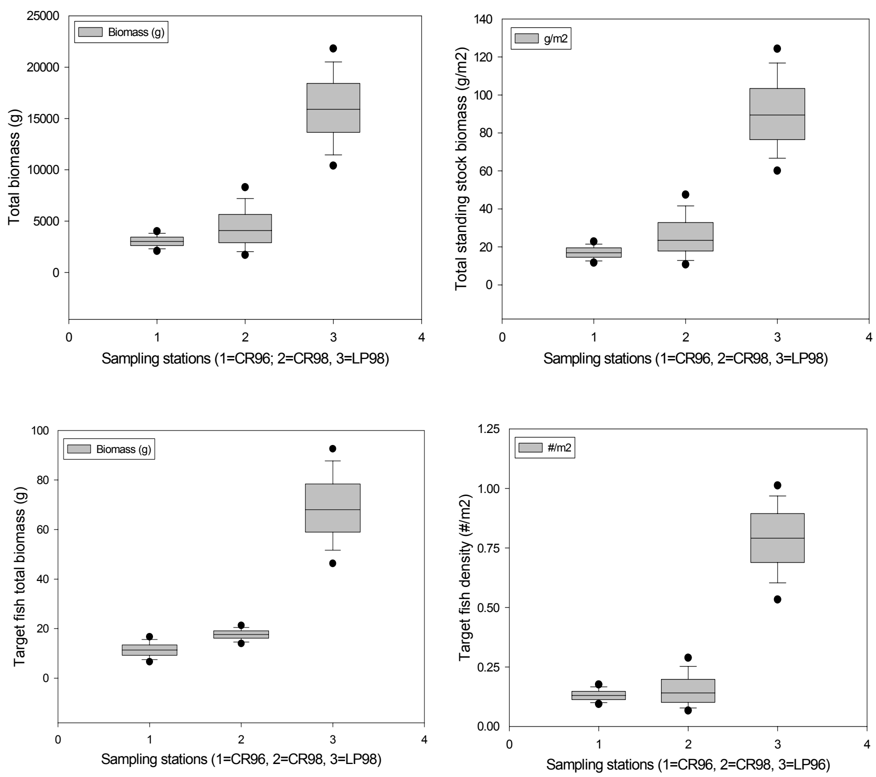


FIGURE 5. Box and whisker plots after bootstrapping analysis (n=1000 replicates) for reef fish community data (from top left to bottom right): a) total fish biomass (g); b) target fish standing stock biomass (g/m^2); c) target fish total biomass (g); d) target fish density ($\#/m^2$). The horizontal line within each box represents the mean value, boxes represent the 75% percentile, error bars represent the 90% percentile, dots represent the 95% percentile.

Fish abundance increased from 105.7±19.5 in CR96 to 118.7±34.6 in CR98, a change which was not significant (Figure 4 b). However, fish abundance was significantly higher in LP98 (225.9±36.2) when compared to CR98. Diversity also decreased from 2.0634±0.0978 in CR96 to 1.9874±0.2052 in CR98, and averaged 1.9075±0.1367 in LP98 (Figure 4c). However, these differences were not significant. Evenness (Figure 4d) also decreased from 0.7210±0.0371 in CR96 to 0.6979±0.0744, and averaged 0.6209±0.0469 in LP98. These differences were also not significant.

Total biomass (Figure 5a) was significantly higher in LP98 (16007.0±3407.6 g) than in CR98 (4418.7±2029.7 g), which suggests that fishes are more abundant and larger in Cayo de Luis Peña. Although there was a slight increase in average biomass in CR98 when compared to that of CR96 (3039.1±593.7), that difference was not significant. Standing stock biomass (Figure 5b) was significantly higher at LP98 (90.72±19.75 g/m^2) than in CR98 (25.74±11.19 g/m^2). Although there was also an increase in total standing stock fish biomass in CR98 when compared to CR96 (17.04±3.45 g/m^2), that difference was not significant. Similarly, total biomass of fishery target species (Figure 5c) was significantly higher in LP98 (68.86±13.95 g). CR96 averaged 11.45±3.06 g and CR98 averaged 17.64±2.25 g, a difference which was not significant. The proportion of target fish biomass from the total fish biomass was 0.38% for CR96, 0.40% for CR98 and 0.43% for LP98. Finally, density of target fish species followed a similar trend (Figure 5d). Density at LP98 (0.7857±0.1439 individuals/m^2) was significantly higher than that at CR98 (0.1557±0.0699 individuals/m^2). CR96 averaged 0.1316±0.0254 individuals/m^2, a difference which was not significant when compared to CR98.

DISCUSSION

This is first study to document the structure of fish and coral communities of the candidate MFR of Culebra Island, Puerto Rico. A total of 69 coral species, including 40 scleractinians were identified, which rivals other coral reef communities from the northeastern Caribbean (Goreau, 1959; Almy and Carrión-Torres, 1963; Goenaga and Boulon, 1992). The fish community is also highly diverse, with a total of 221 species identified so far. Thus, the coral reefs of the proposed MFR are representative of the highly diverse epibenthic and fish communities of the northeastern Caribbean. In addition, living coral cover is higher than in many other coral reefs in the region (Hernández-Delgado, in preparation). Moreover, the unusual dominance of the columnar morphotype of *Montastrea annularis* (75%) and its location upstream of a system of Natural Reserves (i.e., La Cordillera, Cabezas de San Juan, Espíritu Santo River Estuary), gives this coral reef system a high bio-constructional value and makes it highly important in terms of fish and coral larval dispersion.

However, our quantitative data suggest that, in spite of the fact that coral reef epibenthic communities at Carlos Rosario Beach showed no significant variation between 1997 and 1998, there were, in fact, differences in the abundance of coral colonies in sampling station CR2. This increase in colony abundance do not reflect the effects of recruitment. Although there were some coral recruits of coral species characterized by relatively high recruitment rates, such as *Porites porites*, *P. astreoides* and *Agaricia* spp., most of this fluctuations were the result of partial colony mortality associated to damselfish (Pomacentridae) territorial behavior and to death caused by the white plague (Hernández-Delgado et al., in preparation), as evidenced in the 5% to 7% observed reduction in living coral cover. Even in the absence of known point-source pollution sources, corals within the proposed MFR are already showing signs of degradation, possibly as a direct or indirect consequence of overfishing.

An analysis of the ecological condition at the level of individual coral colonies carried out in 1997 at Carlos Rosario Beach (data not shown) showed that only 29% of the stony corals were considered healthy, 46% were overgrown by filamentous algae, 37% were overgrown by macroalgae and 20% showed signs of bioerosion (Hernández-Delgado, in preparation). More than 50% of the corals were also showing signs of partial mortality, in part associated to the territorial activities of damselfishes, mostly *Stegastes planifrons*. In fact, damselfish abundance in Carlos Rosario Beach has significantly increased between 1997 and 1998 (Hernández-Delgado, unpublished data). In addition, several lethal diseases have been identified in corals, including: white plague, black band disease, white band disease, yellow band disease, sea fan lethal fungus disease and sea fan red band disease. It is unknown if there is any relationship between the prevalence and frequency of theses diseases and overfishing.

There is also evidence that fish communities are overfished in Carlos Rosario Beach (CR98) when compared to Cayo de Luis Peña (LP98). Although we observed an increase in fish abundance, biomass, standing stock biomass, and other parameters in Carlos Rosario Beach between 1997 and 1998, these were not significant and were considered to be part of the natural fluctuations of the fish community. However, significantly higher values in parameters such as fish abundance, total biomass, standing stock biomass, and in the target fish species biomass and density in Cayo de Luis Peña (CR98) can be considered direct evidence of a higher fishing pressure in Carlos Rosario Beach. The fact that the coral reef in Cayo de Luis Peña is isolated from the island of Culebra by the Luis Peña Channel and can be accessed only by boat,and that sea conditions are sometimes rough for SCUBA diving and other recreational activities, including fishing, provide a higher degree of natural protection to the fish community. In contrast, Carlos Rosario Beach can be easily accessed by walking or driving. It is mostly frequented by local and tourist recreational fishermen and SCUBA divers. Effects of overfishing can be suspected from the dramatically low proportion of target fish biomass from the total fish biomass which never exceeded 0.43% and from the behavior of target fish species when approached by humans. In addition, large individuals of species of groupers, snappers, grunts and parrotfishes are rarely seen. The above scenario suggest the immediate need of establishing management measures to prevent additional loss of the reef fish stock by designating it a MFR.

CONCLUSIONS

The proposed MFR of Culebra Island is dominated by seagrass beds and coral reef communities, which present a high biological diversity representative of northeastern Caribbean coral reefs. Coral reefs still support a relatively healthy epibenthic community characterized by a high percentage of living coral cover, colony abundance and species richness. However, we detected what could be considered a possible early sign of degradation, including a decline in the percentage of living coral cover in Carlos Rosario Beach between 1997 and 1998, and lower values in parameters such as fish abundance, total biomass, standing stock biomass, and in the target fish species biomass and density in parameters such as fish abundance, total biomass, standing stock biomass, and in the target fish species biomass and density in Carlos Rosario Beach than in Cayo de Luis Peña. These results suggest that overfishing seems to be a major factor affecting fish communities at easily accessible sites, such as Carlos Rosario Beach, and requires the establishment of management measures.

MFRs have been demonstrated to be an excellent tool to help restore depleted fish stocks (Ballantine, 1991; Roberts and Polunin, 1991; Bohnsack, 1994; Roberts, 1994, 1995; Lincoln-Smith et al., 1997) and produce important socio-economic benefits to base communities (Dixon et al., 1993; Bojos, 1994). The designation of the MFR of Culebra Island may help to protect and manage representative examples of coral reefs and other associated ecosystems to ensure its long term viability and to maintain a high genetic diversity. It can also protect declining reef fish populations, including those commercially important, as well as endangered marine turtles and their critical habitats. A MFR can also protect coral reef communities in a healthy ecological state, with a high aesthetic and recreational value, prevent the negative impacts of human activities within and outside of the MFR, and establish a "no take zone" for the propagation of fishes, corals and other organisms. It can facilitate the interpretation of marine ecosystems with the purpose of conservation, education, research and low-impact tourism. A MFR designation can also allows co-management, which can provide participation in the planning, administration and management of the MFR to local base communities, fishermen, divers, Municipal Government of Culebra, Authority for the Conservation and Development of Culebra, U.S. Fish and Wildlife Service, academia, voluntary citizens, environmental organizations and other interest groups through a co-management model.

Our data suggest that there is no time to lose and that a MFR designation should be enacted as soon as possible if the government of Puerto Rico wants to conserve and restore depleted fish stocks in Culebra Island. This zone becomes even more important due to its strategic location upstream of other healthy coral reefs.

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