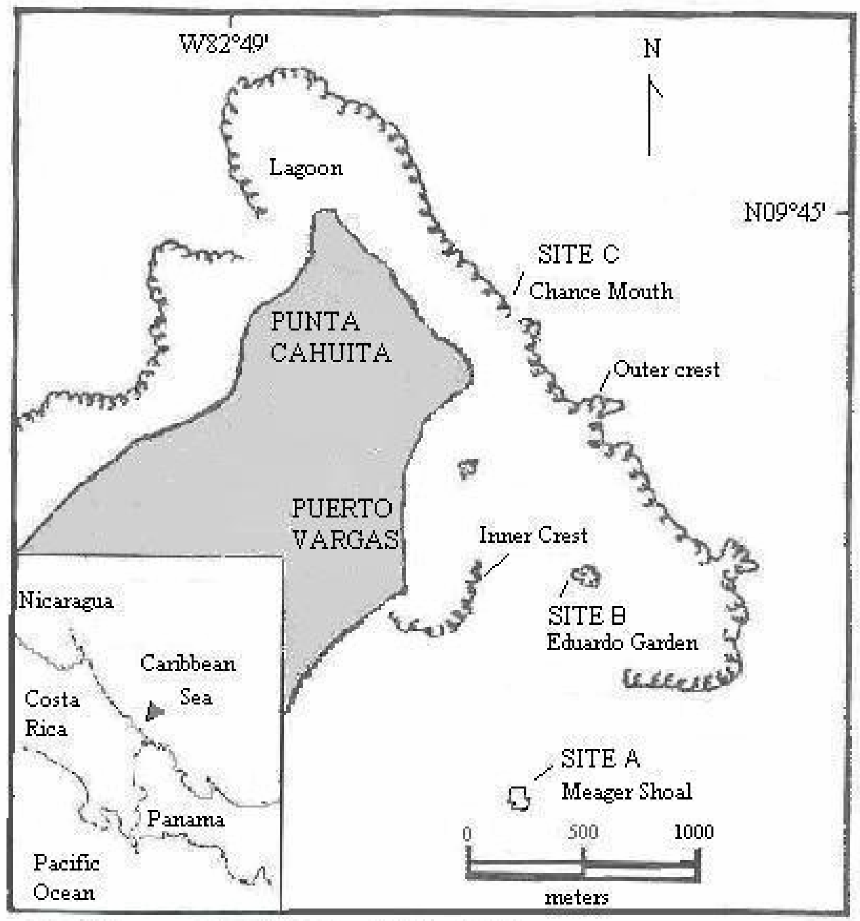

Figure 1. AGRRA survey sites in Cahuita, Costa Rica (modified from Cortés, 1998).

A RAPID ASSESSMENT AT CAHUITA NATIONAL PARK, COSTA RICA, 1999 (PART 1: STONY CORALS AND ALGAE)

BY

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ABSTRACT

Live stony coral cover, which has deteriorated in Costa Rica's Cahuita National Park, was 2-3% in three reefs during October 1999. About eight percent of all "large" scleractinians (≥25 cm in diameter) were diseased. The number of scleractinian species and the densities of recruits and *Diadema antillarum* were greatest in a carbonate hardground, where total (recent + old) partial-colony mortality of large scleractinians and macroalgal abundance were lowest. Colonies of *Acropora palmata* that were mostly dead were found only in a shallow patch reef where old partial-colony mortality was highest and where the largest corals were found. Recent partial-colony mortality was lowest in an outer fore-reef habitat. Recovery of deforested watersheds, the main source of the sediment stress in this and other reef systems on the Caribbean coast of Costa Rica, is urgently required.

INTRODUCTION

Cahuita National Park, situated 35 km south of the city of Limón, has the largest fringing reef on the Caribbean coast of Costa Rica (Cortés, 1998). Its main outer reef, situated 1 km from the coast, arcs around the northern tip of Punta Cahuita, runs southeast about 5 km, and bends inshore towards Puerto Vargas (Fig. 1). A narrow spur-and-groove system reaches depths of 10 m on the outer fore reef. Several small patch reefs occur among meadows of seagrass (*Thalassia testudinum, Syringodium filiforme),* algae, and coral fragments in a 3 m-deep lagoon shoreward of the outer reef. Several shallow carbonate hardgrounds (7-10m) are located south of the main reef and offshore of Puerto Vargas beach. A small (500 m long) inner reef is located 100 m off the north end of the beach. Stony coral cover (measured by the chain transect method) averaged 40% across this inner reef in 1981 (Cortés and Risk, 1984).

Rainfall at Cahuita averages about 300 cm/year. The nearshore current, which flows from northwest to southeast, is strong, and wave energy is high, but the tidal amplitude is low (30-50 cm) (Cortés, 1998). Stony coral growth rates and diversity are

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low. As summarized by Cortés and Risk (1984), species inhabiting the Cahuita reefs are considered to be good sediment rejecters (e.g., *Siderastrea, Diploria*), or to have morphologies that inherently facilitate sediment removal (e.g., frondose *Agaricia agaricites*) and/or efficiently intercept light (e.g., foliacious *Porites astreoides*).

Since 1970, 600 ha of the reef have been afforded partial protection by the creation of the Cahuita National Park (Cortés and Guzmán 1985). However, deforestation of the highlands and inappropriate agricultural practices, particularly on the coastal banana plantations, had already increased the input of noncarbonate (terrigenous) sediment and other pollutants in runoff, especially from Rio La Estrella. Physical damage to the reefs from visitors (trampling, diving, and anchoring) has also increased (Cortés, 1994). Both local inhabitants (who are allowed to fish with hook-and-line) and tourists walk through the shallow lagoon causing further disturbance to shallow habitats.

Other stressors have included the 40% mortality of stony corals, particularly *Acropora palmata* and *A. cervicornis,* during the 1983 El Niño-Southern Oscillation (ENSO) event and the near-demise of *Diadema antillarum* in 1983 and again in 1992. Shallow-water colonies of *Agaricia agaricite*s and *Porites porites* were severely impacted by the 50 cm uplift of the coastline during the 1991 Limón earthquake (Cortés, 1994). By 1993 stony coral cover had fallen to 11% in 5 m at the Caribbean Coastal Marine Productivity (CARICOMP) monitoring site on the inner reef near Puerto Vargas (Cortés, 1994) where macroalgae were reported to be smothering stony corals and possibly affecting larval settlement. More recently, mild bleaching occurred in the reefs at Cahuita in 1998 (Garzón-Ferreira et al., 2000).

The purpose of this study was to characterize and update the condition of the coral and benthic algal communities in Cahuita National Park in October 1999 at the end of the millennium using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol. Similar data were obtained the following year south of Cahuita close to the Panamian border in the fringing fore reef off Manzanillo, where live stony coral cover was 1.9% in 1988 (Cortés, 1992). Results of the companion fish censuses are given in Fonseca and Gamboa (this volume).

METHODS

Three sites (Fig. 1) that are each considered representative of a habitat type in Cahuita National Park were strategically selected for survey by two divers.

- Meager Shoal is a circular 10,000 m^2 hardground located south of the southern end of the outer reef. Seaward of Puerto Vargas beach, at an average depth of 7.0 m and about 1 km from the coast; it was chosen for its high coral diversity. The sediment that surrounds this bank is predominantly terrigenous muds and easily resuspended by currents.
- Eduardo Garden, a shallow (2 m) patch reef of 6,060 m^2 in the lagoon between the outer and inner reefs, is about 200 m from the coast. Constructed of largely dead colonies of *Acropora palmata*, it is known to be in better condition than other lagoonal sites, and local guides take tourists snorkeling here. Eduardo Garden was the

"outer patch" reef in Cortés and Risk's (1985) investigation of siltation stress at Cahuita.

- Chance Mouth is a shallow (~5.5 m) spur-and-groove formation in the area of maximum topographic relief in the outer fringing reef. Located about 1 km from the coast, Chance Mouth was chosen because it is adjacent to the mouth of the only natural boat channel crossing the outer reef crest. The shallow fore reef that was surveyed at similar depths (4 m) off Manzanillo is a low-relief platform.

The following modifications were made to the AGRRA Version 2.2 benthos protocol (see Appendix One, this volume). The maximum diameter of every stony coral covered by the transect line was recorded. Colonies of *Siderastrea* were only identified to genus due to difficulties with species identification in the western Caribbean. *Millepora* was not included in the surveys of individual corals. Coral sizes were measured to the nearest cm. Sediment was brushed gently off the substratum before estimating the abundance of crustose coralline algae. The abundance of sponges and other invertebrates in the algal quadrats was recorded. We used Humann (1993) for a field guide.

Species diversity (H'), equity (J) and Morisita similarity (Mi) indices, based on maximum colony diameters, were estimated for all scleractinians under the transect lines. Coral diversity indices were compared using a Student t-test.

RESULTS

Stony Corals

The dominant "large" scleractinians (≥25 cm in diameter) in the transects were *Siderastrea, Porites astreoides* and *Montastraea faveolata* in Meager Shoal, *Acropora palmata, Siderastrea* and *Diploria strigosa* in Eduardo Garden, and *Agaricia agaricites* and *Siderastrea* in Chance Mouth. Only *Siderastrea* was relatively abundant in all three sites. Species diversity differed significantly among sites ($p<0.0001$), being highest in Meager Shoal, which had twice as many large scleractinian taxa (eight versus four, respectively) as were present in each of the other two reefs (Table 1). The equity index was slightly higher in Eduardo Garden. The similarity of scleractinian taxa was somewhat greater between Meager Shoal and both Eduardo Garden (Mi=0.48) and Chance Mouth (Mi=0.41) than between Eduardo Garden and Chance Mouth (Mi=0.19).

Although the average density of large scleractinian corals in all three reefs was approximately 0.5 colonies/m (Table 1), the live stony coral cover (scleractinians and *Millepora*) was only 2-3%. The mean size (as maximum diameter and height) of the large corals was substantially greater in Eduardo Garden, where *A. palmata* and *Siderastrea* were especially large (Tables 2, 3), than in the other two reefs.

Recent partial-colony mortality (hereafter recent mortality), which averaged <10% in most surveyed scleractinians, was highest (mean=3%) at Meager Shoal. Estimates of old partial-colony mortality (hereafter old mortality) were more variable (~10-33%) with 34-78% of the colonies in Eduardo Garden and Meager Shoal,

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respectively, having less than 10% old mortality. The highest live:dead ratio (mean=7) was found in Meager Shoal.

Bleaching was only seen in Meager Shoal, where 2% of the large scleractinians were affected (Table 2). The percentage of large colonies affected by disease varied from 7-9%. White-plague disease affected proportionately more colonies of *Siderastrea*, *P. astreoides*, *D. strigosa* and *A. agaricites* in Chance Mouth and Meager Shoal than in Eduardo Garden. Black-band disease, found only in Chance Mouth, had infected one colony of *Siderastrea*. One colony of *Diploria strigosa* that appeared to have red-band disease was recorded in Eduardo Garden. The margins of less than five percent of the live scleractinians were being conspicuously overgrown by sediment-trapping turf algae in all reefs, or by macroalgae in Eduardo Garden and Chance Mouth.

Recruitment by scleractinians, primarily *Siderastrea* (12/18 recruits), was highest in Meager Shoal (Table 4). Recruits were rare in the other two reefs: one *Siderastrea* recruit was seen in Eduardo Garden, whereas two each *Agaricia agaricites* and *Dichocoenia stokesii* had recruited in Chance Mouth.

The following year at 4 m in the Manzanillo fore reef, where the mean live stony coral cover was 1.5%, large scleractinians averaged 32 cm in diameter (Tables 1, 2). Fifteen percent (7/47) of the surveyed corals were scored as diseased, including two colonies of *Siderastrea* with circular lesions ("white spots") of unknown origin. Only one recruit of *Porites astreoides* was found during the entire survey.

Algae and *Diadema antillarum*

Turf algae (and the cyanobacterium *Schizothrix*) constituted the predominant algal functional group in Meager Shoal (mean relative abundance = 67%) and were somewhat more abundant than crustose coralline algae in Eduardo Garden and Chance Mouth (Table 4). The relative abundance of macroalgae, of which the most common were *Dictyopteris, Sargassum* and *Halimeda*, varied from 14-25%. Macroalgal height and macroalgal indices (relative abundance of macroalgae x macroalgal height) were both substantially higher in Chance Mouth (means = 5.5 cm and 134, respectively) than elsewhere. Sponges and other invertebrates were less abundant in Eduardo Garden than in Chance Mouth and Meager Shoal. Tall macroalgae (mean=7.5 cm) predominated at Manzanillo in 2000 where the relative abundance of turf algae and crustose corallines were each less than 25% (Table 2).

The mean density of *Diadema antillarum* at Cahuita in 1999 was considerably greater in Meager Shoal than in the other two reefs (~60 versus 1-7 individuals/100m^2, respectively). *Diadema antillarum* densities in Manzanillo averaged 10 individuals/100m^2 in 2000.

DISCUSSION

The disparity in live stony coral cover between the 1999 AGRRA transects (<3% in three reefs) and those in the inner reef at the 5 m Caribbean CARICOMP site, which have averaged 11% since 1993 (Cortés, 1994; Fonseca, 1999, CARICOMP unpublished report), is due partially to natural differences among the reefs and partially to differing methodologies. AGRRA data are based on projected length under a line and underestimate cover relative to values obtained by counting chain links draped over the contours of the substratum.

Live stony coral cover off Cahuita was lowest in Meager Shoal, where large (≥25 cm in diameter) scleractinians were the most diverse, smallest in size, and had low partial-colony mortality values (Tables 1, 2, 3) and primarily laminar or crustose morphologies. Ambient illumination on the substratum is low: the muddy sediment surrounding the hardground is easily resuspended by currents and it is slightly deeper (7 m versus 5 m, respectively) than the mean annual vertical Secchi depth in this location (Fonseca, 1999, CARICOMP unpublished report). The bleached scleractinians found here in 1999 probably represented colonies that, due to the chronically low-light levels, had not yet recovered from the mild bleaching event the previous year. The slightly higher values of live coral cover (Table 1) as well as the more robust morphologies of the dominant scleractinians in Eduardo Garden and Chance Mouth may be related to their shallower and more highly illuminated locations. Eduardo Garden and Chance Mouth are surrounded by sandy, autochthonous sediment which presumably also contains fewer pollutants (see Cortés, 1994) than the riverine muds that are more likely to accumulate in Meager Shoal.

The high percentage of colonies with signs of active disease (7-9% at Cahuita in 1999; 15% at Manzanillo in 2000), coupled with the low cover of live stony corals in these Caribbean reefs, is of great concern. Estimates of recent partial mortality for large scleractinians were low in both years (0.5-3%). However, as exposed skeletal surfaces are rapidly covered with sediment and/or overgrown by algae (personal observations), snapshot assessments of recent mortality, as employed in the AGRRA benthos protocol, are likely to underestimate the magnitude of recent soft tissue loss in Costa Rica's coastal scleractinians. Old (and total) partial-mortality values were also fairly low (<20%) in all but Eduardo Garden, which had a higher proportion of large scleractinians (*Acropora palmata* and *Diploria strigosa*) that were mostly or entirely dead. Given its shallow location in the lagoon, some of these corals may have died during the 1983 ENSO event; alternatively, the *A. palmata* may have been infected by white-band disease, as seen elsewhere throughout the Caribbean (Aronson and Precht, 2001).

Densities of *Diadema antillarum* are still much lower than were found in Cahuita during the late 1970's and early 1980's (Cortés, 1994). Nevertheless, individuals were reasonably common in Meager Shoal (Table 4), where several *Diadema* were seen spawning and where they appeared to exert more control on benthic macroalgae than in the two other surveyed reefs. However, it is also likely that benthic algal productivity in this hardground is limited by the dim ambient illumination. Crustose coralline algae and macroalgae were relatively more abundant in Eduardo Garden and Chance Mouth, where *Diadema* was comparatively rare (Table 4). Less fishing occurs in these two reefs, yet their larger populations of herbivorous fishes (Fonseca and Gamboa, this volume) appear less effective at consuming macroalgae (Hughes et al., 1987; Hughes, 1994) than the *Diadema* in Meager Shoal. In Chance Mouth, where the higher surge and wave action may inhibit feeding by herbivorous fishes (Hay, 1981), the macroalgae were taller and the macroalgal index (a proxy for biomass) was correspondingly higher. *Diadema* were also scarce and reef fishes were far less abundant in Manzanillo in 2000 than in Chance Mouth in 1999 (Fonseca and Gamboa, this volume). Macroalgae were more abundant and larger here than had been found the previous year in Cahuita. Hence coral reefs that are currently in poor condition are not restricted to Cahuita National Park.

Between 1993 and 1999, suspended particulate matter increased from 9 mg/l to about 20 mg/l at monitoring sites in the Cahuita National Park, including Meager Shoal and Eduardo Garden (Cortés, 1994; Fonseca, 1999, CARICOMP unpublished report), which doubtless is contributing to the continued low stony coral cover and low diversity of this reef system. Watershed owners must be encouraged to conscientiously and consistently follow the national regulation which requires a 50 m wide forested buffer along the rivers to ensure good water quality and improve conditions in coastal aquatic ecosystems. Moreover, as Cortés and Murillo (1985) have noted, "Coherent units of reefs and terrestrial environs must be considered when establishing a marine park or reserve. Watershed of rivers near the reef must be included in the protected area."

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Table 1. Site information for AGRRA stony coral and algal surveys in Cahuita and Manzanillo, Costa Rica.

Site name	Site code	Reef type	Latitude (º ' " N)	Longitude (º ' " W)	Survey date	Depth (m)	Benthic transects (#)	≥25 cm stony corals (#/10 m)	% live stony coral cover (mean ± sd)	All scleractinians			
										S[1]	N[2]	H'[3]	J[4]
Cahuita													
Meager Shoal	A	Carbonate bank	9 43 50	82 48 32	Oct 7 1999	7.0	10	5	2.0 ± 1.0	8	2052	1.9	0.6
Eduardo Garden	B	Lagoonal patch reef	9 44 30	82 48 30	Oct 22 1999	2.0	10	4.5	3.0 ± 1.0	4	3730	1.6	0.8
Chance Mouth	C	Fore-reef spur & groove	9 45 00	82 48 35	Oct 22 1999	5.5	10	4.5	3.0 ± 1.0	4	2823	1.4	0.7
Manzanillo	D	Fore-reef platform	9 38 22	82 39 13	Oct 4 2000, Oct 11 2000	4	10	4.7	1.5 ± 0.5	-	-	-	-

[1]S = species number
[2]N = sum of maximum diameters
[3]H' = linear species diversity index, based on N
[4]J = species equity index

Table 2. Size and condition (mean ± standard deviation) of all stony corals (≥25 cm diameter), by sites in Costa Rica.

Site name	Stony corals			Partial-colony mortality (%)			Dead	Stony corals (%)			
	#	Diameter (cm)	Height (cm)	Recent	Old	Total	ratio	Standing dead	Bleached	Diseased	Other[1]
Cahuita											
Meager Shoal	49	44.5 ± 28.0	17.5 ± 27.0	3.0 ± 9.5	9.5 ± 15.0	12.5 ± 24.5	7.0	0	2.0	8	4.0
Eduardo Garden	44	86.5 ± 5 8.5	53.5 ± 37.0	1.5 ± 6.4	33.0 ± 31.2	34.5 ± 37.6	1.9	7.0	0	7	4.5
Chance Mouth	45	62.5 ± 72.5	19.0 ± 19.5	0.5 ± 1.5	20.0 ± 21.0	21.0 ± 22.5	3.8	0	0	9	4.5
Manzanillo		31.5 ± 30.0	10.1 ± 11.0	3.0 ± 7.5	9.5 ± 15.5	13.0 ± 22.8	6.8	0	0	15	0

[1]Other = demosponges and other invertebrates

Table 3. Diameter (mean ± standard deviation) of coral species by site in Cahuita, Costa Rica.

Site name	*Siderastrea*	*Porites astreoides*	*Porites porites*	*Montastraea faveolata*	*Dichocoenia stokesii*	*Acropora palmata*	*Diploria clivosa*	*Diploria strigosa*	*Mycetophyllia*	*Agaricia agaricites*
Meager Shoal	54.5 ± 37.0 n=21	30.0 ± 6.0 n=16	30.0 n=1	55.5 ± 20.0 n=6	30.0 n=1	0	60.0 n=1	0	37.0 n=1	35.0 n=2
Eduardo Garden	85.5 ± 45.0 n=14	27.5 n=2	0	0	0	103.0 ± 77.5 n=16	0	75.0 ± 40.0 n=12	0	0
Chance Mouth	70.5 ± 37.0 n=10	36.0 ± 16.5 n=4	0	0	0	0	42.5 ± 15.5 n=4	0	0	69.0 ± 90.5 n=27

Table 4. Algal characertistics and density of stony coral recruits and *Diadema antillarum* (mean ± standard deviation), by sites in Costa Rica.

Site name	Quadrat	Relative abundance (%)			Macroalgal		Recruits	*Diadema*
	(#)	Macroalgae	Turf algae[1]	Crustose coralline algae	Height	Index[2]	(#/.0625 m^2)	(#/100 m^2)
Cahuita								
Meager Shoal	45	14.0 ± 21.0	67.0 ± 21.5	18.5 ± 18.0	3.5 ± 3.0	48	0.4 ± 0.6	61 ± 32
Eduardo Garden	50	25.0 ± 20.5	43.0 ± 22.5	32.0 ± 24.5	3.0 ± 1.5	78	0.0 ± 0.1	1 ± 3
Chance Mouth	50	25.0 ± 22.0	39.5 ± 16.5	35.5 ± 21.5	5.5 ± 4.5	134	0.1 ± 0.3	7 ± 7
Manzanillo	45	56.0 ± 28.0	23.0 ± 16.0	21.5 ± 18.0	7.5 ± 4.0	416	0.02 ± 0.16	10 ± 22

[1]Includes the cyanobacterium *Schizothrix*.
[2]Macroalgal index = % relative abundance of macroalgae x canopy height.

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