PROCEEDINGS

OF THE THIRD SYMPOSIUM

ON THE GEOLOGY OF THE BAHAMAS

Editor

H. Allen Curran

Production Editor

Donald T. Gerace

Sponsored by CCFL Bahamian Field Station

June 6 - 10, 1986

Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

Articles in this volume should be cited as follows:

Author(s), 1987, Article title, in Curran, H.A., ed. Proceedings of the Third Sympoisum on the Geology of the Bahamas: Fort Lauderdale, Florida, CCFL Bahamian Field Station, p. xx-xx.

ISBN 0-935909-24-9

Printed by Don Heuer in the U.S.A.

PRELIMINARY OBSERVATIONS ON THE VITALITY OF REEF CORALS IN SAN SALVADOR, BAHAMAS

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INTRODUCTION

The skeletons of reef corals form the structural framework of modern coral reefs. Sediment becomes entrapped within and behind coral skeletons and is then lithified in place forming reef rock. The growth of a coral reef is, therefore, tied to the growth and vitality of the corals that construct the reef framework. The term vitality refers to the degree to which organisms of the reef ecosystem can carry out their natural life functions, and long term monitoring studies are required to assess changes in coral abundance, growth, and reproductive success. But it might be possible to gain insight into the vitality of reef corals, i.e. their state of health, by surveying coral populations for signs of distress or tissue and/or skeletal damage. It might even be possible to detect changes in the vitality of reef coral populations by carrying out a series of temporally spaced surveys which might provide a basis for predicting the future condition of reef coral populations. An underlying assumption to the interpretation of such survey data would be that an undamaged coral will not need to allocate metabolic energy for tissue and skeletal repair and regrowth. Instead, it may be able to put significantly more of its energy resources into new growth and reproduction. In this communication, I shall describe preliminary results from the first vitality surveys of the reef coral populations of San Salvador, Bahamas. Coral populations were surveyed in Graham's Harbor and Fernandez Bay, and several other reef sites around the island were visited and photographed.

CORAL CONDITIONS

Hermatypic corals consist of a hard calcareous skeleton covered by an unbroken continuous layer of living coral tissue. The skeleton results from the secretion of calcium carbonate by the calicoblastic tissue directly in contact with the mineralized skeleton. Skeletal growth is enhanced by the photosynthesis of symbiotic zooxanthellae which give corals their yellow-brown color. Corals are carnivorous in that they catch and consume zooplankton. A healthy coral has a continuous layer of unbroken tissue covering its skeleton. The tissue is usually uniformly pigmented with no signs of tissue bleaching (loss of zooxanthellae) or tissue necrosis. Healthy tissue is not usually covered by large quantities of sediment and is usually free of excess mucous. The causes of coral mortality may be grouped into five catagories: animal predation, physical destruction, algal overgrowth, disease, and sediment damage.

One of the major diseases implicated in coral mortality is Black Band Disease (Antonius, 1974). The disease is easily identified by a dark red or purple-black band on the perimeter of healthy coral tissue with bare skeleton immediately bordering the dark band. The band of filamentous algae extends as a front across the live coral tissue leaving bright white, exposed coral skeleton in its wake (Fig. la,b). The exposed corallium is soon colonized by filamentous algae and other macro- and microscopic marine life.

Members of the genus *Oscillatoria*, a cyanobacterium, form the black band in the Florida Keys (Antonius, 1974); *Beggiatoa* and *Desulfovibrio* have been implicated in Bermuda (Garrett and Ducklow, 1975); and most recently a taxonomic reevaluation of black band diseases in Belize has resulted in the description of a new species, *Phormidium corallyticum* (Rutzler and Santavy, 1983). The disease can be transmitted from one coral to another by innoculating the healthy coral with a small piece of the algal filaments that form the black band. Field and aquarium experiments have shown that this disease cannot infect healthy coral tissue (Antonius, 1974). However, if the coral tissue is damaged before innoculation, the disease readily infects the damaged tissue and spreads throughout the colony. However, the pathogenic agent of Black Band Disease has not yet been isolated and Koch's postulates satisfied. The species composition of black bands varies, and it may be the case that the various bacteria and filamentous algae frequently found embedded in the black band interact with the principal cyanophyte which results in the "disease" condition (Dustan, 1977).

White Band Disease, or White Plague, appears to be a bacterial infection of coral tissue. This disease, like the black band disease, often results in the death of a colony. Microscopic examination of diseased tissue has revealed a variety of bacteria (Dustan, 1977; Peters, 1984), but a bacterial pathogen for this disease has not been defined. This disease is easily identified by the presence of a sharp interface between healthy appearing coral tissue and bare skeleton (Fig. 1c; Dustan, 1977; Gladfelter, 1982). Over time the tissue recedes and the bare skeleton is colonized by an assemblage of flora and fauna as happens with the black band disease.

Other types of biological damage that reduce the vitality of corals include algal overgrowth by macroalgae, smothering by filamentous algal mats, and loss of tissue and/or skeleton from predation. Direct algal overgrowth, sediment trapping, and other shading effects decrease zooxanthellae photosynthesis. Algal colonies growing at the edge of coral tissue trap sediment that corals normally slough-off. The sediment accumulates at the edge of the coral and smothers the bordering coral tissue. Sometimes filamentous algal mats overgrow coral tissue which results in the coral tissue being shielded from light and water circulation. Coral tissue necrosis follows soon afterwards. Predators of coral tissue in the Bahamas include the polychete worm, *Hermodice carunculata*, and a gastropod, *Coralliophila abbreviata*. Both eat coral tissue and do not damage the coral skeleton. Also, the three spot damsel fish, *Pomacentrus planifrons*, has been observed to kill coral tissue in order to establish an algal garden feeding territory (Kaufman, 1977).

Physical damage to corals includes direct physical damage from storms, anchors, excess sedimentation, and abrasion of the coral tissue and skeleton. A damaged coral will heal itself by growing new tissue, or skeleton and tissue. However, before healing can occur the damaged area provides an excellent substrate for algal colonization and the exposed edge of the injured tissue is a prime site for the initiation of diseases. In an environment with high amounts of suspended sediment, a coral will have an even tougher time overgrowing its old skeleton as the sediment "competes" with the coral for substrate space (Dustan, field observation).

METHODS

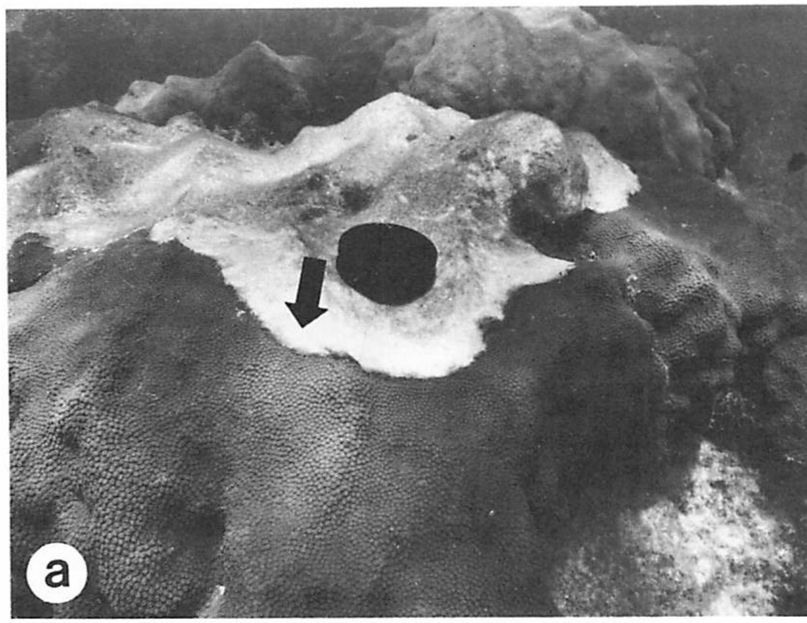
Observations were carried out underwater using SCUBA and underwater photographic documentation. Coral populations were surveyed using a method that catagorized each individual colony into one, or more, of 18 conditions that ranged from healthy appearing to recently dead (see Table 2). In this way it was possible to swim over a reef and categorize a large number of colonies quickly. The data were then transcribed to computer format and analyzed for percentage of the population with a particular condition. As it is possible for a coral to exist in more than one character state (multiple coding), the percentages may rise to over 100% when categories are combined.

Observations on diseases and their rates of tissue destruction on *M. annularis* and *A. palmata* were made on Gaulin Cay Reef, Graham's Harbor. The interfaces of tissue and newly uncovered skeleton were marked and followed over a period of approximately three weeks between June 13 and July 4, 1986.

Samples of macroalgae were collectd for identification from the borders of 12 colonies *Montastrea annularis* on Gaulin Cay Reef. This was a first step in trying to assess the impact of macroalgal growth on the growth and vitality of *M. annularis*, a major reef-building coral species in San Salvador.

The data presented in this communication were gathered during two field sessions on San Salvador and are not to be considered comprehensive, only representative of the few locations, and species, surveyed. For this reason, I consider the results to be preliminary.

Fig. 1a. Black Band Disease on *Montastrea annularis*. The arrow points to the infection which is progressing across the coral tissue. (lens cap = 8.5 cm diameter)



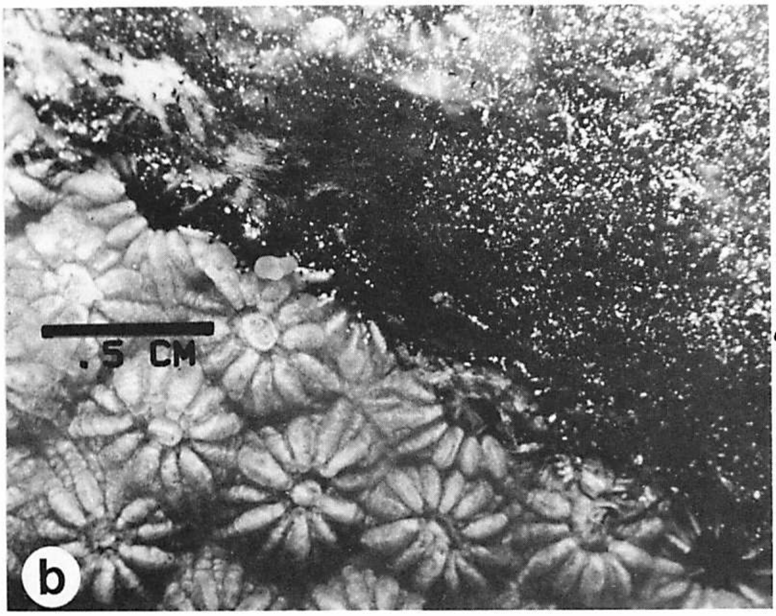
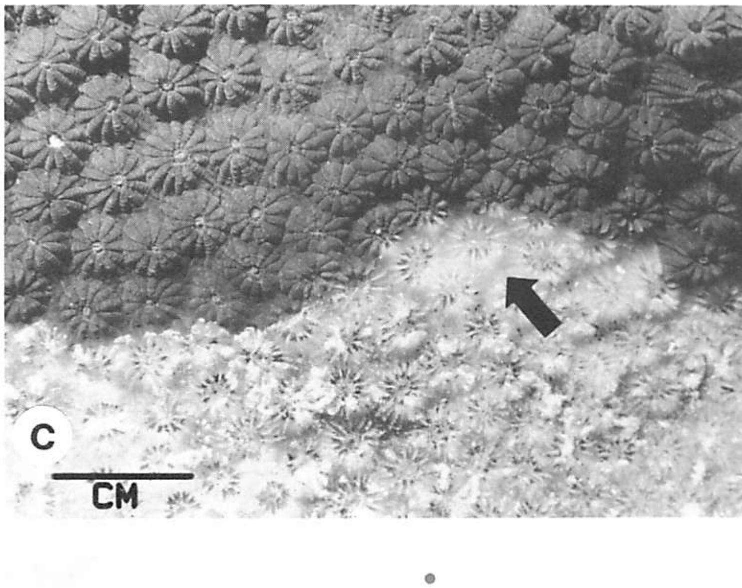


Fig. 1b. Black Band Disease on *M. annularis*.

Fig. 1c. White Plague on *M. annularis*. Arrow points to active infection.



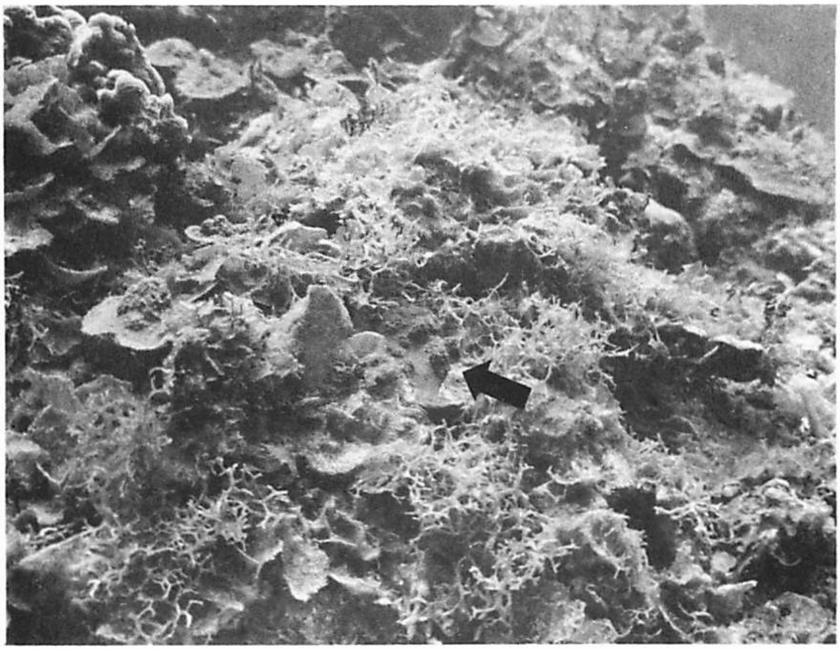


Fig. 2. *M. annularis* being overgrown by *Dictyota* sp. and *Microdictyon* sp. Arrow points to a small section of coral that has not yet been overgrown.

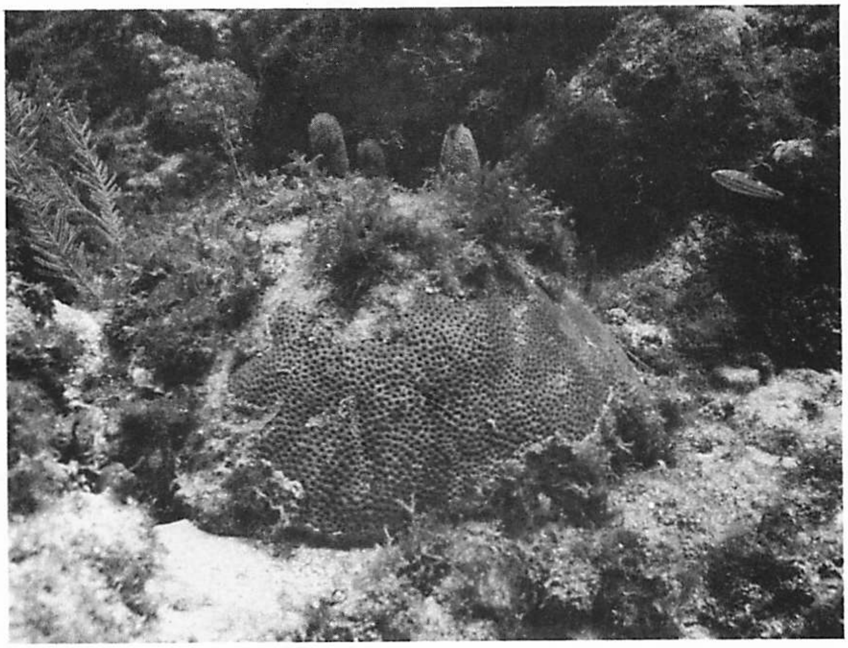


Fig. 3. A large island on top of a colony of *S. sidera*. Islands start in areas of damaged coral tissue which cannot be healed by the coral.

Table 1. Species of Diseased Scleractinian Corals encountered in San Salvador, Bahamas (W=White Plague, B=Black Band).

Species	Fernandez Bay		Graham's Harbor	Northwest Slope	High Cay
Depth range of dives (m)	0-6	10-50	0-10	10-30	0-5
Acropora palmata			W		W
Acropora cervicornis	W	W	W		
Agaricia agaricites		W		W	
Colpophyllia natans		W			
Montastrea annularis		W	WB		
Montastrea cavernosa				W	
Siderastrea sidera	B			W	W
Diploria strigosa			B		
Diploria labyrinthiformis	B				

Reefs visited:
Fernandez Bay (0-6m): Staghorn, Telephone Poles, Snapshot
(10-50m): Bamboo Pt., Grouper's Gully
Northwest Slope (10-30m): Barker's Pt., Rocky Pt.
Graham's Harbor (0-10): Catto Cay, Gaulins Cay, and isolated patch reefs behind White Cay
High Cay (0-6m): reef flat directly seaward of High Cay

RESULTS

During our exploratory dives, 9 species of diseased corals were encountered. The distribution of diseases varied with species and habitat (Table 1). *Montastrea annularis* and *A. palmata* were the most commonly seen diseased corals. In Graham's Harbor white plague was common on *A. palmata.* Black Band Disease was easily found on *M. annularis* on Gaulin's Reef and the lee side of Catto Reef, but was not seen on the seaward side of Catto, a region of intense wave energy. Black Band disease was not common on *M. annularis* in Fernandez Bay, reefs that have suffered severe declines in coral coverage in the last five years. Diseased corals were rare below 30 m depth but the team only made 6 dives to 30 m or deeper.

Rates of tissue necrosis due to Black Band Disease on *M. annularis* on Gaulin Reef varied between 1.18 and 6.0 mm/day (Y = 3.2, s = 2.49, n = 3 colonies). Another *M. annularis* colony with receding tissue due to fine sediment damage (possibly diseased) lost tissue at a rate of 0.25 mm/day. This coral had no sign of either White Plague or Black Band, but had obviously been decreasing in tissue coverage. Rates of tissue destruction due to White Plague for *A. palmata* highly variable during the observation period (0.2 to 16 cm lost tissue in 21 days). Two infected branches died off after losing 16 cm of tissue while another branch showed little change over 21 days. The tissue sloughed off in patches on some branches and receded as a front in others. Most colonies of *A. palmata* showed signs of damage due to White Plague with exception of colonies on the northern platform of Graham's Harbor where wave action and water movement are

Table 2. Summary of 1986 San Salvador Preliminary Coral Reef Vitality Survey. Percentage of each condition for selected species on selected reefs.

Condition Code	Staghorn n	Staghorn % Total	Telephone Pole n	Telephone Pole % Total	Catto Cay n	Catto Cay % Total	Description of Condition
2	49	35.5	22	25.0	12	16.0	Unblemished
3	1	0.7	3	3.4	0	0.0	Damaged but healed
4	0	0.0	0	0.0	0	0.0	Antifouling bottom paint
5	1	0.7	0	0.0	1	1.3	Fresh damage to coral
6	0	0.0	0	0.0	0	0.0	Excessive sediment
7	1	0.7	0	0.0	1	1.3	Tissue damage only
8	0	0.0	3	3.4	2	2.7	Tissue bleaching
9	0	0.0	0	0.0	0	0.0	Excess mucous
10	0	0.0	2	2.3	1	1.3	Active Black Band
11	47	34.1	26	29.6	26	34.7	Algal mat smothering
12	57	41.3	51	58.0	36	48.0	Sediment damage
13	0	0.0	0	0.0	0	0.0	White Plague
14	19	13.7	0	0.0	24	32.0	Algal islands damage
15	0	0.0	0	0.0	0	0.0	Recently dead
16	1	0.7	0	0.0	6	8.0	Algal tufts on surface
17	19	13.8	42	47.7	3	4.0	Macroalgae damage
18	28	20.3	5	5.7	31	41.3	Colony almost perfect
19	1	0.7	0	0.0	3	4.0	Other (unknown)
Totals	138	161.6%	88	175.1%	75	194.6%	

intense.

The results of the survey of 301 individual coral colonies on 3 reefs show that 16 to 35% of the corals were unblemished with 31 to 57% considered to be healthy (Codes 2 and 18, Table 2). A very small percentage showed signs of recent fresh damage to either tissue or skeleton. Colonies with active White Plague or Black Band Disease were rare and confined to only a few species, most notably *M. annularis* and *A. palmata.* These species were not included in the data presented in Table 2. A very large percentage of colonies show signs of stress from algal-sediment interactions that result from excess sediment and the growth of algae at the colony borders. This prevents the corals from effectively clearing their tissues of sediment, and coralites eventually die from suffocation.

Observations on the interactions of macroalgae and corals revealed 9 species of macroalgae that grow around the perimeter of *M. annularis* tissue (Table 3). This does not include numerous species of filamentous algae that are often associated with the macroalgae. The shaded coral tissue often shows signs of zooxanthellae bleaching or abrasion from the algal fronds moving in the wave surge. Macroalgae appear to be responsible for the decrease in living tissue surface area in *M. annularis* and other species. *Microdicyton* sp., a reticulate green alga, had the appearance of green fiberglass lettuce, and was observed to completedly cover the living tissue of large colonies of *M. annularis*, *Agaricia agaricites*, and *Montastrea cavernosa* (Fig. 2). This alga was common on the reefs in Fernandez Bay between 10 and 25 m. *Dictyota* sp. was also observed to "overtop" coral colonies as the species grows into small algal bushes that can severely restrict the quantity of light and wave action at the surface of the living coral tissue. Colonies of *Dictyota* become

Table 3.Abundance of Macroalgae on *Montastrea annularis*, Gaulin Cay Reef, San Salvador, Bahamas.

Algal Species	Number of Plants/ Coral Colony											
Coral Colony#	1	2	3	4	5	6	7	8	9	10	11	12
Turbinaria turbinata...				1	1				4	2	1	1
Dictyota dentata.......	2	3	2	3	9			3	5	4	7	1
Dictyosphaera cavernosa								1			8	8
Lobophora variegata....			4	8	3	1	9	9	13		1	
Stypopodium zonale.....		1	2					1			1	
Microdictyon marinum...								1			8	8
Halimeda sp............				1						2		
Padina sp..............						1					1	
Sargassum sp...........									1			
filamentous forms......					*	*	*	*	*	*	*	*
Total Species	1	2	3	4	3	2	2	4	3	3	6	4
Total Plants	2	4	8	13	13	2	1	15	23	8	27	18

established at the edges of coral tissue and in areas of necrotic tissue within the perimeter of some colonies forming algal islands. Algal islands continue to trap fine sediment which, along with algal overgrowth, increases the death rate of coral tissue (Fig. 3).

Another source of coral tissue necrosis observed on San Salvador was caused by the anthropogenic deposition of dead gastropod shells, *Strombus gigas*, onto the tissue of living coral. The heavy shells rest on the coral tissue which results in the death of large patches of tissue. On Gaulin Cay Reef, 15 piles of conch shells were found that contained between 50 and 150 shells in number. The shell piles apparently resulted from fishermen cleaning conch and tossing the shells overboard. Another anthropogenic source of damage to corals was observed on the eastern coast at a headland just east of South Victoria Hill Settlement. A large piece of polypropylene fishing net had drifted inshore and had become entangled on a coral outcrop. The net had snagged on the coral, and it's waving action in the surge was abrading the coral's surface. The eastern coast of San Salvador is heavily littered with plastic floats, line, and other debris from fishing and other vessels. Much of this debris may snag coral heads as it washes in from the open sea.

DISCUSSION

The reef corals of San Salvador are challenged by a number of biotic and abiotic factors. Diseases appear to be a significant factor in the mortality of *Acropora palmata*, *A. cervicornis*, and *M. annularis*. After having first been described from the northern limits of coral reef distribution in the western North Atlantic Ocean, coral diseases have now been reported throughout the Caribbean (Antonius, 1974; Dustan, 1977; Gladfelter, 1982; Rutzler and Santavy, 1983). However, little is know about the distribution of coral diseases, species specificity, and epidemiology.

The 1982-83 mass mortality of sea urchins on the reefs of the Bahamas and elsewhere in the Caribbean was reported by Lessios and others, 1983, 1984; Bak and others, 1984; Hunt and others, 1986; and Liddell and Ohlhorst, 1986. A mortality rate of 98 percent was reported for most of the Caribbean, and a water-born disease was suggested as the causal agent of the die-off. Herbivorous urchins crop algal populations close to the reef substrate, which has been demonstrated to have an effect on the settlement and survivorship of juvenile corals (Sammarco 1980, 1982). The mass mortality of sea urchins two years ago could account for the large algal standing crop in the shallow reef areas of San Salvador. Virtually all species of coral are challenged by macroalgae that grow in great profusion around the borders of coral colonies. The algae colonize the dead coral skeleton substrate, which in turn results in the die back of the coral tissue which opens up more substrate for colonization. The local fish populations do not appear to be significant enough herbivores to graze down the present crop of macroalgae, mainly *Dictyota* sp. which may contain compounds distastful to herbivores (Hay, personal communication).

San Salvador is remote from centers of civilization. There are no major sources of industrial pollution on the island, and its small population size suggests that there is little anthropogenic nutrient loading of the local waters. There is little commercial fishing and most sport fishing occurs in the pelagic oceanic waters offshore. San Salvador's eastern location on the Bahamian Bank bathes it in water from the tropical Atlantic and Sargasso Sea. On an otherwise pristine island, the beaches on the eastern side of the island are littered with debris from the Atlantic fishing grounds and drift bottles from the northeast North American coast and Europe have been found on East Beach. Thus oceanic drift debris, mostly plastic, forms the bulk of the pollution on the windward shoreline of San Salvador. This raises questions about the epidemiology of coral diseases and possibly links their distribution with aspects of oceanic circulation as has been suggested for the sea urchin *Diadema antillarum* (Lessios and others, 1984).

I realize that the data I have presented only describe the present state of corals in the region. They do not distingush between cause and effect, nor does it uncover the sources and/or causes of the problems. It is a preliminary description of the state of the corals on various reefs within the region. I view it as a map which points to potential areas of research which might help to manage better the San Salvadoran reefs as a resource for all concerned.

Reefs have long been thought to be stable, climax communities that change very slowly in ecological time. More recently, researchers have begun to realize that reefs are very dynamic communities that can undergo rapid change over relatively short periods of time. The effect of storms has long been known, but the rates of change due to biological factors has been little documented. The *Acanthaster planci*, crown of thorns starfish, population explosions in the Pacific demonstrated that large scale episodic predation on corals may be significant. The increase in coral mortality that has resulted from an increase in the growth of macroalgae is but one more example of the speed at which change can occur on coral reefs as a result of biological factors.

ACKNOWLEDGMENTS

This research was carried out with the assistance and support of Don and Kathy Gerace of CCFL. Lorraine Dustan, J. Kostka, D. Slice, and E. Womack assisted in diving and field data collection. William Hoffluron collected and identified the macroalgal samples. Partial funding for this research was provided by the Jeanette and Lafayette Montgomery Foundation and the College of Charleston. Special thanks are due to Jim Carew who sparked my interest in the coral reefs of San Salvador. This is contribution number 75 from the Grice Marine Biological Laboratory.

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