PLEISTOCENE, HOLOCENE, AND MODERN CARBONATE SYSTEMS, BAHAMAS

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SAN SALVADOR ISLAND, BAHAMAS: A NATURAL LABORATORY FOR THE STUDY OF CARBONATE SEDIMENTS AND ROCKS - PART III

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INTRODUCTION

The third Keck Geology Consortium research project in the Bahamas was conducted on San Salvador Island during June, 1990. The research group consisted of ten rising senior geology majors, representing seven of the Keck Consortium colleges, and four faculty supervisors as above. During the time of the project, the group received a stream of faculty visitors, including Steve Burrell (Beloit), Bill Fox (Williams), Molly Miller (Vanderbilt), Paul Myrow (Colorado), and Pat Spencer (Whitman). These visitors were of great assistance in helping the students to formulate their research plans and to initiate their research.

GEOLOGIC SETTING OF THE BAHAMA ISLANDS AND SAN SALVADOR

The Bahama Archipelago is an arcuate system of carbonate platforms, commonly capped with low islands, located to the east and south of the continental margin of North America (Fig. 1). The archipelago extends for a distance of some 1,400 km (870 mi.), from Little Bahama Bank to the north (27.5° N latitude), off the coast of Florida, south to the Turks and Caicos Islands, Silver Bank, and Navidad Bank (20° N, just south of the area of Fig. 1), offshore from the island of Hispaniola. Water depths on these banks normally are less than 10 m, but the banks are separated by inter- or intra-platform, deep-water basins and troughs with depths of up to 4,000 m.

These shallow-water platforms are underlain by thick sequences of carbonate rock; drill hole logs from several exploratory wells reveal thicknesses of at least 5.4 km (Meyerhoff and Hatten, 1974), and other data suggest thicknesses of up to 10 km in the southwestern Bahamas. The platforms are tectonically stable, and it appears that shallow-water carbonate sedimentation on the banks has kept pace with the subsidence of the Bahamian platforms since at least Early Jurassic time (Mullins and Lynts, 1977).

Indeed, the shallow-water banks of the Bahamas truly are "carbonate factories." The products are a diverse array of carbonate sediments formed by both physical and biogenic processes and deposited in a spectrum of environments ranging from lakes and dunes to deep-sea basins. The environments on and adjacent to the banks and the rates of carbonate production have been in a considerable state of flux with the conditions of changing sea level since the onset of Pleistocene glaciations.

San Salvador is a small island, about 11 km wide by 19 km long (Fig. 2). The island is bordered by a narrow shelf with an abrupt shelf-edge break leading to a very steep slope. The topography of the island is dominated by arcuate ridges interpreted as representing successive stages of carbonate eolian accretion. Shallow hypersaline lakes occupy the low inter-dune ridge areas.

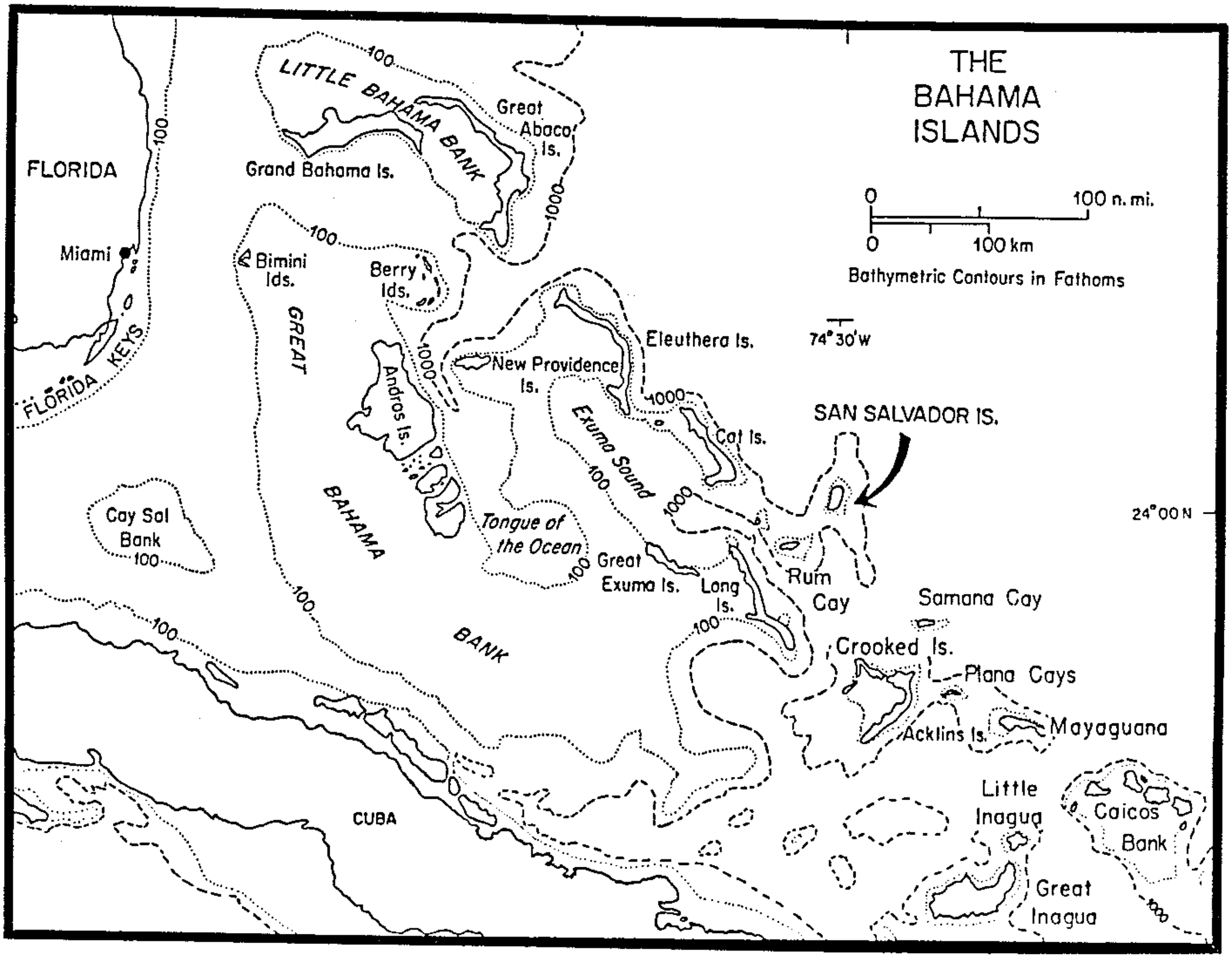

Figure 1. The Bahama Archipelago and location of San Salvador Island.

The island's shoreline is characterized by cliffed headlands of eroded eolianite; fine- to medium-grained carbonate sands form beaches between headlands, and Holocene beachrock is common.

Natural rock outcrops largely are confined to the coastal areas of the island. A dense vegetation cover restricts access to the island's interior, a karst surface with calcrete or caliche crusts, red soils, and solution phenomena, all of which further obscure characteristics of the underlying rock. Road cuts and several quarries along the island's coastal highway also can provide good exposures for study. As a result of intensive geologic investigations by a number of workers over the past decade, the Pleistocene and Holocene bedrock geology of the island now is reasonably well known and has been summarized in a series of guidebooks, the most recent edited by Curran (1989).

Because San Salvador lies on a tectonically stable platform surrounded by deep water, the Pleistocene and Holocene rocks exposed on the island have particular significance as markers of Quaternary eustatic sea-level change. Vertical facies changes are abrupt, allowing precise interpretation of former sea-level positions. Based on detailed mapping of the Cockburn Town and Sue Point (mapped during Keck Bahamas Project I) fossil coral reefs (Fig. 2) and dating of fossil

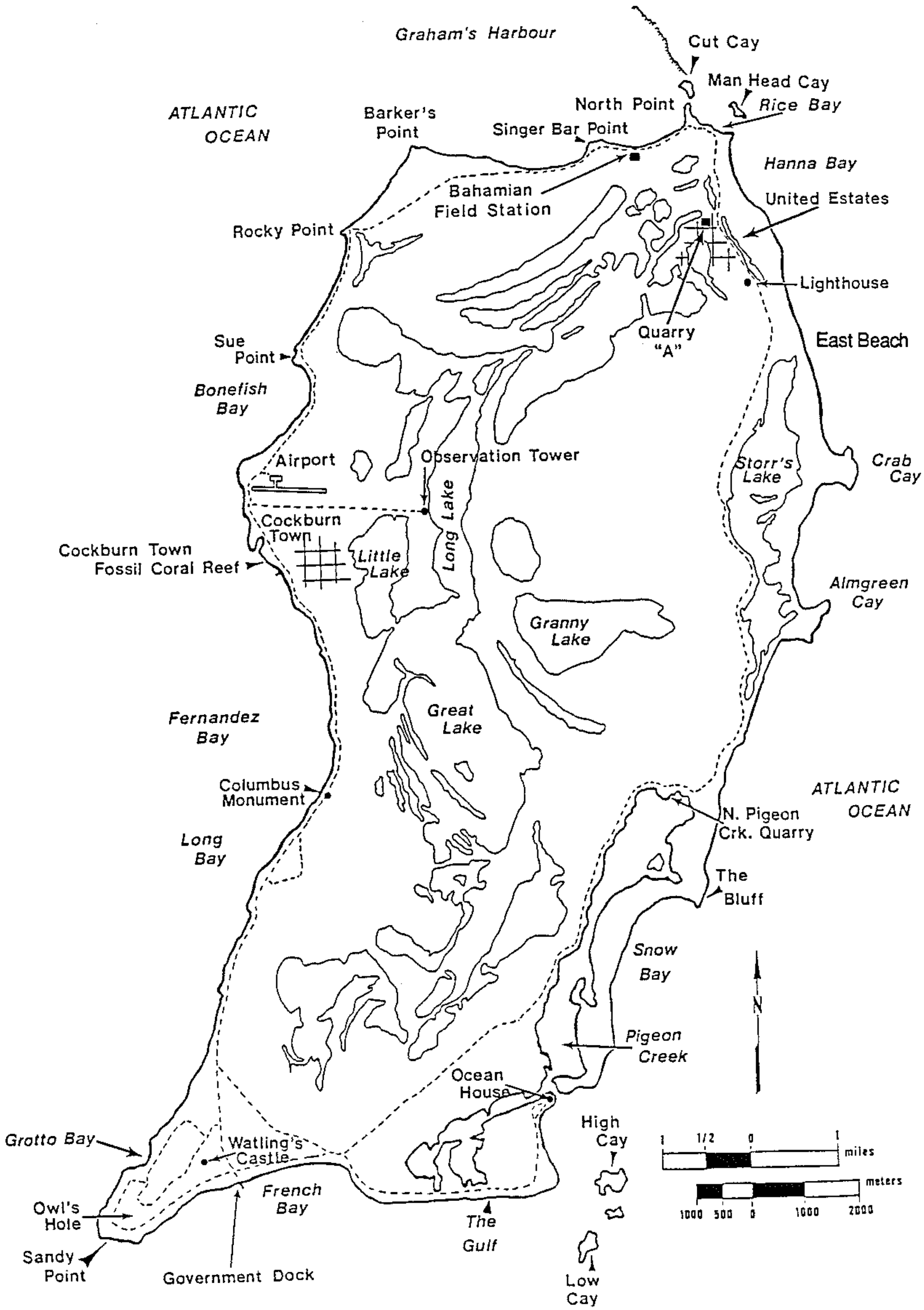

Figure 2. Index map to San Salvador Island.

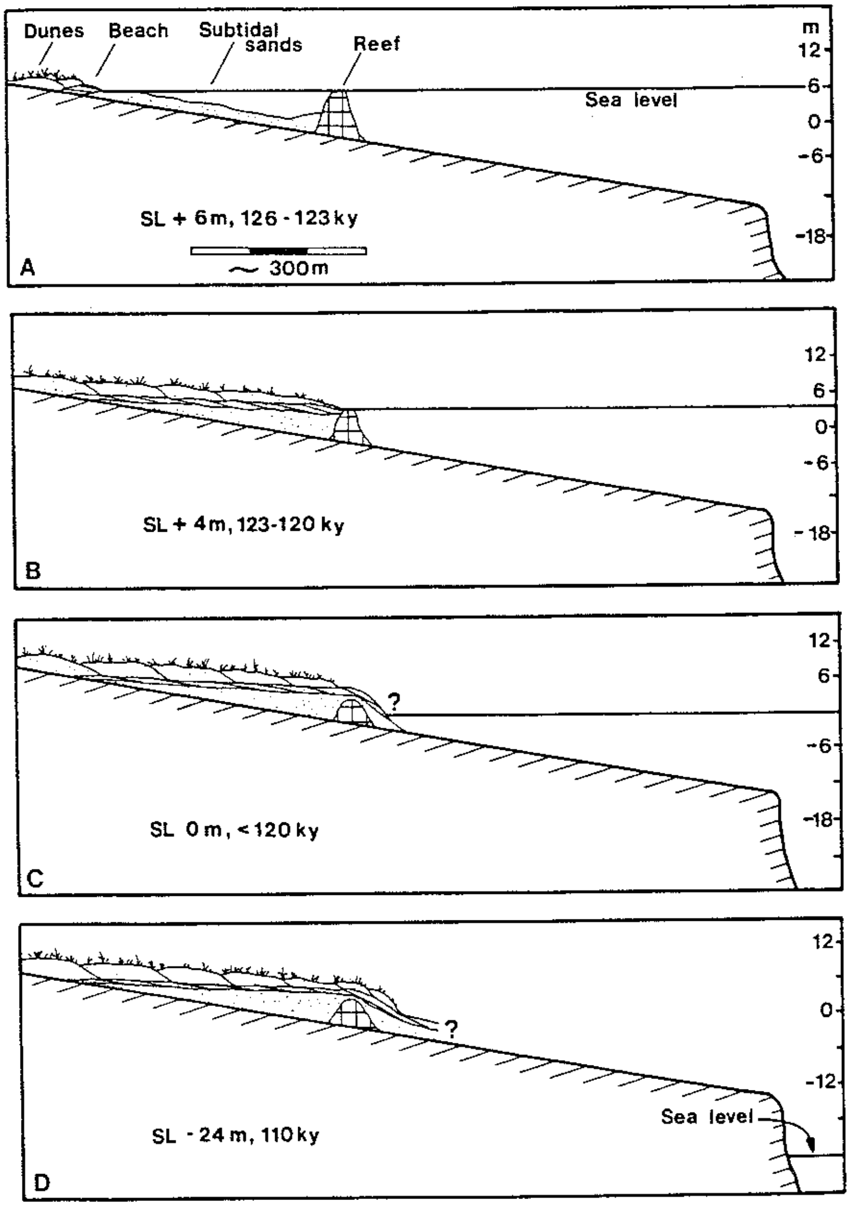

Figure 3. Profile reconstructions across the Cockburn Town coral reef complex from time of its maximum development (A) to complete burial (D) at the beginning of Wisconsinan glaciation (from Chen and others, 1991). Sea-level position for profile D from Harmon and others' (1983) curve from Bermuda.

coral samples using the recently developed mass spectrometric technique for ^{238}U-^{234}U-^{230}Th age determination, a precise chronology of sea-level history for late Pleistocene (Sangamon) time has been developed (Fig. 3, from Chen and others, 1991). At about 126 to 123 thousand years before present (ky), sea level was at a highstand about +6 m above its present position. With the onset of Wisconsinan glaciation, sea level dropped to about its present position by 119 ky and to about -24 m, below the San Salvador shelf/slope break, by 110 ky. Sea level began to rise rapidly with the retreat of Wisconsinan glaciers, and by early Holocene time, about 7 ky, marine waters started to flood the San Salvador platform (Colby and Boardman, 1989). By 3 ky, sea level was about 1 m below present (Colby and Boardman, 1989) and this principally eustatic episode of sea-level rise continues today. With this bank flooding, a diverse array of shallow-water marine environments has been created around and on San Salvador. These all-carbonate environments, with their diverse tropical floras and faunas and the analogue relationships with the Pleistocene and Holocene carbonate rocks of the island, truly make San Salvador an outstanding natural laboratory for the study of carbonate systems.

KECK RESEARCH PROJECTS - 1990

With previous studies of the geology of San Salvador and the Keck Bahamas '87 and '88 research reports as background, our group conducted four weeks of research investigations on San Salvador during June, 1990. After several days of reconnaissance field trips for familiarization with the carbonate environments and rock record of the island, each of ten student participants began to formulate their individual research project.

Tim Donohue (Colorado), Rob Noble (Wooster), and Sarah Wittenbrink (Smith) chose to work on rock record projects. Rob and Sarah braved the rigors of San Salvador's jungle-like interior vegetation to map and sample from the poorly known late Pleistocene lagoonal facies of the northeastern section of the island. With supervision from Prof. White, Sarah took samples and made field observations for a petrographic study. Rob worked with direction from Prof. Curran to sample the molluscan faunas of the lagoonal facies for paleoecological analysis. Tim climbed the cliffs on the south coast of the island to measure sections and collect samples for a petrographic study of the Pleistocene subtidal to eolian sequence there. He was supervised by Profs. White and Myrow.

Andrew Brill and Nick Loizeaux (both Williams), with initial supervision from Prof. Fox, covered themselves with sun screen and successfully avoided rogue waves to study the dynamics of sand transport in the modern beach-dune systems of East Beach and Sandy Point, respectively. Both studies also incorporated analogue observations from Holocene rock sections exposed near their study areas. Susan Beck (Whitman) and Elizabeth Haynes (Smith), with field and lab assistance from Profs. Mendelson and Spencer, chose to investigate the modern shallow-subtidal bottom environments of Grahams Harbor and sample for benthic foraminifera. Initial foram identifications and analysis of distribution patterns was begun in our Bahamian Field Station laboratory.

Eric Beck (Beloit) and Amy Berger (Pomona) worked with Prof. Mankiewicz to study the relationship between modern coralline algae and the energy levels of their environments of occurrence. Both studies had several field sites around the island, and Amy included fossil coral reef sites for modern-ancient comparative work. Megan Bresnehan (Smith), with help from Prof. Curran and Rob Noble, organized arduous canoe expeditions to study and sample sediments, flora, and fauna from an extensive modern carbonate sand tidal flat in Pigeon Creek. Data from this modern setting will be used to make comparisons with similar ancient tidal flat sequences described in the literature.

Our research group is grateful to the Bahamian Field Station and its staff on San Salvador Island for full logistical support during the period of summer field work. We also thank the Keck Foundation for providing funding to the Keck Geology Consortium which sponsored this project.

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THE RESPONSE OF CORALLINE ALGAE TO HERBIVORY AND ENERGY OF THE ENVIRONMENT

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Coralline algae (Family Corallinaceae) are red calcareous algae that encase their cells in calcium carbonate. Because coralline algae calcify their cells, they have a relatively small surface area exposed to the environment for gathering light and exchanging gasses. The resulting decrease in photosynthesis causes coralline algae to grow slower than soft, fleshy algae, which are completely exposed to the environment. The difference in growth rates leads to fouling of coralline algae by soft algae. Because coralline algae have no means of remaining free of highly productive epiphytic soft algae, external mechanisms are required for the cleaning process (Steneck, 1986). The two main environmental mechanisms that prohibit soft algae from fouling coralline algae are herbivory and energy of the environment, i.e. wave action.

Intensity of herbivory and energy in the environment also help shape the morphology of coralline algae (Minnery, 1990). Thickly, more densely branched crusts dominate the intertidal or shallow subtidal zones where wave action and herbivory are moderate. In areas that experience higher energy and/or herbivory, thick crusts predominate. Finely branched or thin, delicate crusts typically are found in areas of low energy and minimal herbivory.

The morphology of coralline algae is very plastic, and each species may occur in many different forms (Steneck and Adey, 1976). These forms are controlled by the particular conditions of the environment in which the algae are living. These ecological characteristics of coralline algae, and their extreme preservability due to calcification, render them valuable in ecological and paleoecological analysis of shallow-marine environments. By studying the morphology, taxonomy, and spatial arrangement of coralline algae present under various modern conditions it is possible to make some interpretations about past environments by examining coralline algae preserved in the rock record.

During June, 1990, I studied three areas on San Salvador Island, Bahamas: Hanna Bay (off East Beach), Bonefish Bay, and the area just outside the mouth of Pigeon Creek. These areas represent widely differing environmental settings in terms of energy and herbivory.

Methods

I compared the coralline algae present in these environments in a number of ways that enabled me to make observations about the response of coralline algae to conditions of the environment. By mapping algal distribution, measuring energy, observing herbivory, and taking depth measurements of all three areas, I was able to document and compare the distribution of coralline algae in diverse environments. Samples were taken from each location, and from various sub-environments at each location, allowing me to compare dissimilar morphologies and taxonomies present in areas with differing environmental conditions.

I conducted experiments to test the response of coralline algae to a change in environmental conditions. I relocated heads of coralline algae to observe the success of morphologies in an environment different from the one in which they were growing. I isolated one patch of coralline algae at each site with wire cages to observe the effects of reduced grazing by herbivores.

Results and Observations

Branching heads of coralline algae dominated all three study sites. The density of branching and thickness of branches varied between locations. Crusts of coralline algae were present at each site, and finely branching forms grew at Pigeon Creek and in sheltered locations at East Beach.

	EAST BEACH	BONEFISH BAY	PIGEON CREEK
Relative Energy	High	Moderate	Low
Rel. Herbivory	Moderate	Moderate	High
Herbivore Type	Fish	Hermit Crabs	Fish
Branching Density	High	Low	Low
Ave. Branch Diameter	2.6 mm	2.0 mm	1.5 mm