

**PROCEEDINGS OF THE 11<sup>TH</sup> SYMPOSIUM  
ON THE GEOLOGY OF THE BAHAMAS  
AND OTHER CARBONATE REGIONS**

**Edited by  
Ronald D. Lewis and Bruce C. Panuska**

**Production Editor:  
Ronald D. Lewis**

**Gerace Research Center  
San Salvador, Bahamas  
2004**

Front Cover: Close-up view of a patch-reef coral head in Grahams Harbor, north of Dump Reef. As shown here, Caribbean shallow-water reefs have declined since the mid-1980s and are now largely overgrown by fleshy green macroalgae and a variety of encrusting organisms. See Curran et al., "Shallow-water reefs in transition," this volume, p. 13. Photograph by Ron Lewis.

Back Cover: Dr. A. Conrad Neumann, University of North Carolina, Chapel Hill, NC, Keynote Speaker for the 11<sup>th</sup> Symposium and author of "Cement loading: A carbonate retrospective," this volume, p. xii. Photograph by Mark Boardman.

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**ISBN 0-935909-72-9**

# CARBONATE PRODUCTIVITY RATES OF *HALIMEDA* IN TWO DIFFERENT LOCATIONS, SAN SALVADOR ISLAND, BAHAMAS

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## ABSTRACT

The calcareous algae are recognized as major contributors to reef and lagoon sediments. *Halimeda* meadows, bioherms, and banks, the principal source of this carbonate productivity, have been extensively described in the literature. For this study, two areas are compared for their *in situ* algal carbonate productivity. Graham's Harbor (GH) is a large sheltered lagoon at the north end of San Salvador, while Snow Bay (SB) is a small, higher energy, inner shelf lagoon on the SSE side of the island.

Total calcareous algal densities,  $\text{CaCO}_3$  mass, and an *in situ* growth rate were used to establish annual carbonate productivity. Measurements were conducted during July 2000 and December 2001. A total of 180 quadrats for GH and 119 quadrats for SB were counted. On average, GH contained 28 thalli of the rhipsalian (upright) species of *Halimeda*/m<sup>2</sup>, while SB contained 39 thalli. Each thallus had an average of 59 segments for GH and 81 segments for SB. A total of 150 individual segments were cleaned, oxidized, and weighed. The average segment has a  $\text{CaCO}_3$  mass of 0.0110g. Plots of algae were dyed with Alazarin Red S stain and sampled at regular intervals. New growth was measured as a function of new segments over total segments on a thallus.

It was determined that *H. incrassata* grows at a rate consistent with a complete turnover every 46.7 days in GH and every 19.8 days at SB. This gives a figure of 7.8 crops/yr for GH and 18.4 crops/yr for SB. If these turnover rates are assumed for all rhipsalian species, then these species produce 141.7g and 639.4g  $\text{CaCO}_3$ /m<sup>2</sup>/yr in Graham's Harbor and Snow Bay, respectively. In addition, at Snow Bay *Halimeda opuntia* buildups occur. These are small, elongated, cushion-like

structures (maximum size 5.4m L x 3.1m W and 1.0m thick). The incipient *Halimeda* mounds roughly follow the thickest and densest part of a *Thalassia* meadow. Preliminary calculations show that a clump of *Halimeda opuntia* (20% cover) can generate 1229.9g of  $\text{CaCO}_3$ /m<sup>2</sup>/yr. Considering compaction rates and cementation, as well as some transport of this sediment, it is conceivable that Snow Bay alone can account for over 2m/1000yrs of carbonate sedimentation. *Halimeda* and calcareous algae, in general, are a more important  $\text{CaCO}_3$  sink than was previously acknowledged.

## INTRODUCTION

The benthic marine macro algae (Bryopsidales) belonging to the genera *Halimeda*, *Penicillus*, *Udotea*, and *Rhipocephalus* (Division Chlorophyta) are all calcifying and produce copious amount of aragonite in both the <63  $\mu\text{m}$  (silt and clay) and >63  $\mu\text{m}$  (sand-granule) size fractions. *Halimeda* is recognized as an important producer of carbonate sediment on coral (coralgal) reefs and in adjacent lagoons (Judd, 1904; Chapman and Mawson, 1906; Emery et al., 1954; Hillis, 1980, 1986c; Flugel, 1988; Mankiewicz, 1988; Fornos et al., 1992; Milliman, 1993; Freile et al., 1995; Freile and Hillis, 1997), and it has long been known to be a prolific contributor to carbonates in both the Pacific (Drew, 1983; Orme, 1985; Hillis, 1985, 1986b, 1986c; Drew and Abel, 1988; Payri, 1988) and the Atlantic (Purdy, 1963; Hudson, 1985; Littler et al., 1986; Boss and Liddell, 1987; Liddell et al., 1988). *Halimeda* bioherms are prominent features in Australia (Davies and Marshall, 1985; Drew and Abel, 1985; Phipps et al., 1985; Roberts et al., 1987a,b; Marshall and

Davies, 1988; Orme and Salama, 1988; Searle and Flood, 1988) and on the Nicaraguan Rise (Hine et al., 1988). *Halimeda* plates are the dominant skeletal component in reef-top sediments (e.g. Milliman, 1974; Bathurst, 1975). Dense patches of *Halimeda* have been documented at depths greater than 20 m in lagoons and on the slope break of various reef areas of the Pacific and the Atlantic (Goreau and Graham, 1967; Drew and Abel, 1985, 1988; Hillis, 1985, 1986a,b,c, 1991; Colin et al., 1986; Roberts et al., 1987 a,b, 1988; Orme and Salama, 1988; Hine et al., 1988; Liddell et al., 1988; Ginsburg et al., 1991; Freile et al., 1995). Terms used to describe these habitats include 'meadow' (Orme et al., 1978; Drew and Abel, 1985; Freile et al., 1995), 'mounds', 'banks' (Orme, 1985; Phipps et al., 1985) and 'bioherm' (Davies and Marshall, 1985; Roberts et al., 1987 a,b, 1988; Hine et al., 1988). The primary types of *Halimeda* found in these environments are the rhipsalian or upright species. Hudson (1985), however, described an area in the Marquesas Keys, Florida, in less than 2 m water depth, as a high energy *Halimeda opuntia* sand accumulation that resembled a "loosely interlocking series of connected plates that coalesce to form compact clumps and large cushion-like mats, some of which exceed 3 m in diameter".

## STUDY AREA

Carbonate productivity rates of *H. incrasata*, the predominant *Halimeda* species of the study sites, were measured in two shallow lagoons at San Salvador Island, Bahamas. San Salvador lies approximately 23°57' N to 24°10' N and 74°23' W to 74°30' W (Figure 1). This is a tropical marine dry climate where there are two seasons: wet and dry. Rainfall is less than 1000 mm/yr and temperatures average 23° C in the dry season and 32° C in the wet (Sealey, 1992).

Two study areas were investigated. Snow Bay (SB) is a shallow (<3 m) lagoon in the windward southeastern margin of San Salvador (Figure 1). It is a high-energy inner shelf lagoon 1 x 2 km in area rimmed by a barrier reef complex (Andersen and Boardman, 1989). Graham's Harbor (GH) is a shallow (<6 m) windward lagoon 2 x 3 km in

area in the northeastern part of San Salvador. It is a high-energy area, protected by cays, dunes, and a barrier-reef complex (Colby and Boardman, 1989).

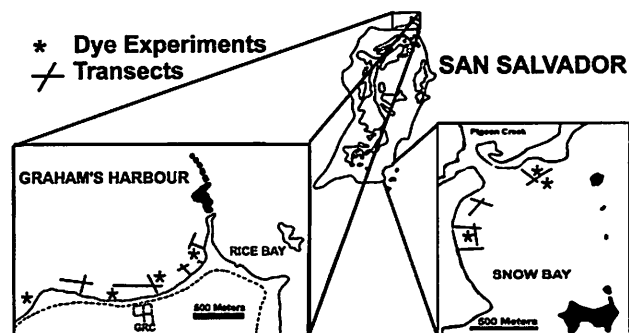


Figure 1. Map of Graham's Harbor and Snow Bay showing location of transects and sites of the dyeing experiments. Each asterisk represents several aquaria in the dye experiment.

## METHODS

### Diversity and Density Counts of Calcareous Algae

Several transects, both parallel and perpendicular to the shore, were established at both Snow Bay and Graham's Harbor. Each transect consisted of up to 12 stations, 15 meters apart. In addition, other randomly sampled quadrats were counted as well. Density counts were made using a 0.5 m x 0.5 m frame, producing a 0.25 m<sup>2</sup> quadrat. The stations on a transect were surveyed in the following manner: the frame was shifted one unit length to the right and left of the station marker and densities were again counted. Two divers counted three quadrats for each station and a fourth quadrat was harvested for laboratory work. A total of 299 quadrats were analyzed at the study sites during 2 field seasons, July 2000 and December 2001. In total, 180 quadrats were counted at Graham's Harbor and 119 at Snow Bay. Within each quadrat, the genera *Halimeda*, *Penicillus*, *Udotea* and *Rhipocephalus* were counted. Select species were identified when possible.

## Dyeing Experiment

The algae were dyed *in situ* using Alizarin Red S stain (Sigma® Alizarin Sodium Sulfonate) dissolved in seawater (Wefer, 1980; Hudson, 1985; Multer, 1988; Payri, 1988; Freile and Hillis, 1997). Glass, plastic or Plexiglas® aquaria (Figure 2) were inverted over algal patches containing at least 15 thalli (plants). The aquaria were banked up with surrounding sediment and weighted with lead weights to prevent accidental overturning by currents. A volume of 240 cc of approximately 25,000 ppm Alizarin Red S stain was introduced through a syringe and hose. This gave a final concentration of 300 ppm in the aquaria. This concentration was one or two orders of magnitude greater than the concentrations used by Wefer (1980) or Payri (1988) and was determined after previous attempts (Freile and Hillis, 1997) at lesser concentrations failed to give observable results. Several aquaria were placed at different parts of the lagoons during several different days.

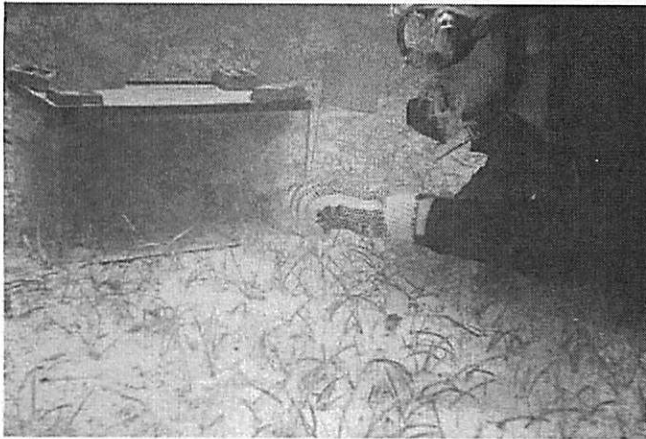


Figure 2. *In situ* dyeing experiment. A glass aquarium is inverted over a patch of 15 or more thalli and Alizarin Red S dye is introduced through a syringe and tube. The aquarium is weighted down with lead weights and marked with flags.

A total of 108 algal thalli were dyed (56 at Graham's Harbor and 52 at Snow Bay). The algae at Graham's Harbor were sampled at intervals of 2, 4, 5, 8, 10, 11, 14, and 17 days, and the Snow Bays algae were sampled at 2, 6, 7, and 9-day intervals. The algae were harvested by removing the

entire thallus and holdfast, were air-dried, and then stored for further analysis. Once in the laboratory, the algae were soaked in a mixture (1:1) of distilled water and Clorox® for 3 minutes to remove organic matter, washed with distilled water, and then allowed to air-dry. Dyed and new-growth segments were clearly observable. All segments were counted. Growth rate was measured as the proportion of new segments per total segments (Wefer, 1980; Multer, 1988; Freile and Hillis, 1997).

## Carbonate Production

Multiple quadrats were harvested near station markers throughout the study areas. The algae lying within the quadrat were picked. A total of 203 thalli of *H. incrassata* were measured from Snow Bay and 216 from Graham's Harbor. The height and the number of branches of the thalli were measured, and their plates (segments) counted. *H. opuntia* from Snow Bay was measured as a percentage cover of the substrate within the frame of a quadrat. The holdfasts of the rhipsalian algae were removed. In order to remove all organic material, they were subsequently oxidized with a Clorox® and water mixture, then washed in distilled water and air-dried, and stored for further analysis. The *H. opuntia* clumps were oven-dried after digestion in a Clorox® and water mixture and weighed as a whole to obtain  $\text{g/m}^2$  of algal carbonate mass. Representative samples of segments ( $n=150$ ) were also cleaned, oxidized, and weighed to obtain a representative figure of grams of  $\text{CaCO}_3/\text{segment}$ .

## RESULTS

### Algal Diversity and Density of Calcareous Algae

Three species of *Halimeda*, the sand-growing taxa *H. incrassata* and *H. monile* (Section Rhipsalis) and the sand-rock sprawler *H. opuntia* (Section Opuntiae) were counted. Other *Halimeda* species (*H. scabra* and *H. simulans*) were also noted. *Halimeda incrassata* predominated at most sites and thus was used to determine production rates. Density data for Snow Bay and

Graham's Harbor are illustrated in Tables 1 and 2. *Halimeda incrassata* densities range between 0 and 184 thalli/m<sup>2</sup> for Snow Bay and from 0 to 164 thalli/m<sup>2</sup> for Graham's Harbor, and their mean annual densities are 27 and 26 thalli/m<sup>2</sup> respectively. These figures are comparable to Multer's (1988) figures of 26 to 36 thalli/m<sup>2</sup> in his 3 environments on Antigua. At Snow Bay, *H. incrassata* predominated at sites with moderate to sparse grass beds and *H. opuntia* predominated at sites with dense grass beds. The features described by Hudson (1985) most closely resemble the nascent bioherms observed at Snow Bay, which constitute most of the *Halimeda* carbonate productivity at that site. Multer (1988) also noted that the greatest overall number of rhipsalian *Halimeda* species were to be found in medium density grass beds. Davis and Fourqurean (2001) have established a relationship between the presence of sea grass and the decreased size of *H. incrassata* thalli by over 20%. They believe that competition for nitrogen is the mechanism for the interaction and not a problem of light limitation. *H. opuntia*, however, grew in clumps or 'nascent' bioherms within these dense grass beds (Figure 3A&B). This growth may be due to the increase in nutrient supply from the detrital organic matter from grass blades, which is generated by vigorous wave agitation in this very shallow area. Because *Halimeda* obtains nutrients through both the water column and primarily through the substrate (Fong et al., 2001), their close association with grass beds that contain higher nutrient values within the muddy substrate is not unusual. These *H. opuntia* build-ups are very similar to those described by Hudson (1985). A total of 13 build-ups were measured at Snow Bay; these data are shown in Table 3. In addition to the algae represented in Tables 1 and 2, other algae and sea grasses were noted, but in most cases represented <2 thalli/m<sup>2</sup>.

The time of year (July vs. December) did play a role in the total rhipsalian *Halimeda* densities measured at both Snow Bay and Graham's Harbor. In Graham's Harbor, the density of *Halimeda* in December was close to 4 times that found in July and the density of *Halimeda* at Snow Bay in December was on the order of 1.5 times that found in July. This is opposite of what Lirman and Biber (2000) showed for the northern

Florida reef tract. They measured maximum percent cover of macro algae (*Halimeda* and *Dicthyota*) in July vs. December (56.7% vs. 25.8%). Both Graham's Harbor and Snow Bay show a decrease in salinity from July to December of 1-3 ‰ (35.6‰ December vs. 38.0‰ July for GH and 35.5‰ December vs. 37.0‰ July for SB). Graham's Harbor appeared to maintain a relatively constant water temperature throughout the year, but Snow Bay was on average 3-4 °C cooler in December (22.3°C v. 26.7°C).

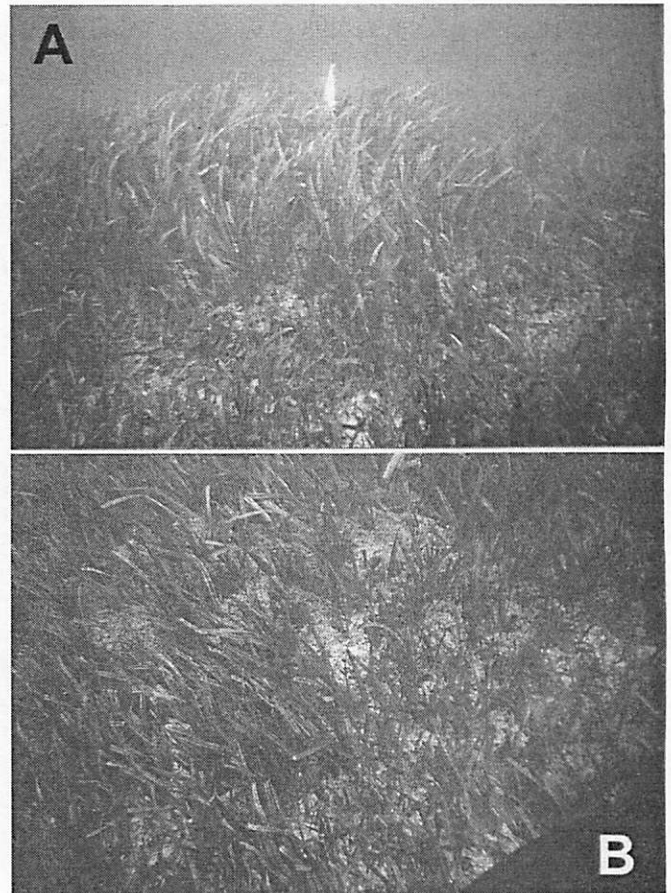


Figure 3. A) Incipient *Halimeda* 'bioherm' at Snow Bay. The feature is approximately 2.5 meters across and 0.75m high. B) Looking down on a *H. opuntia* 'bioherm.' Note the thickness of the grass bed and the bulbous clump-like nature of the build-up.

#### Dyeing Experiment

New growth, as indicated by absence of pink (alazarin stained) segments, was clearly observed on approximately 70% of the *H. incrassata* thalli. It was difficult to observe on *H. monile* and



Species	Range (thalli/m <sup>2</sup> )	Mean (thalli/m <sup>2</sup> )
<i>Halimeda incrassata</i>	0-184	27
<i>Halimeda</i> sp.	0-44	6
<i>H. monile</i>	0-104	6
Rhipsalian <i>Halimeda</i> species		39
<i>H. opuntia</i>	0-100%cover	20%
<i>P. capitatus</i>	0-20	4
<i>P. dumentosus</i>	0-16	1
<i>Penicillus</i> sp.	0-20	1
<i>Udotea cyanthiformis</i>	0-16	3
<i>Udotea</i> sp.	0-24	4
<i>Rhypocephalus</i> sp.	0-20	12

Table 1. Algal density data for Snow Bay.

Species	Range (thalli/m <sup>2</sup> )	Mean (thalli/m <sup>2</sup> )
<i>Halimeda incrassata</i>	0-164	26
<i>Halimeda</i> sp.	0-8	1
<i>H. monile</i>	0-132	1
Rhipsalian <i>Halimeda</i> species		27
<i>Penicillus capitatus</i>	0-52	14
<i>P. dumentosus</i>	0-44	9
<i>Penicillus</i> sp.	0-32	6
<i>Udotea cyanthiformis</i>	0-40	3
<i>Udotea</i> sp.	0-20	1
<i>Rhypocephalus</i> sp.	0-24	3

Table 2. Algal density in Graham's Harbor.

Length	Width	Height
2.1	1.6	0.62
2.4	2.2	0.55
5.0	3.2	1.00
1.5	1.4	0.40
2.6	1.4	0.30
5.4	3.1	0.55
1.3	1.2	0.40
2.5	2.3	0.75
2.6	1.25	0.50
1.65	1.55	n/a
1.65	1.10	n/a
1.9	1.80	n/a
1.25	1.15	n/a

Table 3. Measured *H. opuntia* build-ups (nascent bioherms). All numbers are in meters.

*H. opuntia* thalli, whereas *H. simulans* and *H. scabra* did not constitute a large enough population in the aquaria experiment to analyze statistically. Regression analysis ( $R=0.918$  and  $R=0.797$ ) of the data are shown in Figures 4-5 for Graham's Harbor and Snow Bay, respectively. The best-fit regression lines show a doubling time (100% replacement) of 46.7 days (GH) and 19.8 days (SB). If this figure represents one crop of segments, then a figure of 7.8 and 18.4 crops per year are obtained for these areas respectively. The term 'crop' is a helpful concept when considering production; yet in terms of growth pattern it may be misleading. A new thallus may be produced, or the equivalent in new segments may be added to an older, perennial type of base, as new leaves are added to trees. The data indicate that conditions for *Halimeda* growth at these site remain similar throughout the year, 7.8 and 18.4 'crops' (*sensu lato*) would be produced. There appeared to be no statistically valid changes in the growth rate between July and December. These figures are within the range of the general 3 to 19 crops per year provided by Hillis (1991) for *Halimeda* (most species and environments).

The growth rates for *H. incrassata* at Snow Bay is 50 to 100% greater than what other researchers have found in the Caribbean (Wefer, 1980; Multer, 1988; Freile and Hillis, 1997) (Figure 5), while those of Graham's Harbor correlate well with the figure of Multer (1988). Doubling rates in Bermuda (Wefer, 1980) and Panama (Freile and Hillis, 1997) were 32 days and in Antigua, W.I., 39 days (Multer, 1988). In making these comparisons, it should be remembered that physico-chemical parameters for these different study areas may be very different and are based on extrapolations from a few months of data. Turn-over figures must be applied with care until more data on different species, and the impact of temperature, salinity, currents, and photosynthetic photon flux are known.

#### Carbonate Production

From the measurements of 216 thalli, it was determined that each *H. incrassata* thallus contained an average of 59 segments at Graham's Harbor. Similar counts on 203 *H. incrassata* thalli

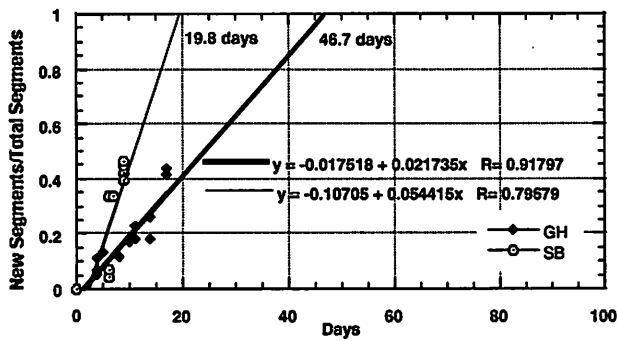


Figure 4. In situ growth rate for *Halimeda incrassata* at Graham's Harbor and Snow Bay. Growth rate is expressed as a ratio between new segments/dyed segments over a maximum period of 17 days.

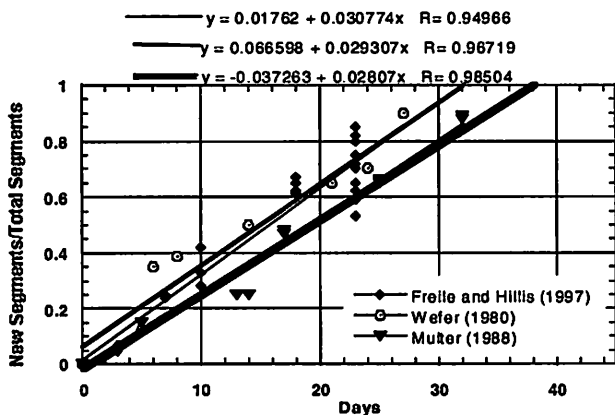


Figure 5. In situ growth rate for *Halimeda incrassata* data from Freile and Hillis (1997), Multer (1988) and Wefer (1980). Growth rate is expressed as a ratio between new segments/dyed segments over a maximum period of 32 days.

at Snow Bay showed an average of 81 segments/thallus. Total carbonate content of the segments is calculated by individual weight of representative segments ( $n=150$ ). When the 150 individual segments were weighed, a mean value of 0.0110 g/segment was obtained. This value is comparable to Multer's (1988) value of 0.009 grams. In addition,  $\text{CaCO}_3$  accounts for 81% of the total algal biomass of *H. incrassata* and 89% of *H. opuntia*, values similar to that obtained by Multer (1988) of 88%. These values are obtained by measuring total dry weight of the algae before and after digestion with Clorox®.

Carbonate productivity can be determined from density counts (26 or 27 thalli/ $\text{m}^2$  *H. incrassata*) or percent cover (20% *H. opuntia*), turnover time of the algal population (46.7 and 19.8 days), and from calculations of average number of segments/thallus (59 and 81) and weight in grams of  $\text{CaCO}_3$  per segment (0.0110g).

### Graham's Harbor

For Graham's Harbor, based on the growth rate obtained (46.7 day turn-over), 7.8 crops per year are calculated. The average number of segments per thallus is 59 and the total mean dry weight of  $\text{CaCO}_3$  for each segment was calculated at approximately 0.011 g of  $\text{CaCO}_3$  ( $n=150$ ). Each thallus then produces 0.649g of carbonate. This figure is approximately 20% less than the figure of 0.8 g reported by Hillis (1980). There are a total 28 thalli/ $\text{m}^2$  of the rhipsalian species of *Halimeda* (*H. incrassata*, *H. monile* and *Halimeda* sp.), 26 of which are from *H. incrassata*. The amount of  $\text{CaCO}_3$  contributed by the total *Halimeda* populations is 17.50 g  $\text{CaCO}_3/\text{m}^2$  and *H. incrassata* alone accounts for 16.87 g  $\text{CaCO}_3/\text{m}^2$  of this total. If the experimentally derived figure of 7.8 crops/yr is used, then *Halimeda* in this area produces 136.80 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$ , and *H. incrassata* alone is responsible for 131.59 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$  of that figure. This is more than twice the figure of 58 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$  reported by Armstrong and Miller (1989) for Graham's Harbor and equal to the 136 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$  they report for all calcareous algae and epibionts on the blades of the sea grass *Thalassia*. Armstrong and Miller's (1989) method was based on getting a post-mortem disaggregated weight for the thalli of each genera and multiplying that by individuals/ $\text{m}^2$  as well as obtaining calcification rates from the literature. In this manner they estimated each thallus to produce 0.628g of carbonate. Multer (1988) reported values in Antigua for *H. incrassata* and *H. monile* of 56.9, 65.7, and 114 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$  for an open lagoon area, a fringing reef lagoon, and behind a bank barrier reef, respectively. Other estimates of *Halimeda* productivity in lagoons have spanned the range of 24 to 48 g  $\text{CaCO}_3/\text{m}^2/\text{yr}$  (Neumann and Land, 1975) in



the Bight of Abaco to 105 g CaCO<sub>3</sub>/m<sup>2</sup>/yr from the Florida Keys (Bosence et al., 1985).

### Snow Bay

Based on figures obtained for Snow Bay, the average number of segments per thallus is 81. There are a total 39 thalli/m<sup>2</sup> of the rhipsalian species of *Halimeda* (*H. incrassata*, *H. monile*, and *Halimeda* sp.), 27 of which are from *H. incrassata*. The amount of CaCO<sub>3</sub> contributed by all upright *Halimeda* species is 34.75 g CaCO<sub>3</sub>/m<sup>2</sup> and *Halimeda incrassata* contributes 24.06 g CaCO<sub>3</sub>/m<sup>2</sup> of that figure. If the experimentally derived figure of 18.4 crops/yr is used, then *Halimeda incrassata* in this area produces 442.70 g CaCO<sub>3</sub>/m<sup>2</sup>/yr and all rhipsalian species of *Halimeda* produce 639.38 g CaCO<sub>3</sub>/m<sup>2</sup>/yr. This number is over twice what Small and Adey (2001) attribute to *Halimeda* as part of the whole coral reef ecosystem. From a microcosm experiment they conducted, Small and Adey (2001) attribute calcification to be on the order of 4000 g CaCO<sub>3</sub>/m<sup>2</sup>/yr for the whole ecosystem, and they attribute only 7.4% or 296 grams of calcification to *Halimeda*.

In addition, a clump of *Halimeda opuntia* equivalent to 20% cover can generate 66 g CaCO<sub>3</sub>/m<sup>2</sup>. If the experimentally derived figure of 18.4 crops/yr is used, then the opuntiod algae in this area produce 1227.65 g CaCO<sub>3</sub>/m<sup>2</sup>/yr. Hudson (1985) reported a value of 1088 g CaCO<sub>3</sub>/m<sup>2</sup>/yr for *H. opuntia* in the Marquesas Islands. The combined total for all *Halimeda* species is then 1867.03 g CaCO<sub>3</sub>/m<sup>2</sup>/yr. Based on these calculations, carbonate productivity in this lagoon is nearly equal to other tropical areas. For example, Freile and others (1995) estimated 2400 g CaCO<sub>3</sub>/m<sup>2</sup>/yr on Great Bahama Bank; Freile and Hillis (1997) estimated 2323 g CaCO<sub>3</sub>/m<sup>2</sup>/yr for San Blas, Panama; and Drew (1983) and Drew and Abel (1985) obtained values of 2234 and 2519 g CaCO<sub>3</sub>/m<sup>2</sup>/y., respectively from the Great Barrier Reef. Payri (1988, 1995) obtained figures of 2300 and 3000 g CaCO<sub>3</sub>/m<sup>2</sup>/yr from a Tahitian reef.

## DISCUSSION AND CONCLUSIONS

Carbonate productivity due solely to the rhipsalian species of *Halimeda* in Graham's Harbor is larger than that of other similar areas in the Caribbean, particularly the figures obtained by Neumann and Land (1975), Bosence et al. (1985), and the value previously calculated by Armstrong and Miller (1989) of 58 g CaCO<sub>3</sub>/m<sup>2</sup>/y for *Halimeda* in Graham's Harbor. The value calculated herein for GH of 136.8 g CaCO<sub>3</sub>/m<sup>2</sup>/y is comparable to the value of 114 g CaCO<sub>3</sub>/m<sup>2</sup>/y obtained by Multer (1988) in Antigua for the area behind the bank barrier reef.

Based on the preliminary calculation of 1867.03 g CaCO<sub>3</sub>/m<sup>2</sup>/y, total *Halimeda* carbonate productivity at Snow Bay is nearly equal to other tropical and near tropical areas (Drew, 1983; Drew and Abel, 1985; Payri, 1988, 1995; Freile and Hillis, 1997). *In situ* accumulation of these *Halimeda* sediments alone would produce a vertical build-up of at least 2m/1000 years, assuming no export of material. Export obviously exists since the sands of the Pigeon Creek tidal channel consist mainly of *Halimeda* segments. Mitchell (1986) found that Pigeon Creek consisted of 12 lithofacies. Three of these lithofacies accounted for 67% of the total surface sediment of Pigeon Creek: 1) the "*Halimeda*" Lithofacies (H), consisting of *in situ* beds of *Halimeda* which he could break down into *H. monile*, and *H. incrassata*, and *H. opuntia*; 2) the "*Transported Halimeda*" Lithofacies (HT), which consisted of *Halimeda* segments transported by tidal currents; and 3) the "*Transported Halimeda-Peloid Sediment*" Lithofacies (ST2), consisting of peloids transported into a HT facies. Export of *Halimeda* to the bank edge and then down the bank slope is no doubt also taking place at San Salvador as it does on western Great Bahama Bank (Wilber et al., 1990; Freile et al., 1995).

Andersen and Boardman (1989) cored several sites in Snow Bay where they encountered a thick (in some places over 1m) sequence of a *Halimeda* packstone/wackestone facies. The species of *Halimeda* that primarily makes up this facies was not given. They also noted that mud layers dated within this facies showed ages that were

600-3140 years younger than the interbedded sands. One mud layer within the *Halimeda* packstone/wackestone facies, approximately 66 cm from the top of the core, indicated an age of 490 y.b.p. (Andersen and Boardman, 1989). A recently published molecular study on *Halimeda* (Kooistra et al., 2002) suggests the possibility that *H. opuntia* is a recent migrant to the Caribbean. *H. opuntia* is an invasive, opportunistic species that is an important constituent of the reef habitat and its population in the Caribbean may represent inter-oceanic dispersal that may be as recent as the onset of inter-oceanic shipping: i.e., the last 500 years (Kooistra et al., 2002, *pers. comm.*). I believe that export of these *Halimeda* sediments in Snow Bay plays a more active role than the *in situ* deposition of them, and that the resulting build-ups of *H. opuntia* sediments are a recent (possibly less than 500 years ago) occurrence. Though Pigeon Creek and Snow Bay have a Pleistocene analogue (Thalman, 1983) and *Halimeda* is a constituent grain of those deposits, it is not found in the relative abundance that it currently exhibits in Snow Bay and Pigeon Creek. Contributing factors to this growth may be the abundance of detrital organic matter from the copious *Thalassia* meadows and nutrients transported from upwelling and ocean currents, as well as the opportunistic nature of the alga. Its continual growth will greatly increase the sediment supply both on the bank tops and slopes. Similar build-ups primarily composed of *H. opuntia* in the Caribbean may one day resemble those of the Great Barrier Reef and the Java Sea described by Davies and Marshall (1985) and Roberts et al. (1987a,b; 1988), respectively.

Given the continuous cycle of sea level high- and low-stand which affect the Bahamian platforms as well as the associated lateral progradations (Kenter et al., 2001), and continuous upwelling from the bank-edge, these nascent bioherms might resemble those observed on the bank-edge of western Great Bahama Bank (Freile et al., 1995) and the Nicaraguan rise (Hine et al., 1988). A submersible dive and some seismic work off the bank edge SE of Snow Bay might show some evidence of these features on the bank-edge break.

If *in situ* production, accumulation rate, and burial of algal carbonates (specifically of

*Halimeda*) are as high as shown in this and other studies, then the calcareous algal input by tropical and near tropical shelf areas to global carbonate sedimentation is vastly underrepresented in carbonate models. In some regions of the tropics, algal meadows may produce more carbonates than their framework coral reef counterparts (Borowitzka and Larkum 1986; Hillis 1986c), and unlike reefs in which corals predominate, some algal meadows may be sequestering carbon rather than releasing it. This could play a major role in the analysis and balancing of the carbon budget as CO<sub>2</sub> increases in the atmosphere. This concept demands further study.

*Halimeda* and other calcareous algae could be much more important as a carbonate source and as a sink in tropical and near tropical continental shelf areas than has been previously acknowledged. Algal-derived carbonates are an important constituent of the rock record as well. Their high alteration rates (Freile et al., 1992) mask their true provenance. Ancient rock sequences, which have previously been labeled as nondescript carbonate muds, should be looked at in this new light.

#### ACKNOWLEDGMENTS

Two Faculty Development Grants from Berry College provided funding for this study. The work was conducted under the auspices of the Gerace Research Center (formerly the Bahamian Field Station), San Salvador, Bahamas. I would like to specially thank Kenny Buchan and Vince Voegeli for their gracious assistance during July 2000 and December 2001, respectively. A very special thanks goes to my students Christopher R. Faulkner and Justin Edge for their assistance in the field and laboratory.

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