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NOTES

CHANGES IN A FRINGING REEF COMPLEX OVER A THIRTY-YEAR PERIOD: CORAL LOSS AND LAGOON INFILLING AT MARY CREEK, ST. JOHN, U.S. VIRGIN ISLANDS

Rónadh Cox, Rebecca K. Atkinson, Blakely R. Bear, Mark E. Brandriss, Carla B. Chokel, Jana C. Comstock, Ethan D. Gutmann, Lauren B. Interess, Taylor F. Schildgen, Samantha J. Teplitzky and Malana P. Willis

Recent decline in the diversity and percent cover of hard corals in reef environments worldwide has been extensively documented (Done, 1992; Gladfelter, 1982; Kuta and Richardson, 1996; Precht and Aronson, 1997; Rogers, 1990). To understand this decline, long-term records of reef environments (e.g., Aronson and Precht, 1997; Hughes, 1994; Precht and Aronson, 1997) are essential, but relatively few such records exist.

The subject of this study is a fringing reef in the U.S. Virgin Islands, the Mary Creek reef complex (MCRC), located within the St. John National Park (Fig. 1). In addition to the 1998 field study reported here, the MCRC has been the site of several undergraduate research projects over the last 30 yrs (MacLeod, 1986; Mayall, 1993; Stoeckle et al., 1968). In aggregate, these studies furnish a picture of large-scale change in the MCRC between 1968 and 1998. During this time, the reefs of St. John have been subject to increasing tourist visitation and impact from human settlements (e.g., Hubbard et al., 1987; MacDonald et al., 1997) and the island has been battered by several hurricanes (e.g., Rogers et al., 1991), but the long-term effects of these phenomena are unknown because continuous reef-monitoring programs in the National Park have been undertaken only recently. No multi-decade studies have been published to date, and to the best of our knowledge, the MCRC is the only reef in the area for which such a continuous record exists.

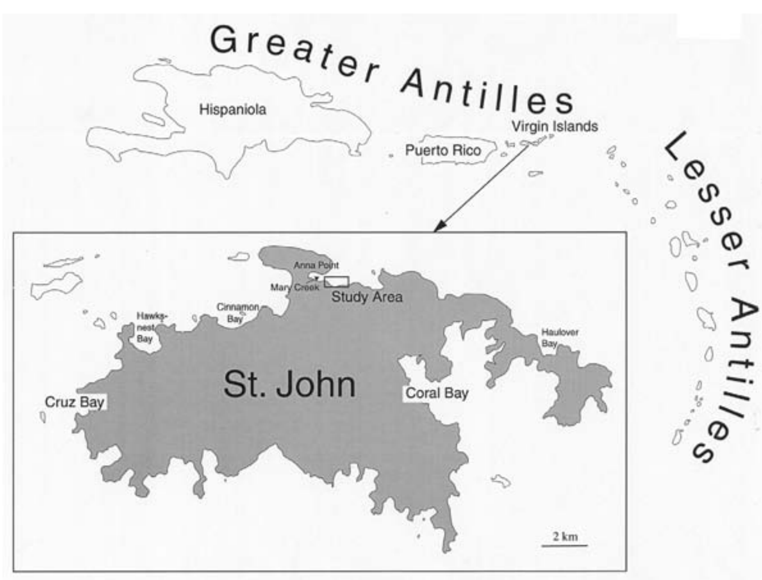

Figure 1. The island of St. John is on the northern margin of the Caribbean. The location of the study area on the northern coast of St. John is shown.

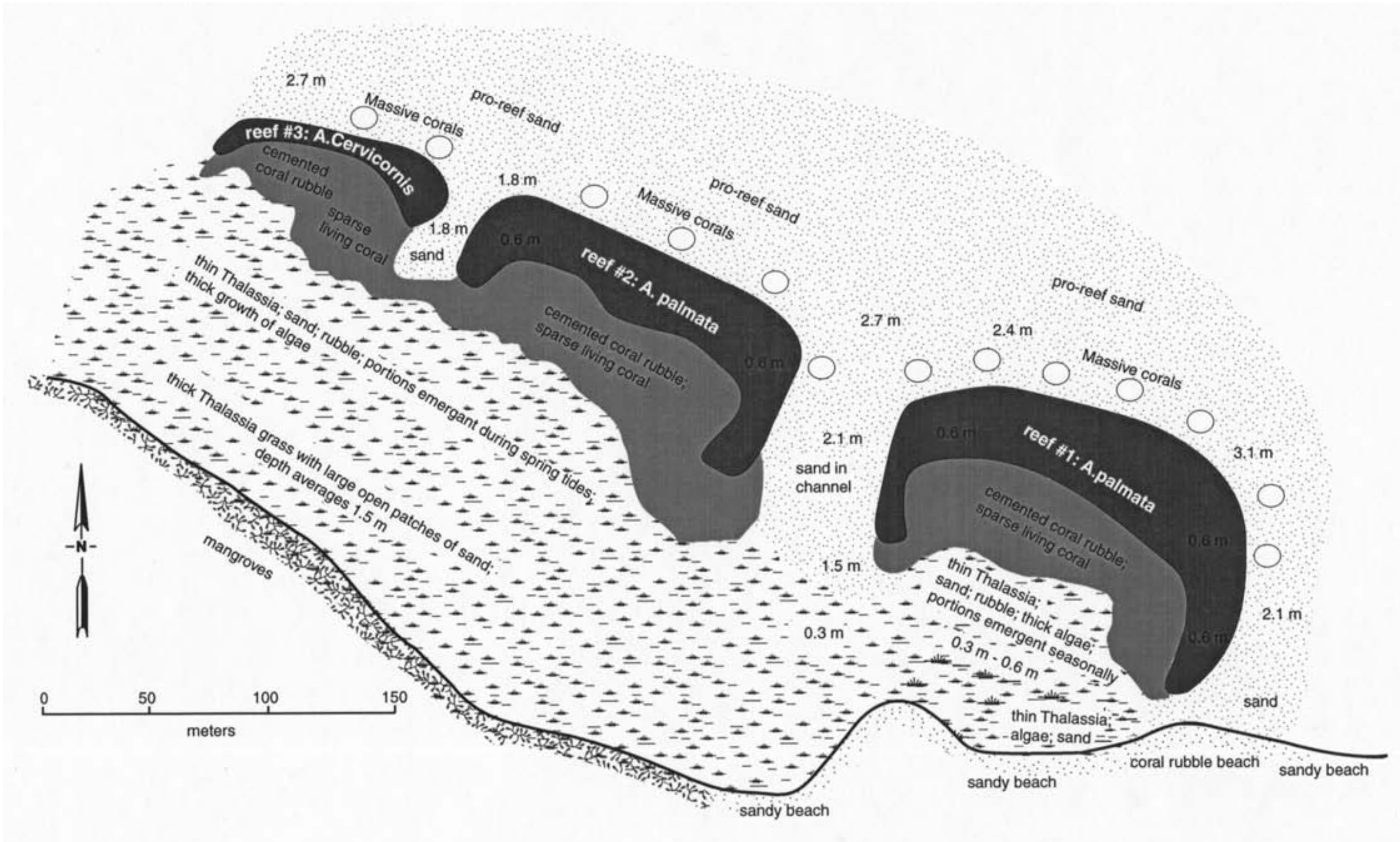

Figure 2. Map of the MCRC in 1968 (redrafted from Belt et al., 1968).

Summary of Pre-1998 Studies

The marine environments of St. John were first mapped in 1958 and 1959 as part of a marine biological survey of the then newly-created St. John National Park, and the MCRC was identified as one of the most spectacular shallow-water reef areas (Kumpf and Randall, 1961). Subsequent detailed mapping of the MCRC (Stoeckel et al., 1968) showed that the reef in 1968 consisted of three lobes, separated by deeper, sandy channels (Fig. 2). The reef crest was dominated by well-developed stands of *Acropora palmata*, the branches of which were aligned parallel to the direction of wave travel. Living *A. palmata* was abundant throughout, but was especially dense on the eastern lobe, which had the greatest exposure to wind and waves. *A. cervicornis* was also a prominent member of the reef community, most notably in the westernmost part of the reef complex (Fig. 2). The back-reef zone was dominated by beds of *Thalassia*, with a mean water depth of about 1.5 m. The MCRC at that time was considered to represent a classic example of a well-developed fringing reef (Belt, 1968).

By the mid-eighties the coral cover had changed significantly. Data in MacLeod (1986) show that most *A. palmata* colonies were dead, although still standing in growth position. Living *A. palmata* occurred in less than 5% of surveyed quadrats (n = 215; data collected every 5 m on traverses spaced 25 m apart) and living *A. cervicornis* was recorded in just 2% of quadrats. A few years later, Mayall (1986) noted live *A. palmata* at only 4% of points surveyed on the reef.

Methods

To map the MCRC in January 1998 we constructed a baseline by making a decimeter-scale tape-and-compass survey of the shoreline, using the seaward limit of mangrove growth as the datum. From the shoreline we ran 17 traverses across the study area, spaced 25 m apart. Data were collected at 5 m intervals along each traverse, ending on the seaward side of the fringing reef when water depths reached 3.5 m. Depths were measured using a plumb bob or weighted tape. Species abundances, sediment type, and substrate information were recorded from 0.25 m^2 quadrats. The quadrats were lightly weighted. Blind placement of the quadrats was achieved by setting them on the water surface at each 5 m interval and allowing them to fall to the bottom unguided. Because the quadrats had only slight negative buoyancy, they wafted to the bottom along an unpredictable, non-linear path. In addition, their landing was gentle and caused no damage to benthic organisms. Once the quadrats were in place, data were collected either using aluminium trash cans fitted with perspex bases to view the bottom in shallow water, or in deeper areas by diving with masks and snorkels.

Description of the Mary Creek Reef Complex

Fore-Reef.—The fore-reef area is defined by the absence of continuous coral buildup. It slopes gradually seaward and is the deepest-water zone of the reef complex (Fig. 3). The sea floor consists of bioclastic sand with occasional siliciclastic fragments. The sand is typically well-sorted, and usually medium- to coarse-grained. Isolated heads or clusters of massive coral (mainly *Montastraea* sp. and *Diploria* sp.) and various gorgonian soft corals are distributed on the sandy substrate. The clusters average about 1–3 m in diameter and about 1 m in height. They are concentrated near the main reef zone and become less abundant seaward.

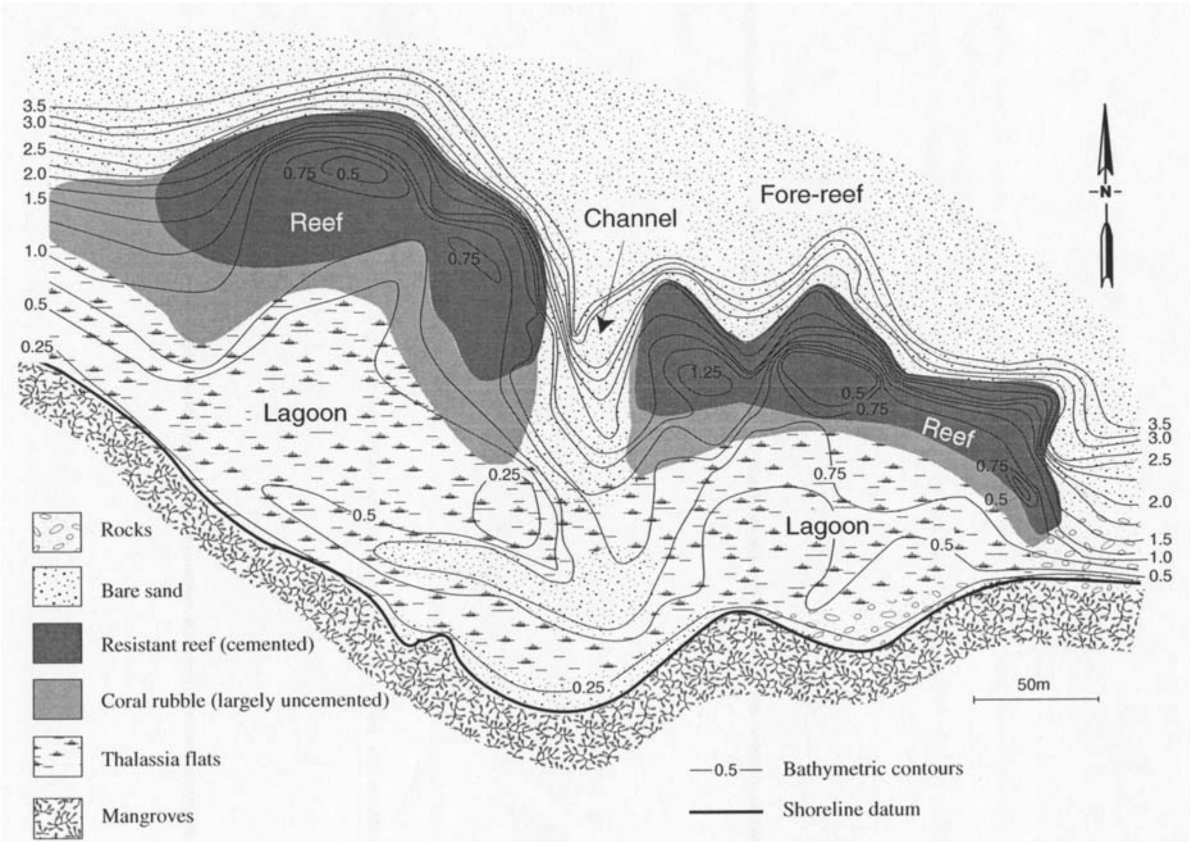

Figure 3. Map of the MCRC in January 1998 showing ecologic and sedimentologic zones and bathymetry, based on data from 420 data stations along surveyed traverses. Traverses were oriented 20° E of N, and spaced 25 m apart along the shoreline. Data were collected at 5 m intervals along each traverse. The bathymetric contour interval is 0.25 m.

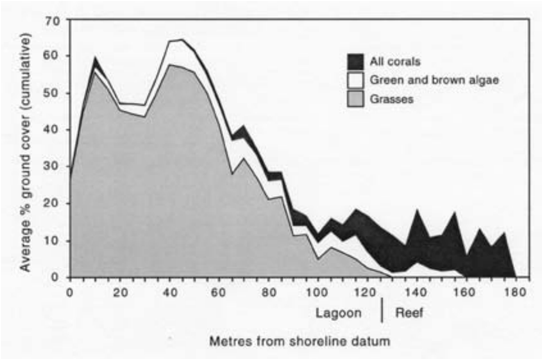

Figure 4. Abundance of corals, algae (mainly *Dictyota* sp. and *Caulerpa* sp.) and grasses (*Thalassia* sp. and *Syringodium* sp.) in the back-reef lagoon and reef buildup of the MCRC, as a function of distance from shore.

Main Reef.—The bathymetric and ecologic transition from the fore-reef zone to the main reef buildup is quite abrupt. The reef, which forms two lobes separated by a sandy channel, consists of a resistant coral framework on the seaward side, with a coral rubble zone to landward which grades into the back-reef lagoon (Fig. 3). The resistant reef consists mainly of dead coral heads and fragments cemented by encrusting coralline algae, with some green and brown fleshy algae, sponges, abundant urchins (mainly *Diadema antillarum*), and sparse live coral (Figs. 4,5). The non-resistant rubble zone consists of finer coral debris, generally loose and uncemented or weakly cemented. A small portion of the reef crest is emergent at low tide. Low-tide water depths in the reef zone range from 0 m on parts of the crest to about 2.5 at the base of the reef buildup. The average topographic elevation of the reef crest with respect to the sea floor in the nearby fore-reef area is approximately 2 m (Fig. 3).

The bulk of the reef surface is covered with broken branches of *A. palmata*. All dead *A. palmata* colonies are toppled: none remain upright. In addition, dead *Diploria* sp. and *Montastraea* sp. boulders occur in growth position. The dead colonies and coral rubble are overgrown and cemented by calcareous algae. Living corals cover less than 10% of the reef on average (maximum coverage is 16%), and are dominated by massive forms

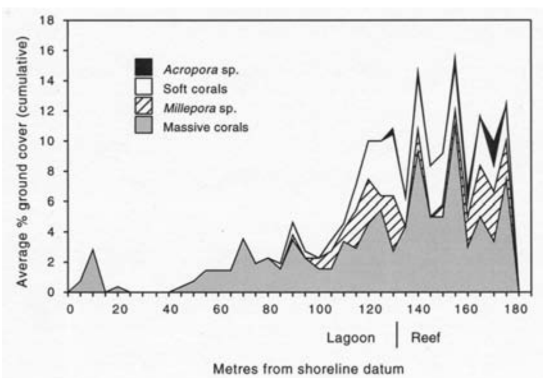

Figure 5. Average abundance of the major coral types in the lagoon and on the reef, as a function of distance from shore . The “massive corals” include *Montastraea*, *Diploria* and *Porites* spp.

(mainly *Porites asteroides* and *Millepora* sp., with minor amounts of *Diploria* sp. and *Montastraea* sp.) (Fig. 5).

The average size of coral fragments on the reef decreases landward. The surf zone is characterised by large *A. palmata* pieces with an average length of approximately 30 cm, and this grades into a quieter-water zone of gravel-sized (1-6 cm) coral rubble with abundant small (<15 cm) *Montastraea* and *Diploria* recruits in addition to urchins and sponges. The size and abundance of coral recruits decreases landward, and increasing volumes of grasses (mainly *Thalassia testudinum* and *Syringodium filiforme*) mark the transition to the back-reef lagoon (Figs. 4, 5).

REEF CHANNEL.—The channel between the reef lobes (Fig. 3) is floored with a mixture of well-sorted gravel-sized coral rubble (dominated by *A. cervicornis* fragments) and bioclastic carbonate sand. In addition to scattered live gorgonians, there are some small (<30 cm) heads of living coral, mainly *P. asteroides* and *Montastraea* sp., but otherwise the seafloor is bare of organisms. Wave ripples and tidal current ripples are common. Water depths in the channel range from 1–3 m.

BACK-REEF LAGOON.—The transition from the main reef to the back-reef area is gradual. The back-reef lagoonal zone is defined as having less than 25% gravel-sized coral rubble. It is dominated by *Thalassia* sp. with subordinate *Syringodium* sp. and varying amounts of brown algae (mainly *Dictyota sp.*) and green algae (dominated by *Caulerpa sp.*) (Fig. 4). There are some bare sandy patches, especially close to the reef channel. The sediment consists mainly of medium- to coarse-grained bioclastic sand. Fine-grained silt and mud occur only in occasional patches close inshore, near mangroves. Water depths range from 0-1 m (Fig. 3).

DISCUSSION: CHANGES IN THE MCRC FROM 1968–1998

The MCRC has undergone massive changes in recent decades. Its designation as one of the most attractive fringing reefs of St. John in 1958 (Kumpf and Randall, 1961) was borne out by detailed mapping a decade later (Stoeckle et al., 1968). However, massive coral mortality had occurred by the mid-eighties (MacLeod, 1986), and today the reef crest is almost barren of live coral. The reef morphology has also changed considerably, and in addition, ongoing sediment accumulation has led to substantial infilling of the back-reef lagoon.

REEF MORPHOLOGY.—The shape and layout of the MCRC has altered strikingly. In 1968 there were three distinct reef lobes (Fig. 2), but our mapping (Fig. 3) shows that only two wave-resistant structures remain at present. These correspond to reefs #1 and #2 of Stoeckle et al. (1968) (Fig. 2). The *A. cervicornis*-dominated reef #3 (Fig. 2) no longer exists as a resistant feature, and is probably represented by the extended coral rubble zone at the western edge of the present reef complex (Fig. 3), which consists largely of *A. cervicornis* fragments. Comparison of Figures 2 and 3 also shows that the small sandy inlet that separated reefs #2 and #3 in 1968 has disappeared, although its former existence is evident from the present-day bathymetry (Fig. 3). In addition, the eastern inlet between reefs #1 and #2 (Fig. 2) has become narrower and shallower (Fig. 3).

LAGOON INFILLING.—Net sedimentation in the back-reef environment has led to a substantial decrease in water depth in the last 30 yrs. In 1968, depths in the lagoon averaged 1.5 m (Fig. 2), and in places were in excess of 2 m (E. S. Belt, unpubl. data). In contrast, the average depth in the lagoon in 1998 was approximately 0.4 m, and the deepest high-

Table 1. Representative Mary Creek tide data from the Oceanographic Products and Services Division of NOAA (Tide Station 9751414, monitoring dates November 6th to 21st, 1985).

Date	Time (mm)	Max. (mm)	Min.	Tidal Range in cm
6 Nov	p.m.	1,100	917	18.3
7 Nov	a.m.	1,009	887	12.2
	p.m.	1,131	887	24.4
8 Nov	a.m.	1,070	887	18.3
	p.m.	1,131	917	21.4
9 Nov	a.m.	1,131	887	24.4
	p.m.	1,100	887	21.3
10 Nov	a.m.	1,192	887	30.5
	p.m.	1,100	856	24.4
11 Nov	a.m.	1,192	826	36.6
	p.m.	1,039	826	21.3
12 Nov	a.m.	1,222	735	48.7
	p.m.	1,131	856	27.5
13 Nov	a.m.	1,314	765	54.9
	p.m.	1,161	887	27.4
14 Nov	a.m.	1,253	674	57.9
	p.m.	1,161	856	30.5
15 Nov	a.m.	1,192	735	45.7
	p.m.	1,222	887	33.5
16 Nov	a.m.	1,192	735	45.7
	p.m.	1,253	948	30.5
17 Nov	a.m.	1,070	796	27.4
	p.m.	1,161	856	30.5
18 Nov	a.m.	1,039	765	27.4
	p.m.	1,131	856	27.5
19 Nov	a.m.	948	796	15.2
	p.m.	1,070	826	24.4
20 Nov	a.m.	948	765	18.3
	p.m.	1,070	826	24.4
21 Nov	a.m.	978	826	15.2
	p.m.	948	856	9.2

Minimum range = 12.2 cm
Maximum range = 57.9 cm
Average range = 29 cm

tide water recorded in the back-reef was 0.6 m. The shallowing cannot be accounted for by tidal differences: the maximum recorded tidal range in this bay is 58 cm for spring tides and 12 cm for neap tides (Table 1). The average range is less than 30 cm. Tidal variation during the study period was 10–15 cm. This 1.1 m decrease in average depth over the 30-yr period corresponds to an average annual sedimentation rate of 3.6 cm yr^{-1}.

Ecological Changes.—Massive biological changes are evident from comparison of ecological profiles made in 1968 with data from this study (Fig. 6). In 1968 the reef was covered with living stands of *A. palmata*, but in 1998 living *A. palmata* was recorded in less than 2% of surveyed quadrats (2 of 106) on the reef. There is no evidence for reef

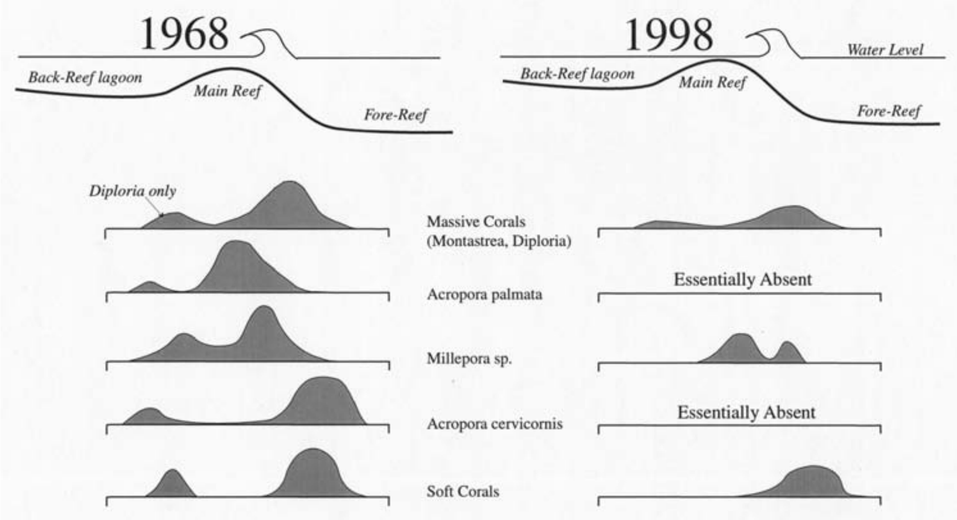

Figure 6. Schematic cross sections across the reef complex to illustrate the changes in species abundance from 1968 (after Belt et al. (1968), modified based on personal communication from E.G. Belt) to 1998 (this study). The horizontal axis represents distance in each case.

regeneration in the study area, and no *A. palmata* recruits were observed. The reef crest (Fig. 3) is currently composed mainly of dead and toppled *Acropora* fragments, ranging from a few centimeters to over a meter in length, with the coarsest material concentrated at the highest point of the buildup. The fragmentation and reworking are clearly the result of high-energy storm waves, but since most of the dead *A. palmata* colonies were still in growth position in the mid-1980s (MacLeod, 1986), storm waves were not the cause of their demise.

Conclusions

Substantial changes have occurred in the MCRC over the last thirty years. in 1968, the reef crest zone was dominated by dense stands of *A. palmata*, and the reef was actively prograding; in 1986, few *A. palmata* colonies remained alive; and in 1998 only two living colonies, both small (about 30 cm high, with fronds less than 30 cm across), were recorded. During the same period the average water depth in the back-reef zone decreased, from about 1.5 m in 1968 to about 0.4 m in 1998, which corresponds to an average sediment aggradation rate of approximately 3.6 cm yr^{-1}.

The present situation in the MCRC may result from a combination of factors, and it is possible that the affected coral communities will reestablish in the future. The interplay of environmental stimuli and their effects on reef ecology, and in particular the role of time, are only beginning to be understood (Done, 1992). Therefore, the existing 30-yr record makes this site an excellent candidate for a long-term reef monitoring study.

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Address: *Department of Geosciences, Williams College, Williamstown, Massachusetts 01267.* Corresponding Author: (R.C.) *Tel: (413) 597-2297. E-mail <rcox@williams.edu>.*

Lauren Interess was hit and killed by a speeding car on October 3rd, 1999. She was twenty-three years old. We will all remember and cherish the role Lauren played in producing this publication, and in each of our lives. Though none of us will again have the opportunity to explore new lands and new ideas with Lauren, we will always remember her warm humor, her enthusiasm for adventure, her dedication to work, and her unwavering friendship.
