VIRGIN ISLANDS RESOURCE MANAGEMENT COOPERATIVE

BIOSPHERE RESERVE
RESEARCH REPORT NO.17

INITIATION OF A LONG-TERM MONITORING PROGRAM FOR CORAL REEFS IN THE VIRGIN ISLANDS NATIONAL PARK

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U.S. MAN AND THE BIOSPHERE PROGRAM

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ABSTRACT

A long-term monitoring program was initiated for the coral reefs of the Virgin Islands National Park and Biosphere Reserve in recognition of the need for quantitative baseline data to provide information for resource assessment and effective management. Major stresses to the reefs in the park include terrigenous runoff, storm damage, and boat damage.

Transects were established on reefs in Reef, Fish, and Hawksnest Bays. During the study period, the most conspicuous damage to St. John's reefs resulted from heavy seas associated with Tropical Storm Klaus in November 1984. The storm resulted in a statistically significant decrease in the mean percent of live coral cover (from 26 to 21), an increase in diversity and evenness, and a slight decrease in spatial index at the Fish Bay site. The percent cover by the dominant coral *Agaricia agaricites* decreased significantly from 17 to 11. At Reef and Hawksnest Bays (for which there are only post-storm data), mean percent coral cover was 20 and 26, respectively.

Monitoring of changes in the amount of living coral cover and other parameters along the transects on reefs in these three bays will allow assessment of future damage from turbidity and other stresses.

ACKNOWLEDGMENTS

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INTRODUCTION

Major stresses affecting the coral reefs of the Virgin Islands National Park (VINP) on St. John, U.S. Virgin Islands, include, 1) terrigenous runoff, 2) storm damage, and 3) boat damage. Pollution from land-derived chemicals and from vessel discharges may also be damaging the coral reefs. One of the major environmental concerns on St. John is siltation of nearshore marine habitats from accelerated erosion following watershed development. Erosion and runoff are potentially serious problems on St. John because of its extremely steep hillsides and accelerated development activity.

Rapid, and in some cases, uncontrolled development on St. John has led to increases in terrigenous runoff. After heavy rains, bays both within and outside the park have highly turbid water. St. John residents believe that corals in Hawksnest and Cinnamon Bays on the north shore of the island were killed from siltation following exceptionally heavy rains in April, 1983 (457 mm in 24 hr). Both development of private lands within the park boundary and development outside the park boundary can contribute to turbidity in park waters which encompass 2,286 ha around the island. New subdivision roads are continuously being carved into the hillsides creating the potential for accelerated erosion and runoff.

Storms have undoubtedly caused the greatest destruction to coral reefs off the south side of the island. Hurricanes David and Frederic (1979), known to have caused considerable damage to reefs off St. Croix, are most likely responsible for the widespread fragmentation of the dominant branching coral species seen in Fish Bay, Reef Bay, Coral Bay and elsewhere. Tropical Storm Klaus hit the U.S. Virgin Islands on November 6 and 7, 1984, with winds gusting to 50 knots and very heavy sea swells. About 229 mm of rain fell during the storm, but the damage was primarily from the heavy swells rather than from turbidity. (The effects of the storm on one coral reef studied during this project are described below.)

Close to 1 million people annually visit Virgin Islands National Park, with most of them using the marine resources (boating, snorkeling, diving). While not as extensive as storm damage, damage from boats striking and grounding on coral reefs near and within popular bays is a serious problem in localized areas. Collection of corals for souvenirs and breakage by careless snorkelers are other consequences of excessive use, particularly evident at the underwater trail in Trunk Bay.

White band disease has killed extensive amounts of the most abundant coral (Acropora palmata) at Buck Island Reef National Monument, St. Croix, and on other St. Croix reefs. The disease has not been correlated with human activities. It is present on several St. John reefs (Beets, et al., 1986).

Studies carried out in 1984 by the Virgin Islands Resource Management Cooperative (VIRMC) resulted in an extensive amount of general information on the nearshore marine ecosystems off St. John, including qualitative surveys and maps of major benthic communities (e.g., Beets, et al., 1986). VIRMC projects for 1985 emphasize an interdisciplinary approach to watershed management in three bays on St. John, including studies of fisheries, sedimentation, and coral reefs. This VIRMC project was initiated as part of a long-term monitoring program for the coral reefs of the Virgin Islands National Park and Biosphere Reserve.

A major objective of this study was to select areas for long-term monitoring to allow documentation of deterioration or recovery of coral reefs around St. John. Research was carried out in disturbed and undisturbed watersheds in conjunction with other VIRMC studies. Several 1985 VIRMC studies were intended to begin to answer the following management questions: To what extent is terrigenous runoff affecting the reefs of St. John? Are the reefs within the Virgin Islands National Park and Biosphere Reserve deteriorating, and if so, what can be done to eliminate or minimize the damage? Monitoring and management recommendations are presented.

Other objectives of the project were to involve local people in an applied research study with educational and training aspects; and to select methods that could be easily taught, and repeated accurately without an extensive amount of training. Seven individuals have assisted in this study, five of them College of the Virgin Islands students. We made an effort to use methods which could be taught easily and which might prove suitable for use on other Caribbean islands with limited resources for monitoring and management. The eventual goal would be a model monitoring program that could be used by other Caribbean island countries in their parks/reserves.

Study sites

This study focussed on coral reefs associated with three watersheds on St. John (Figures 1-6, Table 1), each with different development histories.

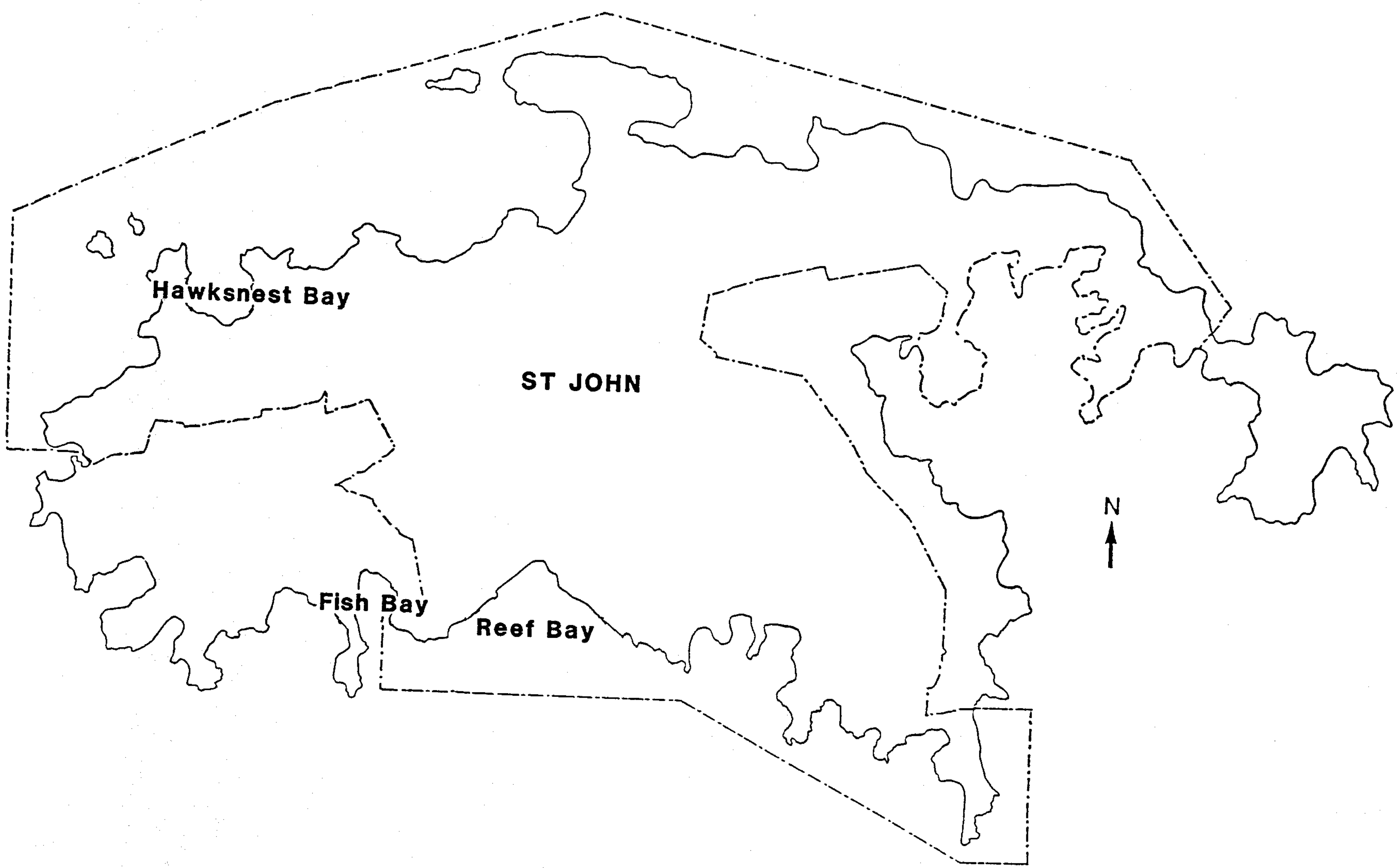

Figure 1. Map of St. John, USVI, showing locations of study sites. Broken line indicates boundary of Virgin Islands National Park.

Figure 2. Aerial photograph of Reef Bay anf Fish Bay, St. John, U.S. Virgin Islands. ☆ denotes study site. Photograph scale 1:15,000.

Table 1. Zone and subzone designations for Figures 3, 4 and 6 (from Beets, et al., 1986).

	Acronym
A) Shore Zone	S
1) Beach rock	Sb
2) Sand	Ss
3) Mangrove	Sm
4) Gravel/cobble	Sg
B) Subtidal Bedrock	SR
C) Lagoon	L
1) Sand	Ls
2) Pavement	Lp
3) Seagrass bed	Lg
4) Patch reef	Lpr
a) pavement	Lprp
5) Fringing reef	Lf
D) Shallow Bay	SB
1) Sand	SBs
2) Pavement	SBp
3) Seagrass bed	SBg
4) Patch reef	SBpr
a) pavement	SBprp
5) Mud	SBm
6) Algae	SBa
7) Artificial reef	SBar
E) Reef (fringing and barrier)	R
1) Backreef	Rb
a) head coral/grotto	Rbh/Rbg
b) pavement	Rbp
2) Reef crest	Rc
3) Fore reef	Rf
a) upper (arborescent)	Rfu
b) lower (massive)	Rfl
c) pavement	Rfp
4) Sand	Rs
5) Gorgonian-dominated pavement	Rgo
6) Pavement	Rfp
F) Bank	B
1) Gorgonian-dominated pavement	Bgo
2) Pavement	Bp
3) Sand	Bs
4) Seagrass bed	Bg
5) Patch reef	Bpr
a) crest	Bprc
b) fore reef upper/lower	Bpru/Bprl
c) pavement	Bprp
d) gorgonian-dominated pavement	Bprgo
6) Bank reef (linear aspect)	Br
a) crest	Brc
b) fore reef upper/lower	Brfu/Brfl
c) backreef	Brb
7) Algal plain	Ba
G) Shelf Edge Reef	SER

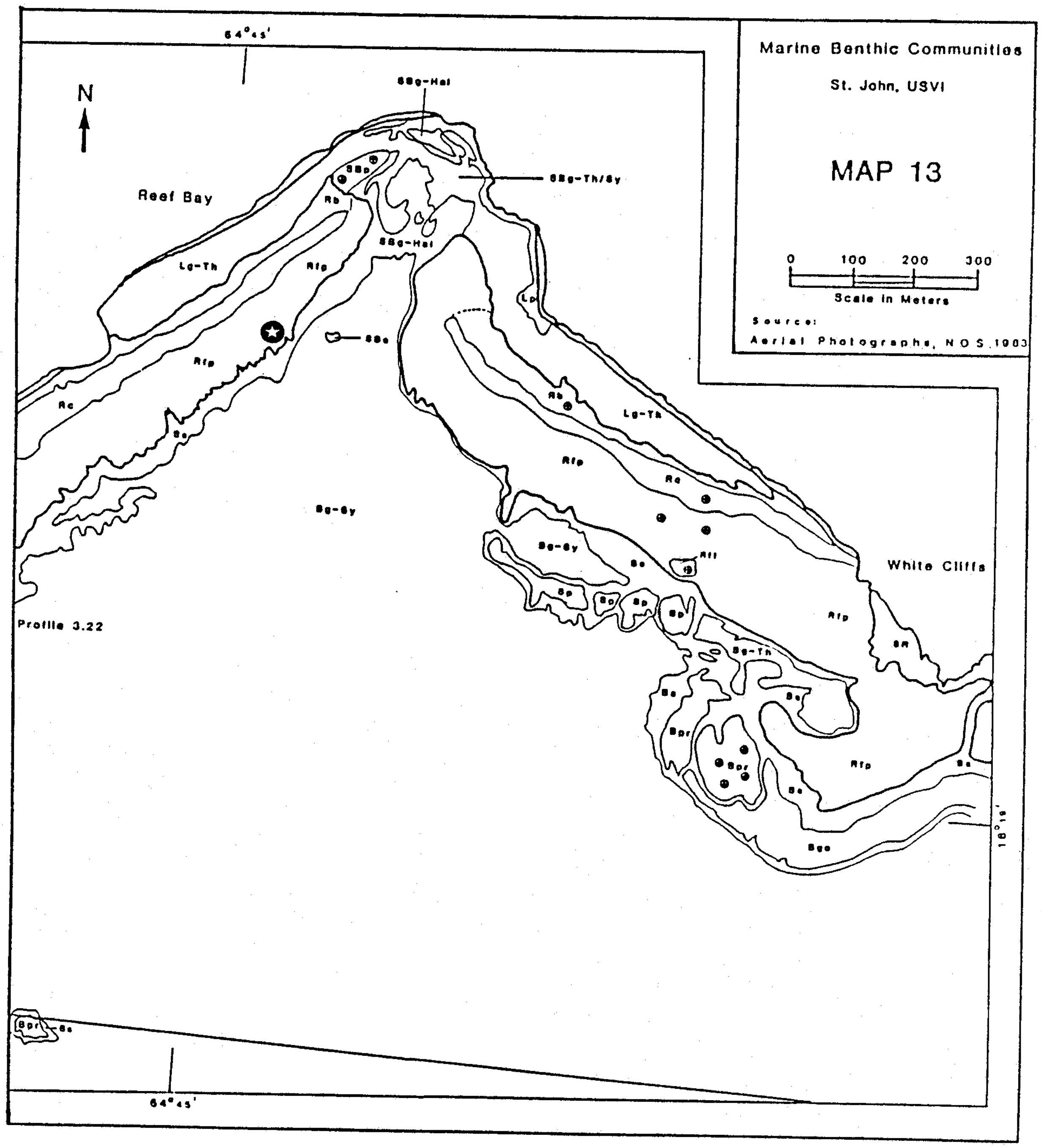

Figure 3. Marine communities in Reef Bay, St. John
denotes study site

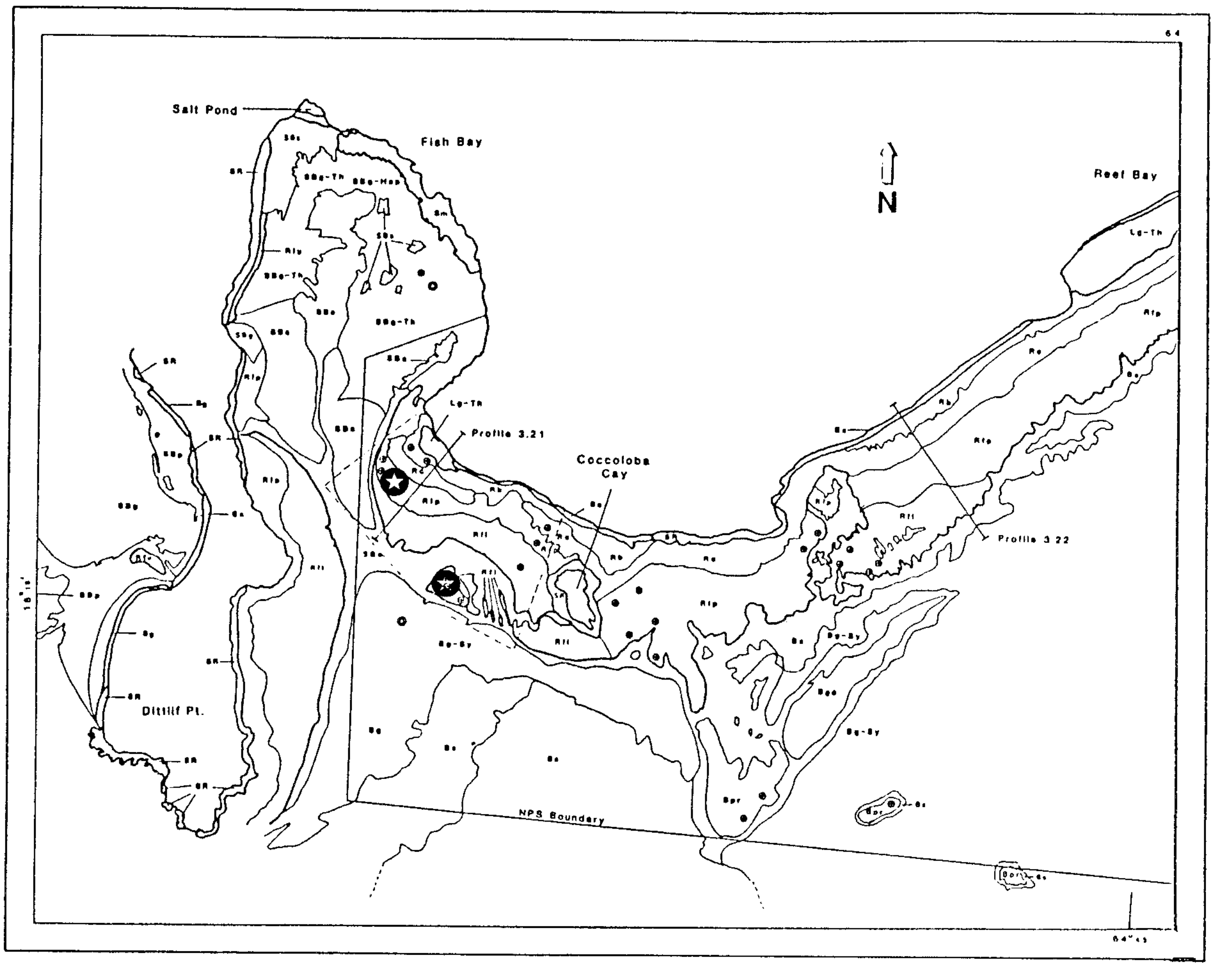

Figure 4. Marine communities in Fish Bay, St. John
✪ denotes study sites

Figure 5. Aerial photograph of Hawksnest Bay, St. John, U.S. Virgin Islands. ☆ denotes study sites. Photograph scale 1:15,000.

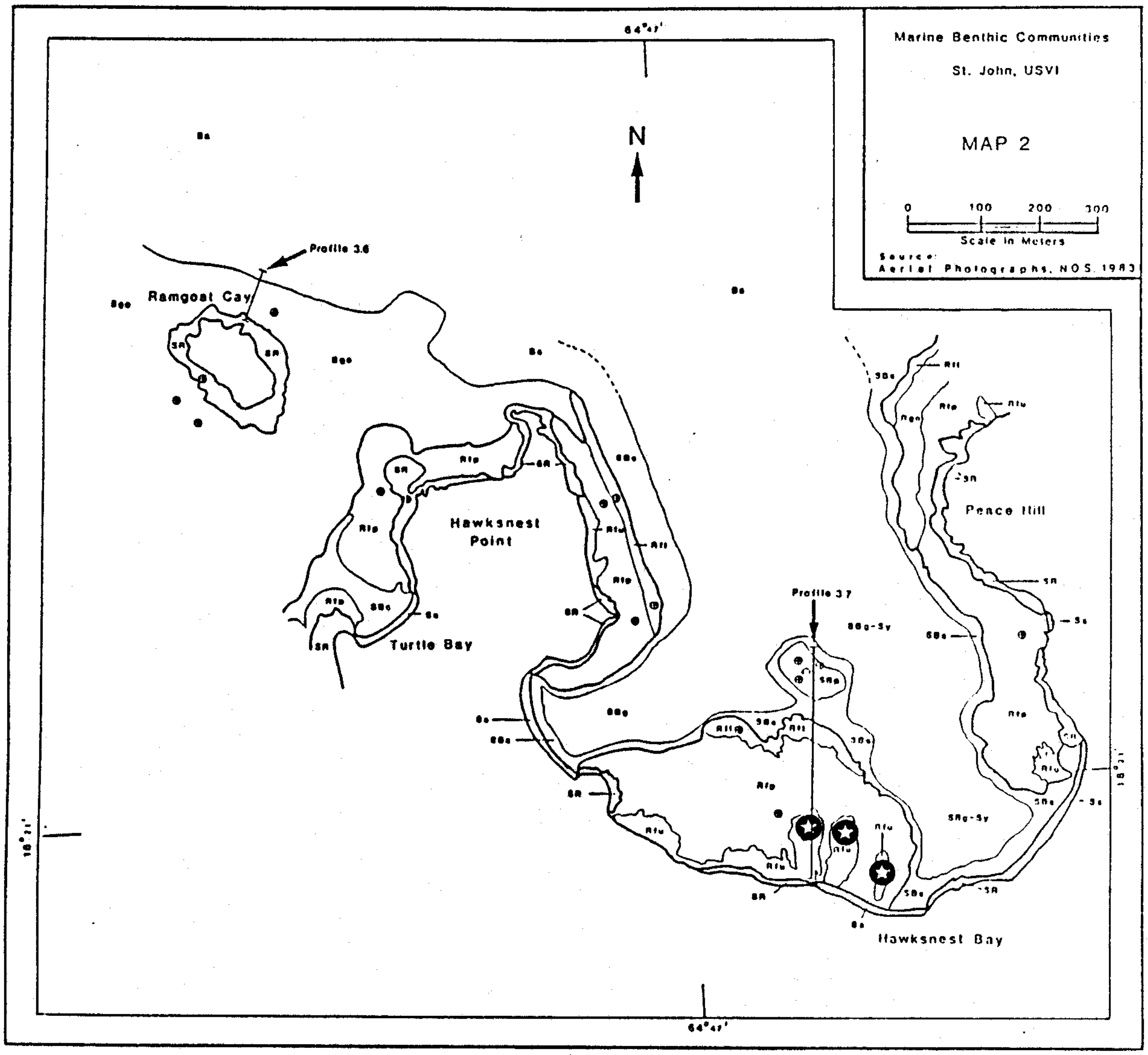

Figure 6. Marine communities in Hawksnest Bay, St. John
✪ denotes study sites

Reef Bay The Reef Bay watershed has remained undisturbed since the decline of the sugar plantation there in the late 1800's. (A small plot which has been cleared recently in the western portion of the bay is far from the study site.) The study site, near the center of the bay, is along a fairly steep slope, ranging from c. 11 m up to c. 3 m. At the base of the slope at about 11 m is a sand channel which often has very turbid water.

Fish Bay The Fish Bay watershed is currently undergoing subdivision, roadbuilding and construction of houses. Although the lands are outside the park, the study reefs are in park waters and could deteriorate with increased siltation from erosion associated with the rapid development of this area. The shallow study area (3 m) is just seaward of the reef crest and emergent rubble zone of the reef in the eastern side of Fish Bay. The area was apparently severely damaged by Hurricanes David and Frederic. The deeper study site (11 m) is in a fore reef area with a well-developed and diverse coral community.

Hawksnest Bay The Hawksnest Bay watershed on the north side of the island is the site of a new medical clinic. Construction of the clinic in 1982 may have contributed to siltation in the bay. Study areas in shallow patch reefs near the bay's southern shore ranged from c. 3 m deep to the surface.

At all study sites, with the exception of the shallow storm-damaged area in Fish Bay, the areas with the most live coral and best developed reef structure were intentionally selected because the objective was not to characterize the overall reef, but to establish a baseline against which future changes in structure could be compared.

METHODS

Two different methods were used to quantify reef structure at permanently marked transects in Fish and Reef Bays, while only one method was suitable at the very shallow site in Hawksnest (Appendix I). Comparison of the two methods allowed us to evaluate their relative effectiveness when used at reefs with different structural characteristics.

Linear transects

Use of a linear transect method allowed calculations of: 1) the percent of live and dead coral, 2) the number of hard coral (scleractinian and *Millepora* spp.) species present and their relative abundance, 3) diversity and evenness, and 4) the complexity of the substrate ("spatial index") (Loya, 1972; Porter, 1972; Rogers, et al., 1983). The percent live coral cover was considered the most significant parameter to monitor, as an indicator of change in the reef structure over time.

Ten 10 m long transects were established in Reef Bay and at the deeper site in Fish Bay using rebar stakes to mark the two ends of each transect. (In previous studies [e.g., Rogers, et al., 1983], plots of cumulative species number against number of meters along a transect indicated that 10 m was a sufficient transect length as, in general, a levelling off of the cumulative number of species occurred after six meters were surveyed.) Where feasible, transects were parallel to each other with successive transects 5 m apart. Systematically spacing the transects 5 m apart allows two divers to work on parallel transects without interfering with each other and facilitates re-establishment of transect locations if one of the rebar stakes is removed. A line was stretched tightly along each transect between the two rebar stakes. Then a diver carefully placed a lightweight chain (2.6 cm links) directly under the line, as exactly as possible, along the contour of the substrate. All surfaces immediately beneath the line were characterized by type (live coral, dead coral, sand, sponges, other) and measured in terms of number of chain links. Coral cover percentages were based on the total number of chain links along the transect. The spatial index provides an estimate of topographical relief and is calculated as the ratio of total number of centimeters of chain to total number of centimenters in the line. Transects were measured during three intervals at Fish and Reef Bays over a twelve-month period.

Diversity

The diversity index for a particular reef area in itself conveys little and comparing indices for different reef sites adds little to the information one can easily get from a list of species and their relative abundance. However, comparison of indices for the same site over time can reveal interesting shifts and can indicate something of the sensitivity of this index to changes in community composition.

The Shannon formula for diversity (Shannon and Weaver, 1949) was calculated for linear transect data as follows (for the hard corals), with a projection of 1.3 cm (one half-link) under the line considered an "individual":

$$H' = -\sum p_i \ln p_i$$

where $p = n/N$, N = total number of individuals of all species under the line, and n = the number of individuals of species i under the line. (This index underestimates the actual value of H' for the whole commuity [Pielou, 1977], but here we were only interested in comparing indices for the same areas over time.)

The formula $J' = H'/H'$ max (Pielou, 1966) gives a value for evenness which represents the diversity of the total number of meters under consideration divided by the diversity which would exist if all of the coral species were distributed equally. Maximum evenness is 1.00. Diversity and evenness for each of the twelve sampling periods were based on combined data from all transects.

Quadrats along transects

Quadrats (1 m^2 and divided into 100 squares) were used at Hawksnest Bay and at the shallower study site at Fish Bay. Estimates of the percent cover of each hard coral species and other reef components were made along transects defined by rebar stakes.

In Fish Bay, five 10 m transects were established in the shallow rubble zone, and a diver estimated coral cover by placing a quadrat on either side of a line stretched between the rebar stakes, at meter intervals, resulting in 20 quadrat data sets for each transect.

At Hawksnest, measurements were made along 10 transects on each of three different shallow patch reefs. The quadrat was centered along each successive meter of each transect under the line stretched between the rebar stakes. Ten sets of quadrat measurements were taken for each transect. This work required extremely calm conditions, for the dominant branching *A. palmata* coral colonies grew to within centimeters of the surface. Transects were established in March, April, and May. Three of the transects were relocated and remeasured in December, 1985, but other transects could not be relocated because of missing rebars (possibly removed by snorkelers).

The quadrat method was also used along the transects established in Reef Bay and at the deeper Fish Bay site to allow for a comparison between the quadrat and linear transect methods at both of the sites. Ten quadrats per transect were used to estimate the total amount of live coral along each transect. The percent cover by individual coral species was recorded for 4 transects at Reef Bay to determine if the 2 methods gave similar information on relative coral abundance.

Statistical analyses

All percentage data were transformed (arcsine) prior to statistical analyses (Sokal and Rohlf, 1969). When analysis of variance (ANOVA) indicated that a significant difference in means existed, the Student-Newman-Keuls test was used to indicate which means differed significantly (Sokal and Rohlf, 1969). A confidence level of $p < 0.05$ was used for all statistical tests.

RESULTS

Fish Bay and Reef Bay: reef structure and effects of Tropical Storm Klaus

Reef structure. Eighteen species of hard corals were observed in deeper Fish Bay, with 15 of these occurring in the transects (Table 2). *Agaricia agaricites* was dominant in each of the 10 transects, comprising about 70% of the total live coral present prior to Tropical Storm Klaus and about 55% after the storm. This species accounted for about 18% of the total substrate in the transects, decreasing to 11% after the storm.

Twenty species of hard corals were seen in Reef Bay, with 11 of them in the transects (Table 1). *Montastrea annularis* was dominant in all but three of the transects, making up about 40% of the live coral cover and 8% of the total substrate. *Agaricia agaricites* was the second most abundant coral species, making up 24% of the total live coral.

Effects of Tropical Storm Klaus. A survey of reefs around St. John (e.g., in Reef Bay and Greater Lameshur Bay) following Tropical Storm Klaus revealed that many branching corals in shallow water were fragmented. *Acropora palmata* colonies were shattered in some locations and numerous pillars of *Dendrogyra cylindrus* were sheared off at the bases. Initially, the Fish Bay reefs at 10 m showed little conspicuous damage, but a closer look revealed numerous plates of *A. agaricites* which had broken off and were half-buried in sand or lodged in holes in the reef. Because most of the plates broke off at their algal-encrusted bases, no white skeleton was exposed as in the case of *Acropora* spp. and other species. Bleaching of coral tissue was evident on portions of plates which were buried in sand. While many fragile corals remained intact, there was some breakage of *Porites porites* colonies and bleaching of *M. annularis* colonies.

Table 2. Hard coral species in Fish, Reef, and Hawksnest Bay study sites
* indicates corals observed in transects;
X indicates corals observed at site but not in transects

Coral Species	Reef	Fish Depth=10m	Fish Depth=3m	Hawksnest
Stephanocoenia michelinii	*			X
Madracis decactis	X			
Acropora palmata	X	X	X	*
A. cervicornis	*	*	X	X
Agaricia agaricites	*	*	X	*
Helioseris cucullata	X	*		
Siderastrea siderea	*	*	X	X
S. radians			X	X
Porites astreoides	X	*	X	*
P. porites	X	*	X	*
P. furcata		*		
Favia fragum	X	X	X	*
Diploria clivosa				*
D. labyrinthiformis	X	*		X
D. strigosa	*	X		*
Colpophyllia natans	*	*	X	X
Montastrea annularis	*	*	X	X
M. cavernosa	*	*	X	X
Oculina diffusa	X			X
Meandrina meandrites	X			X
Dichocoenia stokesi			X	
Dendrogyra cylindrus	*	*		X
Isophyllia sinuosa				X
Isophyllastrea rigida		*	X	X
Mycetophyllia lamarkiana				X
Eusmilia fastigiata	*	*	X	
Millepora spp.	*	*	X	*

Tropical Storm Klaus passed over the island after field work began at Fish Bay but prior to initiation of field work at Reef Bay. A comparison of reef structure parameters in Fish Bay over the study period (Table 3) shows a statistically significant decrease in the mean percent coral cover, an increase in diversity and evenness, and a slight decrease in spatial index attributable to the physical effects of the storm. No statistically significant difference in these parameters were noted in Reef Bay (Table 3). However, even after the storms, the percent cover by _Agaricia agaricites_ decreased slightly at both reef sites. The percent cover of hard coral species at the deeper Fish Bay site after Tropical Storm Klaus decreased in most of the transects and was significantly lower than before the storm (Figure 7). The percent of _A. agaricites_, the dominant coral in each of the 10 transects, decreased significantly as a result of the storm (Figure 7). (No statistically significant differences were found between data for the second and third surveys at Fish Bay.)

Comparison of transect and quadrat methods. A comparison of data from the linear transect and quadrat methods (Appendix II) in both Fish and Reef Bays reveals that the quadrat method consistently underestimates percent cover by hard corals. The mean percent cover at Fish Bay was 21 $\pm$ 6 (SD) [SD = standard deviation] with the transect method and 9 $\pm$ 3 (SD) with the quadrat method. Comparable values for Reef Bay were 20 $\pm$ 9 (SD) _vs_. 15 $\pm$ 8 (SD).

For four transects in Reef Bay (the only ones where cover by individual coral species was measured with the quadrat method) a ranking of the most abundant corals differed although the same four species were dominant at each site. The ranking, in decreasing order, was _M. annularis_, _M. cavernosa_, _S. siderea_, and _A. agaricites_ for the quadrat method, and _M. annularis_, _A. agaricites_, _S. siderea_ and _M. cavernosa_ for the linear transect method.

Fish Bay (shallow site)

Thirteen hard corals contributed a mean living cover of only 6% $\pm$ 5 (SD) along the five shallow transects in the Fish Bay rubble zone, with a range of 2-14%. Dominant corals were _Colpophyllia natans_ (a few large colonies), _Acropora palmata_ and _Agaricia agaricites_ (these last two were more widely scattered). The low amount of living coral and the slow growth rates make frequent transect measurements unnecessary. These data serve as a quantitative baseline for future measurements to assess recovery of this zone

Table 3. Reef structure parameters in Fish and Reef Bays

Location	Sampling Time	Live Coral (%) mean $\pm$ S. D.	Agaricia (%) Cover*	Diversity H'	Evenness J'	Spatial Index mean $\pm$ S. D.
Fish	Sept. '84	26 $\pm$ 7	17 $\pm$ 9	1.31	0.47	1.7 $\pm$ 0.3
	April '85	21 $\pm$ 6	11 $\pm$ 6	1.66	0.59	1.6 $\pm$ 0.2
	Nov. '85	18 $\pm$ 4	8 $\pm$ 4	1.71	0.63	1.6 $\pm$ 0.3
Reef	Dec. '84	20 $\pm$ 6	5 $\pm$ 3	1.78	0.66	1.5 $\pm$ 0.2
	June '85	20 $\pm$ 9	3 $\pm$ 3	1.79	0.75	1.4 $\pm$ 0.2
	Nov. '85	18 $\pm$ 6	2 $\pm$ 2	1.76	0.69	1.4 $\pm$ 0.2

* data taken from linear transects.

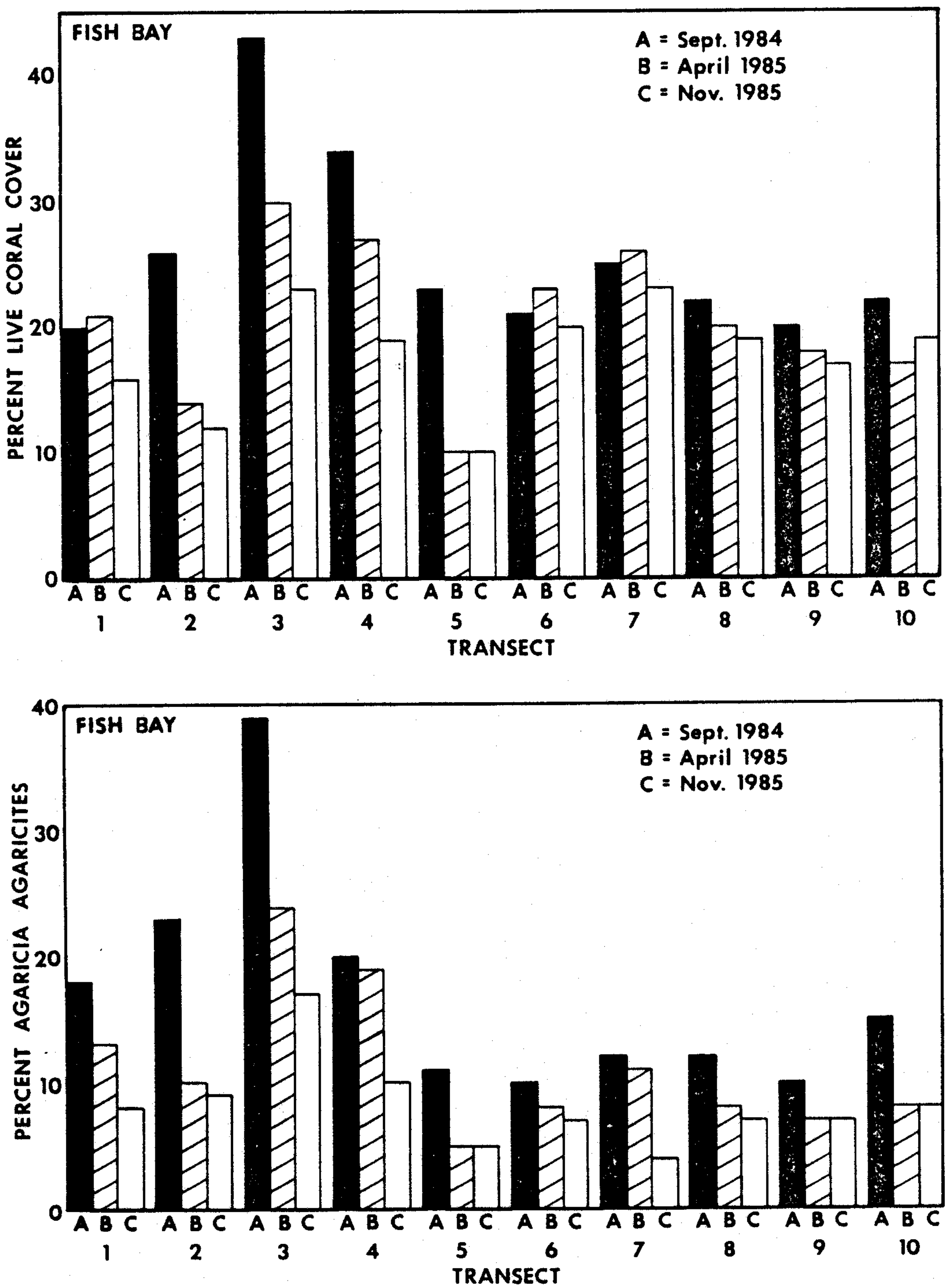

Figure 7. Live coral cover, and cover by <u>Agaricia</u> <u>agaricites</u>

from storm damage. Terrigenous runoff associated with Fish Bay development could further stress this reef and delay recovery.

Hawksnest Bay

When first measured in the spring of 1985, the ten Hawksnest transects had live coral cover ranging from 20% to 34%, with a mean of 26 $\pm$ 5 (SD) (Table 4). The only coral species present were *A. palmata* (92% of the live coral), *P. astreoides*, *Millepora* spp., *P. porites*, *D. clivosa*, *F. fragum*, and *A. agaricites*. The 3 transects which were remeasured in December all had less live coral than initially. With this small data base, we can not determine the repeatability of the method and the limits of error, or the significance of this "decrease." The initial data serve as good baseline data, however, for assessing damage from runoff and white band disease.

DISCUSSION

Changes in reef structure

Agaricia agaricites, the most abundant coral in each of the ten transects at the deeper site in Fish Bay, was more susceptible to storm damage than the other species. Bak and Engel (1979) noted that large colonies of *A. agaricites* were rare in shallow reef zones in Curacao and their growth rates were slower than those of colonies in deeper water. *Agaricia agaricites* is less abundant in the shallower reef in Reef Bay. Physical forces (primarily consistently heavy swells) in this shallow reef may favor massive corals like *Montastrea annularis*, dominant at Reef Bay.

Bak and Engel (1979) suggested that sedimentation in shallow reef zones could be responsible for the lack of large *A. agaricites* colonies on a Curacao reef, as large colonies of this species often acquire a horizontal surface which is inefficient in sediment removal. However, we would expect that sediment effects (both light attenuation and direct smothering by particles) would be greater at Fish Bay than along the slope at Reef Bay. Also, the *A. agaricites* colonies in the Fish Bay transects took the form of vertical plates, densely packed together and often parallel to each other. This morphology could be an adaptation to sediment stress as sediment particles will not adhere easily to the vertical surfaces.

Table 4. Hawksnest Bay transects: percent cover

Transect #	Live coral (%) March, April, May 1985	Live coral (%) December 1985
1	34	27
2	20	16
3	30	24
4	28	
5	20	
6	22	
7	22	
8	22	
9	27	
10	34	
Mean	26	22
SD	5	6

In the Caribbean, A. agaricites juveniles settle in greater numbers than juveniles of other species. In contrast, M. annularis juveniles are rarely found, and reproduction is apparently largely asexual. Agaricia agaricites and M. annularis are both considered "moderately" capable of rejecting sediments, and even if differences in sedimentation exist at the Reef Bay and Fish Bay study sites, they may not explain the different species composition at the two sites. The more exposed Reef Bay site probably favors survival by M. annularis, a much less fragile coral than A. agaricites.

Lesions on M. annularis colonies regenerate more quickly and effectively than those on A. agaricites colonies (Bak and Engel, 1979). Once Agaricia plates are broken or dislodged, they are presumably less likely to survive than M. annularis colonies which, in addition to being more difficult to dislodge initially, have a better chance of settling in a position where more of the living surface can avoid smothering by sediments.

Montastrea annularis is more aggressive to other species than A. agaricites, but it is not known to what extent this controls distribution. Montastrea annularis colonies live longer and reach larger size than A. agaricites colonies.

Acropora palmata, the dominant coral at the shallow patch reefs in Hawksnest is a fast growing species which reproduces sexually and asexually (through dispersal and subsequent growth of fragments). We concentrated on this species in Hawksnest because it is the most abundant coral species there and because it is very susceptible to siltation. During this study, there were no exceptionally heavy rains, and we noted no damage, attributable to sedimentation from runoff, at the study sites.

A mean percent decrease in the amount of Agaricia within transects at Fish Bay as a result of the Tropical Storm led to an increase in the diversity index from 1.31 to 1.66. Evenness also increased, from 0.47 to 0.59. Changes in reef structure occur even in the absence of detrimental human activities and natural events like storms (Bak and Luckhurst, 1980).

Sedimentation patterns in Fish, Reef, and Hawksnest Bays

During a concurrent VIRMC study, Hubbard, et al. (1987) concluded that the primary controls of sedimentation patterns within Fish, Reef, and Hawksnest Bays are natural (related to watershed size, location of guts, and degree of exposure) rather than related to land-based development activity. They measured markedly higher amounts of terrigenous material in sediments on the eastern side of Reef Bay than on the western side. The source of much of the terrigenous sediments is White Cliffs Point which defines the eastern end of the bay. In contrast, sediments in the mouth of the bay are primarily from runoff from the major guts. Flushing action in this relatively exposed area results in fairly low amounts (5% - 15%) of terrigenous material.

Some of the fine-grained sediments which presumably flow through the channel in the mouth of the bay, separating the eastern and western reefs (Figure 3), apparently settle in a depression just seaward of the fore reef site near the deeper ends of the study transects, resulting in consistently turbid conditions and sediment stress to the deeper corals on this slope. The site is west and downstream from the major guts which drain the watershed, but probably because it is more exposed, it has a higher amount of living coral than other areas of the bay. The steep slope at the study site, most likely related to erosion by the central channel, facilitates sediment shedding by the reef.

The factors controlling reef distribution are complex. Coral cover in Fish and Reef Bays is presumably a response to sedimentation patterns and to physical factors such as water circulation and exposure to heavy seas. At both Fish and Reef Bays, the highest amounts of living coral cover are found in the lower fore reef areas, often associated with slopes. The reef communities differ at the Fish and Reef Bays study sites, with *Agaricia* dominating at Fish Bay and *Montastrea* at Reef (see above). While the overall sedimentation patterns at the two study sites may differ, the percent terrigenous matter in the sediments was similar, ranging from 5 - 10 (Hubbard, *et al*., 1987). As discussed above, physical factors such as the consistently heavier swells at the more exposed Reef Bay site are possibly more significant in determining the composition of the coral communities.

Hawksnest, a leeward bay, has the least developed reef system of the three bays. The easternmost patch reef is less developed than the larger reefs to the west. Hubbard, *et al*. (1987) suggest this is a consequence of lower energy levels and proximity to the major gut which drains the watershed. Hubbard, *et al*. (1987) also found that decreases in growth rates of *M. annularis* colonies in the bay were correlated with heavy rains in 1981 and 1983 following construction of the medical clinic at the head of the watershed. It is not known to what extent runoff has caused the death of A. palmata colonies in the bay. Unfortunately, it is not feasible to subject the dominant coral A. palmata, which is more sensitive than M. annularis to siltation, to the same growth rate analysis. The considerable number of dead A. palmata colonies in the bay may have been killed by runoff or white band disease.

Coral reef monitoring

Monitoring of coral reefs is not the same as managing them, but data from monitoring forms the basis for important management decisions. The type of monitoring that is appropriate depends on the stress currently or potentially threatening the reef. For example, numerous measurements of salinity are unnecessary unless the reef is in an area likely to be influenced by discharge from a desalination plant or an area where runoff is severe. Measurements of nutrients such as phosphates and nitrates are critical for reefs near sewage outfalls or at the bases of actively farmed watersheds where fertilizers leach into the runoff. For basic monitoring, a large amount of valuable information can be derived from a relatively small amount of field effort. Different activities are appropriate for different levels of monitoring (Table 5).

The more complex the reef structure, the more error is inherent in any method which aims to quantify the amount of cover attributable to each reef component. Overhangs, deep holes, and crevices overlapping coral colonies lead to inaccuracies. Subtle, but possibly significant, changes may not be documented unless experienced people do the transects or the same individuals take the measurements each time.

At Fish and Reef Bays, the quadrat method underestimated the amount of live coral at the study sites. With the transect method, there is an attempt to measure all surfaces and layers of reef structure under the line. With the quadrat method, only the live coral in the topmost, two-dimensional plane is measured. (Quadrats do not provide information on topographical relief or spatial indices.) The quadrat method, where a diver observes the substrate from directly above, underestimates the amount of Agaricia agaricites growing in the vertical plate morphology. With the transect method, the chain is draped over the living coral surfaces of the vertical plates, and more of the living surface is included in the measurements. At Reef Bay, where there is roughly four times less A. agaricites and there are fewer colonies with the vertical plate growth form than at Fish Bay, the mean cover as estimated with the two methods was much closer, 20 ± 9 (transects) vs. 15 ± 8 (quadrats).

Table 5. Coral reef monitoring guidelines

Parameters	Minimal	Low	Moderate	Comprehensive
Total living cover (%)			x	x
Live coral (%)	x	x	x	x
Coral species (#)			x	x
Spatial index				x
Diversity, evenness			x	x
Fish, shellfish populations			x	x
Algae			x	x
Other organisms				x
Sedimentation			x	x
Water quality			x	x
Currents			x	x
Nutrients				x
Reef metabolism				x
Methods				
Aerial photography	x	x	x	x
On-site photography	x	x	x	x
Benthic mapping		x	x	x
Fixed photoquadrats			x	x
Random quadrats			x	x
Established permanent transects			x	x
Linear transects, fixed sites				x
Quadrats, fixed sites				x
Fish censuses		x	x	x
Sediment cores			x	x
Coring of coral colonies			x	x
Coring of reef structure				x
Recording of broken coral branches, other damage		x	x	x

The quadrat method is preferable in shallow (usually rough) areas with large quantities of *Acropora palmata*, where the chain transects would be almost impossible. Also, the chain can become entangled in fragile corals like *P. porites*, causing breakage. The nature of the reef zone under study will determine the preferable method.

In places where trained scientists are not available to do the work, the status of a particular reef can be assessed by using the quadrat method to estimate the percent total live coral cover, without differentiating the coral cover attributable to each coral species. While the linear transect method could also be used to estimate percent of total live coral cover, it would still be necessary to count all chain links to allow percent calculations, which would be far more time consuming than using quadrats. The percent of live coral cover in most cases will be the most significant parameter to monitor. The quadrat method requires less training than the transect method. In spite of difficulties inherent in both of these methods, they provide much more useful data than visual estimates of percent cover which are usually too subjective and which are insufficient for detection of all but the most dramatic changes in reef structure.

Frequency of monitoring will depend on several factors. Financial resources and trained personnel may be very limited. The desired frequency of monitoring will be governed by the type of stress to which the reef is subjected, its duration and magnitude. Monitoring every six months should be adequate to follow changes in living coral cover unless an obvious stress such as an oil spill or major runoff event occurs within this time interval. If significant bleaching of corals is observed, monitoring should be increased and the cause determined. Monitoring is expensive and often in itself involves some inevitable though usually slight damage to reef organisms. For these reasons, it should not be too frequent. In most cases, however, the problem will be to assure monitoring which is frequent enough and effective enough to allow assessment of the status of the selected reefs in time to take appropriate management decisions.

Management of coral reefs within the Virgin Islands National Park

Effective management of coral reefs within the Virgin Islands National Park requires a synthesis of information from observation and research by National Park Service research and resource management staff, VIRMC members, visiting scientists and case incident reports prepared by park rangers. In some cases, resource management directives will be issued requesting that the Division of Visitor Services and Protection enforce regulations pertinent to reefs.

Some stresses, such as storms and coral diseases, are not amenable to preventative management strategies. However, damage from boats can be decreased with better management. With the dramatic increase in the number of boats using park waters, there has been an alarming increase in boat damage to reefs. Of all reefs within the Virgin Islands National Park, Windswept Reef on the north shore, between Trunk and Cinnamon Bays, appears to have suffered the most damage from boat groundings. In one 2 month period (June - August, 1985), nine boats ranging from 16' - 50' in length hit this reef. On December 8, 1985, four boats hit this reef. Marker buoys were installed near this reef in May, 1986, resulting in a dramatic decrease in boat damage. A Reef Protection Plan for the Virgin Islands National Park (November, 1985) includes other recommendations, for example: holding of meetings with charterboat company owners and other boaters to increase awareness of potential damage to reefs; more frequent issuing of fines for destruction of resources; and incorporation of additional information on reefs in the Safe Boating Brochure presently issued by the park. Permanent moorings can be installed to decrease anchor damage (to both reefs and seagrass beds). Pressure can be put on the local Coastal Zone Management program to deny certain permits for development if there is a good scientific basis to indicate that damage to park resources will ensue.

The Code of Federal Regulations pertaining to coral reefs and reef organisms within the Virgin Islands National Park includes the following measures to help protect these resources:

1) prohibits removal or injury of underwater growths or formations.

2) prohibits dredging.

3) prohibits anchoring in such a way as to strike or cause damage to any "living" underwater features.

4) prohibits taking of fishes or other marine life except with a hand-held rod or line, or with traps of conventional Virgin Islands design; allows baitfish to be taken (by anyone and at any frequency) with nets less than or equal to 20' in length.

5) prohibits the use or possession of spearfishing equipment.

6) allows harvesting of 2 lobsters per person per day by hand or hand-held snare; prohibits taking of lobsters with eggs and possession of more than 2 days' limit.

7) allows harvesting of 2 conchs per person per day by hand; prohibits possession of more than 2 days' limit.

8) restricts collecting of organisms for research.

There is currently no limit on the number of boats allowed in park bays, and the only permanent moorings (21) are those authorized for use by park concessionaires. There has been a dramatic increase in boats using park waters, and an increase in the number of large boats (mini-cruiseships) using the park. A December 1985 regulation issued by the park superintendent prohibits anchoring of any boat for more than 14 days without a special permit.

The Virgin Islands National Park and Biosphere Reserve currently lacks a comprehensive coral reef management program. A Natural Resources Management Plan for the Virgin Islands National Park and Biosphere Reserve was developed in December 1985. The plan proposes projects on numerous resource management and research issues and proposes a comprehensive monitoring strategy for coral reefs inside the park. A 1987 VIRMC study focuses on boat damage to reefs.

The following recommendations are suggested for management of coral reefs within the park and biosphere reserve.

1) continue long-term monitoring of selected reefs.

2) initiate a carrying capacity study (as outlined in the Natural Resources Management Plan).

3) attempt to provide protection for the limited black coral population in park waters.

4) install marker buoys to indicate presence of reefs frequently hit by boats; include information on location of these reefs in park brochures distributed to charterboat companies and others.

5) evaluate feasibility of establishment of permanent moorings in popular bays and establishment of areas where anchoring is prohibited.

6) consider advisability of prohibiting the taking of all fish and shellfish within the Virgin Islands National Park, or specific areas of the park, following a synthesis of information from VIRMC studies and Caribbean Fishery Management Council research.

7) consider zoning of reefs for certain activities to avoid conflicts among resource users.

8) increase awareness of park regulations and environmental concerns within the park through a series of seminars at the new Virgin Islands Biosphere Reserve Center.

9) increase awareness of ways to minimize environmental damage associated with watershed development (see Hubbard, et al., 1987, for specific recommendations).

10) manage reefs in conjunction with seagrass beds and mangroves where appropriate.

In conclusion, this study focussed on reefs in three St. John bays, but it serves, along with other VIRMC projects, as a jumping-off point in the structuring of a comprehensive strategy to deal with long-term monitoring and management of both terrestrial and marine resources in the Virgin Islands National Park and Biosphere Reserve. Dramatic increases in the number of people visiting St. John and accelerated development activity, both within and outside park boundaries, are severely damaging the island's natural resources and present a challenge to both local and federal government resource managers.

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APPENDIX I

Marking of transects

Marking of permanent transects and study sites underwater is a challenge. When possible it is preferable to establish transects parallel to each other and a set distance apart. In this way, if rebar stakes marking the ends of transects are lost, the transects can be relocated by measuring from rebars which remain. In Reef and Fish Bays, compass headings were recorded using an exceptionally large colony of pillar coral (*Dendrogyra cylindrus*) as a reference point.

Compass headings in Hawksnest Bay and the shallow Fish Bay site were recorded, but there were no adequate reference points, and relocation of precise transect positions depends on some rebars staying in place.

Compass Headings: Reef Bay Transects

Transect #	Distance to seaward rebar(m)	Compass heading	Distance to shoreward rebar(m)	Compass heading
1	19.7	52	23.5	40
2	15.9	40	20.3	30
3	11.4	50	15.5	20
4	6.2	50	11.7	10
5	2.6	108	7.3	344
6	3.6	220	*	*
7	7.6	231	11.4	280
8	12.2	230	14.6	270
9	16.4	230	19.0	260
10	20.9	230	25.0	255

* = No data

Note: Three rebars were driven into the substrate near the *Dendrogyra* colony ($\simeq$ 3.8 m from the colony at 120 degrees) as a landmark to take compass headings and measurements to the rebars of the transects. The Reef Bay transects are parallel to each other and approximately 5 meters apart.

APPENDIX I (Cont.)

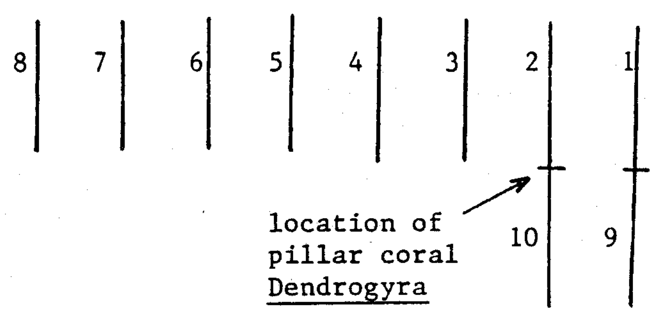
Compass Headings: Fish Bay Transects (deeper site)

Transect #	Distance to seaward rebar(m)	Compass heading	Distance to shoreward rebar(m)	Compass heading
1	2.2	260	10.9	330
2	7.3	270	12.8	320
3	12.2	260	15.7	300
4	17.2	260	19.3	280
5	21.8	260	*	*
6	26.8	260	*	*
7	31.4	255	*	*
8	9.7	170	2.6	80
9	9.9	175	same rebar as seaward #1	260
10	11.9	200	same rebar as seaward #2	270

* = No data

Note: Three rebars were driven into the substrate near the Dendrogyra colony ($\simeq$ 1 m east of the colony) as a landmark to take compass headings and measurements to the rebars of the transects.

Diagram showing approximate layout of Fish Bay transects



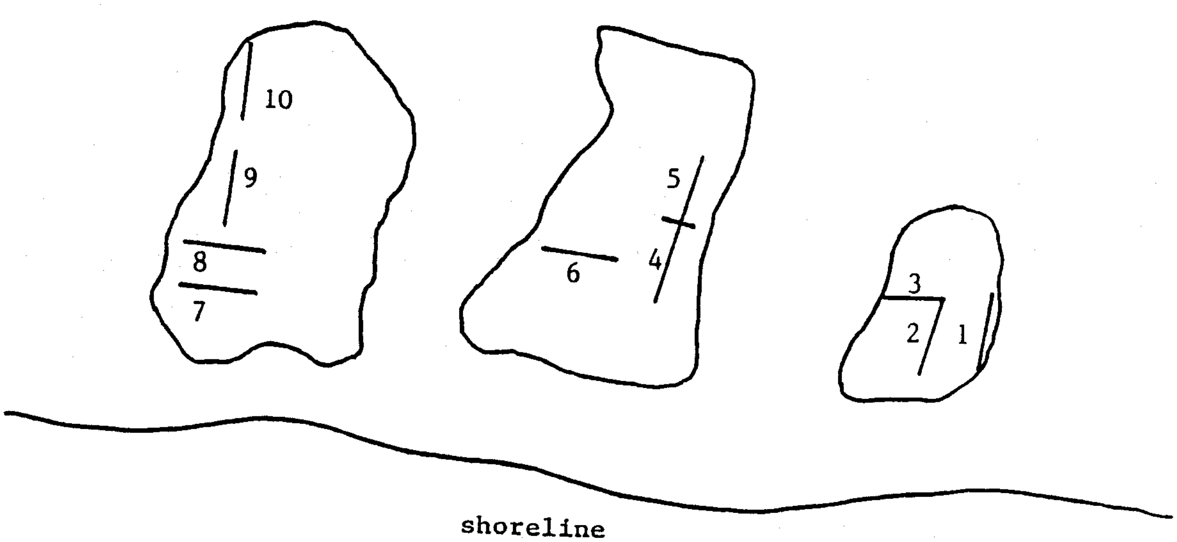
APPENDIX I (Cont.)

Compass Heading: Hawksnest Bay Transects

Transect #	Direction of Transect (Meter 1-10)	Compass Heading
1	shore - seaward	48
2	shore - seaward	40
3	East - West	276
4*	shore - seaward	30
5*	shore - seaward	30
6	East - West	307
7	East - West	291
8	East - West	300
9	shore - seaward	0
10	shore - seaward	21

* - Transects # 4 & 5 are phototransects from VIRMC I fieldwork. See Beets and Lewand, 1986.

Diagram showing approximate locations of transects on the Hawksnest patch reefs



APPENDIX II

Comparison of live coral cover estimates with quadrat and linear transect methods

Reef Bay	Transect number	Linear transect method	Quadrat method
	1	19	19
	2	17	22
	3	30	30
	4	11	11
	5	31	20
	6	33	16
	7	18	5
	8	10	13
	9	14	10
	10	6	5
mean		20	15
SD		9	8

Note: both sets of measurements made in June 1985.

Fish Bay	Transect number	Linear transect method	Quadrat method
	1	21	14
	2	14	8
	3	30	11
	4	27	8
	5	10	5
	6	23	8
	7	26	10
	8	20	9
	9	18	10
	10	17	6
mean		21	9
SD		6	3

Note: quadrat measurements made in June 1985; transect measurements made in April 1985.