ENVIRONMENTAL STUDIES OF BUCK ISLAND REEF NATIONAL MONUMENT

ST. CROIX, U. S. V. I.

Prepared for
THE NATIONAL PARK SERVICE
U. S. DEPARTMENT OF INTERIOR

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TABLE OF CONTENTS

INTRODUCTION

There is at the present time a wealth of information on a variety of aspects of the geology and biology of Caribbean coral reefs (Coral Reef Symposia II, III 1974, 1977; Jones and Endean, 1973). Perhaps the most noteworthy generalization that can be made regarding this morass of information is that the structure and dynamics of reef ecosystems in this region are nearly as variable as the number of localities that have been studied. It is therefore difficult to justifiably extrapolate the conditions found in a particular system to those found elsewhere. Generalities certainly exist, but the reefs of Jamaica (Goreau,1959) or Barbados (Lewis, 1960) or Curacao (Bak 1975) are quite different in terms of their structure and composition.

Since the establishment of the national monument at Buck Island in 1961, intermittent studies have been carried out in the underwater portion of the park, most notably by Littlefield (ms) and Robinson (ms), but no systematic effort has been made to determine the structure of the reef ecosystem, to inventory the important species present or to study important aspects of the dynamics of the ecosystem such as productivity or reef growth although Littlefield has been monitoring certain quadrats for several years.

The present study was undertaken to provide the NPS a baseline of information on the structure and function of the reef ecosystem against which to compare the reef at some future time. There have been three principal objectives:

1) To determine in a general way what the principal resources of the underwater portion of the park are (reef structures, corals, fishes) and to map their distribution;

2) To determine the rates of accrual of the more important of these resources (especially major coral species); and

3) To assess the effects of important or potentially important agents destructive to living coral (man, disease, predators). These objectives have in large part been met but our understanding of the reef ecosystem is still in a rudimentary stage. It is hoped that more than anything, the present study will stimulate further research into the dynamics of the Buck Island reef community.

ACKNOWLEDGEMENTS

A large number of people have in one way or another participated in and contributed to this study. Members of the local NPS staff have been most helpful in providing encouragement and assistance during the fieldwork, as well as suggestions as to what the most pressing problems of local management have been. Former Chief Ranger Carroll Shell, Park Supervisor Marvin Madrey, and the new Chief Ranger , Bob Thomas and the remainder of the staff working almost daily at the park have been most cooperative and have helped make this project go smoothly.

Several of the boat captains, especially Llewellyn, have been most useful sources of information as to the history of daily use of the park over the last 17 years and to changes that have taken place.

Several members of the WIL staff have contributed tirelessly to the completion of this project. In particular we thank Joan Doane who has uncomplainingly typed the entire final report and Debbie Kennedy who has kept track of our spending. The efforts of other staff members have been greatly appreciated.

A number of students of the WIL have participated at various times and we would like to thank them collectively, singling out Mike Drago, who did much to help us in the preparation of final figures.

Finally, we would like to thank our colleagues who have contributed their physical and mental efforts to various aspects of this project; especially Dr. W. Adey for discussions of reef growth and Dr. E. Shinn and Dr. H. Hudson for sampling <u>Montastrea</u> cores.

II. PHYSICAL DATA

Objectives

Physical data were gathered many of the days that field work was carried out at Buck Island. These were taken for two reasons: first to provide background information for some of the field experiments carried out over the course of the year, and second to find the range of conditions which the public encounters during peak visitation hours of the day during the year.

Measurements were made once during the day, usually in the morning, thus data on wind speed, cloud cover, and other parameters which have daily fluctuations cover primarily the range of conditions encountered during the hours when Buck Island is most heavily used by visitors.

Methods and Materials

Temperature was measured 2 m below the water's surface with a Celsius thermometer.

Wind direction was determined by facing into the oncoming wind and reading the direction on an Ikelite underwater compass, while velocity was determined with a Dwyer wind meter.

Cloud cover was estimated visually.

Water clarity was determined by a variation on the Secchi disc method. A chlorox bottle was suspended 2 m below the boat. A diver, releasing a marked line attached to the bottle would swim in the direction of the sun and note the distance at which the bottle disappeared from view.

Results

The general trend in wind and water conditions is for minor fluctuations the entire year with average conditions mild, providing year around pleasant conditions at the monument. (Figs. II-1, II-2).

Temperature (Fig. II-1) shows an annual maximum of 29.5° C which remained constant from August through November. It gradually decreased over a period of six weeks to a minimum of 26° C which was maintained with no more than 0.2° C fluctuations until May when the temperature again began to increase.

The easterly trade winds (Fig. II-2) blow at varying strengths the entire year, with short periods (up to 5 days) of light breezes from the west. This year the winds seemed to be primarily from 90° - 120°, but this is subject to ± 20° variation according to past St. Croix records (available at the FCC control tower, Alexander Hamilton Airport).

Water clarity (Fig. II-1) was never measured to be less than 50 feet. When observed during the winter months (November to February) visibility often exceeded 100 feet. Visually observable plankton (ctenophores, copepods, etc) appeared in the summer months (May - August) when visibility was slightly less than the winter maximum. Also, the lowest visibility occurred under two conditions: (1) periods of westerlies and generally calm water and (2) during storms with heavy northerly swells.

Cloud cover was unusually low for St. Croix as a whole since this happened to be a particularly dry year.

Recommendations and Conclusions

Gathering of seasonal climatic data and water information is best carried out by the NPS patrol unit which regularly visits the island.

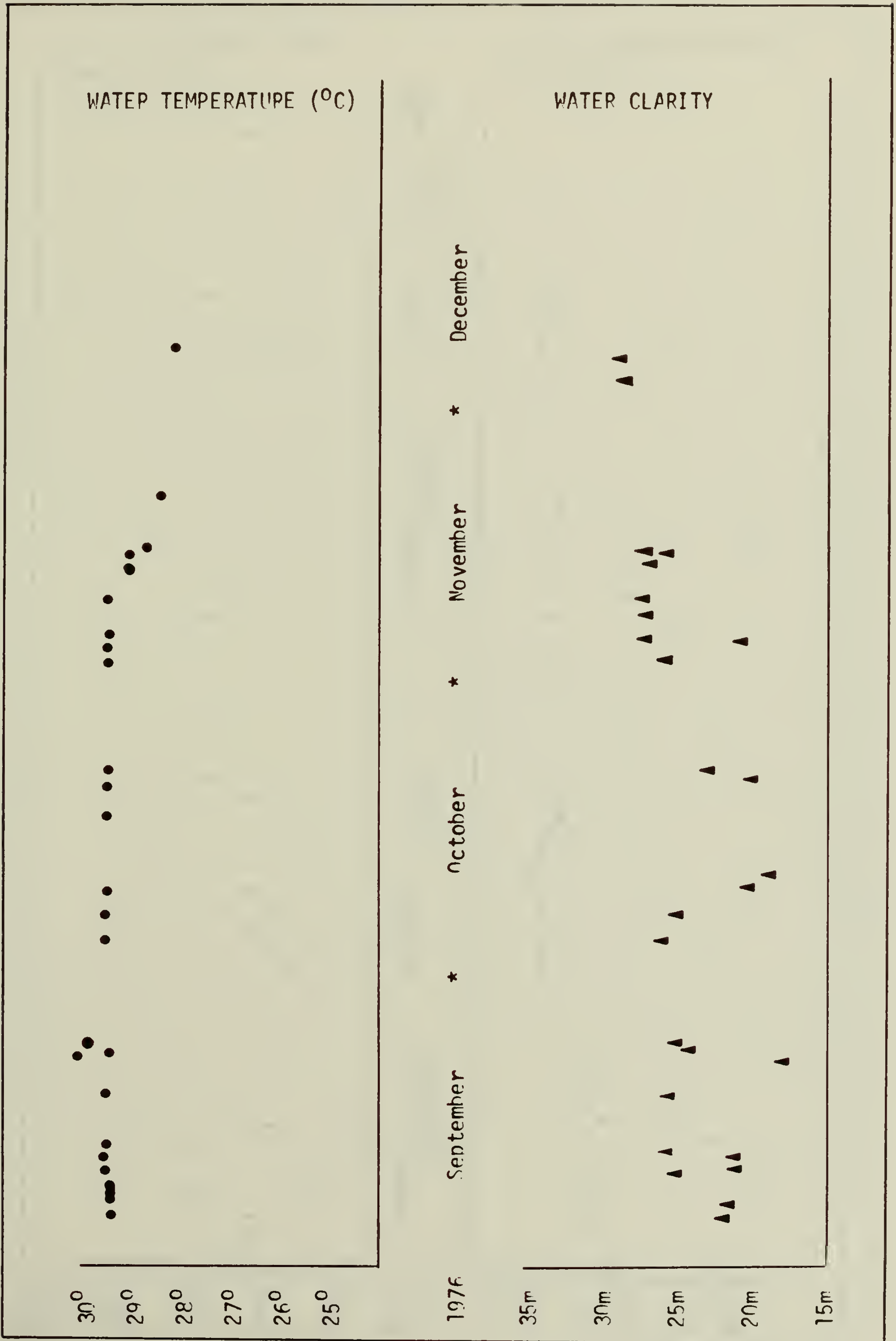
The local management has already begun to gather this information. The NPS might consider setting up an automatic weather station on the island (either at West End Beach or on the peak). This would only have to be attended to each ten days to change batteries and collect the tapes. Rainfall, wind direction and velocity, could then be monitored continuously.

FIGURE LEGENDS - Chapter II

Fig. 1 - Water temperature and water clarity plotted for 9 months for the underwater trail area, Buck Island

Fig. 2 - Wind velocity and direction at the underwater trail, Buck Island: September 1976 - May 1977

Fig. II-1



WATER TEMPERATURE (°C)
WATER CLARITY
1976
September
*
October
*
November
*
December
30°
29°
28°
27°
26°
25°
35m
30m
25m
20m
15m

Fig. II-1 continued

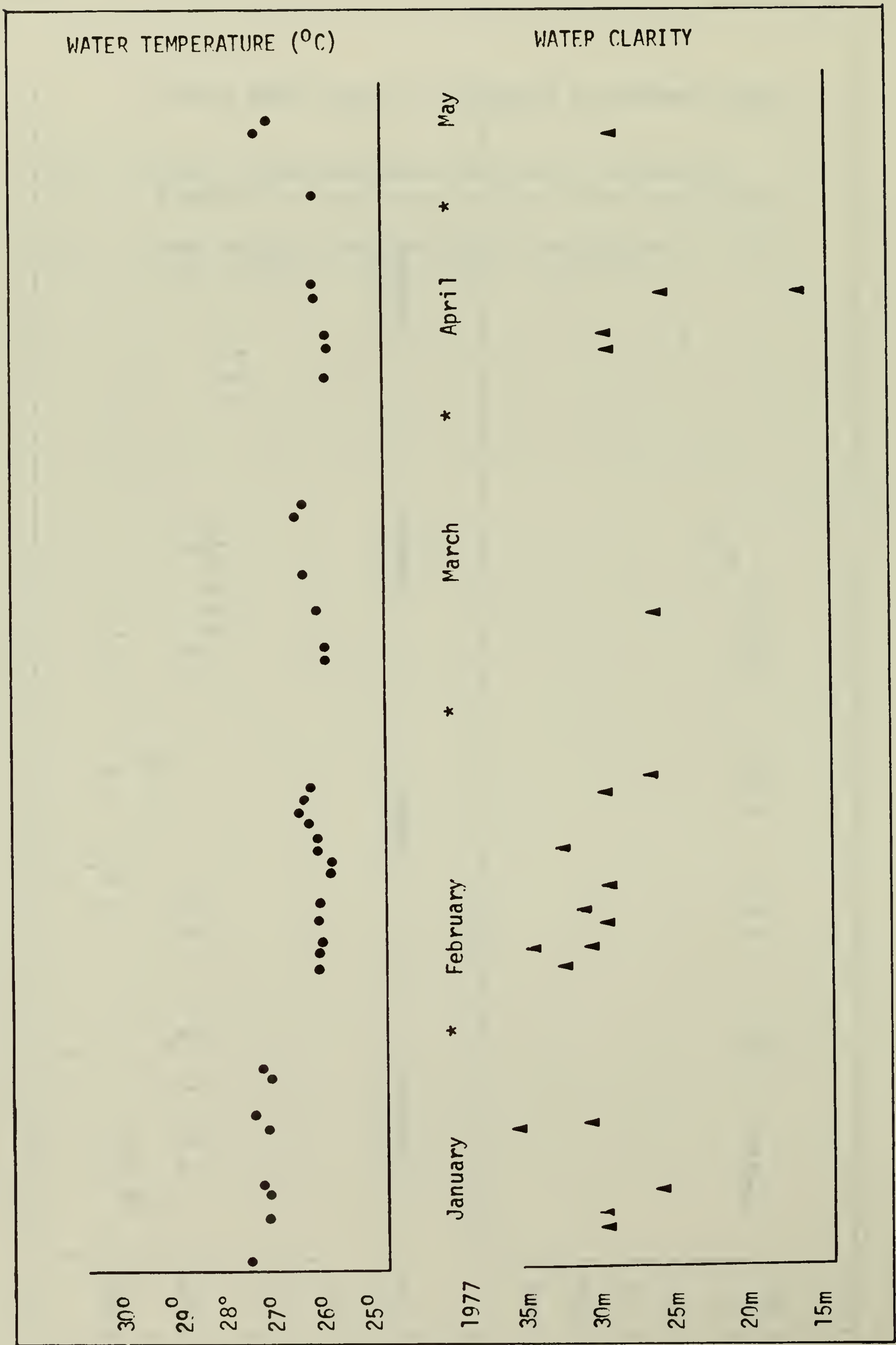


Fig. II-2

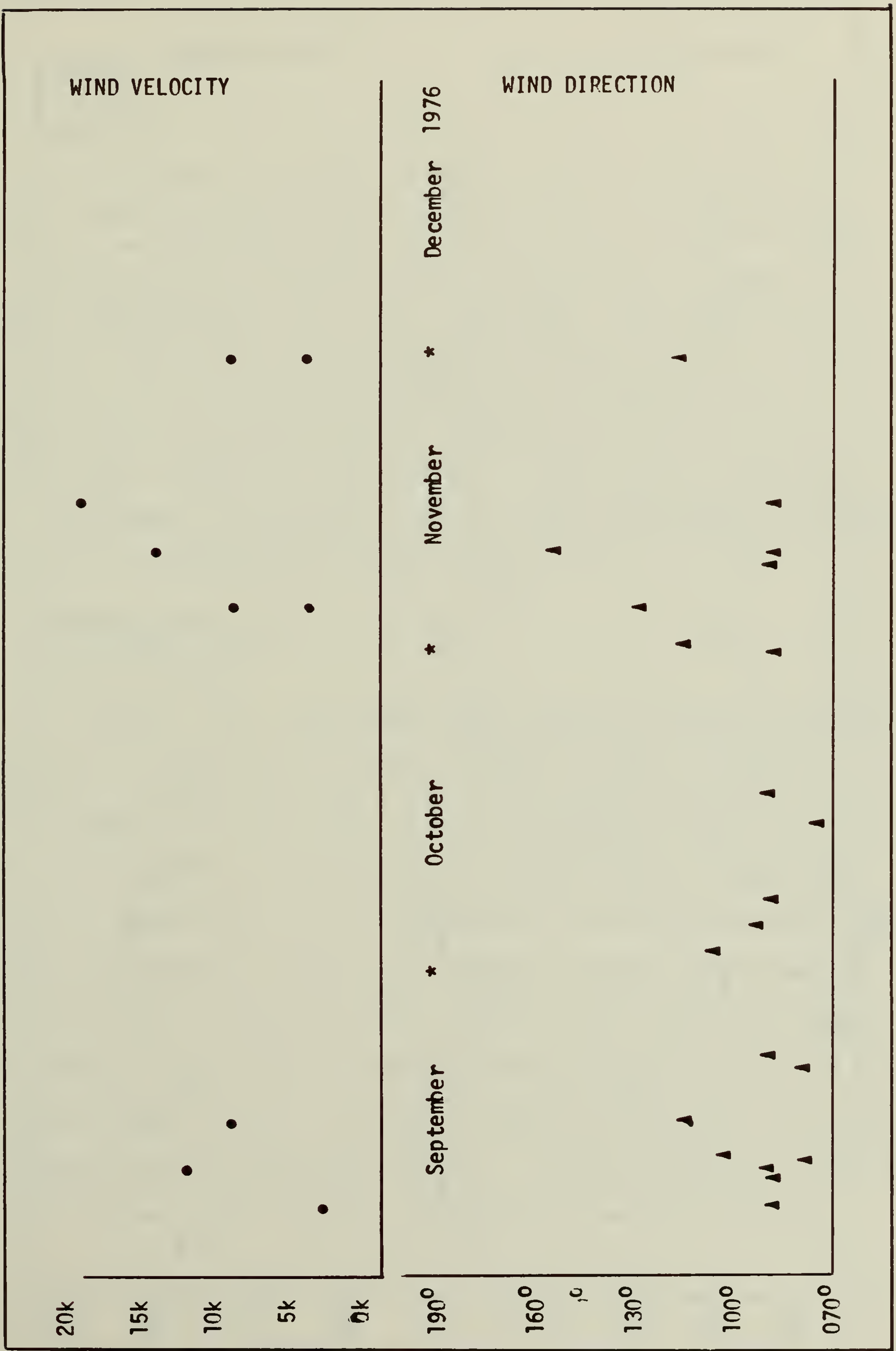
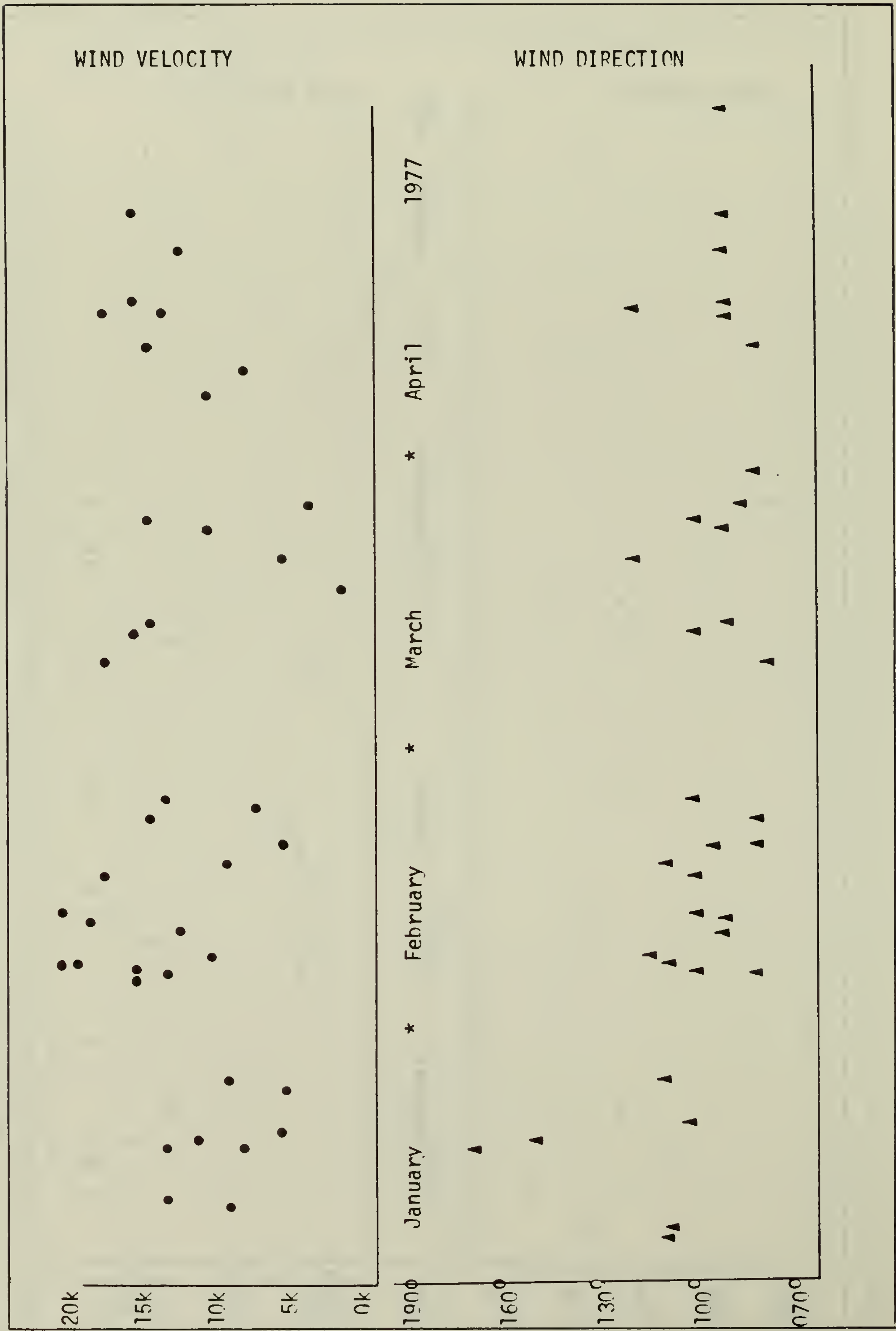

WIND VELOCITY
WIND DIRECTION
September
October
November
December 1976
*
*
*
20k
15k
10k
5k
0k
190°
160°
130°
100°
070°

Fig. II-2 continued



III. CURRENTS

Objectives

Surface currents in Buck Island Lagoon, surface currents across the Buck Island bank barrier reef, and subsurface currents were measured.

Currents across the reef were measured to determine if community studies could be made by using a flow method (Odum & Odum, 1955; Kohn & Helfrich, 1957;,etc). Currents within the lagoon were measured to determine rates encountered within this waterway and also to see the effect of wind strength on surface currents. Information on currents in Buck Island channel was gathered to provide some information on the direction and velocity of water movement past the island.

Methods and Materials

Buck Island Lagoon

Six stations, established between Buck Island and the reef (Fig. III-1) were used for determination of surface currents at monthly intervals between October 1976 and May 1977. A boat was anchored at a site; a 5 meter line was extended from the stern. A snorkeler held the end of the line taut. Approximately 50 ml of concentrated flourescein dye solution was placed 1/2 m below the surface with a hypodermic needle or squeeze bottle. The direction the dye moved was determined with a hand-held Ikelite underwater compass, and the velocity was determined by timing the horizontal movement of the dye through 5 meters. A series of three or more runs was made to yield a mean speed and direction at each station. The wind direction and velocity was also recorded at each station. Directional arrows in Fig. III-1 indicate true rather than magnetic bearings.

Across Buck Island Reef

To determine water movement across the reef, the same method described above was employed, i.e. dye was released from a spot on the reef crest and the time it took to move a measured distance was recorded. Four areas: the middle of the south reef, the easternmost tip, the trail area and 400 yards west on the north reef were tested once in May 1977 during a period of mild easterly winds at midtide. Concurrently, current velocity and direction in the Buck Island channel adjacent to the south reef and inside the north part of the lagoon was also determined.

Buck Island Channel

On February 13, 1977, divers using SCUBA placed a film recording current meter in 20 m depth at Porpoise Patch, Buck Island Channel, St. Croix. The film recorded direction and relative strength of current each 12 minutes. The meter was retrieved February 25. The film was analyzed and direction and strength (none, weak, moderate or strong) was plotted. Currents in this area have been monitored and velocities as high as 3 knots have been recorded.

Results

Buck Island Lagoon

The highest current recorded was .43 knots in the south lagoon (Fig. III-1). This station consistently had the strongest current, usually flowing straight down the channel parallel to both the shore and the reef. The two stations at the underwater trail mooring area usually had the weakest current, often hard to measure. The three stations along the north lagoon showed intermediate currents usually flowing westerly (parallel to shore and the reef) but occasionally flowing southerly toward the island. At these periods there may have been some flow across the reef. All stations were in the middle of the lagoon; counter-currents along shore or along the reef were not detected. The measured wind directions varied up to 20° at different stations on a given sample day. Current directions were similar to wind direction, but seemed to vary up to 35° between stations. Generally stronger winds caused stronger surface currents (App. B). Wind has an important influence on surface current direction and velocity, but other factors (especially configuration of the reefs) play a role.

Across Buck Island Reef

Currents were negligible across the south reef, at the eastern most tip of the reef and across the north reef. Dye dispersed very slowly in these areas. At the same time currents in Buck Island channel, and within the lagoon were consistent with the measurements reported above for other times of the year.

Buck Island Channel

The current in the channel, which impinges on the eastern tip of Buck Island showed a diurnal rhythmicity with westerly currents of varying strength alternating with periods of no current or a slight easterly current (Fig. III-2). The reverse flow is associated with high tides, and from this one study, seems to be especially prevalent during the spring tides of the month. Since weather during the study was normal (15-20 knot winds from 90° to 110° with a mild period 5-10 knots from the 16th to the 20th).

The tides seem to be of major importance in determining current speed and reversal.

Recommendations and Conclusions

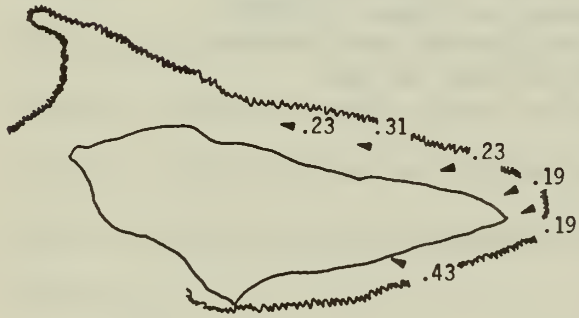
The current across the reef is not strong enough or steady enough to be used for flow studies as community metabolism, so other methods must be considered. The current in Buck Island channel is generally stronger than the normal ocean current. Perhaps changes in the pattern of this current coupled with storm waves is responsible for the annual cycle of buildup and then removal of sand at the southwest part of West End Beach.

FIGURE LEGEND - Chapter III

Figure 1 - Surface currents in Buck Island Lagoon. The arrows indicate the direction of water movement; velocity is indicated in knots.

Figure 2 - Currents in Buck Island Channel, February 13 - February 24, 1977. The diagram shows strength, duration and direction of current, and the time of the tides during each 24 hour period.

10/21/76



11/24/76

12/9/76

1/10/77

2/7/77

3/23/77

5/2/77

FIG. III-1

Figure III-2

Currents in Buck Island Channel, February 13-February 24, 1977. The diagram shows stength, duration and direction of current, and the time of the tides during each 24 hour period.

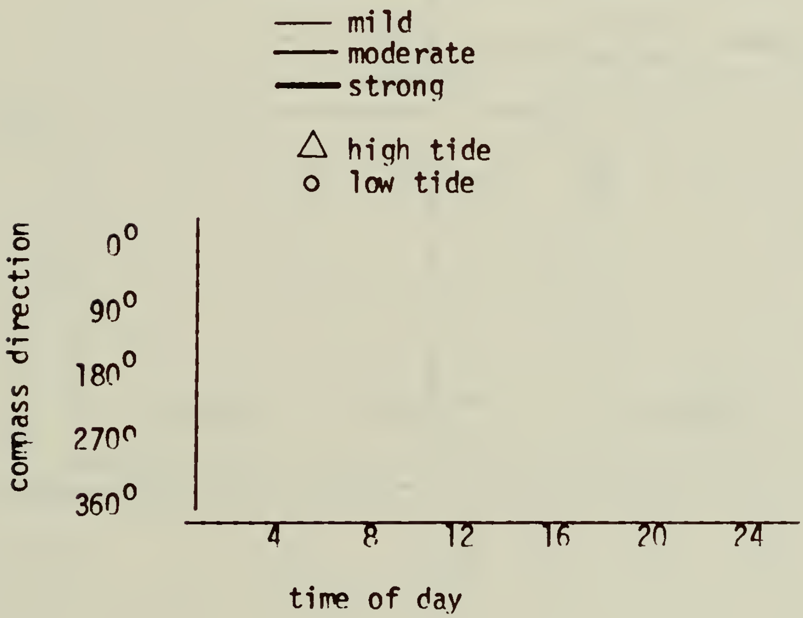


Figure III-2 continued

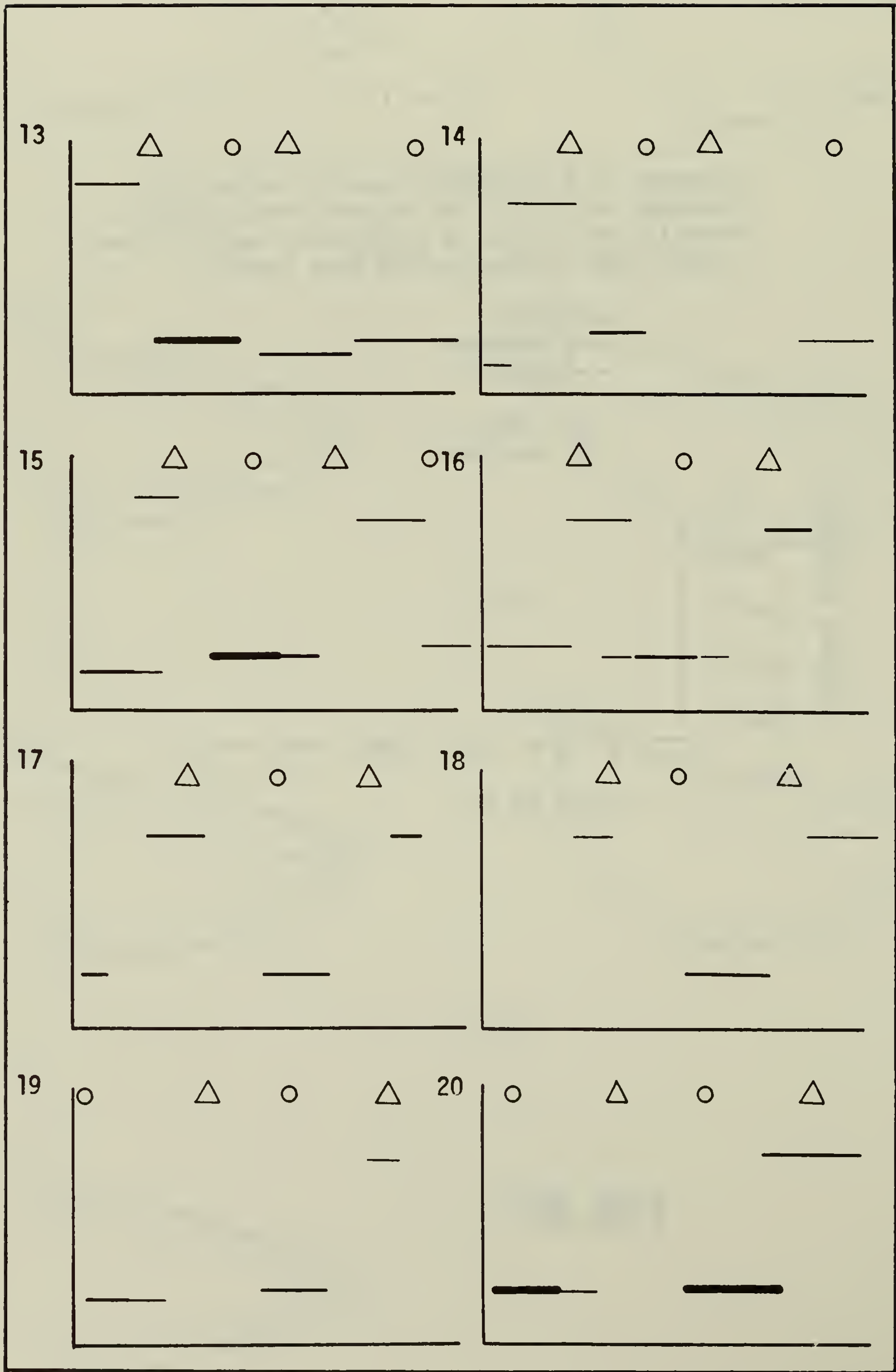
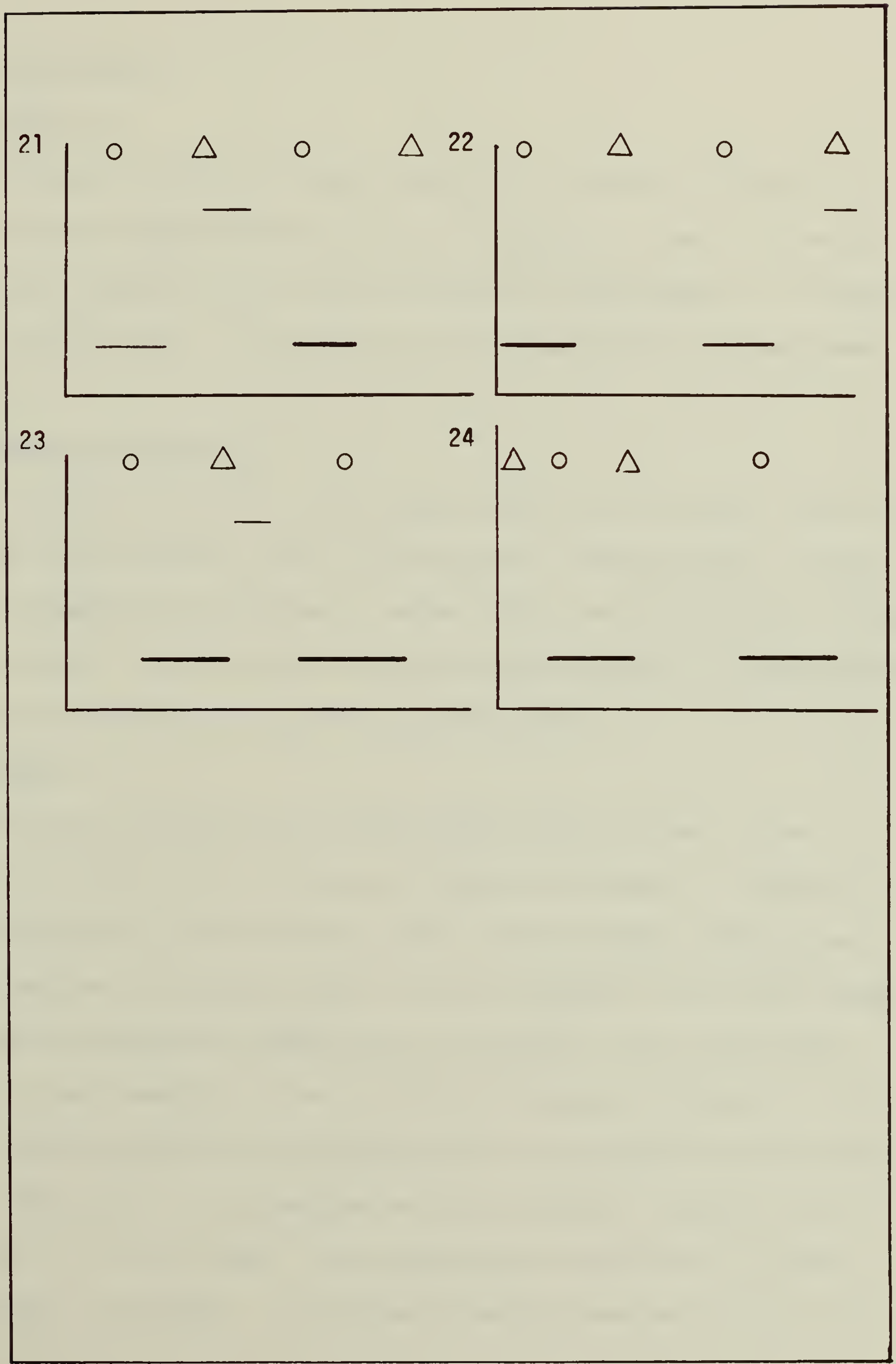


Figure III-2 continued



IV. BEACH PROFILES

Objectives

The beach profiles were established, first to monitor the rate of erosion at the northwest tip of the island through this year, and second to provide a baseline set of profiles showing maximum changes in the beach over a one year cycle. Future profiles can be compared to the set taken this year.

Methods and Materials

Ten stations (Fig. IV-1) were established from the northern limit of the beach to its southeastern limit on the west end of Buck Island. A rebar stake was hammered in the ground to serve as the zero point for each transect. Each month (and also after storm periods with heavy swells) a beach profile was made at each station using 150 cm profile poles.

Results

The sand on the beach moved considerably during the year. The greatest variation in the profiles was between the October 14, 1976 set and the February 14, 1977 set (Fig. IV-2). From September through June erosion occured at station #2 (App. C) on the northwest tip of the island. This area had progressive undercutting of manchineel trees, and Indian artifacts were exposed. The main section of the beach (Stations 4 - 7) had a broad flat profile which became shorter and steeper during the winter months (especially after storms)and during the spring it appeared to be returning to the broad shape. The southernmost stations (#9, #10) were rocky shores in September. A sand beach gradually developed through the winter, which is being eroded again towards the summer.

The same general pattern of the westerly and southerly facing sections of the beach has been noted for up to 15 years by persons familiar with Buck Island (boat captains and other island residents). The erosion at the northwest tip (especially after storm periods) and the resultant undercutting the manchineel trees appears to be a relatively recent, catastrophic event rather than an annual cyclic occurrence. The dead trees now in the water still had leaves in September. This may be related to a shift in current throughout this part of the Caribbean as similarily oriented beaches on nearby islands (i.e. St. John) are showing a similar pattern (Hoffman, Robinson & Dolan, 1974).

Recommendations and Conclusions

The local NPS knows the positions of the ten stations and can make comparison profiles at any time deemed necessary.

FIGURE LEGEND - Chapter IV

Fig. 1 - Map showing the positions of the 10 beach profile stations.

Fig. 2 - Overlapping profiles taken 10/14/76
and 2/14/77
at ten stations located on West End Beach, Buck Island. Dotted line indicates sea level.

Scale Vertical: 1/10 inch = 15 cm
Horizontal: 1/10 inch = 15 cm

FIG. IV-1

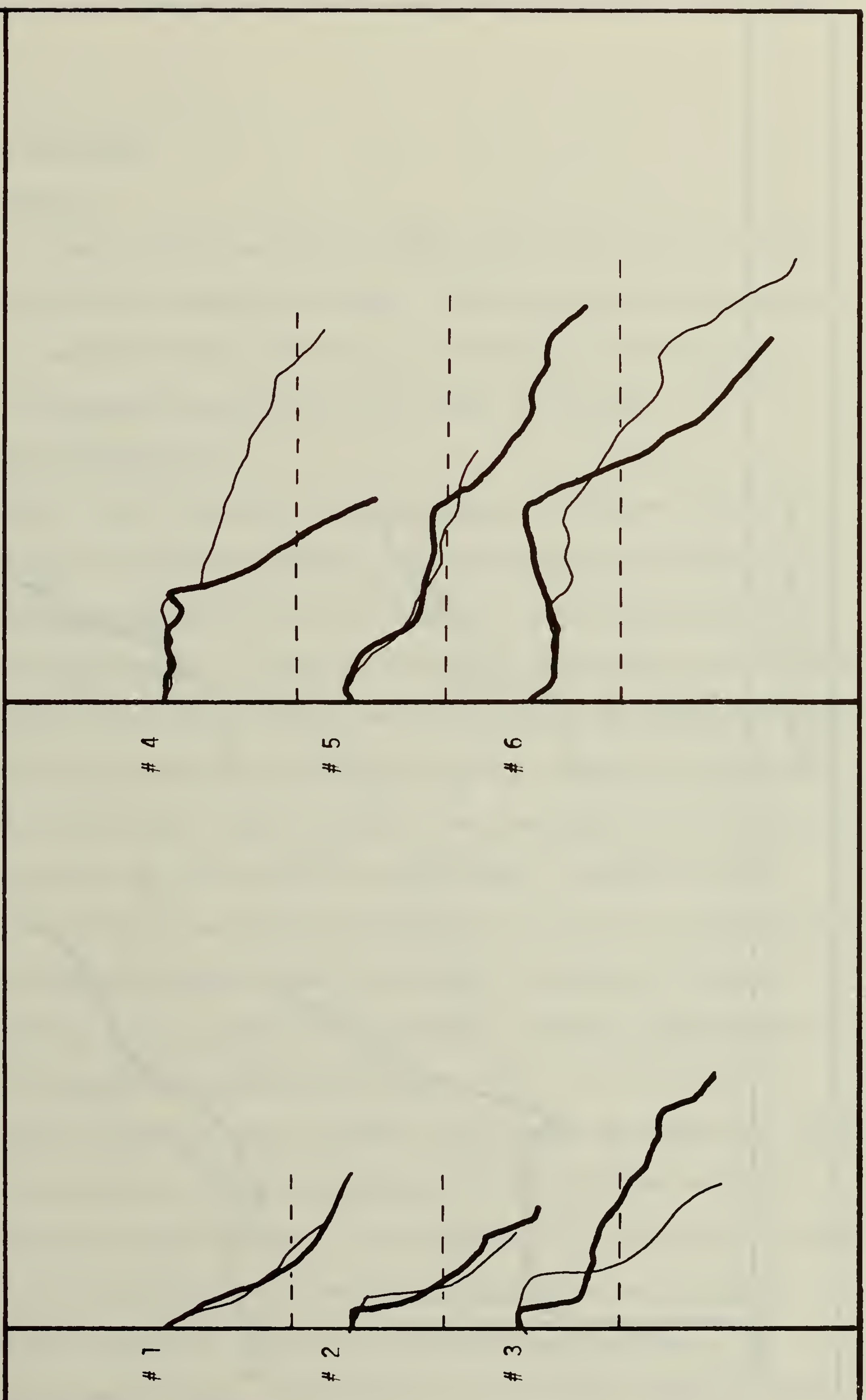
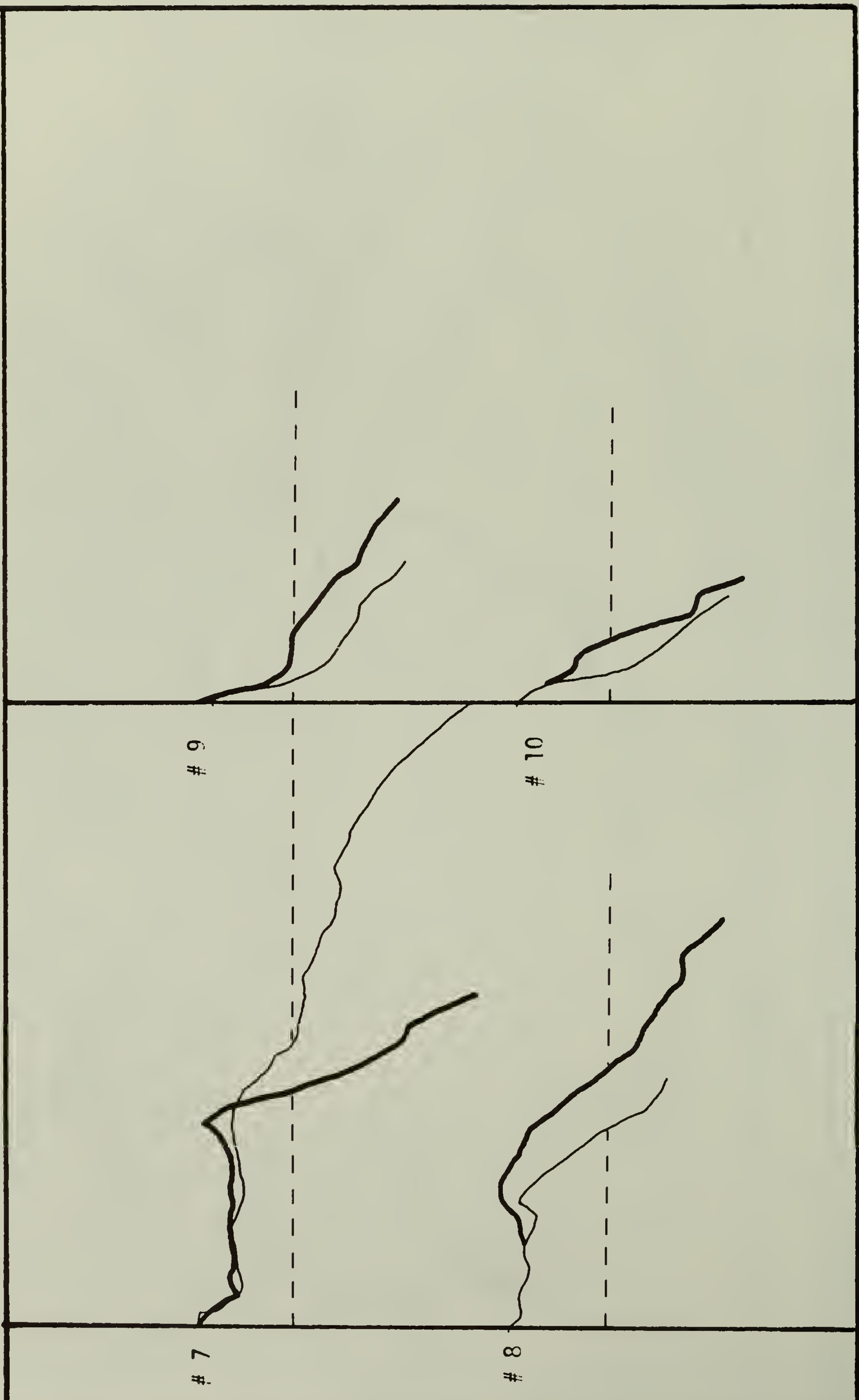


Figure IV - 2

Figure IV-2 continued



V. MAN'S INFLUENCE

Objectives

Man's contact with the marine habitat at Buck Island is concentrated at the underwater trail and mooring area. Patterns of human utilization of the trail were determined, disturbance caused by boat moorings was assessed, and damage caused to the reef by boats was noted.

Methods and Materials

Patterns of use of the Buck Island Underwater Trail were determined during the days of observation during a relatively heavy visitation period from January 20 to February 12, 1977. A map of the trail was made from an aerial photograph (Fig. V -1) and the trail (i.e. that area of the reef set aside by signs) was divided into six major areas: #1 - the entrance to the first grotto at the start of the trail; #2 and #3 - the first grotto; #4 - the second grotto, with a rest float; #5 - the deep grotto and cut to the forereef; and #6 - the area by the last rest buoy. An observer and a recorder were on a boat moored near the start of the trail. Each minute the position of each group snorkelling the trail was noted. Data were collected during the peak hours of visitation on the given sample days to determine the patterns during heaviest use.

Disturbance caused by mooring chains was assessed by comparing a transect in the relatively undisturbed windward portion (60°) and one in the disturbed leeward portion (240°). Three moorings (Fig. V-2) were studied. A transect chain was positioned from the mooring pin in the direction indicated, and a series of adjacent 1 m^2 quadrats were analyzed. The mooring chains were 8m long. The number of coral species present, percent live coral coverage of each, percent coverage of Zoanthus and Palythoa, and estimates of algal coverage were determined for each transect. The area in which the moorings are placed is in a head coral zone (see Chapter VI).

Several boats ran into the reef during the course of study at Buck Island. The damage was noted and subsequent recovery followed (Fig. V-4).

Results

The underwater trail is visited mainly by small groups (4-6 persons) with a guide. Since visitation is spread out from 1030 - 1320, this usually results in no more than 25 people on the trail at one time and often many fewer. However, in unusual circumstances there may be over 50 persons at one time (Fig. V-3, Table V-1). The maximum number of boats at the moorings during the course of this study was 19, but only 14 were present on the day that over 50 people were on the trail simultaneously. Average time spent on the trail by a person is 12.4 minutes (Table V-2). The most "popular" areas of the trail are the areas around the rest floats (#1, #4, #6) but especially the deep water grotto entrance on the forereef (#5).

The mooring chains have an observable effect on the bottom. A comparison of the windward (undisturbed) and leeward (disturbed) transects (Table V-3), shows that the number of coral species present does not differ, relative importance of particular species is not affected, but the total living coral coverage is 50% greater in the disturbed habitat. It is also clear that the standing crop of benthic algae (which consists of Laurencia, Martensia, Halimeda, Dictyota, and numerous smaller forms) is much higher in the undisturbed portion, being virtually absent from the disturbed area.

Conclusions and Recommendations

Groups of people snorkelling through the trail area in small numbers, cause minimal damage to the reef system. Minor damage to the reef occurs when boats, unable to maneuver,run into the reef. The effects of such damage can be reduced by divers righting overturned head corals; the branching corals heal themselves (see Chapter VII - Calcification), and broken framents often grow into new colonies. Too many boats at the mooring area at any given time increase the probability of such accidents. Boat traffic movements are the most serious threat to both the safety of the swimmers and possible errors and collision with the reef. There is a real need to spread out visitation during more daylight hours during the peak visitation periods. The local park management is already addressing itself to this problem. Two suggestions which are being encouraged are to spread out use over the day (i.e. stagger visits) and second, limit time spent at the mooring.

Mooring disturbance is not a major problem and is certainly preferable to anchoring which was the practice before 1961 when very few boats visited the area. The present system of 11 buoys was established in the mid 1960's, after a period of 4 or 5 years of private moorings, which were set up by the original charter captains. The major effect the mooring chains have had in the area is to prevent settling of benthic algae, which has apparently enabled more coral to settle and grow. This phenomenon has also been reported by Birkeland (1977) who has found that more coral colonies are founded on experimental settling plates with low algal cover than those with more. In the present case it is the action of the anchor chains which controls the algal settlement rather than light as in Birkeland's study.

If more moorings are deemed necessary to regulate boat and swimming traffic and safety, there are similar areas adjacent to the present mooring areas which could be utilized. These lie just to the north-east of the present site. Care should be taken to avoid placing these in or near fragile Acropora prolifera stands. The problem which arises is where the people using these additional moorings would snorkel. The reef adjacent to this area has several swim through cuts to the forereef, and beautiful coral formations including large head corals, and is comparable to the trail area. If boat captains using this area could encourage their visitors to use this section of the reef, some of the pressure could be taken off the trail mooring area during peak visitation hours. Particularly striking in these potential areas are several spectacular cuts through the reef crest (similar to the most frequented area in the present trail).

FIGURE LEGEND - Chapter V

Fig. 1 - Map of Underwater Trail showing reef zones present

Fig. 2 - Diagram of relative positions of the present 11 buoys. Moorings #1, 3 and 7 were assessed for disturbance from anchor chains.

Fig. 3 - Histograms of the number of visitors snorkelling the Underwater Trail versus time, during ten days of observation. These graphs do not represent total number of visitors for that day; they do represent distribution of snorkelers during the observation period.

Fig. 4 - Damage caused to A. palmata in the trail area where "Reef Queen" went aground, Fall 1977.

TABLE LEGEND - Chapter XII

Table XII-1 - Analysis of the use of the Underwater Trail based on ten days of observation from January 20, 1977 to February 12, 1977

Table XII-2 - Analysis of the time a visitor spends snorkelling the Underwater Trail. The time is broken down into mean actual time spent in each area and into mean % of the total time spent in each area. Overall means of the ten days' values for each set of figures are also given.

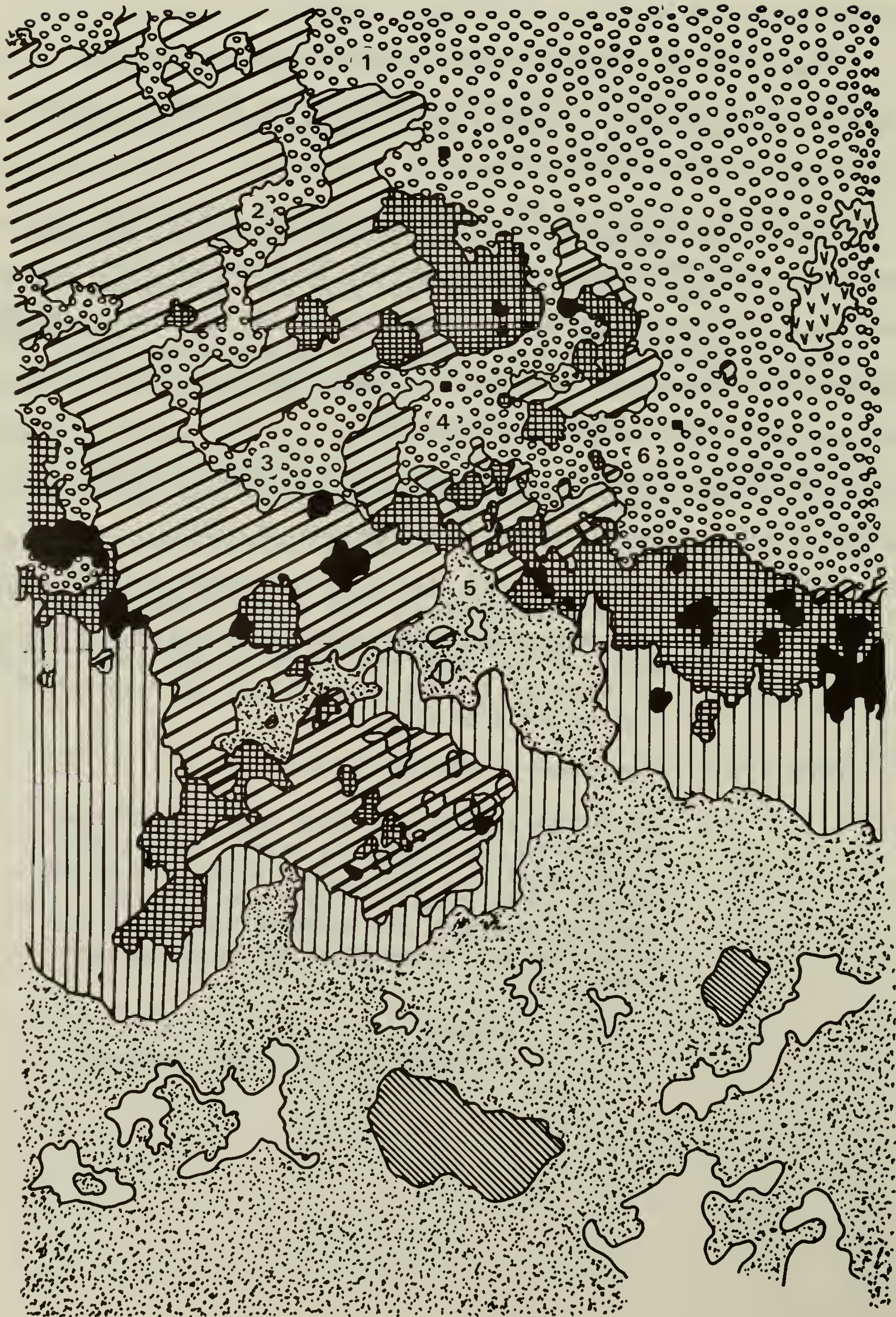
Table XII-3 - Assessment of Mooring Disturbance.

The bottom adjacent to three buoys is surveyed to compared the disturbed, leeward area (240°) to the relatively undisturbed windward area (60°). Percent total live coral coverage, percent zoanthid coverage, and relative importance (as determined by % coverage)of the coral species present.

1	present
+	10-50% of total coral coverage
++	50% " " " "

FIG. V-1

REEF ZONES: UNDER WATER TRAIL
SCALE 1:880
JUNE 1977 RKM & EHG



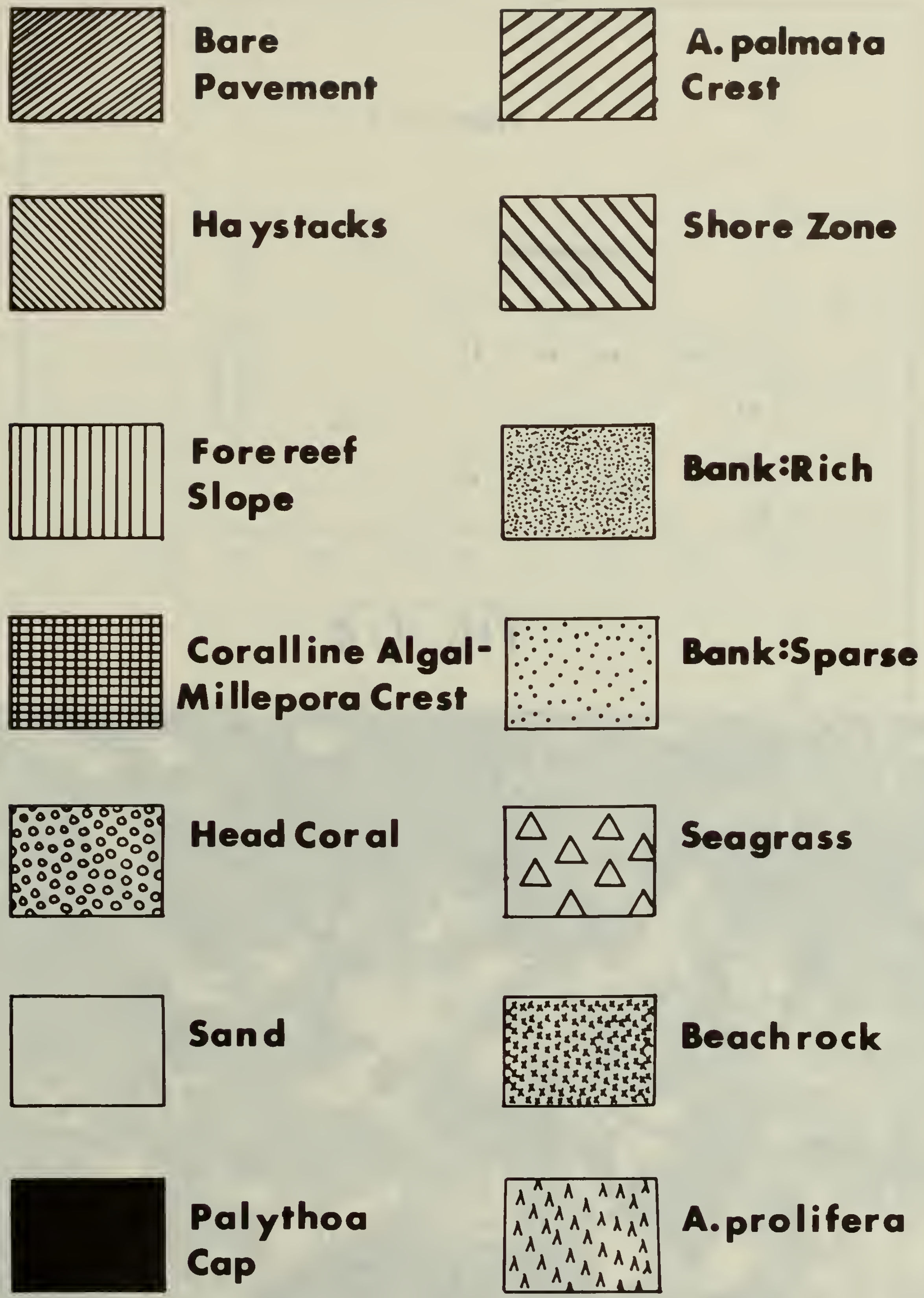

Bare Pavement
A. palmata Crest
Haystacks
Shore Zone
Fore reef Slope
Bank:Rich
Coralline Algal-Millepora Crest
Bank:Sparse
Head Coral
Seagrass
Sand
Beachrock
Palythoa Cap
A. prolifera

FIGURE V-2

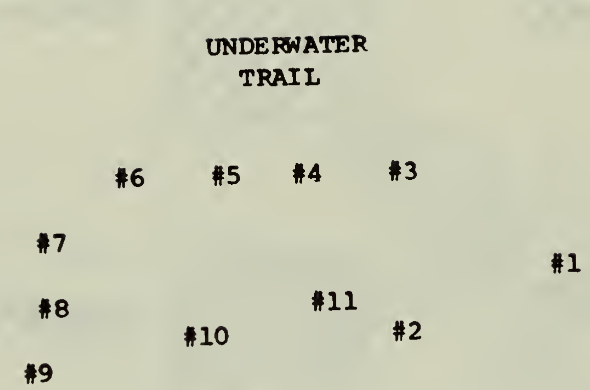


FIG. V·4

Figure 3

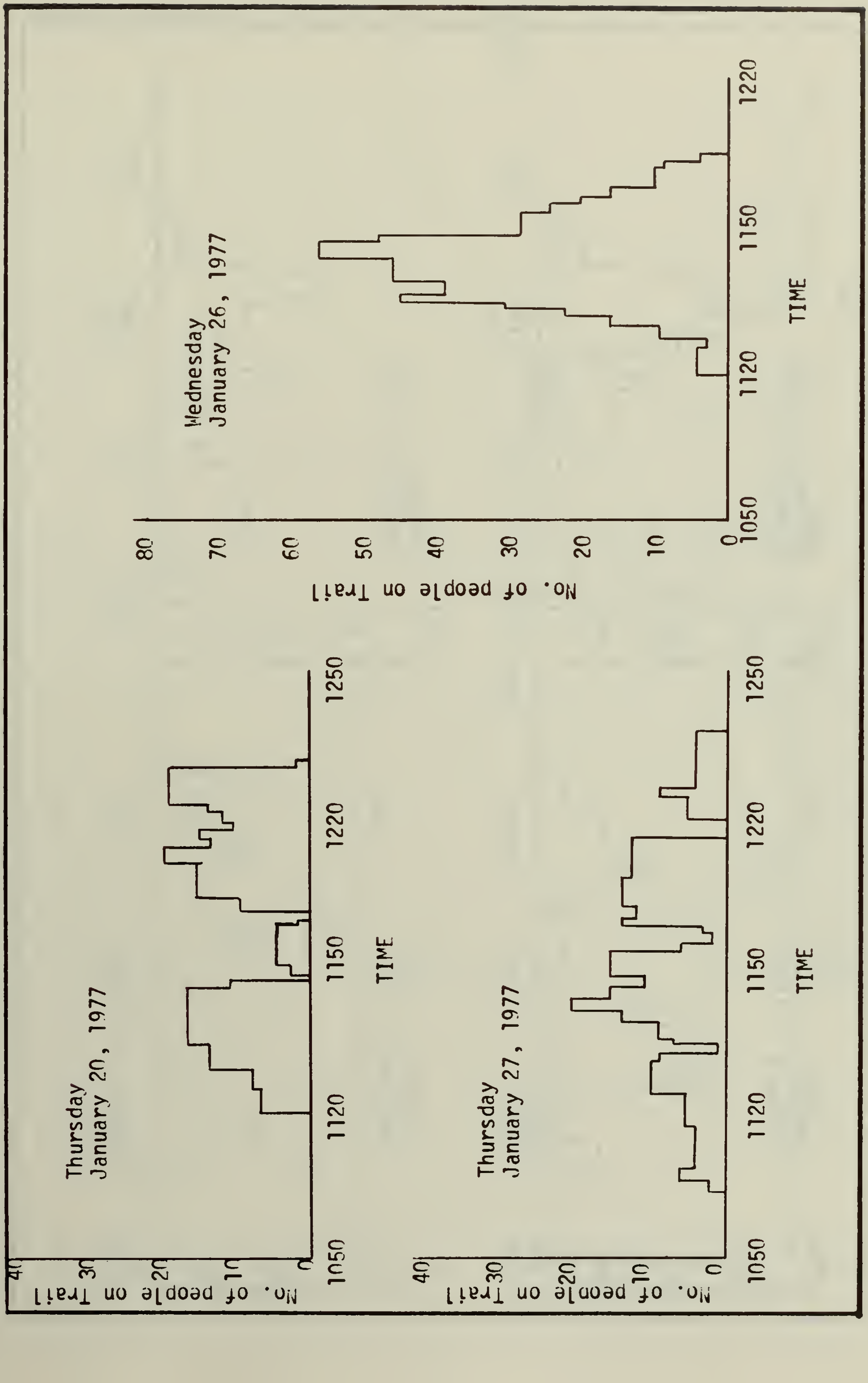

Thursday
January 20, 1977
No. of people on Trail
0
10
20
30
40
1050
1120
1150
1220
1250
TIME
Thursday
January 27, 1977
No. of people on Trail
0
10
20
30
40
1050
1120
1150
1220
1250
TIME
Wednesday
January 26, 1977
No. of people on Trail
0
10
20
30
40
50
60
70
80
1050
1120
1150
1220
TIME

Figure 3 continued

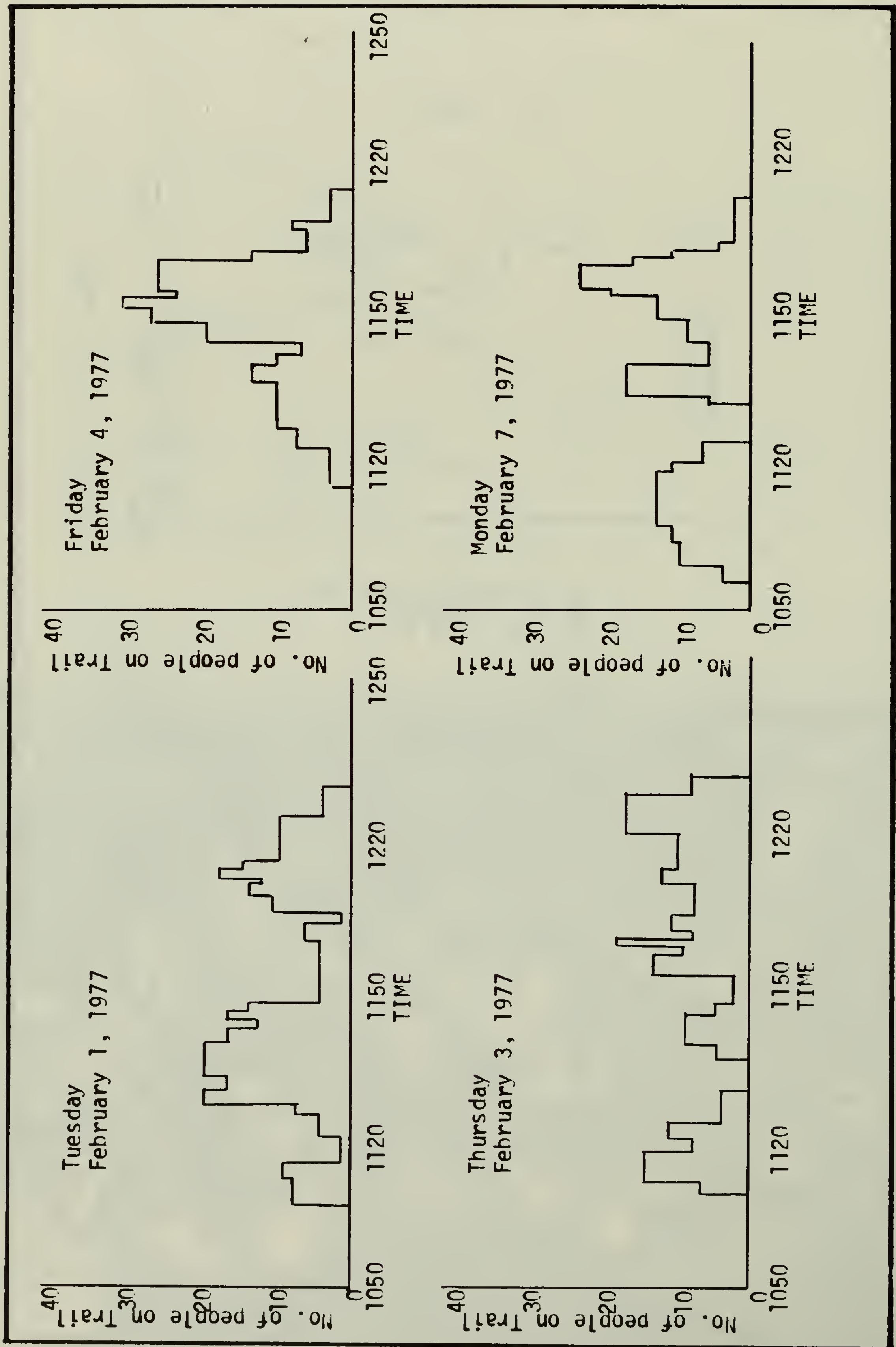


Figure 3 continued

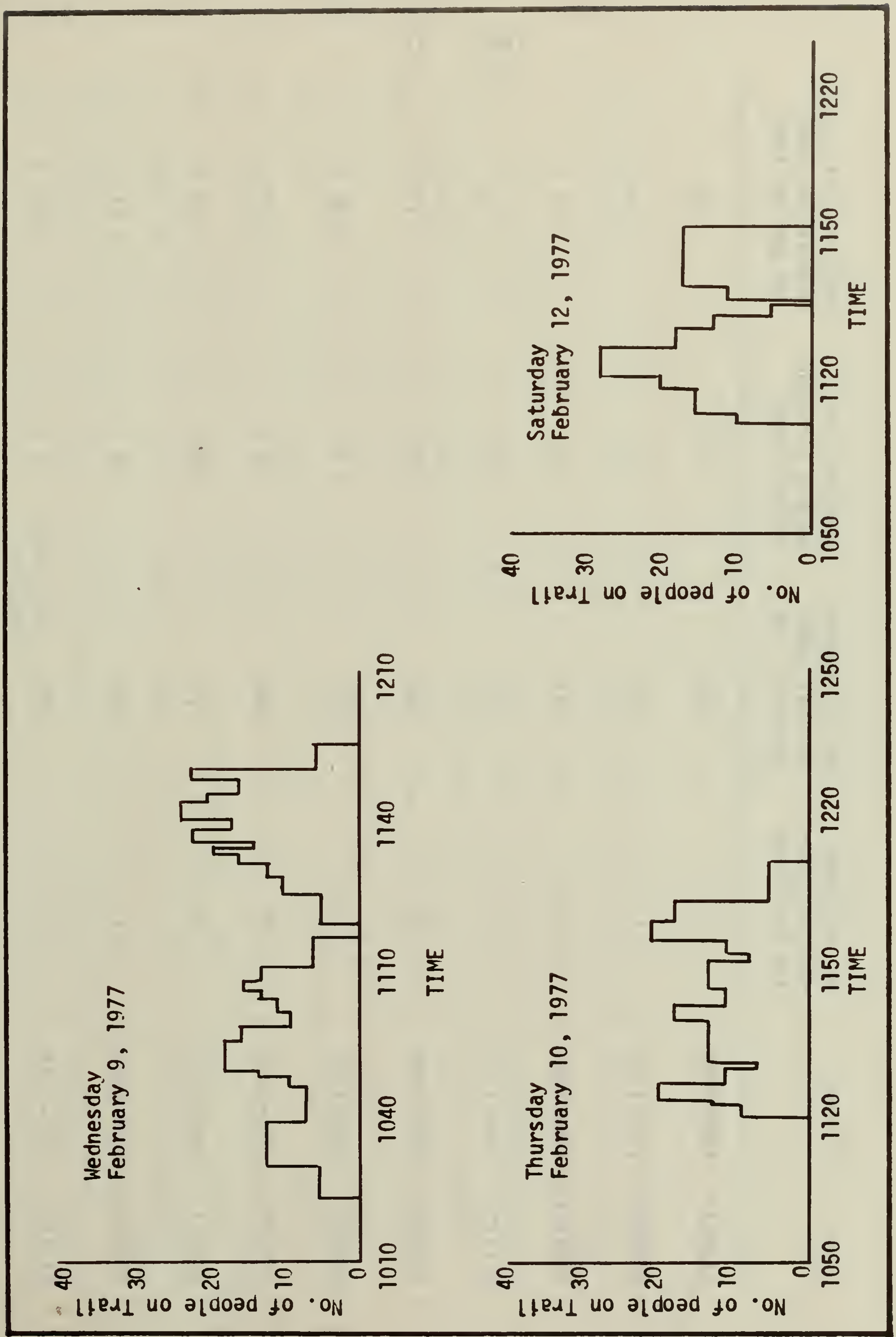


TABLE V-1

Date	Time	No. of boats at trail during this time	No. of people on trail during this time	Mean no. of people per snorkeling group	Max. no. of people snorkeling trail at any one time
1/20/77	1120-1230	16	62	5	19
1/26/77	1120-1219	14	67	5	54
1/27/77	1104-1239	14	73	4	21
2/1/77	1000-1222	16	56	4	19
2/3/77	1007-1228	15	64	5	17
2/4/77	1030-1213	16	41	4	30
2/7/77	1055-1216	19	59	5	22
2/9/77	1002-1156	14	72	4	23
2/10/77	1115-1320	19	59	6	21
2/12/77	1030-1214	17	45	6	28
				Mean= 5	Mean= 25

TABLE V-2

Date	No. of minutes spent in Areas: 1	2	3	4	5	6	Total time spent on Trail (min)	% of Total time spent in Areas: 1	2	3	4	5	6
1/20/77	1.9	1.2	.9	2.1	4.9	1.1	12.1	15	10	7	18	40	10
1/26/77	1.5	1.6	.8	2.7	5.8	1.5	13.9	10	12	6	19	42	11
1/27/77	1.4	1.3	.9	1.9	3.2	1.7	10.4	13	13	8	19	31	16
2/1/77	1.6	1.7	.9	2.4	3.6	1.6	11.8	14	15	7	20	31	13
2/3/77	1.8	1.3	.9	2.0	1.8	1.6	9.4	19	14	10	21	19	17
2/4/77	1.4	1.6	2.2	2.9	5.4	2.6	16.1	9	10	14	18	33	16
2/7/77	1.7	1.3	.9	2.2	4.5	1.2	11.8	15	11	7	19	38	10
2/9/77	1.7	1.3	.9	2.5	4.9	2.2	13.5	13	10	6	18	37	16
2/10/77	1.3	1.4	.8	1.6	3.9	1.6	10.6	13	13	7	15	37	15
2/12/77	1.9	1.3	1.0	3.1	6.4	1.0	14.7	12	9	7	21	44	7
Means	1.6	1.4	1.0	2.3	4.4	1.6	12.4	13	12	8	19	35	13

TABLE V-3

Assessment of Mooring Disturbance

Mooring #						
Transect Direction:	60°	240°	60°	240°	60°	240°
#Spp.	7	8	6	9	8	6
%total live coral coverage	5.5%	7.5%	3.8%	6.2%	6.2%	9.2%
coral Spp. present						
Diploria clivosa	1	1	++	++		++
D. strigosa	++	++		+	+	1
Porites porites	1	1	1	1	1	1
P. astreoides	+	+	+	1	+	+
Siderastrea sidera		1				
S. radians	+	1	1	+	1	1
Acropora prolifera					+	1
Montastrea annularis	1					
Isophyllia sinuosa					1	
Agaricia sp		1		1	1	
Dichocoenia stokesii			1	1		
Mussa angulosa	1			1	1	
Manicina areolata		1	1	1		
%total zoanthid coverage						
Palythoa	1.9	.1	.1	7.1	3.0	2.0
Zoanthus	5.4	8.9	13.9	23.4	24.3	24.4

VI. REEF ZONES

Introduction

Zonation in reefs along the shoreward-seaward gradient has been analyzed in many parts of the Caribbean region: Goreau and Goreau, 1959 (Jamaica); Lewis, 1960 (Barbados); Bak,1975 (Curacao) Glynn,1973 (Western Atlantic); MacIntyre and Glynn, 1971 (Panama); and Geister, 1976 (San Adnres). Adey (1975) in his extensive analyses of the history of eastern Caribbean reef development has contributed much information on the major reef zones of eastern St. Croix. The present study has been an extension of that work, analyzing and mapping the major reef zones (or communities) of Buck Island Reef National Monument. These major reef communities in general are a function of the shoreward-seaward gradient but are secondarily a function of the windward-seaward gradient of the island - the principal species comprising these zones have been determined and the variability found among local patches of a given reef community (zone) treated as well.

Methods and Materials

Because of time and personnel limitations of the present study, most attention was devoted to the bank barrier reef eastward of the western end of the island. Overlapping sets of nearly vertical color aerial photographs were taken from a Cessna 172 during the fall of 1976 when water surface conditions minimized subsurface distortion. Photo series were made from elevations of 400' - 4000' using a Nikon F2 35 mm camera equipped with 55 mm or 105 mm lens. For maximum resolution, extremely fine grained Kodachrome 25 film was used, a resolution of about 6" was obtained optimally. Because photos were taken with a hand held camera, either out of an open window or with the door removed from the aircraft, most photos are not perfectly vertical. However, most series had greater than 50% overlap between adjacent frames and the effects of distortion due to non-verticalness were somewhat lessened. The best set of aerial photos were combined and projected onto a horizontal surface to make a composite map of the reefs extending from the eastern limit of the park to somewhat west of the western shore of the island (Fig. VI-6). The zones mapped in this study were those clearly recognizable by color and texture, from the aerial photographs. When the first draft of the map was completed, sections were xeroxed, carried into the field and ground-truthed, and the composition of the zones by major species determined. At particular locations, zone composition was studied in somewhat more detail and percentage coral cover (i.e. importance) as well as coral abundance (i.e. frequency) and diversity were determined, using the data from 15-35 haphazardly chosen m^2 quadrats or contiguous m^2 quadrats per site. Transects of about 350 m in length were made radially seaward from shore at the five positions indicated in Fig. IV-1. Using 10 m transect chains, compass and depth gauge, students from the West Indies Laboratory, Fall 1976 Class, determined depth and coral species composition along each of the transects.

Results and Discussion

The Buck Island Reef system consists of a bank barrier type reef (bioherm) lying 100-200 m offshore and forming a nearly continuous barrier along the entire north side of the island, around its eastern tip and along nearly two-thirds of the southside; refer to Reef zone map. Leeward (northwest) of this barrier reef is a broken system of shallow patch reefs that extend nearly to the shelf edge of the western park boundary. As is generally the case in the eastern Caribbean (Adey, 1976) reef development is most active on the windward (upstream) side of the islands providing there is a shallow shelf to serve as a base. The precise reason for this is not clear, but the most active reef-builders, Acropora palmata and several species of crustose coralline algae are best adapted to living in high energy zones. If the history of the Buck Island reef has been similar to that of the bank barrier reef forming the southern boundary of Buck Island channel (Adey,1975) then the reef is probably about 40 feet thick and about 4000 years old. The wind vector averaged over the course of the present study lies between 90-110° or somewhat southeasterly. Differences in the structure of the North and South arms of the Buck Island reef may be due to this.

The fourteen major zones or reef communities (map of Reef zones) fall into three general regions: the lagoon, the bank barrier reef shelf and the bank proper, lying seaward of the reef. These zones are summarized below.

I. Lagoon
   - shore zone
   - beach rock zone
   - sand zone
   - A. prolifera zone

II. Reef
   - head coral zone
   - Palythoa cap
   - bare pavement
   - A. palmata crest
   - coralline algal - Millepora crest
   - forereef zone

III. Bank
bank: rich
bank: sparse
haystack zone

Table VI-1 summarized the coral species distribution and percent coral coverage (importance) for the zones containing coral. Table VI-2 gives detailed information on particular areas of these zones, and this is presented below.

The shore zone forms a band about 20-30 m wide around eastern half of the island. In general this is a shallow zone (1 m) fairly rich in certain species of coral. At the eastern tip a true fringing reef exists, an elevated limestone platform rich in A. palmata, D. clivosa, D. strigosa and M. annularis. Particularly large heads of the latter species are common here, their size apparently directed only by water depth. The D. strigosa heads in particular are in extremely good condition when compares to those in the trail area, with no signs of erosion, abrasion, predation or disease. Along the south lagoon, the shore zone is especially rich in P. astroides (Table VI-2), which comprises about 50% of all coral coverage. Total coral coverage of this southshore area is less than 10% but approaches 30-40% at the eastern tip. Along the north lagoon, zoanthids, gorgonians, anemones, D. clivosa, D. strigosa and S. radians predominate with some Millepora on topographic highs. A. palmata, P. asteroides and M. annularis are locally common, as are A. prolifera and P. porites. There is good development of crustose coralline algae in places with small caves developed (which serve as excellent shelter for fishes). Among other invertebrates, the anemone Stoichactis, the urchins

Echinometra and Tripneustes, and gastropods, are common. Fleshy algal cover is well developed.

Along the southwest end of the island there is a well developed shelf of beachrock along the shore extending from above the mean tide line to a depth of about 0.5 m. Because of its proximity to sand, sometimes the beach rock (as from November 1976 - March 1977) is covered by sand. During the summer it develops a cover of fleshy algae.

Seaward of the shore zone, the center and deepest part of the lagoon has a bottom bare sediment mostly in the silt to sand size range. The depth in this region is 2-4 m in the south lagoon, 3-5 m in the north lagoon (refer to transects Fig. VI-5; transects 1-5). In the south lagoon, which is generally shallower and free of obstructions such as patch reefs, there are wave-induced ripple marks and very little evidence of bioturbation. From June to September 1976 large masses of detached floating benthic algae (Dictyota, Acanthophora) remained in the lagoon and harbored large numbers of juvenile fish. Occasional heads of M. annularis occur in this zone but most do not appear healthy, indicating that perhaps the colonies were established when the extent of this silt sand zone was less than at present. In the north lagoon this zone is interrupted by reef and pavement. Most of this region is characterized by extensive turbation (Fig. VI-1A). Patches of rubble with gorgonians are scattered through this area.

Sediment characteristics were determined by Messenger and Realini (1977) and the West Indies Laboratory Fall, 1976 class, during the course of the study at several lagoonal sites: at the south boat entrance, at the north cut (SCUBA diving buoy) and along transect #3 in the northeast lagoon. Just inside the two cuts the taxonomic composition of the sediments was determined in a nonquantitative way. The major identifiable components of the sediments are remains of the following organisms:

coral fragments; Homotrema (foraminifera); Halimeda (Chlorophyta); echinoid spines; mollusc fragments; serpulid tube fragments (Polychaeta); gorgonian spicules.

At transect #3 sediments were samples from four stations along the shoreward-seaward gradient and the composition in terms of particle size distribution and percent carbonate were determined and are summarized below:

Zone	Shore	Bare Sand	Head Coral	Bank
Distance from shore	0 m.	20 m	100 m	380 m
% carbonate sediment	50%	79%	98%	100%
Grain Size (% by weight)				
2mm	67.5 - 46.8	19.4 - 39.0	5.0 - 0.4	1.2
1 - 2 mm	8.0 16.0	13.7 13.6	8.9 - 1.8	5.3
0.5 mm	6.5 - 18.0	18.5 - 25.4	14.5 - 4.0	9.8
0.063 - 0.5 mm	18.0 - 19.0	51.7 - 22.0	69.8 - 93.0	82.0
0.063 mm	0 0	0.5 -trace	1.7 - 0.7	1.6

Near shore, it can be seen that the sediments are dominated by large particles with a high proportion of non-carbonate (terrigenous) material. Farther out the sediments are dominated by particles in the very fine sand size range. It was also determined during the course of this study (Berelson, 1976) that there is a high rate of turnover of the sediments on the north lagoon by callianassid shrimps. There is a vertical turnover of 24.5 cm/yr and a lateral transport of up to 91 m/yr. Further information on this phenomenon can be found in Berelson.

Seaward of the shore zone in the western portion of the lagoon are extensive stands of the branching coral Acropora prolifera in water depths of 1'-4' (Fig. VI-1C). About 60% of the coverage of this zone consists of this species and associated flora and fauna; the remainder is largely sand, with scattered P. astreoides, D. strigosa, D. clivosa, M. annularis and Agarcia agaricites. In dense stands of A. prolifera there are up to 350 growing tips/m^2. The lower branches are generally dead and covered with a variety of algae and coelenterates such as Zoanthus, Stoichactis and Briareum. Just off the eastern tip of the island itself are localized stands of A. cervicornis.

Scattered throughout the north lagoon and generally lying just inside the entire reef is a highly variable group of coral assemblages that have been lumped together for convenience as the head coral zone because of the predominant coral growth form found there. In the northwest this zone consists of a highly fragmented series of reef areas of diverse composition. From the northwest around the eastern end of the lagoon and along the outer half of the southern lagoon this zone is broad (175 m wide at the eastern end), but high variable. In general the landward portion of this band is an elevated flat platform with scattered small to medium sized coral heads with a lower density of large heads: large patches of Palythoa are common. See Table V-3 for a description of the head coral zone near the moorings; total coral coverage is about 10% (Fig. VI-4).

The outer portion of the band forming the inner boundary of the reef, consists of a dense array of large head corals including M. annularis and D. strigosa in particular (Fig. VI-1B, VI-4A). Particularly abundant and important in the areas surveyed(Table VI-2) are D. strigosa, D. clivosa,

P. astreoides, and S. radians. In other areas of the zone M. annularis is the dominant form. Coral coverage in the north part of this zone is 15-20%, while it is about 10% in the south. In the north, gorgonions are abundant,especially (Fig VI-3A) Briarium, Plexaura homomella, Pseudoplexaura sp. and Plexaurella sp. The shade loving Zoanthus sociatus covers extensive areas. There is also a high coverage of fleshy algae and mixed schools of grazing fishes (Fig. VI-3A) are often observed. Scattered colonies of A. palmata also occur in this zone, especially in the backreef areas of the north. In terms of visitor use, it is this zone which receives the heaviest swimmer traffic.

There are two principal areas of bare pavement, largely devoid (less than 1%) of coral cover and gorgonians. The first of these, forming the top of the south reef has 20-50% algal cover (Laurencia, Halimeda, filamentous greens and reds). In the northwest end of this island is an extensive bare pavement characterized at the time of the study by dense populations of the urchin Diadema antillarium.

Several zones are recognizable along the reef crest; dense stands of A. palmata dominate in the east and south (Fig. VI-2A) but in the northeast there are extensive areas of the encrusting zoanthid Palythoa caribbea (Fig. VI-2B) covering the tops of the A. palmata colonies. In the northern and western portions, the reef top is dominated by crustose coralline algae and Millepora (Fig. IV-2C). During low spring tides much of the reef crest is exposed aerially, especially the Millepora zone and secondarily A. palmata. Along the south reef many of the upper tips of A. palmata are dead and covered by algae. The reef crest is relatively broad in the east, a little less broad in the south and considerably narrower along the north. Whereas the east and south reef crests consist of dense stands of A. palmata intermixed with some Millepora, Palythoa and other minor contributors, along the north side the reef crest is a consolidated structure, quite steep on the outer and inner sides, probably constructed of dead A. palmata skeletons overgrown and consolidated by several feet of crustose coralline algae (especially Lithophyllum congestum). The cracks and holes provide shelter for many invertebrates including burrowing clams, chitons, snails, Echinometra, Tripneustes, Diadema and crabs and worms. The north reef crest is broken by a series of gaps, increasing in frequency and depth toward the west. Most of these gaps are extensions of the head coral zone. It is in the eastern part of this region that a second trail area could be established (see Chapter V).

The lower slope of the forereef covers the depth range of from 1-2 m to 9-15 m. In the east this slope is very gradual, giving rise to a very broad zone. It is somewhat narrower (terminating at 8 m) along the south side and is abruptly vertical along the north side. Along shallow eastern forereef the best developed stands of A. palmata occur. This is a relatively high energy zone and the individual A. palmata colonies have few large trunk-like branches, oriented perpendicular to the incoming wave fronts. These highly oriented large branches (reaching lengths of 2-3 m) can be readily seen in aerial photographs. In the east A. palmata dominates the forereef slope right to the bank at a depth of 10-15 m (Fig VI-3C). Along the south-reef there are distinct bands of coral running parallel to the reef axis. (Fig VI-3B). A. palmata extends from the surface to 3-4 m. The lower portion of this band has much Millepora alcicornis. Below the A. palmata M. alcicornis assemblage is a band of P. porites to a depth of 6 m then a broad band of predominately M. annularis and A. cervicornis dominates the lower fore reef which has a much shallower slope than the upper 6-7 m and gradually merges with the bank at a depth of 12-15 m. The forereef slope of the north reef (Fig. VI-4B) is very steep, vertical in places. The entire structure is heavily encrusted by coralline algae giving rise to a number of caves and grottos. Below the Millepora crest, discussed previously, is a band of A. palmata colonies. Flattened colonies of P. astreoides are prevelant and to a lesser extent Agaricia lamarki and Mycetophyllia ferox (Table VI-2). To the west the lower limit of the forereef slope becomes shallower (8 m). A number of medium sized head corals mark the lower limit ot the forereef slope in this region, especially Siderastrea siderea, Colpophyllia and Mussa.

The flat plain seaward of the reef is part of the St. Croix bank and consists of a mixture of carbonate pavement, superficial sands, and tall reef like structures (= haystacks). Five zones comprise this region: bare sand, seagrass beds, areas of poor coral cover, (bank: sparse) areas of rich coral cover (bank: rich) and the haystacks. Sand and grassbeds dominate the south bank area within the park boundary (see Chapter IX - Seagrass), with some A. cervicornis and M. annularis. The north bank is characterized by a large number of tall conical haystacks, dominated by A. palmata and with a vertical zonation similar to that of the adjacent forereef. In the areas of rich coral (Table VI-2) cover there is a high diversity of small to large head corals as well as numerous gorgonians of many species. Sea turtles are frequently seen over these bank zones.

FIGURE AND TABLE LEGEND - Chapter VI - REEF ZONES

Fig.1 - 4

Photographs illustrating features characteristic of the marine zones of Buck Island Reef National Monument.

1A Bare sand, bioturbated
1B Head coral zone - north bankreef showing large Diploria Strigosa heads
1C Acropora prolifera zone showing the dominance of this species in this zone
2A Acropora palmata crest; showing the dominance of this species in this zone.
2B Palythoa cap, growing on dead coral
2C Millepora dominating certain parts of the crest
3A Surgeon fish schools grazing in a head coral zone
3B Forereef slope - south reef
3C Forereef slope - north reef dominated by A. palmata
4A Head coral zone in the north dominated by Montastrea annularis
4B Forereef slope - north reef to the west showing cones and grottos
4C Head coral zone near the mooring area

Fig. - 5

Transects of the Buck Island reef. See Fig IV-1 for positions of these transects. The code under the contour is only meant to indicate the zone to relate the transects to the Reef Zone Map; it does not reflect the character of the underlying substrate.

Fig. - 6

Map of Buck Island showing the positions of the photographs projected to construct Reef Zone Map.

Table - 1

Species importance (i.e. % coral coverage) and distribution in the zones with heavy coral growth

+	present
++	greater than 8% of total coral coverage
+++	greater than 50% of total coral coverage

Table - 2

Species diversity (H based on % coral coverage), importance (% coral coverage) and abundance (i.e. frequency of sampling this coral in 100 random m^2 quadrats in this zone).

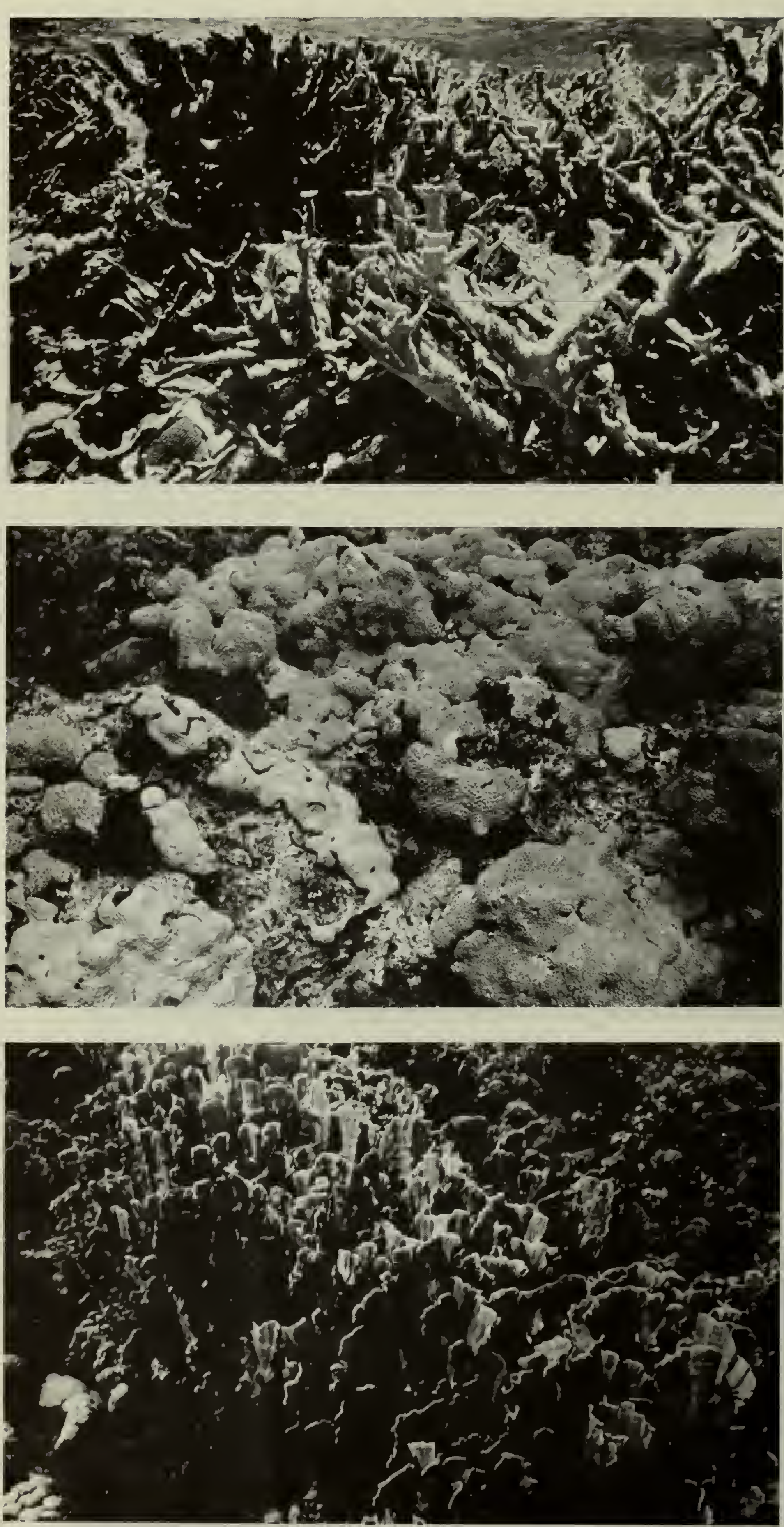
FIG. VI·1

A

B

C

FIG. VI·2

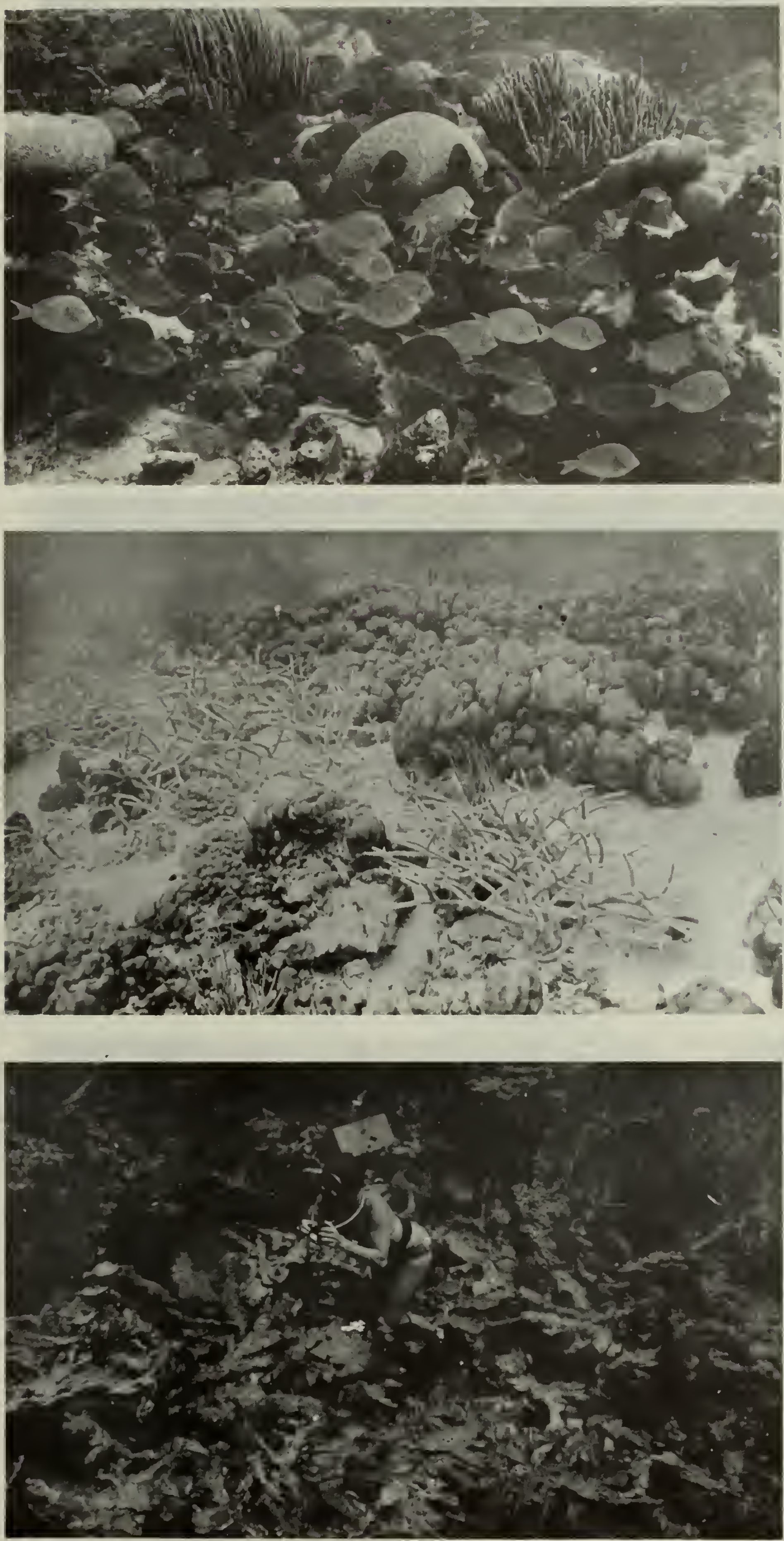


A

B

C

FIG. VI·3

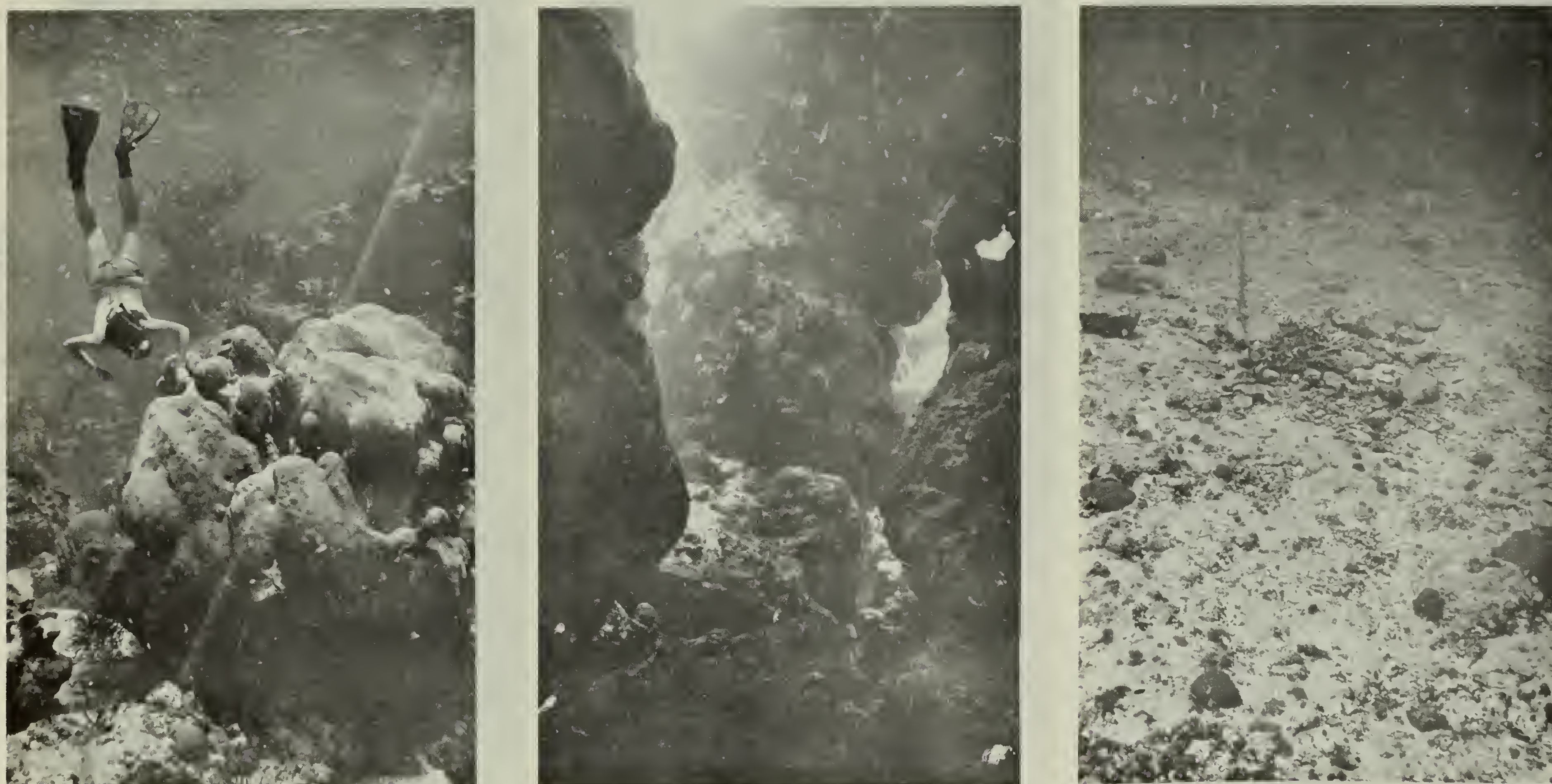


A

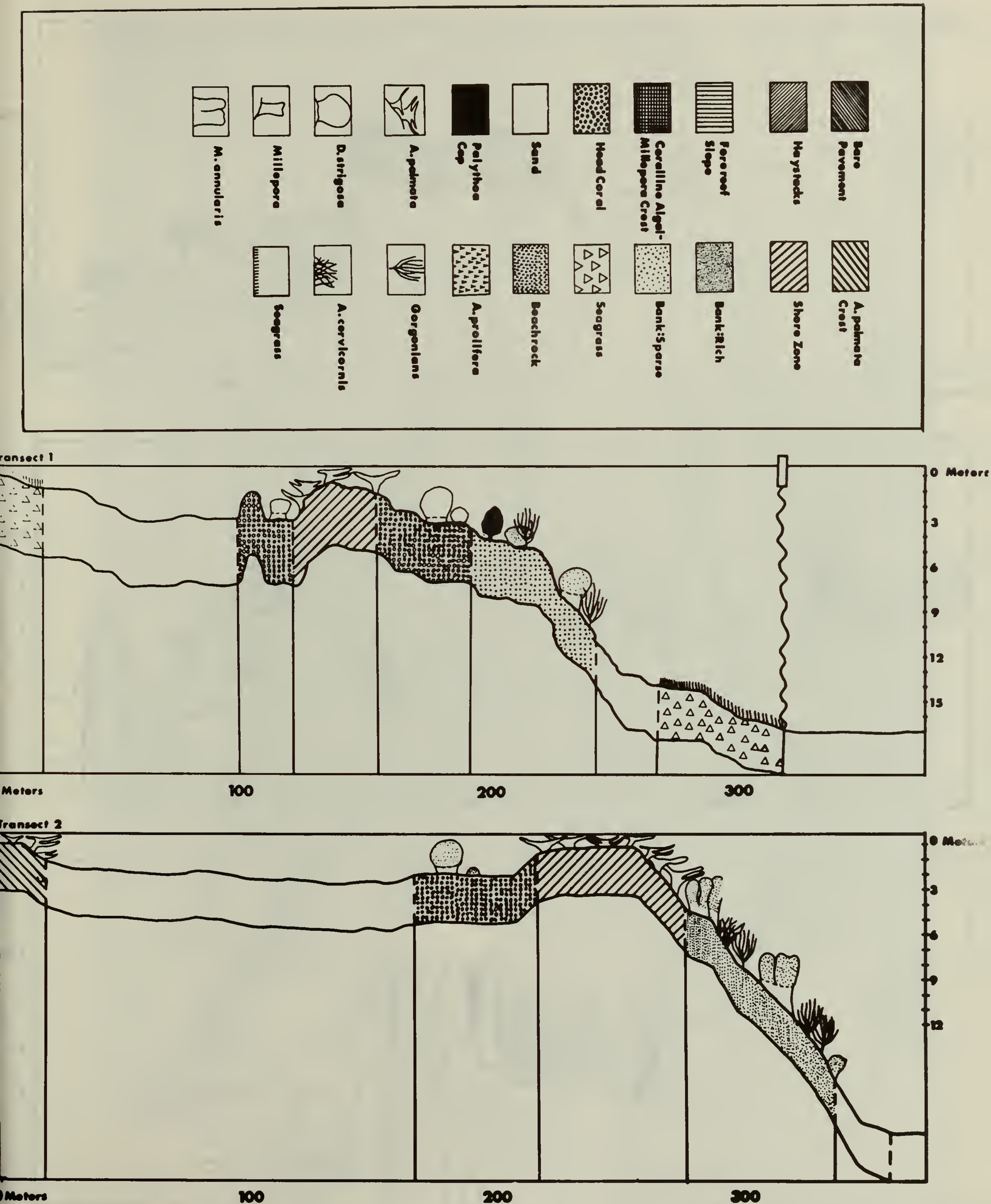
B

C

FIG. VI·4

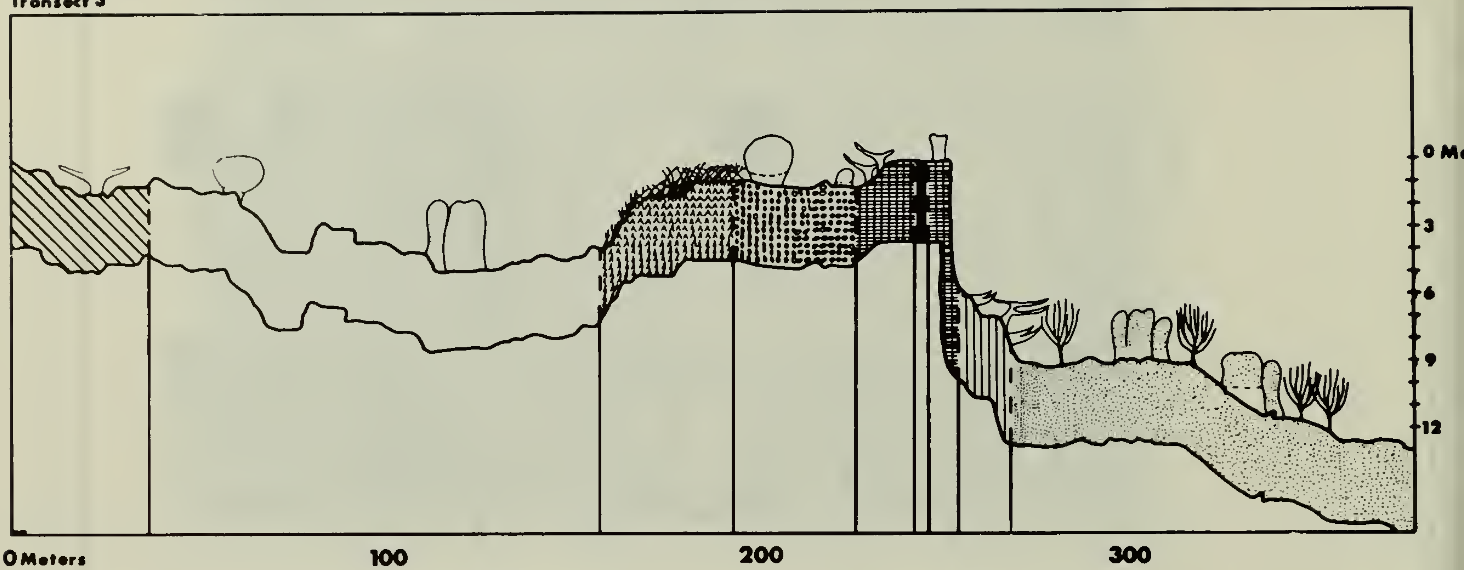


A B C

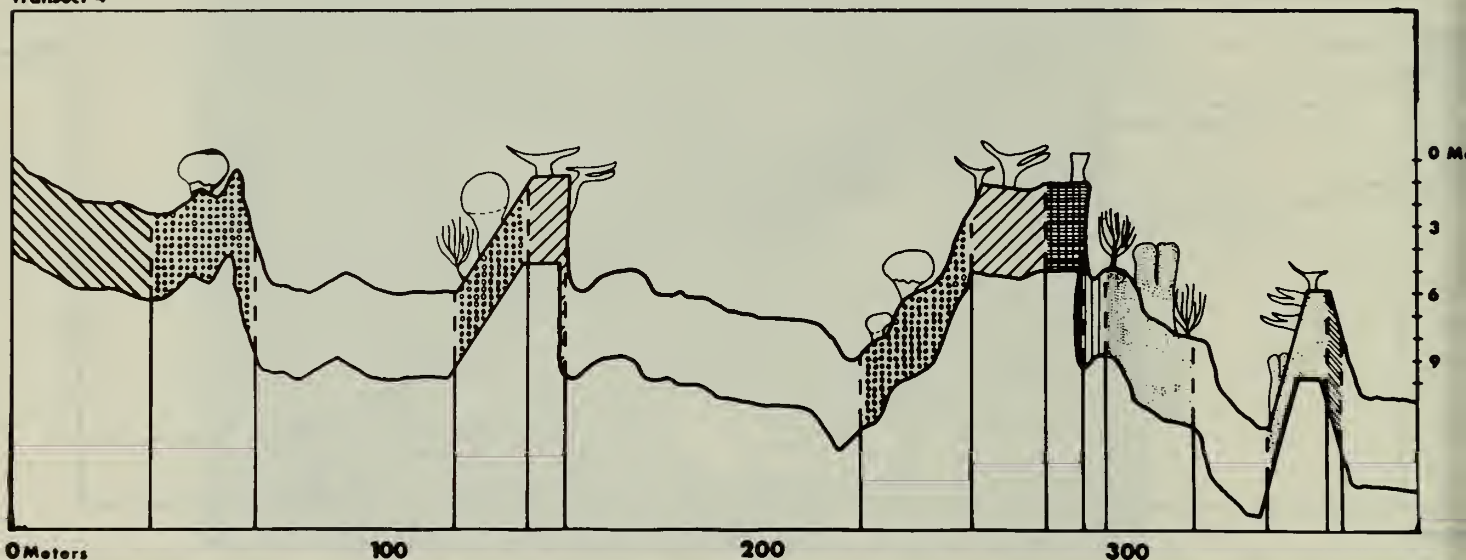


Bare Pavement
Haystacks
Forereef Slope
Coralline Algal-Millepora Crest
Head Coral
Sand
Palythoa Cap
A. palmata
D. strigosa
Millepora
M. annularis
A. palmata Crest
Shore Zone
Bank: Rich
Bank: Sparse
Seagrass
Beachrock
A. prolifera
Gorgonians
A. cervicornis
Seagrass
ransect 1
0 Meters
3
6
9
12
15
Meters
100
200
300
Transect 2
3
6
9
12
Meters
100
200
300

Transect 3



Transect 4



Transect 5

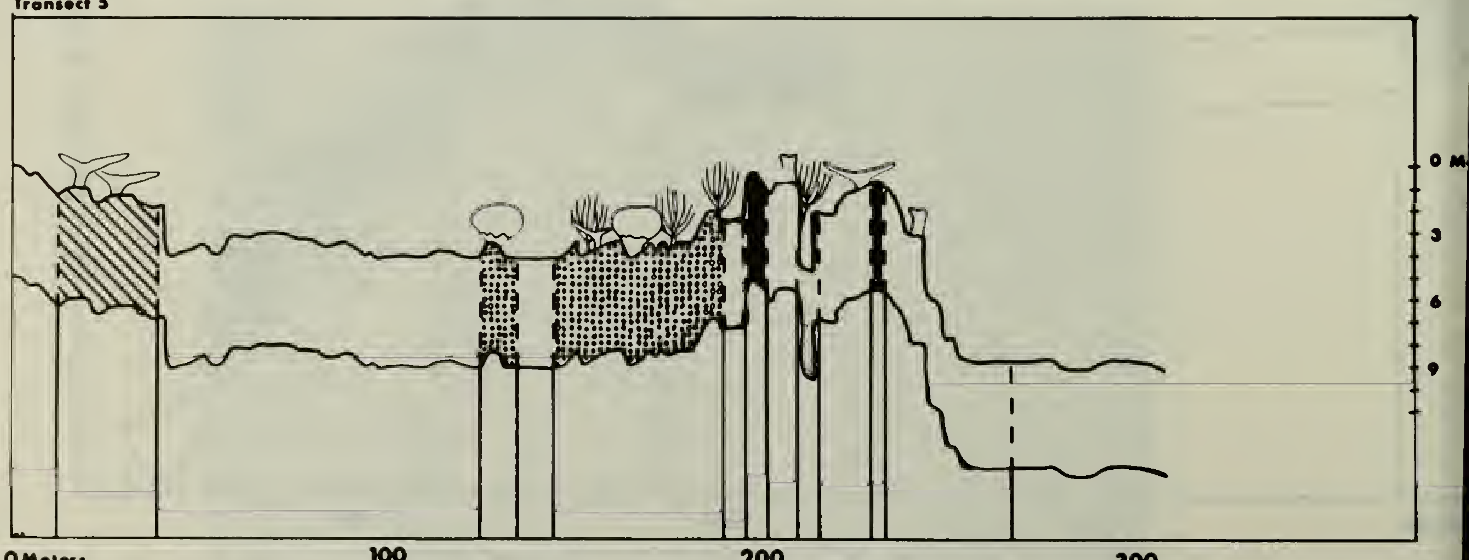


FIG. VI - 6

Scale 1:10,600

TABLE VI-1 Coral Species Distribution and Importance in the Reef Zones at Buck Island

SPECIES	SHORE		A.prol.	HEAD CORAL		REEF CREST		DEEP FR		BANK	
	n	s		n	s	n	s	n	s	n	s
Stephanocoenia michelini										+	
Acropora cervicornis			++						++	+	++
A. prolifera	+		+++								
A. palmata	+			+		+++/+++		+++	++	+	+
Agaricia agaricites	+	+	+	+	+	+	+	+	+	+	+
A. lamarki								+		+	
Helioseris cucullata						+		+		+	
Siderastrea radians	+	++		++	+	+			+	+	
S. siderea								+		++	
Porites astreoides	+	+	+	++	+	+	++	++	+	++	+
P. porites				+	+				+	+	+
P. furcata									+		
Favia fraga	+			+		+	+				
Diploria clivosa	+	+		++	++	+			+	+	
D. labryrinthiformis									+	+	+
D. strigosa	++	++		++	++	++	+	+	+	+	
Colpophyllia sp.				+				+		+	+
Manicina areolata	+										
Montastrea annularis	++			++	++	+				++	++
M. cavernosa				+					+	+	+
Meandrina meandrites									+		+
Dichocoenia stokesii	+	+		+		+			+	+	
Dendrogyra cylindrus									+		+
Mussa angulosa									+	+	
Scolymia sp.				+				+		+	
Isophyllastrea rigida				+					+	+	
Mycetophyllia ferox								+	+	+	+
M. aliciae										+	
Isophyllia sinuosa				++		+	+		+	+	
Eusmilia fastigiata									+	+	+

TABLE VI-2 Coral Species Importance and Abundance & Diversity Selected Areas of the Reef Zones

	%cover	freq.	#quad	H'	total coral cover	%cover-other organisms		freq.
SOUTH SHORE			15	1.84	6.92%			
P.astreoides	53	41				0.8	Palythoa	6
D.strigosa	23	18				00.0	Zoanthus	0
S.radians	14	41				22	Algae	94
D.clivosa	7	12						
Dichocoenia	1	12						
A.agaricites	1	12						
HEAD CORAL(n.cut)			20	1.80	18.09%			
D.strigosa	43.7	28				1	Palythoa	32
D.clivosa	39.8	34				10.9	Zoanthus	94
P.astreoides	8.2	36				5	Briarium	72
S.radians	4.3	76						
Colpophyllia	1.7	7						
A.agaricites	1.5	8						
Dichocoenia	.5	6						
Isophyllia	.3	23						
HEAD CORAL(s.reef)			20	1.68	11.75%			
D.strigosa	44	40				0	Palythoa	0
D.clivosa	40	50				0	Zoanthus	0
S.radians	8	10				11	Algae	80
P.astreoides	7	20						
FOREREEF SLOPE(n.)			20	1.36	43.70%			
A.palmata	70.5	64				0	Palythoa	0
P.astreoides	14.9	60				0.9	Zoanthus	15
A.agaricites	10.5	68				8	Millepora complanata	8
S.siderea	2.5	12						
D.strigosa	1.6	11				0.1	M.squarrosa	16
Dichocoenia	tr	4				0.4	M.alcicornis	4
						2	Briarium	38

TABLE VI-2 continued

	%coral cover	freq.	#quad	H'	total coral cover	%cover-other organisms		freq.
RICH BANK(n)			35	3.07	26.95%			
M.annularis	25.6	5				0.2	Palythoa	10
S.siderea	24.5	43				4	Zoanthus	60
P.porites	16.7	10				1	M.alcicornis	2
P.astreoides	5.9	53				4	Briarium	84
A.agaricites	5.6	65				1.6	Sea whips	50
D.labyrinthiformis	4.5	13				10.	Algae	60
M.ferox	3.7	18						
Colpophyllia	3.3	3						
D.clivosa	2.4	15						
A.cervicornis	1.7	10						
Isophyllia	1.5	14						
Isophyllastrea	1.5	5						
S.radians	0.8	13						
Dichocoenia	0.7	6						
D.strigosa	0.5	6						
M.cavernosa	0.4	8						
Scolymia	0.2	3						
Favia	0.1	7						
Manicina	0.07	3						
Mussa	0.07	3						
Stephanocoenia	0.04	3						

VII. CALCIFICATION

Objectives

Growth studies on several dominant species of scleractinian corals were done to determine (1) absolute growth rates under the extremes of annual temperature fluctuation found in the marine environment at Buck Island, (2) the relationship of coral growth rates to position on the reef, and (3) the contribution each species makes to the total calcium carbonate deposition on the reef.

As discussed in the previous chapter (VI-Reef Zones), living coral is a major component of the living coverage in Buck Island Reef National Monument. Living coral is an important source of primary production in the reef ecosystem (Chapter VIII - Primary Production), while dead coral provides substrate for other organisms as well as becoming pavement and sediment. Coral also forms the framework of the reef. Thus a knowledge of the growth of live coral, as well as a knowledge of the amount of calcium carbonate accrted by growing coral are important to a complete understanding of the coral reef ecosystem.

Methods and Materials

Five species of coral, dominant and/or widespread members of the coral community on Buck Island, were selected for intermediate term growth studies. These include *Acropora palmata*, *A. prolifera*, *A. cervicornis*, *Monastrea annularis* and *Porites astreoides*. Sites and dates of the staining studies are found in Table VII-1.

The corals were stained *in situ* by divers using SCUBA, with Alizarin Red S (Barnes 1972, 1973). A clear plastic bag containing about 20 mg of dye, secured in the corner by a twist tie, was placed over the tip of a branch (in the case of the *Acropora* studies) or over the entire colony (in the case of *Montastrea* & *Porites*). A thin "sponge" gasket was placed between the bag and the coral to prevent leakage of the dye and the bag was tied securely with cotton string. The final concentration of stain in the bag was 10-15 mg stain per liter sea water (Dustan, 1975). The staining bag remained on the coral for 24 hours (except *A. palmata*. in which case the bags only remained for four hours, and were removed). Each stained sample was labelled with an identifying plastic tag tied to the specimen with nylon monofilament. Staining was done in the fall, when the water temperature was greater than 29°C and in the winter spring when the water temperature was about 26°C.

To test the effect of variance in growth between and within colonies of *A. palmata*, five tips were stained per colony. Recovery from damage was tested by breaking one branch in each colony before staining.

After collection the corals were soaked in fresh water over night. All coral tissue was removed by a jet of fresh water leaving the skeleton pink where the dye had been incorporated and white where subsequent skeletal growth had occurred.

Growth was determined by several different methods depending on the form of coral:

A. palmata, A. prolifera, A. cervicornis: The linear extensions of new skeleton adjusted to a yearly interval was determined by making ten equally spaced measurements across the zone of new growth. Calcification rate was determined by removing the new skeletal growth with a saw and weighing it. For A. palmata this weight was divided by the size of the perimeter of the branch at the junction between the stained and the unstained intervals and again adjusting to a yearly interval. Calcification is thus expressed as weight of new skeletal growth per branch perimeter per year (g /cm/yr).

Montastrea annularis & Porites astreoides: These head corals, having a hemispherical growth form, were sectioned along the plane of the polyp axes with a rock saw to reveal the position of the Alizarin Red S band and then allowed to air dry. The section taken from the middle of the head, the site of apparent maximal growth, was used for growth analyses. The distance between the top of the dye line and the top of the polyp calyx was measured to the nearest 0.01 mm on a Bausch & Lomb dissecting microscope fitted with an ocular micrometer. A series of ten measurements spaced evenly across the top of the colony were made, and a mean skeletal extension rate calculated. Before sectioning a pair of calipers was used to measure the diameter of the colony in order to approximate the surface area of the head. Surface area calculation is based on an assumed hemispherical growth from where $A = 2\pi r^2$. One exception to this approach was the colonies of Porites astroides from the deep forereef, where the growth form was flattened platelike colonies. There, the surface area calculation was based on a two dimensional rectangular form.

In order to obtain a record of past coral growth and calcification rates, 17 cores were taken in large heads of M. annularis and analyzed for growth rate over the past eighteen years. These cores were taken by E.A. Shinn and H. Hudson of the USGS during December 1976 at 4 sites within and near the park: 1) in the north lagoon west of trail at a depth of 1'; 2) west of principal boat entrance to south lagoon at a depth of 10-12'; 3) south side of Buck Island channel on forereef at a depth of 20'; and 4) on the shoal reef just east of the part at a depth of 15-20'. The cores were taken by a diver-operated hydraulic coring device 4" in diameter. Cores about 1' long were returned to the laboratory and 1 cm slabs cut along the axis with a carbonate saw and X-radiographs made. Contact photographic positives were made from the negatives and three measurements were made between adjacent density bands (Fig. VII-1).

The distribution and abundance of the 5 species of corals is discussed in the Reef zones - Chapter VI. Colony form was determined for Acropora palmata and A. prolifera. Variations in the morphology of the branching Acropora species were determined in order to determine if the variation in the complex of environmental variables associated with each major region, Backreef (BR), Shallow forereef (SFR) or Deep forereef (DFR) plays a role in controlling gross colony shape and calyx distribution.

Colonies of A. palmata were measured with quadrats and measuring tapes to determine concentration of growing tips, and overall measurements of the colony. Branch length vs. basal width was determined for 25 shallow forereef branches. Polyp density was determined by counting the number of calices per cm^2 on 8 tips from each of the three reef zones. A cone cm^2 grid was placed 5 cm, 3 cm and 1 cm from the tip. The number of calices and condition (whether raised or flush to the skeleton surface) was determined for both the upper and lower surface.

Density of growing tips in the Acropora prolifera zone was determined by use of a 1/4 m^2 quadrat. Twenty-five quadrats were analyzed.

Results

Growth and calcification rates

Linear extension rates of the five scleractinian species (Table VII-1) are comparable to rates determined by other authors (Table VII-2). Acropora prolifera shows a decrease in linear extension rates during the cold water period (Table VII-1b) but not nearly so great a decrease in the amount of calcium carbonate deposited per tip thus indicating a difference in density of skeleton deposited during different periods of the year.

Acropora palmata (VII-1a) shows a similar pattern (i.e. a decrease in extension rates during the winter, but a similar rate of calcium carbonate deposition at all times of the year). Also there is a consistent difference in extension rates as a function of position on the reef. The deep forereef tips show the greatest extension rate, the shallow forereef an intermediate rate and the backreef the lowest rates of linear extension.

Three additional studies, utilizing linear extension rates were carried out using Acropora palmata. First, the effect of staining on growth rate was found to be negligible (Table VII-3). Second, a comparison of variability by means of analysis of variance (Appendix D-1) within and between colonies during staining studies reveals that there is almost as much variability within as between colonies. Only 2 of 16 colonies on the DFR, 4 of 7 on SFR and 5 of 17 on the BR do not show significant variability ($P < .05$) within the colony, and only the spring SFR study (1/20/77 - 4/5/77) does not show significant variability between the colonies. The third analysis was made to ascertain the response of Acropora palmata to damage by broken tips (due to storms, boats, or people). Arms with tips broken recover quickly be means of a new growth zone formed at the broken edge. This zone is conspicuous by its white color (in contrast to the brown zooxanthella-rich area proximal to it). This zone spreads over the broken area within a month after damage, growing over the green filamentous algae which settle and grow on the exposed area within days after breakage. After about one month the wound is healed and the tip begins to extend again. Within two months the extension of the broken tips is half that of intact tips (Table VII-4).

Polyp density varied both among zones and between upper and lower branch surfaces. The SFR colonies have the greatest density, BR colonies are intermediate number and DFR colonies the least (Table VII-5). At each site the density of calices on the upper surface was 1.6 - 1.9 times that of the lower surface. An examination of the growth form of the tip of the branch revealed that there were more raised calices in the newly deposited region than in the older region. As coral growth extends, radially outward calcium carbonate is deposited between these raised calices by connecting coral tissue, thus causing up to 1/2 the originally raised calices to become flush with the surface. This change in surface morphology of the tip was similar in all three areas. This basal deposition of calcium carbonate is also confirmed by the long term staining studies where the observed calcification rate (g/cm/yr) is twice as high as that derived from two month studies (App. D).. Differences in overall colony morphology between the different zones are presented in Table VII-6. Noteworthy is the tremendous subdivision of terminal branch tips in the backreef colonies, or to express it differently, the great decrease in branch tips in forereef colonies.

Rate of calcium carbonate deposition per m^2 reef was determined for the two corals which dominate their respective zones (in terms of % living coral coverage): Acropora palmata and A. prolifera in the following way. In order to determine the amount of calcium carbonate deposition by A. palmata per m^2 reef surface per year, values for the amount deposited by the growing tips, and that deposited by the basal epidermis of the remainder of the colony must both be determined. The following calculations are based on an area rich in the coral on the SFR and give average values of deposition in areas of average and maximum coral density.

1. There are about 12 tips/m^2 SFR reef, and each tip deposits about 15g$CaCO_3$ per year, therefore the growing tips contribute 180 g $CaCo_3$ per m^2 reef surface per year.

2. To determine deposition beneath the basal epidermis several values must be estimated:

a. Total surface area of living tissue in some areas of the SFR is as high a 3 m^2 per m^2 reef surface. For the following calculations a maximum value (based on 3×10^4 cm^2/m^2 reef) and an average value (based on 1.5×10^4 cm/m^2 reef) will be used.

b. Total deposition beneath the basal epidermis is determined by estimating the annual increment in basal thickness: the ratio of branch length to basal diameter (9:1) is divided by the average length of annual extension of the branch (6.5 cm) to yield an increase in basal diameter of 2/3 cm/year. This means the basal epidermis deposits a thickness of 1/3 cm/year.

c. Maximum value: 3×10^4 cm^2 x 1/3 cm = 10^4 cm^3 $CaCO3/m^2$ reef/year

average value: 1.5×10^4 cm^2 x 1/3 cm = 5×10^3 cm^3 $CaCO3/m^2$ reef/year

d. Using Bak's (1976) estimate of 1.5 for the specific gravity of *A. palmata* skeleton, this means that the total weight deposited beneath the basal epidermis is:

Maximum value: 15,000 g/ m^2 reef/year + 180g= 15,180 g

Average value: 7,500 g/ m^2 reef/year + 180g= 7,680 g

Adding the values obtained for the amount deposited by the growing tips (I) and the amount deposited by the basal epidermis of the remainder of the colonies (II), the total amount of CaCO3 deposition in a rich area of SFR is between an average of 7.68 kg and a maximum value of 15.18 kg per m^2 reef surface per year.

A. cervicornis colonies in the lagoon had an average of 362 growing tips per m^2 (S.D. = 122) for beds 2 - 5 m depth and 386 tips per m^2 (S.D. = 81) at platforms less than 2m depth. It is assumed that most calcification is due to growing tips; branches remain about the same thickness the entire length. Taking an average of 370 tips per m^2, and an average of 1.150 g per growing tip per year, this would yield a figure of 425 g $CaCO3$ deposited per m^2 A. prolifera per year. Monastrea annularis and Porites astreoides (Table VII-1 c, d) show similar growth rates during fall warm water and spring cold water periods, as well as similar rates with respect to reef position (i.e. back reef 2 m depth and deep forereef at 10 m depth).

Analysis of periodic density bands in the sections of 12 cores taken from M. annularis heads from 4 sites is summarized in Table VII-7. The average annual skeletal increment for all 12 cores was just less than 9 mm. There was no significant difference in average skeletal growth rate over the last 18 years at sites 1, 2 or 4. At site 3 (south side of Buck Island Channel opposite west boundary of the park) which was the deepest of the 3 sites and probably the site with the most turbid water, the average annual increment was somewhat less (7.3 mm/yr as opposed to 9.3 mm/yr). The average annual skeletal maximum increment found in any of the cores was 15 mm and the smallest increment was 4 mm (discounting local differences within one core e.g. see Fig. VII-1). When the skeletal increment of the 12 cores are ranked by year, beginning with the largest, there is no clear correlation between relative rank of the increments and a particular year so that the 100% variability in band width within any particular coral head can not be simply correlated with general environmental conditions prevailing a particular year. There is Lowever tendency for certain years to produce greater average increment in M. annularis than other years (Table VII-7). It might be instructive to refer to local weather conditions to see for example if the narrow bands were associated with particularly wet (hence high cloud/land cover) years and the broad bands associated with dry years; however the 2 years of lowest overall rank, 1975 and 1976 were not extremely wet years. 1964 and 1967 ranked highest in average growth increment. It is interesting to note that the growth bands measured for 1975 (7.54) and 1976 (7.33) are very similar to those measured in the two short term (5 mo) staining studies adjusted to yearly rates (7.60) and (7.64).

Conclusions and Recommendations

Acropora palmata is the dominant framework builder on the Buck Island reef, as it is on many windward Caribbean reefs (Adey, 1975). The rate of growth is similar to that reported by Shinn (1966) and this results in a calcium carbonate accretion rate of 7-15 Kg/m^2/year in the shallow forereef area where it dominates its environment. This rate is consistent with a vertical accretion of 8 mm/yr determined by McIntyre and Glynn (1974) and Adey (1975) by coring on other Caribbean reefs, and a maximum vertical accretion rate of 15 mm suggested by Adey (1976). This is much lower rate than that determined by Bak (1976) of 10^5 kg/m^2/yr and suggested by Chave, et al (1972), but these rates are almost certainly over estimates perhaps based on rates determined in young colonies. The accretion rate is much higher than that estimated for 4 windward reefs in the Pacific by Smith (1976) who used the flow method to measure changes in calcium ion concentration in sea water. It is felt, however, that the reefs he measured, although perhaps typical of most reefs, are not similar to the very high coral coverage (2-3m/m^2) found in A. palmata dominated reefs, but were a mixed assemblage of coral and other $CaCO_3$ depositors with a much lower surface area of activity depositing tissue.

In other areas of the reef where A. palmata is present, but not dominant, and coral coverage is much lower, the rate of calcium carbonate deposition is probably much lower: in the 1-4 kg/m^2 range given by Smith (1976). The A. prolifera zone has a rate of about .5kg/m^2/yr at Buck Island, which is comparable to lagoon flat measurements made by Smith (1976) in the Pacific. Montastrea annularis is important in certain areas of the park (such as the bank by the north reef - see Chapter VI), but it does not play a major role in reef formation, as it does in other deeper Caribbean reefs (Adey, 1976). Porites astreoides is very wide spread in all the reef zones, but it is a relatively small coral and thus it too does not have a major role in reef construction.

In summary, the present study supports the limited amount of previous work and emphasizes that Acropora palmata in shallow forereef areas comprises some of the fastest growing reefs in the world. It is therefore important that the stands of A. palmata in Buck Island Reef National Monument, which are probably the finest example of this type reef under the protection of a federal agency, be carefully monitored in the future.

FIGURE LEGEND - Chapter VII

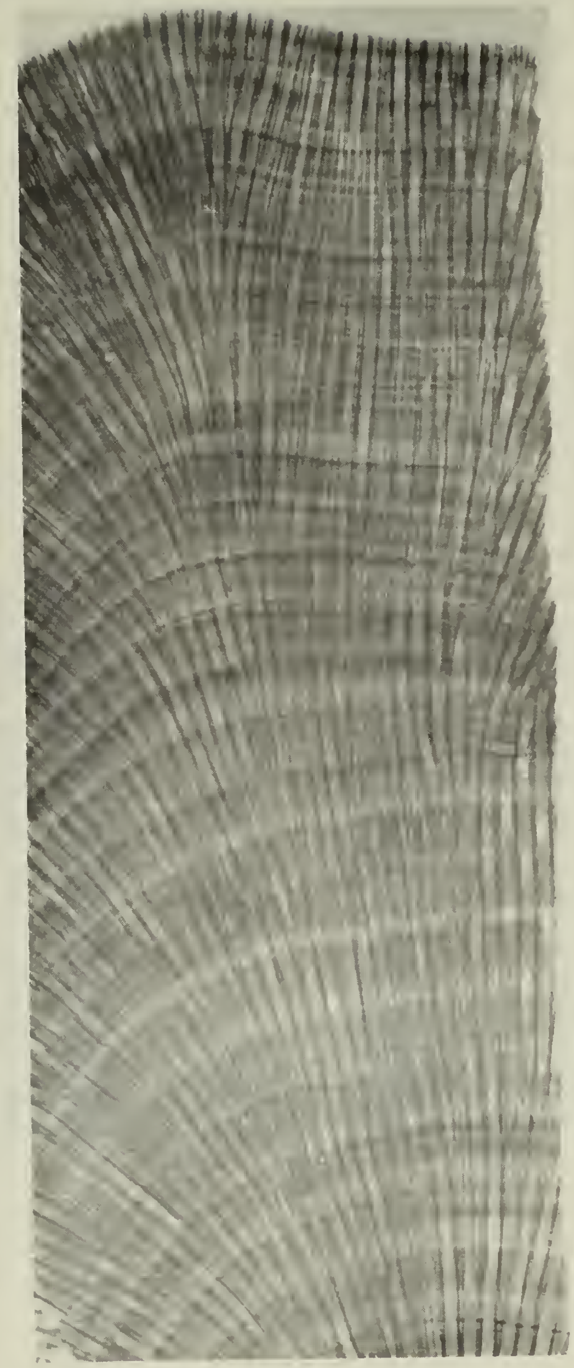
Fig. 1 - Positive prints of x-radiographs of sections of M. annularis cores.

A. Taken area #1: North lagoon; depth 12'
B. Taken area #2: Southwest lagoon; depth 12'
C. Taken Area #3: South Buck Island Channel; depth 20'

In particular, notice the variation in banding patterns in these 3 locations.

The high density band in A are very broad; the banding pattern in B is difficult to interpret; the band in C are well defined and evenly spaced.

A



B

C

TABLE LEGEND - Chapter VII

Table 1 a - d

Summary of linear extension rates adjusted to a yearly rate for all calcification experiments, listing zone, (BR-backreef, SFR shallow forereef, DFR, deep forereef) dates of growth after staining, and sample size. In addition, VII-2 gives the rate of calcium carbonate deposition in terms of $mgCaCO_3$ deposited per cm perimeter per year for the comparable 2 mo. studies in the three reef zones. VII-c & d give surface area of colony size.

Table 2

Summary of coral growth rates obtained in this study compared to those obtained by other workers in the Caribbean on the same species of corals.

Table 3

Effect of staining on colonies of A. palmata

Table 4

Broken tip analysis comparing the linear growth rate (during the period of staining) of a total of 4 broken tips to that of 3-4 normal tips from each of 4 colonies from each zone in Acropora palmata.

Table 5

Calyx number in Acropora palmata. A comparison of the density of raised and lowered calices on 3 positions on the upper and lower surfaces of branch tips from the 3 zones: 1 cm from the growing tip, 3 cm and 5 cm.

Table 6

Colony morphology and distribution. A comparison of the growth form and coral coverage of Acropora palmata colonies in the three reef zones studies.

Table 7-a

Montastrea annularis cores. Position and depth of the cores analyzed by x-radiography to determine rate of linear skeletal extension in M. annularis

Table 7-b

Annual Skeletal increments. A comparison of the linear skeletal growth rate of <u>Montastrea annularis</u>. This table provides the average annual increment of the 12 cores for each year, as well as the average annual increment for each area (Table V11-7a) for the past 18 years.

Table VII-1a

<u>ACROPORA PALMATA</u>

ZONE	DATES	N	mm/yr±1 S.D.	g/tip/yr ± 1 S.D.	$CaCO_3$ (g)/ cm/yr
BR	8/5/76- 9/30/76	12	58.5 ±21.5	6.62 ±5.23	.823 ±.491
	2/10/77- 4/5/77	14	55.4 ±15.3	7.42 ±4.13	.874 ±.195
	8/5/76- 1/7/77	17	69.8 ±22.3		
	10/8/76- 1/6/77	9	63.4 ±15.9		
SFR	8/3/76- 9/30/76	12	82.7 ±24.1	16.85 ±6.05	1.888 ±.684
	1/20/77- 4/5/77	8	47.3 ±11.5	14.80 ±4.29	1.320 ±.642
	8/3/76- 1/6/77	2	77.3 ±13.2		
	10/5/76- 1/7/77	3	41.7 ±15.5		
DFR	8/3/76- 9/30/76	12	99.3 ±24.3	20.07 ±10.39	1.385 ±.670
	1/20/77- 4/5/77	25	65.4 ±22.4	19.04 ±13.43	1.330 ±.379
	8/3/76- 1/6/77	13	81.0 ±20.6		
	10/5/76- 1/7/77	13	56.0 ±10.8		

Table VII-1b

ACROPORA PROLIFERA

ZONE	DATES	N	mm/yr±1 S.D.	$CaCO_3$(g)/tip/yr
BR	9/15/76 11/16/76	39	81.84 ±19.92	1.29
BR	1/11/77- 4/5/77	48	59.16 ±15.12	1.01

ACROPORA CERVICORNIS

ZONE	DATES	N	mm/yr±1 S.D.	$CaCO_3$(g)/tip/yr
FR	2/10/77- 4/5/77	6	71.04 ±15.60	1.01

Table VII-1c

MONTASTREA ANNULARIS

ZONE	DATES	N	Surface area cm^2 ± 1 S.D.	mm/yr ± 1 S.D.
Back-reef	8/12/76-11/10/76	14	-	8.52 ± 2.04
	9/2/76-11/10/76	5	-	7.68 ± 3.24
	1/13/77 5/6/77	14	96.30 ± 70.46	6.60 ± 1.80
	Zone means: ± 1 S.D.		-	7.60 ± .96
Deep Fore-reef	8/12/76-11/5/76	14	-	6.96 ± 1.92
	9/6/76-11/5/76	7	-	7.08 ± 1.92
	1/18/77-5/5/77	17	137.97 ± 84.97	8.88 ± 1.68
	Zone means: ± 1 S.D.			7.64 ± 1.08

Table VII-1d

PORITES ASTREOIDES

ZONE	DATES	N	Surface area cm^2 ± 1 S.D.	mm/yr ± 1 S.D.
Backreef	9/9/76-11/15/76	9	227.21 ± 85.04	3.96 ± 1.08
	9/13/76-11/15/76	10	132.87 ± 105.14	3.12 ± 1.80
	9/9/76 - 5/6/77	3	122.06 ± 19.03	3.36 ± 1.44
	1/13/77 - 5/6/77	12	149.95 ± 85.45	3.36 ± .48
	Zone means: ± 1 S.D.		158.02 ± 47.53	3.45 ± .36
Deep-Fore - reef	1/26/77 5/5/77	4	95.00 ± 39.92	3.00 ± .24

SUMMARY OF CORAL GROWTH STUDIES

* Adapted from Buddemeir & Kinsey
** Adapted from Landon

Montastrea annularis

AUTHOR	METHOD	LOCATION	GROWTH RATE	COMMENTS
Present 1977	real time field " " "	Buck Is. STX " "	.76 ± .96 cm/yr .764 ± .108 cm/yr	2m Backreef, N=33 Deep forereef 10 m N=38
* Vaughn, 1916	" " "	Florida	0.5 - 0.68 cm/yr	N=47
* Hoffmeister & Multer 1964	" " "	Florida	1.07 cm/yr	3 yr study
* Lewis, et al 1968	" " "	Barbados Jamaica	1.93 ± .84 cm/yr 2.50 ± 1.08 cm/yr	transplanted fragments
Present 1977	X-radiography	Buck Is. STX " "	.73 ± .20 cm/yr .88 ± .07 cm/yr	N=12 ave. 1976 N=216 ave. for 12 cores over 18 yrs
* Baker & Weber 1975	"	St Croix	.92 - 1.04 cm/yr	0-15m
* Aller & Dodge 1974	"	Jamaica	0.62 - 0.88 cy/yr	
** Macintyre & Smith 1974	"	Brit. Hon. Florida	0.66 - 0.87 cm/yr	N = 3
** Landon 1975	"	Florida Keys	.742 cm/yr	

Species	AUTHOR	METHOD	LOCATION	GROWTH RATE	COMMENTS
Acropora cervicornis	Present 1977	real time field	Buck Is STX	7.10 ± 1.56 cm/yr	10 m depth N=6
	*Shinn 1966	" " "	Florida (Station "A")	10.92 ± 1.64 cm/yr	
	*Lewis et al 1968	" " "	Barbados Jamaica	14.55 + 5.91 cm/yr 26.6 ± 12.88 cm/yr	
A. prolifera	Present 1977	real time field	Buck Is STX	8.2 ± 2.0 cm/yr	N=39 Fall, adj to yrly Backreef 2m
				5.9 ± 1.5 cm/yr	N=48 Spring, adj to yrly
A. palmata	Present 1977	real time field	Buck Is STX	5.5 - 7.0 cm/yr	ave, Backreef 1/2m 4 studies, N total = 52
		" " "	" "	4.2 - 8.2 cm/yr	ave, Shallow forereef 1/2 m 4 studies N Total = 25
		" " "	" "	5.6 - 9.9 cm/yr	ave Deep forereef 9m 4 studies N Total = 63
Porites astreoides	Present 1977	real time field	Buck Is STX	3.45 + .36 cm/yr 3.00 ± .24 cm/yr	Backreef, 2m; N=34 Deep forereef, 10m N=4

Table VII-3

EFFECT OF STAINING ON COLONIES OF A. PALMATA:

I. Deep Forereef

Mean linear skeletal extension: 8/3-1/6/77: 34.61 mm (S=10.23)

8/3-9/30/76: 16.16 mm (S= 3.77)
[9/30-10/5/76: 1.39 mm]
10/15-1/7/77: 14.66 mm (S=44.3)

32.21 mm

based on

$$\frac{16.16 \text{ mm}}{58 \text{ days}} = \frac{X\text{mm}}{5 \text{ days}}$$

(8/3/9/30)

8/3 - 1/7: 32.21 mm
(8/3-9/30 + 10/5-1/7)
8/3 - 1/6 34.61

II. Backreef

Mean linear skeletal ext: 8/5-1/7/77: 30.11 mm (S=10.11)

8/5-9/30/76: 8.93 mm (S=3.18)
9/30-10/8-76: 1.28 mm
10/8 - 1/6/77: 15.96

26.17 mm

based on approximation
(see above)

8/5-1/7: 30.11 mm
(8/5-9/30 + 10/8-1/6)
8/5-1/6: 26.17 mm

III. Shallow Forereef

Mean linear skeletal ext: 8/3-1/6/77: 33.5 mm (S=5.31

based on approximation
(see above)

8/3-9/30/76: 12.18 mm (S=3.52)
9/30-10/5/76: 1.05 mm
10/5-1/7/77: 10.90 mm (S=3.84)

24.13

8/3-1/6/77: 33.5 mm
(8/3-9/30 + 10/5-1/7)
8/3-1/7/77: 24.13 mm

Table VII-4

BROKEN TIP ANALYSIS
Linear Extension Rates - mm

DFR 8/3-9/30 1976 58 d

Colony #	Broken tip	Ave. colony (N=3-4) X	s
1	9.1	17.4	4.9
2	8.7	16.7	5.2
3	8.4	11.1	4.4
4	8.2	19.0	4.0
	N = 4 X = 8.60 s = .39	N = 12 X = 16.0 s = 4.0	

BR 8/5-9/30 1976 56 d

Colony #	Broken tip	Ave. colony (N=3-4) X	s
1	4.7	13.2	3.04
2	7.0	6.7	2.19
3	2.5	7.7	2.9
4		9.0	1.82
	N = 3 X = 4.73 s = 2.25	N = 12 X = 8.93 s = 3.62	

SFR 8/3-9/30 1976 58 d

Colony #	Broken tip	Ave. colony (N=3-4) X	s
1	5.3	16.8	1.99
2	4.1	9.65	1.6
3	7.4	8.07	1.86
4	7.5	12.9	2.16
	N = 4 X = 6.08 s = 1.66	N = 12 X = 12.18 s = 3.92	

Table VII-5

CALYX NUMBER

(Raised/Flush)

	Upper Surface			Lower surface		
cm. from tip	5	3	1	5	3	1
BR	80/131	102/28	127/45	87/25	97/23	107/16
total	211	184	172	112	120	123
SFR	165/126	193/79	172/41	122/35	136/20	150/15
total	291	272	213	157	156	165
DFR	61/114	76/95	93/48	51/35	50/36	59/25
total	175	171	141	86	86	84

Table VII-6

ACROPORA PALMATA

COLONY MORPHOLOGY AND DISTRIBUTION

	BR	SFR	DFR
# of colonies examined	4	5	9
Average # major branches	10.3	16	8.9
Growing tips/ colony	169	19	19
Tips/major branch	16.5	1.2	2.2
% surface area of reef, covered by live *A. palmata*	50%	85%	10%

TABLE VII-7

7a - Position of *Montastrea annularis* cores

DATE	CORE #	DEPTH	LOCATION
12/3	1-4	12'	West of trail,lagoon,NE reef
12/5	5-8	10-12'	West of boat cut, S reef
12/5	9-13	20'	PullPoint,St.Croix,forereef
12/7	14-19	15-20'	Shoal reef, just east BIRNM

7b - Annual skeletal increments in *M. annularis* (mm ± 1 S.D.) as measured between bands of maximum density

Year(of upper dense band)	Area 1	Area 2	Area 3	Area 4	Mean	Sum of Ranks
1976	6.5±1.5	9.0±0	5.7±2.1	8.5±1.8	7.33±2.01	62
1975	7.0±2.0	8.0±1.0	6.3±3.2	8.8±1.6	7.54±2.06	65
1974	8.0±0.5	9.3±1.2	6.7±2.1	9.3±1.3	8.33±1.64	47
1973	8.7±2.9	9.2±0.8	7.8±3.0	9.3±2.1	8.75±2.11	35
1972	9.7±3.8	8.7±0.6	7.3±3.2	10.2±2.4	8.96±2.62	35
1971	9.5±2.2	8.5±1.3	7.3±2.5	9.2±1.4	8.63±1.86	46
1970	9.3±3.2	9.5±1.3	6.2±1.3	8.5±4.0	8.38±2.70	48
1969	9.2±3.3	8.3±1.5	7.3±2.3	9.0±2.0	8.46±2.17	53
1968	8.5±1.8	8.8±1.3	7.2±2.5	9.3±2.9	8.46±2.06	50
1967	10.3±2.3	9.2±1.3	8.2±3.3	11.8±1.6	9.88±2.38	14
1966	10.3±2.5	9.0±1.0	7.7±2.1	10.7±2.1	9.42±2.11	21
1965	10.0±2.7	9.5±0.9	7.5±2.7	9.7±1.8	9.17±2.07	26
1964	10.7±3.8	9.5±1.3	7.8±4.5	10.2±1.0	9.54±2.83	13
1963	9.5±2.2	10.5±0.5	8.2±2.5	9.3±1.5	9.38±1.79	19
1962	10.3±2.3	9.8±1.3	7.7±3.6	10.0±2.7	9.46±2.45	17
1961	9.3±2.5	10.3±0.6	7.3±4.2	10.0±2.3	9.25±2.61	29
1960	9.8±0.4	8.8±1.4	7.7±2.9	8.0±1.7	8.45±1.84	43
1959	9.5±2.1	10.5±2.3	8.3±3.2	8.2±1.4	9.09±2.25	27
MEAN	9.23±1.13	9.24±0.71	7.34±0.72	9.40±0.94	8.80±0.68	

VIII. PRODUCTIVITY

Objectives

Coral reefs are highly productive areas in the relatively unproductive tropical seas. The contribution to this productivity by coral reef communities have been studied by Odum and Odum (1955) in Eniwetok, Kohn and Helfrich (1957) in Hawaii and others by using a flow method: measuring change in oxygen concentration in the water mass passing across a reef. Other workers (Kanwisher and Wainwright, 1967 and Roffman, 1968) have devoted their efforts to measuring the productivity of individual component coelenterate members of the reef community, finding (Kanwisher and Wainwright, 1967) that "individual coral heads may be as productive as any other organisms in nature".

In the present study on the Buck Island Reef Ecosystem, the flow technique for measuring community metabolism could not be employed, because of the lack of a necessary prerequisite, i.e. a steady flow across the reef (see Chapter III - Currents). Instead, the effort was directed towards determining the rate of primary production of the dominant member of the coral community, *Acropora palmata* (see Chapter VI - Reef Zones).

The objectives of the study were to:

1. determine the maximum rate of primary production in *Acropora palmata*

2. determine the effect of position on the reef, and the effect of temperature on this rate; and

3. determine the total amount of carbon which could be fixed by this organism and relate this to the total energy needs of the coral zooxanthellar symbiosis.

Methods and Materials

Experiments were run from 0900-1100 on sunny days during two periods: September 3 - November 3, 1976 and February 15 - March 14, 1977. The temperature was 29.5°C during the first period and slightly above 26° C during the second. The following procedure was followed for each run: 7 pieces of Acropora palmata averaging 50 cm^2 (35-85 cm^2) were carefully broken off with a rock hammer and placed in a mesh collecting bag. The pieces were carried back to the boat where each one was transferred under water to a 1000 ml jar filled with seawater. Each vessel was closed with a plastic screw top lid; care was taken to insure that no bubbles were trapped in the container. Six light bottles and one dark bottle were prepared for each run. Each coral piece was tested twice. The bottles were attached by string and rubber band to a wooden frame whose depth was regulated by means of an air filled float. For shallow water experiments the apparatus was attached by line to the back of an anchored boat; for deep forereef runs it was attached by line to a coral colony growing at the base of the forereef, or suspended from an anchored boat at the proper depth. Runs were made at the depth from which the coral was collected: 1/2 m for the backreef and shallow forereef samples and 9 m for the deep forereef.

Each experiment was run for 1/2 hour. At the end, 300 m were transferred by siphon from the experimental chamber to a 300 ml B.O.D. bottle. The sample was then fixed the manganous sulphate and an alkaline iodide solution for determination of oxygen content by the standard Winkler method (Strickland and Parsons, 1972). A sample of seawater was taken and fixed at the beginning of each run so that changes in oxygen concentration could be determined. The B.O.D. bottles were brought back to the laboratory where all titrations were performed between 1400-1700 on the day of the experiment. The pieces of coral were brought back to the laboratory to determine surface area covered by coral tissue; both top and lower surface areas were included.

Net productivity was determined by averaging the results of all experiments done at one position on the reef during one study period. The respiration rate was computed by averaging all the results for one study period, since the respiration rate did not vary with the position of the coral on the reef. Gross primary productivity was derived by adding the net primary productivity to the respiration. This figure reflects the total amount of energy fixed by the zooxanthellae.

Results

The rate of net primary productivity is significantly different ($P < .05$, Student's t) between the study sites in the fall warm water period (Fig. VIII-1) the SFR having the highest rate, the BR having an intermediate rate while the DFR had the lowest rate. During the cold water period, however, although the trend remains the same, only the SFR had a significantly higher rate ($P < .05$) than the BR and DFR. The BR had only a slightly higher rate than the DFR at this time.

In comparing the rates of net primary productivity (Fig. VIII-1) at the two annual extremes of water temperature, there is a trend for reduced production in the colder water. The mean productivity in all three zones is lower during the cold water (spring) period (significant to the $P < 0.1$ level at the BR site; to $P < 0.2$ at the SFR site and only slightly lower at the DFR site).

The respiration rate is also lower in the spring. The mean respiration rate for all three zones was 330 mg $O_2/m^2/hr$ (S.E. = 13, N=15) in the fall and 277 mg $O_2/m^2/hr$ (S.E. = 18.3, N=12) in the spring. This is different at the $P < 0.1$ level. The net primary production rates and the respiration rate therefore tend to show some degree of temperature dependence.

Once the rate of primary production was established, it was used to examine two other aspects of the metabolism of the coral-zooxanthellar unit. First, a P_G/R value was derived by dividing the maximum rate of gross primary productivity by the rate of respiration. A value of 2.0 would indicate that the symbiotic unit of coral and zooxanthellae were "fixing" exactly the same amount of energy in the form of organic carbon compounds as it was consuming in maintenance metabolism, assuming that a 24 hr day consists of 12 hours of light and 12 hours of dark. It must be made clear that the P_G/R values thus derived and applied to daily ratios are maximum values for the following two reasons: 1) a maximum rate of photosynthesis does not occur for a full twelve hour period; 2) the energy consumed is only that necessary for maintenance and does not take into consideration that necessary for growth and reproduction. Thus a ratio of 2.0 or slightly above, as a maximum derived value, does not imply that over a 24 hr day, solar energy fixed by the symbiotic algae, will be enough to meet the total energy requirements of the coral and contained zooxanthellae.

In Acropora palmata the P_G/R ratios range for 2.2- 2.9 (Table VIII-1) and do not vary with change in water temperature encountered in situ. The SFR had the highest ratio, reflecting the high rate of primary productivity of that site. The highest value derived 2.9 for SFR coral might indicate that the coral in this site is indeed functioning as a "plant", i.e. their sole energy source could be solar. However, the coral growing in the other two sites, and probably that of the SFR as well do require other energy sources also. Potential sources of this energy: plankton, bacteria and other microscopic sources, and dissolved organic material form the subject for further and future work. The P_G/R values measured for Acropora palmata (2.2 - 2.9) are within the range of values of the ten species of Caribbean scleractinians obtained by Kanwisher and Wainwright, 1967 (1.9 - 5.0) and those obtained by Roffman (1968) on nine species of Pacific scleractinians (1.7 - 5.0).

The second aspect to consider is the total amount of carbon which could be fixed by Acropora palmata (Table VIII-1). The values of 20-30 gm carbon per m^2 coral tissue per day, are again maximum, based on a maximum rate of photosynthesis for a 12 hour light period. However, there are 2-3 m^2 of living coral tissue per m^2 of rich A. palmata reef (see Chapter VII - Calcification), and therefore a value of about 25 g C/m^2 reef/day is very realistic. This means that a rich, healthy stand of Acropora palmata is as productive as very rich terrestrial areas.

Conclusions and Recommendations

Acropora palmata is an important contributor to the primary production of the Buck Island reef. Since the island probably receives little nutrient or dissolved organic supply from the ocean current in whose path it lies, it must depend in a large degree on fixing its own source of organic material through photosynthesis. The major sources of this primary production in the Buck Island marine ecosystem are the symbiotic algae in the corals, the free living benthic algae and the seagrass beds (see Chapter IX - Seagrass) which lie mainly downstream of the reef and thus probably do not contribute heavily to the productivity of the Buck Island bank barrier reef. Further work on the component productivity of these various sources would be of value in assessing the energy flow of this ecosystem, and the potential support in terms of energy available to higher levels in the food web.

FIGURE AND TABLE LEGEND - Chapter VII

Table - 1 Productivity values for <u>Acropora palmata</u>: 1) Gross primary productivity to respiration ratio, and 2) gross photosynthesis (i.e. the amount of carbon fixed per m^2 of <u>A. plamata</u> tissue per day). These values were determined at two times of the year for coral growing at the sites: BR - back reef; 1/2 m; SFR - shallow forereef; 1/2 m; DFR - deep forereef, 9m.

Figure - 1 Hourly rates of net primary productivity (± S.D) at two times of year of <u>A. palmata</u> from three sites on the reef.

Table VIII-1

PRODUCTIVITY VALUES

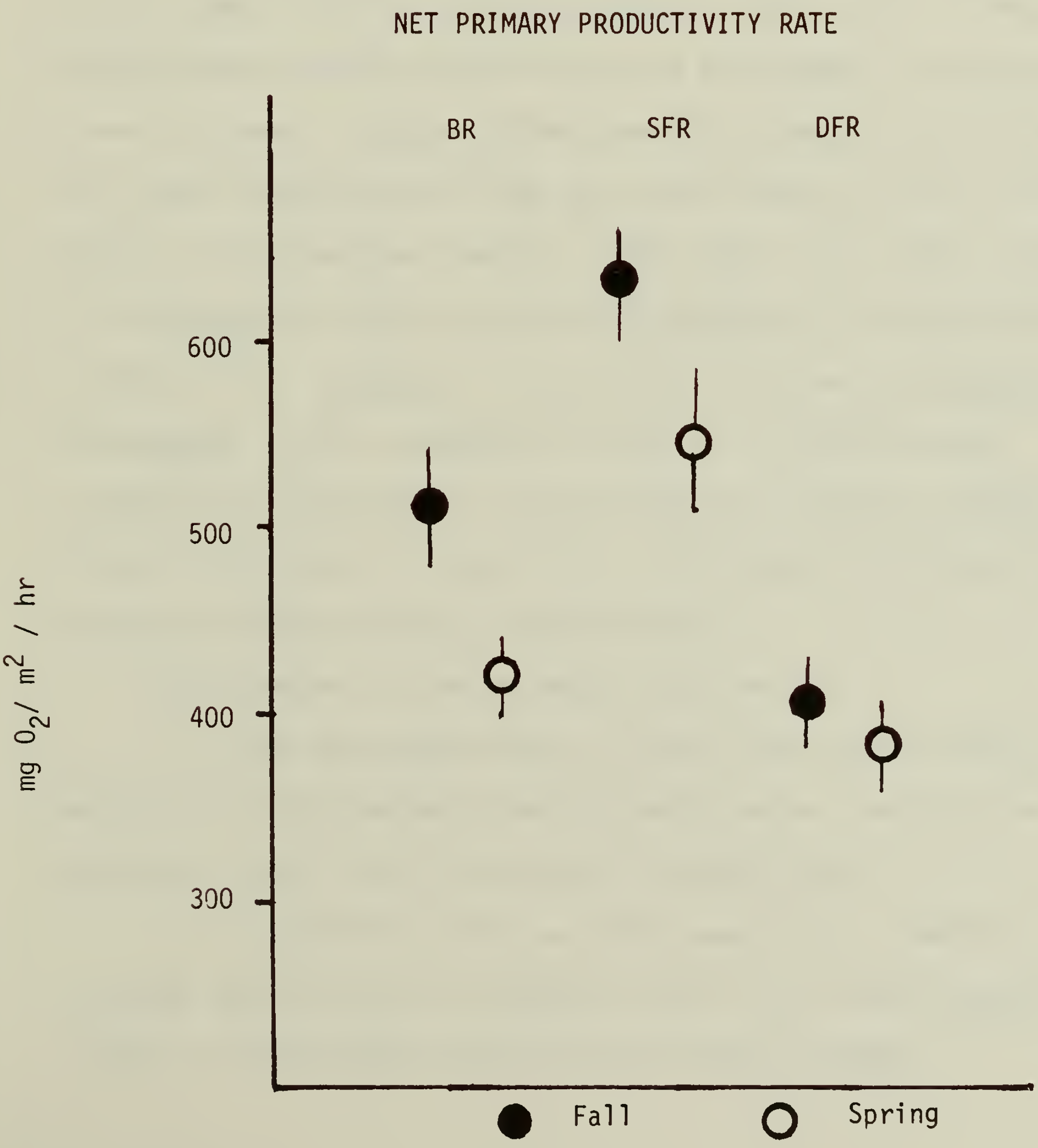
P_G/R Values

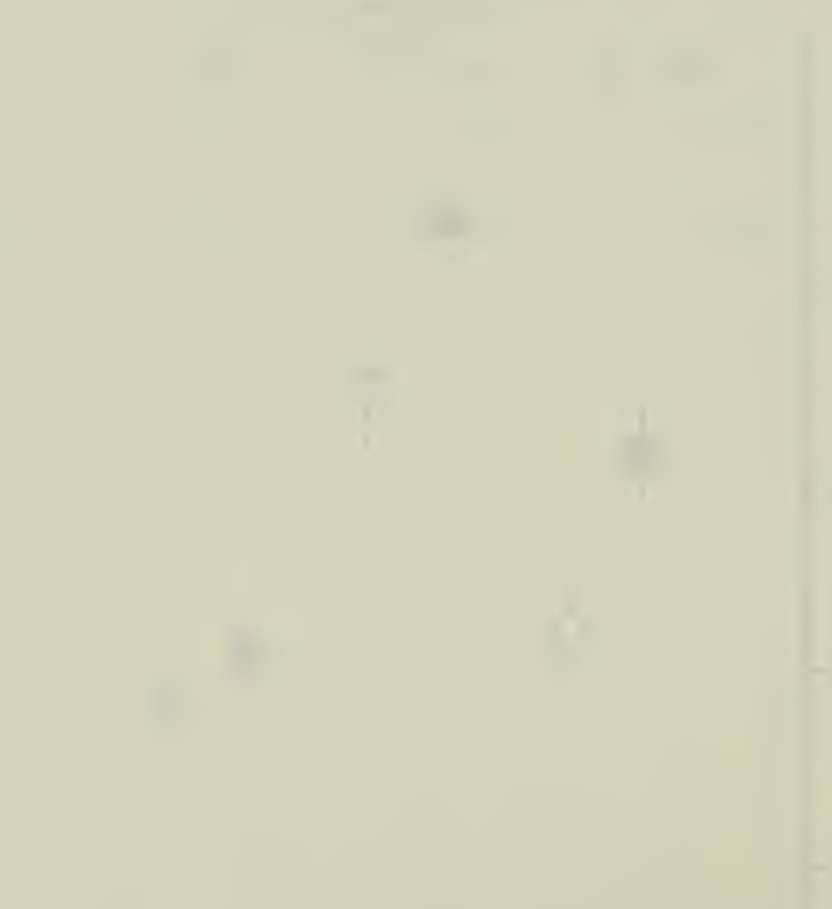
	BR	SFR	DFR
Fall	2.55	2.90	2.22
Spring	2.48	2.96	2.38

Gross Photosynthesis
(g C/ m^2/ day)

	BR	SFR	DFR
Fall	27.3	31.0	23.7
Spring	22.3	26.6	19.3

Figure VIII-1





IX. SEAGRASS

Objectives

Seagrass beds in the Caribbean are composed of mixed associations of marine flowering plants of three major species, *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass) and *Halodule wrightii* (shoal grass) (Phillips, 1960; der Hartog, 1970). They are most conspicuously associated with coral reef development in shallow water less than 10 m deep. On occasion they grow to the bases of nearby reefs, but are usually separated from them by a narrow band or 'halo' of open sand or heavily grazed seagrass (Randall, 1965; Ogden, et al. 1973). Below approximately 10 m *Thalassia* abruptly declines; *Syringodium* is the most dominant species to about 17 m. *Halodule* is often found intermixed with *Thalassia* and *Syringodium*, and in monospecific beds in very shallow water. Deeper sandy slopes may be covered with a fourth species of seagrass, *Halophila*, which grows in thin beds to at least 35 m. This species can also be found in particularly turbid areas in shallow water.

The objectives of the following study were to:

1) survey the seagrass beds of Buck Island and to draw a preliminary map of their distribution along the depth gradient running from the west end beach to the drop off just west of the NPS buoy.

2) to characterize the beds with respect to a) organisms living within and upon the sediments and seagrasses, and b) the large organisms such as fishes and invertebrates associated with the grass beds.

Methods and Materials

The major part of this survey was done on March 10-11, 1977 with support from the Spring, 1977 West Indies Laboratory class. Three long transects were run, using divers towed behind boats to get a preliminary picture of the distribution of major seagrasses. These details were later added to a map prepared from an aerial photograph, which showed the dark outline of the seagrass beds. Major sampling sites were selected and temporarily marked with buoys.

Seagrasses and associated macro-algae were collected by hand in a series of 10 x 20 cm quadrats. These were dried and weighed for standing crop determinations. Infauna and epifauna were collected with an airlift tube 8 cm in diameter and about 2 m long which was powered by means of a SCUBA tank. All sediment was removed from 2 or 3 quadrats, one m^2, and to a depth of several centimeters. This was then flushed through a 5 mm mesh bag. Smaller infaunal organisms were collected using a core tube 20 cm in diameter which was driven about 40 cm into the sediment. A core was then washed through a window screen mesh, and the organisms collected were characterized. Macroinvertebrates were counted by two observers within a circle 10 m in radius, laid out using a central stake and a 10 m chain. Fishes were counted by the visual observations of two swimmers who surveyed a quadrat of about 50 m to a side in a 1/2 hour sampling period.

Results

The distribution of seagrass beds in the western part of the monument was found to be quite patchy (Fig. IX-1). This disjunct pattern is probably related to the presence of scattered areas of hard bottom only thinly covered with sediment, which are unsuitable for seagrass development.

The shallow beds are largely Thalassia and Syringodium , but Halodule appears abundantly in patches at about 35' near the West End Buoy. There is a remarkable contact between Syringodium and Halophila at about 17 m (55'). Syringodium grows luxuriantly to a clearly defined edge, where it abruptly disappears and the bottom is then covered with Halophila which continues to grow to about 35 m (120'), which corresponds to the deepest known occurance of seagrasses.

The percent composition of the 4 sampling stations shown in Figure IX-1 are indicated in Table IX-1. Note that the shallow beds are composed primarily of mixtures of 2 species of grasses with some macro-algae, particularly Penicillus , a calcareous green alga, and Caulerpa, a fleshy green.

The air lift collections (Table 2) which sampled a 1 m^2 area, show a large percentage of gastropods The core collections (Table 3) are of a much smaller area (0.12 m^2) and do not sample the gastropods well. The polychaete worms, unsampled in the airlift device, dominate in the cores. The number of organisms decreases with depth because the deep seagrass beds are less dense and therefore contribute less organic material to the sediments and hence to the infaunal organisms.

A variety of sessile and motile invertebrates were sampled in the large circles(315 m^2) in each of the sites (Table 4). The queen conch (Strombus gigas) is abundant in the shallow seagrass beds and is extensively taken by local fishermen operating within and just outside the monument boundary.

Direct observation of fishes (Table IX-5) is difficult in seagrass beds since the observer provides a disturbance. There are also numerous night active fishes such as grunts, snappers, sharks and other carnivores which range widely over the beds. To a large extent the number of species associated with a seagrass bed is a function of the proximity of coral reefs. Note that many species appear to be limited to certain depths or seagrass communities; certain herbivorous parrotfishes are found only in the shallow Thalassia beds, while the garden eels burrow in the more open sandy Halophila beds in deeper water.

A recent study has revealed the presence of a series of grazing scars, made by the green turtle, Chelonia mydas, which have been observed feeding in the area (Fig. IX-1 Section A).

Conclusions and Recommendations

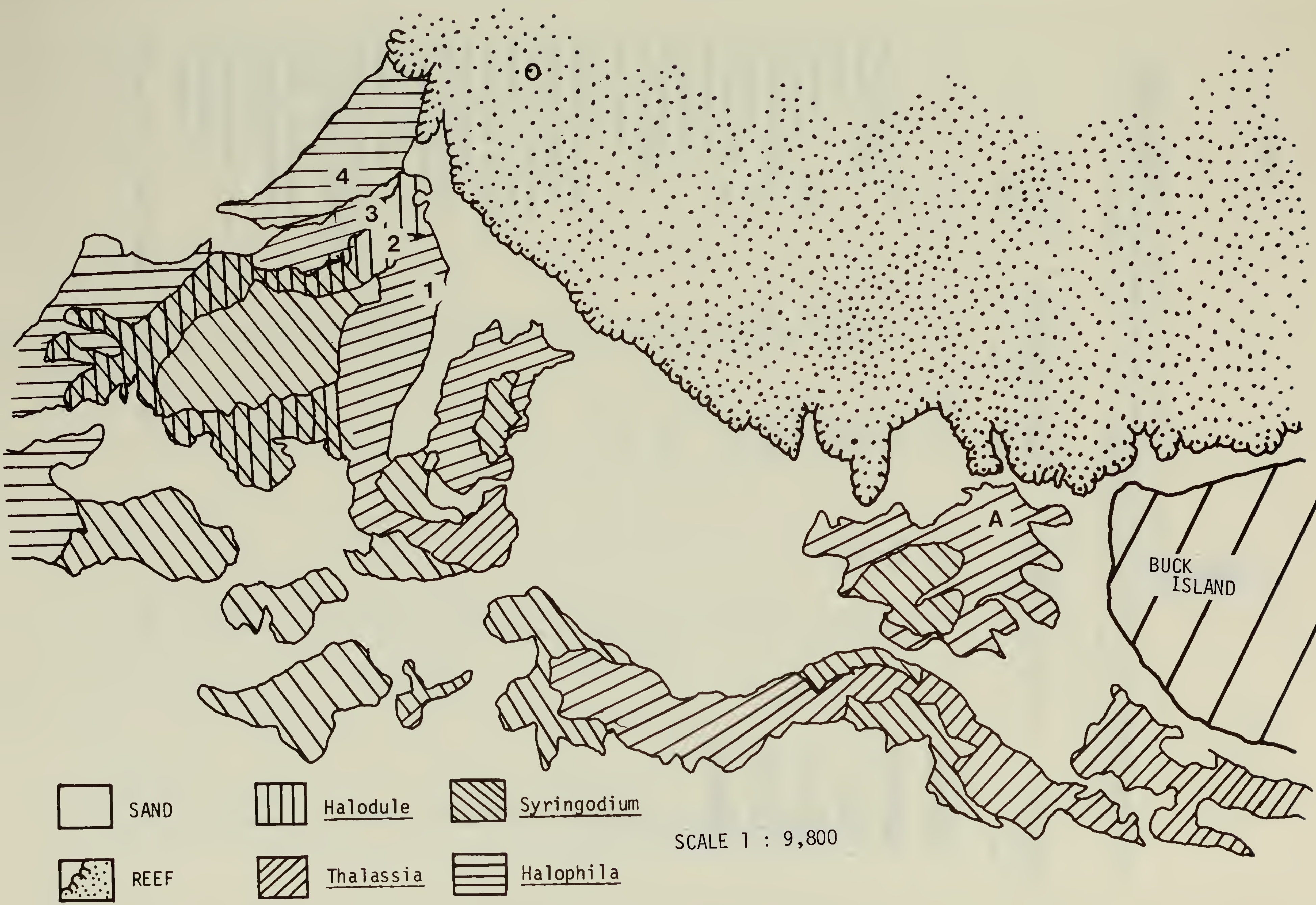
The seagrass beds of Buck Island are an important aspect of the natural history of the region, and represent a valuable natural resource. The high growth rate and high turnover of the densely packed plants of the seagrass beds creates a storehouse of organic material that nourishes a food chain of great complexity. The infauna and epifauna of grassbeds is exploited by a variety of reef fishes which move into the grassbeds to feed at night, returning to the reef at dawn. In addition the grassbeds provide shelter and food for numerous juvenile fishes, which then move onto the reef with maturity. The beds are also visited periodically by large predators, such as barracuda, sharks and mackeral which hunt their prey found there.

Seagrass beds of Buck Island, with their dramatic depth gradient briefly examined in this report will be the subject of intensive work on the part of the Seagrass Ecosystem Study (West Indies Laboratory) during 1978.

Further work is necessary to determine the importance of seagrasses to the productivity of coral reefs (see Chapter VIII), and to examine the sensitivity of seagrass beds to human impact, particularly in high use areas such as the West End Beach at Buck Island.

FIGURE AND TABLE LEGEND - Chapter IX

FIG. IX - 1


4
3
2
1
A
BUCK ISLAND
SAND
REEF
Halodule
Thalassia
Syringodium
Halophila
SCALE 1 : 9,800

Percent composition of standing crop(dry weight) of seagrass beds on the West end of Buck Island. Samples based on 10 x 20 cm quadrats.

	Station 1 25' n=5	Station 2 35' n=6	Station 3 50' n=7	Station 4 60' n=9
Thalassia	71%	3%		
Syringodium	10%	19%	1%	1%
Halodule	18%	61%	69%	
Halophila			6%	97%
Penicillus		15%	22%	
Caulerpa				2%

TABLE IX-2

Infaunal and epifaunal organisms collected with an airlift. Sample area = $1m^2$

	Thick *Syringodium* 35' n=3		Sparse *Syringodium* 50' n=2	*Halophila* 60' n=2
	x	± 1S.D.	x	x
Polychaetes	27	26.8	14	4.5
Hermit crabs	4.6	1.5	15	1
Crabs	18.6	4.6	22	10.5
Shrimps	18	20.8	7	8.5
Lobsters	0.3	0.57	0.5	1
Other decapods	1.6	0.57	4	5
Chitons	0.6	1.1	0	0
Pycnogonids	0.3	0.57	0	0
Asteroidea	0		1	1
Ophiuroidea	15.6	10	1	0
Echinoidea	0.6	0.57	1.5	0
Holothuroidea	0		0.5	0
Sea hares	1.3	2.3	1	0
Bivalves	1.6	1	11.5	17.5
Banded Dove Shell	0		8	1
Emerald Nerite	2		2	0
Small false Donax	0		3.5	0
Bavay's Scallop	0		1	0
Polka-dot Pheasant	1		16	0
Dwarf Nassa	0		1	0
Milk moon shell	1		1.5	0
Paper bubbles	0		1.5	1
Buccinidae	0		0	1
Beaded Phos	0		0	2
Puerto Rican Phos	0		0	1.5
Cerithium litteratum	4		0	0
Lined Phos	0		0	1.5
Other gastropods	15.6	10.0	7	8
Cephalochordates	0.3	0.57	1	0
Amphioxus	1	0.57	0	0
Scorpianfish (juv.)	0		25	1
Pikeblenny	0		0	1
Dragonet	0		0	1
Total # of Individuals	113.3	67.6	122	68

TABLE IX-3

Infaunal and epifaunal organisms collected within a 20 cm core

	Thick *Syringodium* 35' n=5			Sparse *Syringodium* 45' n=1		*Halophila* 60' n=2	
	x ± 1	S.D.	%	x	%	x	%
Polychaetes	4.4	3.4	15	4	33	9	53
Spider crabs	1.4	0.89	5	0	0	1	3
Shrimp	0.4	0.55	1	0	0	0	0
Amphipods	0.6	1.34	2	0	0	0.5	3
Worm tubes	5.2	9.55	18	0	0	0	0
Sipunculids	0.2	0.45	1	1	8	0	0
Ophiuroids	0.6	1.34	2	0	0	0.5	3
Echinoids	0.2	0.45	1	0	0	0	0
Cerithium algicola	3.2	4.66	11	0	0	0	0
C. litteratum	5.4	2.2	19	0	0	0	0
Murex sp.	0.2	0.45	1	0	0	0	0
Turbo sp.	1.4	1.67	5	0	0	0	0
Green gastropods	1.2	1.79	4	1	8	1.5	3
Other gastropods	2.6	4.34	9	4	33	3.5	21
Bivalves	0.4	0.55	1	1	8	0	0
TOTAL	23	24.55		12		34	

TABLE IX-4

Macroinvertebrates/100 m^2 recorded in a 10 m radius circle

	Thalassia (30') n=3			*Syringodium* (45') n=1		*Halophila* (60') n=1	
	x ± 1	S.D.	%	x	%	x	%
Sabellastarte	0.2	0.2	4	1.3	6	4.4	8
Serpula	0		0	0	0	2.2	4
Sponge	0.6	0.7	11	5.4	25	13	24
Sea fans	0		0	1.3	6	0.9	2
Other gorgonians	0		0	6.7	30	15	27
Zoanthids	0		0	0.3	1	0	0
Condylactis	0		0	0.9	4	0.3	1
Ophiuroids	0		0	0	0	1.6	3
Strombus gigas	4.5	1.3	81	1.9	9	1.3	2
Bivalves	0.2	0.2	4	0	0	0	0

TABLE IX-5

Fish Census of the Seagrass Community,
West End, Buck Island
50 m quadrat

Species-Common name	30'	40'	50'
Bucktooth parrotfish	20	0	0
Queen parrotfish	1	0	0
Rainbow parrotfish	1	0	0
Rosy parrotfish	3	0	0
Slippery dick	2	5	0
Bluehead wrasse	0	4	10
Cleaning goby	0	15	0
Red hind	0	1	0
Harlequin bass	0	1	0
Green razorfish	22	0	0
Pearly razorfish	10	2	0
Spotted goatfish	32	0	0
Buffalo trunkfish	1	0	0
Lizardfish	1	0	0
Squirrelfish	0	4	0
Bicolor damsalfish	0	50	50
Queen angelfish	0	1	0
Bar jack	0	1	8
Soapfish	0	1	0
Flying gurnard	0	1	0
Sand tilefish	0	0	3
Ocean surgeonfish	0	0	11
Southern stingray	0	1	0
Garden eels	0	0	100's
TOTAL # SPECIES	10	13	6

X FISH COMMUNITY

Objectives

The varied colorful fishes found in the shallow waters of the park constitute one of the major attractions for visitors. The species composition and abundance of this fish community was analyzed for 4 areas of the park using visual censusing techniques. The principal objectives of this study were:

1) To provide an overall faunal list of fish species found in the 4 major reef zones frequented by visitors.
2) To compare the fish assemblages in these different zones to determine which fish characterize each zone and where various species are most likely to be found in the park.
3) To provide a baseline of fish abundances in different areas for future comparisons.

Methods

Visual censuses were carried out at the four principal locations for durations of 1/2 or 1 hour using SCUBA. Diurnal and nocturnal censuses were done. The areas censused were:

1 The underwater trail

2 The back reef and lagoon

3 The reef crest

4 The deep forereef and bank bottom

Fish species observed were ranked in abundance categories I-V for both juveniles and adults:

I: 1 individual/census

II: 2-10 " "

III: 11-20 " "

IV: 21-50 " "

V: greater than 50 individuals/census

The 111 species of fish observed during the day are summarized in Table X-1. The overall composition by species and abundance rank is comparable in the four areas (Fig. X-1). Indices of similarity calculated comparing the fish assembleges of the 4 reef zones (Fig. X-2) reveal that though there is much overlap in fish species in the different zones, there are a number of differences as well. The most important of these differences are summarized below:

1. Diurnal planktivorous fishes are generally restricted to the fore-reef areas, because of the much greater availability of zooplankton food outside the reef. These fishes are generally abundant outside the north and south reefs forming large single species or multispecies schools that are sometimes stationary, but sometimes range widely along the reef front. These fishes generally do not venture more than 30 meters off the reef. This group includes *Inermia vittata* (Boga)

* *Chromis cyanea* (Blue chromis)

* *C. multilineata* (Brown chromis)

* *Abudefduf saxatilis* (sargeant major)

Clepticus parrae (Creole wrasse)

Melichthys niger (Black durgeon)

The three species of pomacentrids (*) are also found just inside cuts through the reef crest, as on the trail area, but never in the lagoon proper.

2. A number of species are restricted to particular habitats rather than particular zones. The most important of these habitats are stands of A. palmata and caves formed in the coralline algal ridges. Stands of A. palmata harbor particularly dense groups of fish including many crepuscular and nocturnally active species including grunts (Pomadasyidae), snappers (Lutjanidae) and squirrel fishes (Holocentridae). The caves harbor larger members of these latter groups as well as a number of other groups such as large basses (Serranidae), sweepers (Pempheridae), chubs (Kyphosidae) and large urchin-eating grunts (Pomadasyidae) such as the black margate (Anisotremus surinamensis) and the spanish grunt (Haemulon macrostomum). Other specialized habitats include the bare sand areas of the inner lagoon and barren reef pavement areas where the sand tilefish (Malacanthus plumieri) is found, and vertical walls and overhanging ledges inhabited by the fairy basslet (Gramma loreto).

The underwater trail area appears to have fewer species and lower abundances than the other zones. This is directly attributable to the small size of the trail area compared with the size of the area sampled in other censuses (often 500 m X 20 m). The fish population of the trail area and adjacent mooring zone is at least as concentrated as comparable areas to the west and north along the reef. The only change in species composition noted and due primarily to people, is the high abundance of yellow tail snappers in the lagoon area, around the moorings, which are attracted to the free food. There are other fish which also occur in higher abundances here than elsewhere (ballyhoos, houndfish) but this is probably due to the configuration of the reef at this point rather than man's influence.

In terms of the trophic composition of the fish community, most notable is the abundance of herbivores (parrotfishes, surgeonfishes, damselfishes and chubs) and the large carnivores (snappers, basses) when compared to other similar reef environments on eastern St. Croix. Also noteworthy are the relatively high abundances of urchin eating species (black margate, spanish grunt, caesar grunt and queen triggerfish). Three factors appear to be responsible for the latter: (1) the abundance of available food (Diadema antillarum); (2) the restriction on fishing these large choice species; and (3) the availability of choice habitat for the first two species (i.e. caves). When compared with other similar reefs on St. Croix there is a notable reduction in the number and abundance of small omnivorous and invertebrate eating fishes, causing the overall species diversity (though not abundance of individuals) to be relatively low in the eastern part of the monument.

Several nocturnal censuses were carried out in the vicinity of the trail and 13 species not observed during diurnal censuses were counted Table X-2. Though the number of species of night-active fishes is much lower than the number of day active species here as well as on other St. Croix reefs, elsewhere the total abundance of nocturnally active fish is comparable to the abundance of diurnally active species. At Buck Island, however, the abundance of nocturnally active fish is much less than that of day active species.

The effect of fish predation on living corals is discussed in the Chapter XI - Destructive Agents.

Conclusions and Recommendations

In general the fish community at the eastern end of Buck Island consists of relatively large individuals, a high abundance of individuals but low species diversity. The number of species seen at Buck Island is high, but a great number of these are represented by one or at most only a few sightings over the course of the year. The high abundance of individuals is due to a few very common species (such as several species of parrotfishes, several species of damsalfishes, and several snappers). Certain trophic and taxonomic groups are particularly well represented because of the abundance of food or available shelter and also because of protection from fishing. The possible effects of such protection on balance within the coral reef community are discussed in Chapter XI - Destructive Agents and Chapter XIII - General Conclusion.

FIGURE LEGEND - Chapter X

Fig. 1 - A comparison of half hour-long and hour-long fish censuses in four different areas of the Buck Island reef. The fish were broken down into the number of groups* with 1) 1-10 individuals, 2) 11-50 individuals, and 3) greater than 50 individuals. A group* corresponds to a species with one exception; adults and juveniles of the same species were counted separately. Values plotted are mean values plus or minus one standard deviation.

Fig. 2 - This shows the overlap of species between each of the zones sampled.

Table 1 - A list of the species of diurnal fish found at Buck Island National Monument. Each species is assigned an abundance value based on what could be seen during an hour-long census covering a distance of approximately 500 meters. All individuals are adults (A) unless otherwise indicated (J=juvenile).

Key to abundance values

1:	1 individuals	Tr	= Trail
11:	2 - 10 individuals	Br	= Backreef
111:	11 - 20 individuals	RC	= Reef Crest
IV:	21 - 50 individuals	FR	= Deep Forereef
V:	greater than 50 individuals		

Table 2 - A list of fishes seen during one 1/2 hour nocturnal census at the underwater trail, Buck Island. Abundances listed are the same ranking as the diurnal counts.

Figure X-1

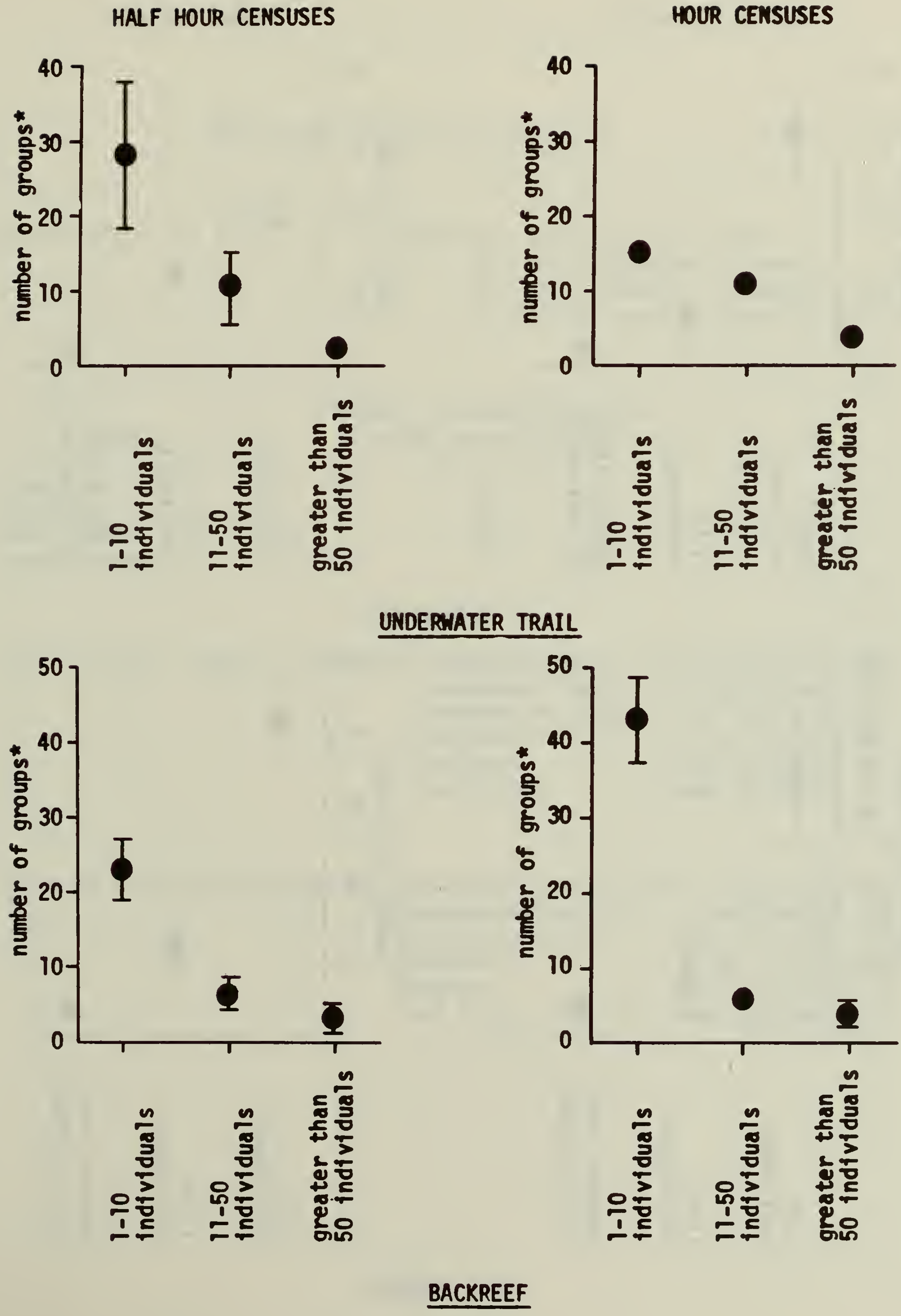

HALF HOUR CENSUSES
HOUR CENSUSES
number of groups*
0
10
20
30
40
50
1-10 individuals
11-50 individuals
greater than 50 individuals
UNDERWATER TRAIL
BACKREEF

Figure X-1 continued

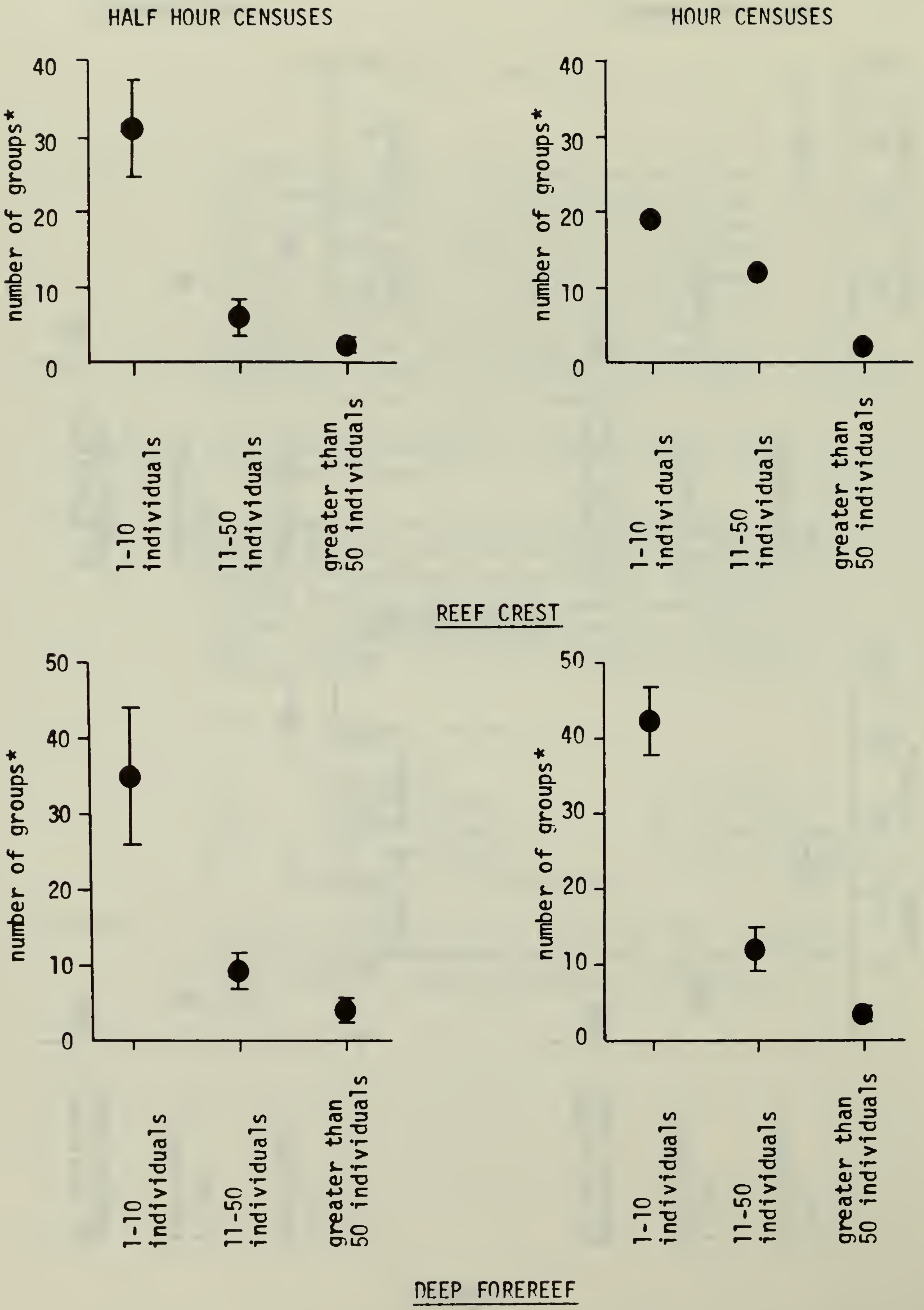


Figure X-2

Fish Census Indices of Similarity

Definition: $S = \frac{2C}{A + B}$ where S = Index of Similarity
A = No. of species in zone a
B = No. of species in zone b
C = No. of species common to both

Zone	Number of diurnal species which occur there
Underwater Trail	61
Backreef	80
Reef Crest	58
Deep Forereef	81

No. of species common to both the Underwater Trail and the Backreef: 56
" " " " Underwater Trail " Reef Crest: 45
" " " " Underwater Trail " Deep Forereef: 51
" " " " Backreef " Reef Crest: 47
" " " " Backreef " Deep Forereef: 61
" " " " Reef Crest " Deep Forereef: 49

Index of Similarity between the Underwater Trail and the Backreef: .79
" " " Underwater Trail " Reef Crest: .76
" " " Underwater Trail " Deep Forereef: .72
" " " Backreef " Reef Crest: .68
" " " Backreef " Deep Forereef: .76
" " " Reef Crest " Deep Forereef: .71

Table X-1. Distributional Checklist of

of the Fishes of Buck Island Reef National Monument.

	Tr	BR	RC	FR
CARCHARHINIDAE				
Carcharhinus springeri - reef shark			I	
Negaprion brevirostris - lemon shark			I	
MYLIOBATIDAE				
Aetobatus narinari - spotted eagle ray		I		I
DASYATIDAE				
Dasyatis americana - southern stingray				I
OPHICHTHIDAE				
Myrichthys oculatus - goldspotted eel		I		
SYNODONTIDAE				
Synodus intermedius - sand diver		II		II
HEMIRAMPHIDAE				
Hemiramphus brasiliensis - ballyhoo		II		
BELONIDAE				
Tylosurus crocodilus - houndfish		V		
AULOSTOMIDAE				
Aulostomus maculatus - trumpetfish	I	II	II	II
FISTULARIIDAE				
Fistularia tabacaria - cornetfish		I		
SERRANIDAE				
Cephalopholis fulva - coney		I	I	II
Epinephelus adscensionis - rock hind			I	
E. guttatus - red hind	I	I	I	II
E. striatus - nassau grouper	I	I		I
Hypoplectrus chlorurus - yellowtail hamlet		I		I
H. guttavarius - shy hamlet		I	I	II
H. nigricans - black hamlet		I		I
H. puella - barred hamlet		I		II
H. unicolor - butter hamlet				I
Mycteroperca tigris - tiger grouper	I		I	I
Petrometopon cruentatum - graysby			I	I
Serranus tabacarius - tobaccofish				I
S. tigrinus - harlequin bass	I	I		II
GRAMMIDAE				
Gramma loreto - fairy basslet	I	I	I	III
GRAMMISTIDAE				
Rypticus saponaceus - greater soapfish		I		
BRANCHIOSTEGIDAE				
Malacanthus plumieri - sand tilefish	I	I		I
ECHENEIDAE				
Echeneis sp. - sharksucker				I
CARANGIDAE				
Alectis crinitus - african pompano	I			
Caranx fusus - blue runner		I	I	I
C. ruber - bar jack	II	II	II	II
EMMELICHTHYIDAE				
Inermia vittata - boga				III

Table X-1. (cont'd)

LUTJANIDAE		TR	BR	RC	FR
Lutjanus analis - mutton snapper		I	I		
L. apodus - schoolmaster		IV	II	II	III
L. griseus - gray snapper		I	II		
L. jocu - dog snapper		I	I	I	I
L. mahogoni - mahogany snapper		II	II	II	II
L. synagris - lane snapper					I
Ocyurus chrysurus - yellowtail snapper		II	III	II	II
POMADASYIDAE					
Anisotremus surinamensis - black margate				I	I
A. virginicus - porkfish				I	
Haemulon macrostomus - spanish grunt			I		
H. aurolineatum - tomtate					I
H. carbonarium - caesar grunt		I		I	
H. chrysargyraeum - smallmouth grunt		I			
H. flavolineatum - french grunt		II	IV	II	II
H. plumieri - white grunt		II	II	I	I
H. sciurus - bluestriped grunt		II	II	I	I
SPARIDAE					
Calamus sp. - porgy			I		
SCIAENIDAE					
Equetus punctatus - spotted drum			I		
MULLIDAE					
Mulloidichthys martinicus - yellow goatfish		II	II	II	II
Pseudupeneus maculatus - spotted goatfish			I		I
KYPHOSIDAE					
Kyphosus sectatrix - bermuda chub		I	I	II	II
EPHIPPIDAE					
Chaetodipterus faber - atlantic spadefish		I	I		
POMACANTHIDAE					
Holacanthus ciliaris - queen angelfish					I
H. tricolor - rock beauty				I	I
Pomacanthus arcuatus - gray angelfish			I		I
P. paru - french angelfish		I	I		I
CHAETODONTIDAE					
Chaetodon capistratus - foureye butterflyfish		I	II	I	II
POMACENTRIDAE					
Abudefduf saxatilis - sergeant major	A	III	I	II	III
	J			II	
Chromis cyanea - blue chromis		IV	I	IV	V
C. multilineata - brown chromis		II		III	III
Microspathodon chrysurus - yellowtail damsel	A	III	II	IV	IV
	J	II		I	
Eupomacentrus mellis - honey damselfish		II	II	II	I
E. fuscus - dusky damselfish	A	IV	III	IV	III
	J		I	I	
E. leucostictus - beaugregory		II	IV	I	
E. partitus - bicolor damselfish		II	I	I	IV
E. planifrons - three-spot damselfish	A	III	IV	III	IV
	J	III	III	II	IV

Table X-1. (cont'd)

		Tr	BR	RC	FR
E. variabilis - cocoa damselfish	A	III	II	I	II
	J	II		I	
LABRIDAE					
Bodianus rufus - spanish hogfish	A	I	I		I
	J				I
Clepticus parrae - creole wrasse	A				III
Halichoeres bivittatus - slippery dick	A	II	III	II	II
	J	II	IV	I	II
H. garnoti - yellowhead wrasse	A		II		II
	J	I	II		III
H. maculipinna - clown wrasse	A	I	I		
	J		I		
H. poeyi - blackear wrasse	A		II	I	I
	J		I		
H. radiatus - puddingwife	A	I	I	I	I
	J	II	II	II	II
Thalassoma bifasciatum - bluehead	A	I	II	I	II
	J	V	V	V	V
SCARIDAE					
Scarus coelestinus - midnight parrotfish		I	I	I	
S. coeruleus - blue parrotfish	J		I		I
S. croicensis - striped parrotfish	A		I		I
	J	IV	IV	IV	IV
S. guacamaia - rainbow parrotfish		I	I		I
S. taeniopterus - princess parrotfish	A		I	II	I
	J	IV	IV	IV	IV
Sparisoma aurofrenatum - redband parrotfish	A		I	II	II
	J	I	II	I	III
S. chrysopterum - redtail parrotfish	A	II	I		I
	J		II		II
S. radians - bucktooth parrotfish	A	I	I		
	J		I		
S. rubripinne - yellowtail parrotfish	A		I	II	II
	J		III	I	
S. viride - stoplight parrotfish	A	III	III	III	II
	J	III	III	IV	IV
SPHYRAENIDAE					
Sphyraena barracuda		I	I	I	I
CLINIDAE					
Labrisomus nuchipinnis - hairy blenny			I		
Malacoctenus triangulatus - saddled blenny			I	I	
BLENNIIDAE					
Ophioblennius atlanticus - redlipped blenny		I		II	I
GOBIIDAE					
Coryphopterus glaucofrenus - bridled goby		III	IV		II
Gnatholepis thompsoni - goldspot goby		I	I		
Gobiosoma sp. - cleaning goby		II	I		II

Table X-1. (cont'd)

		Tr	BR	RC	FR
ACANTHURIDAE					
Acanthurus bahianus - ocean surgeon	A	III	V	III	V
	J	IV	III	II	III
A. chirurgus - doctorfish			I		
A. coeruleus - blue tang	A	IV	IV	IV	IV
	J	II	II	II	II
SCORPAENIDAE					
Scorpaena plumieri - spotted scorpionfish			I		
BOTHIDAE					
Bothus lunatus - peacock flounder		I	I	I	I
BALISTIDAE					
Aluterus scriptus - scrawled filefish			I		
Balistes vetula - queen triggerfish		I	I	I	I
Cantherhines pullus - orangespotted filefish			I		I
Canthidermis sufflamen - ocean triggerfish				I	
Melichthys niger - black durgeon					I
Monacanthus tuckeri - slender filefish					I
OSTRACIIDAE					
Lactophrys bicaudalis - spotted trunkfish			I	I	I
L. triqueter - smooth trunkfish		I	I	I	II
Acanthostracion polygonius - honeycomb cowfish					I
CANTHIGASTERIDAE					
Canthigaster rostrata - sharpnose puffer				I	II
TETRAODONTIDAE					
Sphoeroides spengleri - bandtail puffer					I

Table X-2. Nocturnal Fishes of the Underwater Trail

	Tr	FR
HOLOCENTRIDAE		
Adioryx coruscus - reef squirrelfish	III	
A. vexillarius - dusky squirrelfish	V	
A. poco - saddle squirrelfish	I	
Holocentrus ascensionis - longjaw squirrelfish	I	
H. rufus - squirrelfish	IV	IV
Flammeo marianus - longspine squirrelfish	II	II
Myripristis jacobus - blackbar soldierfish	IV	IV
PRIACNATHIDAE		
Priacanthus cruentatus - glasseye	I	
APOGONIDAE		
Apogon binotatus - barred cardinalfish	III	III
A. maculatus - flamefish	II	
A. townsendi - belted cardinalfish	IV	IV
Apogon sp.	II	
Phaeoptyx sp.	V	V
PEMPHERIDAE		
Pempheris schomburgki - copper sweeper	III	V
POMADASYIDAE		
Haemulon flavolineatum - french grunt	III	
H. plumieri - white grunt	II	
SCIAENIDAE		
Odontoscion dentex - reef croaker	III	
Equetus punctatus - spotted drum	I	
MULLIDAE		
Mulloidichthys martinicus - yellow goatfish	II	

XI. CORAL DESTRUCTION

Objectives

A large variety of agents, both natural and man-induced, are known to damage living corals. These have been summarized for the Caribbean by Antonius (1977), Glynn (1974), Bak (1976) and others. These agents operate on a range of scales from very localized to reef-wide. Their impact ranges from trivial to catastrophic, but in many cases there is potential for widespread reef destruction by any one of these agents. From the point of view of local park management it is desirable to know what these agents are, how they operate, what their present impact is, what their potential impact is, and how they can be controlled if necessary.

Known destructive agents of corals can be classified in a number of ways and the scheme presented below is only one of the many:

I. Natural Agents

   A. Physical, catastrophic disturbances (storms, tidal waves, earthquakes, etc.)

   B. Biological agents

      1. Bioeroders (cause weakening of the supporting skeleton and may cause collpase of the colony)

      2. Predators (feed on live coral tissue)

      3. "Disease" causing organisms (generally microbes that cause necrosis of live coral tissue; may cause extensive damage)

      4. Competitors for space (may kill coral at zone of contact, and overgrow coral skeleton)

II. Man-induced Agents

   A. Mechanical damage (caused by boats, human contact, etc; may result in breakage, or abrasion of living tissue)

   B. Sedimentation (due to dredging, or heavy concentration of boat and human traffic)

C. "Pollution"

1. Chemical pollution (caused by sewage, chemical plant effluents, etc)

2. Thermal stress (caused by effluents from power plant cooling systems in particular)

Of these various potential sources of coral (reef) destruction quantitative information was obtained only on "Disease-causing" organisms, which at the present time seems to be the principal source of coral mortality within the monument and on nearby reefs as well. Anecdotal information has been obtained on certain other sources of mortality and will be discussed as well.

Methods and Materials

The "white-band disease" of *Acropora palmata* is characterized by a sharply defined band at the zone of necrosis of the coral tissue and the newly exposed skeleton, which is pure white. Proximal to this bright white zone is a succession of colonizing algae.

Analysis of the "white-band disease" was carried out in two phases. The first phase consisted of determining the incidence of "infection" of *A. palmata* colonies on the reefs of Buck Island and adjacent areas by swimming long transects parallel to the reef front and by running a transect by motorboat surveying the entire eastern part of the monument, on a remarkably calm day when subsurface features could easily be seen. In addition, the rates of advance of the disease were determined on infested colonies at Buck Island and tbe reef on the south side of the Buck Island Channel. Photographs were taken *in situ* of infected *A. palmata* branches marked proximally with plastic tags(Fig. XI-1). The branches were photographed at weekly intervals for a month, the photographs developed, printed and measurements made on the weekly rates of advance of the "disease". In addition a series of photographs were made to determine if there was a difference in rate of advance between day and night by taking close-up shots of infected tips in the morning, evening and following morning (Fig. XI-2).

The second phase of the analysis of this disease was an effort to determine the causitive agent. Microscopic examination of a large number of tips was carried out in the laboratory. An effort to induce the disease by contact and by filtered extract (Yoder, 1977), were also tried, unsuccessfully.

Results

The incidence of infestation of *A. palmata* colonies with the "white-band disease" is summarized in Table XI-1. Within the monument the incidence of infection is quite low at the present time (no more than a few percent of the colonies are infested in any area). However, in a stretch of *Acropora* reef opposite the monument on the south side of Buck Island Channel the percentage of infested colonies is extremely high and the reef has a generally "devastated" appearance. There are similar devastated areas within the monument boundary; for example, just east of the underwater trail area. The cause of such areas is unknown, but it is possible that this or a similar infective agent may have been responsible.

The rates of progress of the disease are quite variable (Table VI-2) ranging from less than 1 mm/da. (24 hrs) to more than 14 mm/da., but as can be seen from Fig. XI-3 there is a general tendency for the rate of advance to increase in the more distal parts of the colony (i.e. toward the tips). In more than 99% of infected colonies the disease progressed from base to tip. In experiments conducted over the 24 hr day (Fig. XI-2) it was shown that there is no significant difference between rates of advance in the daytime (light) and at night (dark). In general the infection progresses evenly around the circumference of the branch, and at a similar rate on each branch of an infected arm (Fig. XI-1).

Occasionally the progress of the infection ceases and the remaining coral tissue forms a lip and grows back down the branch. Generally, however, the disease progresses to the tip of a branch and until a whole colony is destroyed.

At the present time nothing is known of the organism causing this disease or the mechanism of spreading the infection. Microscopic investigation of a large number of infected branches has revealed that a large number of organisms occur in the bare centimeter proximal to the edge of the *A. palmata* tissue. These include:

blue-green "algae"
ciliate protozoans (at least 4 species)
turbellarian flatworms
copepod crustaceans
amphipod crustaceans
nematodes (at least 3 species)

None of these organisms were present in large concentrations on 100% of the infected branches. Both ciliates and nematodes, however, were present in dense concentrations in a large proportion of the pieces inspected. The ciliates were in fact eating coral tissue as evidenced by the dense concentrations of zooxanthellae in their "guts" Beginning 1-2 cm proximal to the edge of the dying tissue, colonization by diatoms and filamentous algae begins. As a byproduct of doing these analyses it was found that the bare carbonate surface exposed by the progressive destruction of live coral which is colonized by a sequence of organisms provides one of the best examples of natural succession in the coral reef environment.

During the course of the study a number of other agents were casually observed to damage living coral, but the only one of these which did significant damage were parrotfishes, which occasionally made extensive bites on living P. astreoides, A. palmata, D. strigosa, and M. annularis. The incidence of such biting was very patchy and localized but sometimes extensive damage was done to the head(s) bitten. Some of the coral heads regenerated tissue over the damaged areas and recovered completely, while others degenerated when algae and other organisms settled in the bite marks and progressively killed the coral tissue.

In the limited space available on the reef, many organisms often grow into contact. In such cases one often kills or overgrows the other (Lang 1972). In the monument, the organism most often observed to overgrow living coral at the zone of contact was the encrusting zoanthid Palythoa caribbea.

Conclusions and Recommendations

It does not appear that the reefs of the national monument are being overrun by any destructive agents. However, this study has revealed at least two agents potentially harmful to the living corals of Buck Island

Reef do exist: 1) an unknown agent causing the "white-band disease" of *A. palmata*, and 2) parrotfishes, which because of protection might reach abnormally high densities in the Buck Island Lagoon. Both of these phenomena should be periodically monitored in the future.

FIGURE AND TABLE LEGEND - Chapter XI

Table 1 - Incidence of infestation of _Acropora palmata_ colonies with the "white-band disease" in areas of Buck Island Reef National Monument, and nearby reefs.

Table 2 - Rates of progress (mm) of the"white-band disease" measured weekly over a four week period.

Fig. 1 - This shows the progress of the "white-band disease" on one colony of _Acropora palmata_ photographed at two week intervals. A. Time 0 - "white-band disease present, as shown by the distinct pure white band between the living coral tissue and dead encrusted areas below. B. Time 2 weeks. The disease has progressed about 7 cm towards the tip. Notice previous white areas are becoming encrusted with other organisms. C. Time 4 weeks. The disease has progressed another 7 cm; note that tip on extreme right is completely devoid of living coral tissue.

Fig. 2 - Photographs of the progress of the "white-band disease" of _A. palmata in situ_ over a 24 hour period, showing no significant difference in the rate between day and night.

Fig. 3 - Rates of advance of the "white-band disease" as affected by distance of the disease from the tip.

Table XI-1. Incidence of "White-band Disease" of *Acropora palmata* in different areas

Location	Total # Colonies	# Infected Colonies	% Infected Colonies
Haystacks	100	2	2%
Trail	50	1	2%
Eastern tip: Shallow forereef	150	7	5%
Deep forereef	100	1	1%
South forereef	200	8	4%
Tague Bay Reef (South side Buck Is. Channel):			
Opposite Romney Pt.	100	42	42%
Opposite Tague Pt.	100	6	6%

Table XI-2. Rates of Advance of "White-band Disease" on *Acropora palmata*.

Colony & Branch #	Distance of White band from tip (cm)	Advance of White band (mm) 11/5-11/19	Advance of White band (mm) 11/19-12/2	Advance of White Band per day (mm/da) 11/5-11/19	Advance of White Band per day (mm/da) 11/19-12/2
1a	33	49.3	79.9	3.5	6.1
1b	22	118.7	83.1+	8.5	6.4+
1c	17	195.0+		13.9+	
1d	21	113.0	95.6+	8.8	7.4+
2a	29	73.3	105.3	5.2	8.1
2b	13	85.1		6.1	
3a	100+	48.2	76.0	3.4	5.8
3b	61	68.6	83.3	4.9	6.4
3c	27	140.9	128.1+	10.1	9.9+
4a	25	109.4	56.6	7.8	4.3
4b	16	69.5	90.2	5.0	6.9
4c	23	54.6	57.0	3.9	4.4
4d	25	57.0	51.3	4.1	3.9
4e	33	38.0	28.5	2.7	2.2
4f	25	59.9	58.1	4.3	4.5
5a	25	95.7	139.9	6.8	10.8
6a	27	52.1	82.8	3.7	6.4
6b	27	56.4	55.3	4.0	4.3
6c	57	52.2	51.0	3.7	3.9
7a	35	106.4		3.9	
7b	38	166.1		6.1	
7c	39	47.6		1.8	
7d	34	103.7		3.8	
7e	38	223.2		8.3	
8a	26	45.8	10.0	3.3	0.8
8b	27	60.0	53.9	4.3	4.1
				x=5.59 (n=21)	x=5.61 (n=19)
				x=4.41 (n=16) s=1.32	x=5.18 (n=16) s=2.34

x=5.51 mm/day

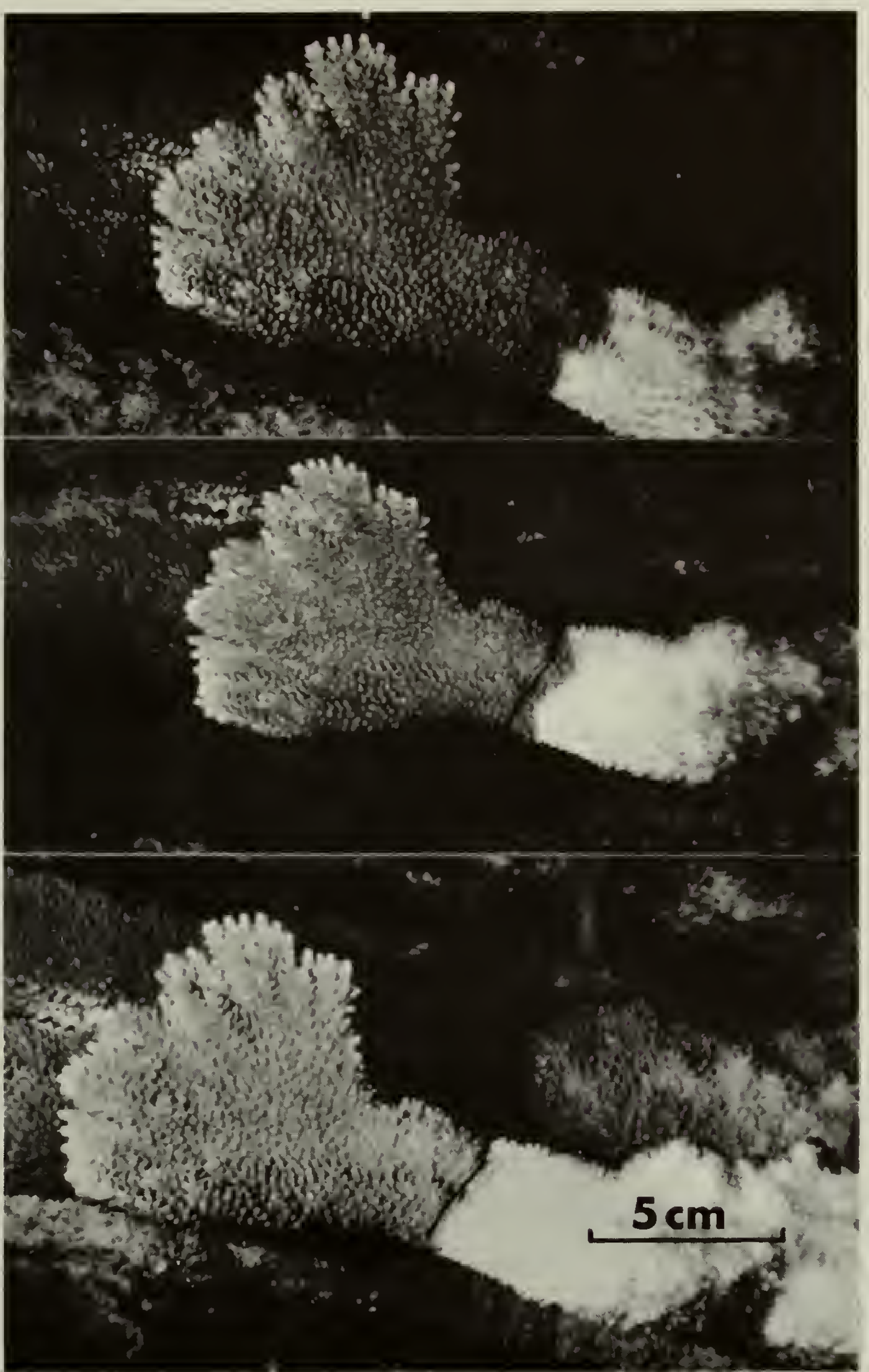
FIG. XI - 1

A

B

C

FIG. XI - 2

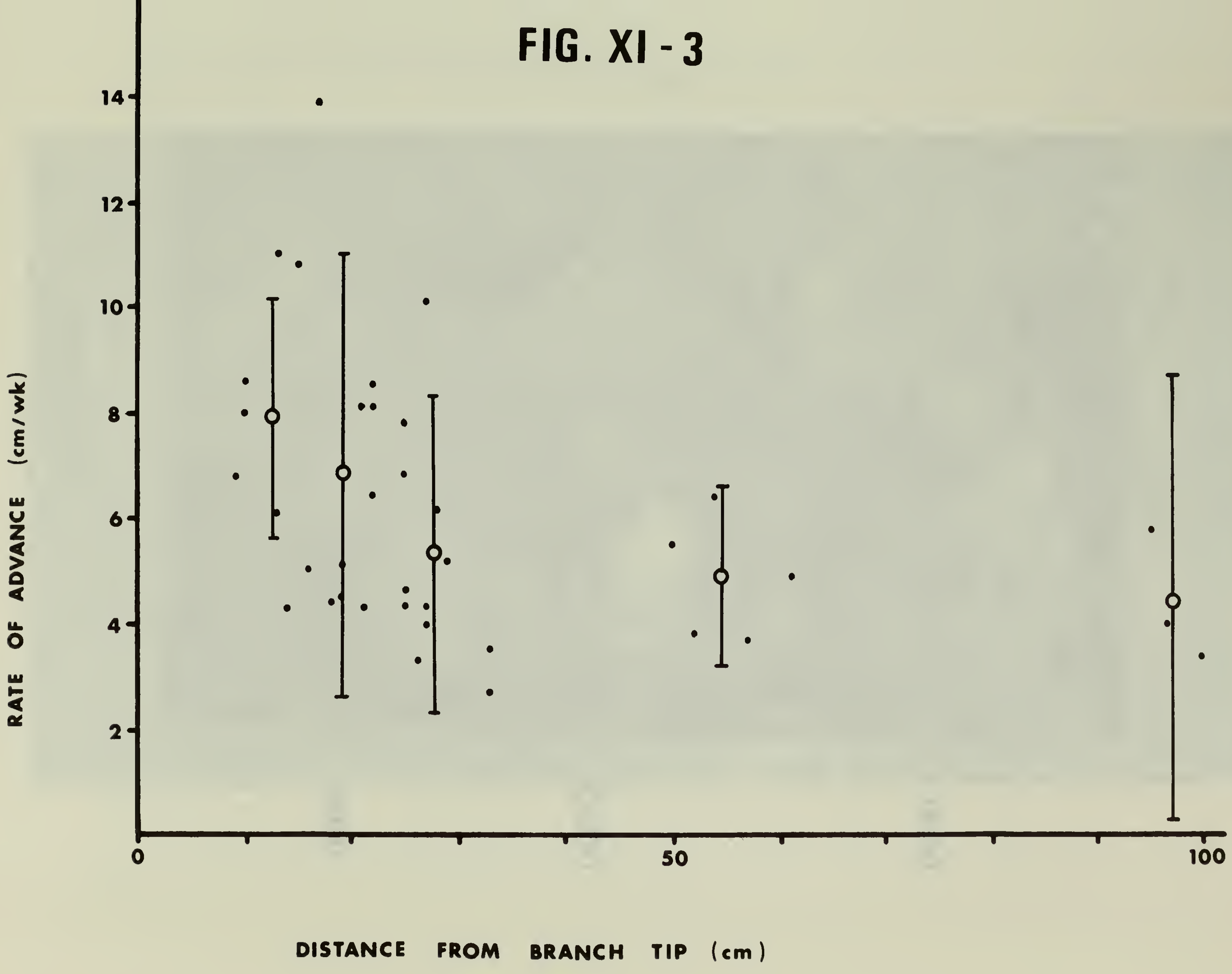


1800

0700

1800

FIG. XI - 3


RATE OF ADVANCE (cm/wk)
14
12
10
8
6
4
2
0
50
100
DISTANCE FROM BRANCH TIP (cm)

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