

**ENVIRONMENTAL
STUDIES
OF
BUCK ISLAND REEF
NATIONAL MONUMENT
ST. CROIX, U.S.V.I.
II**

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CHAPTER I

INTRODUCTION

by

William B. Gladfelter and Elizabeth H. Gladfelter

During the past two years, some of the important resources of Buck Island Reef National Monument have been inventoried (especially reefbuilding corals and fishes, the two major visitor attractions) and some of the basic processes controlling their interactions and rates of change have been investigated (see Gladfelter et al., 1977). The principal objective in this study was to increase our understanding of the dynamics of reef ecosystems in general, Buck Island Reef in particular. In order to fulfill this objective, the project was divided into two separate portions: biological and geological, which were integrated in the overall analysis to develop a better understanding of reef history.

A. REEF DEVELOPMENT

To determine some of the longer-term processes responsible for the formation of the Buck Island Reef, a study of the large reef structures called "haystacks" located just north of the north reef was undertaken. Evidence from direct observations, seismic profiling and cores (obtained from drilling on the Buck Island Bar, north of the Buck Island Reef National Monument) was assessed.

Since sediment production and movement is such an important process in the development of reefs, a model for relating information gathered about carbonate sediment (including size and shape) to known predictions of the movements of terrigenous sediments was proposed and tested, using sediment samples from the Buck Island lagoon.

B. ACROPORA PALMATA GROWTH

During the previous year, extensive studies of coral growth rate were carried out, especially on the dominant coral, Acropora palmata. However, only growth of the tips of the colonies was measured, and extrapolations were made as to the increase in thickness of the more proximal parts of the branches. In order to determine an accurate rate of accrual of reef substrate in the A. palmata reef, it was necessary to carry out further, long-term studies of increase in girth of the colonies. Unpublished studies by Macintyre showed that although the distal branches of A. palmata do not have the annual growth rings characteristic of some other species (e.g., Montastrea annularis; Gladfelter et al., 1977, Chapter VII), more proximal sections did show such bands. Sections were taken from the bases of large A. palmata branches on the forereef to supplement staining data on the peripheral growth of these colonies.

C. SEDIMENTARY PROCESSES

Studies by Gladfelter et al. (1977) documented the variability that can occur along the beaches of Buck Island, especially that at the west end of the island. During the 1977 study, trees and Indian middens on the western margin were undermined or destroyed by shoreward erosion. These observations further indicate that these changes are somehow related to the oceanic swell regime of the region and are complicated in that they do not represent simple erosion or deposition. For example, between 22 September 1976 and 25 January 1977, considerable erosion was measured. Between 25 January and 30 June 1977, erosion continued, but at a slower pace. Since that time, the beach profiles made by E.H. Gladfelter (Gladfelter et al., 1977) showed that the slopes returned nearly to their original configuration. Because of the potential damage that can again occur to archeological sites and shoreline trees, it was felt that this phenomenon required a more comprehensive study during the 1978 period. The profiles measured in 1977 were continued during 1978. The total amount of sand gained or lost in each section of the beach was determined for each sampling period over the two-year period (1976-1978). Seasonal patterns of erosion and deposition were detected and preliminary correlation with seasonal climatic patterns was made.

D. DYNAMICS OF THE BENTHIC COMMUNITY

As dominant members of the coral reef community, corals are subjected to a wide variety of natural damaging agents. Based on the findings of the previous year's study, the three principal categories of agents that destroy living coral are: (1) competitors for space, (2) disease, (3) fish and invertebrate predators. Bare space is an uncommon commodity on the solid substrates of a coral reef. Newly vacated surfaces are relatively rapidly colonized by adjacent organisms or new larvae. Therefore, attached, benthic organisms are generally bordered by zones of contact with other organisms. From the limited evidence available, it is clear that many of these zones of contact are areas of dynamic change (Connell, 1976; Lang, 1973; Jackson and Buss, 1975). Because of their importance in the overall construction, economy, and aesthetics of the reef, it was imperative to develop a better understanding of the interactions between corals and other benthic organisms which are potential competitors for space. Casual observations made at Buck Island Reef during the previous study revealed a large and diverse group of organisms that form interfaces with living corals (and between each other), including: algae, sponges, sea anemones, zoanthids, Millepora (fire coral), other corals and gorgonians.

Predation on coral by parrotfish and invertebrate grazers can cause a direct effect on the viability of the coral and serves in addition to open new space for colonization by other benthic forms. To monitor the interactions of benthic organisms with each other, with disease-causing agents and with mobile grazers, a photographic transect was set up, and the interactions identified and followed for a nine-month period.

The greatest proportion of surface area within the Buck Island reef ecosystem is covered by various algae, though these are often overlooked because most of these algae are encrusting or nearly microscopic filamentous forms. This large proportion of surface is utilized by numerous grazers present (fishes by day, sea urchins by night) in such a way that algal succession is maintained at an early stage in many areas. The importance of this to the overall dynamics of space utilization by benthic organisms is unknown, but is of potential importance. Little is understood about the competition of algae and corals;

however, if grazers did not maintain the algal cover at an early successional stage, it is possible that the successive algae colonizers would more successfully compete for space with corals. A series of settling plates were placed in various parts of the reef, and succession followed over a one-year period.

It is additionally felt by a number of authors (Odum and Odum, 1955; Adey, ms) that this early successional stage of algae is far more productive than later stages with higher biomass. During the present study, cages were used to control the density of a major herbivore, i.e., Diadema, and the algal succession in these cages was followed. Productivity measurements were made of early and late successional stages using plastic domes as chambers.

E. PREDATION ON CORALS BY URCHINS AND FISHES

Although some knowledge of the effects of interaction of mobile predators on living coral could be gained by the methods employed in the last section, it was felt that more detailed information focusing on that question specifically was needed.

Diadema is a potential hazard to visitors in the monument, and although not presently in evidence during the day, is exceedingly abundant at night on many parts of the reef, including the underwater trail area. Furthermore, Diadema has been implicated in the destruction of corals in certain parts of the Caribbean (Bak, 1975). Although this has never been documented locally, if this extremely abundant urchin were actually or potentially a grazer of live coral, it would be necessary to know its effectiveness and the factors which may cause this change to a coral diet. To this end, experiments on food choice as a function of urchin density were carried out.

During the 1977 Buck Island environmental study, instances of predation by parrotfishes on living coral were observed. Several species of fishes (Sparisoma viride, Scarus vetula) as well as a number of species of corals (Diploria strigosa, Porites astreoides, Acropora palmata) were involved. Little

is known about this relationship, but in general, reef fishes have been presumed not to feed on live coral in the Caribbean. Given the number of parrotfishes at Buck Island, and their rate of conversion of dead coral substrates to sand and silt ($0.5 \text{ kg/m}^2/\text{hr}$; Ogden, 1977), a change in diet from dead coral surfaces overgrown with fine filamentous algae to live coral could result in large-scale destruction of reef corals.

The problem of fish grazing on live coral was approached in several ways. Incidences of predation by parrotfishes on living coral were recorded, and the location noted and the area left so as not to interrupt the process. The damaged areas were marked and revisited to determine the amount and rate of damage. These results are presented in Chapter V of this report. To see the relative importance of different species of parrotfishes in coral grazing, colonies of Acropora palmata were followed in detail to note the frequency and extent of fish grazing. In addition, individuals of Sparisoma viride and Scarus vetula were observed in the field in order to determine food selection and feeding behavior. Controlled experiments to determine the effect of fish density on coral grazing were set up outside the park using large cages and controlling the densities of included corals and fishes to determine if, in fact, live coral grazing is a function of fish population density.

F. FISH COMMUNITY DYNAMICS

In their role as major consumers in the reef community, fishes may exert an important influence on community structure (Bakus, 1969; Paine, 1966). Because of the generally widespread exploitation of (reef) fishes, there is little documentation of this potentially important role of reef fishes in a system undisturbed by man. Buck Island Reef National Monument provides a uniquely protected environment in which such studies can be carried out. Although the general composition and distribution of the fish fauna in the eastern part of the Monument is known based on the past year's study, little can be said at present about the structure of the fish community or the effect of the fishes on the remainder of the community. However, casual observations made during the 1976-1977 period of study suggest that fishes are important in the Monument in a number of ways:

- as a major tourist attraction,
- as potentially destructive agents of living corals (undocumented for Caribbean species),
- in maintaining arrested, possibly highly productive successional stages of benthic algal cover (Odum and Odum, 1955; Adey, ms),
- in controlling potentially detrimental species such as Diadema (Bak, 1975),
- in converting significant quantities of carbonate substrate to sediment (Ogden, 1977).

Therefore, it was important that we obtain essential information on the distribution, abundance, population dynamics and movement of the important or potentially important species of fishes both within the lagoon and outside the reef where exploitation is permitted. Monthly visual censuses made in replicate at each of several reef quadrats in the various major zones provided the basic data needed to obtain a better understanding of fish community structure. These counts were supplemented by trapping, tagging and retrapping to provide more concrete data on growth rates of some of the more abundant species such as pomadasysids (grunts), acanthurids (surgeonfish) and scarids (parrotfishes). Growth rates obtained for fishes within the protected portion of the Monument were compared with rates obtained in an exploited "control" area (Tague Bay). These studies have indicated whether the fish community or certain portions of it may be particularly stressed by composition due to protection from fishing within the Monument, and perhaps causing some fishes (e.g., parrotfishes) to feed on items not normally in their diet (i.e., corals). In addition, a tagging program enabled studies on the movements of certain species to be carried out. It is important to know the movements of fishes within the Monument as an aid in understanding which types of habitat are most important to this major tourist attraction (i.e., fish). It is also important to know how much movement there is of fishes between the protected lagoon and the unprotected forereef and bank areas.

G. PLANKTON AS A REEF RESOURCE

A number of authors have emphasized the importance of plankton in the nutrition and energetics of the reef community (Odum and Odum, 1955; Glynn, 1977; Johannes et al., 1970; Porter, 1974, 1977) but quantitative evidence on this role played by plankton is slim. Earlier studies (Odum and Odum, 1955; Glynn, 1973) calculated plankton consumed by the reef where currents across the reef could be measured. The differences between plankton taken on the upstream and downstream sides of the reef are assumed to be consumed by the reef. More recent studies have shown that a significant fraction of the plankton community appears in the water column only at night and is capable of maintaining station near the reef surface. This fraction, the demersal plankton (Alldredge and King, 1977) may be significant in quantity and must be taken into account in upstream and downstream analyses.

Plankton is a valuable food source both for a number of fishes as well as members of the invertebrate fauna (including many corals). Furthermore, it has been suggested that feeding by corals on plankton enhances their calcification rate (Vandermuelen and Muscatine, 1974). The two principal categories of plankton, drifting the water column by day and night, and the demersal plankton, which emerges from the substrate in the evening (Alldredge and King, 1977) provide a rich food source for nocturnal fishes and corals. Both these fractions of the plankton were sampled inside the lagoon and outside, day and night, on a monthly basis. This portion of the study provided important baseline information on the composition and abundance of this important external food source for the reef community.

Thus, in this year's study, an important understanding of some of the underlying processes governing the geological and biological development and succession of the reef ecosystem was gained. In addition, some preliminary monitoring of important components of the community (fish, plankton) was conducted which will give a baseline for monitoring these resources in the future.

CHAPTER II

REEF DEVELOPMENT AND SEDIMENTARY PROCESSES

by

Dennis K. Hubbard

Introduction

To date, most of the biological and physical studies within the park have been aimed at documenting or monitoring short-term phenomena. In this study, investigation of (1) reef development in and around the park, and (2) sedimentary processes occurring in the lagoon were carried out in an attempt to define some of the longer-term processes occurring within Buck Island Reef National Monument.

In order to gain some preliminary insight into the geologically recent development of the area, a program of diver investigations, bathymetric surveys, and a correlation to existing core data outside the park was initiated. The conclusions from this study provide us with a working hypothesis for the development of a constructional model for reefs in and around the park.

In the study of lagoonal sediments, there were two objectives in mind: (1) we wanted to document the nature of the sediments in the lagoon, and (2) we wanted to address some of the fundamental problems encountered by sedimentologists working in the carbonate environment. Sedimentation in the marine environment depends upon the interactions of gravity, the fluid medium, and its effects on the particular grains that are settling. The basic concepts (i.e., the larger and heavier grains will settle more rapidly than the smaller, lighter types) have been long established. Many of the properties of carbonate grains are not considered by these concepts, however.

Traditionally, sediment transport studies have assumed grain shape as spherical (Krumbein and Sloss, 1963). In a carbonate setting, however, finding spherical grains occurring naturally is an exception rather than the rule (Ginsburg, 1973).

The validity of using physical relationships based on settling velocities of terrigenous grains in direct correlation with sieve analysis of carbonate sediments is therefore suspect because carbonate grains settle more slowly than do terrigenous grains of a similar physical grain size. Furthermore, grain shape seems to be a critical parameter in determining the settling velocity (and, therefore, the "hydraulic" grain size) of the sediment. It was hypothesized that as the ratio of round-to-platy grains (R:P) changed in any given sample, the settling velocity of that sample would vary predictably. If this assumption is warranted, then one could reasonably "adjust" the size of any given carbonate sample to a terrigenous equivalent upon which state-of-the-art sediment transport relationships are based.

PART I - REEF DEVELOPMENT

Methods and Materials

Data on reef development came from three major sources:

1. The character of the reef framework and the extent and nature of boring, sedimentation and cementation within the reef was determined from observations made by divers using SCUBA and those made by students (including those made by the investigators doing projects). The rather loose framework of the reef allowed access, in some cases, to the internal portions of the reef where samples were taken to examine the effects of boring organisms within the reef. These were compared to similar samples taken elsewhere in the reef complex.

Specimens of dead coral branches were removed and taken back to the laboratory for slabbing and identification of biological and chemical processes occurring within each specimen (Bennett, 1978; Marvel, 1978).

2. Bathymetric data to show the topographic relationship of Buck Island reef to surrounding structures were gathered using a Raytheon Recording Echo Sounder.

3. Correlations were made with core holes drilled outside the park. The submersible drilling rig described by Macintyre (1975) was used. The unit has a hydraulic power source and is operated by divers on the bottom.

Results

Conclusions from this portion of the Buck Island study are only preliminary in nature. From available data, two conclusions are made. First, although the most visible part of the reef framework is the active, living coral that covers the reef surface, the majority of the reef is comprised of "dead" coral skeletal material that is being actively bored, infilled and recemented over and over again. Furthermore, the piling up of dead coral debris at the base of the reef provides substrate for new growth and is a major (if not the major) mechanism for lateral reef extension. Results of experiments elsewhere on St. Croix indicate the original coral skeleton can be completely replaced by the boring-recalcification process in less than 20 years (Zankl, pers. commun.).

The second conclusion involves the origin of the pinnacle reef located north of the trail. These features, locally called "haystacks" are made up almost entirely of Acropora palmata which has died and been cemented together into a reef framework, either in place or after being broken off and falling into some lower position. The framework of the pinnacles is extremely open, and some openings are large enough to provide a diver access to the internal portions of the haystacks. The internal walls of the cavities are heavily encrusted and bored. Circulation through the haystacks is open and wave surge can be felt within. The walls are composed entirely of Acropora palmata. No heads of Montastrea annularis or deeper water corals found outside the pinnacles were observed. It would appear, therefore, that these features have always occurred in shallower water and did not start as deeper water features which have subsequently grown up to sea level.

Further evidence for this conclusion can be seen in a core drilled by Ian Macintyre in Buck Island Bar to the north of the park (Fig. 1). In the core at a depth of 10.2 m (MSL), the dominant coral type changes from A. palmata to Porites sp. and M. annularis, indicating a change in reef conditions between 3500 and 4000 y.b.p. (carbon). If we look at a bottom profile from Buck Island lagoon, through the haystacks and across Buck Island Bar (Figs. 1 and 2), it appears that a reef dominated by Acropora palmata occurred in the vicinity of

Buck Island Bar and that the haystacks were patch reefs occurring in the lagoon behind.

Since that time, the haystacks have risen at a rate comparable to the rate of sea-level rise, which slowed at about 3100 y.b.p., according to the Neumann sea-level curve. There appears to have been a degradation in water quality along Buck Island Bar at 3500 to 4000 y.b.p. (carbon) which either stopped reef growth for a period of time, after which the reef restarted in deeper water (mostly Porites sp. and Montastrea annularis) or else provided an unsuitable environment for the growth of Acropora palmata. Adey et al. (1977) described a similar phenomenon for other shelf edge features on St. Croix, but the application to this area cannot be positively identified based on the present data. More cores are needed.

PART II - SEDIMENT DYNAMICS STUDY

Methods and Materials

Fifteen surface sediment samples were taken in Buck Island lagoon (Fig. 1) using a 20 cm long by 5 cm in diameter hand core. Samples were sieved at 0.5 phi intervals from -1.00 phi (2.0 mm) to +1.50 phi (0.35 mm) and at 0.25 phi intervals thereafter. The graphic method of Folk (1974) was used to determine the physical grain-size characteristics (mean, median, standard deviation) of the sediments.

In order to test the working hypothesis that the settling velocity of the grains would behave predictably, depending on physical grain-size and shape, groups of ten grains from a number of grain size and shape (R:P) classes were dropped through a 2 m water column and settling velocities were recorded. Terrigenous grains in the same size classes were treated in a similar fashion.

The goal of the experiment was to determine whether the grain size determined for a given carbonate sample could be "adjusted" to a terrigenous equivalent

using settling velocity as a common variable. If the carbonate grains behaved in a predictable fashion, then existing terrigenous-based sediment transport relationships could be applied to carbonate sediments after this "adjustment" is made.

Results

There is a strong indication that the results of our settling experiments can be used to more closely relate movement of carbonate sediments to physical processes occurring in the marine environment. Preliminary studies (Fig. 3) indicate that coral and terrigenous grains of equivalent sizes behave similarly, but not identically with respect to their relative settling velocities. Coral grains of 2.50 mm (ϕ -2.0) or larger, settle more slowly than similar sized terrigenous material. This difference is due primarily to density differences and shape of the carbonate grains. Grains finer than 0.250 mm (ϕ 2.0) were found to settle at essentially equal velocities regardless of their composition.

Data also indicate that the effects of grain shape behave in a predictable manner. Figure 4 shows the good correspondence between predicted velocity values based on our working hypothesis and observed values from the settling experiment.

Given this relationship between carbonate grain size and shape, and a corresponding terrigenous grain size, it becomes possible to "adjust" the physical grain size values obtained by sieving the carbonate sands to a terrigenous hydraulic equivalent grain-size, that is, the terrigenous grain size that would be expected to have similar settling properties in the marine environment. This method is illustrated in Figure 5A. The graph is entered at the appropriate point corresponding to the physical size and shape (R:P) of the carbonate sediment in question. The terrigenous size with an identical settling velocity is the hydraulic equivalent. This value can then be used in existing sediment transport relationships (for example, the Hjulstrom diagram shown in Figure 5) to determine the magnitude of the current necessary to move sediment of a given grain size. Once a terrigenous hydraulic equivalent

grain size is determined, the critical velocities for erosion and deposition are easily determined.

Discussion

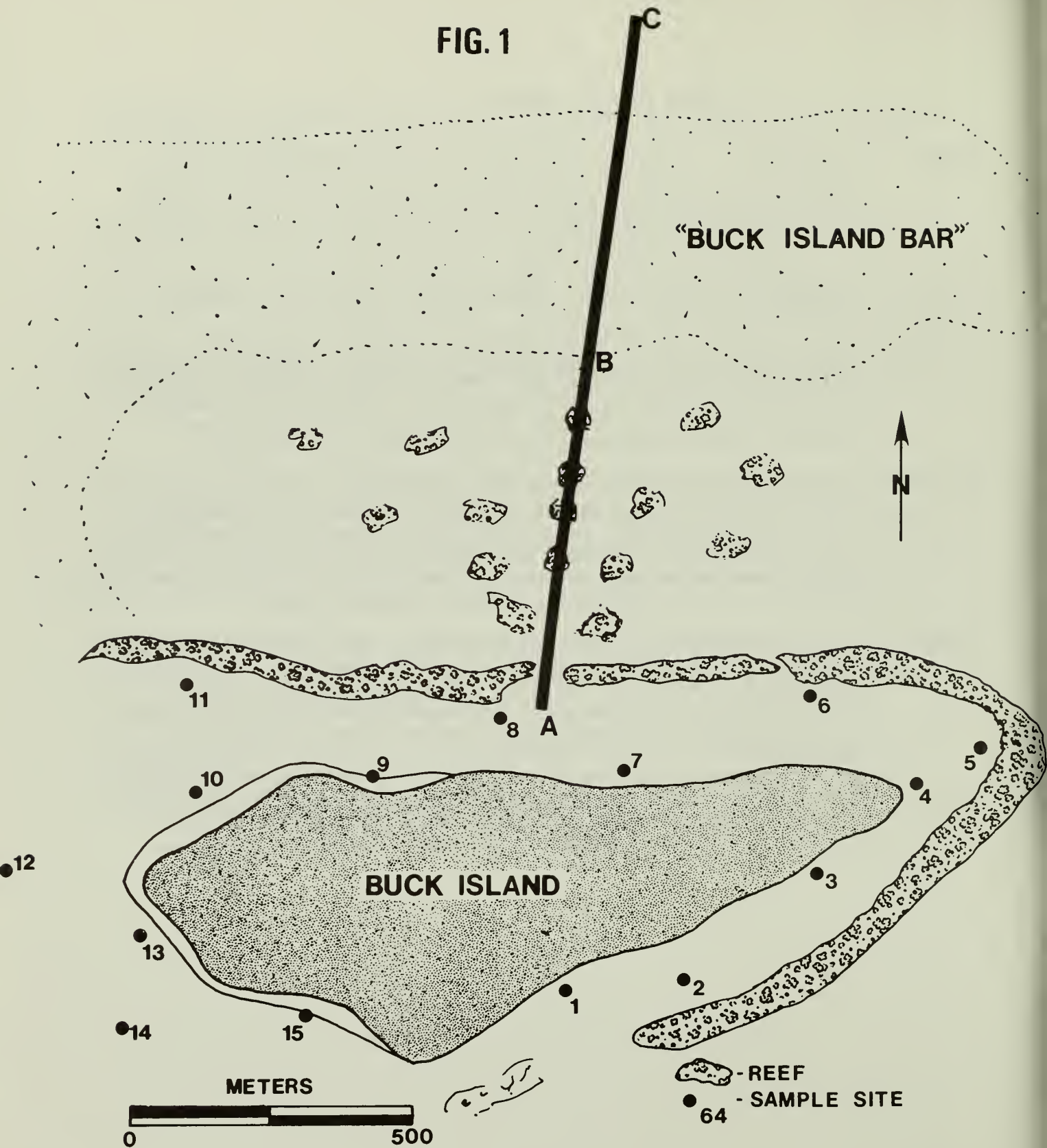
It should be stressed that these experiments are only preliminary. The relationships between grain size, type and shape is clear. A number of other factors (bioturbation, submarine cementation, organic content of the sediment) need to be considered before a reliable predictive sediment transport model can be generated, however.

Even at this stage of development, the concept can be used to explain some of the sedimentation patterns observed in the reef-lagoon complex. For example, sediments in the lagoon are generally bi-modal and poorly sorted (Levin, 1978). The dominant grain-sizes are coarse and fine sands. The coarse fraction is composed of Halimeda sp. which grows in the lagoon and cannot be carried away by the weak currents. To a sedimentologist looking at this sample, the coarse grained material gives an anomalous indication of a higher energy environment. If the coarse, platy Halimeda grains are "adjusted" to their terrigenous equivalent grain size, however, it becomes obvious that hydraulically they are similar in size to the rest of the finer sediments occurring in the lagoon. By this method, a more accurate picture of the energy level in the lagoon emerges.

FIGURE LEGEND - CHAPTER II

- Figure 1 Map showing: 1) position of bathymetric bottom profile (Fig. 2) located along transect A-C, 2) position of fifteen surface sediment samples taken from Buck Island Lagoon (#1-15), and 3) the position of the Buck Island Bar (where a core was drilled) to Buck Island and the Buck Island North Reef.
- Figure 2 Bathymetric profile taken along transect A-C (Fig. 1). Vertical exaggeration is 28:1.
- Figure 3 Settling velocities of carbonate and terrigenous sediments of comparable grain sizes. Note that particles smaller than 2 ϕ behave similarly, but that with increasing larger particles, the settling velocities of carbonate particles are less than terrigenous particles and in addition, round carbonates settle faster than platy carbonates.
- Figure 4 Plot showing observed vs. expected settling velocities for groups of ten grains of varying shape distributions. Expected velocity was computed using the ratio of round to platy grains in the group and the fall velocities for round and platy grains of that size. Observed velocity was the average velocity of the ten grains dropped simultaneously. The line $Y = X$ is not a statistically determined line.
- Figure 5 Diagram illustrating a simplified concept of determining the velocity required to move carbonate grains of a given size and shape. The upper graph is entered at the physical grain-size (from sieves of the sediment (1)). At the point corresponding to the ratio of round to platy grains in the sample, a horizontal line (2) is drawn to intersect the terrigenous settling curve. That point corresponds to the terrigenous grain-size with an equivalent settling velocity (3). This "adjusted" size is carried into the lower diagram (4) until it intersects the line denoting critical velocity (5). The velocity required to move the sediment (6) is read from the right ordinate.

FIG. 1



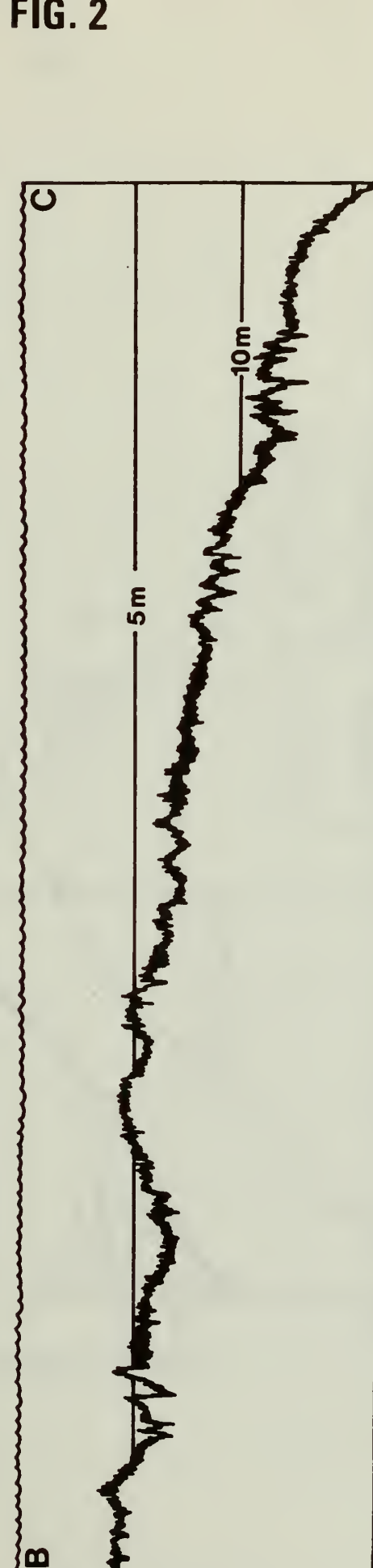
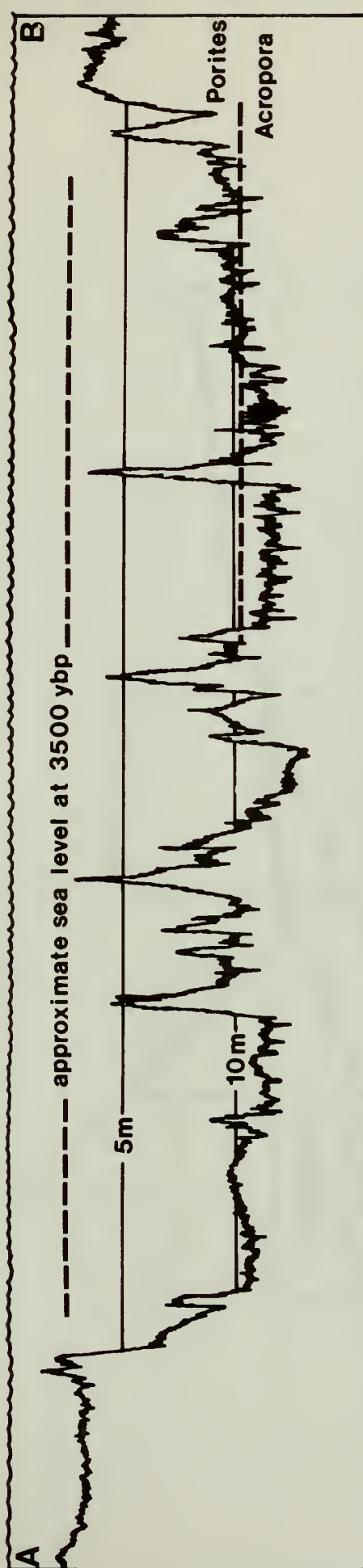


FIG. 2

FIG. 3

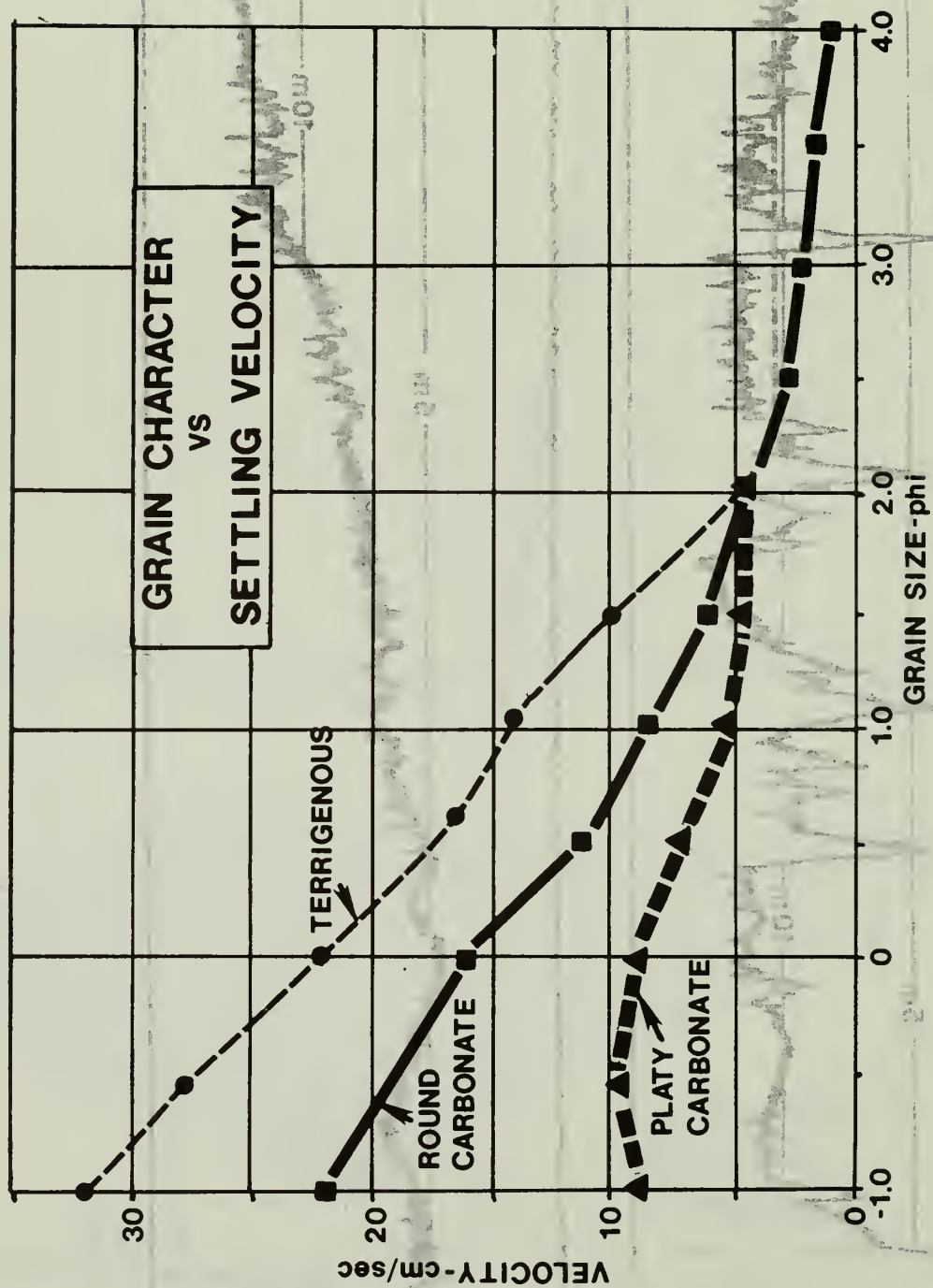


FIG. 4

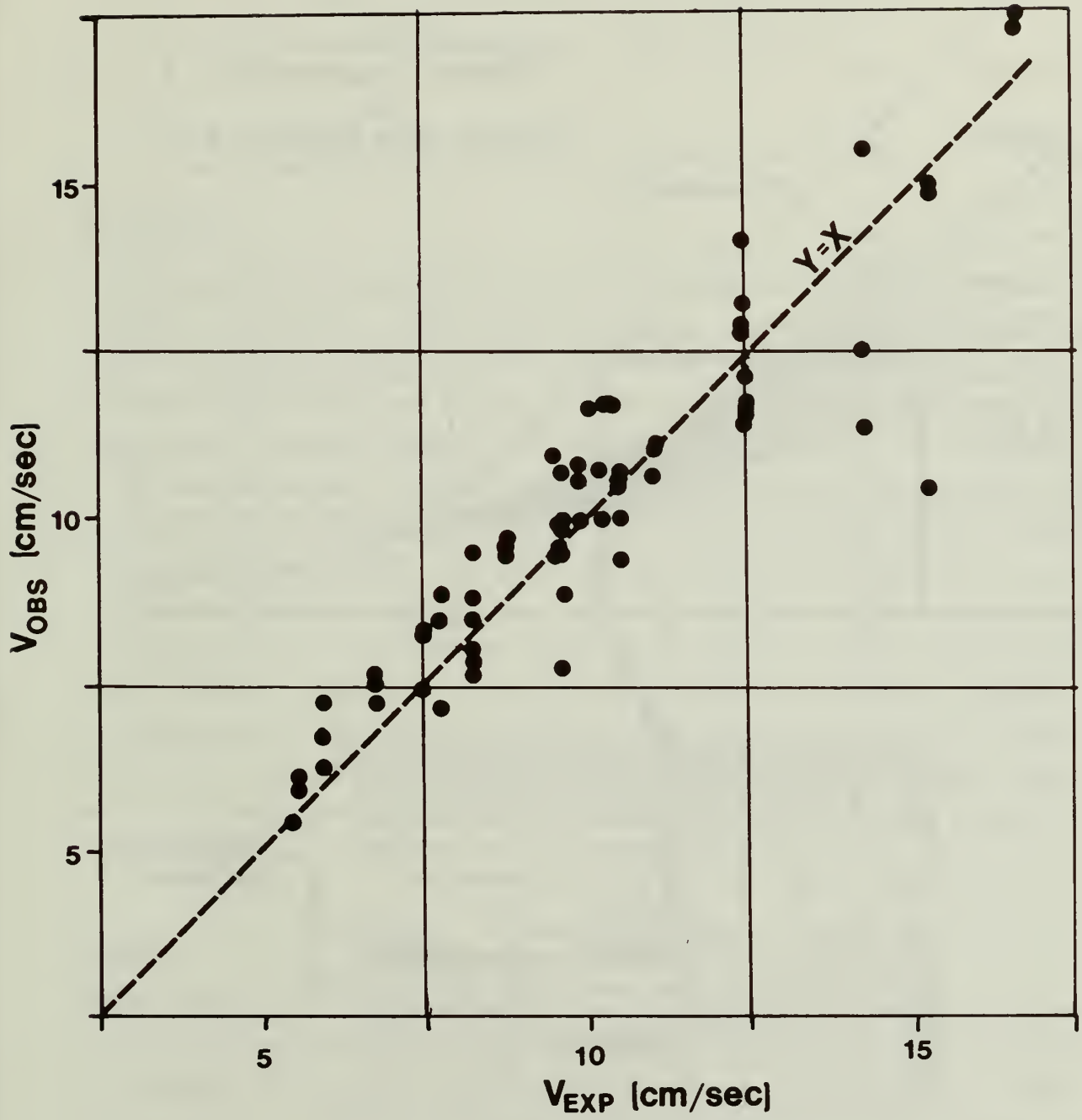
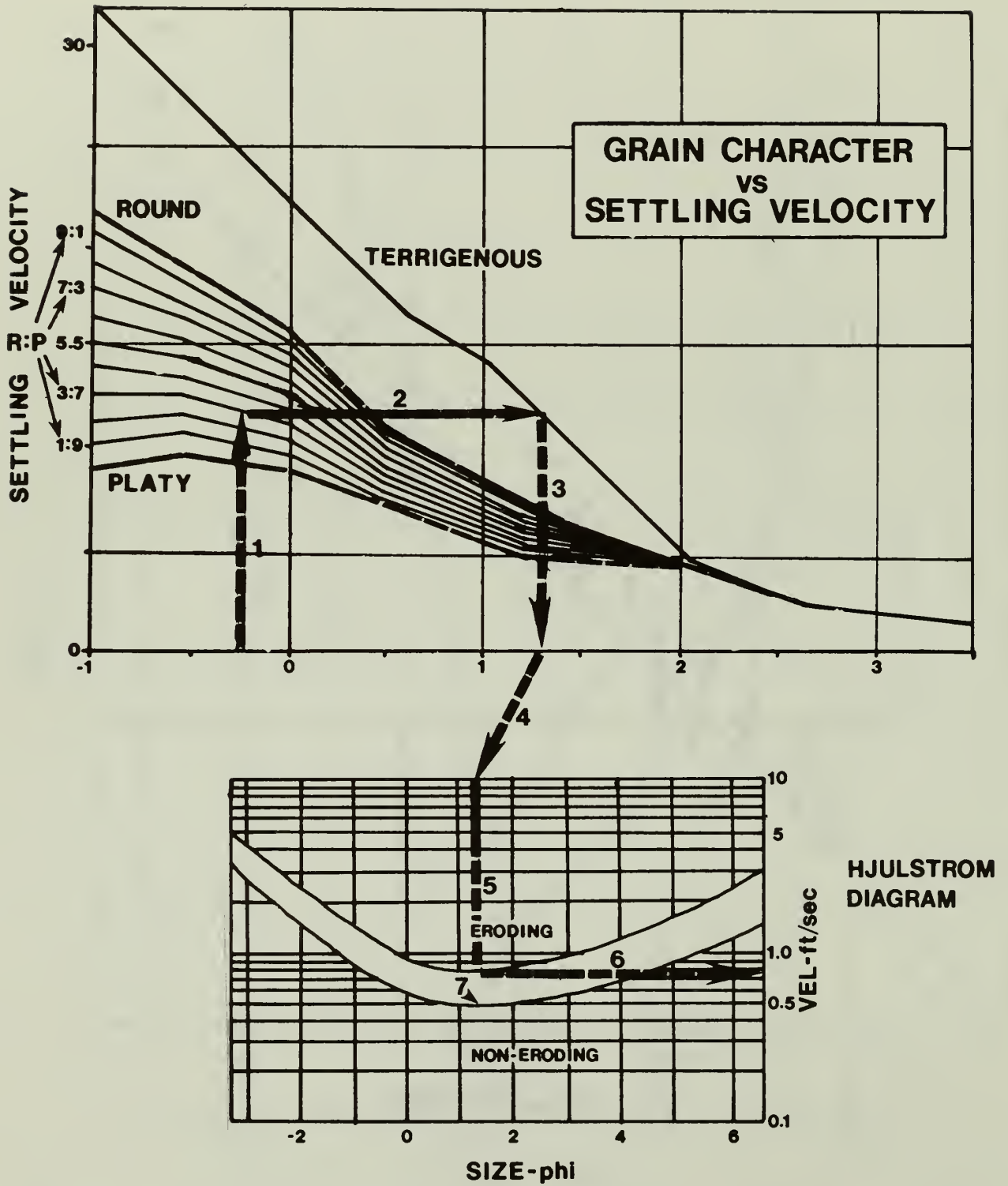


FIG. 5



CHAPTER III

GROWTH AND TOTAL CARBONATE PRODUCTION BY ACROPORA PALMATA ON WINDWARD FOREREEF

by

William B. Gladfelter & Elizabeth H. Gladfelter

Introduction

Studies carried out at Buck Island 1976-1977 (Gladfelter et al., 1977; Gladfelter and Monahan, 1977; Gladfelter et al., 1978) determined linear growth rates of Acropora palmata from three major reef zones at Buck Island. Rates were determined during two 2-month periods of maximum and minimum water temperature. Carbonate deposition rates per unit area of tip were greatest on the shallow windward forereef near the eastern boundary of the park. This eastern tip of the Buck Island barrier reef has the densest and best developed stand of A. palmata within the park (and one of the best on St. Croix, and probably the Virgin Islands). Total rates of production of calcium carbonate by A. palmata were estimated for this zone by indirect methods (Gladfelter et al., 1977, p. VII-7). Because of the unique nature of this portion of the reef as a resource within the park and because of the controversial nature of the magnitude of carbonate production on modern reefs (Smith and Kinsey, 1976; Bak, 1976), more precise, longer term studies of total carbonate deposition in that zone were carried out.

Methods

Twenty large arms of forereef colonies of A. palmata at depths of 2 m, 3 m and 4 m were stained with Alizarin Red S by methods described previously (Gladfelter and Monahan, 1977) but using appropriately large clear plastic bags. Arms approximately 1 m in length were stained in mid-August 1977 for 8 h then tagged with plastic flagging. One year later (August 1978), these arms were removed and returned to the West Indies Laboratory and serially sectioned at 15 cm intervals proximally from the tip. Slabs <1 cm thick were taken at each interval and x-rayed and the resulting negatives analyzed on a light table. The position

of the dye marker beneath the colony surface was measured as well as the periodicity of the more or less concentric density bands. The dried coral tissue was removed from the distal tips with chlorox and the new growth beyond the dye marker measured and weighed.

Density of A. palmata on the shallow forereef was determined in the following way. Three widely spaced transects were swum with a Nikonos camera and 21 mm lens. Photos were taken vertically downward at more or less regular intervals (every 20 kicks) to minimize bias. A meter scale was included in the first and last frames of each transect. The resulting color slides (high resolution Kodachrome 25) were analyzed in the following way. The percent coverage in each of twenty-five randomly chosen slides by A. palmata was determined under the dissecting microscope with an ocular grid. The number of tiers of the coral was then estimated. These values were multiplied and doubled to give the total surface area of live A. palmata per m².

The total calcium carbonate deposited per m² was determined by multiplying the total surface area of live coral per m² by the mean radial increment as determined in the earlier part of this section, to yield total volume, then multiplying by the specific gravity of A. palmata skeleton (after Bak, 1976). To this was added the weight of the tips to reach the final value of carbonate deposition per m² of reef surface.

Results

A total of nine colonies were successfully stained, relocated and examined. Staining confirmed that the density bands present in cross sections of A. palmata branches have an annual periodicity (Fig. 1). Linear extension over a period of 1 yr is plotted against radial increases in the arms in Figure 2. The radial increase in the colonies examined was relatively uniform along the length of the arms. However, the upward increment (mean = 4.9 mm; s.d. = 1.1; n = 11) toward the light was more than twice the increment on the lower side (mean = 2.3 mm; s.d. = 1.1; n = 11). There was a strong negative correlation between linear extension and upward radial increment ($y = -.03x + 8.65$; $r = .96$) and between

linear extension and mean radial increment ($y = -.03 + 6.35x$; $r = .87$). It is also suggested (Fig. 2), but by no means conclusive because of the small sample size, that shallower colonies are characterized by a greater degree of radial increment of the whole branch and a lesser linear extension of the distal tip. This is supported by the findings of Gladfelter et al. (1977, Table VII-1a) that deep forereef colonies had greater linear extension.

The values for surface area coverage by A. palmata are presented in Table 1. These values when multiplied by annual mean increases in radius and by the specific gravity of A. palmata skeleton and added to the annual increments of weight of colony tips yield a mean value of $10.3 \text{ kg/m}^2/\text{yr}$. This value is comparable to the estimates made by Gladfelter et al. (1977) using less precise methods. This value represents a mean increase in thickness of reef surface of about 0.7 cm/yr ($10 \text{ kg} = 10^4 \text{ g}$, divide by specific gravity: $10^4 \text{ g}/1.5 \text{ g/cm}^3 = .7 \times 10^4 \text{ cm}^3$, divide by $10^4 \text{ cm}^2/\text{m}^2 = .7 \text{ cm/yr}$).

Discussion

The value for reef growth rate on the shallow eastern forereef at Buck Island obtained by direct measurement of annual deposition of calcium carbonate is comparable in magnitude to the maximum reef growth rates obtained for other shallow water, single species dominated reefs using core drilling and radiocarbon dating. Adey (1975), also working at eastern St. Croix, found maximal reef growth rates of shallow Acropora palmata stands to be as high as $15 \text{ m}/1000 \text{ yr}$ or 1.5 cm/yr . Macintyre and Glynn (1976) working off the Caribbean coast of Panama found rates of $10.8 \text{ m}/1000 \text{ yr}$ or 1.1 cm/yr for A. palmata stands. Glynn and Macintyre (1977) working on stands of Pocillopora damicornis on the Pacific coast of Panama found rates of $7.5 \text{ m}/1000 \text{ yr}$ or $.75 \text{ cm/yr}$. All these values are of comparable magnitude and represent the maximal values known for reef growth rates. Heretofore, rates were determined by historical analysis (radiocarbon dating of cores).

The present analysis has shown that most of the carbonate deposited in shallow forereef A. palmata stands is due to increase in thickness of the arms, rather than their apical extension ($10 \text{ kg/m}^2/\text{yr}$ vs. $0.3 \text{ kg/m}^2/\text{yr}$ for tips).

Furthermore, the ratio of new carbonate produced circumferentially to new apical growth was relatively greater for shallower colonies than deeper ones, which had relatively greater linear extension, thereby resulting in slender, longer branches deeper on the forereef. The mechanism of this phenomenon is being examined at present.

Table 1. — Total Carbonate Production by A. palmata on Shallow Windward Forereef (Depth 2-3 m)

% Coverage by <u>A. palmata</u>	# Tiers	Total <u>A. palmata</u> Surface/m ²	Total Volume <u>A. palmata</u> Deposited 1000 cm ³ /m ² /yr	Total Weight <u>A. palmata</u> Deposited kg/m ² /yr	Total Growing Tip Width (m)/m ²	Total Growth in Tips kg/m ²	Total CaCo ³ Deposited kg/m ² /yr
70	1.1	1.54	5.9	8.8	.5	.2	9.0
85	1.8	3.06	11.6	17.4	.5	.2	17.6
75	1.2	1.80	6.8	10.2	.4	.2	10.4
95	1.4	2.66	10.1	15.1	.8	.3	15.4
85	1.7	2.89	11.0	16.5	1.1	.4	16.9
90	1.5	2.70	10.3	15.4	1.2	.5	15.9
95	2.0	3.80	14.4	21.6	.3	.1	21.7
45	1.5	1.35	5.1	7.6	.5	.2	7.8
40	1.1	.88	3.3	4.9	.9	.4	5.3
15	1.0	.30	1.1	1.6	.4	.2	1.8
35	1.1	.78	3.0	4.5	.8	.3	4.8
55	1.2	1.32	5.0	7.5	1.3	.5	8.0
30	1.3	.78	3.0	4.5	.4	.2	4.7
75	1.2	1.80	6.8	10.2	.5	.2	10.4
50	1.3	1.30	5.0	7.5	.5	.2	7.7
35	1.1	.77	3.0	4.5	.5	.2	4.7
85	1.6	2.72	10.3	15.4	1.5	.6	16.0
95	1.3	2.47	9.4	14.1	.8	.3	14.4
80	1.1	1.76	6.7	10.0	.9	.4	10.4
50	1.4	1.40	5.3	7.9	.1	.1	8.0
45	1.1	.99	3.8	5.7	.7	.3	6.0
100	2.0	4.00	15.2	22.8	.3	.1	22.9
45	1.1	.99	3.8	5.7	.4	.2	5.9
30	1.0	.60	2.3	3.4	.3	.1	3.5
50	1.2	1.20	4.6	6.9	.7	.3	7.2
mean		1.75	6.6	10.0		.27	10.3
s.d.		1.01	3.8	5.8		.13	5.8
n =		25	25	25		25	25

FIGURE LEGEND - CHAPTER III

Figure 1 X-radiographs of cross-sections through large branch of Acropora palmata from Buck Island forereef showing annual periodicity of skeletal density.

a. 50 cm from tip.

b. 75 cm from tip.

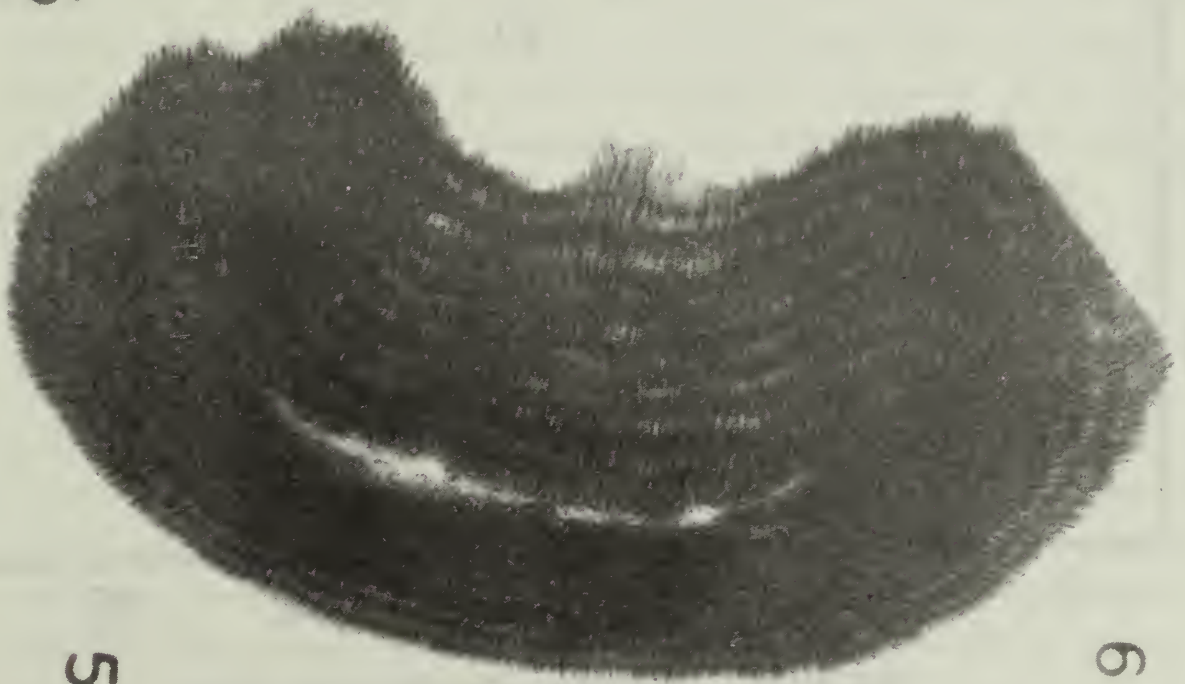
Figure 2 Growth components of Acropora palmata on the shallow forereef at Buck Island. Radial increment is plotted against linear extension at the branch tip for a 12 month period. Dark symbols indicate upward radial growth increment; light symbols indicate mean radial growth. Circles indicate colonies at 2 m depth; squares, colonies at 3 m depth; and triangles, colonies at 4 m depth. The upper regression is: $y = -0.3x + 8.15$, $r^2 = .92$; the lower is: $y = -0.3x + 6.85$, $r^2 = .75$.

FIG. 1

a



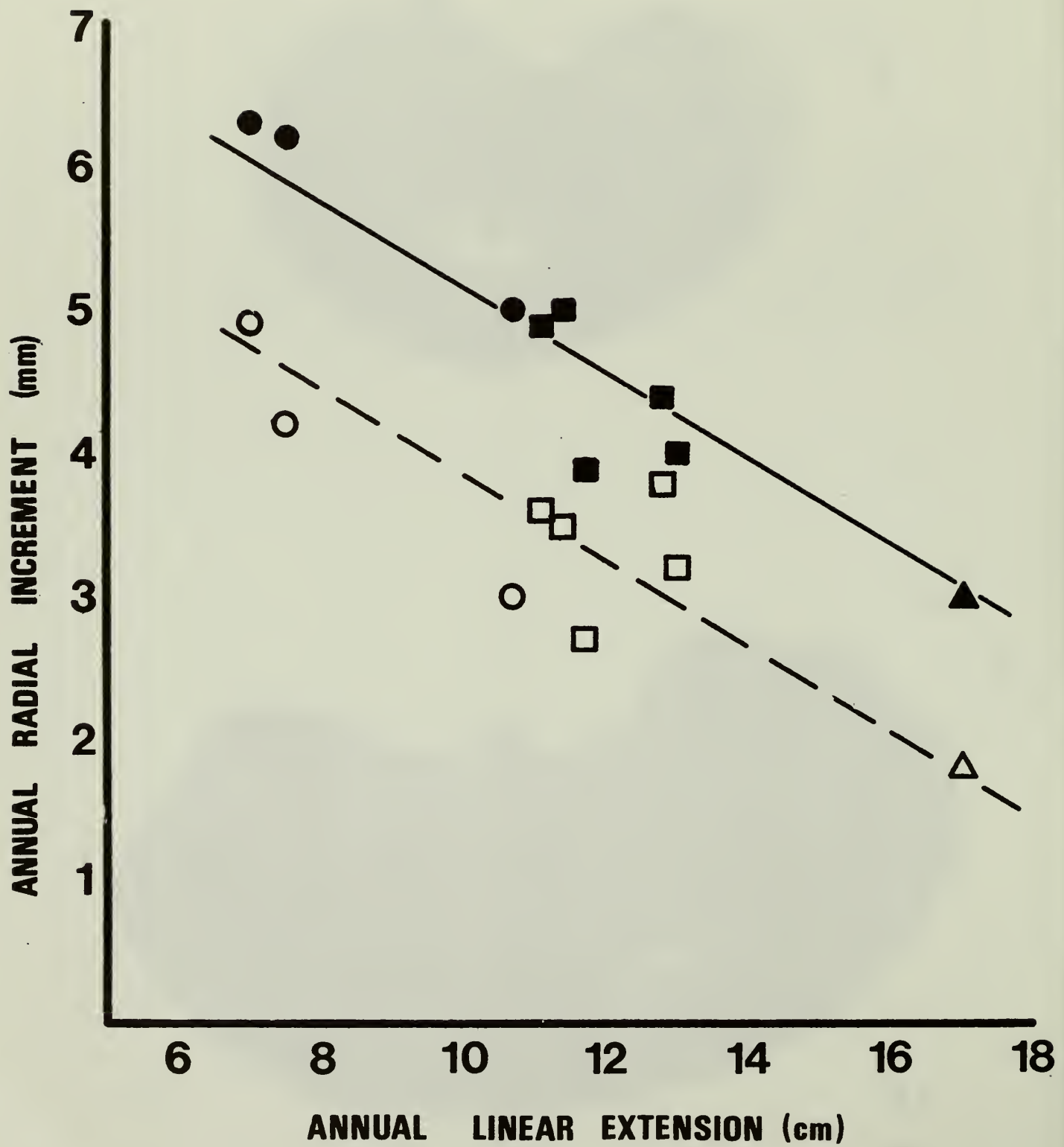
b



50

65

FIG. 2



CHAPTER IV

BEACH PROCESSES

by

Dennis K. Hubbard

Introduction

In November 1976, ten permanent beach profiles were established to monitor changes in the beach at the western end of Buck Island. These profiles (Fig. 1) were run for a period of one year as part of a larger National Park Service (NPS) contract to study resource utilization within the National Monument. The study described below was a continuation of that program. In addition to the initial goal of beach monitoring, it was hoped that seasonal trends in beach changes could be documented and some preliminary relationships between these changes and local weather patterns might be identified.

Methods and Materials

The ten profiles established during the first year (Fig. 1) were monitored regularly using the leveling method described by Emery (1961) and modified by Hayes et al. (1973). A typical profile is shown in Figure 2. With this method, beach profiles are run from a permanent reference point and can be compared to determine volumetric changes in the beach between measurement points. During the second year, two additional profiles (3a and 6a) were established to monitor changes not covered by existing profiles. Also, some of the profiles were moved landward because of erosion threatening the profile markers.

In the laboratory, beach profiles were plotted and the area (in m^2) under the profile was calculated to a constant datum below the profile. This value can also be expressed as m^3/m of beach. In order to determine the total amount of sand gained or lost within a section of beach, it was assumed that changes recorded along a single profile were representative of the section of beach half-way to either adjacent profile. The volume of sand gained or lost was calculated using the formula:

$$\Delta V_p = \Delta V_m \cdot \left(\frac{L_{p_1} + L_{p_2}}{2} \right),$$

where:

ΔV_p = change in volume (in m^3) along the beach section represented by the profile

ΔV_m = the change in volume (in m^3/m) measured at the profile

L_{p_1} = distance (in m) between the reference profile and the next profile to the right

L_{p_2} = distance (in m) between the reference profile and the next profile to the left.

The total amount of sand gained or lost from the entire beach was calculated by summing the ΔV_p values for all profiles.

The unit m^3/m was chosen to standardize beach changes from area to area, and is a widely accepted engineering term. It is, however, often hard to think in m^3/m . Therefore, the linear change necessary to produce one m^3/m of volumetric change was determined. For purposes of estimation, a value of 0.3 - 0.5 m of linear change corresponds to a value of one m^3/m .

Results

The beach on Buck Island is similar to a number of beaches found on Trade Wind islands (Murray et al., 1977). It is similar in position and probably processes, to the leeward beaches of St. Croix. The beach can be divided into three zones depending on the dominant erosion-deposition patterns (Fig. 1).

Zone I. — Zone I consists of Profiles 1, 2, and 3, and is located on the northwest corner of the island (Fig. 1). The beach is backed by a wide vegetated bench, and is typically narrow (10-15 m) and steep (Fig. 2). With only a few exceptions (generally on Profile 3a), changes were small in this zone and the

area was characterized by overall stability (Figs. 3-5). At Profiles 1 and 2, volumetric changes were generally less than $2 \text{ m}^3/\text{m}$ between measurements.

Zone II. — Zone II, the main bathing beach, is represented by Profiles 4-8 (Fig. 1). The beach is generally wide and convex-upward in profile (Fig. 6). The upper profile is generally vegetated by dune grasses and other stabilizing flora. Profiles 5-8 are terminated on their landward ends by vertical cliffs of the Caledonia formation, which forms the core of Buck Island.

The largest changes seen in any of the profiles occurred in this section (Figs. 7-11). For example, between 13 October and 28 November 1977, a sand loss of $44 \text{ m}^3/\text{m}$ of beach was measured at Profile 7 (Fig. 10). The profile eroded over 20 m during that time period.

Zone III. — Zone III is located on the southerly-facing side of Buck Island beach (Profiles 9 and 10; Figure 1). The beach is typically narrow and backed by Caledonia cliffs (Fig. 12). In terms of mobility, this beach is intermediate between Zones I and II. Volumetric changes on the order of $1-3 \text{ m}^3/\text{m}$ are typical in this area (Figs. 13 and 14). The active beach is a thin veneer over a beachrock pavement.

Beach Changes

Comparison of the 1976-1977 and 1977-1978 periods indicate that during the past year the beach has been considerably more stable than during the preceding period of record (Fig. 15). Despite the dissimilarity of the data from one year to another when considered on a month-to-month basis, a number of inferences can be made. First, there is a rough seasonality about the changes that occur. Between October and the April to June period, sediment is added to the beach system. Then, there is a short 3-4 month period of accelerated erosion. Interestingly, however, the accretion occurs during the winter and spring months, just opposite to the pattern predicted by Shepard (1973).

In order to explain this seemingly anomalous pattern of erosion and deposition, some of the individual profile changes must be examined. Tables 1 and 2 show

the changes in the volume of sand contained within the beach of each shore-line segment between November 1976 and July 1978. It can be seen that, in general, the dominant process is one of exchange between Zones II and III. Accretion in one zone occurs at the expense of the other. During the October to April period, there is an overall gain of sediment to the beach and a corresponding shift of material from Zone II to Zone III. During the rest of the year, sand moves from Zone III to Zone II and off the beach (Fig. 16).

This pattern can be related to seasonal wind patterns. The Fall and Winter periods are dominated by strong northeasterly flow related to the periodic passage of low pressure cells through the Virgin Islands area. During the Spring and early Summer months, in contrast, strong winds from the southeast often occur. Also, this is the time when the strongest winds are recorded, generally from the east.

It appears that during the October to April period, the larger northeasterly waves refract around Buck Island and move sediment from Zone II to Zone III (Fig. 16). Although the mechanism by which sand is added to the overall system is not apparent, two possibilities have been identified. Inasmuch as the currents that occur in Buck Island lagoon are generated by the mass physical transfer of energy from incoming wind and waves, the current energy should be higher during this time period. It is possible, therefore, that the added beach material is delivered by periodic stronger currents and redistributed by the refracted waves. Alternately, sand stored in the immediate nearshore area may be being returned to the beach during this time. We have no quantitative seasonal measurements of nearshore bottom changes, but have observed an apron of sand along the nearshore shelf seaward of Profiles 9 and 10 during period of erosion. Possibly, sand is stored in this and other similar areas for later return to the beach. The potential importance of either mechanism can be tested by a number of methods and should be done as part of future studies.

During the Summer and early Fall period, strong easterly and southeasterly winds affect a clockwise shift of sediments from Zone III to Zone II (Fig. 1). This is accomplished by two mechanisms. First, the wind-generated waves move

sand along the beach in the active swash zone (Fig. 16). Secondly, the wind itself carries large quantities of medium- to fine-sand in a westerly direction. During several visits to the beach, a 30-40 cm thick sediment traction carpet (a zone of water mass movement in which sand is maintained in partial suspension) was observed, and large quantities of sand were in transit. During these periods of strong winds, the beachfaces of Profiles 7 and 8 were essentially migrating dune slipfaces. The slope of the beach was higher than was characteristic of calmer periods. In addition, the beach face seemed to be comprised of much finer-grained material, also indicative of a wind-dominated environment.

Sand transport from Zone III to Zone II by waves was observed to occur in the form of beach protuberances or giant cusps (Fig. 17). This method of transport is quite common in the beach environment and results from a local reorientation of the beach into the prevailing wind direction. Inasmuch as the beach cannot entirely align itself into the wind, it is broken down into smaller segments (the protuberances), each with an aligned beach (Fig. 17).

The migration of such features through an area can have a marked effect on changes within individual profiles. As a protuberance moves past a profile, rapid accretion or erosion will be noted, depending on where the protuberance is relative to the profile (Fig. 17). A good example of this occurred at Profile 7 between 26 April and 15 June 1978. On 3 May, one protuberance moved past the profile area and caused significant erosion ($7.25 \text{ m}^3/\text{m}$). By 15 June, however, the protuberance had moved by and accretion continued (Fig. 10). Many of the short-term variations in the beach profile can be explained by this mechanism.

One other important observation involves the effects of various types of storms on the beach. During the Fall and early Winter months, storms are generally of two types, wind storms and rain storms (both may occur simultaneously). In general, the wind storms seem to affect the northern profiles (Profiles 1 and 2; Figure 1) because of their exposure. In contrast, rain storms generally do the most damage on the southerly-facing beaches. This is related to the nature of the back-beach area. The northern beaches are backed by a wide, vegetated

plain which effectively buffers the runoff from most storms. The southerly beaches, however, are backed by cliffs and runoff flows directly onto the beach. Often during even moderate rainstorms, deep gullying and severe local erosion have been observed, even if no significant wave activity had occurred previously (Fig. 8). Much of the erosion occurring at Profiles 9 and 10 between August and October 1977 can be attributed to runoff problems.

Discussion

There are presently two schools of thought concerning beach changes and their controlling factors. Shepard (1973) described the Summer-Winter beach profile cycle for California. During the Summer months, the beach described was wide and convex-upward in profile. During the Winter, the beach underwent significant erosion and assumed a concave-upward profile. Most of the sand lost from the beach was generally "stored" in an offshore bar for return to the beach during the following Summer.

Hayes et al. (1973) considered the beach profile to be less directly tied to strict seasonal boundaries and related beach profile changes to the passage of major storms. Their post-storm beach is similar to the "Winter" beach of Shepard (1973); their recovered beach is Shepard's "Summer" beach.

Interestingly, the beach at Buck Island seems to correspond to neither classification (or perhaps both, depending on how the data are viewed). Seasonal changes do occur, but not in the pattern or with the regularity predicted by Shepard. Furthermore, "Summer" and "Winter" profiles can be viewed simultaneously at different areas on the island. On the other hand, changes in beach morphology are not always directly linked to major frontal passages as described by the Coastal Research Group (1969).

This apparently anomalous situation can be explained as a result of Buck Island's position in the Trade Winds belt. Similar to the California coast, where Shepard developed his beach cycle, the wind blows dominantly from one sector, and except for small changes in direction, the only significant variable is wind

speed. The main difference between the California coast and Buck Island beach is one of exposure. In California, the westerly winds blow onshore, while on Buck Island, the Trades blow offshore. It is therefore not surprising that the seasonality associated with changes on the main bathing beach (essentially, Zone II; Figure 1) is inverse to that predicted by Shepard.

The variability in the beach changes from zone to zone is a function of the wider variability in beach orientation with respect to the wind. Owens (pers. commun.) came to a similar conclusion in his study of the Magdalen Islands in Canada. The westward (windward) facing beaches followed the Summer-Winter profile cycle predicted by Shepard (1973). In contrast, the eastward facing beaches were more subject to storm-related wave attack, and behaved according to the scheme of Hayes et al. (1973).

Based on our present understanding of the transport system on Buck Island, the next phase of investigation should be to more closely document the amounts of sediment being transported onshore-offshore vs. alongshore, and to identify the physical mechanisms responsible for this shift. It is therefore recommended that the interval of profile monitoring be increased so as to only reflect larger-scale seasonal changes in beach volume. The beach would still have to be visited often to determine where the profiles should run, however. In conjunction with the profiling, two programs should be initiated. The first would be a sediment tracer experiment to document seasonal sediment motions; a current measurement program should be run concurrently. In addition, an organized process monitoring program should be established. Important variables would be daily measurements of wind velocity and direction and wave height and approach direction.

Table 1. — Total $\Delta V(M^3 \times 10^2)$ 1976-77

	1-3	Profile Numbers 4-7	8-10
22 November	-10.06	+ 3.96	- 2.70
13 December	- 1.07	+16.23	+12.0
05 January	+ 2.86	- 6.54	-13.1
25 January	+ .61	-14.97	+17.0
14 February	+ 0.41	-16.77	- 2.83
07 March	+ 0.10	+29.74	+11.25
30 March	- 0.86	+ 0.61	- 5.8
27 April	- 1.67	+15.73	-14.9
30 June	+ 0.79	+ 6.81	+ 6.1
22 August	- 2.53	+ 4.07	- 3.1
09 October	- 2.96	+ 5.63	-54.22

Table 2. — Total $\Delta V(M^3 \times 10^2)$ 1977-78

	1-3	Profile Numbers 4-7	8-10
28 November	- 3.12	-17.40	+29.88
25 December	- .29	+ 2.26	- 1.28
02 February	+ .16	- 7.95	+ 8.09
28 March	+ 5.11	-41.1	+37.92
19 April	+ .21	+ 2.16	+ 9.07
26 April	- 3.98	- .99	- 3.84
03 May	+ 2.69	-10.62	- 3.13
15 June	+ 1.55	+24.26	- 8.59
31 July	- 2.48	+ 8.15	-24.16

FIGURE LEGEND - CHAPTER IV

- Figure 1 Map showing location of permanent beach profiles (1-10) on Buck Island. The three major beach zones are identified (I, II, III).
- Figure 2 Typical profile from Zone I.
- (A) Photograph of Profile BI-1 (see Figure 1 for location). Note the scarp at the landward end of the profile and the cobble beach. The cobbles are primarily disc-shaped and composed of abraded coral reef material.
 - (B) Beach profile BI-1 measured on 31 July 1978.
- Figure 3 Volumetric changes in Profile BI-1 between 1 November 1976 and 31 July 1978. Changes on this, and all subsequent graphs, are referred to the volume of the beach on 9 October 1977 (the first profile monitoring period of Year II). Note that changes are relatively small.
- Figure 4 Volumetric changes in Profile BI-2 between 1 November 1976 and 31 July 1978. Note that changes are relatively minor, with the exception of the 20 April to 28 November 1977 period. Considerable erosion during the same interval in 1977 exposed the shell midden near the profile.
- Figure 5 Volumetric changes in Profile BI-3,3a between 1 November 1976 and 31 July 1978. Note the severe erosion during the November 1976 period. Erosion during the same time frame in 1977 washed the profile away, resulting in the data gap between 9 October and 25 December 1977. This erosion was followed in both cases by a period of considerable beach recovery.
- Figure 6 Typical profile from Zone II.
- (A) Photograph of Profile BI-7 (dashed line) taken in August 1978. Note the high berm backing the beach and the low, wide secondary berm in front. This is an area of extreme change (Figures 7-11).
 - (B) Beach profile BI-7 measured on 31 July 1978.
- Figure 7 Volumetric changes in Profile BI-4 between 1 November 1976 and 31 July 1978. Note the large changes that occurred during both years of study. Also, note the similarity between the two curves.

- Figure 8 Volumetric changes in Profile BI-5 between 1 November 1976 and 31 July 1978. Note the large changes in volume. The fact that the pattern of erosion and deposition is nearly inverse to that of Profile BI-4 suggests an exchange of sediment between the two profiles.
- Figure 9 Volumetric changes in Profile BI-6. Note the large changes. During the 1 November 1976 to 9 October 1977 period, the profile behaved similarly to BI-4. Since January 1978, however, there has been almost continual erosion.
- Figure 10 Volumetric changes in Profile BI-7. The largest changes occurring on the entire beach were measured at this profile. Between 9 October 1977 and 3 May 1978, over 80 m³/m of erosion were noted. Generally, the profile behaved similarly during both years of record.
- Figure 11 Volumetric changes in Profile BI-8. Note the large changes, especially the erosion between August and October followed by nearly continuous accretion ever since. Severe erosion can be expected again this fall.
- Figure 12 Typical profile from Zone III.
(A) Photograph of Profile BI-9 (arrow) taken in August 1978 after a heavy rain. The beach is intermediate in character between Zones I and II. During May 1978 (Figure 13), the beach was much wider, and the beach rock now exposed in the surf zone was covered.
(B) Profile measured at BI-9 on 15 June 1978.
- Figure 13 Volumetric changes in Profile BI-8 between 1 November 1976 and 31 July 1978. Note that changes are less than those occurring at BI-7 and BI-8, but greater than those in Zone I (Figures 3,4 and 5).
- Figure 14 Volumetric changes in Profile BI-9. Note the decrease in variability from Profiles BI-8 and BI-9. This profile has been relatively stable.
- Figure 15 Total volumetric changes in Buck Island Beach from November 1976 to July 1978. There is a rough trend of accretion between October/November and April/June during both years. During the fall months, erosion dominates.

- Figure 16 Diagram showing the transport of sediments during different seasons and wave conditions. During late fall and spring, transport is from Zone II to Zone III. During summer and early fall, the pattern is reversed, probably in response to the change in average wave approach direction.
- Figure 17 Diagram showing the effect of migrating beach protuberances on profile character. During the passage of the "horn" ($T = 0$), the profile is at its maximum width. During passage of the "bay" ($T = 1$), the profile indicates serious erosion. In reality, however, the total volume of sand contained in the beach system has not changed, only rearranged.
- Figure 18 Photograph of Profile BI-9 taken after a severe rainstorm. Note the gullyng in the vicinity of the profile.

FIG. 1

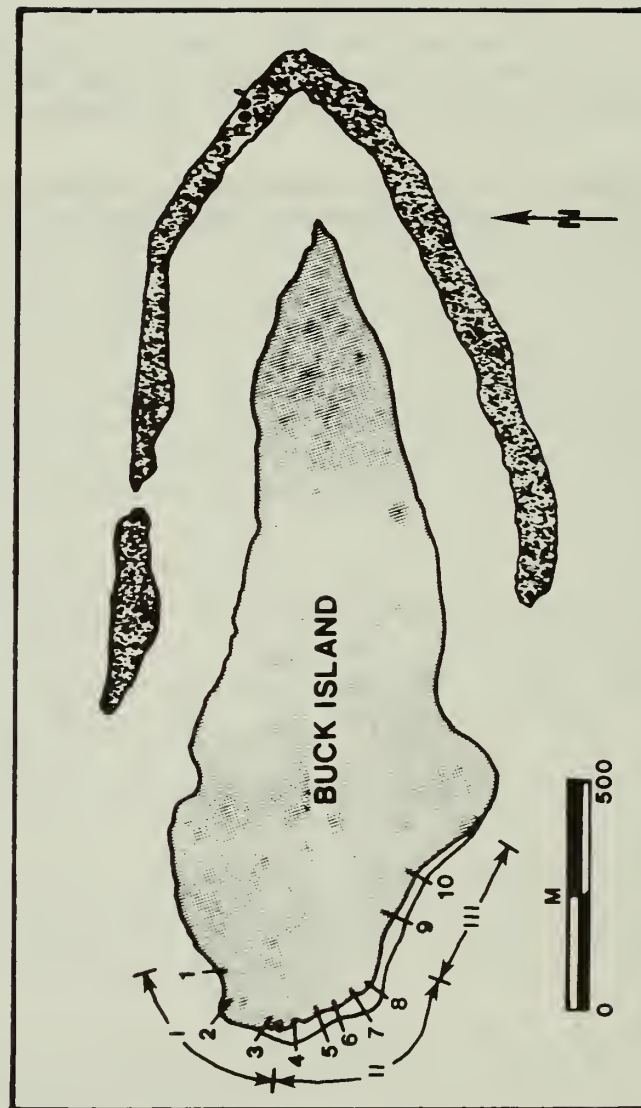


FIG. 2

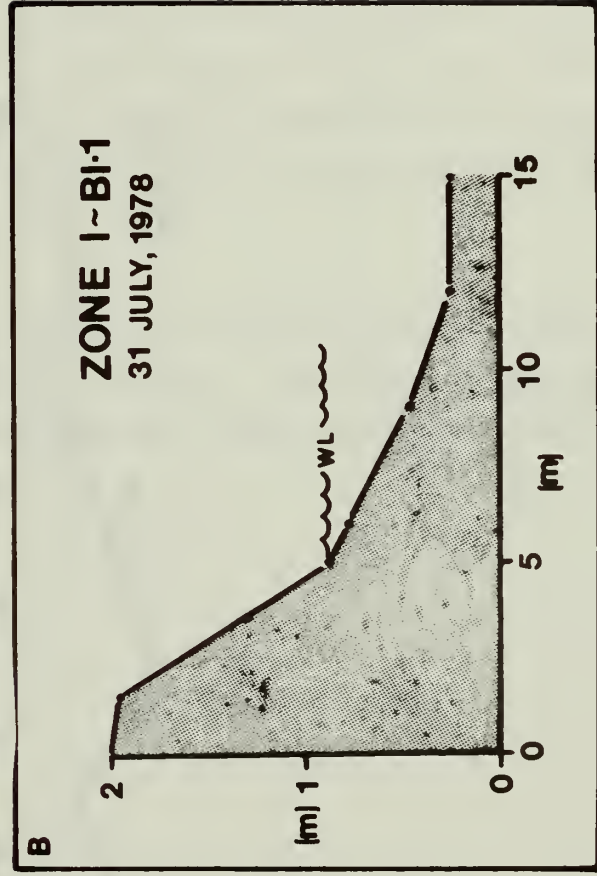
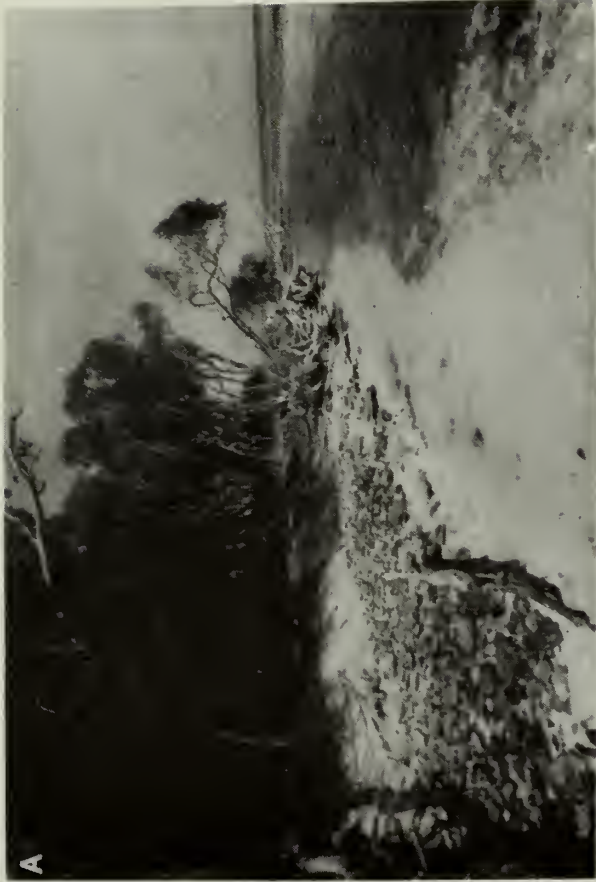
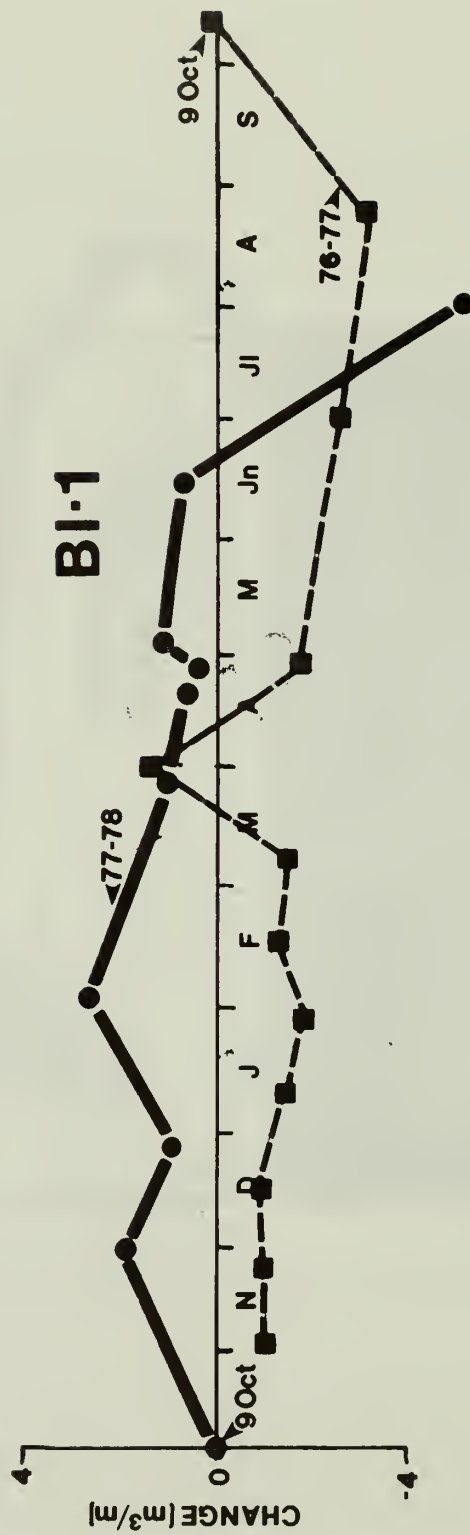


FIG. 3



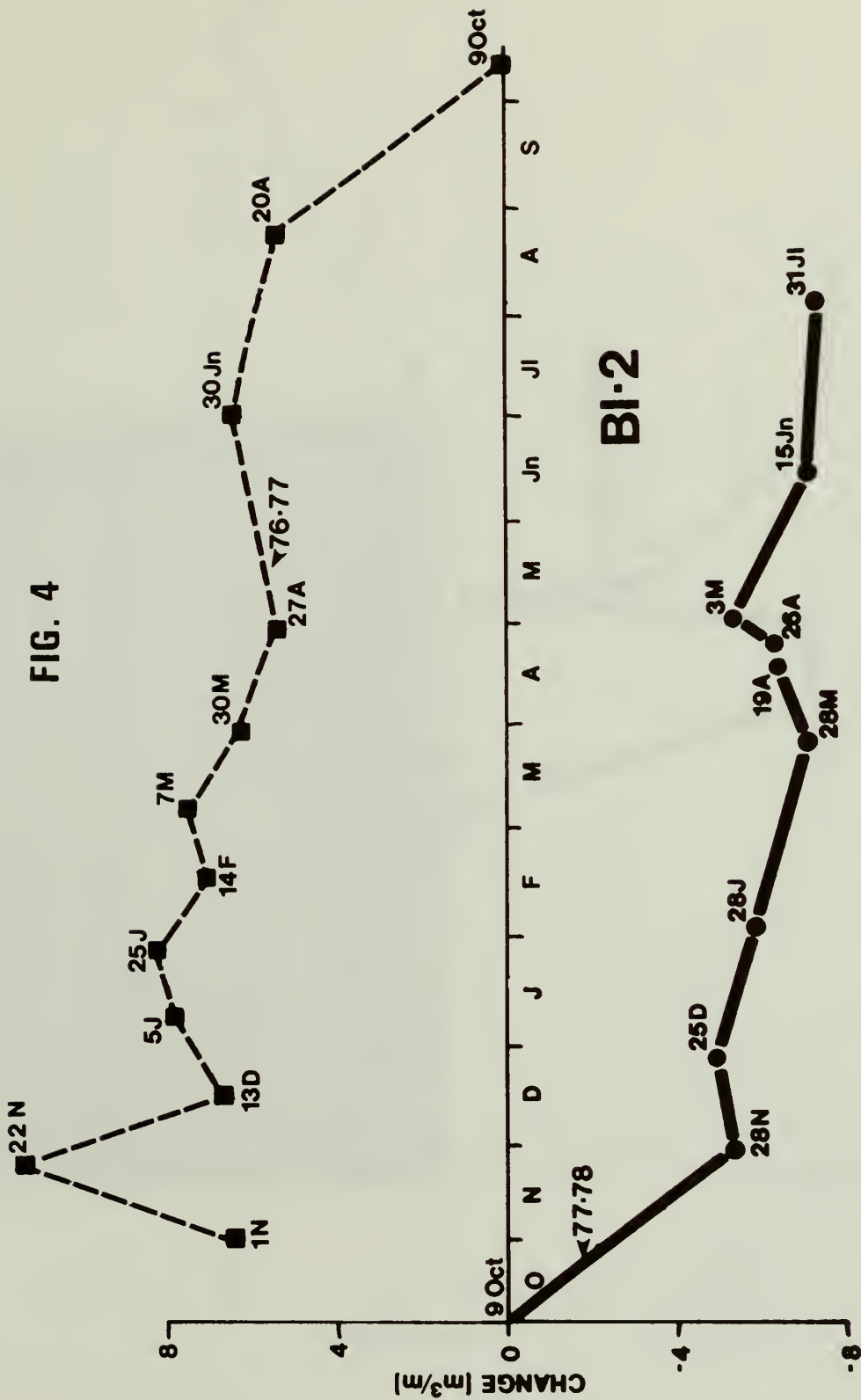
Of the fishes repeatedly recaptured, it is quite evident that the growth rate is practically zero during the period of the study (up to four months). This may be due to several factors. First, fish have indeterminate growth, i.e., under conditions of limiting resources (such as food) they will be able to maintain size, but not increase it. Also, several of the fish in the study may have been near their maximum size at the time of the study.

Although neither rate of growth nor effects of fishing pressure on maximum size of fish could be conclusively shown from this study, a great deal of information on the average sizes of a number of species of fishes has been obtained. This can serve as a baseline study to monitor changes in fish distribution and sizes in future years.

The lack of movement of many individuals away from the site of capture indicates the sedentary nature of many reef fish species. This supports the work of other authors such as Bardach, 1958; Randall, 1962; Ogden and Buckman, 1973.

Key to Table 1 and Table 2

Abundance Category	No. of Fish
1	1
2	2 - 5
3	6 - 10
4	11 - 24
5	26 - 50
6	51 - 100
7	> 100



BI-2

FIG. 5

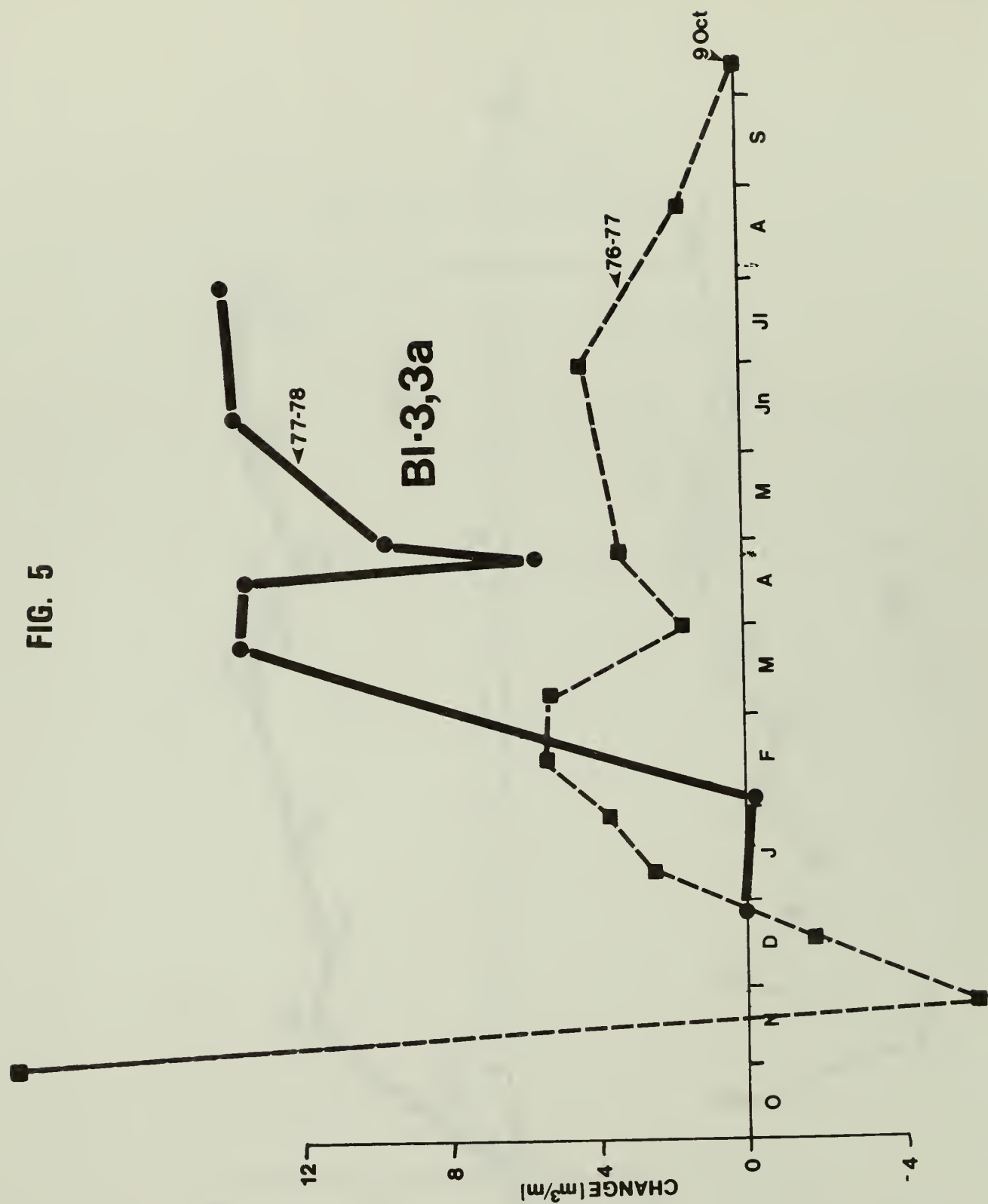


FIG. 6

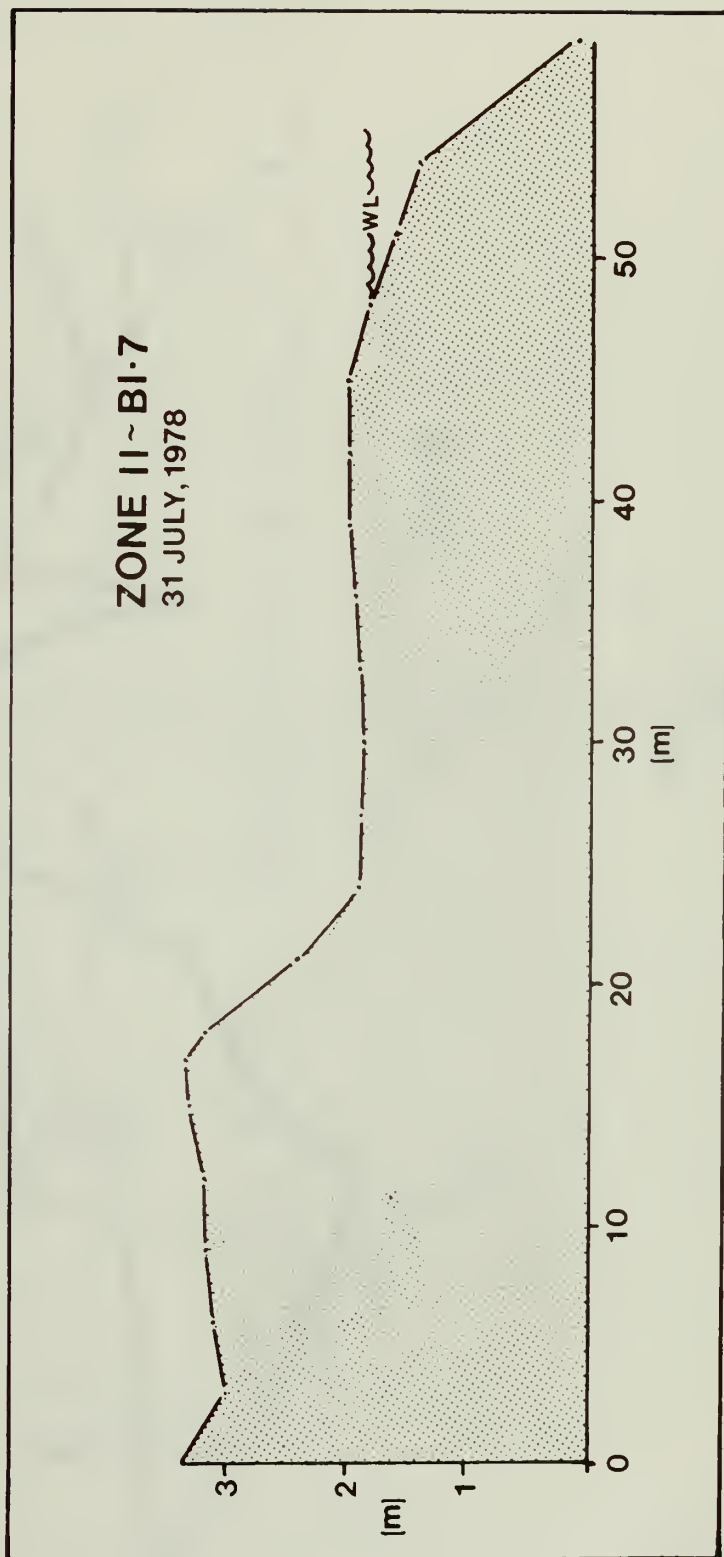
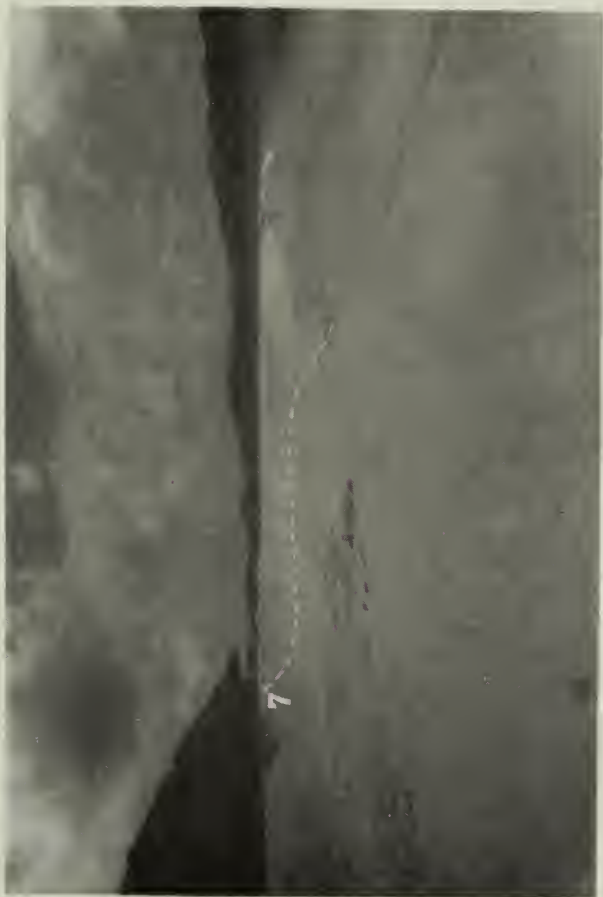


FIG. 7

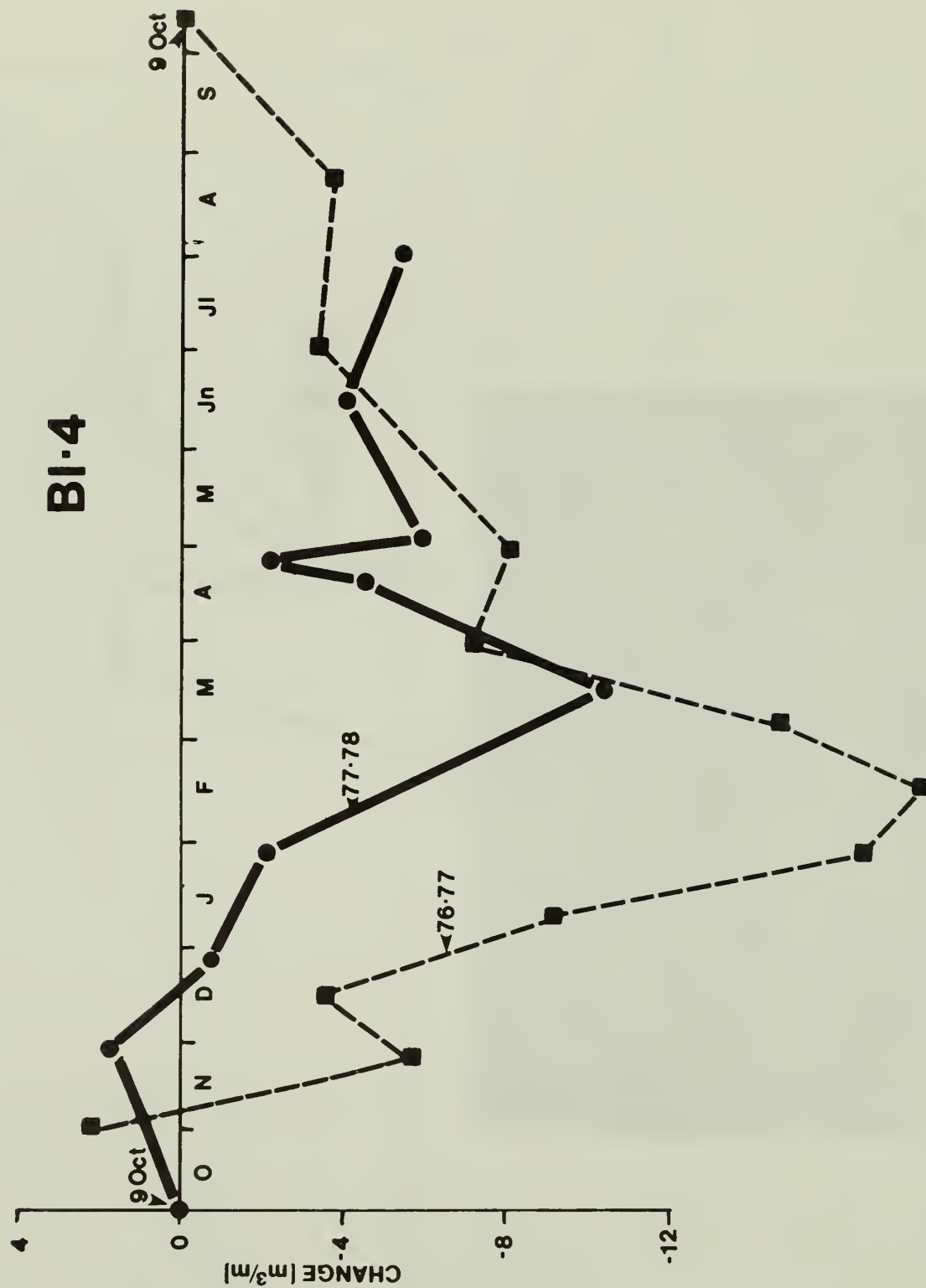


FIG. 8

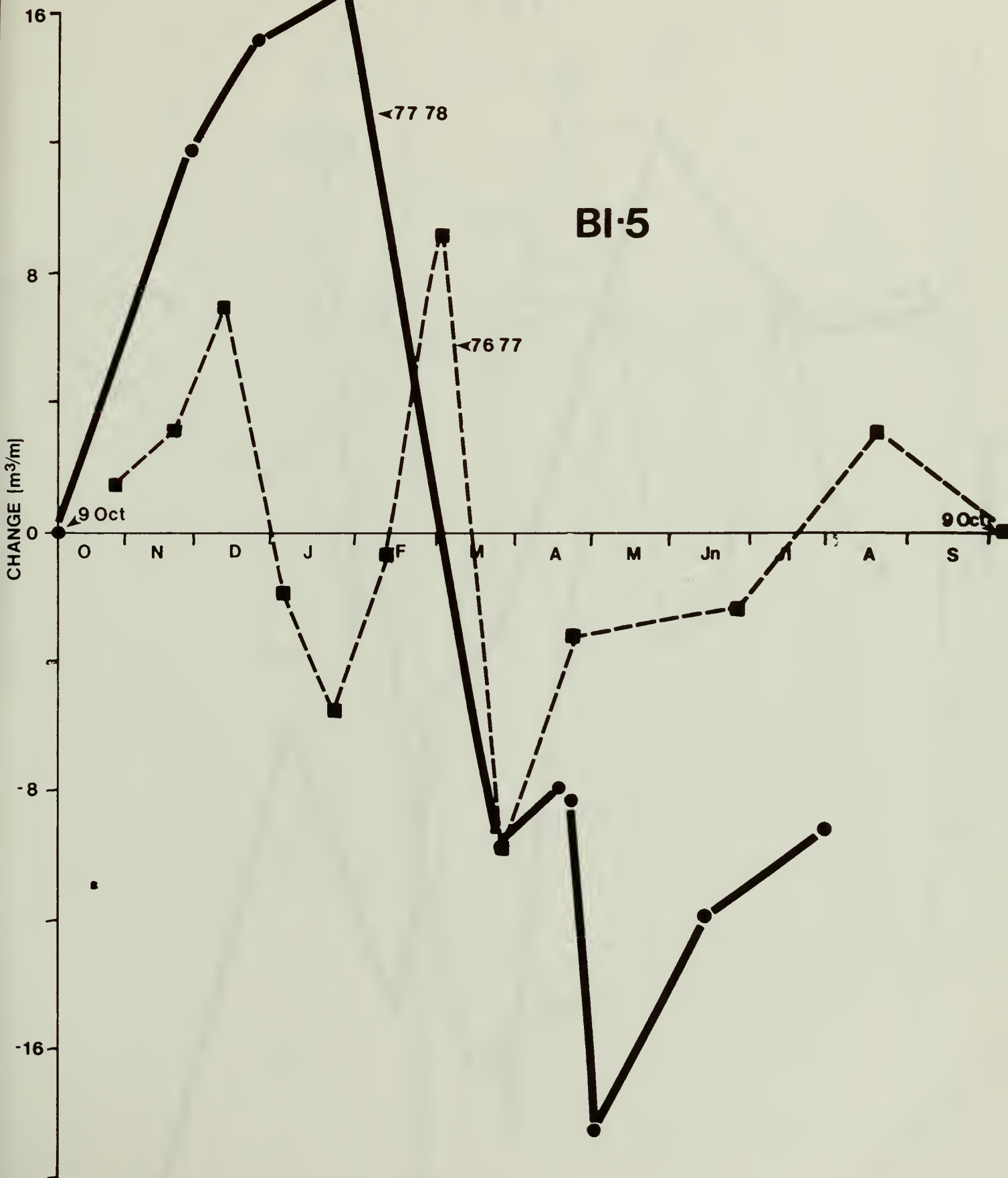


FIG. 9

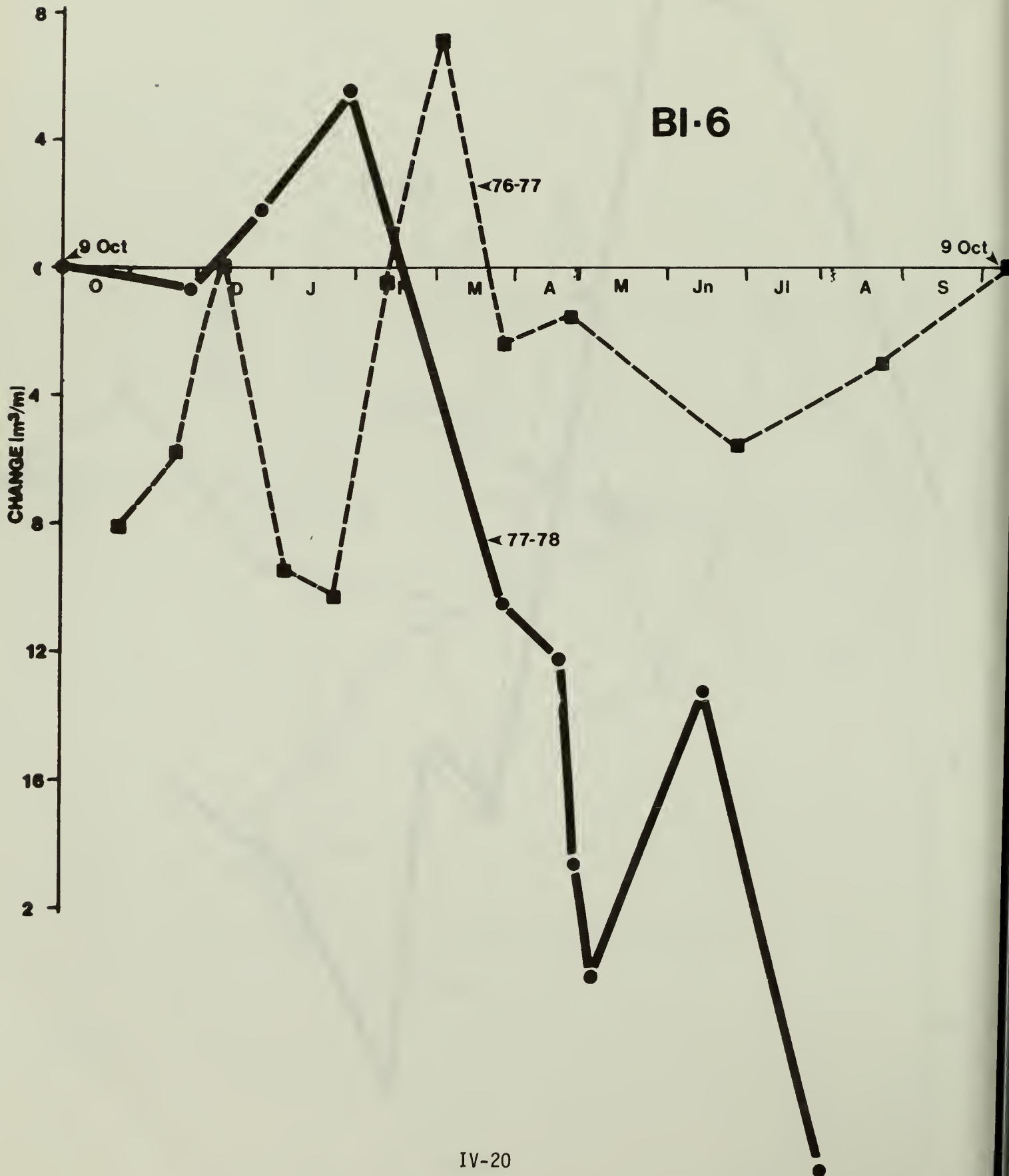


FIG. 10

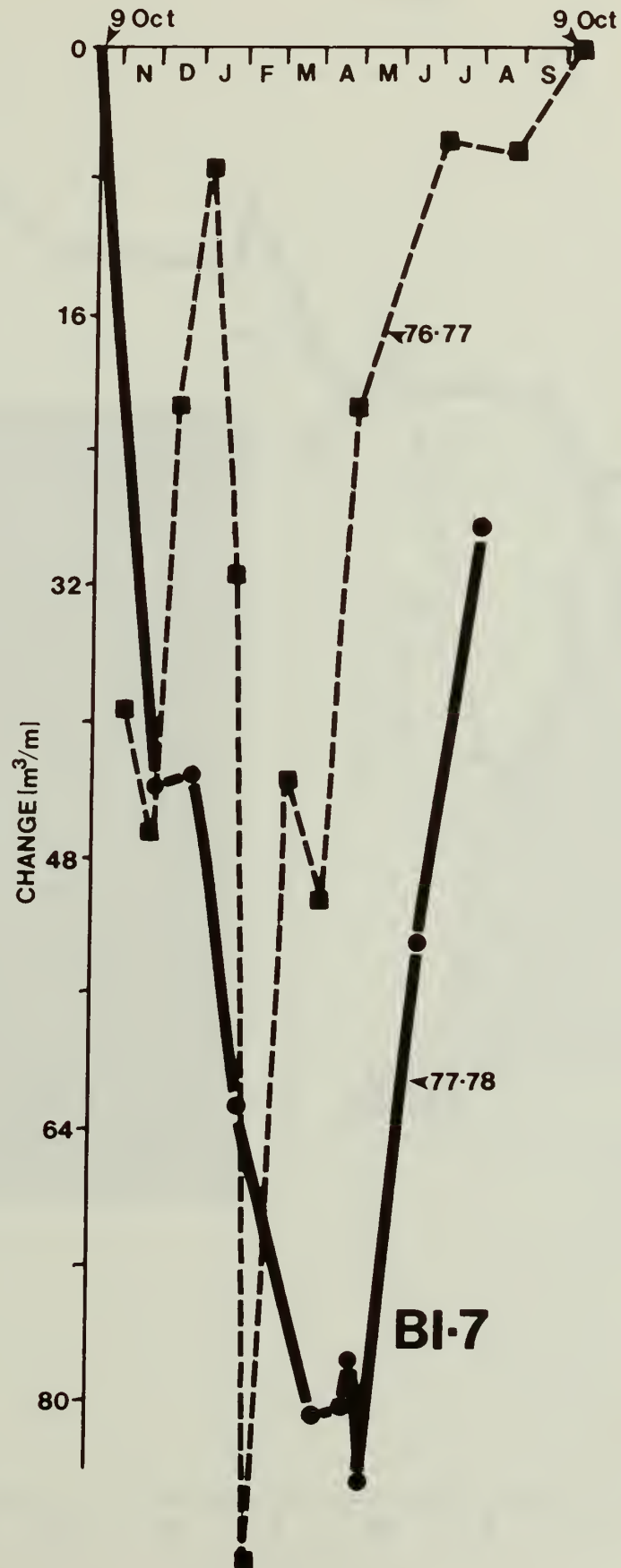


FIG. 11

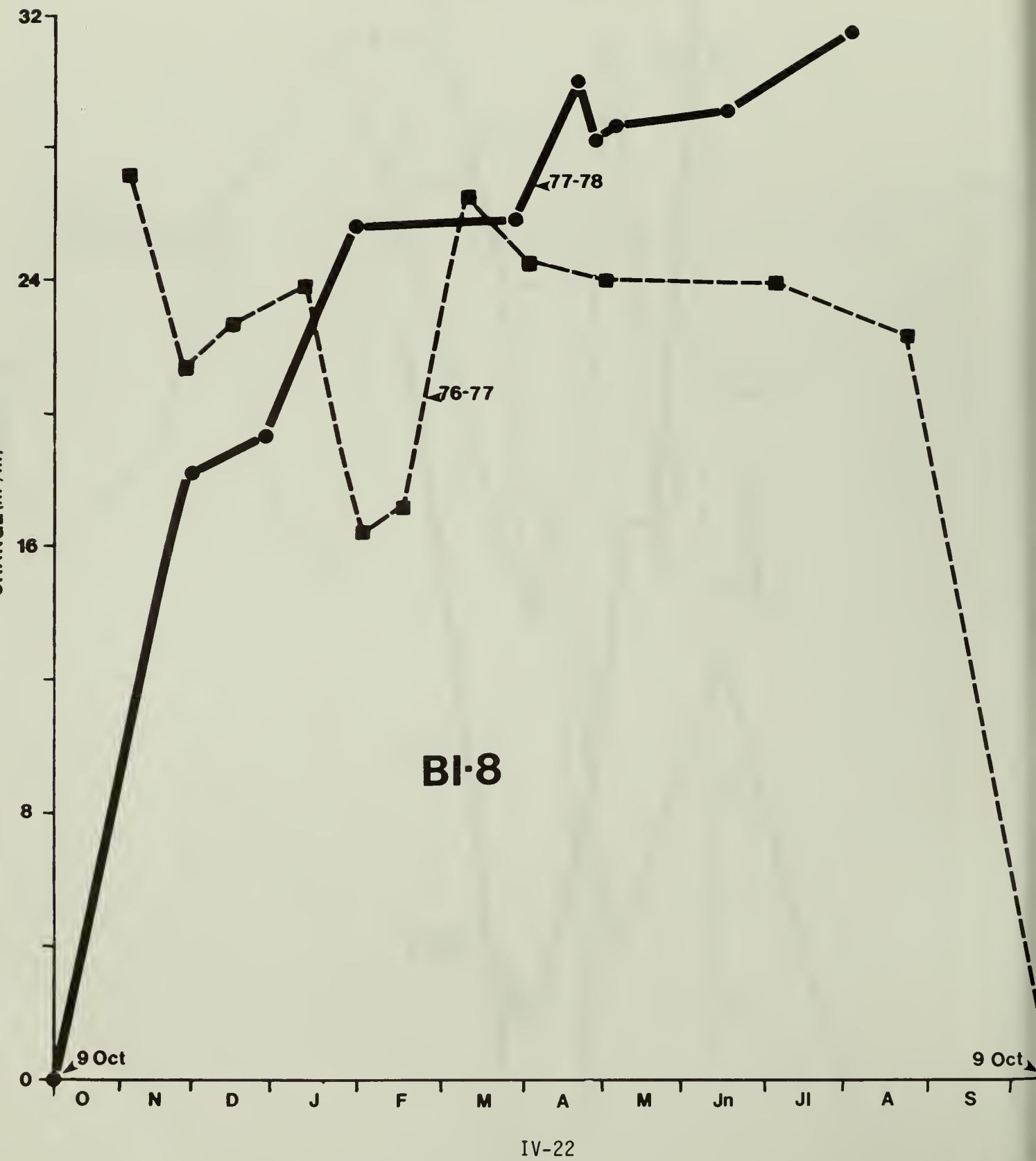


FIG. 12

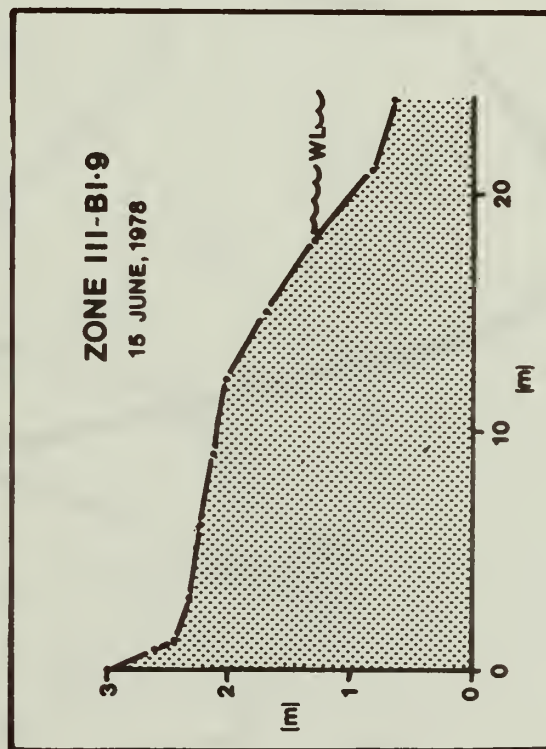
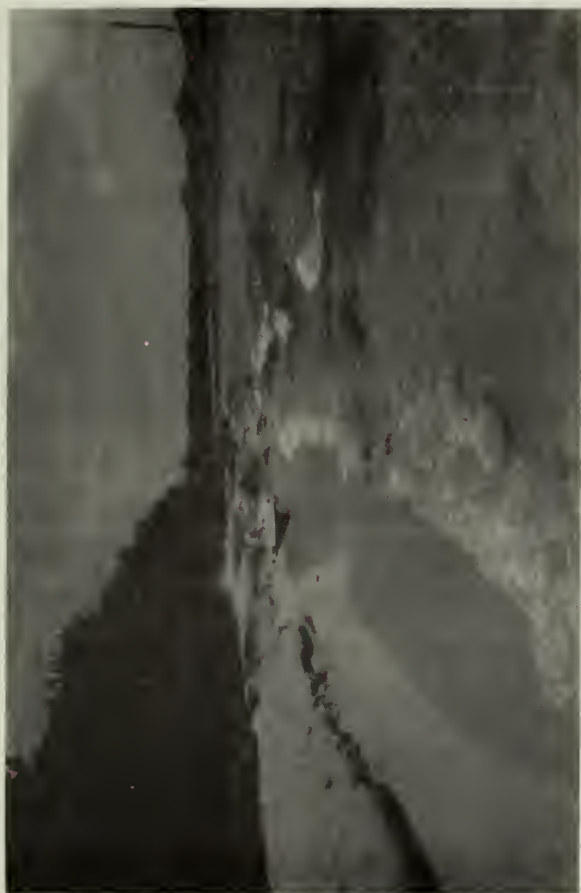


FIG. 13

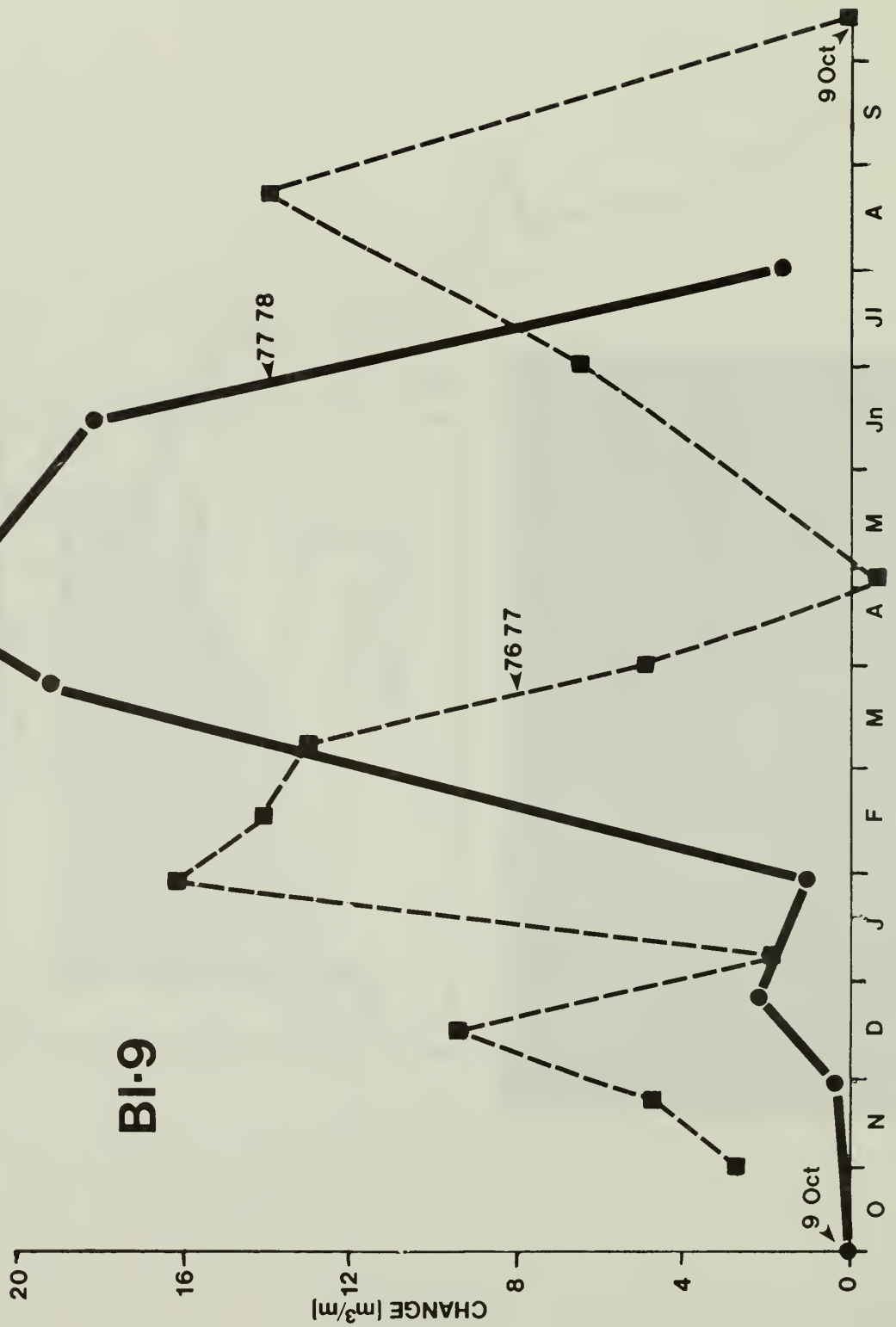


FIG. 14

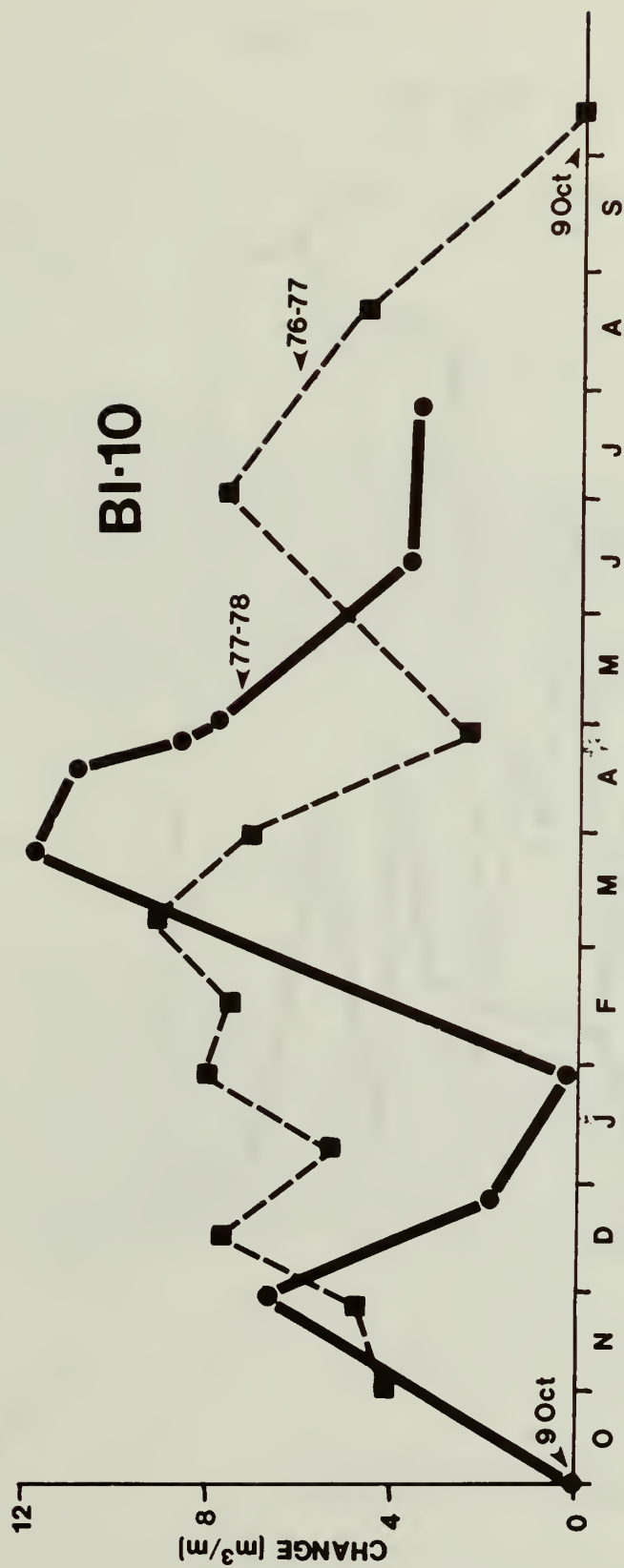


FIG. 15

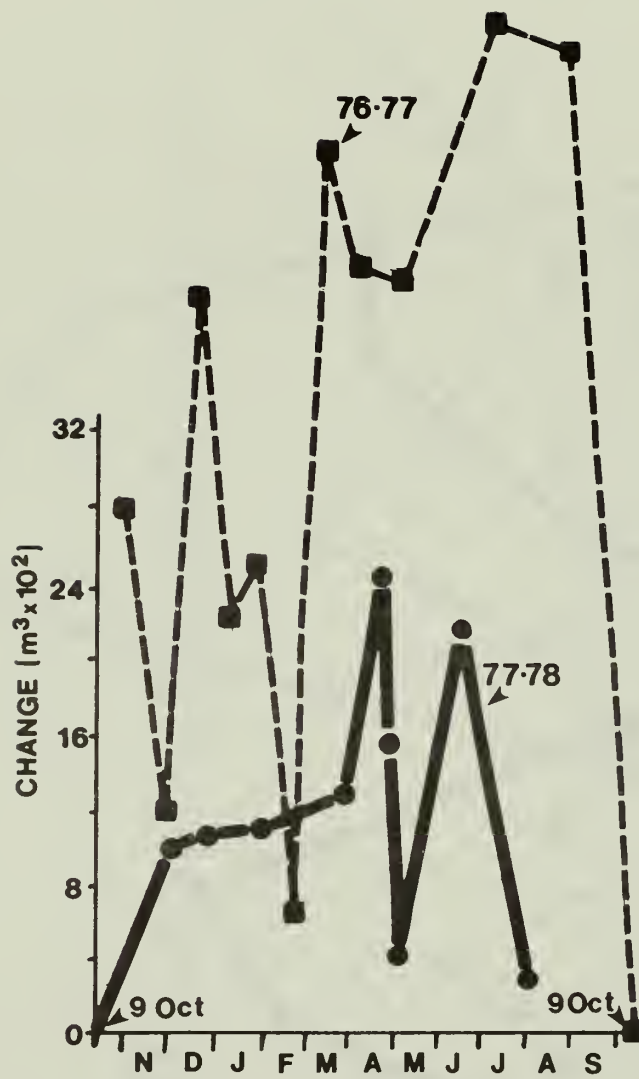


FIG. 16

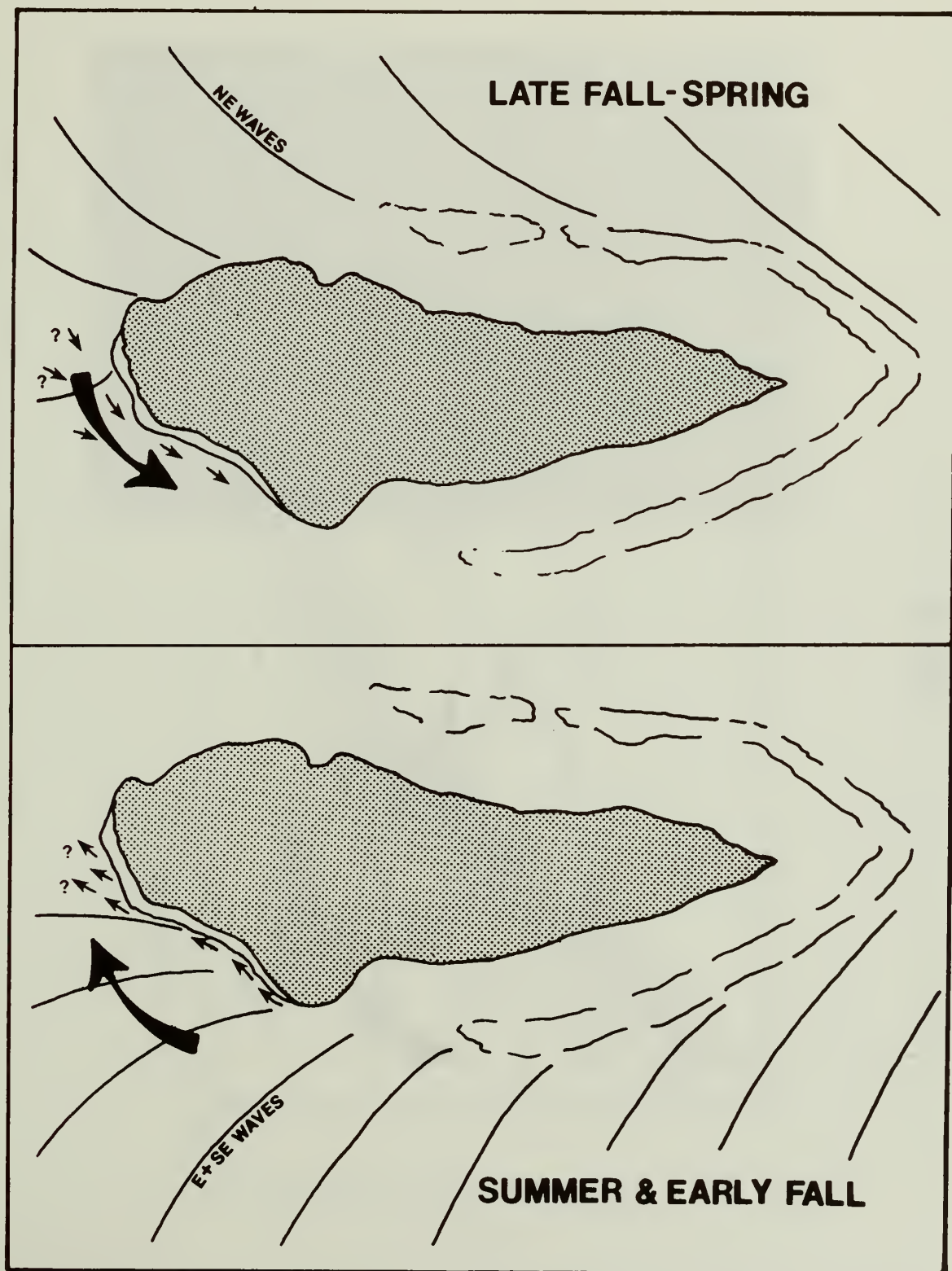


FIG. 17

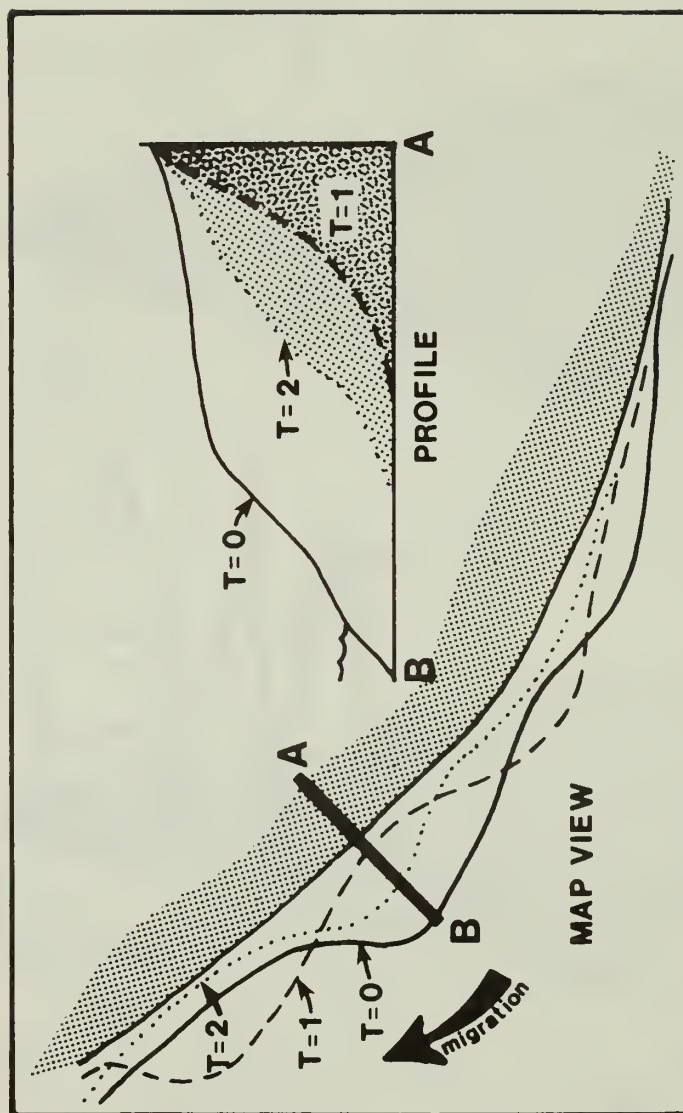
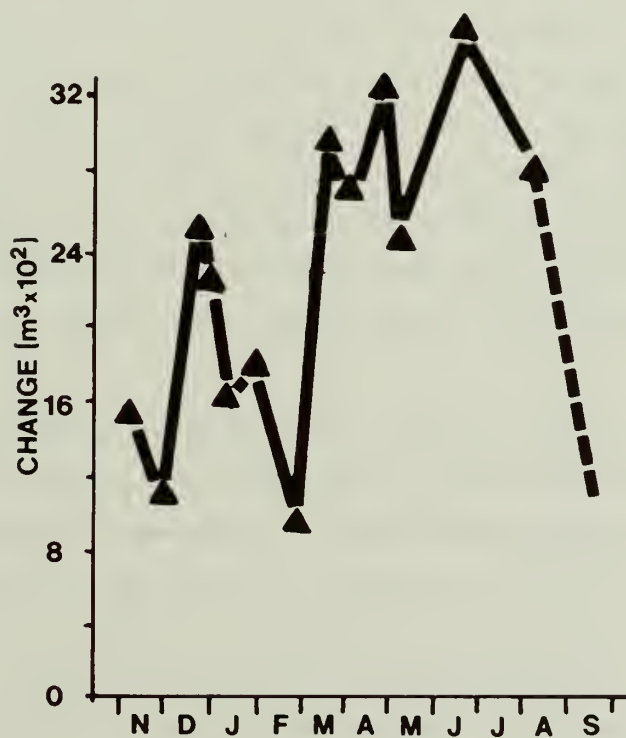


FIG. 18



CHAPTER V

GROWTH AND COMPETITIVE DYNAMICS OF THE SESSILE BENTHIC COMMUNITY

by

Robert Carpenter and Elizabeth Gladfelter

Introduction

The reef ecosystem at Buck Island is a complex structural and biotic assemblage with diverse taxonomic representation. Gladfelter et al. (1977) provided general descriptions of the reef community along transects around the park. The principal components of the benthic community here are scleractinian corals, other anthozoans, the hydrozoan coral Millepora spp. and benthic algae. It is well established that surface space is a limiting resource in terms of the growth of species populations in many benthic environments, especially where species diversity and growth rates are high (e.g., Jackson, 1977). Casual observations made over the years at Buck Island have indicated short- and long-term changes in the structure of the benthic community. Among those members of the benthic community which are presently important in terms of abundance, little is known of their relative abilities to compete for space except among some of the scleractinian corals (Lang, 1973). Casual observations made here and elsewhere have suggested benthic species form a complex web of spatial interactions and that the overall health of the reef in terms of live coral coverage may depend upon such a web of interactions.

It was therefore our goal in the present study to reach a greater understanding of those dynamic interactions which ultimately influence the health of the coral community. We chose to investigate several aspects which we have felt were actually or potentially critical parts of this web: (1) interactions between major benthic coelenterate species and destruction of live coral by several important agents, (2) the recolonization of bare space created by the latter, and (3) the control of benthic algal species and, indirectly, other forms by grazers. These studies are presented separately with a combined discussion.

PART I - BENTHIC INTERACTIONS

Methods and Materials

A two-meter wide transect was established between the underwater trail and the SCUBA buoy along the backreef (a distance of ~625 m). Initially, all incidence of coral damage or interactions with other benthic organisms were identified with a DYMO-TAPE tag nailed to substrate and marked with flagging tape. These were photographed with a Nikonos camera and a 1:6 close-up lens with a reference frame. A metric ruler was used for scale. The transect was surveyed every one to two months and new incidences were marked and photographed; previously marked incidences were rephotographed.

Analysis of the resulting color photographs was carried out by identifying several unique features along or near the line of contact between the two organisms and measuring the distance changed under the dissecting scope with reference to an ocular micrometer and the metric ruler in the photograph.

Results

Table 1 presents the progression of the interactions which were observed over a period of time along the fixed transect in the backreef. These interactions include both the effects of mobile predators (grazers) on the benthic biota (fish-invertebrate), as well as interactions between sessile forms: i.e., invertebrate-invertebrate, invertebrate-algae, invertebrate-"disease organisms", and algae-algae.

The corals growing in the transect which were subject to grazing by parrotfish included Acropora palmata, Montastrea annularis and Porites astreoides. The colony of A. palmata showed complete regeneration after grazing; of the three incidences of grazing on M. annularis, one resulted in death of coral with subsequent algal succession occurring while the other two showed a pattern of continued grazing pressure along with continued regeneration of coral tissue. The number of colonies of Porites astreoides grazed upon reflects their abundance in this ecological zone. It should be noted (Table 1, I.A.3. c,d,e,g) that

four of the colonies follow the pattern mentioned above for M. annularis, i.e., grazing, and regeneration proceeding at about the same rate, while four colonies (Table 1, I.A.3. a,b,f,h) show progressive deterioration of the colony and in some cases death.

A source of mortality for Acropora prolifera was the damselfish, Eupomacentrus planifrons which expanded its algal patch at the expense of living coral.

Invertebrate-invertebrate interactions are summarized in Figure 1. In all interactions with other benthic invertebrates, Palythoa caribbearum always was the competitive dominant. Porites astreoides generally lost ground to other benthic species (Palythoa, Briareum, sponge) but did not out-compete Agaricia. During the time-course of the study, two species (Diploria strigosa and Zoanthus sociatus) showed little change of space in interactions with several other species with the exception of interactions with Palythoa, which they lost. These results are confirmed by the more detailed accounts of individual interactions in Table 1, II.

"Coral disease" was observed in one colony each of Acropora palmata, Diploria strigosa and D. clivosa (Table 1, III) resulting in death in the first case, near-death in the second, both of which were incidences of "white-band" disease and little change in the third, which was the "black-band" disease.

Algal succession was followed in several instances, usually resulting in a sequence of filamentous greens to corallines. Occasionally, the damaged coral which was being colonized would regrow over the algae (Table 1, IV.A.a.).

Table 2 presents the number of interactions which occurred in the transects as well as the area affected by these occurrences. Parrotfish predation was the cause of the highest number of interactions and also affected the most space. Interactions between benthic species was next followed by disease, urchin predation and other causes. This ranking partially reflects the nature of the zone where the transect is located which influences the type of interactions which occur.

PART II - RECRUITMENT TO THE BENTHIC COMMUNITY

Methods and Materials

Unglazed clay settling plates (225 cm²) were set at three locations on the reef: (1) the north patch reef, (2) the south patch reef, and (3) the northeast forereef outside the underwater trail. At each of the three sites, 18 plates were set up in the following configurations:

Horizontal	3 caged	3 uncaged
Vertical	3 caged	3 uncaged
Natural substrate	3 caged	3 uncaged

Natural substrate was obtained by chiseling the reef pavement to a depth of 1 cm for 225 cm². Cages were made from 0.5 cm² mesh and were designed to exclude major grazers from the substratum. Because of fouling problems, these could not be used. Photographs were taken of all uncaged plates at various intervals.

Results

Several trends are readily apparent from the settling plate experiment (Fig. 2, Table 3). Colonization occurred very rapidly on the horizontal and natural plates, with a very rapid development of a turf community. The amount of sediment on these two surfaces in all three zones (Forereef, North Patch Reef (NPR), South Patch Reef (SPR)) also built up rapidly (by 45 days) and then declined. The vertical plates showed a slower rate of colonization (note the slower decrease in the amount of bare space) and a slower increase in the amount of turf. Due to vertical positioning, the amounts of sediment accumulation on these plates was negligible. These plates did show an increase in the amount of coralline algae (especially in the forereef and NPR sites). The other zone to show development of coralline was the horizontal plate on the forereef. A small part of the plates showed settlement of benthic invertebrates (serpulids, Zoanthus) after a short period (Table 3).

It appears that the orientation and nature of the substrate was more important in determining the sequence of succession, rather than the position on the reef. The succession on natural substrates is almost identical in all three areas.

PART III - EFFECT OF GRAZERS: DIADEMA ANTILLARUM

Methods and Materials

To test the effect of Diadema antillarum grazing on algal community structure and biomass, four inclusion and two exclusion cages (each 1 m²) were set up on a patch reef. Densities of Diadema set up in inclusion cages were established so as to be comparable to existing literature (Sammarco et al., 1974: Ogden et al., 1973, etc.). "Normal" densities were placed in two cages (8 urchins/m²) and 16 urchins/m² were placed in the other two inclusion cages. Subsequent sampling showed "normal" density for this patch reef to be 4.9 urchins/m². These cages were left in position for 302 days.

The effect on the algal community was characterized by biomass measurements and relative abundance of various algal species. Diversity was reflected in the number of species in each cage. These were compared with controls outside the cages. The "cage" effect was not tested and the exclusion cage results did not distinguish between release from urchin grazing or release from large fish grazing. Mesh size was large, so small fish were able to graze inside the cages (schools of striped parrotfish were observed grazing inside).

Results

There is an inverse relationship between algal biomass and urchin density (Fig. 3). The difference in algal biomass between the higher experimental and lower field values is probably due to the reduction of fish grazing in the cages. Since this was largely prevented, the algal biomass estimates in the cages indicate mostly the effects of urchin grazing.

The effects of varying urchin grazing intensity on the number of species of algae surviving in the cages are shown in Figure 4. The results demonstrate a significant difference in species numbers due to grazing intensity, the maximum number of algal species occurring at intermediate levels.

The data do not permit unequivocal conclusions as the effects of urchin grazing on algal productivity. As shown in Figure 5, significant differences in

productivity due to urchin grazing intensity can be demonstrated only when results are pooled over all sampling times, the 302-day results not being significantly different when analyzed separately.

The species composition of algae differed in the grazed and ungrazed cages (Table 4). Of the 12 species in the ungrazed cages, 3 were macro-algae which are generally uncharacteristic of normal turf areas susceptible to urchin grazing. No clear differences between the grazing treatments were apparent.

Discussion

In this study, various organisms interacting with members of the benthic community have been studied. These included mobile predators and grazers (including fishes and sea urchins) as well as interactions between the benthic organisms themselves in competition for space. The most "competitively successful" invertebrate was Palythoa caribbeorum which overgrew each invertebrate in which it had contact, and which in the past two years has spread over a considerable area of the pavement area bordering the backreef area east and north of the Buck Island trail (E. Gladfelter, pers. obs.). Other invertebrates showed a range of behaviors, outcompeting some and being outcompeted by others, with the exception of Zoanthus and Diploria strigosa which showed no change in interactions followed more than six months.

Parrotfish grazing did little damage to Acropora palmata and Montastrea annularis (see Chapter VII, this report), but seemed to influence at least the pattern of distribution of Porites astreoides by destroying some colonies, and restructuring the space occupied by others. This may explain the change in colony shape noted by Lewis (1974) in a series of photographic quadrats taken yearly in Barbados. In general, the present levels of parrotfish grazing do not seem to be affecting the abundance of live coral in the national monument.

The settling plate results suggest that bare space is occupied very quickly in the reef environment, which can also be seen in the recolonization of bare space provided by parrotfish grazing on live coral. A turf community develops

quickly, especially in horizontally-oriented substrates which can initially collect sediments. In vertically-placed substrates where less sediment collects and light levels are lower, a succession to the slower-growing coralline algae occurs more quickly. These plates were subject to grazing, which may explain the lack of macro-algae.

It is suggested from the Diadema experiments that sea urchin grazing may prevent dominance by macro-algae. Feeding observations suggest that urchins avoid macro-algae but may inadvertently ingest germlings while grazing, thereby controlling macro-algal abundance. The minimal amount of urchin grazing necessary to prevent macro-algal dominance is unknown.

Algal turf can cover up to 85% of patch reefs and may be responsible for up to 80% of the total community primary productivity (Adey, unpubl.). If intermediate urchin grazing is eventually shown to maximize algal productivity, as incompletely demonstrated here, then comparative studies of the effects of Diadema and other grazers may indicate the extent to which total reef production is mediated by them. The structure of these algal communities will probably be better understood after extensive experimental manipulation of all grazers, including urchins, fish, molluscs and polychaetes. The possibility that intermediate levels of grazing generally maximize algal species numbers depends on future experimental studies in many different reefs. Such studies may not only be of theoretical interest but may help in the management of reefs affected by human activities. The results presented here suggest that removal of grazers or their predators by hunters or collectors may eventually affect the algal community and the primary productivity of coral reefs. It has been recently demonstrated (Glynn et al., 1979) that urchin grazing on live coral limits reef growth. It may also affect the number of coral species in the same manner as demonstrated here for turf algae. These results emphasize the importance of expanded experimental studies of the effects of urchin grazing on coral reefs.

Table 1. — Progress of Biotic Interactions Observed Within the Photo Transect

Interaction	Damage and/or Recovery
I. FISH - INVERTEBRATE	
A. Parrotfish - coral	
1. <u>Acropora palmata</u>	
a. 10/08/77	Parrotfish predation on coral.
02/09/78	Complete regeneration of coral over killed area.
2. <u>Montastrea annularis</u>	
a. 10/08/77	Parrotfish predation of <u>M. annularis</u> .
10/15/77	Freshly killed substrate covered with green filamentous algae.
12/09/77	Algal succession.
07/23/78	Coralline algae and coral growing back over scar.
b. 04/12/78	40% coral head grazed.
07/23/78	10% newly grazed; 20% rejuvenation.
c. 04/12/78	60% coral head grazed.
07/23/78	5% newly grazed; 40% rejuvenation.
3. <u>Porites astreoides</u>	
a. 10/09/77	Parrotfish predation.
12/10/77	All but 24 cm ² has been eaten.
02/09/78	All coral eaten; algal covered.
04/12/78	Advanced algal succession; corallines.
07/23/78	Grazed; early algal succession; no corallines.
b. 10/09/77	Parrotfish predation on small coral (1.3 cm ²).
02/09/78	.6 cm ² left; some algae settled.
04/12/78	.3 cm ² left; no algae visible.
c. 10/15/77	Parrotfish predation of coral.
12/09/77	Complete rejuvenation.
07/23/78	Regrazed - 50% dead.

Table 1. — Continued

Interaction	Damage and/or Recovery
3. <u>Porites astreoides</u> (con't)	
d. 10/31/77	Parrotfish predation of coral; small scars.
12/10/77	Some algal settlement; 80% regeneration.
02/09/78	90% regeneration.
04/12/78	Same as previous.
07/23/78	Complete regeneration.
e. 10/31/77	Parrotfish predation of coral; 50% of head is dead.
12/10/77	50% regeneration; algal settlement.
02/09/78	60% regeneration; advanced coral succession; corallines.
04/12/78	80% regeneration macro-algae (<u>Dictyota</u>).
07/23/78	Coral growing into dead spot from edges; algae has been grazed.
f. 12/10/77	Parrotfish predation on coral; 50% dead.
02/09/78	60% dead due to grazing.
04/12/78	75% dead due to grazing; macro-algae.
g. 02/05/78	Parrotfish predation on coral.
04/12/78	90% regeneration.
07/23/78	40% regrazed.
h. 02/05/78	Predation on coral; 50% dead.
04/12/78	Algal settlement.
07/23/78	Further grazing and algal settlement; 75% dead.
B. Damselfish - coral	
1. <u>Acropora prolifera</u>	
a. 10/09/77	Corals at edge of <u>Eupomocentrus planifrons</u> territory; branches healthy.
12/10/77	Coral unchanged; still healthy.
04/12/78	~200 cm ² of original 222 cm ² area killed and covered with algae.
b. 10/09/77	<u>A. prolifera</u> at edge of 3 spot territory. 30% dead.
12/09/77	50% dead.
02/09/78	65% dead.
07/23/78	80% dead.

Table 1. — Continued

Interaction	Damage and/or Recovery
II. INVERTEBRATE-INVERTEBRATE	
A. Coral-coral	
1. <u>Diploria strigosa</u>-<u>D. strigosa</u>	
a. 10/09/77	White groove where two colonies have met.
02/09/78	No change.
04/12/78	No change.
07/23/78	No change.
B. Coral-zoanthid	
1. <u>Palythoa</u>	
a. 10/08/77	<u>Palythoa</u> overgrowing <u>Porites astreoides</u> .
07/23/78	Complete overgrowth with 33.8 cm ² killed.
b. 02/09/78	<u>Palythoa</u> overgrowth of <u>Diploria strigosa</u> .
04/12/78	Overgrowth advanced 2 cm.
07/23/78	Overgrowth advanced 1.5 cm more.
c. 02/05/78	<u>Palythoa</u> overgrowth of <u>Porites porites</u> .
04/12/78	Overgrowth continues.
07/23/78	Overgrowth continues.
d. 12/09/77	<u>Palythoa</u> settlement on <u>D. strigosa</u> .
e. 10/08/77	<u>Palythoa</u> overgrowth of <u>D. clivosa</u> .
2. <u>Zoanthus</u>	
a. 02/05/78	<u>Porites astreoides</u> contact with <u>Zoanthus</u> .
04/12/78	No advance by either; algae outgrows <u>Zoanthus</u> .
07/23/78	No change.
C. Coral-other	
1. <u>Acropora palmata</u>	
a. 02/05/78	<u>A. palmata</u> eaten by <u>Hermodice</u> ?
04/12/78	50% regeneration.

Table 1, — Continued

Interaction	Damage and/or Recovery
III. CORAL-"DISEASE"	
A. White Band Disease	
1. <u>Acropora palmata</u>	
a. 10/09/77 04/12/78	White band disease. Branch completely dead (2.8 cm ² /mo; ~1 cm linear/mo); advanced algal succession to corallines.
2. <u>Diploria clivosa</u>	
a. 02/05/78 04/12/78 07/23/78	White band disease? 75% dead, 90% dead. 95% dead - algal succession.
B. Black Band Disease	
1. <u>Diploria strigosa</u>	
a. 04/12/78 07/23/78	Black band disease. No change.
IV. ALGAL SUCCESSION	
A. Algae-coral	
a. 12/10/77 02/09/78 04/12/78 07/23/78	Dead <u>D. strigosa</u> (parrotfish?). Algal succession. Advanced algal succession - coralline algae. Coral readvancing 1 mm/mo.
b. 12/09/77 02/09/78 07/23/78	Algae on <u>Montastrea annularis</u> . 2.5 cm ² of coral killed. 38.5 cm ² of coral killed.

Table 2. — Number of New Incidences of Benthic Interactions and Area Affected

Total New Incidences		Parrotfish Predation		Overgrowth by Benthic Organism		Disease		Urchin Predation		Possible Man-Induced Effects		Other		
Date	No.	1/xm ²	No.	1/xm ²	No.	1/xm ²	No.	1/xm ²	No.	1/xm ²	No.	1/xm ²	No.	1/xm ²
10/09/77	20	1/40	11	1/71	5	1/167	2	1/333	0	0	1	1/804	1	1/804
All damage new														
10/31/77	3	1/250	3	1/250	0	0	0	0	0	0	0	0	0	0
12/10/77	9	1/91	7	1/111	2	1/333	0	0	0	0	0	0	0	0
02/09/78	14	1/59	7	1/111	3	1/250	2	1/333	1	1/804	0	0	*	1/804
04/12/78	4	1/200	3	1/250	0	0	1	1/804	0	0	0	0	0	0
07/23/78	1	1/804	1	1/804	0	0	0	0	0	0	0	0	0	0

1/xm² = 1 occurrence per x meters square.

Transect 402 m long x 2 m wide from SCUBA buoy to trail area along backreef.

*Three-spot or Hermodice.

Table 3. — Partitioning of Space on Three Types of Settling Plates (Horizontal, Vertical and Natural) Located in Three Locations (Forereef, North Patch Reef, South Patch Reef) with Time

Figures indicate mean percentage of space occupied $\pm$ S.D.

Day No.	Macro-algae %	Turf %	Coralline algae %	Sediment %	Bare Space %	Invertebrates %
FOREREEF						
<u>Horizontal</u>						
50 n = 3	-----	63 $\pm$ 33	2 $\pm$ 2	23 $\pm$ 27	12 $\pm$ 8	-----
145 n = 3	-----	78 $\pm$ 25	-----	18 $\pm$ 28	3 $\pm$ 6	-----
325 n = 3	-----	35 $\pm$ 13	55 $\pm$ 13	2 $\pm$ 2	7 $\pm$ 3	-----
<u>Vertical</u>						
50 n = 3	-----	20 $\pm$ 10	15 $\pm$ 5	2 $\pm$ 2	50 $\pm$ 10	3 $\pm$ 3*
145 n = 3	2 $\pm$ 2	35 $\pm$ 30	35 $\pm$ 18	-----	25 $\pm$ 17	3 $\pm$ 3*
325 n = 3	-----	7 $\pm$ 8	83 $\pm$ 16	-----	10 $\pm$ 9	-----
<u>Natural</u>						
50 n = 1	-----	50	-----	45	5	-----
145 n = 2	-----	63 $\pm$ 4	3 $\pm$ 4	33 $\pm$ 11	3 $\pm$ 3	-----
325 n = 1	-----	70	-----	20	10	-----
NORTH PATCH REEF						
<u>Horizontal</u>						
50 n = 3	-----	58 $\pm$ 8	2 $\pm$ 2	18 $\pm$ 3	15 $\pm$ 5	7 $\pm$ 3*
145 n = 3	-----	82 $\pm$ 28	-----	17 $\pm$ 28	2 $\pm$ 2	-----
325 n = 3	-----	83 $\pm$ 10	-----	-----	17 $\pm$ 10	-----
<u>Vertical</u>						
50 n = 3	2 $\pm$ 2	47 $\pm$ 31	23 $\pm$ 12	-----	28 $\pm$ 20	-----
145 n = 3	15 $\pm$ 13	22 $\pm$ 21	62 $\pm$ 10	-----	2 $\pm$ 2	-----
325 n = 2	8 $\pm$ 4	23 $\pm$ 4	63 $\pm$ 4	-----	8 $\pm$ 11	-----
<u>Natural</u>						
50 n = 2	-----	85 $\pm$ 21	-----	15 $\pm$ 21	-----	-----
145 n = 3	-----	90 $\pm$ 10	-----	10	-----	-----
325 n = 3	-----	90 $\pm$ 17	-----	-----	-----	10% Zoanthus

Table 3. — Continued

	Macro-algae	Turf	Coralline algae	Sediment	Bare Space	Invertebrates
	%	%	%	%	%	%
SOUTH PATCH REEF						
Horizontal						
50 n = 3	-----	75 ± 22	-----	18 ± 24	5 ± 5	2 ± 2*
145 n = 3	-----	93 ± 3	-----	-----	7 ± 3	-----
325 n = 2	-----	93 ± 11	-----	-----	7 ± 11	-----
Vertical						
50 n = 3	-----	27 ± 29	18 ± 8	-----	53 ± 24	2 ± 2*
145 n = 3	2 ± 2	42 ± 8	18 ± 6	-----	40 ± 9	-----
325 n = 1	-----	40	10	-----	50	-----
Natural						
50 n = 3	-----	50 ± 40	-----	50 ± 40	-----	-----
145 n = 3	-----	90 ± 0	-----	10 ± 0	-----	-----
325 n = 3	-----	92 ± 8	-----	3 ± 6	5 ± 9	-----
*serpulid						

Table 4. — Algal Species Lists for Cages Containing Differing Densities of *Diadema* Sampled After 302 Days

	Density of Urchins 0/m ²	Density of Urchins 8/m ²	Density of Urchins 16/m ²
Algal species present after 302 days -	<u>Gelidium pusillum</u> <u>Padina sanctae-crucis</u> <u>Champia parvula</u> <u>Halimeda</u> spp. <u>Laurencia</u> spp. <u>Polysiphonia</u> spp. <u>Gelidiella trinititensis</u> <u>Cladophora</u> spp. <u>Sphacelaria</u> spp. <u>Gelidium</u> spp. <u>Notocasae</u> spp. <u>Oscillatoriaceae</u> spp.	<u>Taenioma</u> spp. A <u>Ceramium</u> spp. <u>Polysiphonia</u> spp. <u>Champia parvula</u> <u>Griffithsia</u> spp. <u>Giffordia</u> spp. <u>Taenioma</u> spp. B <u>Uvella</u> spp. <u>Nostocasae</u> spp. <u>Ostriobium</u> spp. <u>Oscillatoriaceae</u> spp. <u>Cyanophyceae</u> spp. A <u>Cyanophyceae</u> spp. B <u>Rivulariaceae</u> spp.	<u>Taenioma</u> spp. <u>Griffithsia</u> spp. <u>Eulothrix</u> spp. <u>Rivulariaceae</u> spp. <u>Oscillatoriaceae</u> spp. <u>Polysiphonia</u> spp. <u>Ceramium</u> spp. <u>Giffordia</u> spp.

FIGURE LEGEND - CHAPTER V

- Figure 1 Interactions between benthic invertebrates. Arrows point toward organism which is being overgrown. An "o" indicates no dominance occurred during the period of observation.
- Figure 2 Changes in surface cover of freshly prepared surfaces at three sites at Buck Island reef during the year. The three surfaces were unglazed pottery plates placed horizontally, vertically and scraped natural substrate. Major categories of space coverage are:
- algal turf
 - · — coralline algae
 - - - - - bare surface
 - · · · · sediment
 - - - - - other
- The experiment ran 325 days.
- Figure 3 Graph of log algal biomass against the number of urchins per square meter for experimental cages (open circles) and field study sites (closed circles). Regression line for experimental cages, $\log Y = 2.231 - 0.030 X$, $P < 0.005$. Regression line for field values, $\log Y = 1.838 - 0.042 X$, $P < 0.001$. Slopes of the two lines were found to be not significantly different by analysis of covariance.
- Figure 4 Plot of the number of algal species occurring in cages with different densities of urchins. Triangles represent means for each cage type, circles are the raw data. Analysis of variance using orthogonal polynomials indicates a significant difference among densities ($P < 0.005$) and a significant quadratic trend ($P < 0.001$). The linear trend is not significant.
- Figure 5 Two-way analysis of variance over times and treatments shows a significant difference between times ($P < 0.005$). When data is pooled over times, a one-way analysis of variance shows a significant difference between treatments ($P < 0.001$).

Figure 1.

	D. strigosa	D. clivosa	Mussa	Porites	Montastrea	Agaricia	Siderastrea	Mycetophyllia	Millepora	Palythoa	Zoanthus	Lebrunea	Ricordia	Briareum	Sponge
Diploria strigosa				↑			0			↑	0		0		
D. clivosa			↑							↑↑↑	0	↑			
Mussa											0				
Porites astreoides						↑				↑↑↑	00			↑	↑
Montastrea annularis								↑							
Agaricia agaricites											0			↑	
Siderastrea													↑		
Mycetophyllia															
Millepora														↑	
Palythoa											↑				
Zoanthus															
Lebrunea															
Ricordia														↑	
Briareum															
Sponge															

FIG. 2

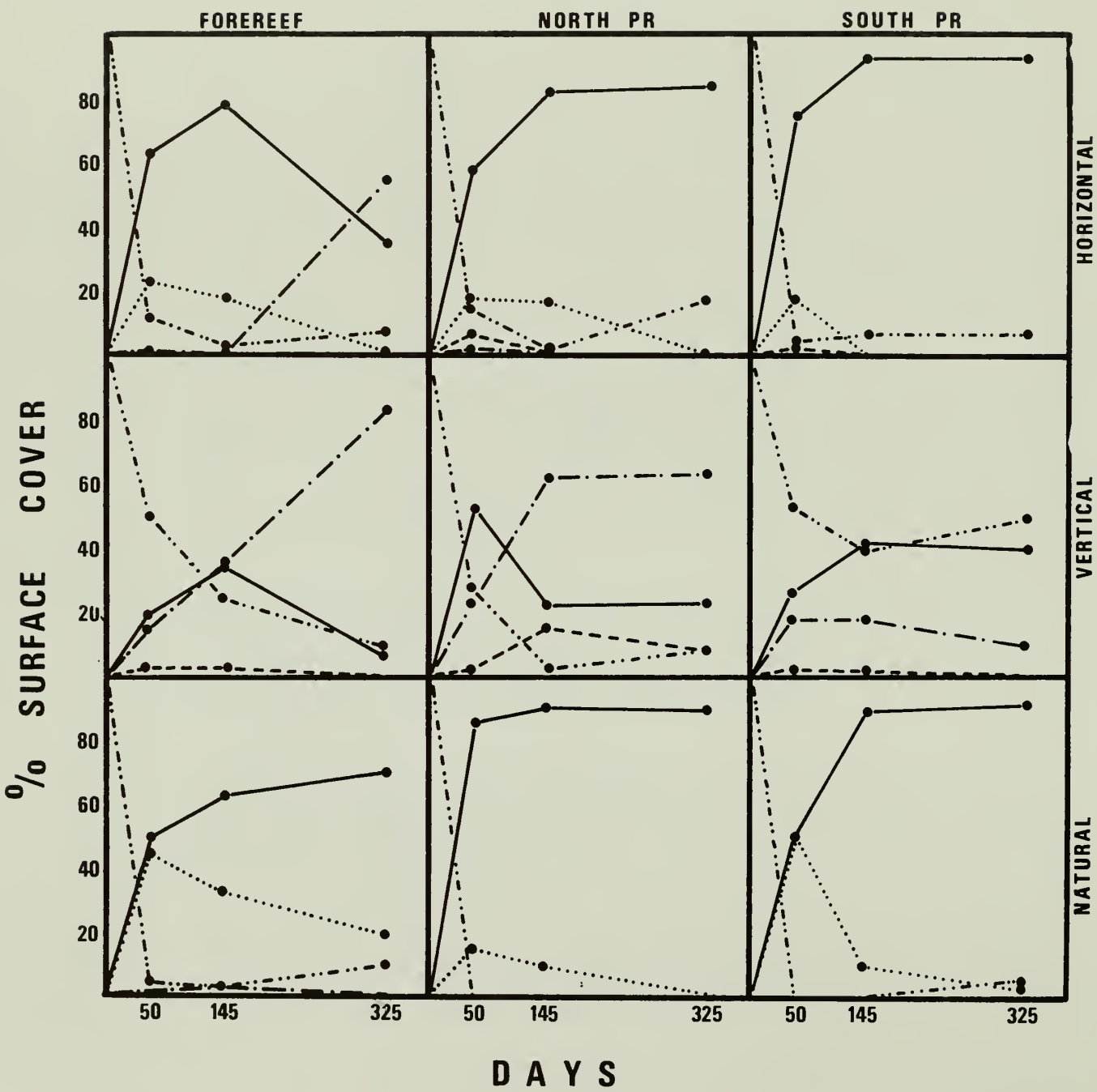


FIG. 3

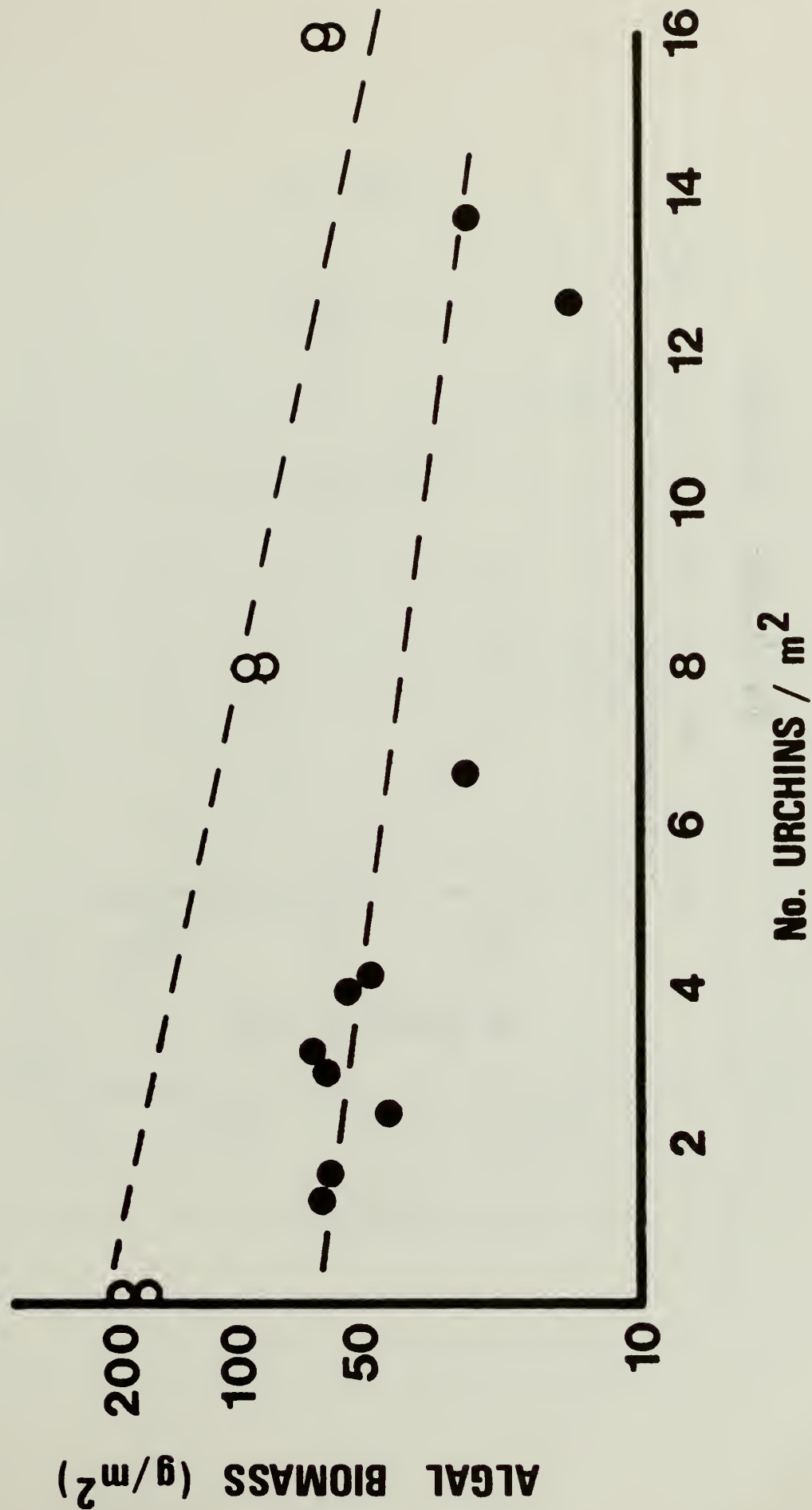


FIG. 4

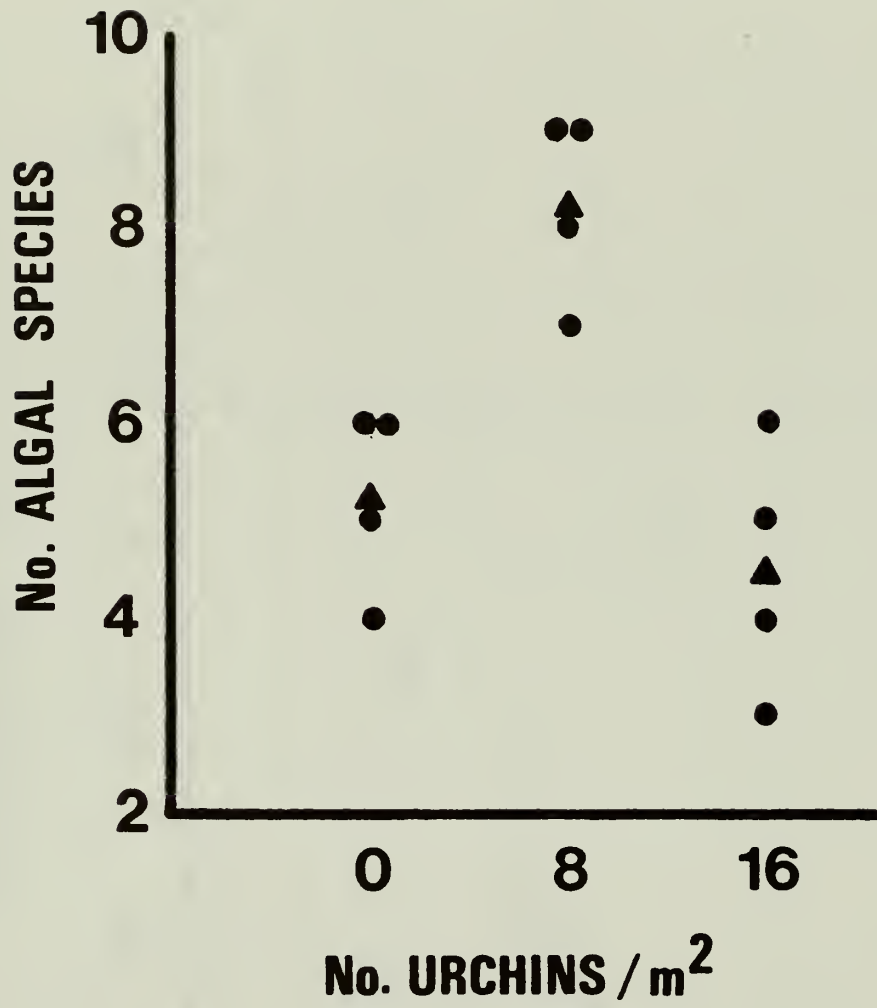
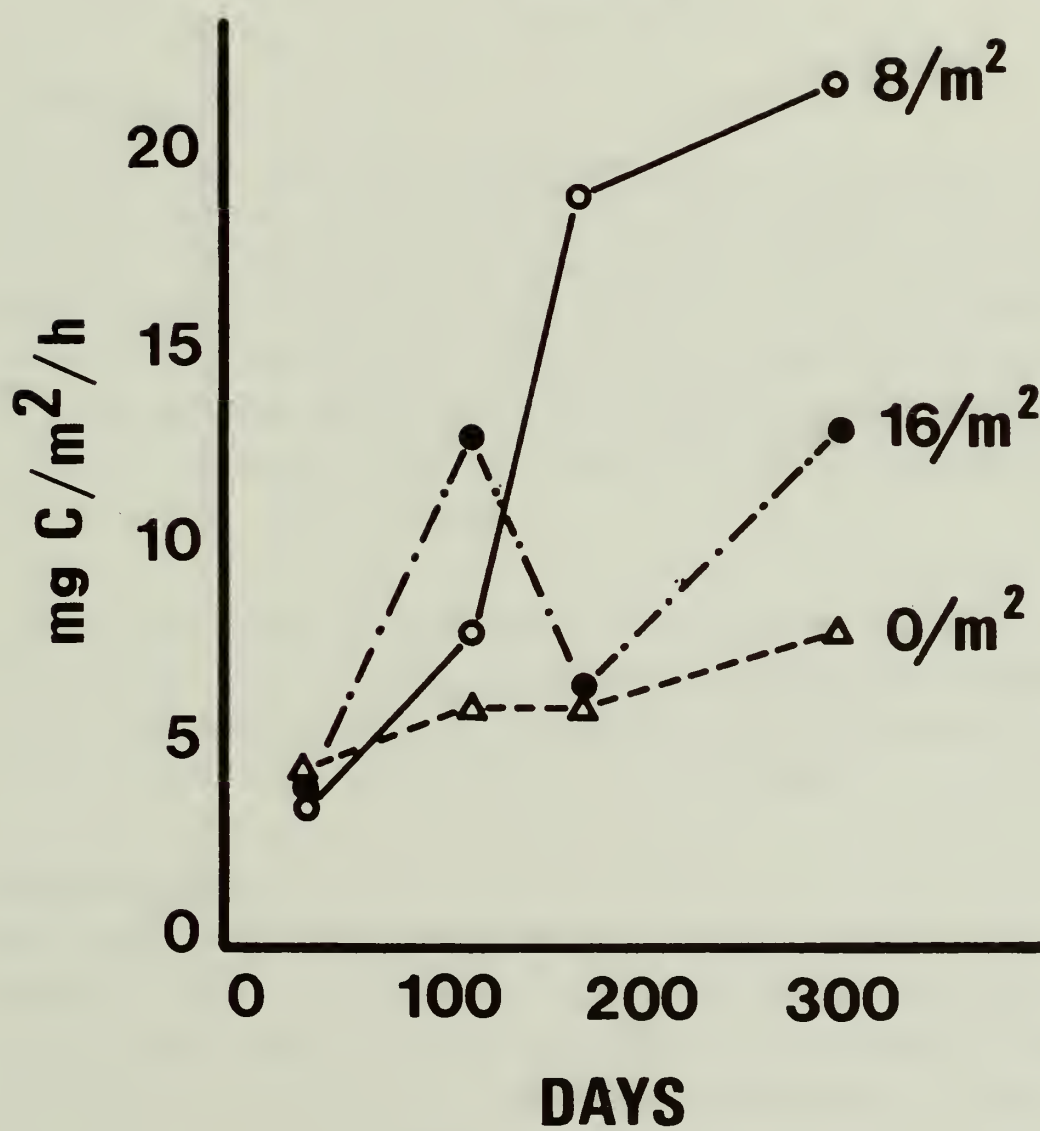


FIG. 5



CHAPTER VI

PREDATION ON LIVE CORAL BY THE ECHINOID DIADEMA ANTILLARUM

by

Robert Carpenter

Introduction

The long-spined sea urchin, Diadema antillarum, is an abundant inhabitant of the reef ecosystem at Buck Island Reef National Monument. Its importance as a grazing herbivore has been reviewed by Lewis (1964), Randall et al. (1964), Sammarco et al. (1974) and Lawrence (1975). Its role as a predator on live coral has been examined only by Bak and van Eys (1975). Their study on reefs of the Netherlands Antilles (Curacao and Bonaire) established Diadema as a significant predator on live coral with 4.5 - 8.0% of the urchin population utilizing coral as a food source.

We have found evidence of urchin grazing on live coral tissue at Buck Island Reef National Monument. The present study has attempted to determine the impact of this source of mortality on live corals of the reef and also to elucidate the factors which may be responsible for this phenomenon.

Methods and Materials

This study was conducted at five sites within the Buck Island Reef National Monument (Fig. 1) during the spring of 1978. Urchins observed on live coral surfaces were brought to the laboratory and dissected within an hour of collection. Examination of the gut showed zooxanthellae, nematocysts and coral tissue to be present. The mode of feeding and the scars left on the coral surface are described by Bak and van Eys (1975). Since these scars (illustrated in Fig. 2) are the known result of urchin predation, their presence or the actual observance of Diadema predation were used as criteria in the choice of the five study sites.

Depths of the five areas ranged from 1 to 3 meters. Three 10-meter transects were established in each area. Determinations of urchin density, size and prey item were made from three random 1 m² quadrats for each transect, yielding a total of nine quadrats/area. Urchins occurring in each quadrat were measured to the nearest millimeter at the maximum test diameter using long-jawed calipers. Urchins were categorized into two groups: those feeding on live coral and those feeding on other prey items or not feeding at all. The species of coral being eaten was recorded in each case. Since Diadema is primarily a nocturnal feeder, all counts and measurements were made after 1900.

Percent coverage of live coral, dead coral, pavement, and sand of each transect was determined by the chain method described by Porter (1972). This yielded a measure of three-dimensional coverage since the chain was laid to fit the contours of the substrate. This total amount of coverage divided by the linear 10-meter distance gave a measure of substrate complexity, here called heterogeneity index (H.I.). A totally flat substrate would give an H.I. value of 1.0.

Algal cover was determined at each area by three random tosses of a 625-cm² wire mesh with 1 cm squares. Algal types were divided into turf and fleshy categories. The number of squares covering each type were then determined for each toss. The height of the algae was also measured to the nearest millimeter and assumed to be uniform for each type over the entire 625 m² area.

In order to determine the rate of destruction of live coral due to Diadema predation, observations on three specific coral heads were made over a three-month period. By means of baseline markers, rates of coral mortality due to this source were estimated.

Results

The topography and the heterogeneity indices of the five areas are given in Table 1. The heterogeneity indices were similar in all areas. Live coral coverage was higher in areas 1, 2 and 5, while area 4 had a very large pavement

coverage. Table 2 presents biota cover for each area. Algal turf predominated in areas 3 and 4, while fleshy algae was abundant only in area 4.

Table 3 contains density data, variance : mean ratios, mean Diadema size, and the percentage of the Diadema population feeding on live coral. High densities occurred in area 2. Densities in the other areas were somewhat low as compared to that reported in a similar area (Ogden et al., 1973) and personal observations. High degrees of clumping were evident in areas 2 and 5 with distributions in areas 1, 3 and 4 being closer to random. Mean individual sizes range from 4.06 to 7.71 cm. The percent of Diadema population feeding on live coral is fairly consistent for areas 1, 2 and 5. No urchins were found preying on live coral in areas 3 and 4.

Table 4 presents a breakdown of the live coral coverage of each area into its constituent species and what percent each comprises of the total live coverage. Also presented are the percents of the total coral feeding-urchin population that were feeding on each species of coral. From these values, electivities (Ivlev, 1961) were calculated (see Table 4). No strong preferences are indicated. Correlation coefficients between the percentage of the population feeding on each species and the availability of each species are given. The trend was for urchins to feed on different species in response to their availability. Exceptions occurred in areas 3 and 4 where no coral feeding was observed. Table 5 gives electivity values for total coral in each area. Weak positive values occurred in those areas where feeding was observed and strong negative values occurred in areas 3 and 4. Correlations between various parameters are shown in Table 6.

Table 7 shows the average feeding rate of Diadema on a head of Diploria strigosa, 1 m in diameter. Values are mean widths of the freshly eaten coral as measured from baseline markers. Figures 2a, 2b show this head and the zone that has been eaten.

Discussion

The Diadema populations studied must be operating under one of the following conditions: (1) they have a preference for live coral, (2) they are generalist feeders, that is, they eat any prey items in relation to their availability, or (3) they are facultative coral feeders that have adapted to a shortage of their natural prey (algae) and are seeking alternate prey items.

If Diadema have a preference for feeding on live coral, then they should be selectively feeding on coral disproportionately to the coral availability. This would be reflected as strong positive values of the electivity indices. From Tables 4 and 5, it can be seen that no strong positive values exist. In those cases where live coral feeding occurs, the correlations between the percent of feeding population preying on each species of coral and the availability of that coral species seem to indicate that the urchins are feeding on coral species in relation to their availability.

If these Diadema populations are generalists, then all items should be preyed on with respect to their abundance. Gut content analyses from three studies in St. Croix (Sammarco et al., 1973; Atkinson, Hopley, Mendelson and Yacowitz, 1973; Ogden, Brown and Salesky, 1973) indicate that Diadema is a somewhat selective feeder, preferring to graze on algal turfs most abundant on coral pavement. Lewis (1964) and Randall et al. (1964) reported earlier that detritus, crustacea and various animal fragments were found in the guts. This is probably the result of those items being ingested at the same time the urchins were grazing the pavement surface. The idea that Diadema is a herbivore, preferring to graze on algal mats can only be stated in the context of this particular habitat. As Lawrence (1975) pointed out, urchins' diets tend to reflect the composition of their environment and are variable with time, locality and age.

If the urchin populations studied were reacting to a shortage of algal turf by finding alternate resources (i.e., coral), then there should exist a negative correlation between the percent of the population feeding on live coral and algal turf abundance. Although a direct correlation between these parameters is

non-significant, it is still highly negative ($r = 0.84$). The small sample size may account for this non-significance. However, there is a significant positive correlation ($r = +0.91$, $p < .05$) between the percent pavement cover and the percent algal turf abundance, and a significant negative correlation ($r = -0.90$, $p < .05$) between the percent of Diadema population feeding on live coral and the percent pavement cover. By this indirect means, it is possible to substantiate the inverse relationship between the occurrence of coral feeding and algal turf abundance.

Density of urchins was not found to have a significant effect on the occurrence of coral predation. There does exist a significant negative correlation ($r = -0.93$, $p < .05$) between urchin density and mean urchin size. No significant differences in urchin size were found between those urchins eating coral and those eating algae (Anova).

The distributions of Diadema in areas where coral feeding occurred were more clumped than in those areas where it was not observed. This probably reflects the clumped distribution of corals on which the urchins were feeding.

Rate data from Table 7 indicate that on one head of coral, urchins are capable of eating approximately 2.3 mm/day. This rate, extended over the total surface of live coral on this head, leads to a value of 48.07 cm²/day. This assumes that two-thirds of the circumference of the head is covered by live coral. Although this is a very rough figure, it points out that Diadema is a significant source of coral damage and mortality in this locality.

It appears in this locality that as a result of lowered algal abundance, Diadema is seeking alternate sources of nutrition. When algal turf is available, due to space availability provided by pavement, it is the preferred prey item. Urchin density and size do not appear to play a role in this feeding strategy.

This study is continuing at the same sites, plus additional ones, and is being expanded to include other factors such as varying depths and different reef environments (i.e., patch reef, backreef, forereef).

Table 1. — Topography of the Study Areas

Area	% Live Coral ±S.D. N=3	% Dead Coral ±S.D. N=3	% Pavement ±S.D. N=3	% Sand ±S.D. N=3	H.I. ±S.D. N=3
Area 1	14.67 ±9.50	27.33 ±7.77	42.67 ±27.15	15.00 ±10.15	1.39 ±0.17
Area 2	16.33 ±7.51	48.00 ±21.93	22.00 ±11.27	13.67 ±10.41	1.23 ±0.16
Area 3	7.00 ±5.29	36.67 ±10.41	44.33 ±25.01	12.33 ±12.74	1.35 ±0.18
Area 4	9.67 ±6.11	13.67 ±17.21	73.33 ±20.21	3.33 ±3.06	1.40 ±0.26
Area 5	19.00 ±3.46	34.33 ±9.71	25.67 ±6.43	21.00 ±3.61	1.57 ±0.23

Table 2. — Biota Coverage in the Study Area

Area	% Algal Turf ±S.D. N=3	Height (mm)	% Fleshy Algae ±S.D. N=3	Height (cm)	% Other
Area 1	41.00 ±8.38	3.50	0	----	59.00
Area 2	23.33 ±9.02	1.00	0	----	76.67
Area 3	67.33 ±15.27	2.17	3.30 ±5.77	1.50	29.37
Area 4	67.33 ±32.92	2.33	22.67 ±31.01	0.30	10.00
Area 5	47.67 ±39.50	3.33	1.33 ±1.53	1.50	51.00

Table 3. — Diadema Population Parameters

Area	Density/m ² ±S.D. N = 15	$\frac{\sigma^2}{\bar{x}} \pm$ S.D. N = 15	Mean Individual Size ±S.D. (cm) N =	% Population Feeding on Live Coral ±S.D. N = 15
Area 1	5.53 ±2.20	1.47 ±0.25	6.27 ±0.64 N = 81	29.73 ±10.97
Area 2	11.20 ±7.07	3.22 ±3.20	4.06 ±0.22 N = 178	22.83 ±10.87
Area 3	4.20 ±0.80	1.05 ±0.67	6.36 ±0.17 N = 63	0.0
Area 4	4.00 ±0.60	1.03 ±0.81	7.71 ±0.54 N = 58	0.0
Area 5	2.60 ±0.80	1.90 ±1.43	6.90 ±0.55 N = 41	24.83 ±14.85

Table 4. — Percent of Total Live Coral Coverage by Constituent Species, Percent of the Feeding Diadema Population Feeding on Each Coral Species, and the Electivity Indices for Each Coral Species

Location	Coral Species	% Cover	% <u>Diadema</u> Population Feeding on this Species	e
Area 1 r = +0.56*	<u>Acropora palmata</u>	24.24	36.36	+0.20
	<u>Diploria clivosa</u>	17.42	27.27	+0.22
	<u>Diploria strigosa</u>	12.12	9.09	-0.14
	<u>Montastrea annularis</u>	20.45	18.18	-0.06
	<u>Porites astreoides</u>	3.03	4.55	+0.20
	<u>Porites porites</u>	22.73	4.55	-0.67
Area 2 r = +0.92*	<u>Agaricia spp.</u>	<1.0	2.70	<+0.46
	<u>A. palmata</u>	9.17	8.11	-0.06
	<u>D. strigosa</u>	34.17	24.32	-0.17
	<u>M. annularis</u>	12.50	21.62	+0.27
	<u>P. astreoides</u>	4.17	0.0	-1.00
	<u>P. porites</u>	40.00	43.24	+0.04
Area 3 r = 0*	<u>Agaricia spp.</u>	3.45	0.0	-1.00
	<u>D. strigosa</u>	32.76	0.0	-1.00
	<u>M. annularis</u>	20.69	0.0	-1.00
	<u>P. porites</u>	43.10	0.0	-1.00
Area 4 r = 0*	<u>D. clivosa</u>	9.20	0.0	-1.00
	<u>D. strigosa</u>	62.07	0.0	-1.00
	<u>M. annularis</u>	9.20	0.0	-1.00
	<u>P. astreoides</u>	19.54	0.0	-1.00
Area 5 r = +0.99*	<u>Agaricia spp.</u>	0.55	0.0	-1.00
	<u>D. strigosa</u>	5.49	0.0	-1.00
	<u>M. annularis</u>	87.36	88.89	+0.01
	<u>Mussa angulosa</u>	0.55	0.0	-1.00
	<u>P. astreoides</u>	6.04	11.11	+0.30

$$e = \frac{(r_i - p_i)}{r_i + p_i}$$

r_i = % population feeding on live coral

p_i = % live coral available

*Correlation coefficients between the percent of the feeding Diadema population feeding on each coral species and the availability of that coral species.

Table 5. — Electivity Indices for all Coral Species for all Areas

Area	% Live Coral Cover	% <u>Diadema</u> Population Feeding on Live Coral	e
Area 1	14.67	29.73	±0.34
Area 2	16.33	22.83	+0.17
Area 3	7.00	0.0	-1.00
Area 4	9.67	0.0	-1.00
Area 5	19.00	24.83	+0.13

Table 6. — Correlation Coefficients Between Indicated Parameters

Parameters	r	Significance
% <u>Diadema</u> population feeding on live coral. % live coral coverage.	+0.88	p < .05
Mean individual size. Density/m ² .	-0.93	p < .05
% pavement cover. % algal turf.	+0.91	p < .05
% <u>Diadema</u> population feeding on live coral. % algal turf.	-0.84	ns
% pavement cover. % <u>Diadema</u> population feeding on live coral.	-0.90	p < .05

Table 7. — Amount of Diploria strigosa Head Eaten
by Diadema

Day	Mean Width $\pm$ S.D. of Killed Coral (cm)
0	0
2	1.76 $\pm$ 0.77
4	2.99 $\pm$ 1.91
6	3.01 $\pm$ 2.22
8	3.16 $\pm$ 2.35
11	3.36 $\pm$ 2.80
19	4.51 $\pm$ 4.13
27	5.01 $\pm$ 3.81
35	10.26 $\pm$ 3.70
80	18.31 $\pm$ 4.02

Average feeding rate - 2.28 mm/day.

FIGURE LEGEND - CHAPTER VI

- Figure 1 Buck Island reef and lagoon showing Diadema antillarum study sites.
- Figure 2 Head of Diploria strigosa, showing band of dead coral following predation by Diadema antillarum.
a. Whole colony.
b. Close-up of same.

FIG. 1

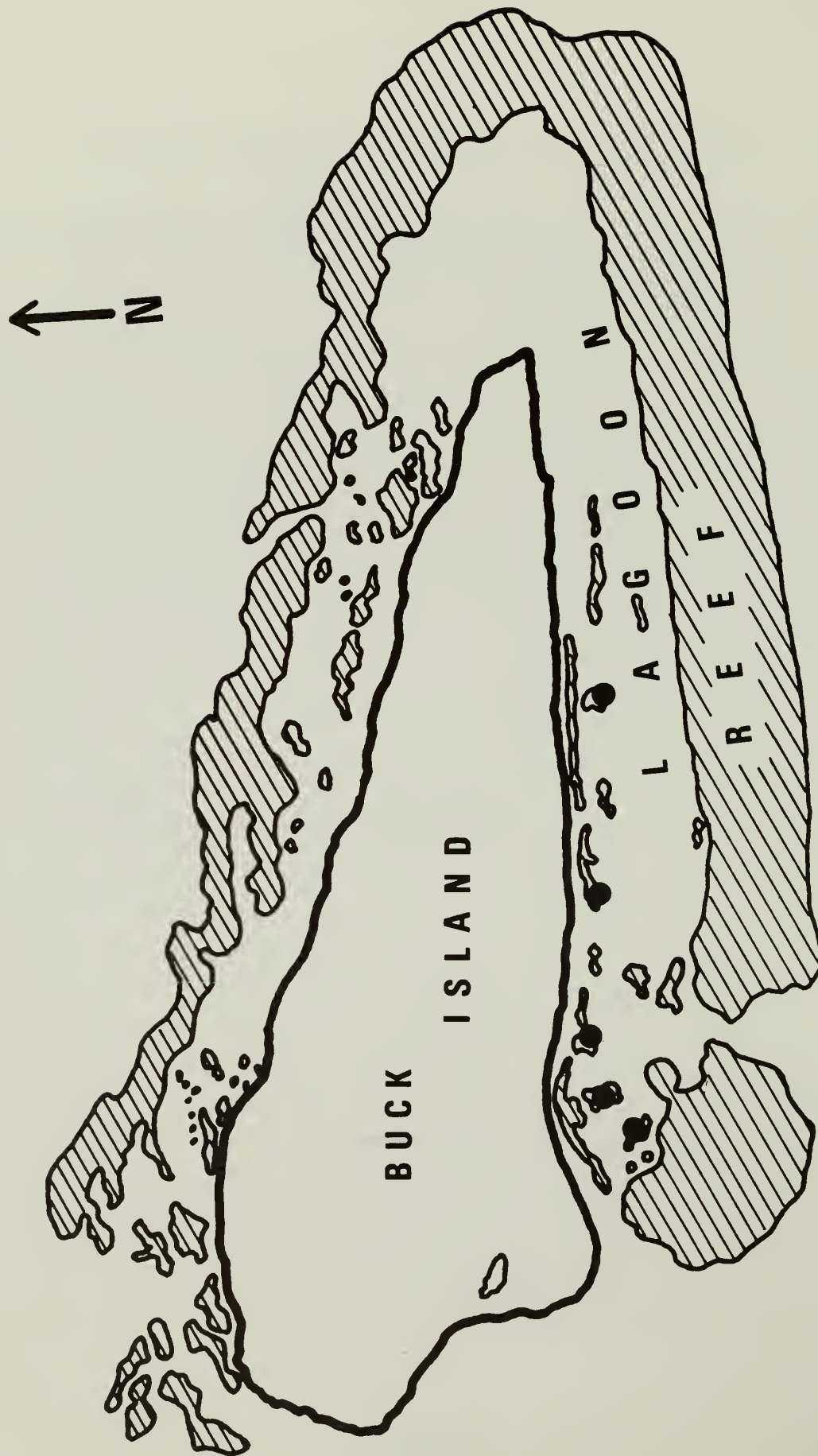
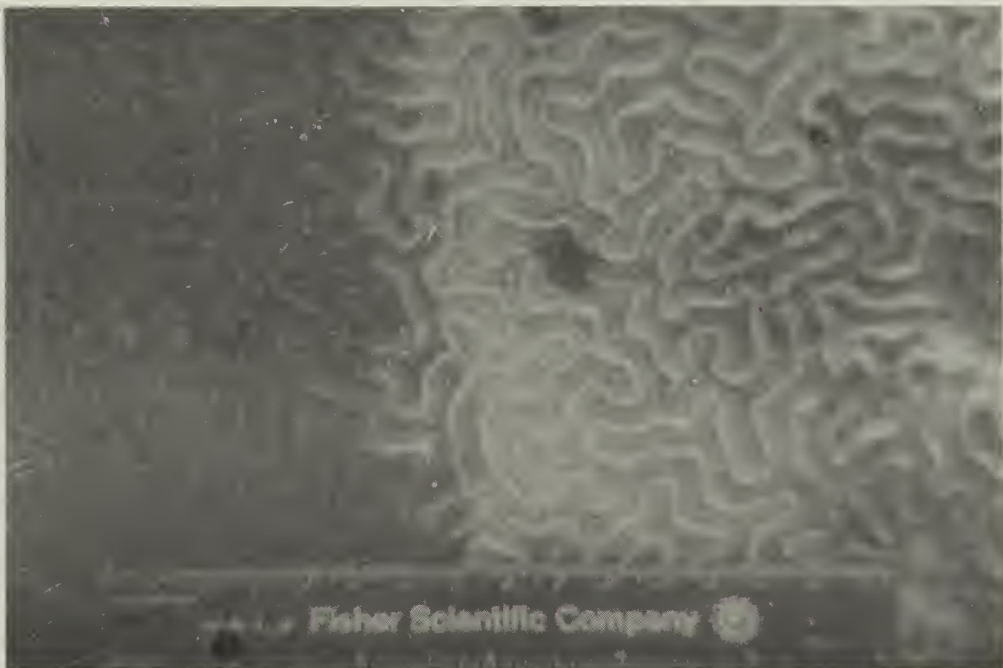


FIG. 2

a



b



CHAPTER VII

PREDATION ON LIVE CORAL BY THE PARROTFISHES

SCARUS VETULA AND SPARISOMIA VIRIDE

by

G. Simpson

Introduction

There is little published evidence on predation by Caribbean reef fishes on live coral. Among the fishes often cited as grazers are the parrotfishes, Scaridae (Randall, 1974). Darwin (1845, 1850), who visited Cocos Keeling Islands during the voyage of the "Beagle", reported from the observations of a resident and his own analysis of intestinal contents that the two species of Scarus subsisted entirely on live coral. Richard H. Randall (personal communication to Randall, 1974) suggested that Bolbometopon muricatus, one of the largest parrotfishes (1.2 m) ranging from the tropical western Pacific to the Red Sea, feeds on live coral. It was observed biting pieces from Montipora verrucosa (Lamarck) outside of the reef off Madang, New Guinea (Randall, 1974).

In contrast, Finckh (1904) stated, as a result of studies at Funafuti in the Ellice Islands, that large numbers of fishes were watched in the neighborhood of coral but in no instance were they seen to browse on it. Choat (1966, p. 266-267), who completed a dissertation (University of Queensland) on the biology of labrid and scarid fishes at Heron Island stated, "It is worthy of note that in no instance were parrotfishes observed to graze on living coral...".

In the eastern Pacific, it has been established that parrotfish graze on live coral. Glynn (1972) stated, "Several individuals in a school of approximately 60 young of Scarus ghobban (Forsskal) were observed biting into a colony of Porites panamensis at the Pearl Islands."

There has only been limited research done in the Atlantic. For example, in Panama (Bakus, 1969) and in Bermuda (Gygi, 1969), the rasping of live corals by scarids is commonplace. Glynn (1973) mentions that on the north coast of Panama the summits of large hemispherical colonies are commonly scraped to depths of 2-3 mm; such feeding is often performed by relatively small schools (5-15 individuals) of Scarus guacamaia (Cuvier) which appear to range over extensive areas.

Predation on coral is quite apparent in several areas of the patch and barrier reefs surrounding Buck Island. Numerous bite marks cover areas of Acropora palmata, Porites astreoides, and Montastrea annularis. The purpose of this study was to investigate this phenomenon through research on the common local parrotfish Scarus vetula (Queen Parrotfish) and Sparisoma viride (Stoplight Parrotfish) on the patch and barrier reefs of Buck Island.

Methods and Materials

Coral predation was followed in the field on four large colonies of Acropora palmata located within Buck Island Reef National Monument. Two colonies were located on the backreef of the north lagoon just east of the north cut or SCUBA buoy. The third colony was almost directly opposite the lagoon from the other two along the north shore of Buck Island. An additional colony was located on the south forereef. The two colonies on the backreef were located approximately three meters apart, and were designated colonies #1 and #2. Colony #1 showed evidence of predation from October 1977, when it was first observed, through June 1978. Colony #2 showed almost no predation during the entire course of this study. Colony #3 showed signs of predation from March 1978, when it was first observed, through September 1978, when the study was terminated. The fourth colony was observed November and December 1978.

The change in the amount of predation over time was followed by means of chain transects done periodically during the study period. A 10 m chain was draped over the colony and the number of links touching live coral, and the number of links touching bite marks were counted. The percentage of surface area being

preyed upon was computed by dividing the number of links touching bite marks by the sum of links touching live coral and links touching bite marks. This was done for each of five replicates taken at each sampling site. Means and standard deviations were computed from replicates and graphed against time in Figure 1.

Sample parrotfish of the species Scarus vetula and Sparisoma viride were collected with a speargun. Five primary and five terminal phase specimens of each species were collected, weighed, and measured. Gut analyses were done to determine if zooxanthellae were present. In situ feeding observations were also made for a total of 10.25 hours using SCUBA and snorkle gear. Fish were divided into four weight classes: small, 0-100 g; medium, 100-500 g; large, 500-1000 g; and extra large, over 1000 g; and two color phases: primary and terminal. In the field feeding observations, individual fish were followed for varying periods of time, usually 9-15 minutes. All observations were broken down into three-minute time periods during which all food types consumed and the number of bites of each food type were recorded.

The amount of coral grazed by Sparisoma viride was analyzed in a large pen constructed in shallow water adjacent to the West Indies Laboratory dock. Fish, divided into same size and color classes as field observations, were placed in the pen along with live coral. To compensate for the occasional recruitment to or disappearance of individuals from the pen, each size class was multiplied by a weight factor so that the densities could be added to give a total density in fish units. Thus, the density of small fish was multiplied by 0.5; medium fish by 1.0; large fish by 1.5; and extra-large fish by 2.0. The summed total of the density, reported in fish units, is graphed against the mean number of bites per day and shown in Figure 2.

Results

Figure 1 shows noticeable increases in the amount of coral predation during the Winter months. A similar occurrence was observed by E. Gladfelter (pers. commun.) during the Winter of 1976. During periods of observation, the effect of predation on a single colony did not exceed about 10% of the surface area. All of the

colonies observed showed decreases in the amount of predation with the approach of Summer. There appears to be a great tendency for a coral colony to be either preyed upon extensively, or not to be preyed upon at all. Even with colonies which are adjacent, such as #1 and #2, this was observed repeatedly. This suggests that a little coral damage attracts other fish to the colony and increases the amount of predation on the grazed colony.

Individual bite marks were labeled on Acropora palmata and followed over time in order to determine if there were any long-term effects upon the colony or skeletal structure. On the fast-growing corals, such as Acropora palmata, a characteristic healing pattern was found for individual bite marks (1 x 2 cm in size). Within one week after the bite was made, tissue had regenerated over the bite. This tissue was clear, i.e., lack of zooxanthellae. In some cases, the beginning of new polyps could be seen by this time. The bite was generally healed by the end of two weeks. By this time, distinct polyps could be seen and the tissue contained zooxanthellae. By three weeks, the polyps had almost reached a size comparable to surrounding ones from the non-bite area making it impossible to tell that predation had occurred there.

On the slower growing corals, such as Porites astreoides and Montastrea annularis, the effects of scarid predation often left severe long-term scarring. Frequently, these corals were found with large areas grazed, especially on the top. Being unable to regenerate tissue fast enough to out-compete the algae growing there, the grazed spot was covered by algal turf. In the long run, the coral slowly grew up around the edges of the algal patch forming a rim. As time progressed, the coral slowly overgrew the algae forming a doughnut-shaped elevation. Eventually, the coral completely overgrew the algae. All the above stages of grazing and regeneration were frequently found on the reef surrounding Buck Island.

Gut analyses (Table 1) showed that only two out of ten primary phase parrotfish had zooxanthellae present in the gut. The fact that these were the only primary phase parrotfish over 40 cm in length and over 2 pounds in weight suggests that perhaps the fused teeth and pharyngeal mill of the smaller fish are not strong enough for biting healthy coral. Six of terminal phase specimens Sparisoma viride

contained zooxanthellae while only two Scarus vetula did. This supports observations by the author that terminal phase S. viride were seen eating live coral several times while the S. vetula was seen eating it only once. Also, although both Scarus and Sparisoma bite marks were counted without differentiation there seemed to be a 3:2 ratio favoring the ungrooved or Sparisoma type bite marks.

In field observations of feeding frequency on various prey items (Table 2), it is seen that as the size of the fish increases, the total number of bites per time decreases. This is possibly due to the larger sized bite allowing more food to be ingested per bite. The volume percent of each food item in the diet was computed by dividing the number of bites per food item by total bites. There was a trend for larger fish to have a lower percentage of algal turf in their diet, with a correspondingly higher consumption of carbonate algae and coral. Small and medium sized fish (as observed in the field) tended to only nip at the polyps of the acroporid corals. Only the large and extra-large fish were observed to leave the deep characteristic bite marks on the Acropora spp. corals, or upon the harder corals such as Montastrea annularis, Porites astreoides, Siderastrea siderea or Diploria strigosa.

In the inshore enclosure, all of the fish placed in the pen lost weight over the course of the experiment. Even under such a starvation regime, however,

Sparisoma viride did not switch to the coral as an alternate food source. The coral colony within the pen did not appear to be preyed upon any more than those observed in the field. This supports the view that coral is not a major food source in the diet of this fish, but merely a small, incidental part of it.

Discussion

Parrotfish clearly are a source of predation on living corals at Buck Island Reef National Monument, as they have been observed to be in other portions of the Atlantic (Bakus, 1969; Gygi, 1969; Glynn, 1973). Grazing pressure is due primarily to larger individuals, who have the ability to rasp more deeply into the coral skeleton. Coral grazing was heaviest during the winter months, perhaps

reflecting a period of lower productivity of the algal turfs and benthic carbonate algae, which appear to constitute the bulk of the parrotfish diet.

The type of coral being grazed upon, in part determines the effect of grazing on the benthic community. Although Acropora palmata is frequently grazed (up to 10% of a colony showing recent evidence of predation), it can regenerate rapidly, and repair grazed areas very effectively before other organisms settle. Thus, this species, at the grazing pressures at present at Buck Island Reef National Monument, can recover fully and rapidly. The slower growing head corals, however, are more frequently found to be more severely damaged, since algae often colonize the scar marks. This can be a potential source of mortality for these forms. However, it should be noted in Chapter V (Benthic Processes) of this report, that even these corals, unless completely dominated by algae and killed very early after grazing, can often recover and regenerate as well over the grazed areas.

It can be concluded that under the present level of grazing, the parrotfish are modifying the benthic community by supplying surfaces for algal settlement, but the corals are generally able to recover from this perturbation. High levels of grazing, however, due perhaps to lower productivity of algal turfs and carbonate algae for some reason would probably lead to a permanent alteration of the present community structure.

Table 1. — Occurrence of Zooxanthellae in the Guts of Different-Sized Parrotfish Freshly Caught in the Field

Specimens			Size	Weight	Zooxanthellae	
					Yes	No
Primary	<u>Sparisoma</u>	<u>viride</u>	41 cm	2 lbs. 4 oz.	x	
"	"	"	33 cm	1 lb. 1 oz.		x
"	"	"	24 cm	9 oz.		x
"	"	"	37 cm	1 lb. 13 oz.		x
"	"	"	40 cm	2 lbs. 2 oz.	x	
Terminal	<u>Sparisoma</u>	<u>viride</u>	39 cm	1 lb. 13 oz.	x	
"	"	"	40 cm	2 lbs. 2 oz.	x	
"	"	"	40 cm	2 lbs. 0 oz.	x	
"	"	"	24 cm	1 lb. 0 oz.		x
"	"	"	28 cm	1 lb. 6 oz.	x	
Primary	<u>Scarus</u>	<u>vetula</u>	31 cm	1 lb. 6 oz.		x
"	"	"	30 cm	1 lb. 1 oz.		x
"	"	"	34 cm	1 lb. 12 oz.		x
"	"	"	22 cm	15 oz.		x
"	"	"	33 cm	1 lb. 10 oz.		x
Terminal	<u>Scarus</u>	<u>vetula</u>	44 cm	2 lbs. 6 oz.		x
"	"	"	40 cm	2 lbs. 1 oz.		x
"	"	"	47 cm	2 lbs. 15 oz.	x	
"	"	"	36 cm	2 lbs. 0 oz.	x	
"	"	"	42 cm	3 lbs. 0 oz.		x

Table 2. — Feeding Frequency on Various Foods and Percentage of Food Items in the Diet of Sparisoma viride (Mean Number of Bites/Three Minutes $\pm$ Standard Deviations)

Colorphase/ Size Class	Algal Turf	<u>Halimeda</u> sp.	<u>Dictyota</u> sp.	Misc. Macro- Algae	Sand	Coral	Total
Primary/ Small	31.1 $\pm$ 15.6 93%	0.5 $\pm$ 1.4 2%	0.1 $\pm$ 0.5 <1%	0.7 $\pm$ 1.1 2%	0.00 $\pm$ 0.00 0	0.7 $\pm$ 2.2 2%	33.3 $\pm$ 15.7
Primary/ Medium	32.6 $\pm$ 13.7 88%	3.2 $\pm$ 3.5 9%	0.5 $\pm$ 1.1 1%	0.4 $\pm$ 1.0 1%	0.2 $\pm$ 0.5 <1%	0.3 $\pm$ 1.1 <1%	37.2 $\pm$ 12.7
Terminal/ Medium	31.4 $\pm$ 15.6 91%	1.0 $\pm$ 1.7 3%	1.0 $\pm$ 2.4 3%	0.4 $\pm$ 1.0 1%	0.5 $\pm$ 1.6 1%	0.1 $\pm$ 0.4 <1%	34.4 $\pm$ 14.1
Primary/ Large	26.7 $\pm$ 11.2 76%	4.0 $\pm$ 4.0 11%	1.3 $\pm$ 1.8 4%	1.3 $\pm$ 2.2 4%	0.7 $\pm$ 1.5 2%	1.0 $\pm$ 2.4 3%	35.0 $\pm$ 11.6
Terminal/ Large	14.2 $\pm$ 9.5 70%	3.3 $\pm$ 3.5 16%	0.9 $\pm$ 1.2 4%	1.8 $\pm$ 4.2 9%	0.1 $\pm$ 0.4 1%	0.1 $\pm$ 0.5 1%	20.4 $\pm$ 11.3
Primary/ Extra-Large	8.7 $\pm$ 7.3 60%	2.1 $\pm$ 3.7 14%	1.8 $\pm$ 1.8 12%	0.7 $\pm$ 1.1 5%	0.7 $\pm$ 1.7 5%	0.4 $\pm$ 0.8 3%	14.5 $\pm$ 8.0
Terminal/ Extra-Large	14.2 $\pm$ 10.1 68%	2.6 $\pm$ 3.7 13%	1.7 $\pm$ 2.0 8%	1.0 $\pm$ 1.6 5%	0.7 $\pm$ 0.6 3%	0.6 $\pm$ 1.2 3%	20.8 $\pm$ 9.5

FIGURE LEGEND - CHAPTER VII

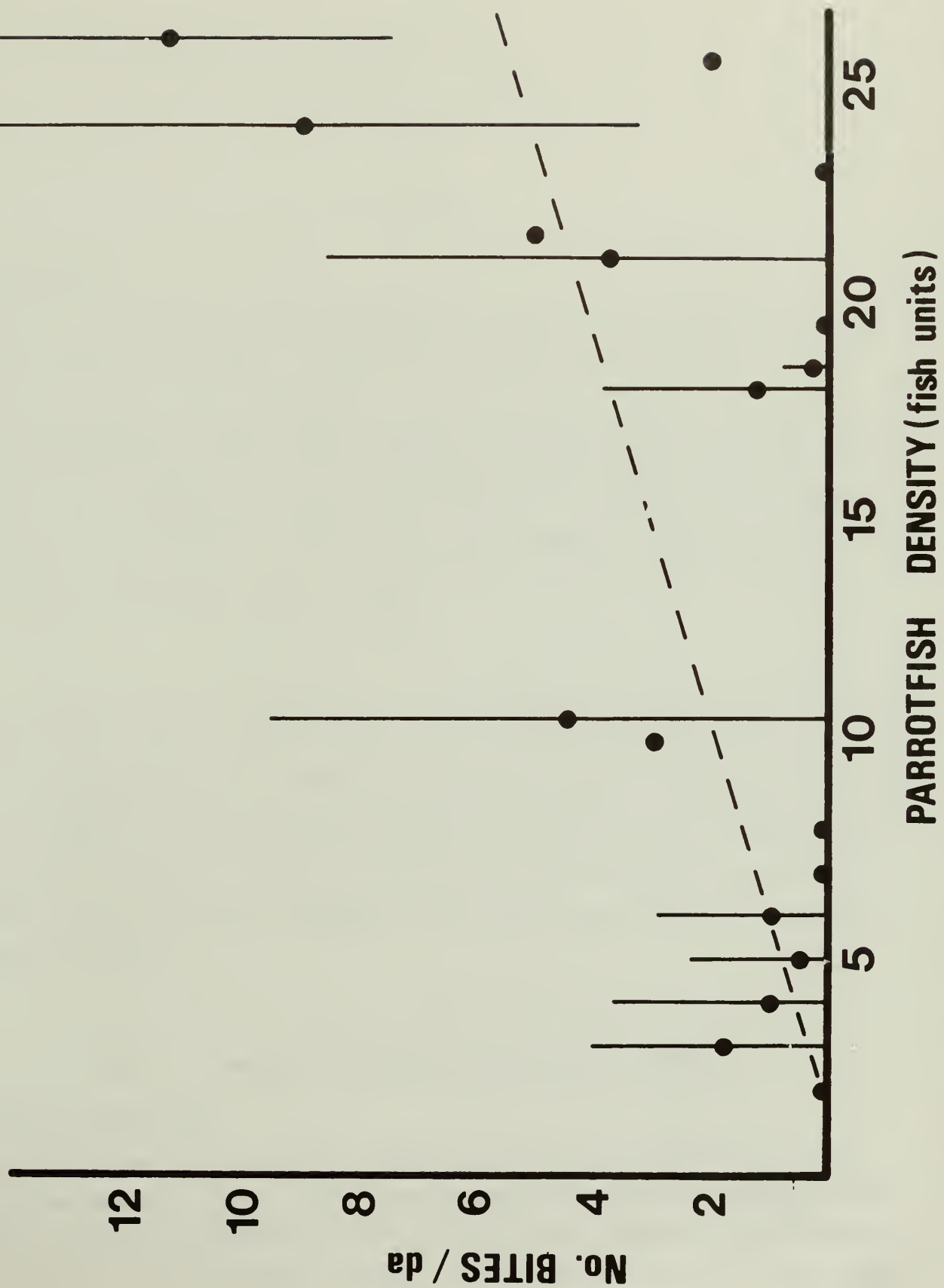
Figure 1 Percent surface area covered by parrotfish predation scars during the year on three colonies of Acropora palmata (means and standard deviations).

Figure 2 Coral predation as a function of parrotfish density.

FIG. 1



FIG. 2



CHAPTER VIII

FISH COMMUNITY DYNAMICS

by

Gary Simpson

Introduction

Fish are a diverse and major component of the coral reef ecosystem, and have been the basis of a number of studies aimed at determining aspects of their ecological role in this community. Territoriality (Sale, 1971; Reese, 1973); cleaning behavior (Feder, 1966; Youngbluth, 1968; Darcy et al., 1974); schooling (Erhlich and Erhlich, 1973; Robertson et al., 1976; Ogden and Erhlich, 1977; Shaw, 1978); movements and migrations (Bardach, 1958; Hobson, 1972; Ogden and Buckman, 1973; Gladfelter, 1979), and general community structure (Sale, 1977; Parrish and Zimmerman, 1977; Gladfelter and Gladfelter, 1978) are only a few of the diverse topics being investigated.

This study had two main objectives: (1) to determine changes in the community structure of fish occupying a patch reef environment by monthly determination of the composition of the community by assessment of abundance and average size of each species present, and (2) to determine the effects of fishing pressure on the growth rate of individual species and the mean maximum size attained by individual species by comparing an area free from fishing pressure (i.e., Buck Island Reef National Monument) with a similar area subject to moderate fishing pressure.

PART I - COMMUNITY STRUCTURE AND POPULATION DYNAMICS

Methods and Materials

Two patch reefs in the lagoon of Buck Island Reef National Monument were selected for this study. The first was designated as North Patch Reef (NPR) and is located lagoonward from the north cut and is composed almost entirely of a dense stand of Acropora palmata. Three sides of the reef are surrounded

by a rocky bottom in two meters of water, while the fourth side abuts on a sand bottom of 3 m depth. The second reef, South Patch Reef (SPR) is lagoonward of the main south cut (i.e., main entrance channel) in about the same depth of water, but shows less habitat diversity than NPR, being primarily a pavement reef.

Each reef was censused visually three times (two diurnal, one nocturnal) each month by two divers (making a total of four day censuses/month and two night censuses/month). Fishes were identified to species and counted and placed in one of five size classes: post-larval, small, medium, large or extra-large.

The median size fish was determined for several species in order to examine the changes in the population throughout the year. The median size fish was determined by assigning to each size class a percentage of the total possible size, i.e., 20% per size class. Thus, post-larval fish were 0-20% of the total possible size; small fish 20-40%; medium fish 40-60%; large fish 60-80% and extra-large fish 80-100%. It was then determined what percentage of the total that each size class represented. The size of the median fish, i.e., the one at the 0.50 position, was then computed by interpolation into the appropriate size class. This value is reported as the median length of that species for that month.

Since volume is the cube of length, the biomass of a species was determined by cubing the median length and multiplying by the monthly mean total. This value is reported as the species biomass for that month.

Results

The monthly fish abundances at the NPR and SPR are listed in Tables 1 and 2. It is clear that the number of species active at night is much lower than the diurnal species, and it can be noted that although many of the nocturnal species were censused by day, their apparent abundance on the reef was an underestimate. The species composition of the two reefs was quite similar, but the SPR was lower than the NPR in both fish abundance, and diversity

(Fig. 1). Diversity and abundance in both areas showed peaks in October and January, and is generally higher in both areas in the winter, and seems to reach a minimum in the summer months.

In a comparison of the population dynamics of common species on both reefs, several trends are evident (Tables 1 and 2 and Figures 2A-J). Some species were in higher abundance at the south reef (Eupomacentrus planifrons, Acanthurus bahianus, Haemulon flavolineatum) while others were more abundant at the North reef (Eupomacentrus fuscus, Acanthurus coeruleus, Haemulon chrysargyreum as well as Scarus vetula, Sparisoma viride and Kyphosus sectatrix and Gramma loreto). Although the two species of Eupomacentrus (Figs. 2A, 2B) have different abundances on the two reefs, their mean length was similar in both areas and did not fluctuate during the year. The two common labrids (Figs. 2C, 2D) Thalassoma bifasciatum and Halichoeres bivittatus also showed similar mean sizes on each reef and throughout the year and also had similar abundances on both reefs. The acanthurids (Figs. 2F, 2G) perhaps show a trend of larger mean size in the summer and fall, with a decrease in mean size in winter (Acanthurus coeruleus on the NPR) or early spring. The parrotfish were much more abundant at the NPR (Table 1; Figs. 2H, 2I). In the species common to both reefs (Sparisoma viride), the average mean size of the fish was greater on the NPR. The common squirrelfish was about the same average size at both reefs but was more abundant at the SPR (Table 2; Fig. 2J).

An estimation of changes in the relative biomass of each abundant species through the year is presented in Figure 3. The pomacentrids (Fig. 3A) were very consistent throughout the year in biomass. Haemulon flavolineatum (Fig. 3B) showed an increase in biomass during the winter, which is partially a reflection of the larger median size of the fish at the time (Fig. 2C). The labrids (Fig. 3C) showed different trends: Halichoeres bivittatus was very uniform on both reefs through the year with increases in abundances dampened out by decrease in median size (see Fig. 2D); while Thalassoma bifasciatum showed much the same trend on both reefs, i.e., high biomass in January and June with a dip in April and a low point reached in the late summer. This

reflects high abundance in January and high median size in June, with low abundance and low median size in the summer (Fig. 2E). With the exception of Acanthurus coeruleus on the North patch reef, the acanthurids showed a similar pattern of biomass throughout the year (Fig. 3D) with very little change, except for a high point in the fall. Increase in abundance of A. bahiensis was generally dampened out by decrease in average size (Fig. 2F) while on the SPR, A. coeruleus generally had a similar abundance and median size throughout the year. The biomass of the Scaridae on the North patch reef was fairly uniform the year around (Fig. 3E).

Discussion

The difference in abundance and diversity of the North and South patch reefs (Fig. 1) can be explained partly by habitat differences and partly by oceanographic location. A patch reef rich in available habitats, such as the North patch reef, is more likely to contain a more diverse fish fauna. The importance of Acropora palmata as an element in increasing habitat diversity and thus enhancing species diversity has been demonstrated by Gladfelter and Gladfelter (1978).

Fishes such as Gramma loreto are excluded by lack of suitable overhangs provided in a complex habitat. Fishes such as the Scaridae may be limited by food resources to the north reef, while the fishes such as Kyphosus sectatrix are more likely to be found near a windward reef.

Total numbers of fishes seemed to reach peaks in the fall and winter, and were lower in the summer months. This could reflect a period of spawning and then recruitment from the plankton occurring during those periods, with most of the species composed of fewer, larger individuals during the summer months. Although median size of fish did not seem to vary too much seasonally, there were cases of apparent recruitment of young (as in the Haemulon flavolineatum on the SPR). A more intense effort following the population of one or just a few species in detail would be necessary to confirm this point. Knowledge of spawning and recruitment of fishes to reefs is still rudimentary. Information

of this sort is necessary to an understanding of the factors which regulate community composition of reef fishes.

PART II — EFFECTS OF FISHING UPON GROWTH RATE AND SIZE OF CORAL REEF FISHES

Methods and Materials

Four study sites were used for this portion of the study. The two sites in Buck Island Reef National Monument were described in the first portion of this chapter (see Community Structure and Population Dynamics - Methods and Materials) and were chosen to represent areas free from fishing pressure. The North Patch Reef site is referred to as Buck Island Patch Reef, while the South Patch Reef site is called the Buck Island Back Reef.

Two sites in Tague Bay, St. Croix, U.S. Virgin Islands were chosen for comparison with the fish community in an area with heavy fishing pressure. Patch Reef #18 in eastern Tague Bay was chosen as one site, and a location about 100 m northwest of Patch Reef #18 on the backreef was the other site. Patch Reef #18 was in water about 3-4 m deep and rose sharply from the surrounding sand. It had numerous large colonies of Acropora palmata on the upper surfaces and several species of mounding corals around the base. The fish trap was placed in a channel about 8-10 m wide between Patch Reef #18 and a nearby patch reef. The backreef site was in water about 2-3 m deep with a sand bottom. Acropora palmata was the dominant coral in the area.

Standard single-funnel West Indian fish traps were used to capture the fish for tagging. The traps are locally called "arrowheads". The downward-opening funnel is located in the apex of the "V". The traps were approximately 1.5 m wide, 1.25 m long and 0.5 m high. They were made of a wooden frame with galvanized chicken wire strung over the wooden supports. Located opposite the funnel was a trap door which allowed for the removal of the captured fish. To remove the fish, a smaller version of the fish trap was designed. This "transfer pot" was a rectangular box approximately 1 m x 50 cm x 50 cm with a

funnel on one end and a trap door on the other. The transfer pot was tied to the fish trap with its funnel opening matched up with the door on the fish trap. The fish were then frightened into the transfer pot by divers, usually requiring 10-20 minutes for the transfer of all the fish. The transfer pot was then taken to the boat and placed in a livebox hung over the side which was drawn up tight to the boat; the trap door of the transfer pots opened and the fish released into the livebox.

Captured fish were tagged with modified Petersen tags. Three-digit, numbered tags were made on plastic tape (DYMO) and cut down to the smallest possible size. A small plastic disc (polyethylene) was made as a blank using a paper punch. Ten pound test monofilament line was used to join the two discs, i.e., a numbered disc and a blank. The monofilament line was attached to the blank prior to entering the field. The fish were tagged through the dorsal musculature using a hypodermic needle.

After tagging, the fish were measured for standard length (S.L.) using a fish board, and weighed. Initially, the most accurate scale available was a spring scale which measured to the nearest ounce, i.e., approximately 28 g. Later, a triple beam balance was used and fish were measured to the nearest gram.

Results

A total of 979 fish from thirty-eight species representing fourteen families were captured and tagged. 140 fish were recaptured with intact tags, and an additional 38 fish were recaptured after having lost their tags. Fish without tags were designated as recaptures based upon characteristic scars which they received from their tags. Thus, a total of 178 fish were recaptured for a recapture rate of 18.1% (Table 3). The individual study sites had the following total recapture rates: Buck Island Patch Reef - 6.5%; Buck Island Backreef - 20.7%; Tague Bay Patch Reef - 30.9%; and Tague Bay backreef - 6.7%.

Of the thirty-eight species that were caught and tagged, 14 species or 36.8% had one or more individuals recaptured. Table 4 shows a breakdown of each species tagged and recaptured at each site.

The mean standard lengths and weights with standard deviations for each species that has more than one individual tagged at more than one site are found in Table 5. These mean sizes are based upon the data from the initial capture of each fish. Statistical analysis (t-test) of each of these six species was also done with the results of the combined data shown in Table 5. In the analysis (t-test), comparisons were made between the patch reef sites, the backreef sites, and a combination of patch reef and backreef site for each major area referred to as the combined data. Between the backreef sites, only two species were found to be significantly different in size. Sparisoma viride was found to be larger in both weight and length ($P < 0.01$ and $P < 0.02$ respectively) at the Tague Bay site. Acanthurus coeruleus was found to be larger in both weight and length ($P < 0.05$ and $P < 0.02$ respectively) at the Buck Island site. Three species were found to be significantly heavier at the Buck Island patch reef. (Acanthurus bahianus, $P < 0.01$; Haemulon sciurus, $P < 0.05$; Lutjanus apodus, $P < 0.001$) and four species were found to be significantly longer (Acanthurus bahianus, $P < 0.01$; Acanthurus coeruleus, $P < 0.05$; Haemulon sciurus, $P < 0.05$; Lutjanus apodus, $P < 0.001$). No species was found to be larger in either weight or standard length at the Tague Bay Patch Reef. When the patch reef and the backreef were combined for the two major areas, only Acanthurus coeruleus and Lutjanus apodus showed significant size difference between Tague Bay and Buck Island. Both were heavier ($P < 0.01$; $P < 0.001$) and longer ($P < 0.02$; $P < 0.001$) at Buck Island (Table 5). There were no other significant size differences between Tague Bay and Buck Island at the $P < 0.05$ level.

The net change in weight and standard length for each fish that was recaptured is seen in Table 6. The data are reported by site with the number of days between initial capture and final recapture (some fish were recaptured more than once, e.g., see Tables 7 and 8). The first scale used to measure weight was a spring scale which only read to the nearest ounce, i.e., approximately 28 g. All measurements were made in an open boat in the field, thus, an error of greater than ± 28 g is probable even with the triple beam balance used in the

later part of this study. Table 6 shows that most fish were recaptured within one month of tagging. Few of these fish show changes in either weight or length that exceed the probable error in measurement. Even fish that were recaptured after long periods of time, e.g., Epinephelus striatus - 115 days; Acanthurus bahianus - 70 days; Kyphosus sectatrix - 91 days; Acanthurus coeruleus - 54 days, showed essentially no growth.

A high proportion of the fishes recaptured were retaken at the same site, indicating that many of these species have definite home ranges and once they have settled in a particular habitat, stay there.

The following is an account of all captured fish by taxonomic category with short observational notes:

FAMILY - Muraenidae - morays

Gymnothorax moringa - spotted moray

One large (approximately 1 m) Gymnothorax moringa was found dead in the Tague Bay backreef trap. No other specimens were captured.

FAMILY - Holocentridae - squirrelfishes

Holocentrus sp. - squirrelfishes

Although members of this genus were captured upon occasion, none were tagged after an initial attempt. These fish proved to be especially difficult to handle because of spines on the operculum and were extremely active when out of the water.

FAMILY - Serranidae - groupers and basses

Epinephelus adscensionis - rock hind

Three Epinephelus adscensionis were tagged at the Tague Bay patch reef. Their standard lengths and weights were: 28.2 cm and 591.0 g; 29.0 cm and 672.0 g; and 20.5 cm and 196.0 g. None were recaptured.

Epinephelus guttatus - red hind

One of the five tagged Epinephelus guttatus was recaptured after seven days (Table 6). Four were tagged in Tague Bay and one at Buck Island. No statistical tests were done due to the small sample size. The tagged individual from Buck Island was 25.0 cm standard length (s.l.) and 420.0 g. The four from Tague Bay ranged from 22.0 - 26.5 cm s.l. and 280.0 - 420.0 g.

Epinephelus striatus - Nassau grouper

One of the six Epinephelus striatus that was tagged was recaptured only once, while another was recaptured six times over a period of 115 days (Tables 6 and 7). The five tagged in Tague Bay ranged in length from 20.0 - 34.5 cm s.l. and in weight from 274.0 - 1120.0 g. The single E. striatus captured at Buck Island measured 33.05 cm s.l. and 1036.0 g.

The numerous recaptures of the specimen from Tague Bay strongly suggests trap conditioning. Bardach (1958) and Springer and McErlean (1962) both found similar possible conditioning for large groupers. They attributed it to the grouper entering the trap to obtain an easy meal as both used traps baited with cut up fish. While in our study we did not bait our traps, on one occasion, the large grouper in question was observed to regurgitate a fair-sized scarid while still in the trap. This scarid was still in good condition and showed little sign of digestion, thus suggesting that it was recently eaten by the grouper.

Petrometopon cruentatum - graysby

A single Petrometopon cruentatum was captured and tagged in Tague Bay, but was not recaptured. It was 20.0 cm s.l. and 243.0 g.

FAMILY - Grammistidae - soapfishes

Rypticus saponaceus - greater soapfish

The one Rypticus saponaceus captured and tagged in Tague Bay was not recaptured. It measured 22.5 cm s.l. and 336.0 g.

FAMILY - Carangidae - jacks

Caranx latus - horse-eye jack

Several Caranx latus were found dead in the Tague Bay traps. No specimens were tagged.

Caranx ruber - bar jack

Three Caranx ruber were tagged with none being recaptured. The two individuals from Tague Bay were: 25.0 cm s.l. and 308.0 g, and; 30.0 cm s.l. and 700.0 g. The single C. ruber from Buck Island was 28.5 cm s.l. and 448.0 g.

Seriola dumerili - greater amberjack

Two large Seriola dumerili (33.0 cm s.l.; 34.0 s.l.) were tagged in Tague Bay. Neither fish could be weighed as they exceeded the limits of our scale, i.e., 610 g. Neither was recaptured.

FAMILY - Lutjanidae - snappers

Lutjanus analis - mutton snapper

A single Lutjanus analis (24.8 cm s.l.; 384.0 g) was captured and tagged at Buck Island. It was not recaptured.

Lutjanus apodus - schoolmaster snapper

A total of 51 Lutjanus apodus were captured and 15.7% were recaptured. One was recaptured three times, the rest only once. Two additional L. apodus were recaptured after having lost their tags. L. apodus was found to be both heavier and longer (s.l.) at Buck Island ($P > .001$ - see Table 5). In Tague Bay, the size ranges were 17.5 - 30.0 cm s.l. and 168.0 - 812.0 g, while at Buck Island, they were 16.5 - 35.5 cm s.l. and 140.0 - 1826.0 g.

Lutjanus griseus - gray snapper

Two Lutjanus griseus were tagged at the Tague Bay patch reef site and neither was recaptured. They were 25.0 cm s.l. and 308.0 g, and 18.5 cm s.l. and 168.0 g.

Lutjanus mahogoni - mahogany snapper

A single Lutjanus mahogoni (19.5 cm s.l.; 168.0 g) was caught and tagged at Buck Island. It was not recaptured.

Ocyurus chrysurus - yellowtail snapper

Three Ocyurus chrysurus were caught and tagged but none were recaptured. The two tagged in Tague Bay measured: 36.0 cm s.l. and 868.0 g, and; 35.0 cm s.l. and 616.0 g.

FAMILY - Pomadasyidae - grunts

Haemulon carbonarium - caesar grunt

A total of two Haemulon carbonarium were tagged at Buck Island with neither being recaptured. They had measurements of: 20.5 cm s.l. and 228.0 g, and 25.0 cm s.l. and 364.0 g.

Haemulon flavolineatum - french grunt

Only two Haemulon flavolineatum were tagged in Tague Bay and one at Buck Island. In Tague Bay the two individuals were: 17.0 cm s.l. and 137.0 g, and 112.0 g. The H. flavolineatum from Buck Island was 16.0 cm s.l. and 112.0 g.

Most of the H. flavolineatum seen at both Buck Island and in Tague Bay were small enough to easily slip through the wire mesh of the traps. Although this species does get larger, Ogden and Erhlich (1977) suggest that H. flavolineatum larger than about 15.0 cm s.l. migrate into deeper water.

Haemulon parrai - sailor's choice

A single Haemulon parrai (17.8 cm s.l.; 169.0 g) was caught and tagged in Tague Bay. It was not recaptured.

Haemulon plumieri - white grunt

This species is generally found resting in schools on the reef during the day, and like Haemulon flavolineatum makes nocturnal forages into the surrounding grass beds to feed. Both species follow the same migratory routes to and from the reef daily and they appear to be established and permanent over long periods of time. Ogden and Erhlich (1977) state that "large numbers of fishes were easily trapped by placing a V-shaped fence" attached to a trap "astride the route".

As we tended to either catch H. plumieri in groups of 4-8 or else singly, it is possible that those sites with large numbers of H. plumieri were located on or very near to these migration routes. Those sites with low numbers merely caught the foraging individual.

A total of 107 Haemulon plumieri were tagged with eight (7.5%) being recaptured with tags and six additional fish being recaptured without tags. At Buck Island, H. plumieri had size ranges of 16.0 - 24.6 cm s.l. and 84.0 - 487.0 g. In Tague Bay, the size ranges were 16.0 - 26.4 cm s.l. and 112.0 - 448.0 g. There was no significant difference in either weight ($P < 0.05$) or length ($P < 0.2$) between Buck Island and Tague Bay (Table 6). Only one individual was recaptured more than once. It was first recaptured after 12 days and then again after 7 days.

Haemulon sciurus - bluestriped grunt

Only three Hemulon sciurus were recaptured with tags out of the 38 initially tagged. Three additional fish were recaptured after having lost their tags. None of the fish were recaptured more than once. In Tague Bay, H. sciurus ranged from 15.5 - 24.5 cm s.l. and 112.0 - 364.0 g. At Buck Island, they were 16.5 - 26.0 cm s.l. and 140.0 - 560.0 g in size. There was no significant difference (t-test) in either weight ($P < 0.1$) or length ($P < 0.2$) (Table 6).

FAMILY - Sciaenidae - drums

Equetus punctatus - spotted drum

A single Equetus punctatus (19.5 cm s.l. and 215.0 g) was tagged at Buck Island. It was not recaptured.

FAMILY - Mullidae - goatfishes

Mulloidichthys martinicus - yellow goat

Although numerous Mulloidichthys martinicus were captured throughout the course of this study, only one was tagged (23.0 cm s.l. and 224.0 g). It was found to be extremely difficult to tag M. martinicus because M. martinicus is a small but broad fish, in fact, too broad to allow the needle to pass through the dorsal musculature. Since it was not possible to securely tag this species of fish, they were released without being tagged.

FAMILY - Gerreidae - mojarra

Gerres cinereus - yellowfin mojarra

A single Gerres cinereus (19.0 cm s.l. and 177.0 g) was tagged at Tague Bay, but it was not recaptured.

FAMILY - Kyphosidae - sea chubs

Kyphosus sectatrix - Bermuda chub

One Kyphosus sectatrix (18.5 cm s.l. and 168.0 g) was caught and tagged at the Tague Bay patch reef site. This fish was recaptured without its tag six times over a period of three months (Table 8). The weights and lengths recorded at each recapture of this individual are typical of those found for individuals that were recaptured repeatedly over a period of time (see also Table 7).

Differing periods of time in the trap and the movements of the boat while taking the reading are the probable reasons for most, if not all, of the variance found in size between successive recaptures. The repeated recaptures of this individual as well as the recapture/capture ratio indicate a definite trap conditioning.

FAMILY - Chaetodontidae - butterflyfish and angelfish

Pomacanthus paru - french angelfish

Neither of the two tagged Pomacanthus paru were recaptured. Both were tagged at the Tague Bay patch reef site and measured 18.0 cm s.l. and 336.0 g, and 16.0 cm s.l. and 224.0 g.

FAMILY - Pomacentridae - damselfishes

Abudefduf saxatilis - sergeant major

Nine Abudefduf saxatilis were tagged, but none were recaptured. The single individual caught at Buck Island was 14.0 cm s.l. and 148.0 g. In Tague Bay, the size ranges were 11.5 - 13.5 cm s.l. and 84.0 - 140.0 g (see Table 5).

Microspathodon chrysurus - yellowtail damselfish

Two Microspathodon chrysurus were recaptured of the seven initially tagged. Both recaptured fish were from the Buck Island backreef site and were captured and recaptured on the same days. Three specimens were tagged in Tague Bay and

they ranged in size from 12.4 cm s.l. and 84.0 - 121.0 g. The four individuals from Buck Island had size ranges of 12.0 - 13.0 cm s.l. and 103.0 - 130.0 g (see Table 5).

FAMILY - Labridae - wrasses

Halichoeres radiatus - pudding wife

Two Halichoeres radiatus were captured and tagged at Buck Island with neither being recaptured. These fish were 27.5 cm s.l. and 532.0 g and 21.0 cm s.l. and 224.0 g. Other than H. radiatus, only Scarus vetula consistently was found with very damaged snouts and generally in poor health after spending some time in a trap. Upon several occasions, dead H. radiatus were found floating in a trap.

Lachnolaimus maximus - hogfish

Only one Lachnolaimus maximus was caught and tagged. This individual was recaptured twice over a two-week period (Table 6). This fish measured 17.2 cm s.l. and 180.0 g.

FAMILY - Scaridae - parrotfishes

Scarus coelestinus - midnight parrotfish

A single, small Scarus coelestinus (23.5 cm s.l. and 392.0 g) was caught and tagged in Tague Bay. It was not recaptured.

Scarus coeruleus - blue parrotfish

None of the twelve Scarus coeruleus initially tagged were recaptured. All were caught in Tague Bay and ranged in size from 21.0 - 25.0 cm s.l. and 252.0 - 364.0 g.

Scarus croicensis - striped parrotfish

Only one Scarus croicensis (20.1 cm s.l. and 270.0 g) was tagged. It was not recaptured. Ogden and Buckman (1973) state that S. croicensis "is the smallest and most abundant Caribbean scarid", however, Ogden and Lobel (1978) state that S. croicensis is not very abundant around St. Croix. Regardless, the small size of this scarid (maximum size is about 20 cm; Ogden and Buckman, 1973) is the probable explanation for so few being captured.

Scarus taeniopterus - princess parrotfish

Two Scarus taeniopterus were caught and tagged. The specimen tagged at Tague Bay (23.0 cm s.l. and 353.0 g) was found dead in the trap 13 days after tagging. The specimen from Buck Island was 25.5 cm s.l. and 280.0 g and was not recaptured.

Scarus vetula - queen parrotfish

Sixteen Scarus vetula were tagged, eight at both Buck Island and Tague Bay. None were recaptured. One large terminal phase individual was seen on the Buck Island patch reef for several weeks after it was tagged. After that, it either lost its tag or migrated, as it was not observed again. The fish from Tague Bay had size ranges of 20.2 - 32.0 cm s.l. and 268.0 - 730.0 g. Those from Buck Island ranged from 20.4 - 31.0 cm s.l. and 251.0 - 952.0 g (Table 5). Bardach (1958) stated that parrotfishes were "delicate and excitable when captured". He observed numerous scarids sink to the bottom after tagging and recovered several dead within 30 minutes. In our tagging, only Scarus vetula appeared to be a "delicate" fish. Frequently, we would arrive at a trap and find one or more dead S. vetula. Only Halichoeres radiatus appeared to survive as poorly in a trap as S. vetula. No fish, however, was observed to die as a direct result of the tagging procedure (i.e., transferral to the boat, handling, or time spent out of the water).

Sparisoma aurofrenatum - redband parrotfish

Thirty Sparisoma aurofrenatum were caught and tagged at the four sites with only one recapture. Twenty of the initially tagged fish were from one station (Table 4). In Tague Bay, the size ranges were 17.0 - 29.0 cm s.l. and 140.0 - 489.0 g, while at Buck Island they were 21.5 - 26.0 cm s.l. and 270.0 - 520.0 g. Table 6 shows the mean weights and standard lengths with standard deviations for S. aurofrenatum. No statistical analysis was done due to the small sample size at Buck Island (n = 4).

Sparisoma chrysopterus - redtail parrotfish

A total of twelve Sparisoma chrysopterus were tagged, ten from one site (Table 4). Two were recaptured with intact tags and one was recaptured without its tag.

None were recaptured more than once. All of the S. chrysopteron were caught in Tague Bay and their size ranges were 17.0 - 27.5 cm s.l. and 140.0 - 573.0 g (Table 5).

Sparisoma rubripinne - yellowtail parrotfish

None of the twelve specimens of Sparisoma rubripinne that were caught and tagged were recaptured. All were captured at the Tague Bay patch reef site and ranged in size from 18.5 - 27.2 cm s.l. and 178.0 - 596.0 g (Table 5).

Sparisoma viride - stoplight parrotfish

Sparisoma viride is one of the larger and more abundant scarids at Buck Island. Seventy-nine individuals were captured between Buck Island and Tague Bay, and five were recaptured. Most of the specimens that were recaptured were not released, however, but were brought back to the laboratory to be used in another experiment. Thus, only 32 fish were tagged and released, for a recapture rate of 15.6%. None of the fish were recaptured more than once. There is no significant difference (t-test) in either weight or length between the fish caught in Tague Bay or Buck Island. Although larger S. viride were observed around the Buck Island patch reef site, few were captured. Size selection by the trap is possible for this species and for several others due to the lack of larger specimens being captured even though they were observed to be in the immediate vicinity of the traps. In Tague Bay, the size ranges were 15.5 - 34.0 cm s.l. and 112.0 - 2123.0 g, while at Buck Island they were 15.9 - 32.0 cm s.l. and 134.0 - 840.0 g (Table 5). One specimen captured in Tague Bay could not be weighed as it exceeded the limits of the scale (i.e., 610 g).

FAMILY - Acanthuridae - surgeonfishes

Acanthurus bahianus - ocean surgeon

This species was the second most abundant species tagged, comprising 20.9 of the total number of fish caught. Two hundred and five fish were tagged with 89 (43.4%) being recaptured with tags and an additional 11 being recaptured without tags. Thirty-three fish were recaptured once, 8 twice, 3 three times, one each four and six times and 2 five times. At Buck Island, the size ranges

were 11.7 - 19.0 cm s.l. and 56.0 - 220.0 g, while in Tague Bay they were 11.0 - 20.5 cm s.l. and 28.0 - 280.0 g. There was no significant difference (t-test) in either weight or length between fish caught in the two study areas (Table 5).

Acanthurus coeruleus - blue tang

A total of 318 Acanthurus coeruleus were tagged at the four sites, making it the most numerous tagged species (32.4%) in this study. Fifty-seven (17.9%) were recaptured with tags and eleven without tags (Table 4). Forty-three were recaptured once, 6 twice, 4 thrice and 4 four times.

A. coeruleus was found to be significantly larger (t-test) in both weight ($P > 0.02$) and standard length ($P > 0.01$) at Buck Island. At Buck Island, A. coeruleus ranged in size from 9.8 - 26.5 cm s.l. and 28.0 - 616.0 g. In Tague Bay, the size ranges were 9.5 - 18.7 cm s.l. and 28.0 - 296.0 g.

This species, as well as Acanthurus bahianus, are generally found traveling in mixed schools with each other. This schooling habit may be a major factor in the capture of such a large number of these two species. The presence of one or more individuals in a trap attracts others. Upon several occasions, individuals were seen on the outside of a trap attempting to get through the wire to join those inside of the trap. Also, several small schools were seen to enter the trap in a follow-the-leader fashion. Therefore, it may be the behavior of these species rather than their abundance which made them so numerous in our study. Although larger individuals were frequently seen in the areas of the traps, only one was captured and tagged. The same was observed with Sparisoma viride and this may suggest that the trap size used was selecting against these larger fish and not giving a true cross-section of the population.

Acanthurus chirurgus - doctorfish

None of the four tagged Acanthurus chirurgus were recaptured. The two individuals from Tague Bay measured 25.0 cm s.l. and 308.0 g and 30.0 cm s.l. and 700.0 g. The single A. chirurgus from Buck Island measured 28.5 cm s.l. and 448.0 g.

FAMILY - Balistidae - triggerfishes

Canthidermis sufflamen ocean triggerfish

A single C. sufflamen was captured at the Buck Island backreef site. It was deemed too large to fit into the transfer pot and was released without tagging.

Balistes vetula - queen triggerfish

A single Balistes vetula was captured at Buck Island and released without tagging.

FAMILY - Ostraciontidae - trunkfishes

Lactophrys bicaudalis - spotted trunkfish

Several Lactophrys bicaudalis were captured throughout the course of this study, and were released without tagging.

Lactophrys triqueter - smooth trunkfish

Numerous Lactophrys triqueter were captured at all sites. No attempt was made to tag them due to their bony carapace.

FAMILY - Diodontidae - porcupinefishes

Diodon hystrix - porcupinefish

No attempt was made to tag the Diodon hystrix that were caught throughout the course of this study.

Conclusions

Only two species of fishes (Acanthurus coeruleus and Lutjanus apodus) were found to be significantly larger in the area of low fishing pressure, Buck Island Reef National Monument. Other species of fishes either showed no significant difference in size, or were caught too infrequently for analysis. The size trap used, however, probably selected for smaller individuals of some of the species (especially the members of the Scaridae). Visual observations suggest that larger individuals of some species of this family are found at Buck Island than are found in Tague Bay.

Table 1. — Fish Abundance (by Categories) in Monthly Diurnal Censuses.
Each Abundance is Mean of Four Censuses.

	North Patch Reef												South Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<i>Harengula humeralis</i>	7	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Anchoa lyolepis</i>	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Synodus intermedius</i>	1	0	1	1	0	0	1	1	1	0	1	0	4	1	1	2	1	1	2	1	1	1	1	1
<i>Gymnothorax funebris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>G. vicinys</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Strongylura notata</i>	1	1	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tylosaurus crocodilus</i>	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Aulostomus maculatus</i>	2	2	2	1	2	2	1	2	2	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1
<i>Holocentrus rufus</i>	4	4	4	3	4	3	4	4	3	2	2	2	4	4	3	4	4	4	4	3	3	3	3	4
<i>H. ascensionis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Adioryx vexillarius</i>	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>A. coruscus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Myripristis jacobus</i>	1	0	0	0	1	1	0	1	1	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Mugil curema</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Sphyaena barracuda</i>	1	1	1	1	0	0	1	0	0	1	0	0	1	-	-	1	-	-	-	1	1	1	1	1
<i>Epinephelus guttatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
<i>E. adscensionis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. striatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hypoplectrus nigricans</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. unicolor</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. guttavarius</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Serranus tabacarius</i>	1	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Gramma loreto</i>	1	1	1	0	1	1	0	1	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Priacanthus cruentatus</i>	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1	1
<i>Apogon maculatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>A. binotatus</i>	1	1	0	0	1	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Caranx ruber</i>	5	4	2	3	2	4	3	2	3	1	1	1	4	3	1	1	1	5	1	1	1	1	1	1
<i>Lutjanus griseus</i>	0	1	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	1	-	-	-	-	-	-
<i>L. apodus</i>	4	3	4	3	4	3	3	2	2	3	2	2	2	2	-	2	2	2	2	2	2	1	1	2

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Table 1. — Continued

	North Patch Reef												South Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<i>L. jocu</i>	1	1	1	1	0	1	1	1	0	1	0	0	1	1	1	1	1	2	1	1	1	1	1	1
<i>L. analis</i>	0	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1
<i>L. mahogoni</i>	1	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2
<i>Ocyurus chrysurus</i>	1	2	0	0	0	0	0	1	0	0	0	0	1	2	1	2	2	3	2	2	2	1	1	1
<i>Haemulon aurolineatum</i>	5	5	5	5	6	5	5	6	7	5	5	5	2	2	1	2	2	2	2	2	2	1	1	1
<i>H. chrysargyreum</i>	2	1	2	1	1	1	1	1	2	1	1	1	1	1	1	3	4	3	2	2	3	3	3	3
<i>H. melanurum</i>	0	1	1	0	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>H. plumieri</i>	3	3	3	2	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
<i>H. carbonarium</i>	7	7	7	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
<i>H. sciurus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>H. flavolineatum</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Anisotremus virginicus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Odontoscia dentex</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Mulloidichthys martinicus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Pseudupeneus maculatus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Pempheris schomburgki</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Gerres cinereus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Eucinostomus argenteus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Kyphosus sectatrix</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Bothus lunatus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Scorpaena plumieri</i>	4	2	1	1	1	1	1	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2
<i>Chaetodon capistratus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Chaetodon striatus</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Pomacanthus paru</i>	0	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>P. arcuatus</i>	6	6	7	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
<i>Eupomacentrus fuscus</i>	6	6	7	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
<i>E. planifrons</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. variabilis</i>	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>E. leucostictus</i>	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
<i>E. partitus</i>	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
<i>Microspathodon chrysurus</i>	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

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	North Patch Reef												North Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Abudefduf saxatilis	3	2	3	4	4	3	1	3	1	2	2	0	3	2	3	4	4	3	1	3	1	2	0	0
A. taurus	2	1	2	2	2	2	1	2	2	1	2	1	0	1	2	1	1	2	2	1	1	2	1	1
E. mellis	-	5	-	-	-	4	5	4	1	-	4	-	4	-	-	-	-	-	-	-	-	-	-	-
Halichoeres bivittatus	1	2	2	0	1	0	1	0	1	1	1	0	1	1	2	1	1	1	1	1	1	2	1	1
H. radiatus	2	4	2	2	2	2	1	2	2	2	2	2	1	0	1	1	1	1	0	1	1	0	0	0
H. poeyi	7	7	7	7	7	7	7	7	7	7	7	7	6	7	6	7	7	7	7	7	7	7	7	6
Thalassoma bifasciatum	-	4	1	1	1	-	2	1	1	1	1	0	-	0	0	0	0	0	0	0	0	0	0	0
H. maculipinna	5	2	1	2	3	1	2	1	1	1	1	0	4	2	1	1	1	1	1	1	1	1	1	1
Sparisoma rubripinne	6	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4
S. chrysopterus	3	2	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
S. viride	2	2	0	0	0	1	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3
S. aurofrenatum	6	4	4	5	5	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
S. radians	2	4	4	5	5	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
Scarus vetula	6	2	4	5	5	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
S. croicensis	6	2	4	5	5	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
S. taeniopterus	4	5	5	5	5	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
S. coeruleus	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
S. guacamaia	-	5	-	6	-	7	-	7	-	7	-	7	-	7	-	7	-	7	-	7	-	7	-	7
S. coelestinus	5	6	6	5	5	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
Scarus juv.	4	6	6	5	5	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
Sparisoma juv.	6	6	6	5	5	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
Acanthurus coeruleus	5	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
A. bahianus	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. chirurgus	-	0	-	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Monacanthus tuckeri	-	0	-	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Cantherhines pullus	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Lactophrys triqueter	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
L. bicaudalis	1	1	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acanthostracion polygonius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canthigaster rostrata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diodon hystrix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeroides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeroides spengleri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drigatis americana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calamus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apogonid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mycteroperca tigris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. — Fish Abundance (by Categories) in Monthly Nocturnal Censuses.

Each Abundance is Mean of Two Censuses.

	North Patch Reef												South Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<i>Harengula humeralis</i>	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Anchoa lyolepis</i>	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Synodus intermedius</i>	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-
<i>Gymnothorax funebris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>G. vicinus</i>	-	-	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
<i>Strongylura notata</i>	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
<i>Tylosaurus crocodilus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Aulostomus maculatus</i>	-	-	-	-	-	1	-	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Holocentrus rufus</i>	-	-	-	-	4	4	-	5	5	5	-	4	-	-	-	-	6	5	-	6	7	6	-	5
<i>H. ascensionis</i>	-	-	-	-	-	-	-	-	3	4	-	-	-	-	-	-	-	3	-	4	3	3	-	3
<i>Adioryx vexillarius</i>	-	-	-	-	2	2	-	4	3	2	-	-	-	-	-	-	4	3	-	4	3	3	-	3
<i>A. coruscus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Myripristis jacobus</i>	-	-	-	-	2	2	-	4	2	2	-	2	-	-	-	-	0	1	-	1	2	4	-	2
<i>Mugil curema</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<i>Sphyaena barracuda</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Epinephelus guttatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. adscensionis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. striatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hypoplectrus nigricans</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. unicolor</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. guttavarius</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Serranus tabacarius</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Gramma loreto</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Priacanthus cruentatus</i>	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	2	1	-	-	4	2	-	-
<i>Apogon maculatus</i>	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	2	1	-	-
<i>A. binotatus</i>	-	-	-	-	6	6	-	7	7	7	-	7	-	-	-	-	7	7	-	7	7	7	-	6
<i>Caranx ruber</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Lutjanus griseus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>L. apodus</i>	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	1	-	1	-	-	-	-
<i>L. jocu</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued on following page

	North Patch Reef												South Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<i>L. analis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>L. mahogoni</i>	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ocyurus chrysurus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-
<i>Haemulon aurolineatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
<i>H. chrysargyreum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. melanurum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<i>H. plumieri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. carbonarium</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. sciurus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. flavolineatum</i>	-	-	-	-	3	3	-	3	3	4	-	2	-	-	-	-	7	4	-	6	6	5	-	5
<i>Anisotremus virginicus</i>	-	-	-	-	-	-	-	1	1	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-
<i>Odontoscion dentex</i>	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-	1
<i>Mulloidichthys martinicus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Pseudupeneus maculatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	-
<i>Pempheris schomburgki</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-
<i>Gerres cinereus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Eucinostomus argenteus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Kyphosus sectatrix</i>	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Bothus lunatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
<i>Scorpaena plumieri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Chaetodon capistratus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<i>Chaetodon striatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Pomacanthus paru</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>P. arcuatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Eupomacentrus fuscus</i>	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	1	-	1	-	1	-	-
<i>E. planifrons</i>	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	1	2	1	-	1
<i>E. variabilis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. leucostictus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. partitus</i>	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
<i>Microspathodon chrysurus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
<i>Abudefduf saxatilis</i>	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>A. taurus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>E. melis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Halichoeres bivittatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued on following page

Table 2. — Continued

	North Patch Reef												South Patch Reef											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<i>H. radiatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. poeyi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Thalassoma bifasciatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. maculipinna</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Sparisoma rubripinne</i>	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
<i>S. chrysopterus</i>	-	-	-	-	2	-	-	2	1	1	-	-	-	-	-	-	1	1	-	2	1	1	-	1
<i>S. viride</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. aurofrenatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. radians</i>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<i>Scarus vetula</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. croicensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. taeniopterus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. coeruleus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1
<i>S. guacamaia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>S. coelestinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Scarus</i> juv.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Sparisoma</i> juv.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Acanthurus coeruleus</i>	-	-	-	-	1	1	-	1	1	1	-	-	-	-	-	-	2	3	-	2	4	2	-	2
<i>A. bahianus</i>	-	-	-	-	1	1	-	1	1	1	-	1	-	-	-	-	2	3	-	3	4	4	-	2
<i>A. chirurgus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
<i>Monacanthus tuckeri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Cantherhines pullus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Lactophrys triqueter</i>	-	-	-	-	2	3	-	1	1	2	-	2	-	-	-	-	3	3	-	2	2	2	-	2
<i>L. bicaudalis</i>	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	1	-	1
<i>Acanthostracion polygonus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Canthigaster rostrata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Diodon hystrix</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>Hemiramphus brasiliensis</i>	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Apogonid</i> sp.	-	-	-	-	-	-	-	-	-	7	-	7	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rypticus saponaceus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	6

Table 3. — Rates of Recaptured Fish at Each Site

Location	Fish Tagged	Recaptures with Tags	Recaptures w/o Tags	% Recapture with Tags	% Total Recapture with & w/o Tags
<u>Tague Bay</u>					
Patch Reef	369	91	23	24.6	30.9
Backreef	134	6	3	4.5	6.7
<u>Buck Island</u>					
Patch	307	16	4	5.2	6.5
Backreef	169	27	8	16.0	20.7
Totals	979	140	38	14.3	18.1

Table 4. — Species List of Tagged and Recaptured Fish at Each Site

Tague Bay Patch Reef

Species	No. Tagged	No. Recaptured+	% of Tagged Total	% of Recaptured Total	No. Recaptured/ No. Captured (%)++
<i>Acanthurus bahianus</i>	86	33	23.3	36.3	67.4
<i>Acanthurus coeruleus</i>	71	39	19.2	42.9	90.1
<i>Haemulon plumieri</i>	67	7	18.1	7.7	11.9
<i>Sparisoma viride</i>	30	2	8.1	2.2	15.4
<i>Lutjanus apodus</i>	21	3	5.7	3.3	23.8
<i>Sparisoma aurofrenatum</i>	20	1	5.4	1.1	5.0
<i>Sparisoma rubripinne</i>	12	1	5.4	1.1	5.0
<i>Sparisoma chrysopteron</i>	10	2	2.7	2.2	22.2
<i>Haemulon sciurus</i>	8	0	2.3	----	----
<i>Abudefduf saxatilis</i>	8	0	2.3	----	----
<i>Scarus vetula</i>	6	0	1.6	----	----
<i>Epinephelus adscensionis</i>	3	0	0.8	----	----
<i>Epinephelus striatus</i>	3	0	0.8	----	----
<i>Epinephelus guttatus</i>	2	1	0.5	1.1	50.0
<i>Acanthurus chirurgus</i>	2	0	0.5	----	----
<i>Caranx ruber</i>	2	0	0.5	----	----
<i>Haemulon flavolineatum</i>	2	0	0.5	----	----
<i>Lutjanus griseus</i>	2	0	0.5	----	----
<i>Ocyurus chrysurus</i>	2	0	0.5	----	----
<i>Pomacanthus paru</i>	2	0	0.5	----	----
<i>Seriola dumerili</i>	2	0	0.5	----	----
<i>Kyphosus sectatrix</i>	1	1	0.3	1.1	600.0
<i>Lachnolaimus maximus</i>	1	1	0.3	1.1	200.0
<i>Scarus croicensis</i>	1	0	0.3	----	----
<i>Scarus taeniopterus</i>	1	1	0.3	1.1	100.0
<i>Gerres cinereus</i>	1	0	0.3	----	----
<i>Mulloidichthys martinicus</i>	1	0	0.3	----	----
<i>Pterometopon cruentatum</i>	1	0	0.3	----	----
<i>Rypticus saponaceus</i>	1	0	0.3	----	----
Totals	369	91	24.7	----	----

Table 5. — Average sizes of Fish at Each Site and the Combined Sizes for each Major Area.
(Mean $\pm$ Standard Deviation)

A. Weight (g)

Species	Buck Island Patch Reef	Buck Island Back Reef	Tague Bay Patch Reef	Tague Bay Back Reef	Buck Island Combined	Tague Bay Combined	t-test Combined
<i>Acanthurus bahianus</i>	152.5 $\pm$ 47.4	110.5 $\pm$ 44.1	123.8 $\pm$ 59.2	90.2 $\pm$ 30.6	126.4 $\pm$ 49.5	120.8 $\pm$ 57.9	P < 0.2
<i>Acanthurus coeruleus</i>	147.6 $\pm$ 66.9	171.7 $\pm$ 101.2	136.4 $\pm$ 67.7	115.5 $\pm$ 49.2	151.4 $\pm$ 73.6	128.5 $\pm$ 64.5	P > 0.02
<i>Haemulon plumieri</i>	280.7 $\pm$ 117.4	235.9 $\pm$ 94.4	219.7 $\pm$ 73.2	210.0 $\pm$ 73.9	250.8 $\pm$ 101.4	216.9 $\pm$ 73.1	P < 0.05
<i>Haemulon sciurus</i>	329.0 $\pm$ 9.9	275.1 $\pm$ 147.9	200.3 $\pm$ 74.0	264.5 $\pm$ 69.0	280.7 $\pm$ 140.5	235.3 $\pm$ 76.9	P < 0.1
<i>Lutjanus apodus</i>	627.3 $\pm$ 366.5	613.1 $\pm$ 459.1	292.1 $\pm$ 76.8	404.0 $\pm$ 195.9	617.4 $\pm$ 424.7	320.0 $\pm$ 123.9	P > 0.001
<i>Sparisoma viride</i>	481.1 $\pm$ 158.8	219.8 $\pm$ 98.2	452.6 $\pm$ 370.1	509.7 $\pm$ 278.9	424.6 $\pm$ 182.8	468.5 $\pm$ 344.8	P < 0.4
<i>Sparisoma aurofrenatum</i>	352.0 $\pm$ 113.5	-----	233.7 $\pm$ 79.4	288.0 $\pm$ 108.3	352.0 $\pm$ 113.5	246.2 $\pm$ 87.7	N.D.
<i>Sparisoma chrysopterum</i>	-----	-----	193.0 $\pm$ 43.0	426.5 $\pm$ 207.2	-----	231.9 $\pm$ 116.9	N.D.
<i>Sparisoma rubripinne</i>	-----	-----	306.0 $\pm$ 155.8	-----	-----	306.0 $\pm$ 155.8	N.D.
<i>Scarus vetula</i>	607.9 $\pm$ 257.0	-----	483.3 $\pm$ 158.9	460.0 $\pm$ 141.4	607.9 $\pm$ 257.0	477.5 $\pm$ 144.9	N.D.
<i>Ocyurus chrysurus</i>	-----	616.0*	784.0 $\pm$ 118.8	510.0 $\pm$ 31.1	616.0	647.0 $\pm$ 173.4	N.D.
<i>Epinephelus guttatus</i>	-----	420.0*	364.0 $\pm$ 0.0	350.0 $\pm$ 99.0	420.0	357.0 $\pm$ 57.7	N.D.
<i>Epinephelus striatus</i>	1036.0*	-----	407.0 $\pm$ 127.0	798.0 $\pm$ 455.4	1036.0	563.4 $\pm$ 325.2	N.D.
<i>Abudefduf saxatilis</i>	-----	148.0*	110.3 $\pm$ 24.8	-----	148.0	110.3 $\pm$ 24.8	N.D.
<i>Microspathodon chrysurus</i>	-----	112.0 $\pm$ 12.4	121.0*	84.0 $\pm$ 0.0	112.0 $\pm$ 12.4	96.3 $\pm$ 21.4	N.D.

*n = 1

N.D. t-test not done due to small sample size.

Table 5. — Continued

B. Standard Length (cm)

Species	Buck Island Patch Reef	Buck Island Back Reef	Tague Bay Patch Reef	Tague Bay Back Reef	Buck Island Combined	Tague Bay Combined	t-test Combined
<i>Acanthurus bahianus</i>	15.9 ± 1.7	14.3 ± 1.7	15.0 ± 2.1	13.4 ± 1.7	14.9 ± 1.9	14.8 ± 2.1	P < 0.5
<i>Acanthurus coeruleus</i>	14.5 ± 1.9	14.6 ± 2.8	14.0 ± 2.4	13.5 ± 1.5	14.6 ± 2.1	13.8 ± 2.2	P > 0.01
<i>Haemulon plumieri</i>	21.5 ± 1.8	19.9 ± 2.4	20.0 ± 2.3	19.8 ± 2.2	20.5 ± 2.3	19.9 ± 2.3	P < 0.2
<i>Haemulon sciurus</i>	23.8 ± 1.0	20.8 ± 2.9	19.4 ± 2.3	20.8 ± 2.2	21.1 ± 2.9	20.2 ± 2.3	P < 0.2
<i>Lutjanus apodus</i>	26.8 ± 5.3	26.1 ± 5.4	19.3 ± 6.2	24.0 ± 3.0	26.3 ± 5.3	21.2 ± 4.8	P > 0.001
<i>Sparisoma viride</i>	25.4 ± 3.5	18.6 ± 2.6	23.8 ± 4.4	24.6 ± 4.3	23.9 ± 4.4	24.0 ± 4.3	P < 0.9
<i>Sparisoma aurofrenatum</i>	23.8 ± 2.3	-----	19.9 ± 2.0	22.5 ± 3.8	23.8 ± 2.3	20.5 ± 2.0	N.D.
<i>Sparisoma chrysopterum</i>	-----	-----	18.9 ± 1.3	25.0 ± 3.5	-----	20.0 ± 2.9	N.D.
<i>Sparisoma rubripinne</i>	-----	-----	21.8 ± 3.2	-----	-----	21.8 ± 3.2	N.D.
<i>Scarus vetula</i>	26.6 ± 3.5	-----	25.2 ± 4.0	25.3 ± 3.9	26.6 ± 3.5	25.2 ± 3.7	N.D.
<i>Ocyurus chrysurus</i>	-----	32.0*	35.5 ± 0.7	28.3 ± 0.4	32.0	31.9 ± 4.2	N.D.
<i>Epinephelus guttatus</i>	-----	25.0*	23.8 ± 0.4	24.3 ± 3.2	25.0	24.0 ± 1.9	N.D.
<i>Epinephelus striatus</i>	33.5*	-----	24.1 ± 2.7	30.5 ± 5.7	33.5	26.7 ± 4.9	N.D.
<i>Abudefduf saxatilis</i>	-----	14.0*	12.6 ± 0.6	-----	14.0	12.6 ± 0.6	N.D.
<i>Microspathodon chrysurus</i>	-----	12.5 ± 0.5	12.4*	13.3 ± 0.4	12.5 ± 0.5	13.3 ± 0.4	N.D.

*n = 1

N.D. t-test not done due to small sample size

Table 6. — Net Changes in Standard Length and Weight of Recaptured Fish

Tague Bay Patch Reef

Species		No. of Free Days*	Net Change in Weight (g)	Net Change in S.L. (cm)
<u>Acanthurus</u>	<u>bahianus</u>	70	0.0	+0.1
"	"	42	-19.0	-0.7
"	"	41	+28.0	0.0
"	"	41	+20.0	+0.2
"	"	35	-32.0	-0.4
"	"	34	+37.0	0.0
"	"	34	+58.0	0.0
"	"	21	+39.0	0.0
"	"	21	-23.0	0.0
"	"	21	-31.0	-0.8
"	"	21	+ 2.0	-0.3
"	"	21	-14.0	+0.3
"	"	19	+28.0	0.0
"	"	19	+28.0	0.0
"	"	14	-20.0	-0.5
"	"	13	+28.0	-0.5
"	"	12	+28.0	-0.5
"	"	12	0.0	-0.5
"	"	8	0.0	+0.1
"	"	8	- 7.0	-0.5
"	"	7	-19.0	-0.7
"	"	7	+ 4.0	-0.7
"	"	7	0.0	0.0
"	"	7	+28.0	0.0
"	"	7	+28.0	0.0
"	"	7	0.0	0.0
"	"	7	+28.0	0.0
"	"	7	0.0	0.0
"	"	6	+28.0	+0.5
"	"	4	-56.0	-0.5
"	"	4	0.0	-0.5
"	"	4	0.0	-0.5
<u>Acanthurus</u>	<u>coeruleus</u>	54	+54.0	-0.5
"	"	41	- 2.0	0.0
"	"	34	-16.0	-0.1
"	"	34	+50.0	+0.5
"	"	34	+15.0	-0.2
"	"	33	+38.0	+0.3
"	"	28	-20.0	-0.2
"	"	21	-26.0	0.0
"	"	21	-23.0	0.0

Table 6. — Continued

Tague Bay Patch Reef

Species	No. of Free Days*	Net Change in Weight (g)	Net Change in S.L. (cm)
<u>Acanthurus coeruleus</u> (con't)	21	- 3.0	0.0
" "	20	-28.0	0.0
" "	20	0.0	0.0
" "	20	+56.0	0.0
" "	19	0.0	0.0
" "	19	0.0	+1.5
" "	14	+ 2.0	-0.3
" "	14	-16.0	+0.1
" "	13	+56.0	0.0
" "	13	+56.0	+0.5
" "	13	+28.0	0.0
" "	12	+84.0	+0.5
" "	11	+28.0	+0.5
" "	11	0.0	0.0
" "	8	- 2.0	0.0
" "	7	-10.0	-0.2
" "	7	-16.0	-0.1
" "	7	-13.0	+0.2
" "	7	0.0	0.0
" "	7	0.0	-0.5
" "	7	0.0	0.0
" "	7	+28.0	0.0
" "	7	+14.0	0.0
" "	6	0.0	+0.5
" "	4	0.0	-0.5
" "	4	0.0	+0.5
" "	4	0.0	0.0
<u>Haemulon plumieri</u>	19	+28.0	-1.0
" "	13	0.0	-0.5
" "	12	+112.0	-1.0
" "	8	+ 6.0	0.0
" "	6	+28.0	-0.5
" "	6	-28.0	0.0
" "	1	0.0	0.0
<u>Lutjanus spodus</u>	21	+40.0	+0.5
" "	13	0.0	+0.5
" "	6	0.0	+0.5
<u>Sparisoma viride</u>	12	+28.0	-0.5
" "	6	0.0	-0.5

Table 6. — Continued

Tague Bay Patch Reef

Species	No. of Free Days*	Net Change in Weight (g)	Net Change in S.L. (cm)
<u>Sparisoma chrysopterum</u>	21	+11.0	+1.1
" "	7	-28.0	0.0
<u>Sparisoma aurofrenatum</u>	15	-10.0	-0.3
<u>Scarus taeniopterus</u>	13	Found dead in trap	
<u>Epinephelus guttatus</u>	7	0.0	+1.5
<u>Lachnolaimus maximus</u>	14	+26.0	-0.2
<u>Kyphosus sectatrix</u>	91	+ 1.0	-0.5

Tague Bay Backreef

<u>Acanthurus coeruleus</u>	23	+16.0	-0.3
" "	10	+ 7.0	-0.3
<u>Epinephelus striatus</u>	115	+56.0	0.0
" "	35	-84.0	-0.5
<u>Haemulon sciurus</u>	8	-28.0	-0.5
<u>Haemulon plumieri</u>	8	0.0	0.0

Buck Island Patch Reef

<u>Acanthurus coeruleus</u>	16	0.0	-0.5
" "	16	+28.0	-0.3
" "	16	+28.0	-0.5
" "	14	-28.0	+1.5
" "	14	-14.0	+0.5
" "	9	0.0	0.0
" "	8	0.0	+0.5

Table 6. — Continued

Species	No. of Free Days*	Net Change in Weight (g)	Net Change in S.L. (cm)
Buck Island Patch Reef			
<u>Acanthurus</u> <u>coeruleus</u> (con't)	8	-28.0	+0.5
" "	7	+28.0	0.0
" "	7	+28.0	0.0
<u>Acanthurus</u> <u>bahianus</u>	23	+28.0	-0.5
" "	8	-56.0	-0.5
<u>Sparisoma</u> <u>viride</u>	7	0.0	-0.5
" "	7	0.0	-0.5
<u>Lutjanus</u> <u>apodus</u>	34	-21.0	+3.4
" "	21	-45.0	-2.0
Buck Island Backreef			
<u>Acanthurus</u> <u>bahianus</u>	34	+ 2.0	+0.3
" "	34	0.0	-0.5
" "	29	- 4.0	0.0
" "	22	+56.0	+1.0
" "	15	+10.0	+0.4
" "	15	-28.0	0.0
" "	12	+ 1.0	-0.5
" "	7	- 3.0	0.0
" "	7	- 2.0	-0.7
" "	7	+28.0	+0.5
" "	7	+28.0	-0.5
" "	6	0.0	-0.5
" "	6	0.0	0.0
<u>Lutjanus</u> <u>apodus</u>	15	0.0	0.0
" "	10	+28.0	+0.5
" "	6	+56.0	+0.2
<u>Haemulon</u> <u>sciurus</u>	15	+28.0	-1.0
" "	6	0.0	-1.0

Table 6. — Continued

Species	No. of Free Days*	Net Change in Weight (g)	Net Change in S.L. (cm)
Buck Island Backreef			
<u>Microspathodon chrysurus</u>	6	+ 9.0	-0.2
" "	6	+17.0	+0.4
<u>Sparisoma viride</u>	15	0.0	+0.5

*Does not include the day of recapture as a free day.

Table 7. — Recapture Data of an Epinephelus striatus (Nassau Grouper)

Date	Standard Length (cm)	Weight (g)
08 Nov 1977	34.5	1120.0
08 Dec 1977	34.0	1092.0
24 Jan 1978	34.0	1120.0
31 Jan 1978	34.5	1176.0
08 Feb 1978	34.5	1148.0
21 Feb 1978	34.0	1204.0
03 Mar 1978	34.5	1176.0

Table 8. — Recapture Data of a Kyphosus sectatrix (Bermuda Chub)

Date	Standard Length (cm)	Weight (g)
31 Jan 1978	18.5	168.0
07 Feb 1978	18.0	196.0
14 Feb 1978	17.7	213.0
21 Feb 1978	17.7	186.0
07 Mar 1978	17.8	199.0
14 Mar 1978	17.5	170.0
02 May 1978	18.0	169.0

FIGURE LEGEND - CHAPTER VIII

Figure 1 Changes in fish abundance and diversity during the year. Circles indicate abundances (scale on left); triangles indicate diversities (scale on right). Dark symbols: NPR; Light symbols: SPR.

Figure 2 Changes in monthly abundances ($\cdot$ — $\cdot$) and median lengths ($\bullet$ $\bullet$) of major species of reef fishes in the lagoon at Buck Island. Abundances are presented in the left-hand scale. One-half the vertical scale represents a median length of 50% (i.e., the median fish present was medium length).

- a Eupomacentrus planifrons
- b E. fuscus
- c Haemulon flavolineatum
- d Halichoeres bivittatus
- e Thalassoma bifasciatum
- f Acanthurus coeruleus
- g A. bahianus
- h Sparisoma viride
- i Scarus vetula
- j Holocentrus rufus

Figure 3 Monthly changes in relative biomass. Biomass unit = (median length)³ x abundance of major species of reef fishes on North and South Patch Reefs, Buck Island lagoon.

North Patch Reef (upper symbol)

South Patch Reef (lower symbol)

Pomacentridae	—·—	<u>Eupomacentrus planifrons</u>
		<u>E. fuscus</u>
Pomadasyidae		<u>Haemulon flavolineatum</u>
Labridae	...:...	<u>Halichoeres bivittatus</u>
	— — —	<u>Thalassoma bifasciatum</u>
Acanthuridae	..:.....	<u>Acanthurus coeruleus</u>
	—·—	<u>A. bahianus</u>
Scaridae	—·—	<u>Sparisoma viride</u>
	— — —	<u>Scarus vetula</u>
Holocentridae		<u>Holocentrus rufus</u>

FIG. 1

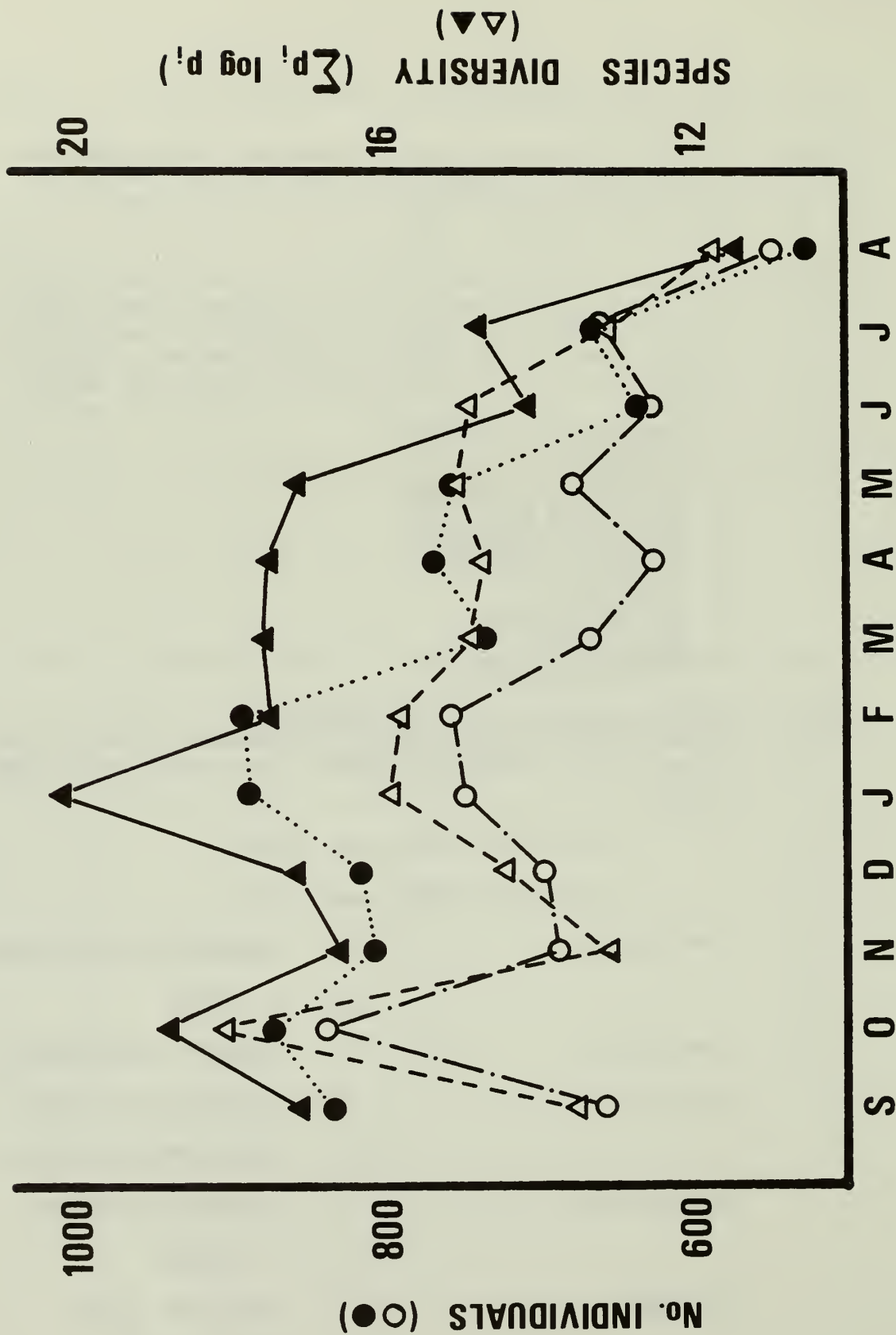


FIG. 2 (a - e)

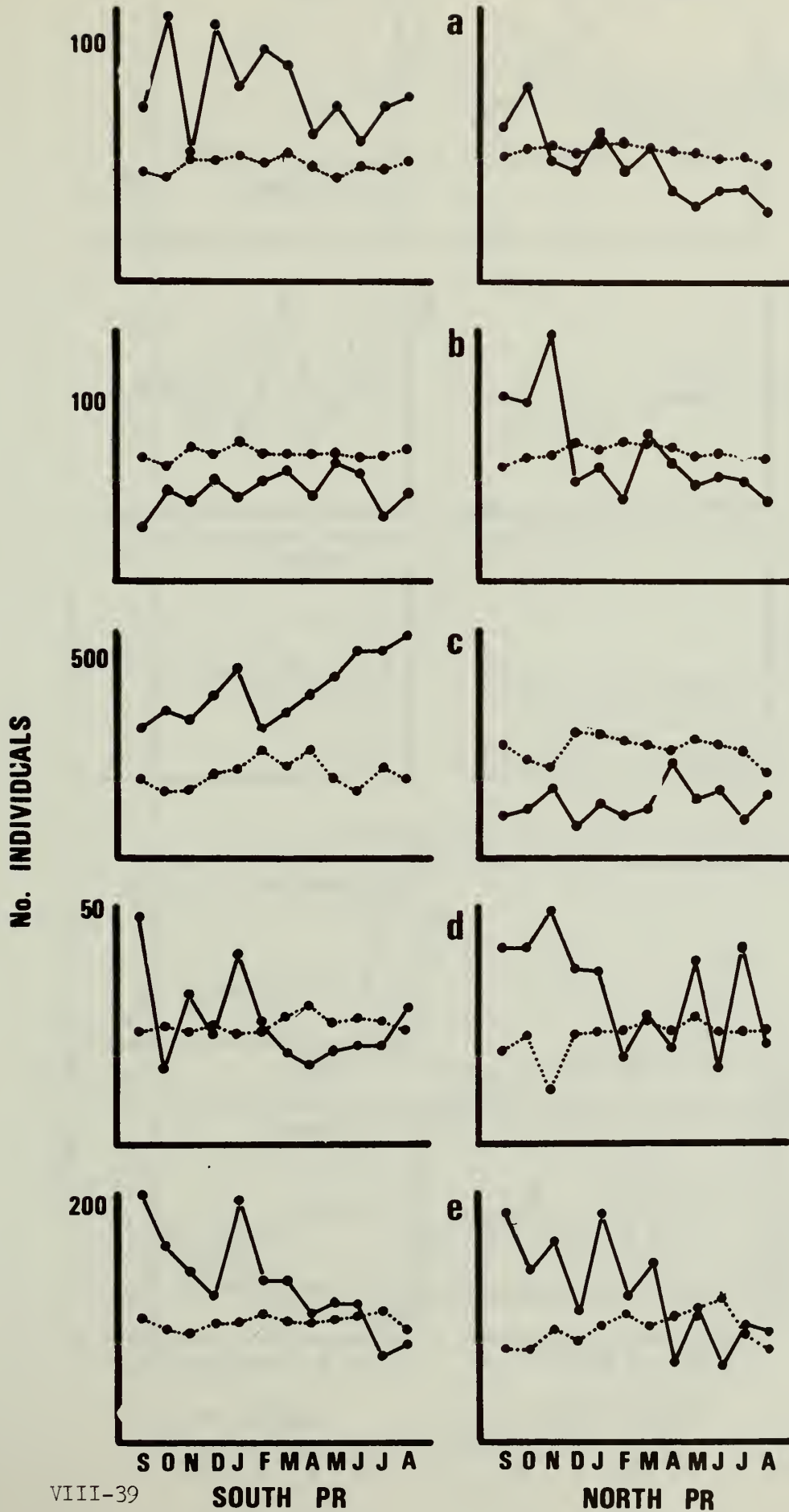


FIG. 2 (f-j)

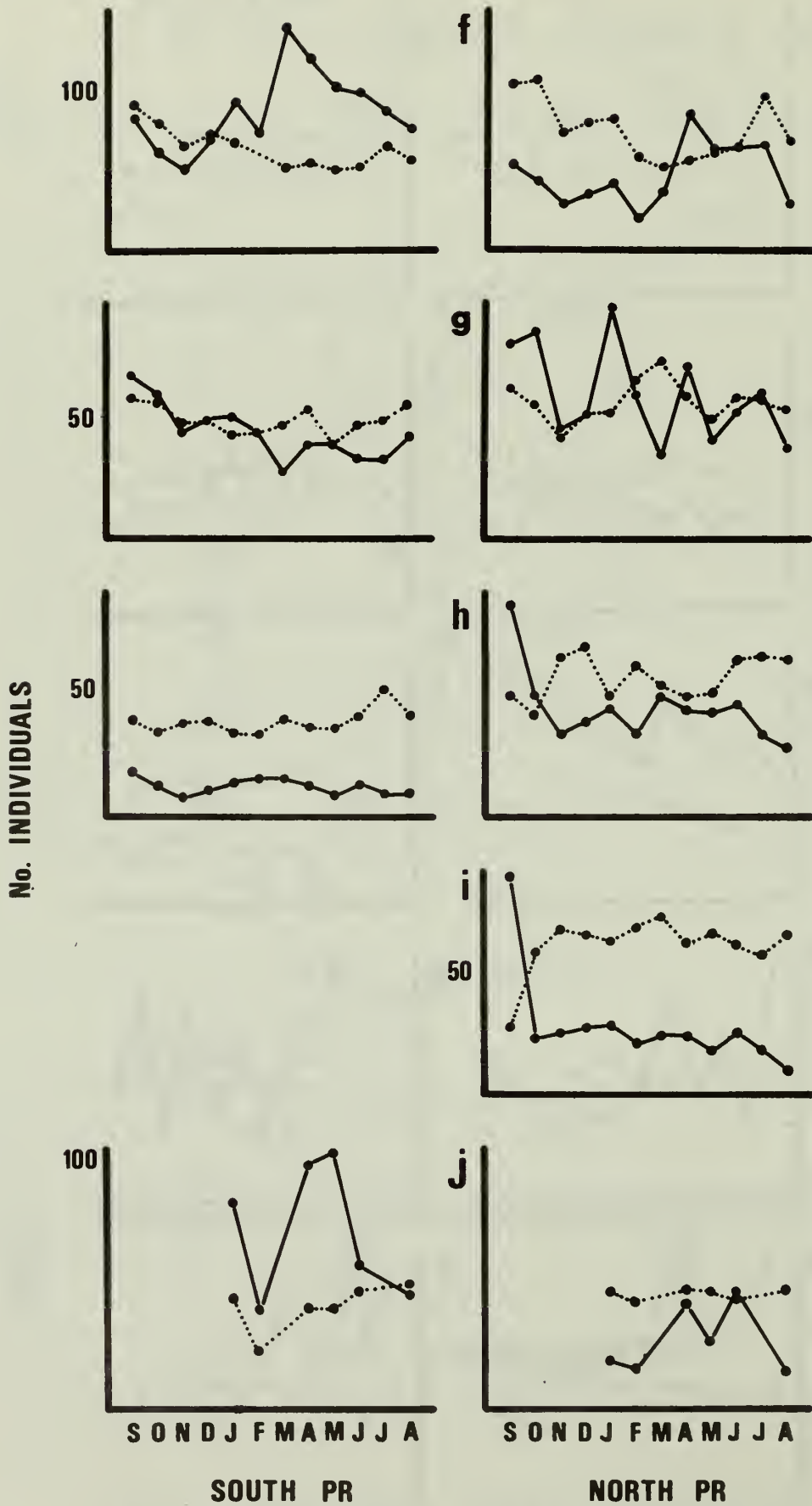
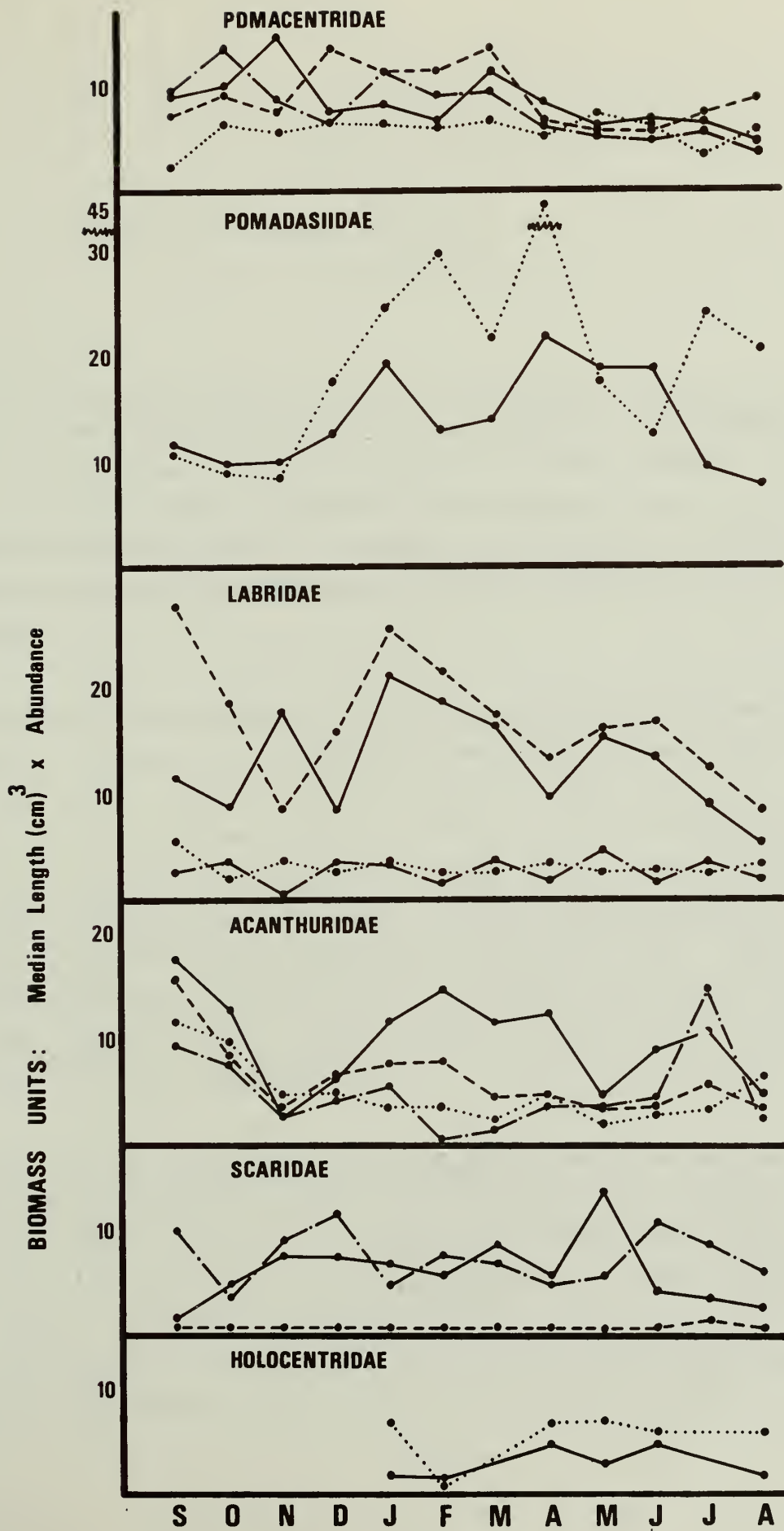


FIG. 3



CHAPTER IX

PLANKTON DYNAMICS

by

E. Gladfelter

Introduction

Plankton has an important role in the trophic web of a reef, as it provides for recirculation of nutrients within the reef ecosystem itself (demersal plankton). Oceanic plankton may also provide one of the external sources of nutrients (particularly nitrogen and phosphorus) and energy to the reef. A knowledge of the quantitative and qualitative change of this resource is necessary to gain an understanding of the energetics of the reef system at Buck Island Reef National Monument.

Plankton has been indicated (although not yet extensively documented) as important in enhancing the growth of living corals (Glynn, 1977; Gladfelter and Monahan, 1977). Although it may not provide a sufficient supply of the caloric needs of coral, plankton probably is the source of nutrients limiting to growth, especially nitrogen and phosphorus (Johannes et al., 1970). Plankton is also the major food supply for the group of fishes especially adapted to utilize this source, the planktivorous fishes (Hobson and Chess, 1976). These include both diurnal and nocturnal species and are an abundant part of the reef fish community, particularly the forereef community at the east edge of Buck Island Reef National Monument (Gladfelter et al., 1977).

Plankton has two components: oceanic plankton, which in the case of Buck Island is carried on easterly currents to the reef; and a local source, demersal plankton, which recedes into the reef by day and emerges at night. These two components of the plankton have been noted by Emery (1968) and Sale (1976), but the demersal plankton has been best quantitatively and qualitatively described by Alldredge and King (1977), who feel that standard plankton sampling devices may well have underestimated the abundance of plankton over the reef.

The effect of the reef on the plankton resource has been determined by Glynn (1973); by using a classical upstream-downstream technique, he showed that 60% of the zooplankton was removed from the water column as it passes across the reef. His study in Puerto Rico also demonstrated differences in seasonal abundances, with 2.5 times greater biomass in the summer (July) than in the winter (January); diurnal abundances; and abundances relative to moon phase (most abundant first quarter and new moon).

The purpose of the present study was a preliminary survey of the abundance and taxonomic composition of the plankton along the inner and outer portions of the south reef at Buck Island Reef National Monument. It has been shown (Gladfelter et al., 1977) that there is very little exchange of water across the reef at this point so that the forereef plankton sample essentially represents oceanic plankton availability, while the backreef sample is more reflective of the lagoon plankton community plus that portion of ocean water which has filtered over the eastern portion of the reef. Seasons of the year, time of day, and phases of the moon were considered in this study. A short study was also conducted to determine the nature of the demersal plankton.

Methods and Materials

Series of plankton tows were made approximately twice a month parallel to the south reef of Buck Island, one set in the lagoon and one set on the forereef. Each set consisted of an east-to-west tow and a west-to-east tow, each 720 m long. A #10 net (diameter: 0.5 m) with a #10 bucket were towed at a uniform slow speed 1 m below the water surface. Day tows were made between 1400-1600, while night tows were between 2000-2200.

Plankton samples thus collected were preserved in 10% buffered formalin and stained with rose bengal. Samples were subdivided an appropriate number of times (for counting purposes) in a plankton splitter, divided into major taxonomic categories and counted. Counts were adjusted to number of organisms per 10 m³ of seawater and east-to-west and west-to-east runs were averaged. These counts did not take into account the efficiency of the net, therefore, the density of the plankton cannot be accurately determined. The relative amounts

at different sites and different times were compared, however, since the same sampling method was used at all times.

Selected groups were chosen for analysis to determine the relative abundance per season; this was done (Fig. 2) by standardizing the number of organisms of a particular taxonomic group present to a "planktonic unit" for that group. Since the abundance of different organisms varied by orders of magnitude in some cases, a convenient unit was chosen particular to one organism (e.g., 1 unit foraminifera = 40 individuals) (Fig. 2A); 1 unit calanoid copepods on the forereef = 350 individuals (Fig. 2A), so that seasonal changes in abundances could be compared between organisms. These units, it should be noted, vary from backreef to forereef due to different abundances in these areas.

Quantitative sampling of demersal plankton was done in November 1977 (Gelpke, 1977) on the lagoon side of the south reef of Buck Island Reef National Monument; four samples were collected by use of emergence traps from each of three habitats: living coral, coral rubble, and sand. These samples were removed to the laboratory for counting and placement into taxonomic groups. These traps were made of garbage bags 84 cm by 112 cm fitted over a metal frame. The metal frame was a cylinder with an approximate diameter of 0.5 m and a height of 0.75 m. Two metal rings were attached at each end by four support wires and another ring was attached in the middle of the cylinder. Both the rings and the support wires were made from 14 gauge galvanized wire. The top ring was sewn into place, while the middle and bottom rings were suspended by the four support wires. The frame was used to keep the plastic bag open under wave surge.

A strip of muslin was sewn around the bottom of the garbage bag and a 170 cm link chain was sewn into the bottom of the muslin to allow for substrate irregularities. Weights were also placed on the chain to anchor the trap to the substrate. Sewn to the top of the garbage bag was #10 bolting cloth in the form of an inverted cone. At the apex of the cone, a 15 cm high cylinder of muslin was sewn in to hold a collecting bottle. The bottom of the polypropylene collecting bottle was cut out. The bottle was held in place by a large hose clamp and was partially filled with air to keep the trap upright.

Results

Plankton was more diverse and more abundant on the forereef (an average of 180 organisms/m³) than the backreef (84 organisms/m³). Forereef samples were generally richer at night than during the day during full moon, while during the new moon the diurnal tows (forereef and backreef) were more similar in size (Fig. 1A). On the backreef, the nocturnal tows were always richer than the diurnal tows (often 10-20 times), and in general, nocturnal new moon tows were richer than nocturnal full moon tows (Fig. 1B).

It appears that the peak plankton periods during the time sampled were in September and April-May for the forereef (Fig. 1A) and December and March-May for the backreef (Fig. 1B). These peaks reflect the individual abundances of certain groups in most cases.

Seasonal abundances of particular groups varied considerably (much more so than overall abundance variations). Foraminifera showed a great increase in the spring in both forereef: 3-5x increase (Fig. 2A), and backreef: 2x increase (Fig. 2B). Chaetognaths and appendicularians showed a peak in September (2x) with rather even distribution the remainder of the year (Fig. 2A). Invertebrate and fish eggs were very scarce in the November forereef and backreef tows (Figs. 2A, 2B) and were rather even the remainder of the year, with the exception of high values during the spring new moon tows on the backreef (Fig. 2B). Copepods, usually the most abundant organism in both sites, were far more abundant numerically on the forereef than the backreef (Tables 1 and 2). Calanoid copepods seemed to be less abundant during winter (January-February) and late spring (Figs. 2A, 2B), while the harpacticoid copepods showed a more even distribution. Decapod larvae and zoeae were much more abundant on the backreef than the forereef (Figs. 2A, 2B) and were particularly abundant during the winter (December, February, March) new moon tows on the backreef (Fig. 2B). Other groups which showed diel differences included the malacostracans which represented the part of the demersal plankton caught primarily on nocturnal tows in the forereef (Table 1).

The proportion of oceanic plankton which was represented in the backreef sample was estimated (Table 3). This reflects a combination of dilution with lagoonal waters and a filtering by the reef which resulted in only 10-20% of the backreef plankton represented by oceanic plankton.

In his study on demersal plankton, Gelpke (1977) found the average density of total plankton emerging in a four-hour night period (1600-2000 hours) from all three substrates to be 394 ± 140 individuals per m^2 /hour. The densities found on the living coral and coral rubble substrates are comparable in magnitude and are twice as large as the density found on the sand substrate (see Fig. 3). Figure 4 shows the relative densities of organisms from different substrates and reflects the greater proportion of forms other than calanoid copepods (especially harpacticoid copepods and decapod larvae) which are found in the sand.

Discussion

Seasonal trends found in the present study were similar to those found by Glynn (1973), i.e., seasonal abundances of particular groups varied throughout the year, but in general (in the present study), late summer and spring samples were somewhat higher than winter counts. Nocturnal counts of backreef forms and the malacostracans in the forereef were generally higher than diurnal counts, reflecting the contribution of demersal plankton to the total resource.

The role of plankton as a food source for coral communities is still unclear, being considered an important energy source by some authors (Emery, 1968), but by others considered as a minor source of energy which probably however supplies an important source of limiting nutrients (Johannes et al., 1970). Glynn (1973) demonstrated a considerable uptake of zooplankton by reef organisms which could account for about 10% of community production, but more significantly, he points out that the percent contribution to suspension feeding components of the community might well be much higher.

The present study did not use an upstream-downstream approach, but the low percentage of oceanic plankton in the lagoonal waters gives some indication of removal of plankton by organisms at the actively growing eastern tip of the reef (see Chapter II) as well as supporting the planktivorous fish community located there.

The lagoonal plankton consisted primarily of demersal plankton which emerged at night. This component (Gélpke, 1977) was comparable in size to that determined by Alldredge and King (1977) on a Pacific reef. The distribution of demersal plankton was dependent on habitat. The branching coral Acropora palmata and dead Porites porites offered a more complex three-dimensional habitat for demersal plankton resulting in twice the abundance of this resource over living coral as opposed to sand.

Further work on plankton availability as a resource on a yearly basis as well as a determination of its quantitative value is being carried out at present. In addition, the investigation of the contribution of plankton to the nutritional needs of suspension feeders (in particular, the coral Acropora cervicornis) is being pursued.

Table 1. — Composition of Forereef Plankton Organisms/10m³ Water

Date Moon	09/23/77		10/10/77		11/27/77		12/16/77		01/23/78		02/06/78		02/22/78		03/13/78		03/28/78		04/21/78		05/04/78		05/22/78		06/04/78	
	Full	D	New	D	Full	D	New	D	Full	D	New	D	Full	D	New	D	Full	D	Full	D	New	D	Full	D	New	D
Foraminifera	---	---	--34	--6	--72	--8	--55	--105	--46	--35	--298	--17	--80	--110	--300	--170	--135	---	--585	--288	--100	--900	--134	--230	--360	--56
Medusae	---	--9	--12	--15	---	--6	---	--0	---	--0	---	---	---	---	---	--2	--2	---	---	---	--1	--4	---	---	---	---
Siphonophora	---	---	--14	--1	---	---	---	---	---	---	--9	---	---	---	---	---	---	---	---	---	--2	---	---	--15	---	---
Chaetognatha	--322	--44	--135	--93	--2	--17	--42	--53	--10	--61	--208	--85	--0	--5	--100	--22	--35	---	--40	--36	--48	--37	--9	--26	--10	--70
Appendicularia	--22	--459	--16	--167	--1	--36	--72	--28	--3	--47	--5	---	--17	--83	--11	--46	--105	---	--18	--24	--33	--82	---	--9	---	--18
Echinoderm larvae	---	--4	--10	--9	---	---	---	---	---	---	---	---	---	---	---	---	--5	---	---	---	--3	---	---	--4	---	---
Invertebrate & fish eggs	--79	--26	--435	--174	--18	--72	--15	--53	--140	--402	--255	--255	--230	--141	--151	--219	--91	---	--300	--479	--102	--132	--213	--282	--361	--322
Fish larvae	--35	--4	--10	--25	---	--0	---	--5	---	--15	--28	--40	--2	--12	--7	--46	--20	---	--44	--124	--12	--23	--1	--18	--6	--23
Polychaeta (all ages)	--13	--18	--32	--10	---	--1	--2	--1	--3	--5	---	---	---	--5	---	--2	---	---	--4	--7	--2	--8	---	--5	--1	--4
Gastropoda (all ages)	--22	---	--47	--16	--2	--15	--36	--3	---	--15	--14	--6	--5	--39	--154	--53	--81	---	--31	--40	--54	--198	--10	--38	--110	--29
Bivalvia	---	---	--10	--2	--0	---	--11	---	---	---	---	---	---	---	---	---	---	---	---	---	--5	--6	--1	---	--20	---
Copepoda calanoida	1223	4171	1589	--968	--52	--817	2066	2527	--245	--297	--460	--433	--53	--879	--933	--614	--390	---	1710	--856	--299	--749	--41	--294	--60	--128
Copepoda harpacticoida	102	--141	--151	--172	--21	--107	--145	--50	--92	--314	--174	--80	--58	--34	--271	--90	--208	---	1304	--274	--116	--310	--179	--154	--496	--94
Cirrepedia (larvae)	---	---	--19	---	--3	--4	---	---	---	---	--6	--2	---	--9	--6	--13	--3	---	---	--2	--3	--2	---	---	---	---
Ostracoda (larvae)	--115	--13	--9	--17	--1	--92	--6	--172	--1	--10	--1	--10	---	--5	--20	--205	--10	---	--5	--2	--2	--336	--2	--49	--4	---
Mysida	--13	--9	--2	--20	---	--7	--1	--9	--1	--1	--4	--8	--1	---	---	---	---	---	---	---	---	--22	---	---	---	---
Amphipoda, Isopoda, Cumacea	--4	--44	--62	--13	--0	--2	--125	--75	--1	--8	--2	--3	--3	--1	--1	--31	---	---	---	--45	--1	--65	---	--51	--2	--9
Stomatopoda	---	---	---	---	---	---	---	---	--1	--3	--4	--11	--1	--2	---	---	---	---	--35	--12	---	---	--8	--25	---	---
Decapod larvae	--97	--199	--2	---	--1	--12	--9	--17	--99	--52	--178	--140	--6	--117	--11	--65	--8	---	--144	--72	--20	--133	--0	--60	--1	--3
Zooae larvae	--48	--71	--9	---	--1	--8	--17	--26	--26	--37	--30	--54	--1	--80	--25	--23	--11	---	--142	--40	--22	--56	--4	--46	--31	--18
Totals	2099	5212	2598	1708	177	1207	2607	3124	680	1302	1677	1147	458	1522	1992	1601	1102	---	4362	2310	825	3063	602	1281	1487	774

Plus Ctenophora, Pteropoda, Cladocera, Euphausiida, Salps, Caridean shrimp: all at least one tow but no more than three tows.

Table 3. — Abundance of Organisms in Forereef and Backreef Samples. Relative Abundance
(by Percent) of Backreef to Forereef Sample.

Date Time	09/23/77	11/27/77	12/16/77	01/23/78	02/06/78	02/22/78	03/13/78	03/28/78	04/21/78	05/04/78	05/22/78	06/14/78
	D N	D N	D N	D N	D N	D N	D N	N N	D N	D N	D N	D N
Chaetognatha												
BR	---1	---0	---3	---0	---10	---0	---7	---12	---1	---6	---7	---2
FR	-322	--44	--17	--42	--53	---	-208	--35	--40	--36	--9	--10
% BR/FR	0%	50%	18%	0%	19%	0%	2%	34%	3%	17%	11%	20%
						0%	8%		15%	35%	27%	0%
Appendicularia												
BR	---	---	---	---	---	---	---	---	---	---	---	---
FR	-22	-459	-36	-72	-28	-17	-83	-105	-18	-24	-33	-18
% BR/FR	18%	0%	400%	19%	7%	39%	0%	19%	0%	113%	18%	0%
						12%	30%		0%	113%	78%	0%

FIGURE LEGEND - CHAPTER IX

- Figure 1 Zooplankton abundance as a function of lunar phase. Circles indicate diurnal tows, triangles indicate nocturnal tows. Dark symbols: full moon; light symbols: new moon.
- Figure 2 Abundances of major zooplankton groups at Buck Island through the year. Abundances are given in plankton units, which vary according to abundance in each group. The number of individuals constituting a plankton unit is given below each group. The time scale ranges from September (9) to June (6).
a. Forereef
b. Backreef
- Figure 3 Emergence rates of demersal zooplankton above different substrata (mean $\pm$ standard deviation).
- Figure 4 Relative abundance of major groups of demersal zooplankton above different substrata in the Buck Island Reef lagoon.

FIG. 1

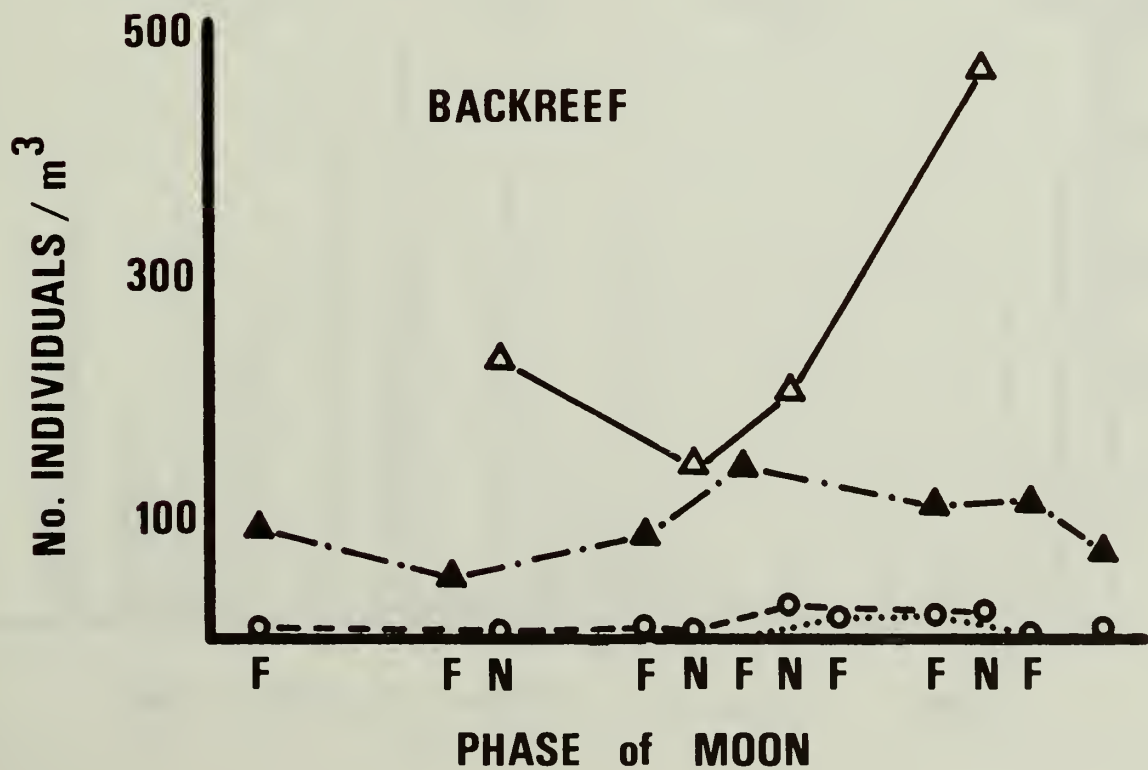
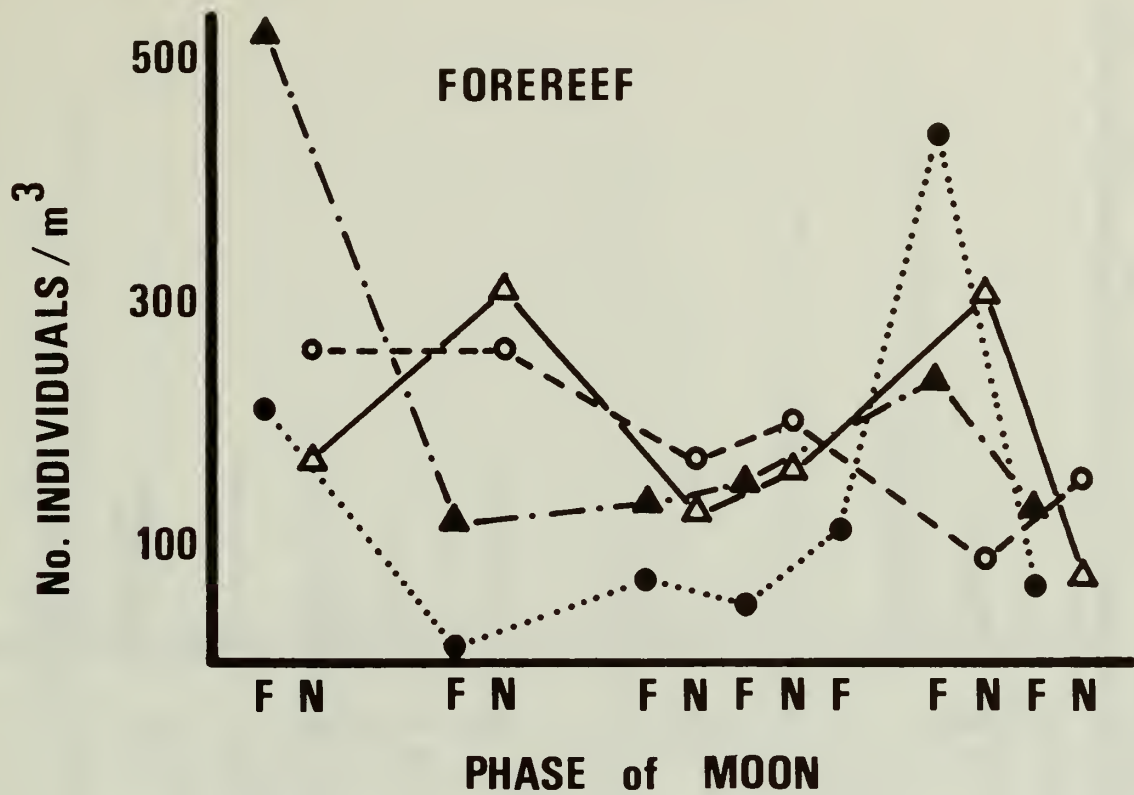


FIG. 2a

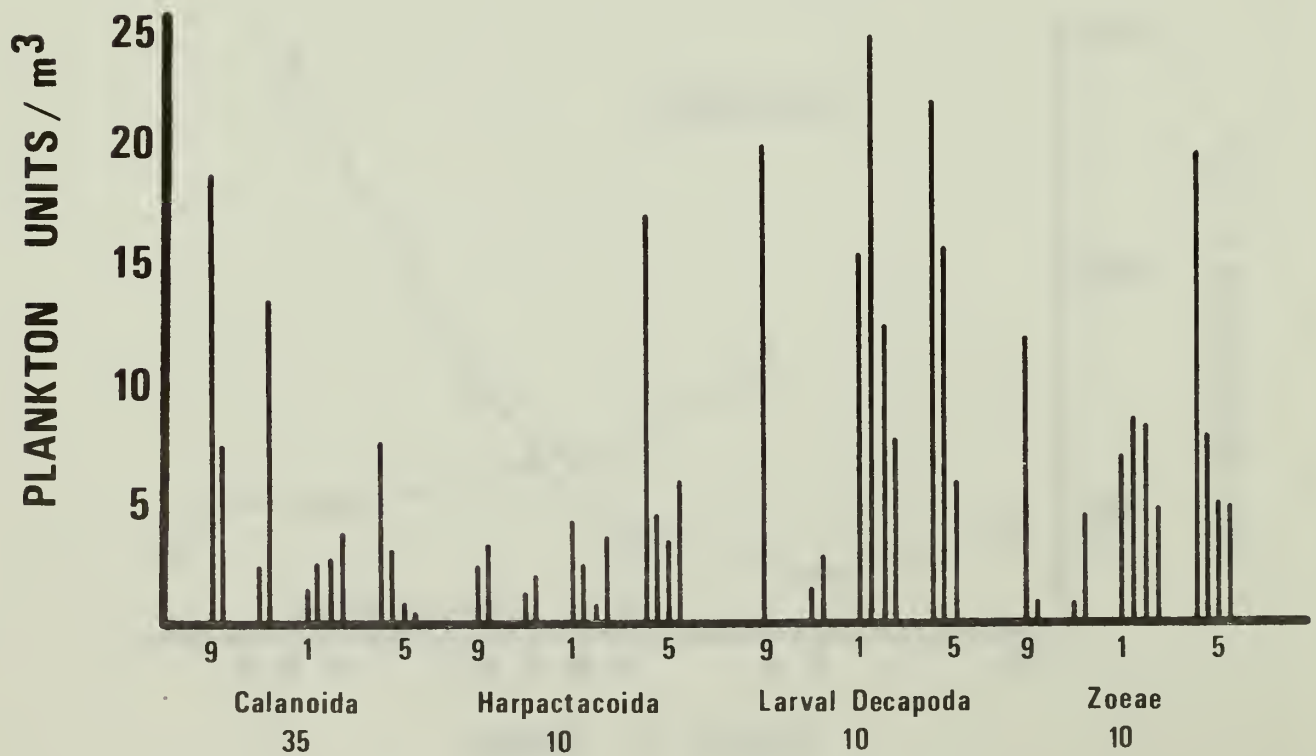
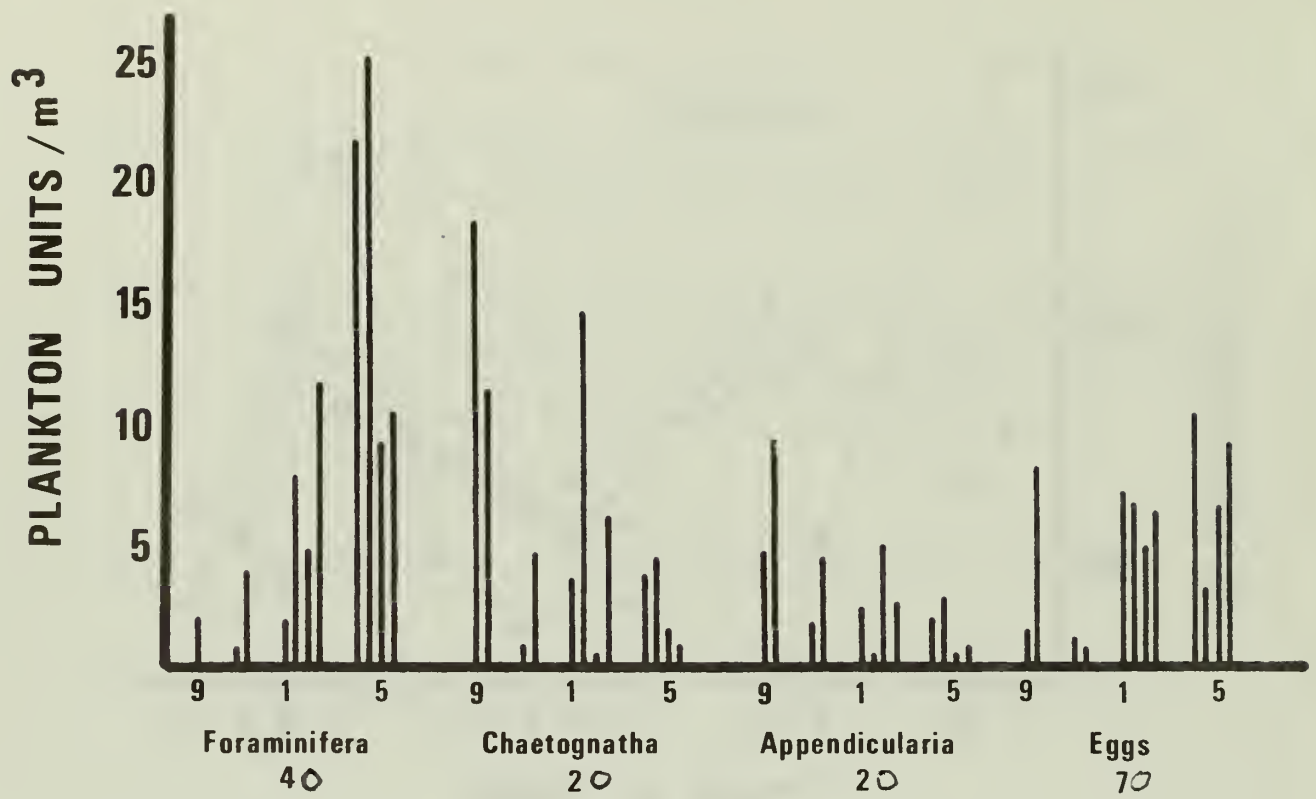


FIG. 2b

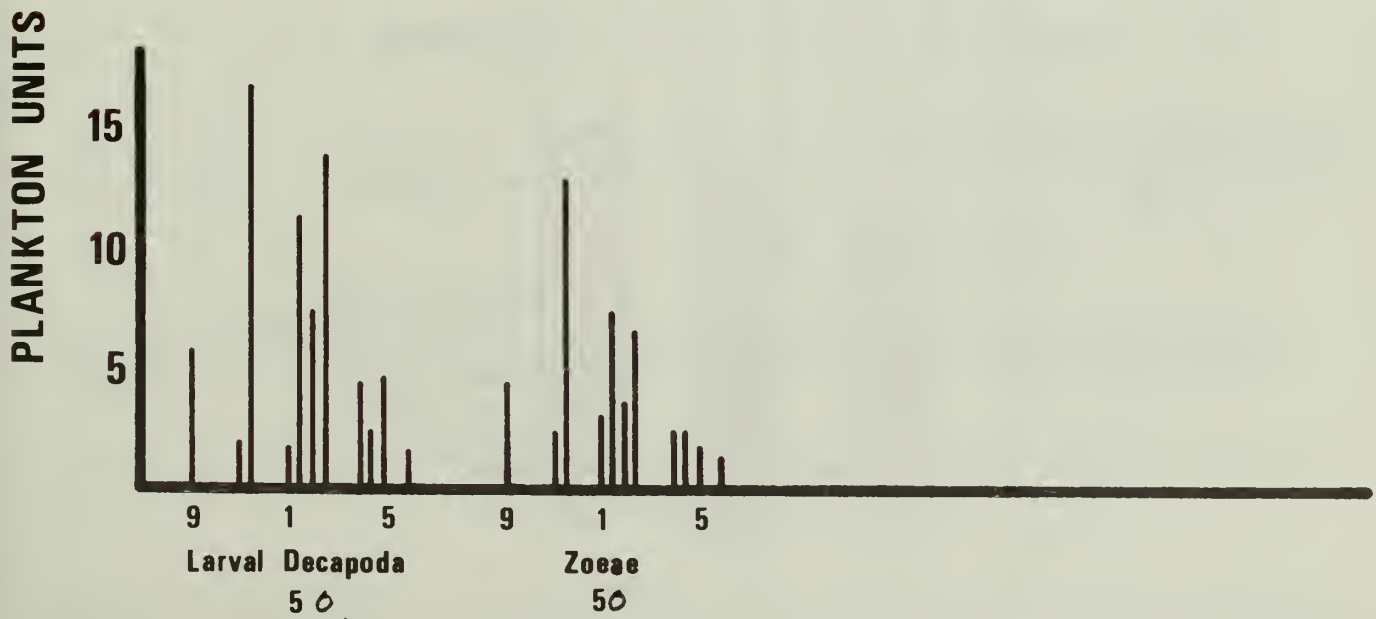
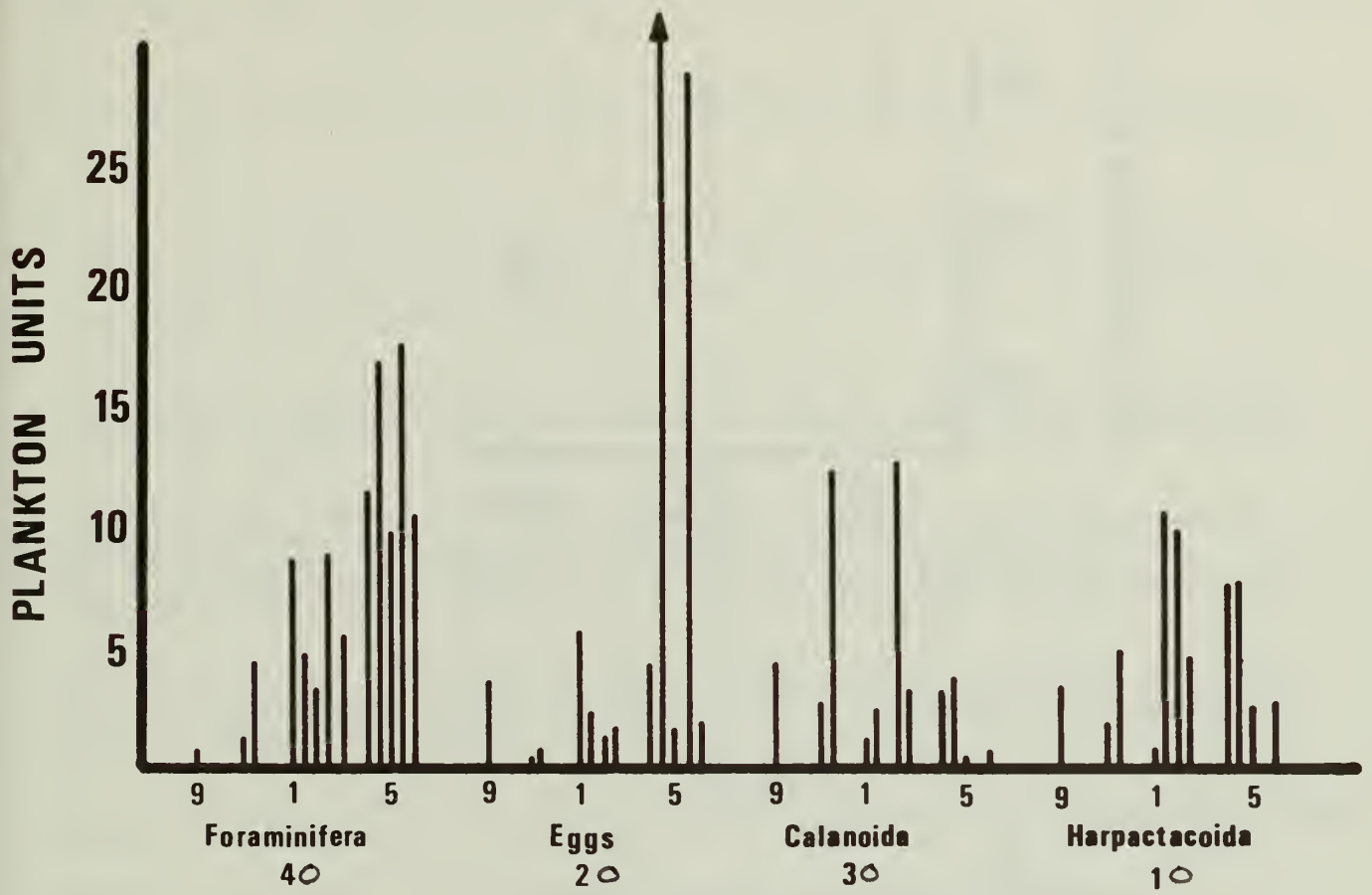


FIG. 3

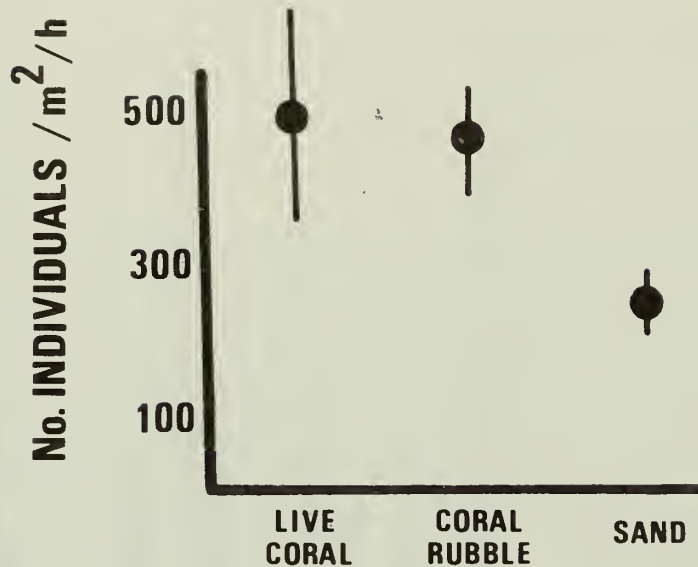
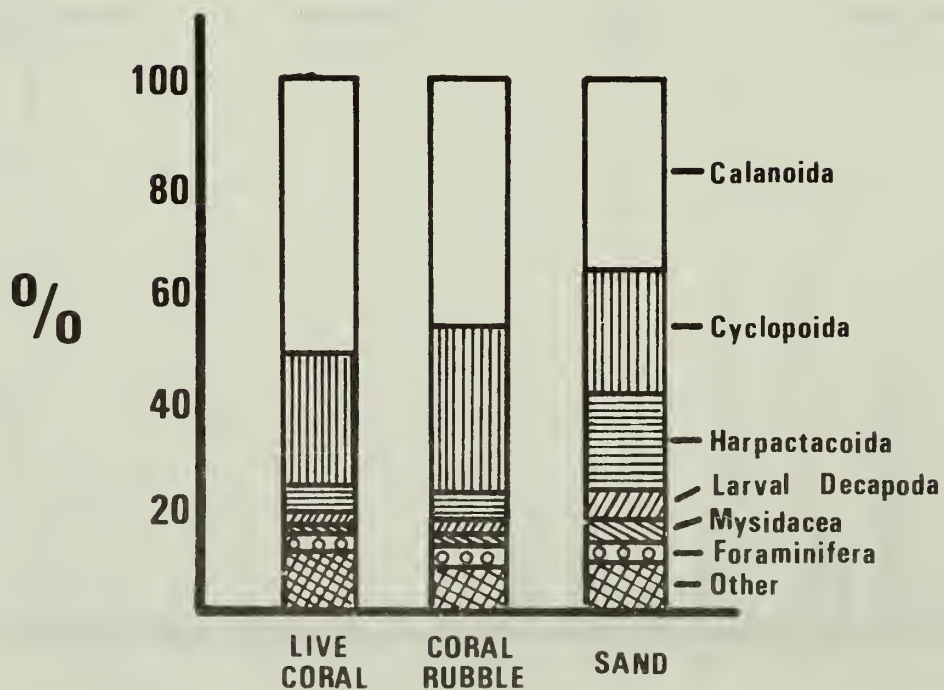


FIG. 4



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