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A Survey of the Living Hermatypic Corals on the West Fore Reef of Discovery Bay, Jamaica After the Occurence of Hurricane Allen

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A SURVEY OF THE LIVING HERMATYPIC CORALS ON THE WEST FORE REEF OF DISCOVERY BAY, JAMAICA AFTER THE OCCURRENCE OF HURRICANE ALLEN

by

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VITA

The author, James Arthur Crawford, was born October 2, 1960, in Springfield, Ohio.

His secondary education was obtained at Fayetteville-Manlius High School, where he graduated in 1978 with Honors in Biology. In September 1978, he entered Southampton College for marine biology and continued his studies at the State University of New York (SUNY) at Oswego the following year. He graduated cum laude from SUNY at Oswego in May 1982, where he received the degree of Bachelor of Science with a major in biology.

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He is co-author of a paper entitled 'The Occurrence and Distribution of a Syndesmid (Turbellaria: Umagillidae) in Jamaican Sea Urchins'.

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CHAPTER I

INTRODUCTION

Coral reef communities have a vast conglomeration of species and niches, and a multiplicity of interspecific relationships. A coral reef community has a very high species diversity with highly specialized organisms, and it has one of the highest rates of productivity of any marine environment. Very little energy is lost from this biome due to its tight configuration of organisms and their biologic efficiency.

A coral reef community is built upon a reef of calcium carbonate produced by hermatypic corals, calcareous algae and other calcium carbonate producing organisms. Hermatypic corals are essential for any coral reef community since they perform the actual construction of the reef, provide food and shelter for organisms, and provide a subtratum upon which organisms colonize (Goreau and Goreau, 1973). Therefore, if corals are disturbed, most of the inhabitants of the reef will be affected.

Coral reefs are very intricate and delicate ecosystems, and are easily perturbed by natural and human elements. The more important natural disturbances are: storms, volcanic activity, extreme low tides, and predation, especially by <u>Acanthaster planci</u> (Goreau, 1964; Stoddart, 1969; Loya, 1972; Porter, 1972; Endean, 1973; Grigg and Maragos, 1974; Endean, 1976; Highsmith et al., 1980; Woodley et al., 1981). In general, these types of disturbances destroy corals on the reef but do not contaminate the substatum; thus, allowing corals to recolonize the reef. It has been demonstrated that such disturbances, while decreasing coral abundance, allow for an increase in species diversity (Porter, 1972; Connell, 1973, 1978; Grigg and Maragos, 1974; Endean, 1976; Loya, 1976).

Human disturbances such as water pollution, dredging, and mining may have long term ill-effects on coral reefs (Loya, 1975, 1976; Endean, 1976). Connell (1978) stated that coral species are adapted to natural disturbances but not to human disturbances. This has been clearly demonstrated by Loya (1975) on a reef in Eilat, Red Sea, where coral colonization was extremely inhibited due to oil pollution.

Disturbance is an important factor in structuring ecological communities by altering competition (Connell, 1975, 1978; Lewin, 1983). When hurricanes perturb coral reefs they expose new areas for colonization and produce large amounts of bioclastics which add to the reef's structure (Goreau and Goreau, 1973). The destruction of corals reduces the competition for space of surviving corals, allowing them to grow into these new areas and colonize via planulae or breakage (Gilmore and Hall, 1976). This disturbance, if not too severe, decreases coral abundance but allows room for new or minor species to colonize larger areas than before; henceforth, increasing the diversity on the reef (Connell, 1978). Although extensive damage occurs during a hurricane, substantial distruction and mortality may continue for several months after the storm has subsided (Knowlton et al., 1981; Woodley et al. 1981).

Numerous studies of naturally perturbed reefs have shown that recolonization is generally successful (Stoddart, 1969; Porter, 1972;

Connell, 1973; Endean and Stablum, 1973; Grigg and Maragos, 1974; Loya, 1976; Shinn, 1976). Grigg and Maragos (1974) found the recovery time for Hawaiian reefs decimated by lava flows to be about 20 years. Additionally, they noted that sheltered reefs may take over 50 years to fully recover. Stoddart (1969) suggested a recovery period of 20-25 years for Rendezvous Cay reef, a once flourishing reef in the British Honduras which was decimated by a major hurricane in 1931. Shinn (1976) observed a recovery period of less than five years for a Floridian reef disturbed by Hurricane Donna in 1960. He concluded that rapid recovery was due to planular recruits, regeneration of scattered living fragments, and the rapid growth of *Acropora cervicornis*.

The rate at which particular coral species colonize exposed surfaces depends largely on the condition of the substrate and the distance of recruitment by coral planulae. If an algal mat develops because grazers were killed, or if the substrate is soft due to the bioclastics produced, colonization by planulae will be prevented (Connell, 1973). If total species are annihilated, then recolonization can only occur by recruitment of planulae from other reefs. Since planulae usually settle within a few weeks (Harrison et al., 1984), the distance that must be traveled by the planular recruits as well as the direction of the water currents are important factors affecting the recovery time of a reef. Many other factors contribute to the rate at which an exposed substrate is colonized, including: coral competition, the type and rate of reproduction, and the sexual maturity of colonies (Connell, 1973; Lang, 1973). Some reefs experience frequent storm damage, and it is questioned whether they can ever reach a climax stage. These reefs generally exhibit high species diversity and low coral abundance (Grigg and Maragos, 1974).

The reefs of Discovery Bay, Jamaica are among the most thoroughly studied reefs in the world (Goreau and Goreau, 1973; Kinzie, 1973; Lang, 1973; Goreau and Land, 1974; Woodley and Robinson, 1977; Knowlton et al., 1981; Porter et al., 1981; Woodley et al., 1981; Williams, 1984). On 6 August 1980, Hurricane Allen, the second strongest ever recorded (Woodley et al., 1980) with central pressures of 899mbar and maximum wind speeds of 285km per hour (Porter et al., 1981), passed near Jamaica's northern coast. Although normally sheltered from severe storms, Discovery Bay, on the north coast of Jamaica, received storm waves 12m in height (Porter et al., 1981). Damage to corals on the West Fore Reef (WFR) of Discovery Bay varied with depth of attachment, reef topography, species morphology and species construction. Destruction was most severe in the shallows (1-5m), where corals were annihilated in some locations, but was evident to depths of 50m (Woodley et al., 1981).

This study was undertaken in January 1981, six months after the storm, to establish the present status of the surviving coral species. Two published reports exist on the effects of Hurricane Allen on the horizontal cover of shallow water (0-15m) living corals on the WFR. One study consists of 8 square meters of reef at one location (Monitor Reef, 6.7m deep), but individual coral species were not reported (Porter et al., 1981). The second report (Woodley et al., 1981) compares 1/4m square quadrats (12 photostations each with 32 quadrats) prior to the storm (Sept. 1978) and 19 days after the storm at the Monitor reef sector of the WFR. For that sector, estimates of the storm effects could be extremely accurate because a comparison of each quadrat before and after the storm eliminates inter-quadrat variation in the subsequent statistical analysis; hence, making those statistics more powerful. Since the above studies covered a small portion of the WFR, they do not spatially detail the post-storm status of the entire WFR. The present study describes the post-storm status of the entire WFR. Effects of the storm on the entire reef have not been determined. This report also presents data on coral species not treated in Woodley et al.(1981).

CHAPTER II

MATERIALS AND METHOD

SCUBA gear was employed in the investigation along with a Nikonos III camera and a Sunpak Marine strobe. Twenty-three parallel transects were placed perpendicular to the reef crest. The transects were started in the Cervicornis Zone at a depth of 12-14m and ended in the Palmata Zone at a depth of 2-5m. The transects, which ranged from 100-150m long, were positioned 15m apart. One square meter quadrats were spaced 10m apart along each transect. As a reference point, the first transect was begun near a permanent mooring (DBML Mooring 1) which survived the hurricane. The remaining parallel transects extended West of the first transect. Photographs were taken vertically at each quadrat until an unmanageable depth was reached, usually 3m. The water depth and the zone in which each quadrat occurred was recorded. Prior to the hurricane, zones were readily identified by coral abundance, composition and water depth (Goreau and Goreau, 1973; Kinzie, 1973). Although many corals were destroyed by the storm, zone identification afterwards was determined by living corals, coral fragments (which tend to remain in the zone inhabited by their parent colonies; Highsmith et al., 1980) and water depth. Even though the zones established prior to the hurricane do not exist due to the changes in coral composition, they were still identifiable. Because dead fragments may have traveled some distance during the storm and because the zone ranges are not clearly defined, the zones in this study should be used only as rough guidelines to reference the data from the reef.

For quantitative analysis, 35mm color transparencies of each quadrat were projected onto a 1m square grid which was divided into 10,000 square centimeters This formed a 1:1 ratio of the actual reef area to the grid. Since a projected 35mm transparency is rectangular, the one square meter in the center of each slide was analyzed and the edges were disregarded. For each slide projected on the grid, the area encompassed by each species of coral was recorded in square centimeters. Since coral colonies fuse together and break apart, the number of colonies was not recorded; instead, the horizontal coverage of the corals was recorded to gain a more accurate representation of their abundance. Also recorded was the area of sand and dead coral in each quadrat to quantify the area of possible recolonization. The following references were used to identify the coral species: Smith, 1971; Colin, 1978; Faulkner and Chester, 1979. Unidentifiable species were recorded as unknown and algae were recorded as dead coral. In some cases it was difficult to distinguish algae from an unidentifiable coral. These cases were recorded as unknown along with the unidentifiable corals; therefore, a large portion of the unknown was most likely algae.

Numerous sand channels traversed the Cervicornis Zone but were absent in the other two zones. Ten quadrats containing only sand were located in these sand channels and were omitted from the results to yield more accurate data of coral coverage on suitable substratum.

After the horizontal cover of each coral species, dead coral rock, and sand were recorded from each quadrat, the quadrats were grouped according to zones. The percentage of each species was recorded per zone along with the percentages of dead coral and sand. The density, relative abundance and frequency of each species were calculated for the entire study area and by zone to fully represent the contribution of each species to the reef. Coral species, dead coral and sand were statistically analyzed for variation in densities between zones to detect which of these, if any, established the different zones. Tukey's multiple range test ($P < 0.05$) was used for the species which showed significant variation between zones (1-way analysis of variance, $P < 0.05$).

This was a two dimensional survey of a three dimensional reef. Two separate corals of the same volume and surface area will not necessarily cover the same area in a photograph taken vertically. Therefore, when reviewing these data, it will be helpful to know the general morphology of the different coral species in question and keep in mind that the results are biased for horizontal, plate-like corals.

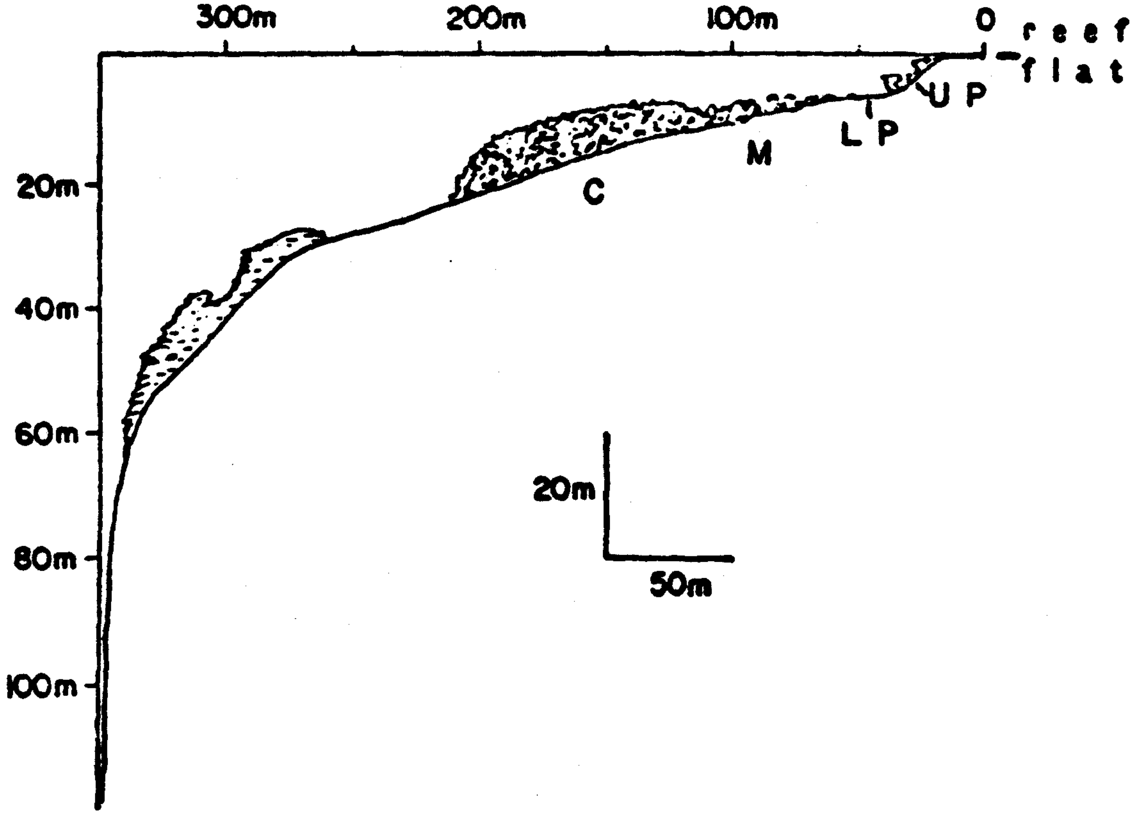
CHAPTER III

RESULTS

Prior to Hurricane Allen, the WFR (0-25m deep) had been divided into four heterogeneous zones (Goreau and Goreau, 1973; Kinzie, 1973): the Upper Palmata or Breaker Zone, the Lower Palmata or Barren Zone, the Mixed Zone and the Cervicornis Zone (FIGURE 1). The Upper Palmata Zone (0-5m) consisted almost exclusively of *Acropora palmata*. The Lower Palmata Zone (3-8m) was dominated by *Acropora palmata*, but also contained several other important coral species, including *Montastrea annularis*, *Porites astreoides* and *Millepora complanata*. In addition, the Lower Palmata Zone contained a large quantity of dead fragments of *Acropora palmata*. The Mixed Zone, which extended from the Lower Palmata Zone to a depth of 11 meters, was composed of a large variety of corals, but was dominated by *Montastrea annularis* and *Acropora cervicornis*. Goreau and Goreau (1973) referred to this zone as a suppressed Buttress Zone relative to other northern Jamaican reefs. The Cervicornis Zone, which extended from 8 meters to a depth of 25m, was characterized by a large variety of corals and was dominated by *Acropora cervicornis*.

A total of 296 one meter square quadrats were examined in this study. Since the 23 transects were 15m apart and the quadrats within a given transect 10m apart, the entire study area formed a grid approximately 330m by 123m. The data from the transects were pooled together

FIGURE I. Typical schematic profile of the West Fore Reef at Discovery Bay before Hurricane Allen showing the zones included in this study. Coral features are exaggerated. Vertical scale is 2.5 times horizontal scale (Adopted from Woodley and Robinson, 1977).



300m
200m
100m
0
reef flat
U P
L P
M
C
20m
40m
60m
80m
100m
20m
50m

according to the previously established zones (Goreau and Goreau, 1973; Kinzie, 1973). Twenty species of Scleractinia and two species of Milleporina were included in this study. Other species were present on the reef, but they were scarce and not found in the quadrats.

THE PALMATA ZONE. The enormous destruction caused by Hurricane Allen almost obliterated this zone. There was no significant difference in coral cover between the Upper and Lower Palmata Zones (1-way ANOV, $P < 0.05$); therefore, they were considered as one zone in this investigation.

The Palmata Zone ranged in depth from 2.5 to 8m in this study. This zone actually reaches the water's surface, but due to the surge it was hazardous to investigate these shallower waters. Mainly rubble from once living Acropora palmata colonies exists here. The total area studied in this zone was 52 square meters with an average of 3.6% of the area covered by living corals. Very few species contributed to this zone (TABLE 1). Montastrea annularis, Acropora palmata and Porites astreoides were the dominant corals with their percentages of abundance being 22.0, 19.6 and 17.3, respectively (FIGURE 2). Only five species of Scleractinia and one species of Milleporina were found in this zone. Sand constituted 0.8% of this zone leaving 95.6% to mainly dead Acropora palmata and a little algae. No sponges or gorgonians were recorded in this zone.

THE MIXED ZONE. The area surveyed in the Mixed Zone was 47 square meters. This zone ranged from the Lower Palmata Zone to a depth of 11m and consisted of 13 species of Scleractinia and two species of

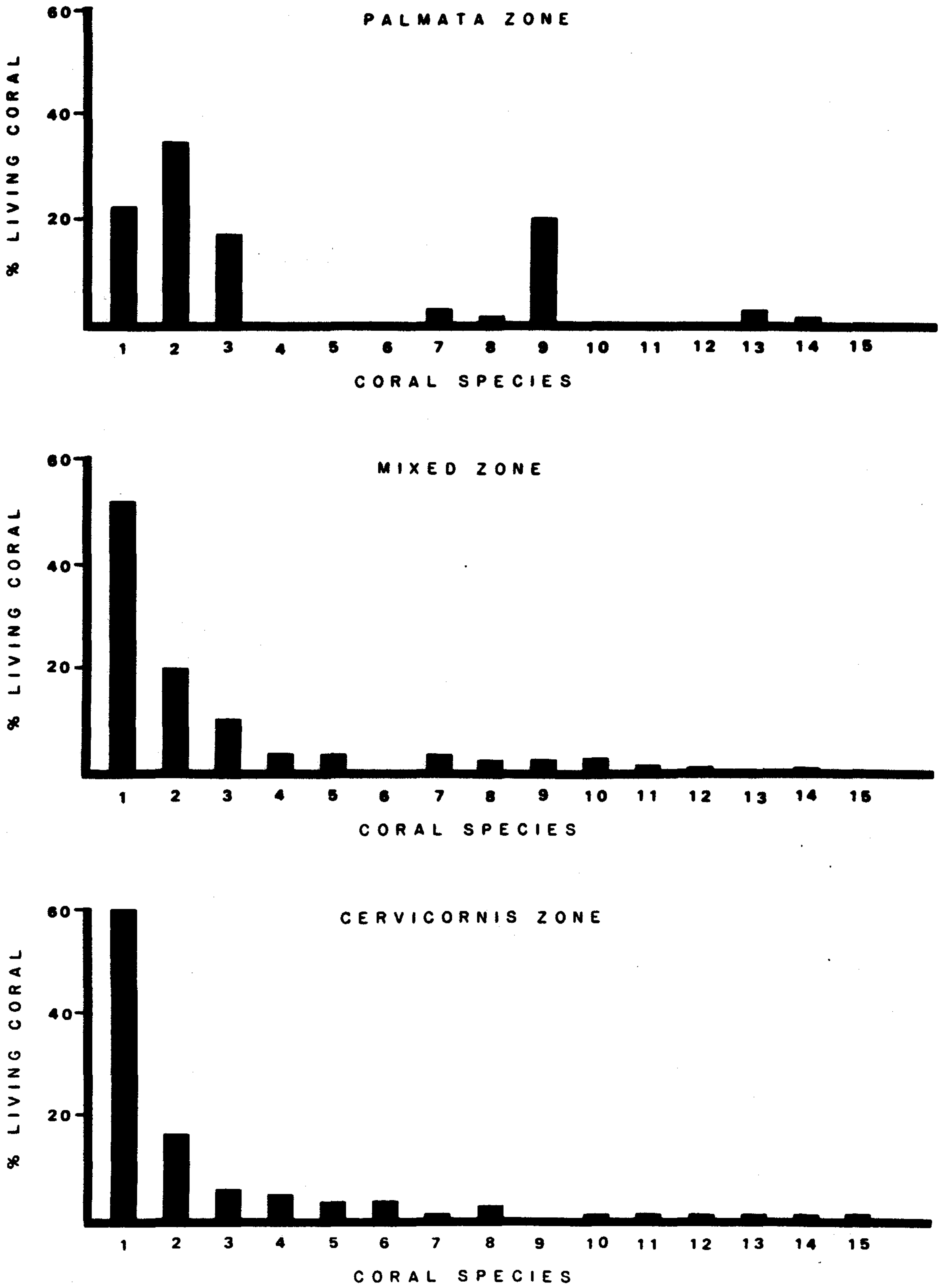
TABLE 1

MEAN PERCENTAGES OF LIVING CORAL ON THE WEST FORE REEF OF DISCOVERY BAY

		ZONES			ENTIRE
	CORAL SPECIES	P	M	C	REEF
1	Montastrea annularis	0.8	8.6	9.2	7.6
2	unknown	1.2	3.3	2.4	2.4
3	Porites astreoides	0.6	1.7	0.7	0.9
4	Siderastrea siderea	-	0.5	0.6	0.5
5	Porites porites	-	0.5	0.5	0.4
6	Madracis mirabilis	-	-	0.5	0.3
7	Millepora complanata	0.1	0.5	0.2	0.2
8	unidentified brain corals	+	0.3	0.2	0.2
9	Acropora palmata	0.7	0.4	-	0.2
10	Colpophyllia natans	-	0.3	0.2	0.2
11	Agaricia agaricites	-	0.2	0.2	0.2
12	Diploria strigosa	-	+	0.2	0.1
13	Diploria labyrinthiformes	0.1	+	0.1	0.1
14	Agaricia fragilis	+	0.1	0.1	0.1
15	Siderastrea radians	-	+	0.1	0.1
16	Acropora cervicornis	-	+	0.1	+
17	Millepora alcicornis	-	+	0.1	+
18	Montastrea cavernosa	-	0.1	+	+
19	Colpophyllia breviserialis	-	-	+	+
20	Stephanocoenia michelinii	-	-	+	+
21	Mycetophyllia ferox	-	-	+	+
22	Mycetophyllia spp.	-	-	+	+
23	Eusmilia fastigiata	-	-	+	+
24	Madracis decactis	-	-	+	+
25	Favia fragum	-	-	+	+
	TOTAL	3.6	16.5	15.4	13.5

P=Palmata, M=Mixed, C=Cervicornis. (+) Represents species that were present but less than 0.1%. (-) Represents species that were absent from the study area. Unknown is all the unidentifiable species other than the unidentified brain corals and one unknown Mycetophyllia spp.

FIGURE II. Mean relative coral abundance on the West Fore Reef of Discovery Bay by zone. Species contributing less than 0.1% were omitted. Coral species correspond to TABLE I.


PALMATA ZONE
% LIVING CORAL
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CORAL SPECIES
MIXED ZONE
% LIVING CORAL
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CORAL SPECIES
CERVICORNIS ZONE
% LIVING CORAL
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CORAL SPECIES

Milleporina. Montastrea annularis dominated this zone with 52.2% of the coral abundance and 8.6% of the total area (FIGURE 2 and TABLE 1). Porites astreoides constituted 10.3% of the total living corals in this zone. Other main contributors and their percentages of coral abundance can be seen in FIGURE 2. The total zone had a mean of 16.5% of live corals, more than four times that of the Palmata Zone. The percentage of sand increased slightly from the Palmata Zone with a mean coverage of 1.1%. This leaves 82.4% of the Mixed Zone comprised mostly of barren coral rock, algae, and scattered sponges and gorgonians.

THE CERVICORNIS ZONE. This was the largest of the three zones studied with data extracted from 197 square meters of reef surface. Water depth ranged from 8-25m, but the study was restricted to a depth of 14m for practicality. The topography here was of a very gentle slope unlike the Palmata Zone (FIGURE 1). The Cervicornis Zone was also dominated by Montastrea annularis, which accounted for 59.7% of the coral abundance and 9.2% of the total zone. Porites astreoides was the second most abundant species comprising 4.8% of the total living corals. There were 19 other species of Scleractinia and two species of Milleporina present. The mean coral density was 15.4% (TABLE 1). The amount of sand increased to 4.3% in this zone, almost four times that of the Mixed Zone. The rest of the zone (80.3%) was mainly composed of dead Acropora cervicornis.

The mean percentage of living corals in the entire study area was 13.5%, most of which was contained in the Mixed and Cervicornis Zones (TABLE 1). More than half of the living coral consisted of Montastrea annularis (7.6%). The second largest contributor was Porites astreoides accounting for 0.9% of the reef. Other coral species present and their contribution to the reef can be seen in TABLE 1. Montastrea annularis increased in density from the Palmata Zone to the Cervicornis Zone as did Agaricia fragilis. Colpophyllia natans, Millepora complanata, Montastrea cavernosa, Porites astreoides and Porites porites were all greatest in density in the Mixed Zone. Most of the other corals exhibited their highest density in the Cervicornis Zone.

There was a significantly greater amount of coral in both the Mixed Zone (16.5%) and the Cervicornis Zone (15.4%) than in the Palmata Zone (3.6%; 1-way ANOV, $P < 0.05$ and Tukey, $P < 0.05$). The amount of coral in the Mixed and Cervicornis Zones did not vary significantly. When individual species were examined, most did not vary significantly between zones. The six species which showed considerable variation in coverage between zones were: Acropora cervicornis, Acropora palmata, Millepora complanata, Montastrea annularis, Porites astreoides and Porites porites (TABLE 2). Montastrea annularis was significantly more abundant in the Mixed and Cervicornis Zones, Acropora palmata was not located in the Cervicornis Zone and Porites astreoides was very abundant in the Mixed Zone. Many species were not present in the Palmata and Mixed Zones. The Cervicornis Zone, named for the thick forests of Acropora cervicornis which once thrived there, was no longer reflective of its name. Furthermore, Acropora cervicornis was one of the rarest species present on the reef after the storm.

There was little difference in the amount of sand found in the

TABLE 2

CORAL SPECIES WHICH VARIED SIGNIFICANTLY IN HORIZONTAL COVERAGE BETWEEN ZONES ON ON THE WEST FORE REEF OF DISCOVERY BAY

CORAL SPECIES	ZONES
Acropora cervicornis	P M C
Acropora palmata	P M C
Millepora complanata	P C M
Montastrea annularis	P M C
Porites astreoides	P C M
Porites porites	P M C
TOTAL LIVING CORALS	P M C

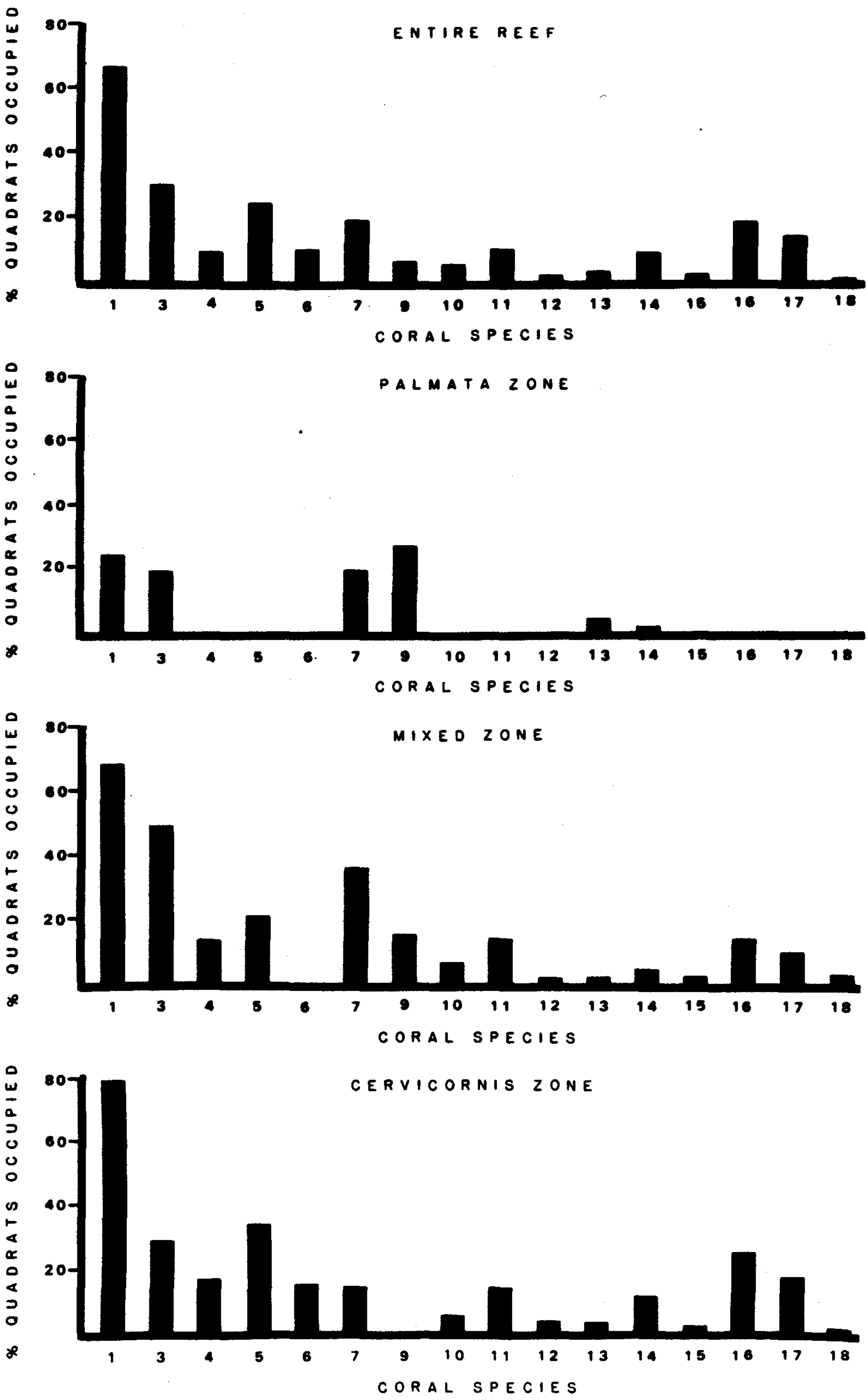
P=Palmata, M=Mixed, C=Cervicornis. Underlining represents no significant difference between zones (1-way ANOV, $P< 0.05$). Tukey's multiple range test ($P< 0.05$).

Palmata and Mixed Zones, but there was a significant increase in the amount of sand found in the Cervicornis Zone (1-way ANOV, P< 0.05 and Tukey, P< 0.05). The mean sand coverage for the entire study area was 3.2%. The rest of the study area (83.3%) consisted mainly of dead corals, algae, sponges, and gorgonians (soft corals).

The relative coral abundance of the entire reef studied, as well as the relative coral abundance per zone, are represented in FIGURE 2. Montastrea annularis was the most abundant species on the entire reef consisting of 56.5% of the total coral cover. Other species in their order of abundance were: Porites astreoides (6.5%), Siderastrea siderea (3.4%), Porites porites (2.9%), and Madracis mirablis (2.3%). Montastrea annularis was the dominate species in each zone. It exhibited an increase in the percentage of coral composition from the Palmata Zone (22.0%) to the Cervicornis Zone (59.7%). Porites astreoides decreased in its percentage of coral composition from the Palmata Zone (17.3%) to the Cervicornis Zone (4.8%). Acropora palmata decreased in its percentage of coral composition from the Palmata Zone (19.6%) to the Mixed Zone (2.3%) and was the only species absent from the Cervicornis Zone.

The frequency of occurrence of coral species (FIGURE 3) emphasizes the species with the greatest distribution on the reef regardless of their sizes. Species which are well distributed may stand a better chance at recolonizing the reef. Montastrea annularis was the most frequently encountered species in the Mixed and Cervicornis Zones and was second to Acropora palmata in the Palmata Zone. Porites porites had the second highest frequency in the Cervicornis Zone, third highest in the

FIGURE III. Frequency of occurrence of the coral species on the West Fore Reef of Discovery Bay. Species occupying less than 1% of the quadrats were omitted. Coral species correspond to TABLE I.


ENTIRE REEF
PALMATA ZONE
MIXED ZONE
CERVICORNIS ZONE
% QUADRATS OCCUPIED
80
60
40
20
CORAL SPECIES
1 3 4 5 6 7 9 10 11 12 13 14 15 16 17 18

Palmata Zone, and the forth highest in the Mixed Zone. Millepora complanata had the third highest frequency in the Palmata and Mixed Zones. Acropora cervicornis was third in the Cervicornis Zone. For the entire study, Montastrea annularis had the highest frequency of occurrence, inhabiting 67% of the quadrats, and Porites astreoides had the second highest frequency occurring in 30% of the quadrats. Porites porites was third inhabiting 26% of the quadrats, and Millipora complanata and Acropora cervicornis were forth and fifth occupying 19% of the quadrats.

CHAPTER IV

DISCUSSION

Past studies on other reefs reported that the large, massive, slower-growing coral colonies are less susceptible to storm damage along with flat, encrusting colonies, such as Millepora complanata and Porites astreoides (Stephenson et al., 1958; Stoddart, 1962, 1963; Glynn et al., 1964; Woodley et al., 1981). Montastrea annularis and Porites astreoides were the most abundant species on the WFR and occurred more frequently throughout the reef than any other species. These two species have also been observed in high abundance on other storm perturbed reefs (Stoddart, 1962, 1963, 1969; Glynn et al., 1964; Goreau and Goreau, 1973).

Stoddart (1962, 1963, 1969) surveyed several reefs after Hurricane Hattie of 1961 perturbed them. Prior to the storm the dominant species were Montastrea annularis, Acropora palmata, and Acropora cervicornis. The chief survivors after the storm were Montastrea annularis, Millepora species and some massive colonies of Acropora palmata. Seventy-five to 80% of the total coral coverage was destroyed. Damage to Montastrea annularis was 50% and damage to Acropora cervicornis was 100%. Massive corals of Montastrea, Diploria and Siderastrea survived well along with Porites astreoides. Species most affected were Acropora cervicornis, Acropora palmata, Porites porites, Porites furcata, Siderastrea radians, Favia fragum, Mycetophyllia lamarckana, and Agaricia agaricites.

In this study Madracis mirablis was the fifth most abundant species in the Cervicornis Zone. Being such a fragile, finger coral, it seems odd to find it in an abundance after the storm. This species may have been extremely abundant prior to the storm. All of the Madracis mirablis colonies along the transects showed breakage and/or mortality. Some of the colonies were almost completely destroyed while others were broken up but still alive. It should be noted that almost all of the colonies were located in water 11-14m deep where surge and scouring were probably less.

There was significantly less coral in the Palmata Zone (TABLE 3; 1-way ANOV, $P < 0.05$ and Tukey, $P < 0.05$) which may relate to the extreme energy released by the waves in that region. Most of the Acropora colonies were fragmented. The slight increase in coral coverage in the Mixed Zone as compared to the Cervicornis Zone reflects the morphological coral types which existed there. The Mixed Zone probably received more surge and abrasion than the Cervicornis Zone but the corals there were mostly the strong, massive and hemispherical types dominated by Montastrea annularis. In the Cervicornis Zone, dominated by Acropora cervicornis, the colonies were more ramose and foliaceous,and more easily destroyed during the storm.

The storm damage was attributed to violent water, rolling corals, suspended fragments and scouring sand (Woodley et al., 1981). Acropora palmata provides much detrital material to build up reef flats and ramparts (Goreau, 1959; Hernandez-Avila et al., 1977). During a severe storm the quantity of detrital material produced by Acropora palmata would be enormous. The result of all that debris in storm conditions would be an intense scouring action on the surrounding substratum. It is obvious that this situation occurred during the hurricane and contributed to the extreme destruction of the Palmata Zone. Most of the coral rubble in the Palmata Zone was worn down possibly by this scouring action. Additionally, many corals which were thrown clear of the water appeared to have little or no abrasion. New islets were formed from Acropora palmata rubble.

Gramzinski (personal communication) examined the WFR in June 1982, and reported an average living coral coverage of 11.7%. This confirms my findings and is well within random sampling variation.

Porter et al. (1981) established photographic stations on the WFR of Discovery Bay prior to Hurricane Allen. They observed a living coral coverage of 51-54% prior to the storm and 10-12% after the storm at a depth of 6.7m, and observed no storm effects at a depth of 32.3m. They stated that prior to the storm shallow water mortality was due mainly to overgrowth competition. During the storm mortality was due to physical factors with the greatest loss to competitively superior species but morphologically inferior species with respect to the storm.

Knowlton et al. (1981) surveyed Acropora cervicornis on the WFR at a depth of 8m and 14m 3-9 days after the storm and estimated a 60% decline in its coverage. To assess the long-term effects of the storm, they surveyed broken fragments of living Acropora cervicornis. Five months later more than 98% of these fragments had died. The cause of this post-hurricane mortality was speculated as disease, predation, abrasion, and/or smothering. This delayed mortality was more severe than that caused directly by the storm.

Woodley et al. (1981) showed that at a depth of 6m on Monitor Reef, on the WFR, branching Acropora species were reduced by up to 99%. Acropora palmata experienced less damage than Acropora cervicornis. Agaricia agaricites was reduced by only 23% and Montastrea annularis by only 9%. Within 4 weeks of the storm 54 fragments of Acropora palmata were tagged. At 16 weeks only 28% of the corals were alive which again demonstrates the high degree of post-hurricane mortality.

Glynn et al. (1964) made similar observations when they studied the effects of Hurricane Edith on a Puerto Rican reef. To a depth of 30 feet 50-100% of the Acropora species were demolished. Large massive and hemispherical colonies like Montastrea and Diploria survived the best along with Porites astreoides. New islets were formed from the debris. Goreau (1959) also observed similar results on a reef in Port Royal, Jamaica, which was struck by a hurricane in 1951. Acropora palmata was severly damaged and was replaced to some extent by Diploria strigosa. Acropora palmata rubble covered 80% of the Palmata Zone and few living corals were present above a depth of 6m.

Recolonization depends on the degree of mortality, availability of larvae and the conditions of the substrate (Connell, 1973). Asexual reproduction via fragmentation resulting from the storm is possible (Gilmore and Hall, 1976; Shinn, 1967) unless the storm is too severe, then tissues would be too damaged to survive as was the case on this reef (Knowlton et al., 1981; Woodley et al., 1981). Even though _Acropora palmata_ is a rapid regenerator (Bak, 1983), recolonization of the Palmata Zone will most likely be slow due to constant wave action, the movement of loose rubble, fouling algae, and the resuspension of bottom sediments which may scour away newly-settled colonies (Stephenson et al., 1958; Goreau, 1959, 1964; Glynn et al., 1964; Endean, 1973, 1976; Endean and Stablum, 1973; Goreau and Goreau, 1973; Dodge et al., 1974; Geister, 1977; Woodley, 1980). Although storms cause severe damage to corals, they may enhance coral growth elsewhere. Boulders moved to sandy areas on a reef flat provide substrate for colonization (Endean, 1976).

Full recovery of the Palmata Zone may take several decades if it is able to recover at all. Should severe storms occur periodically, they may weed out the more fragile corals, namely _Acropora palmata_, and make room for the more storm resistant corals, such as _Montastrea annularis_, _Porties astreoides_, and _Diploria_ species (Goreau and Goreau, 1973). Recovery for the Mixed and Cervicornis Zones will take less time, since destruction in these zones was not as severe and the substratum is more stable.

CHAPTER V

CONCLUSION

The mean coverage for all of the living corals on the reef was 13.5%. Montastrea annularis was the most abundant species with a mean density of 7.6%. Porites astreoides had the second highest density of 0.9%. Montastrea annularis had the highest frequency of occurrence, occupying 67% of the quadrats. Porites astreoides had the second highest frequency, inhabiting 30% of the quadrats. These two species are abundant on other reefs disturbed by storms (Stoddart, 1963), probably due to their resistance to distruction.

There was a great deal of barren substrate suitable for recolonization. A few studies have demonstrated factors which inhibit reef recolonization (Connell, 1973; Endean, 1976), but little is known on the growth rates of entire reefs or on the growth rates of most coral species for that matter. More work is needed in these areas to more accurately predict recolonization and coral growth on reefs.

This study may aid future studies on recolonization and/or regeneration of hermatypic corals on the WFR. It will be interesting to see if new species become established and if old species reclaim their past positions on the reef. Furthermore, it will be interesting to note the time it takes for recovery and the factors which affect the recolonization process.

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The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Masters of Science.

19 April 1984
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