PRELIMINARY REPORT:

EFFECTS OF HURRICANE HUGO ON THE BENTHIC CORAL REEF COMMUNITY OF SALT RIVER SUBMARINE CANYON, ST. CROIX, U.S. VIRGIN ISLANDS

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In February 1989, the National Oceanic and Atmospheric Administration (NOAA) and the National Undersea Research Center of Fairleigh Dickinson University (NURC/FDU) accepted a proposal from the U.S. Virgin Islands Government's Department of Planning and Natural Resources and the University of the Virgin Islands to establish a long term environmental monitoring project to assess the changes in the benthic coral reef community in Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands. The Aquarius Undersea Habitat and saturation diving techniques were utilized at the commencement of this project. Saturation diving allowed the project participants to maximize bottom time for careful site selection, permanently mark study sites, photographically document each quadrat, and collect data to establish a baseline for future monitoring periods in the Salt River Submarine Canyon area.

On September 17th and 18th, 1989, Hurricane Hugo, with sustained winds of 140 miles per hour and gusts over 200 miles per hour, hit St. Croix inflicting major damage to the terrestrial portion and causing significant changes to the submerged lands surrounding the island. During the months of November and December of 1989, the permanent quadrats were relocated and photographed, providing data for an initial comparison between the pre and post Hurricane Hugo state of the benthic coral reef community in Salt River Canyon.

This paper will address the preliminary data compiled from comparing the photographs taken at the start of the project and again at the first sixth (6) month monitoring interval.

INTRODUCTION

With the recent increase in coastal development throughout the Caribbean and the world, scientists, resource managers and government officials realize the need to establish monitoring programs to record baseline data for evaluating changes in coastal and marine resources. Baseline data collection and recording can help in assessing changes that are occurring in near-shore marine communities and whether the changes are the result of natural processes or are a direct result of man's intervention.

In February 1989, the National Oceanic and Atmospheric Administration (NOAA) and the National Undersea Research Center of Fairleigh Dickinson University (NURC-FDU) accepted and funded a proposal from the U.S. Virgin Islands Government's Department of Planning and Natural Resources and the University of the Virgin Islands to establish a long term environmental monitoring project to assess the changes occurring in the benthic coral reef community in Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands.

This project required two saturation missions (89-3 and 89-4C) and involved using the Aquarius Undersea Habitat. The Habitat program is sponsored by NOAA's National Undersea Research Program and is operated by NURC-FDU in St. Croix. By utilizing saturation diving techniques, it was possible for the project participants to maximize daily excursion bottom times from the undersea habitat for careful selection and permanent marking of study sites, photographically documenting each permanent quadrat, and to collect data used in establishing a baseline for future monitoring periods in the Salt River Submarine Canyon area.

Salt River Canyon provides a unique study area. The characteristics of the east slope and west wall are dramatically different. The western wall is steep, often vertical, and has many spur and groove formations which sand is transported to the canyon floor. In several instances, overhangs and caves are present. The first significant groove formation occurs at a point where the wall meets the canyon floor at a depth of 60 ft (20 m). This area is the beginning of station 1. In deeper portions of the canyon, [90-120 ft (30-40 m)], large portions of the wall have broken off and have become part of the canyon fill.

The eastern wall, in contrast, is characterized by alternating zones of near-vertical rock wall and cobble-filled side tributaries, at angles of 15-20 degrees. The innermost 650-800 ft (200-250 m) is of the latter type. Further seaward the wall becomes vertical.

The canyon floor has a gently seaward slope comprised of medium sand to silt (Mz.25 mm). The floor is generally inactive except for the periodic sorting of burrowing organisms, but can become mobile during periods of high wave or current activity.

The lip of the canyon begins at the barrier reef fronting the Salt River estuary. The depth is between 30 and 50 ft (9-15 m) and continues downward to a depth of 12,000 ft (3500 m) where it joins with the Christiansted Canyon. At the lip of the canyon there are scattered *Acropora palmata* stands and head corals (primarily *Diploria* spp.) *Millepora* spp. are also present in this area. The canyon walls are dominated by flattened *Agaricia* spp., *Montastrea annularis* and other corals which are tolerant to lower light levels. Gorgonians and sponges are extremely common. The canyon floor has isolated sea grass (*Halophila decipiens*) and rhizophytic algae that can be found to depths of 100 ft.

METHODS

Eight permanently marked monitoring stations were established throughout the Salt River Canyon, one at 30 ft (10 m), four at 60 ft (20 m), two at 90 ft (30 m), and 120 ft (40 m), as shown in Figure 1.

At each station, except station number eight, there were six, ten meter long transects placed along a depth contour. At station eight, there were ten, ten meter long transects placed along a depth contour. Two brass stakes marked the ends of each transect. Holes were drilled into the substrate with an underwater hydraulic drill. Stakes were placed in each hole and cemented into place with underwater epoxy. A number was stamped into the top of each stake for identification purposes. Along each transect, benthic cover was assessed and quantified by using the chain line method Rogers et al., (1983). This type of measurement gives a three dimensional view of the coral reef. It involves placing a small chain along the transect which is used as a scale for the measurement of the percent of benthic cover along each line.

Fifteen 0.5 m^2 quadrats were sampled at the 30, 60, and 90 ft stations. At the 120 ft site only 12 quadrats were established, due to time constraints. Two corners of the quadrat were marked by using four inch cut nails pounded into the substrate. Each nail has a numbered tag attached to it with a plastic cable tie. These tags were placed in the upper right and left hand corners to insure exact photographic replication.

An aluminum quadrapod with a quadrat size of approximately 0.5 m^2 was used in a frame with a NIKONOS III underwater camera and 15 mm lens with two strobes securely mounted to this frame assembly (Suchanek et al. 1983). The quadrapod was positioned by placing the permanent numbered tags in the upper left and upper right corners of the quadrapod to ensure exact replication.

This monitoring project also included 8mm video recording of each transect line for later analysis, water quality testing, queen conch (*Strombus gigas*) monitoring, and *Acropora cervicornis* growth measurements. This data can be found by writing the National Undersea Research Center and referring to Aquarius missions 89-3 and 898-4C. This paper will only focus on a preliminary analysis of the quadrat measurements.

On September 17th and 18th, 1989, Hurricane Hugo, with sustained winds of 140 miles per hour and gusts over 200 miles per hour, hit St. Croix inflicting severe damage to the terrestrial portion of the island and causing significant changes to subtidal areas. Hugo was a classical Cape Verde hurricane that left a trail of destruction across the Leeward Islands, U.S. Virgin Islands, Puerto Rico, North Carolina and South Carolina (Figure 2). The eye of the Hurricane made landfall on the east end of St. Croix at approximately 0230 hours on the 18th of September and exited the West end at approximately 0400 hours. Minimum surface pressures were approximately 940 mb near the center of the storm.

In its path, it left a trail of destruction estimated to be 2 billion dollars for the U.S. Virgin Islands and Puerto Rico. The Federal Emergency Management Agency estimate of money outlay is currently 0.731 billion for the U.S. Virgin Islands and Puerto Rico and is subject to upward revision.

Between May and June of 1989, the first photographs of the quadrats were taken to establish a baseline for the long term monitoring project. Saturation diving was used initially to carry out this task. Between November and December of 1989, a resurvey of the quadrats was accomplished. A direct comparison can be made of the effects of the storm on the coral reef in Salt River Canyon based on pre and post Hurricane Hugo sampling.

The 35mm color photographic slides were analyzed using the random point method. Each slide was projected onto a poster board with a grid background scaled for a one to one reproduction size. This grid was composed of 231 evenly spaced points. The entire frame was analyzed by counting how many points each material component encompassed within the grid boundaries.

RESULTS

Living substrate. The pre- and post- hurricane substrate counts are illustrated in Figures 4, 5 and 6. The significance of each change was tested using the chi-square test and a level of significance of 0.05. When looking at the significance of each substrate as a whole, the amount of significant change was dramatic, however when viewed on an individual scale, the comparison between the different stations was not as dramatic (Table 1). *Diploria clivosa* had a level of significant change overall but only station 4 was shown to be significant (Table 1).

The proportional coverage of the corals was determined by dividing the total numbers of points counted for that coral by the total number of all coral points in all the different stations. *Dichocoenia stokesi* was most affected by the hurricane, its coverage was reduced by 81%. The other coral species common on the reef, *Diploria clivosa, Colpophyllia natans, Porites porites,* and *Porites astreoides* were all reduced in coverage by values ranging from 28% to 14% (Table 2). Overall, the changes to the coral coverage were minor, however, certain stations received more damage and alteration than others (See Table 3 for pre- and post-hurricane substrate counts). Station 3, located on the 60 ft outer East Slope, station 4, located on the 60 ft inner East Slope, and station 6, located on the 90 ft East Slope, showed the most significant change. It was not possible to re-survey the 120 ft station, located on the East Slope, due to the depth and time constraints. A visual observation was made by a NURC-FDU staff member who reported that on the afternoon of the 17th of September, the entire shallow ridge of the East Slope area of the canyon had breaking water. One possible reason why the East Slope stations suffered the most damage was that the East Slope took the direct hit of the waves, thus somewhat reducing the severity of the waves for the West Wall.

The storm tracked from the SE to the NW across St. Croix. Directional shifts were recorded on a S-4 current meter deployed in Salt River Canyon at a depth of 60 ft (20 m). The

Table 1. Significance of changes in substrate per station by chi-square test. x = significant, o = not significant

	Station number						
	1	2	3	4	5	6	8
Agaricia spp.	0	0	x	0	x	0	0
Colcophyllia natans	0	0	0	-	-	x	x
Dichocoenia strellaris	0	-	-	x	-	-	x
Dichocoenia stokesi	-	-	-	-	-	-	x
Diploria clivosa	-	-	-	x	-	0	0
Diploria labyrinthiformes	-	0	0	0	-	-	0
Diploria strigosa	0	x	0	0	0	0	0
Montastrea annularis	0	0	0	0	0	0	0
Montastrea cavernosa	0	0	0	0	0	0	0
Mycetophyllia ferox	0	-	0	0	0	0	0
Porites asteroides	0	0	x	0	0	0	0
Porites porites	0	0	0	0	0	-	0
Siderastrea radians	0	0	0	0	0	0	0
Siderastrea siderea	0	0	0	0	0	0	0
Sponge spp.	0	x	x	0	0	0	x
Gorgonian spp.	x	0	x	x	0	x	x
Rubble	-	x	x	x	x	x	-
Sand	0	x	x	x	x	x	-
Bare rock	x	-	-	-	-	-	-
DCA	0	0	0	0	0	0	0

DCA = Dead Covered with Algae

Table 2. Percentage loss of coral species

Coral species	Pre-hurricane counts	Post-hurricane counts	% Loss
Agaricia spp.	3312	2986	10
Colpophyllia natans	249	189	24
Dichocoenia stokesi	26	5	81
Diploria clivosa	109	78	28
Diploria strigosa	644	584	9
Montastrea annularis	979	956	2
Montastrea cavernosa	945	841	11
Mycetophyllia ferox	128	113	12
Porites astreoides	279	240	14
Porites porites	111	95	14
Siderastrea siderea	401	380	5
Stephanocoenia michelinii	31	27	13

Table 3. Pre and Post Hurricane Substrate Counts

Substrate	Station 1	2	3	4	5	6	8
Agarcia spp.	824/833	599/567	158/93	149/124	1076/893	310/300	196/176
Colpophyllia natans	8/6	39/34	162/149	--	--	34/-	6/-
Dendrogyra cylindricus	--	--	--	--	--	--	80/97
Dichocoenia strellaris	--	5/7	--	4/1	--	--	-/4
Dichocoenia stokesi	--	--	--	--	--	--	26/5
Diploria clivosas	--	--	--	39/5	--	28/23	--
Diploria labyrinthiformes	--	5/5	64/56	15/17	--	--	52/62
Diploria strigosa	100/96	45/28	225/186	123/118	38/41	60/65	53/50
Eusmilia fastigiata	--	--	--	--	1/-	--	--
Meandrina meandrites	--	2/2	1/2	-/2	--	--	--
Millepora alcicornis	9/11	--	3/-	--	--	--	7/1
Millepora complanata	--	--	--	--	--	--	4/4
Montastrea annularis	196/196	174/185	150/135	112/105	11/14	293/275	43/46
Montastrea cavernosa	122/116	25/14	178/149	250/242	9/11	217/181	144/128
Mycetophyllia ferox	14/16	--	21/13	37/31	17/17	19/12	20/24
Porites astreoides	25/23	14/10	82/57	72/78	5/2	64/57	17/13
Porites porites	16/13	48/43	8/2	20/23	6/4	--	13/10
Siderastrea radians	19/14	30/32	21/22	8/8	258/264	19/20	15/16
Siderastrea siderea	121/118	21/27	62/51	94/91	23/23	39/28	41/42
Stephanocoenia michelinii	--	31/27	--	--	--	--	--
Tubastrea aurea	--	--	3/-	--	--	--	--
Crinoids	--	--	2/-	--	--	--	--
Sponge spp.	22/25	195/156	224/136	128/112	217/222	478/472	64/34
Gorgonian spp.	151/88	56/40	169/95	412/321	3/5	250/194	222/169
Rubble	--	-/17	-/396	-/117	-/7	-/56	--
Sand	181/161	95/34	218/278	6/20	63/134	52/96	--
Bare rock	-/119	--	--	--	--	--	--
Dead Rock Covered with Algae	1852/1876	1724/1837	1629/1549	1671/1722	1558/1643	1066/1130	2101/2191

meter was located near station 1 on the inner West Wall (See Figure 1 for location). After the storm, the current meter was found to have moved laterally 10 ft (3 m) toward the West Wall of the canyon. There was newly exposed substrate along the wall indicating that sand transport and scouring had taken place. The current meter had dropped in level about 3 ft (1 m) indicating how much the floor of the canyon was scoured. Further along the canyon to the north, the depth of scouring had reached twelve (12) ft (4 m) (Taylor and Tragester, 1990).

The sponges and gorgonians were affected significantly by the storm. Sponges decreased by 13 percent and the gorgonians by 28 percent. Stations 2 (West Wall, 60 ft, 3 (East Slope, 60 ft), 4 (East Slope 60 ft), 6 (East Slope, 90 ft), and 8 (West Wall, 30 ft) had higher losses. As discussed earlier, stations 3, 4 and 6 are on the East Slope and that waves were breaking on the East Slope. Station 8 is located on the West Wall in 30 ft depth, therefore, it is conceivable that the wave energy is greater than at a deeper depth.

Non-living substrates. The amount of rubble, sand, and dead rock covered with algae was greater in the resurvey. The classification of rubble for this paper is any dead gorgonians, sponges or coral that was placed there after the storm. Sand increased from 615 counts before the storm to 734 counts after the storm. Rubble increased from zero before the storm to 593 counts after for the greatest significant change. Dead rock covered with algae (DCA) increased only slightly from 1852 to 1876 counts (Table 3). These gains were at the direct expense of the living components of the reef. The increase in sand coverage may have been directly related to the fact that so much sand transport occurred in the canyon itself and thus sand settled into the low lying areas. In some areas the canyon floor dropped a maximum of twelve (12) ft (4 m).

The changes in living and non-living substrates types are significant on an overall scale but when viewed station by station, the changes are significant in only certain areas, predominantly on the East Slope. Figures 7 and 8 are photographs taken before and after the storm of the same quadrat. These pictures are from station 3, 60 ft East Slope. Figure 7 was taken June, 1989, notice the large tubular sponge. Figure 8 was taken November, 1989. The large tubular sponge was missing and there was an increase in gorgonian rubble and sand. Figures 9 and 10 are pictures again taken from station 3. Figure 9 was taken June, 1989 and Figure 10 taken November, 1989. When comparing the two, notice the gorgonian rubble and coral rubble present and pieces of *Acropora cervicornis* found in the bottom right of Figure 10. Figures 11 and 12 are taken from station 4, 60 ft inner East Slope. Figure 11 was taken in June, 1989, and Figure 12 taken November, 1989. In Figure 12 the large *Colpophyllia natans* was completely missing from the site and that there was a significant increase in coral and gorgonian rubble.

These pictures are the more dramatic photographs taken. Others show very little change between monitoring intervals, such as an increase in sand settlement on top of the plating corals.

CONCLUSIONS

This is a preliminary report prepared to describe techniques used in establishing a Long-Term monitoring program using reproducible photographic documentation and initial analysis by comparison of the Salt River Submarine Canyon, in both a Pre and Post Hurricane Hugo state. Follow-up photographs have also been taken for the one year sampling interval and final analysis is planned using computer assisted techniques.

ACKNOWLEDGEMENTS

Many thanks to Susan Rhoades and Bill Cleveland for their diving assistance. A big thanks to all the staff of the Aquarius underwater habitat for their help and assistance in almost every aspect of this project. Also to Doug Kesling for his moral, as well as technical and logistical support that he gave me throughout the entire project - Thank You.

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Taylor, G., and Tragester, J. H. 1990. Directional Wave and Current Measurements During Hurricane Hugo. Proceedings of Marine Instrumentation '90. San Diego, CA. November 1990

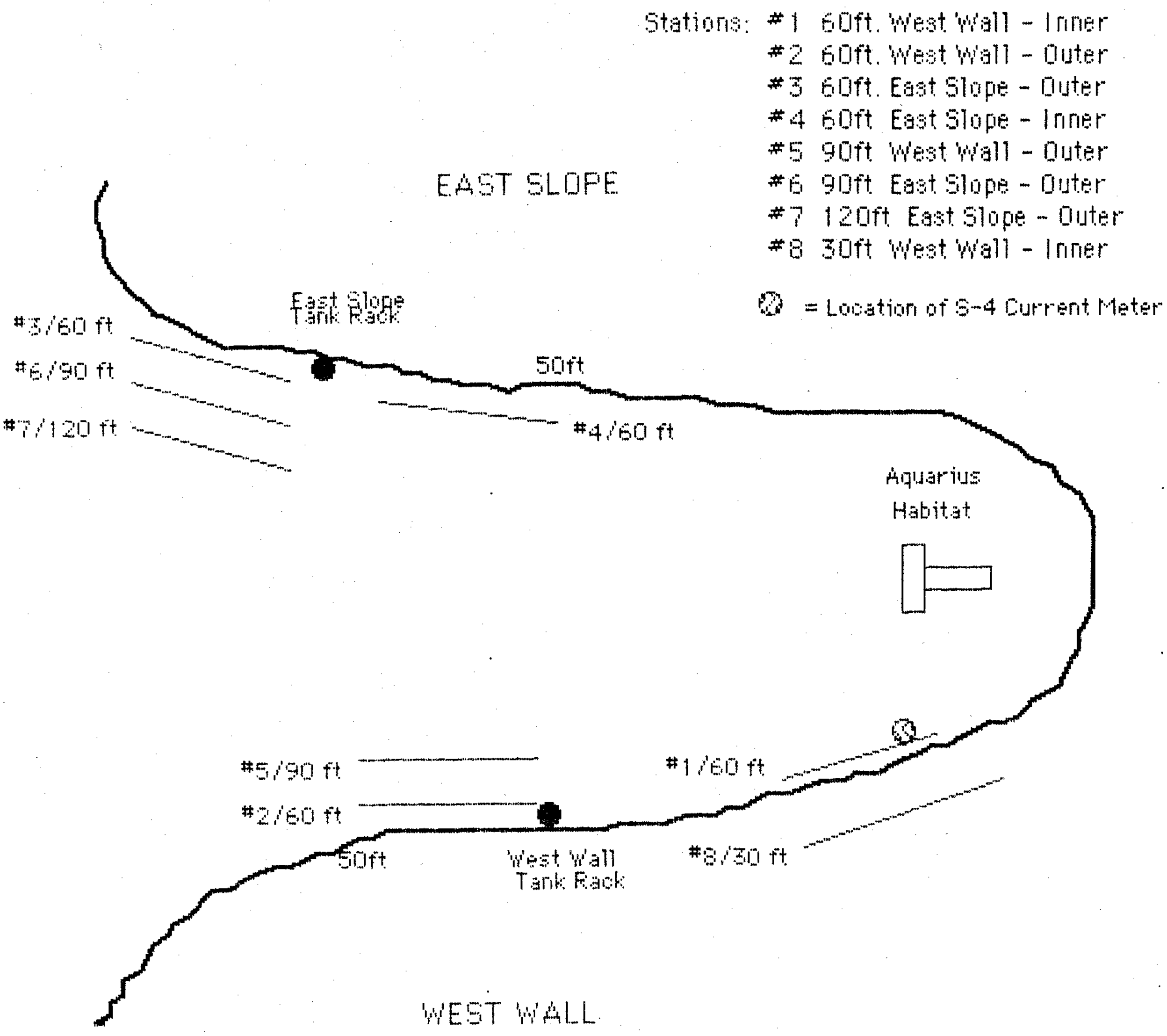

Figure 1. Location of permanently marked stations 1–8. Salt River Submarine Canyon, St. Croix, U.S.V.I.

Figure 2. The path of Hurricane Hugo. Map supplied by the U.S. Department of Commerce NOAA - National Weather Service.

Figure 3. Photo credit D. Kesling.

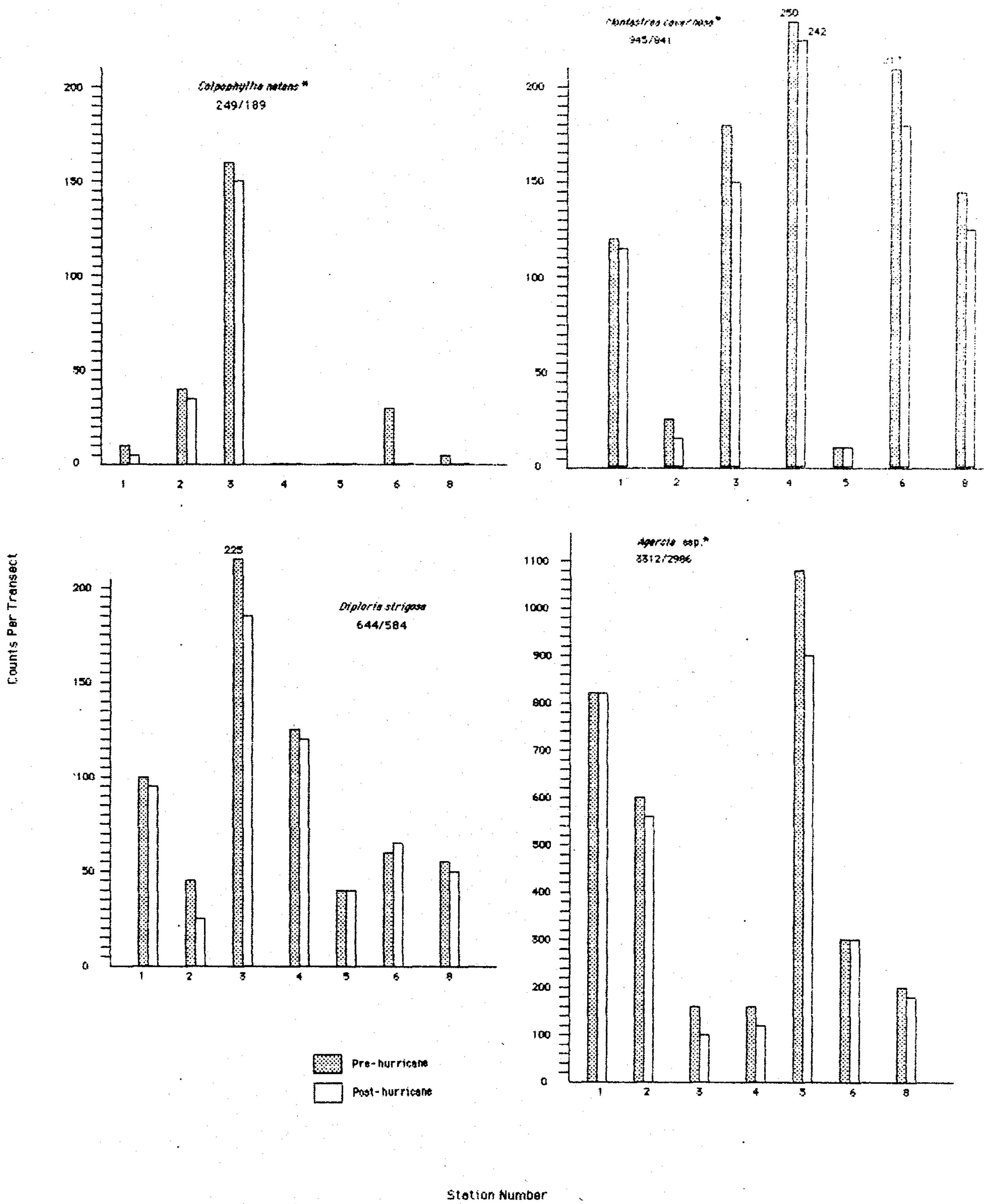

Figure 4. Histograms of the substrates by counts per stations before and after Hurricane Hugo. The numerator of the fraction on each histogram is the total pre-hurricane counts; the denominator is the total post-hurricane counts for the substrate. An asterisk (*) marks a statistically significant difference (x test, significance level of 0.05) between pre- and post-hurricane counts for each substrate.

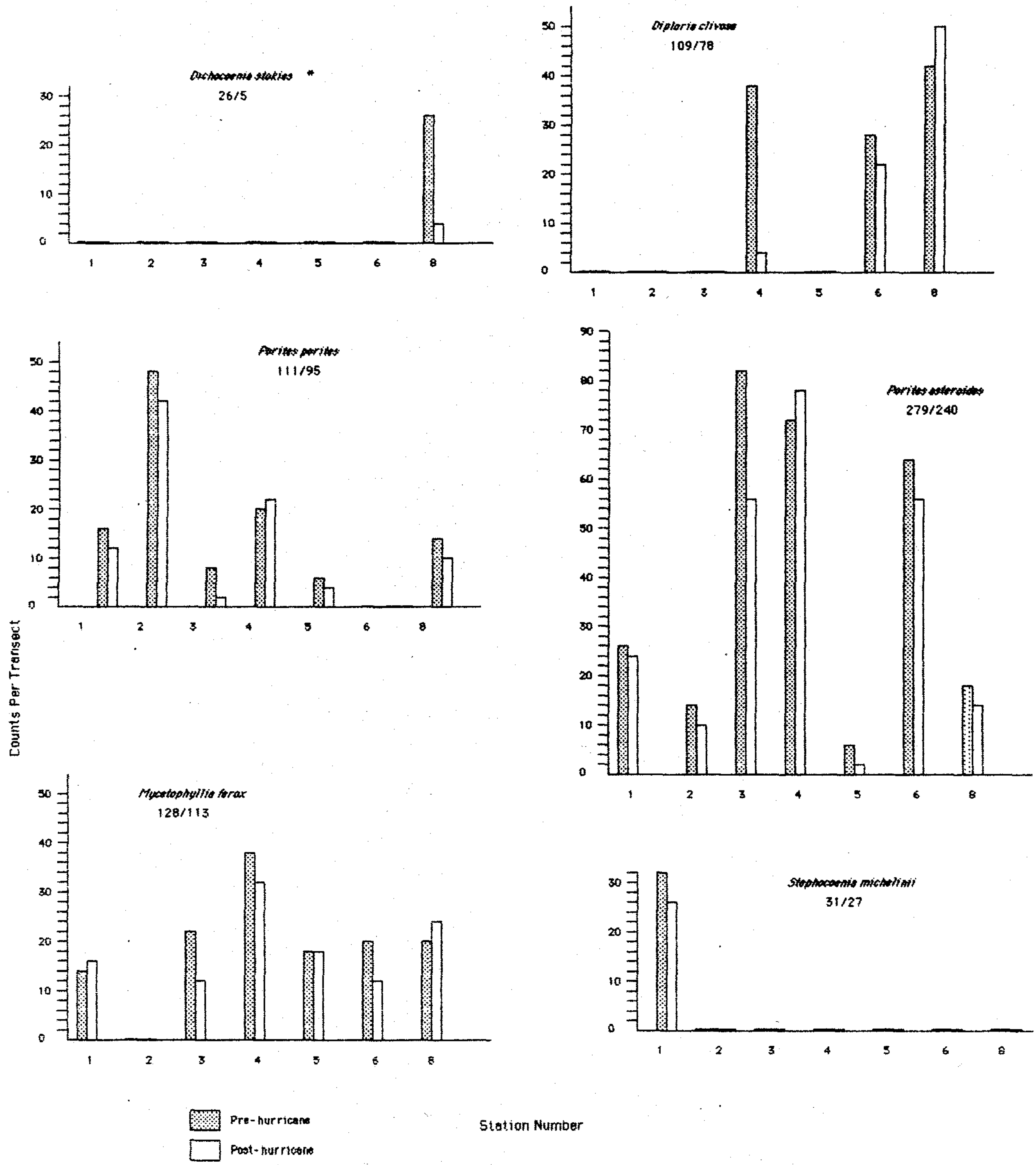

Figure 5. Histograms of the substrates by counts per stations before and after Hurricane Hugo. The numerator of the fraction on each histogram is the total pre-hurricane counts; the denominator is the total post-hurricane counts for the substrate. An Asterisk (*) marks a statistically significant difference (x test, significance level of 0.05) between pre- and post-hurricane counts for each substrate.

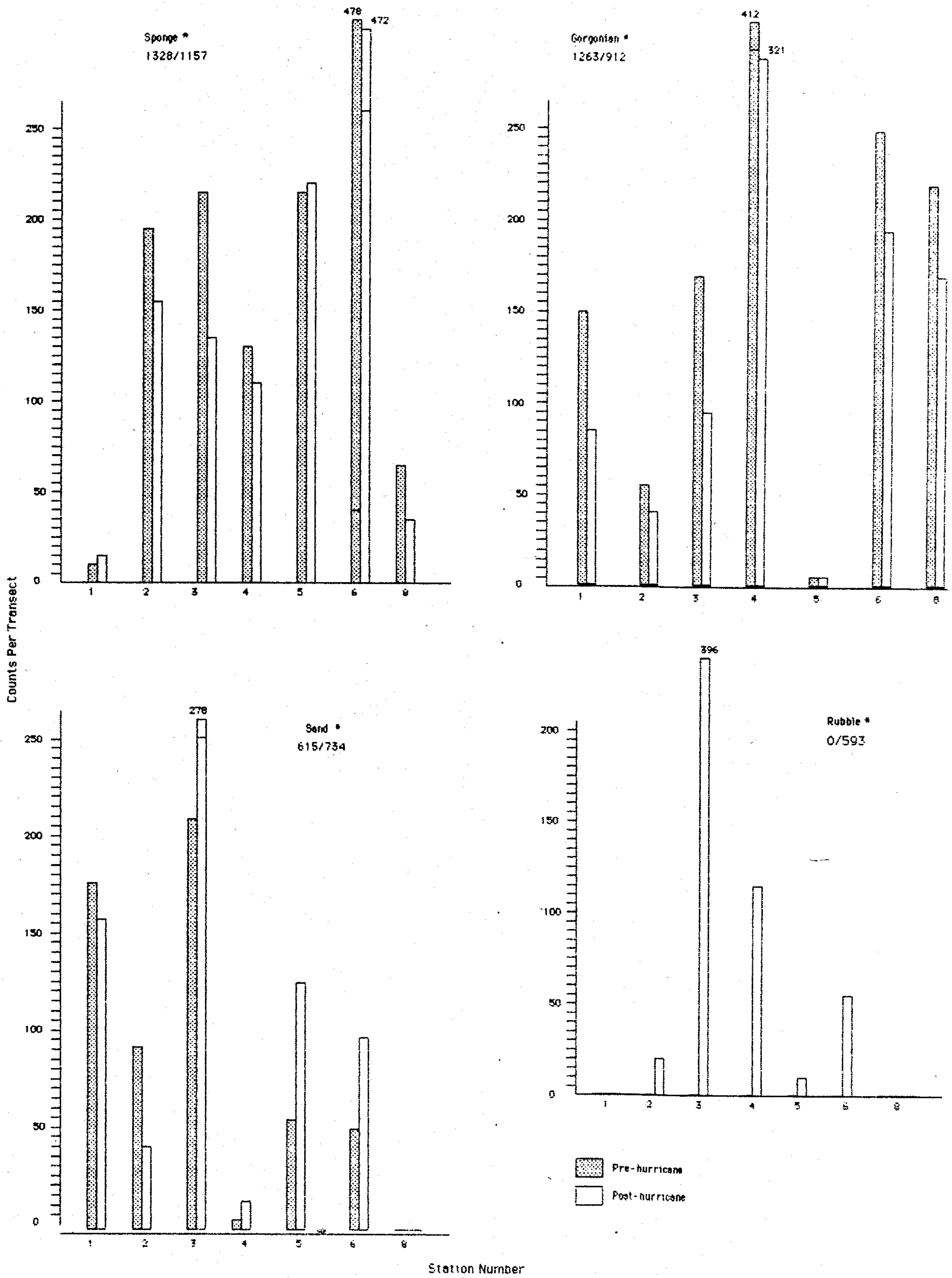

Figure 6. Histograms of the substrates by counts per stations before and after Hurricane Hugo. The numerator of the fraction on each histogram is the total pre-hurricane counts; the denominator is the total post-hurricane counts for the substrate. An asterisk (*) marks a statistically significant difference (x test, significance level of 0.05) between pre- and post-hurricane counts for each substrate.

Figure 7.

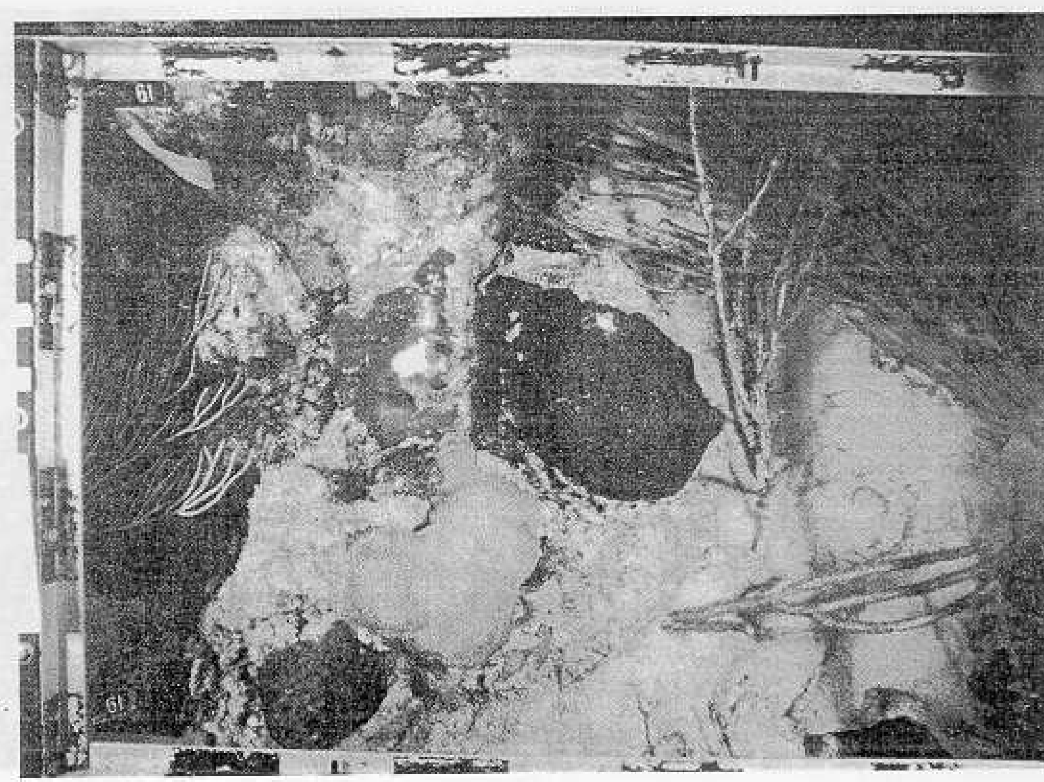

Figure 8.

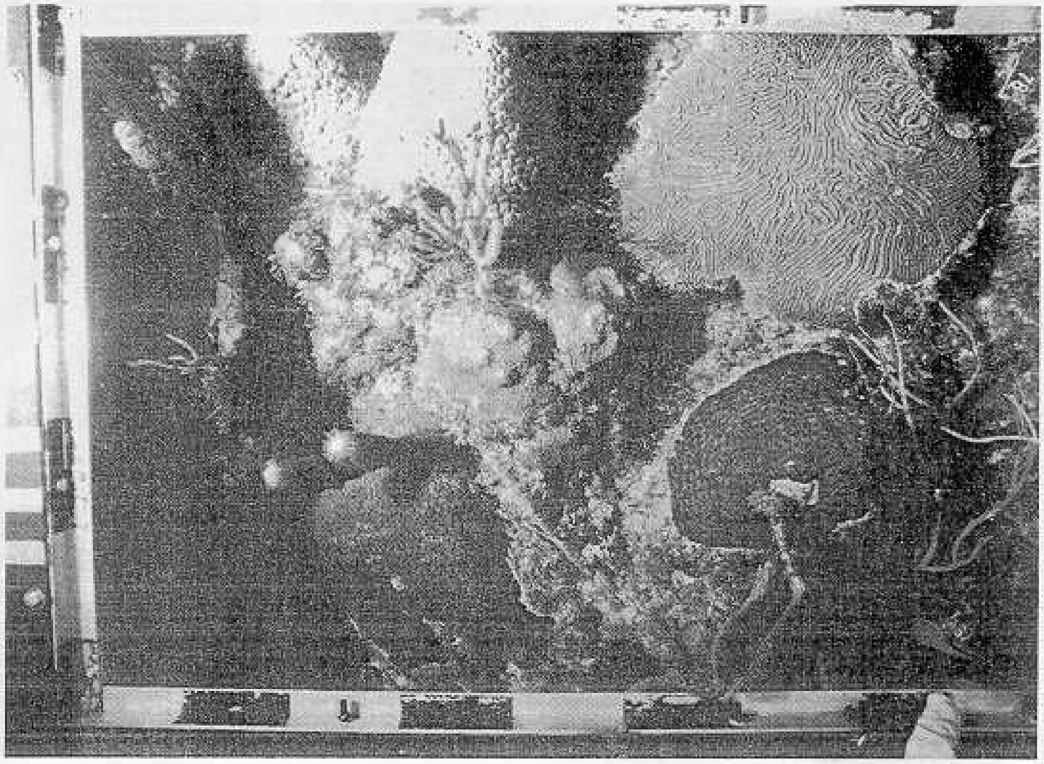

Figure 9.

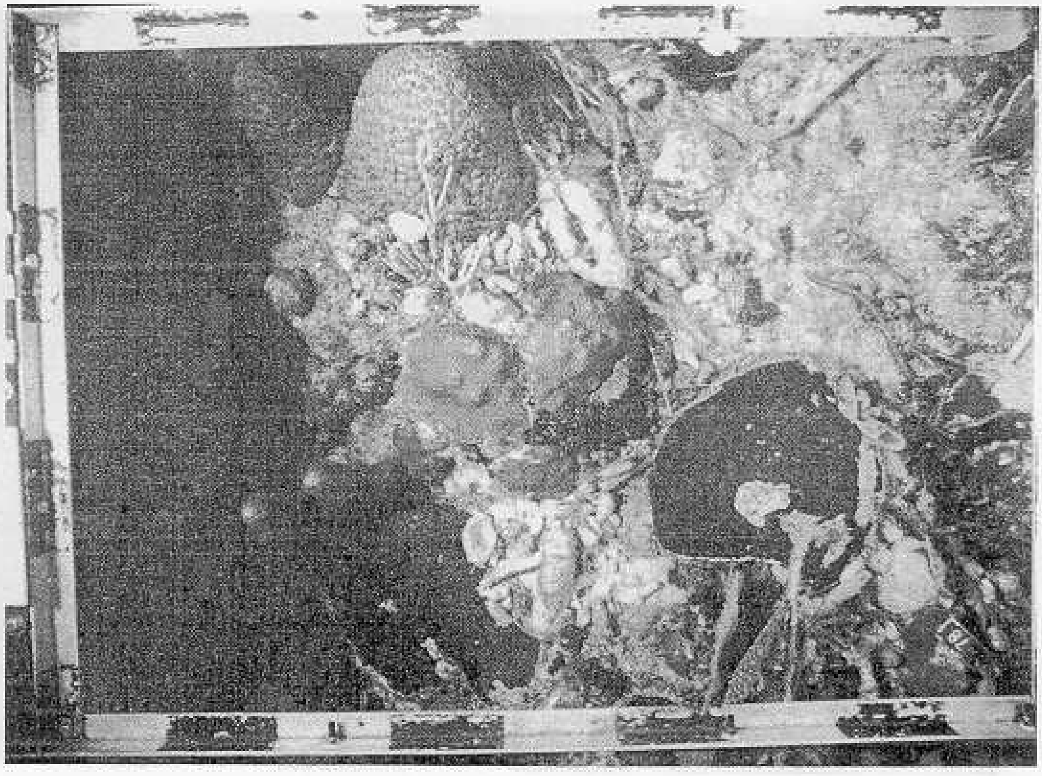

Figure 10.