AN ABSTRACT OF THE THESIS of Dana Marie Rowley for the Master of Science in Biology presented April 11, 1980.

Title: Analysis of Biofouling Communities on Settling Plates at the Proposed Ocean Thermal Energy Conversion Site off Guam

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Charles E. Birkeland, Chairman, Thesis Committee

Concrete blocks with plexiglass and PVC settling plates were submerged off Luminao Barrier Reef, Guam. Settling plates were exposed at 6, 12, 24, and 37 m for 37-, 77-, 100-, and 180-day durations. The plates were placed in replicate groups of four in horizontal, vertical, and shaded orientations. Exposed and protected surfaces were examined.

Biomass accumulation increased as the duration of exposure changed from 37 to 180 days for each depth. There was an increased rate of biofouling from 100 to 180 days at 6 m that was not evident at the other depths. Biomass was greatest at shallower depths and decreased as depth increased. Horizontally-placed plates accumulated more biomass than did vertically-placed plates. Exposed horizontal and vertical plates accumulated more biomass than did shaded plates.

Biomass accumulation rates on small plexiglass plates oriented horizontally at 6 m were compared between Guam, the Caribbean, and the Pacific coast of Panama. Guam and the Caribbean had similar rates of fouling accumulation for the first 100 days, but at 180 days the

fouling was greater off Guam. The rates of fouling off the Pacific coast of Panama was seven times that off Guam after six months and was probably the result of upwelling of nutrients.

Biomass accumulation on large, vertically oriented, PVC plates submerged off Guam was less than fouling accumulations on asbestos plates set off Hawaii. This difference was presumed to be the result of the variance in faunal representatives between the two areas and the increased nutrients from terrigenous run-off around a large island chain such as Hawaii as compared to Guam.

A set of small plexiglass plates was placed at Western Shoals inside Apra Harbor for 77 days to make a comparison of biomass accumulation between a barrier reef and a lagoon. Fouling accumulated twice as fast on horizontal plates at Western Shoals than on horizontal plates at Luminao. This difference was the result of increased sedimentation and larger bivalve populations at the lagoon site.

The proportion of surface coverage increased with exposure duration and decreased with increasing depth. Algae was the predominant cover on exposed surfaces. Protected surfaces had a higher proportion of animals.

Community development, as evidence through the patterns of surface coverage and changes in diversity of fouling assemblages, was found to be influenced by the intensity of fish grazing. The intensity of grazing was greatest at 77 and 180 days. The grazing activities of herbivorous fish affected the proportions of surface coverage of filamentous and crustose coralline algae. The diversity of fouling assemblages increased with duration of exposure and increased grazing pressures.

ANALYSIS OF BIOFOULING COMMUNITIES ON SETTLING PLATES AT THE PROPOSED OCEAN THERMAL ENERGY CONVERSION SITE OFF GUAM

by

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TO THE GRADUATE SCHOOL AND RESEARCH

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INTRODUCTION

Oceanic islands in the western Pacific are surrounded by clear water with low primary productivity. Reduced levels of nitrogen and phosphorous in waters from the low latitudes limits the growth of phytoplankton (Bolin et al., 1979). Pacific islands do not receive or retain the large quantities of terrigenous run-off and the accompanying nutrient increase generally associated with continental land masses (Helfrich and Townsley, 1963). The relative lack of seasonality in production prevents the build up of nutrients and the associated phytoplankton blooms as occur in temperate zones (Riley and Chester, 1971). Nutrients in the westward-flowing North Equatorial Current are depleted by the time the waters reach Micronesia (Sverdrup et al., 1942). Reduced nutrient levels in waters around Guam are believed to affect biomass accumulation rates (Birkeland, personal communication).

The purpose of this investigation was to quantify biomass accumulation and community structure on artificial biofouling surfaces. Comparisons of biomass accumulation were made between the eastern, central, and western Pacific. Community development was assessed by changes in the proportion of surface coverage and diversity of fouling organisms with time.

Biomass accumulation integrates the factors that affect productivity and acts as an indicator of production in an area on a continuing basis. Measurements of biomass accumulation have been done in Panama, Hawaii, and Guam. Birkeland (1977), studied the differences in biomass accumulation between the Caribbean and the Pacific side (an upwelling zone) of Panama. The biomass accumulation in Hawaii was studied by Long (1974) and Grovhoug (letter dated 15 March 1979, Naval Ocean Systems Center, Hawaii Laboratory, P. O. Box 997, Kailua, Hawaii 96734). Neudecker (1978) studied biomass of fouling communities in predator-exclusion cages off Guam; however, this study was not directly comparable to the others.

The evaluation of the fouling community in reef-associated near-shore waters is a factor in determining the suitability of Guam as an Ocean Thermal Energy Conversion (OTEC) site. These waters have higher production levels than do offshore-waters because of the efficient recycling of nutrients by corals. Calcareous algae and other primary producers also contribute to higher production. The benthic organisms that settle and recruit to the available substrate are influenced by the increased productivity around coral reefs.

Guam has the necessary geographical and hydrographical conditions for an OTEC plant (Corey, 1975; Craig et al., 1977). Lassuy (1979) found that a high temperature differences (ΔT) of 19.4°C (35°F) between shallow and deep waters is possible year-round at a depth of 396 m (1300 ft) off Luminao Reef. The combination of deep water close to shore and high temperature differences makes Guam an ideal OTEC site in terms of physical factors.

The western side of Guam near Cabras Island has been suggested as an OTEC site. This biofouling study was conducted west of Cabras Island at the boundary zone between the submerged Calalan Bank and Luminao Barrier Reef (Fig. 1). At the site, from a depth of 6 to 12 m (20 to 40 ft), the reef consists of a gently sloping submarine

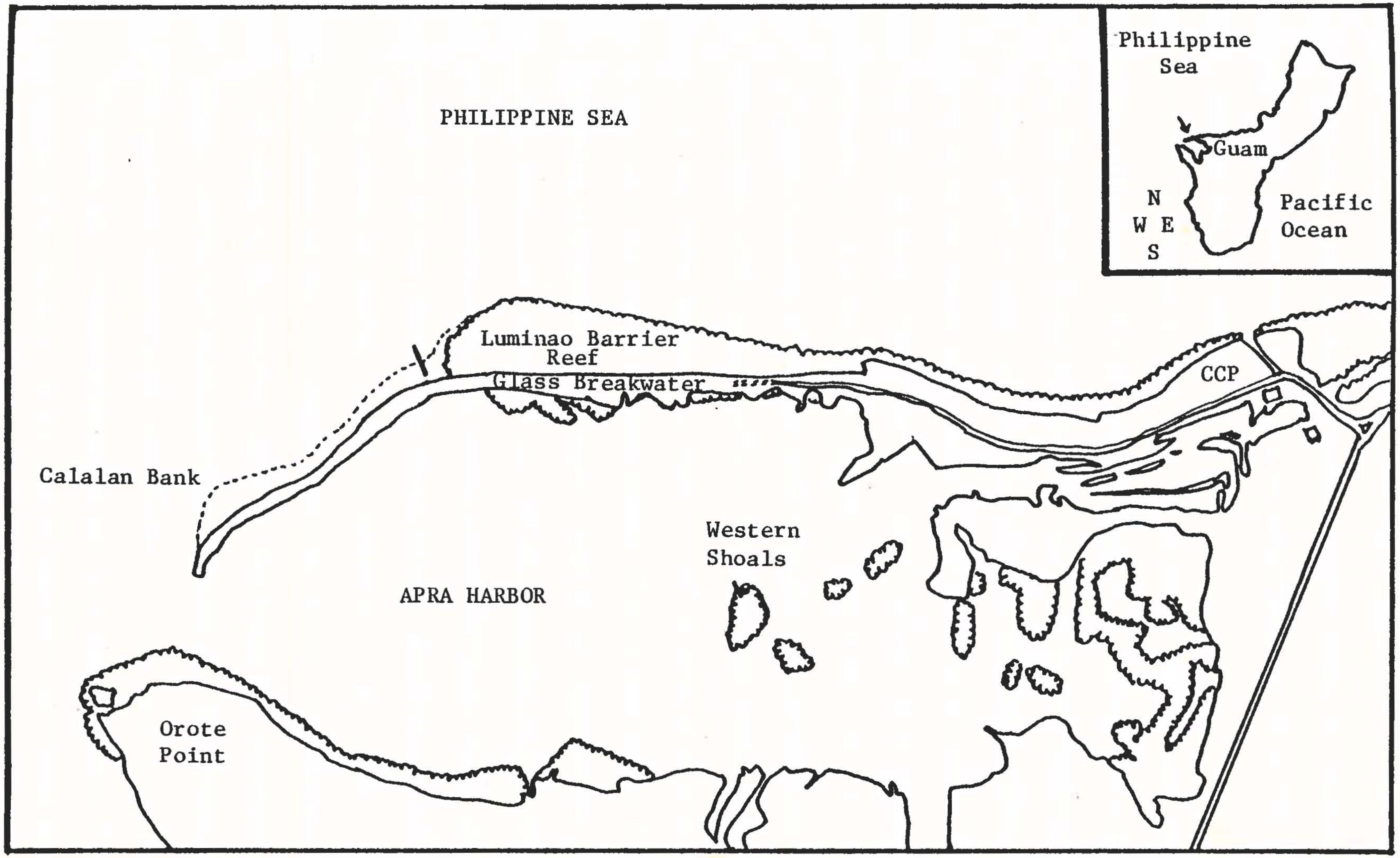


Fig. 1. Map of study sites at Luminao Barrier Reef and Western Shoals, and the potential location of the Ocean Thermal Energy Conversion Power Plant adjacent to Cabras Island Power Plant (CCP).

terrace that supports an established coral community. At the 12-m depth, the outer edge of the submarine terrace drops off rapidly, forming a steep seaward slope that is interrupted at 60 m (197 ft) by a deeper submarine terrace.

Biological fouling of OTEC marine hardware could significantly reduce the efficiency of the heat exchange surfaces and the electrical yield of the system (Fetkovich et al., 1975; Jones and Ostrozynski, 1975; Corpe, 1979). Metz (1977) states that a bacterial slime layer of only 0.25 mm on boiler and condenser surfaces could reduce the plant's performance by 60%. The development of microbial films on surfaces exposed in a marine environment forms a substrate for attachment of larger fouling organisms such as algae and invertebrates (Jones and Ostrozynski, 1975; Corpe, 1979). The pipes and conduits used to distribute salt water in power plants provide a favorable substrate for biofouling. Fouling organisms reduce flow by decreasing dimensions and increasing frictional resistance (Woods Hole Oceanographic Institution, 1952; Sergy and Evans, 1975). If foulants are allowed to build up, the accumulated biomass may break loose and block valves and pumps, and constrict joints (Woods Hole Oceanographic Institution, 1952).

The problem of fouling necessitates a removal strategy to maintain peak performance of an OTEC system (Dexter, 1975). Biomass accumulation rates were used in the present study as the basis for recommendations on the placement depth for warm-water intake pipes and for an optimal cleaning interval during plant operation.

The study of fouling communities has traditionally been done on settling plates or panels. A variety of substrate materials have been used in the past such as wood, metals, asbestos, glass, concrete, and plastic (Visscher, 1928; Woods Hole Oceanographic Institution, 1952; Ingram, 1937; Edmondson and Ingram, 1939; Long, 1974; Hanson and Bell, 1976). The selection of substrate materials, plate sizes, and plate orientations was made to allow the data obtained to be comparable with work done in Hawaii and Panama. Plexiglass was selected for comparisons with studies of Birkeland (1977) and Neudecker (1978). PVC was used for comparisons with studies from Hawaii carried out by Long (1974) and Grovhoug (personal communication). Small (5 x 15 cm) horizontally oriented plates were used by Birkeland (1977) and Neudecker (1978). Large (15 x 15 cm) vertically oriented plates were used by Long (1974) and Grovhoug (personal communication).

The depths for placement of settling plates were selected for comparisons of results of fouling studies with those from Hawaii and Panama and to determine the differences in biomass accumulation with increasing depth. The changes in light attenuation with depth have been considered an important criterion for the development of benthic fouling communities. Hanson and Bell (1976) found that the placement depth of plates had a significant effect upon the rate of fouling as measured by changes in dry weight of removable material. They also found that distinct changes in patterns over depth gradients existed for species composition. Long (1974) found biomass accumulation to be greater at 15 m than at 30 m at his offshore sites. Neudecker (1978) found that the depth at which settling plates were placed was not important in determining the surface coverage; however, depth was a significant factor in determining biomass accumulation because of the effect of the availability of light for algal growth.

The duration of exposure of settling plates in a benthic environment should affect the biomass accumulation and community structure (Birkeland, 1977; Long, 1974). During the early periods of exposure, fouling is expected to increase as the substrate becomes occupied. The development of a stable climax stage has been shown in some studies, but not in others. Haderlie (1969) in Monterey Harbor, California, and Long (1974) at Oahu, Hawaii, found that great variability in community structure, numbers of species, and biomass accumulation existed from year to year. Seasonality in reproduction and settling of larvae of various species was observed by Hanson and Bell (1976) in Northern Puget Sound, Washington, and by Menon et al. (1977) in Magalore waters. Haderlie (1969) and Long (1974) reported similar assemblages regardless of the season of initial exposure.

An understanding of the differences between exposed and cryptic environments (Jackson, 1977), and the fouling organisms that inhabit these specific niches, is important for a total evaluation of the fouling community. In the present study, the plate surfaces were oriented in exposed (facing away from or on the exterior of the mounting block) and protected (facing towards or in the shaded cavity of the block) environments. These surface and plate orientations were compared to elucidate community differences in habitats exposed to and protected from the influences of water circulation, light, and predation.

Comparisons of rates of fouling accumulation were made between a barrier reef (Luminao Reef) and an enclosed lagoon (Western Shoals, Apra Harbor). A similar comparison was done by Long (1974) and Grovhoug (personal communication) at sites outside and inside Pearl Harbor and at Kaneohe Bay, Hawaii.

The determination of proportions of surface coverage by the various taxa allows for statements about the development and occupation of space by the constituents of early fouling communities. Combining the various components of the fouling community into major groups aids in the determination of the patterns of development. Diversity indices were used to evaluate the nature of the communities.

Dayton (1971) and Sutherland and Karlson (1977) found that storms and accompanying wave action, as well as adult mortality, caused, the sloughing off of organisms and created new patches of clear space for recruits. The grazing activities of herbivorous reef fishes freed small patches of bare space which caused changes in the patterns of community development (Vine, 1974; Birkeland, 1977; Brock, 1979). Grazing as a modifier of community development was quantified to explain patterns of change that are not inherently the result of undisturbed succession.

MATERIALS AND METHODS

Settling plates were cut from sheets of 0.32 cm (0.13 inch) plexiglass and PVC into rectangles measuring 5 x 15 cm (75 cm^2) and into squares measuring 15 x 15 cm (225 cm^2). Plates were drilled through the center and mounted with brass bolts to drilled concrete blocks. Plates were uniformly roughened with coarse sandpaper, ten strokes per length and width (Birkeland, 1977). Each plate was numbered with India Ink and covered with a drop of Krazy Glue to prevent removal of the number by scraping. Plates were oven dried at 90°C (194°F) for 24 hours, allowed to reach ambient air temperature in a desiccator for 12 hours, and weighed to the nearest 0.0001 gram.

Plexiglass and PVC plates were used because their uniformly roughened surface varied less than a natural substrate and their size and shape facilitated easy handling in the field and in the laboratory (Birkeland, 1977). Flat plates were used instead of rounded pipes because of the manageability under a stereomicroscope.

To each block were bolted two small plexiglass and two small PVC plates in horizontal and vertical positions; therefore, two blocks made a replicate batch of four plates of similar substrate and orientation for statistical analysis. This arrangement was utilized so that at least half of the data set would be retrievable if a block was lost. Two large plates, one of each material, were mounted in both horizontal and vertical positions on an individual block; thus four blocks carried a replicate batch. The shaded-inside portion of the concrete block was also utilized to mount small plexiglass plates, two per block oriented horizontally.

The plates were mounted 6 cm off the concrete block surface with 8 cm brass bolts and PVC spacer pipes. With this arrangement, exposed and protected surfaces (facing away or towards the block, respectively) provided two types of environments for the settling of fouling organisms. Nuts and washers held the entire assembly together in such a way that plates could be removed and replaced underwater at later dates.

The possibility of minerals leaching out of a new concrete block and affecting early recruitment or settling processes was examined for 37 days of exposure. A new concrete block with four horizontal, four vertical, and two shaded plexiglass plates was placed beside two blocks at 12 m at Luminao Reef that had been submerged a number of months earlier and had therefore "cured". These replacement blocks were treated separately; one was brushed with a wire brush to remove most of the existing fouling and the other was unbrushed. By 37 days, the horizontally-placed plates had accumulated more than twice as many fouling organisms as did the vertical plates (Table 1). When the biomass accumulation on horizontal plates were compared for block treatments, newly submerged blocks had the highest amount of plate fouling, followed by unbrushed and brushed blocks (Table 1). The use of uncured concrete blocks was not found to inhibit early fouling organisms for settling.

Plexiglass and PVC plates were placed at Luminao Reef and recovered according to the schedule in Appendix A. Blocks were placed with the use of scuba at four depths 6, 12, 24, and 37 cm (20, 40, 80, and 120 ft) at Luminao Reef. Because of the possibility of loss or damage

Table 1. Effect of block condition (brushed, unbrushed, or new) on mean biomass accumulation of early 37-day fouling communities. Small plexiglass replacement plates were placed in horizontal and vertical orientations from 22V79 to 28V79. Mean dry weights and their standard deviations are presented.

Block Treatment	Plexiglass Horizontal	Plexiglass Vertical	Plexiglass Shade
Brushed	.1876 ± .0246	.0972 ± .0384	.0560 ± .0092
Unbrushed	.2538 ± .0409	.1065 ± .0389	.0646 ± .0091
New	.2970 ± .0700	.1056 ± .0347	.0306 ± .0014
Mean Biomass	.2461 ± .0551	.1031 ± .0051	.0504 ± .0177

by heavy surge, the blocks at 6 and 12 m were tied down to the reef with steel cable and plastic coated copper wire.

Small (5 x 15 cm) plates oriented horizontally and vertically, were exposed for 37-, 77-, 100-, and 180-day durations in order to obtain data from relatively short- and long-term sets. An exposure duration of seventy-seven days was chosen as the baseline time period in order to make comparisons with Birkeland's (1977) fouling studies in Panama. Small plexiglass shaded plates were mounted horizontally in the cavity of concerete blocks for 37 days, 37-day replacements, and 100 days. Small plexiglass replacement plates were attached to the originally-placed blocks in horizontal and vertical orientations for 37- and 77-day durations at 6 and 12 m. After the original set from February to April, only one 37-day replacement batch was placed at 6 m from April to May 1979 because of the rough wave action and associated recovery difficulties. At 12 m the 37-day duration was originally tested from February to April with replacement batches from April to May and from May to June 1979. The 77-day duration was tested originally from December 1978 to March 1979 with replacement batches set from March to May 1979 at both 6 and 12 m. Large (15 x 15 cm) plexiglass and PVC plates were exposed for 77 days (December to March 1979), 77-day replacements (March to May 1979), and 180 days in horizontal and vertical orientations.

A series of 30 small plexiglass plates were placed at 6, 12, and 24 m at Western Shoals, inside Apra Harbor, for 77 days in horizontal and vertical orientations. These settling plates allowed for comparisoms of biomass accumulation between an enclosed lagoon and a barrier reef.

After the duration of exposure, plates were carefully removed underwater, placed in plastic bags with seawater, and returned to the laboratory. Each plate was fixed in 5% buffered formalin and placed in storage jars for later microscopic examination. Plates were immersed in a tray with freshwater and examined under a binocular dissecting microscope at a magnification of 12 power. Surface coverage was recorded by counting the frequency of bare substrate or organisms under 12 points along an ocular micrometer. Organisms were divided into 29 categories which were later combined into five groupings: bare space, crustose coralline algae, filamentous and mat-type algae, animals (invertebrates and fish eggs) and sediments. Eight fields of vision were tallied both on the exposed and protected surface of each small plate, resulting in 96 sample points per surface. Large plates were divided into 12 fields of vision, four in the central and eight in the peripheral regions of the plate, for a total of 144 sample points. The surface coverage of the four plates in a replicate batch were averaged. The proportion of surface coverage of the five groupings were compared for the four depths and exposure durations and tested for the effect of substrate type, surface exposure, and plate orientation.

Calculations of diversities of fouling communities that covered exposed and protected surfaces were done with a computer. A Fortran IV program was written, utilizing the Shannon-Weiner diversity index formula presented in Lloyd et al. (1968) and Pielou (1975): $H' = -\Sigma p_i \log p_i$. The p_i is the arcsin-transformed proportion of surface coverage of each of the 29 taxa tallied under the microscope.

The grazing activities of herbivorous reef fishes are important in determining the community structure of fouling organisms on settling plates (Birkeland, 1977; Vine, 1974; Neudecker, 1978; Brock, 1979). The effect of such grazing was quantified by counting the number of distinct tooth scrapes found on the settling plates. Tooth scrapes make small patches available for the recruitment of fouling organisms.

After the microscopic work was completed, each plate was rinsed in freshwater to remove salt crystals. The plates were oven dried at 90°C for 48 hours on preweighed filter paper, desiccated for 12 hours, and weighed to the nearest 0.0001 gram.

RESULTS

Biomass Accumulation

Biomass accumulation at Luminao Reef decreased with depth (Tables 2 to 7; Figs. 2 to 5) regardless of substrate type, surface exposure, or plate orientation for all exposure durations. At Western Shoals, the greatest biomass occurred for the 77-day exposure period on the 12-m horizontal and vertical plates (Table 6).

Biomass accumulation increased with longer exposure periods on plexiglass and PVC plates of both small and large sizes. The slope of the line of biomass accumulation, plotted for each depth, was calculated by dividing the increase in biomass (Y axis) by the increase in time (X axis). For small plates at 6 m the slopes from 37 to 100 days and from 100 to 180 days were averaged to take into account the increased rate of biomass accumulation from 100 to 180 days (Fig. 2). The slopes for the remaining depths of 12, 24, and 37 m were determined from 37 to 180 days. The slopes of biomass accumulation for large plates were determined from 77 to 180 days. The shallower depths were found to have a faster rate of biomass accumulation than deeper depths (Table 8) for both small and large plates.

Substrate type (plexiglass vs PVC) and plate orientation (horizontal vs vertical) were not found to have a statistically significant effect on the rate of biomass accumulation on small plates (Table 9). For large plates, PVC accumulated fouling organisms faster than did

Table 2. Mean biomass accumulation of fouling communities on small (5 x 15 cm) plexiglass and PVC settling plates from Luminao Reef. Dry weights (in grams) and their standard deviations are presented for plates with horizontal and vertical orientations.

Duration (Days)	Depth	Plexiglass		PVC	
		Horizontal	Vertical	Horizontal	Vertical
37	6 m	.0129 ± .0141	.0171 ± .0000	.1506 ± .0020	.0925 ± .0000
	12 m	.1483 ± .0208	.1036 ± .0533	.2004 ± .0326	.1026 ± .0201
	24 m	.0392 ± .0281	.0372 ± .0215	.0585 ± .0121	.0233 ± .0001
	37 m	.0324 ± .0085	.0340 ± .0164	.0443 ± .0107	.0284 ± .0110
77	6 m	.6702 ± .1872	.7199 ± .2160	.6377 ± .0506	.4655 ± .1297
	12 m	.4392 ± .0472	.3961 ± .0424	.3144 ± .0381	.2936 ± .0308
	24 m	.4152 ± .0852	.3667 ± .0305	.3074 ± .0292	.2103 ± .0152
	37 m	.4821 ± .0434	.3499 ± .0179	.4353 ± .0678	.2396 ± .0176
100	6 m	1.3701 ± .4573	1.2613 ± .3437	1.3033 ± .4555	.9639 ± .1870
	12 m	.6419 ± .1973	.6501 ± .1575	.4587 ± .0789	.5341 ± .1356
	24 m	.4907 ± .0915	.3062 ± .0547	.6383 ± .0697	.3963 ± .1226
	37 m	.4704 ± .1196	.3637 ± .0584	.5789 ± .0511	.4523 ± .0845
180	6 m	4.3999 ± .2228	2.8207 ± .5461	5.4134 ±1.3078	2.4201 ± .5360
	12 m	1.9811 ± .8596	1.8175 ± .6655	2.0936 ± .7060	1.5469 ± .9844
	24 m	1.4297 ± .3946	1.7270 ± .1828	1.1781 ± .1524	1.3668 ± .1796
	37 m	.7745 ± .1267	.7218 ± .2020	.9900 ± .1698	.6477 ± .1071

Table 3. Mean biomass accumulation of fouling communities on small (5 x 15 cm) plexiglass replacement settling plates from Luminao Reef. Dry weights (in grams) and their standard deviations are presented for horizontal and vertical orientations.

Duration (Days)	Depth	Plexiglass	
		Horizontal	Vertical
37	6 m	.4273 ± .1781	.2955 ± .0976
		.3204 ± .0344	.2570 ± .0838
	12 m	.1692 ± .0334	.0676 ± .0285
		.2197 ± .0309	.1402 ± .0180
77	6 m	.9759 ± .2254	1.3794 ± .4149
		2.8818 ± .3634	1.3635 ± .0858
	12 m	.5657 ± .1481	.9155 ± .2928
		.4562 ± .1165	.5477 ± .1122

Table 4. Mean biomass accumulation of fouling communities on small (5 x 15 cm) plexiglass (shaded) settling plates from Luminao Reef. Dry weights (in grams) and their standard deviations are presented for horizontally oriented plates mounted in the shaded inside portion of the concrete blocks.

Duration (Days)	Depth	Plexiglass - Shaded
		Horizontal
37	6 m	.0683 ± .0503
	12 m	.0119 ± .0083
	24 m	.0326 ± .0173
	37 m	.0158 ± .0075
37 (replacement)	6 m	.0896 ± .0334
	12 m	.1527 ± .0040
	24 m	.0792 ± .0032
	37 m	.0340 ± .0433
100	6 m	.8551 ± .1316
	12 m	.4629 ± .0286
	24 m	.1885 ± .0386
	37 m	.3003 ± .0689

Table 5. Mean biomass accumulation of fouling communities on large (15 x 15 cm) plexiglass and PVC settling plates from Luminao Reef. Dry weights (in grams) and standard deviations are presented for horizontal and vertical orientations.

Duration (Days)	Depth	Plexiglass		PVC	
		Horizontal	Vertical	Horizontal	Vertical
77	6 m	1.8204 ± .2559	1.3567 ± .1622	2.6068 ± .3849	1.1239 ± .3129
	12 m	1.3228 ± .2176	.7904 ± .2931	1.0325 ± .2804	.8593 ± .1216
	24 m	1.2352 ± .4698	.8750 ± .2771	1.1651 ± .2921	.6832 ± .0793
	37 m	.8920 ± .0969	.4826 ± .1250	1.0150 ± .2586	.5058 ± .0372
77 (replacement)	6 m	4.9765 ±2.0608	2.9195 ± .2782	5.7317 ±2.3165	2.5760 ± .3747
	12 m	1.5280 ± .2320	1.3117 ± .3822	1.2586 ± .6133	1.4081 ± .6148
180	6 m	7.5616 ±2.8336	5.5168 ± .8682	8.697 ±5.4561	5.9710 ±2.4258
	12 m	4.1918 ± .9661	4.1330 ± .8927	5.3136 ±1.9939	3.8565 ±1.7654
	24 m	3.9558 ± .7760	3.2147 ± .4702	4.1069 ± .7226	3.1461 ±1.4025
	37 m	2.5480 ± .4209	1.9996 ± .1537	3.6765 ± .4606	2.0156 ± .2792

Table 6. Mean biomass accumulation of fouling communities on small (5 x 15 cm) plexiglass settling plates from Western Shoals, Apra Harbor. Dry weights (in grams) and standard deviations are presented for horizontal and vertical orientations.

Duration (Days)	Depth	Plexiglass	
		Horizontal	Vertical
77	6 m	1.2162 ± .2443	.2791 ± .0269
	12 m	1.5040 ± .6129	.5439 ± .2336
	24 m	1.3367 ± .4018	.3647 ± .1026

Table 7. Comparison of biomass accumulation on replicate plates at 6, 12, 24, and 37 m for the various exposure durations. Analysis of variance was used to test differences between depths for horizontally oriented, small and large, plexiglass and PVC plates.

Comparison	Sample Size (n)	F_s Value	Significance Level
Small plates			
Plexiglass, Horizontal			
37 days	13	32.75	$p < .001$
77 days	16	4.62	$p < .05$
100 days	16	10.66	$p < .005$
180 days	15	34.56	$p < .001$
PVC, Horizontal			
37 days	14	70.25	$p < .001$
77 days	16	39.67	$p < .001$
100 days	16	10.43	$p < .005$
180 days	16	29.85	$p < .001$
Large plates			
Plexiglass, Horizontal			
77 days	16	6.85	$p < .01$
180 days	16	7.42	$p < .005$
PVC, Horizontal			
77 days	15	52.07	$p < .007$
180 days	16	2.47	ns

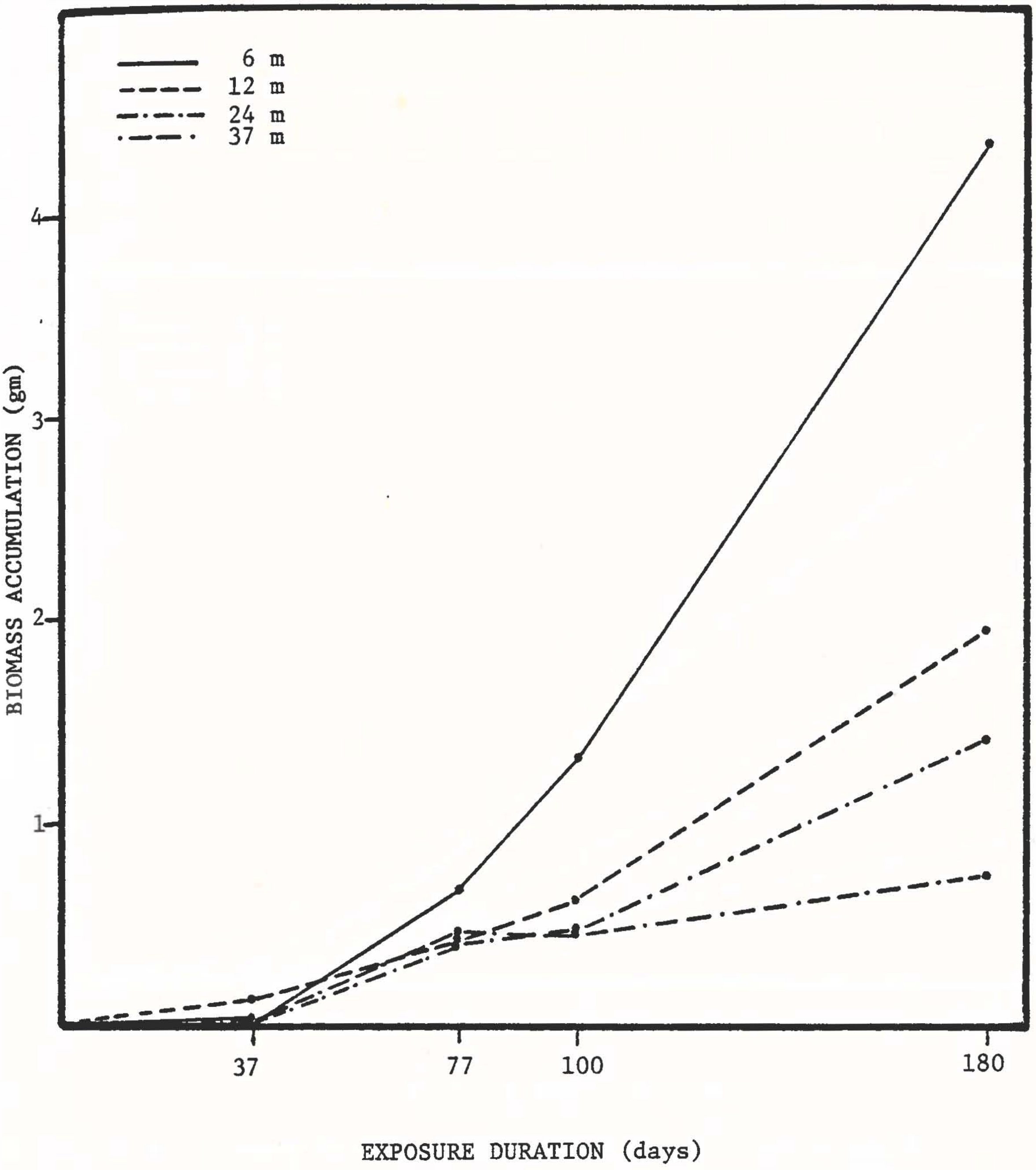


Fig. 2. Changes in biomass accumulation with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 6, 12, 24, and 37 m at Luminao Reef.

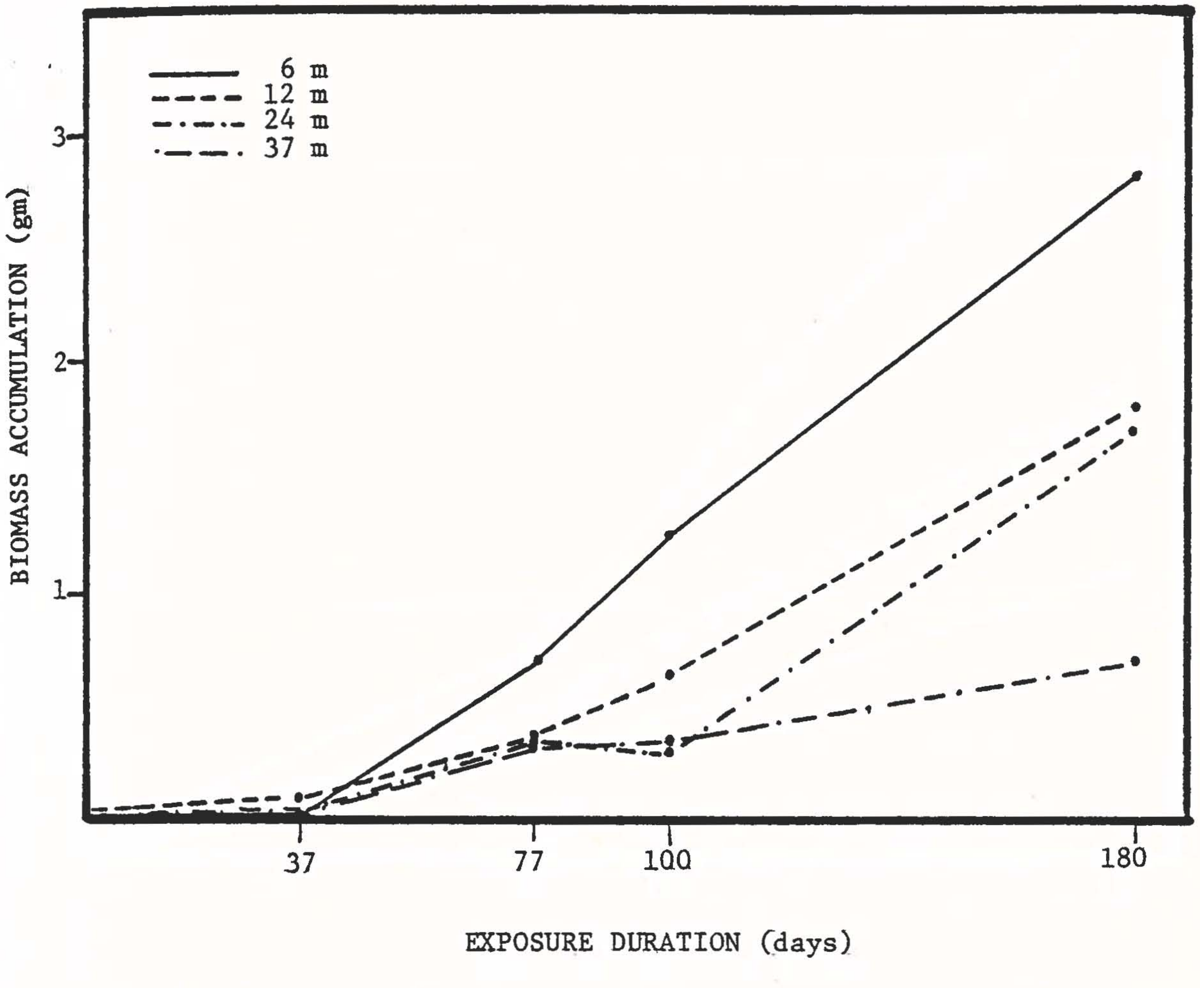


Fig. 3. Changes in biomass accumulation with time on small (5 x 15 cm) plexiglass plates oriented vertically at 6, 12, 24, and 37 m at Luminao Reef.

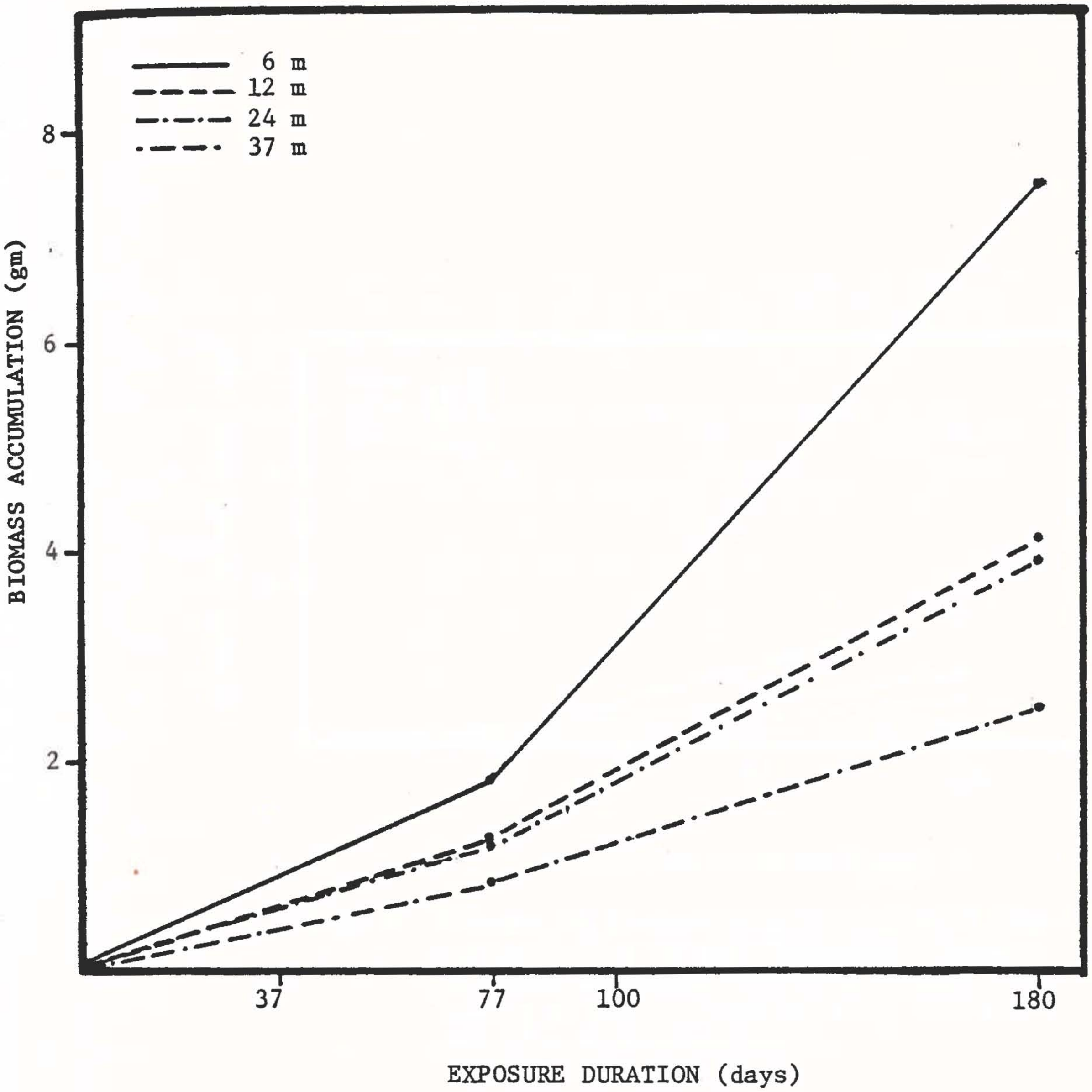
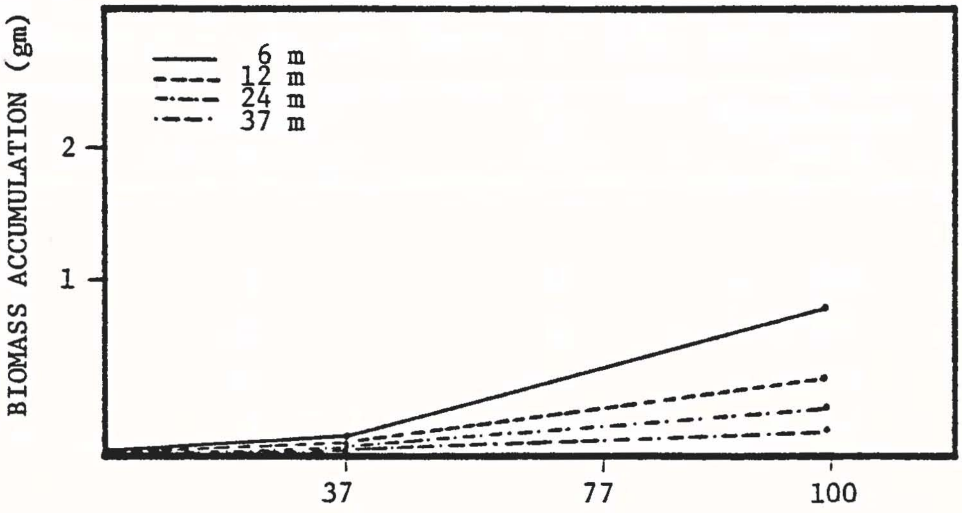


Fig. 4. Changes in biomass accumulation with time on large (15 x 15 cm) plexiglass plates oriented horizontally at 6, 12, 24, and 37 m at Luminao Reef.



EXPOSURE DURATION (days)

Fig. 5. Changes in biomass accumulation with time on small (5 x 15 cm) plexiglass plates oriented horizontally in the shaded cavity of concrete blocks at 6, 12, 24, and 37 m at Luminao Reef.

Table 8. Effect of depth on the slope of mean biomass accumulation with time. The Mann-Whitney U-test was used while combining data for plexiglass and PVC plates oriented horizontally and vertically (n = 4 for each sample, n = 8 for each test).

Comparison	Depth with Greater Slope	U_s Value	Significance Level
Small plates			
6 m vs 12 m	6	16	$p < .025$
12 m vs 24 m	12	15	$p < .05$
24 m vs 37 m	24	16	$p < .025$
6 m vs 37 m	6	16	$p < .025$
Large plates			
6 m vs 12 m	6	15	$p < .05$
12 m vs 24 m	12	15	$p < .05$
24 m vs 37 m	24	14	$.10 > p < .05$
6 m vs 37 m	6	16	$p < .025$

Table 9. Effect of substrate type and plate orientation on the slope of mean biomass accumulation with time. The Wilcoxon paired-comparisons signed ranks test was used while combining data from the four depths.

Comparison	Greater Slope	Sample Size (n)	T_s Value	Significance Level
Small plates				
Plexiglass vs PVC	Plexiglass	8	11	ns
Horizontal vs Vertical	Horizontal	8	7	ns
Large plates				
Plexiglass vs PVC	PVC	7	3	$p < .05$
Horizontal vs Vertical	Horizontal	8	3	$p < .025$

plexiglass; horizontally-oriented plates accumulated more biomass than did vertically-oriented plates (Table 9).

When mean dry weights were compared for the effect of substrate type, the results varied (Table 10). Small plexiglass plates accumulated more biomass than did small PVC plates while large PVC plates tended to accumulate more biomass than did large plexiglass plates. For both small- and large-sized settling plates, PVC accumulated more biomass in the horizontal orientation than did plexiglass, and plexiglass accumulated more fouling biomass in the vertical orientation than did PVC. Regardless of size, horizontal plates accumulated more biomass than did vertical plates (Table 10).

The dry weights of fouling organisms on replacement plates at Luminao Reef were plotted in Figures 6 to 8 to see if duration of exposure and changes in submergence dates affected biomass accumulation. The 6-m replacement plates after 37 days of exposure weighed four times more than did the originally set plates. The weights of biomass accumulation on 12-m replacement plates fluctuated around .2 grams (Fig. 6). For the 77-day durations, small plates at 6 and 12 m and the large plates at 12 m had moderate increases in biomass accumulation (Fig. 7). Large plates at 6 m doubled in fouling accumulation weight regardless of substrate type or plate orientation. The PVC plates had the higher rate of increase in fouling and greater biomass accumulation (Fig. 8).

Plexiglass settling plates that were oriented horizontally in the shaded cavity of concrete blocks accumulated less biomass than did the exposed horizontal plates. A Wilcoxon paired-comparison signed ranks test of the mean biomass values (Tables 2 and 4) demonstrated

Table 10. Effect of substrate type and plate orientation on biomass accumulation. The Wilcoxon paired-comparisons signed ranks test was used while combining data from the various depths and durations.

Comparison	Greater Biomass	Sample Size (n)	T_s Value	Significance Level
Small plates				
Plexiglass vs PVC	Plexiglass	32	197	ns
Horizontal	PVC	16	54	ns
Vertical	Plexiglass	16	18	$p < .001$
Horizontal vs Vertical	Horizontal	32	84	$p < .001$
Large plates				
Plexiglass vs PVC	PVC	16	46	ns
Horizontal	PVC	8	5	$p < .025$
Vertical	Plexiglass	8	15	ns
Horizontal vs Vertical	Horizontal	16	0	$p < .001$

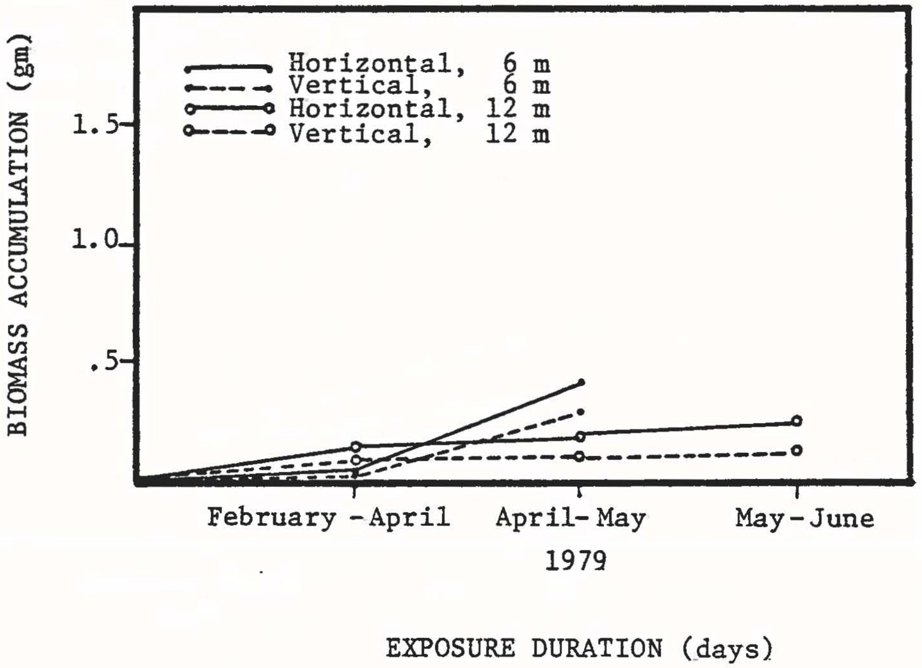


Fig. 6. Changes in biomass accumulation between original and replacement, 37 day, small (5 x 15 cm) plexiglass plates oriented horizontally and vertically at Luminao Reef.

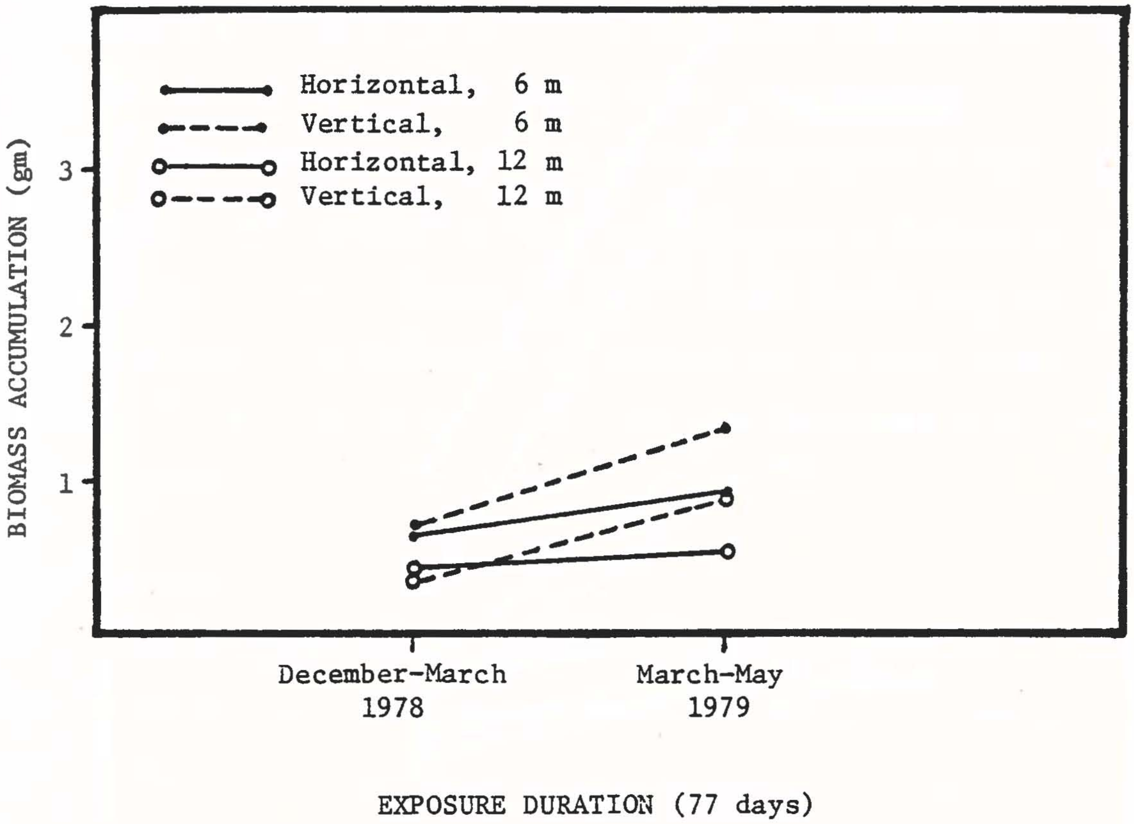
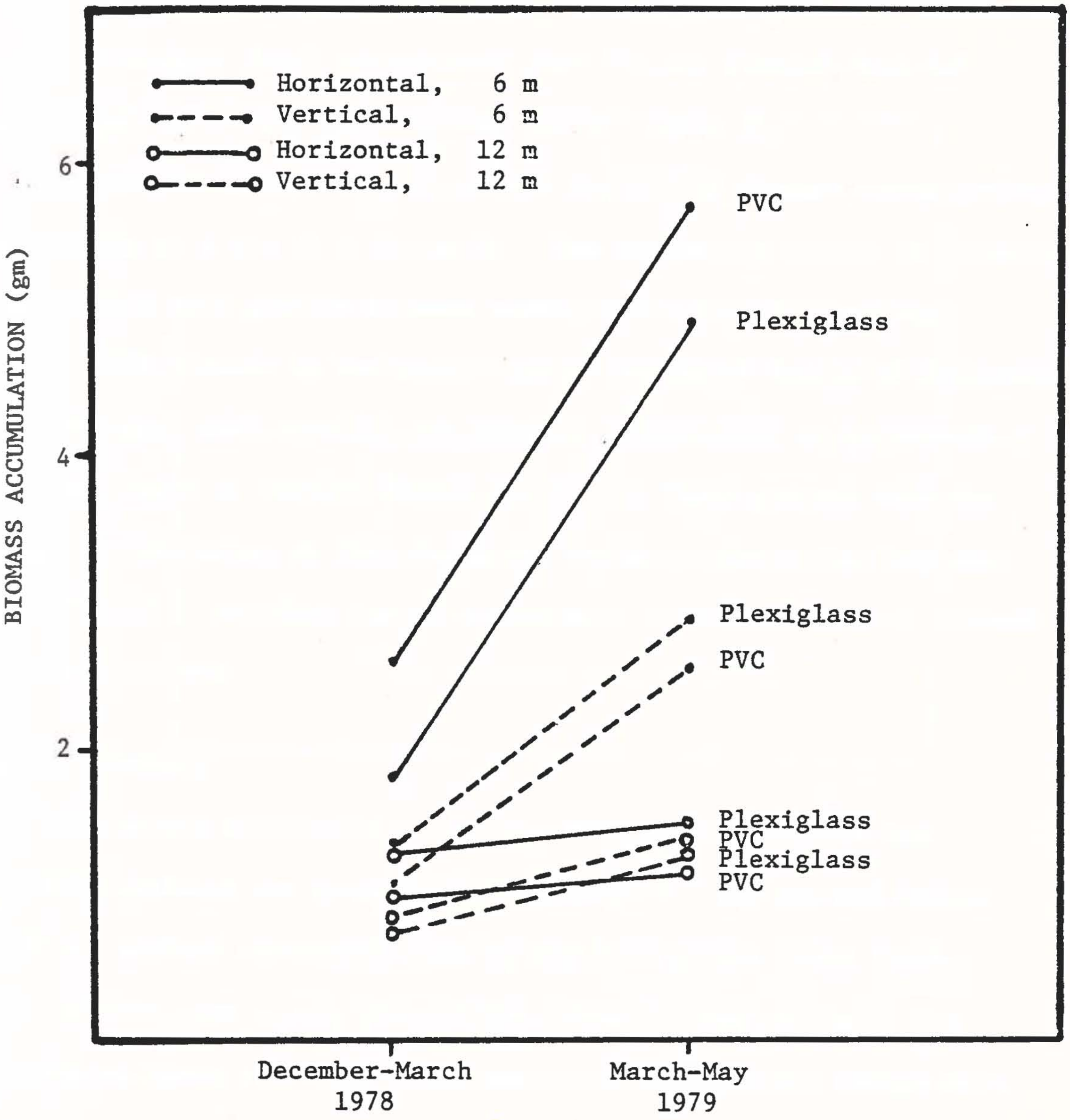


Fig. 7. Changes in biomass accumulation between original and replacement, 77 day, small (5 x 15 cm) plexiglass plates oriented horizontally and vertically at Luminao Reef.



EXPOSURE DURATION (77 days)

Fig. 8. Changes in biomass accumulation between original and replacement, 77 day, large (15 x 15 cm) plexiglass and PVC plates oriented horizontally and vertically at Luminao Reef.

that shaded plates accumulated significantly less biomass ($p < .025$, T_s=3, n=8) than did exposed plates for 37 and 100 days. Shaded plates that were exposed for 37 days on new, brushed and unbrushed blocks at Luminao Reef, accumulated less fouling biomass than did the exposed horizontal and vertical plates (Table 1).

At Western Shoals, plates at 12 m had higher biomass accumulation than plates at 6 and 24 m (Table 6). The horizontal plates at Western Shoals had a much greater biomass accumulation than did vertical plates. The biomass on horizontal plates consisted mostly of sediments and bivalves. Additionally, the biomass accumulation on horizontally oriented plates at Western Shoals was 2 to 3 times greater than the biomass accumulation on horizontal and vertical plates from Luminao Reef (Fig. 9). Vertical plates accumulated similar amounts of biomass at both locations.

Surface Coverage

The average proportion of surface coverage for exposed and protected surfaces are presented in Appendix B. The exposed versus protected surface coverage values of the five groups (bare space, crustose coralline algae, other algae, animals, and sediment) are compared in Table 11. Bare space exhibited inconsistent trends with respect to distribution on the various surfaces and orientations. Horizontally-oriented plates tended to have more bare space on protected surfaces. Vertical plates had more unoccupied space on exposed surfaces. Crustose corallines were more prevalent on exposed surfaces on horizontal plates. Crustose coralline algae on vertical plates were predominantly on protected surfaces. For both horizontal and vertical orientations, other algae were more abundant on protected

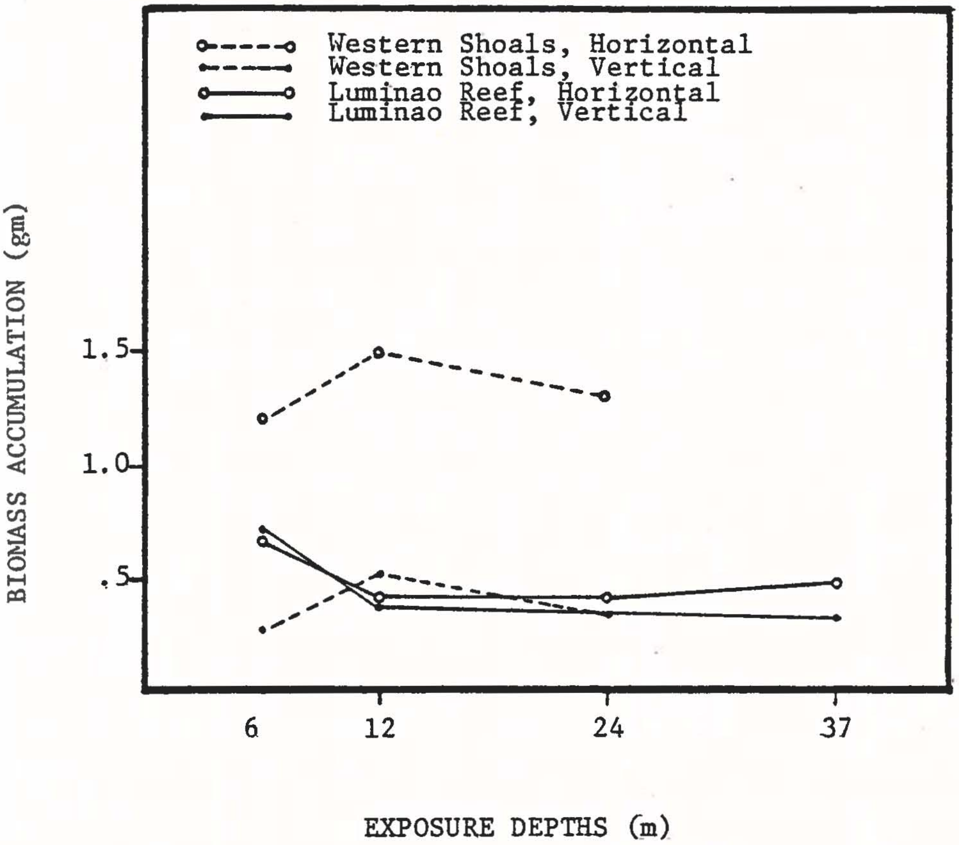


Fig. 9. Changes in biomass accumulation with depth on small (5 x 15 cm) plexiglass plates exposed for 77 days at Western Shoals (inside Apra Harbor) and Luminao Reef.

Table 11. Comparison of the proportion of surface coverage of major fouling groups between exposed and protected surfaces. The Wilcoxon paired-comparisons signed ranks test was used while combining data from 6, 12, 24 and 37 m and 37-, 77-, 100-, and 180-day durations for small plates and 77- and 180-day durations for large plates.

	EXPOSED VERSUS PROTECTED							
	Plexiglass Horizontal		PVC Horizontal		Plexiglass Vertical		PVC Vertical	
Comparison	Small	Large	Small	Large	Small	Large	Small	Large
Bare Space								
Greatest Surface Coverage	exposed	protected	exposed	protected	exposed	protected	exposed	protected
Sample Size	16	9	16	7	16	8	15	8
T_s Value	43	18	49	3	12	0	55.5	14
Significance Level	ns	ns	ns	$p < .05$	$p < .005$	$p < .005$	ns	ns
Crustose Coralline Algae								
Greatest Surface Coverage	exposed	exposed	exposed	exposed	protected	protected	protected	protected
Sample Size	16	8	16	8	16	8	14	8
T_s Value	14	6	49	9	36.5	5	24	12
Significance Level	ns*	$p < .05$	ns	ns	ns	$p < .05$	$p < .05$	ns
Algae								
Greatest Surface Coverage	protected	protected	exposed	exposed	protected	protected	exposed	exposed
Sample Size	16	8	16	8	16	8	16	8
T_s Value	27	10	8	0	39	15	37	3
Significance Level	$p < .025$	ns	$p < .005$	$p < .005$	ns	ns	ns*	$p < .025$

Table 11 (Continued).

	EXPOSED VERSUS PROTECTED							
	Plexiglass Horizontal		PVC Horizontal		Plexiglass Vertical		PVC Vertical	
Comparison	Small	Large	Small	Large	Small	Large	Small	Large
Animals								
Greatest Surface Coverage	protected	protected	protected	protected	protected	protected	protected	protected
Sample Size	15	8	16	8	15	8	16	8
T_s Value	26	11	6	0	20	16	40.5	0
Significance Level	$p < .025$	ns	$p < .005$	$p < .005$	$p < .01$	ns	ns	$p < .005$
Sediment								
Greatest Surface Coverage	exposed	exposed	exposed	exposed	equal	protected	protected	No sediment
Sample Size	9	4	10	1	2	1	4	0
T_s Value	0	0	3.5	0	1	0	0	0
Significance Level	$p < .005$	ns	$p < .005$	ns	ns	ns	ns	0

[*] Almost significant at $p < .05$.

than exposed surfaces of plexiglass plates, and more abundant on exposed surfaces of PVC plates than on protected surfaces. Animals occurred most often on the protected surfaces regardless of the substrate type or orientation. Sediment occurred on exposed surfaces of horizontally oriented settling plates (Table 11).

The proportion of bare space on settling plates was found to vary significantly with exposure duration. Greater amounts of bare space occurred at 37 days and the proportion decreased progressively with increased exposure duration (Table 12). The surface coverage of crustose coralline algae varied significantly with time. Populations increased slightly during the initial 37 days, increased rapidly from 37 to 77 days, decreased slightly from 77 to 100 days, and increased again from 100 to 180 days. The proportion of surface coverage of filamentous, mat, and patch algae varied with time. Algal coverage increased quickly at 37 days, decreased at 77 days, increased until 100 days and dropped again at 180 days. The proportion of animal coverage exhibited the opposite trend as algae in that the populations increased from 37 to 77 days, decreased from 77 to 100 days, and increased from 100 to 180 days (Figs. 10 to 13).

Community Diversity

Shannon-Weiner diversity indices are presented in Tables 13 and 14. Community diversity on settling plates increased as the exposure duration increased from 37 to 180 days (Table 15a). Diversity of fouling assemblages varied inconsistently with depth (Table 15b). When plates from 6 and 12 m were compared for 37 to 180 days, the plates from the shallower depth had more diverse fouling assemblages.

Table 12. The average proportion of surface coverage of the characteristic fouling groups for 37-, 77-, 100-, and 180-day exposure durations. The Friedman's method for randomized blocks was used to rank data from the exposed surfaces of small plates.

Comparison	Rank of Durations 37	77	100	180	Sample Size (a,b)	X^2 Value	Significance Level
Bare space	58	50	29	23	4, 16	13.28	$p < .005$
Crustose coralline algae	17.5	45.5	42	55	4, 16	28.71	$p < .005$
Algae	37	31	49	43	4, 16	6.75	$p < .1$
Animals	28	40	37.5	54.5	4, 16	12.84	$p < .005$

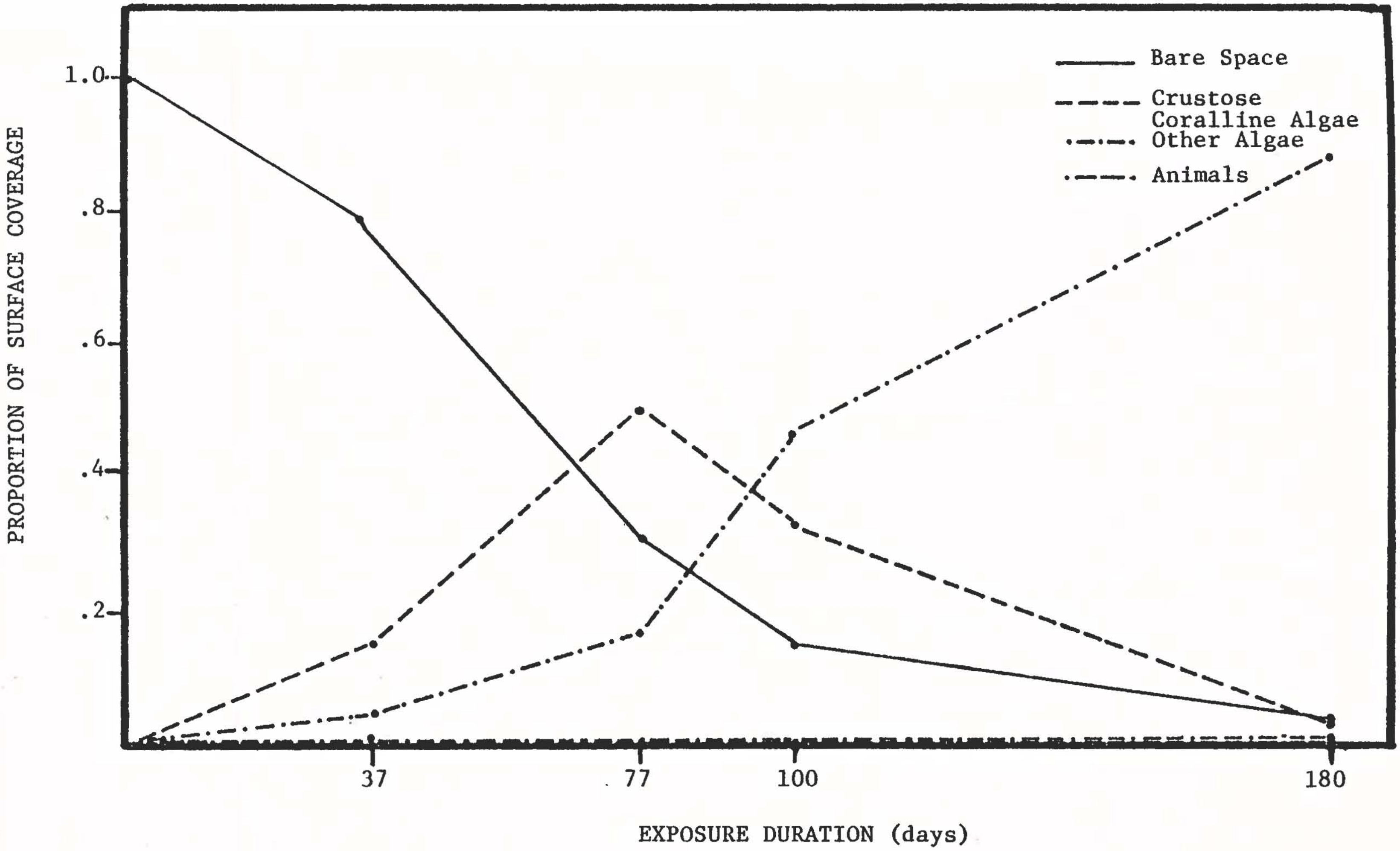


Fig. 10. Average proportion of surface coverage by major fouling groups on exposed surfaces with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 6 m, at Luminao Reef.

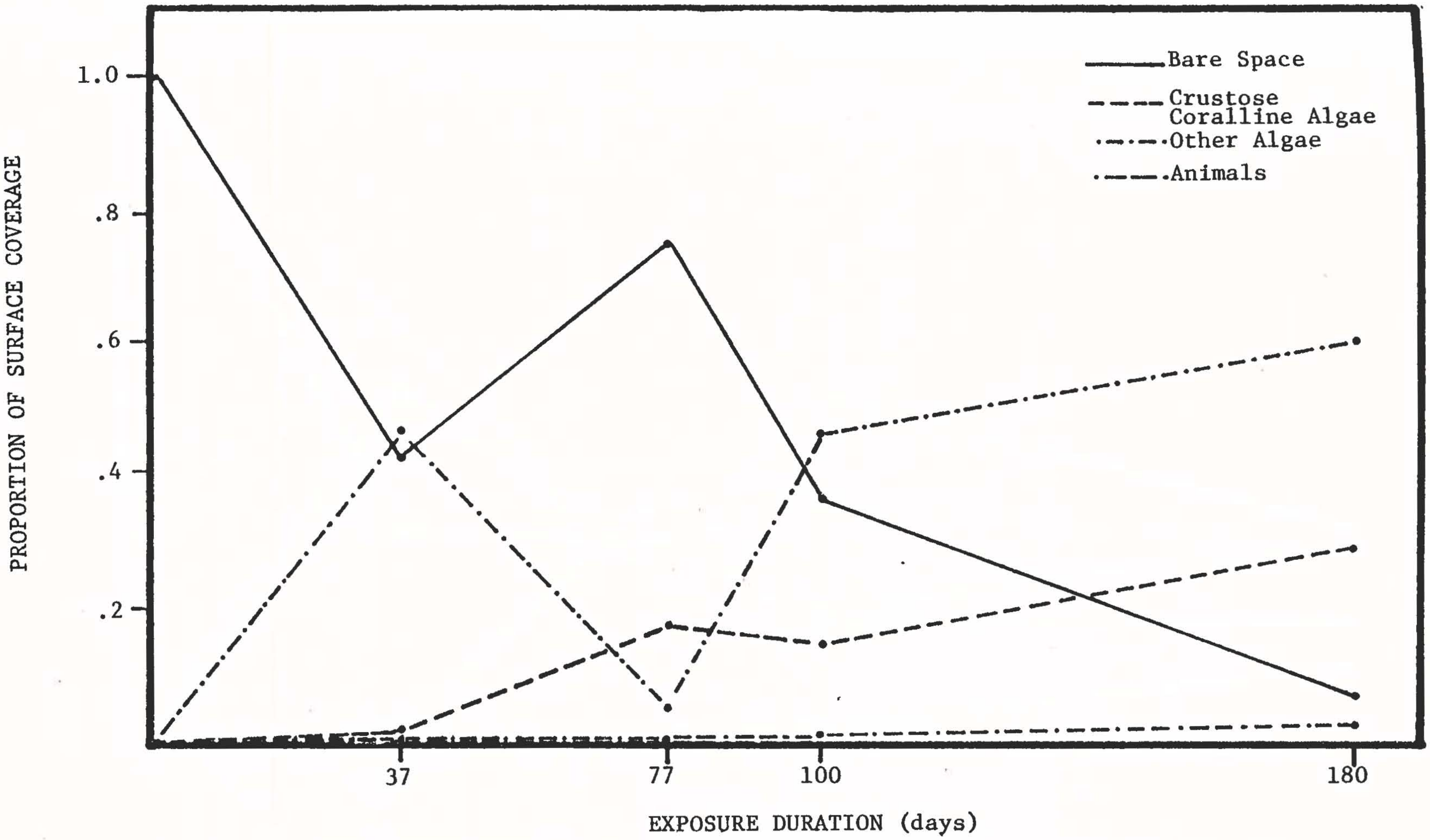


Fig. 11. Average proportion of surface coverage by major fouling on exposed surfaces with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 12 m, at Luminao Reef.

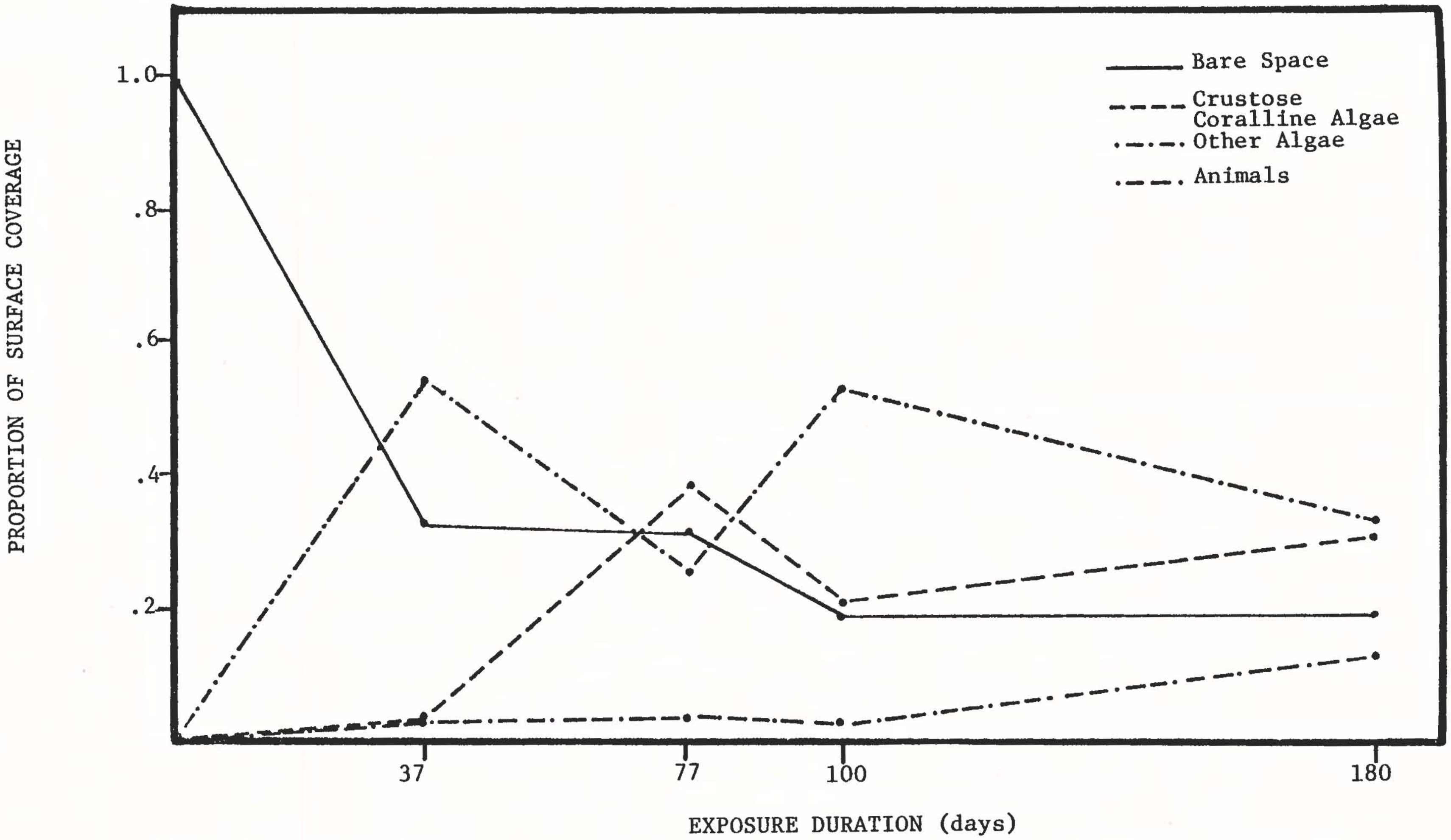


Fig. 12. Average proportion of surface coverage by major fouling groups on exposed surfaces with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 24 m, at Luminao Reef.

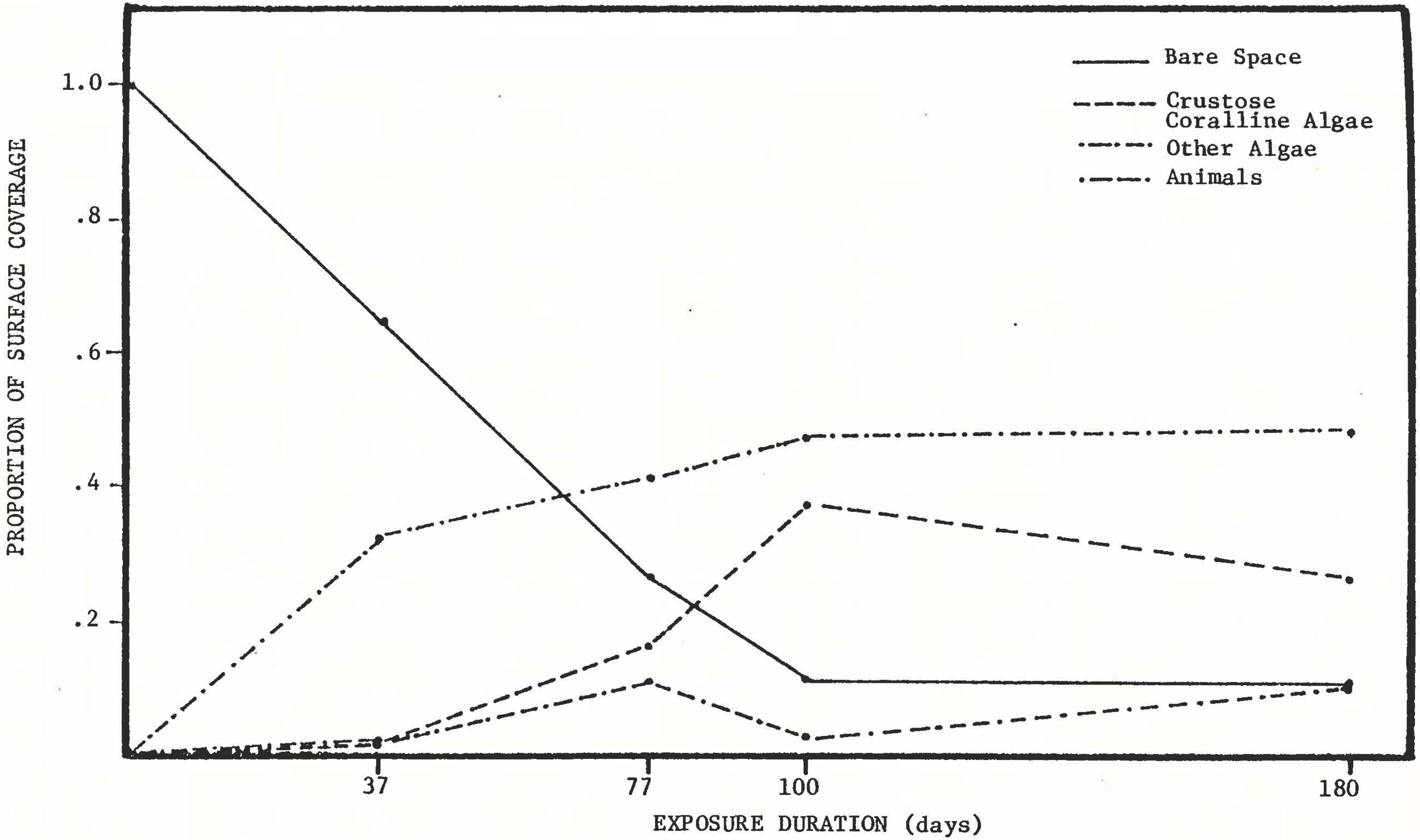


Fig. 13. Average proportion of surface coverage by major fouling groups on exposed surfaces with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 37 m, at Luminao Reef.

Table 13. Shannon-Weiner diversity indices for arcsin-transformed proportion of surface coverage on small (5 x 15 cm) plates. The diversity of fouling assemblages on plexiglass and PVC settling plates oriented horizontally and vertically are presented.

		Plexiglass				PVC			
	Depth	Horizontal		Vertical		Horizontal		Vertical	
Days	(m)	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected
37	6	.9932	1.9167	1.0107	1.9568	1.8741	2.4361	2.3632	2.5830
	12	2.2207	1.4905	1.8503	1.5357	1.5006	2.1185	1.6427	1.8697
	24	2.2910	1,3903	1.9142	1.5943	2.7230	1.7175	1.7873	1.9631
	37	1.6492	2.1436	1.2861	2.2266	2.0865	1.6577	1.9081	1.8709
77	6	1.7383	2.2186	2.1655	2.4006	2.4879	2.9563	2.4411	2.6712
	12	1.2098	1.9751	1.7896	2.1537	1.8582	1.8413	2.4586	1.7729
	24	2.1577	2.1656	2.4684	2.4116	2.5581	1.7605	2.5937	2.6963
	37	2.4874	2.6679	2.1306	2.2046	2.7845	2.3356	2.4239	1.8702
100	6	2.6650	2.5856	2.4166	2.5394	2.5528	2.7767	2.7946	2.9740
	12	2.2486	2.4679	2.3122	2.4112	2.1697	2.6213	2.6555	2.5019
	24	2.5281	2.5893	2.9107	2.7043	2.2624	2.6804	2.5356	2.9576
	37	2.3239	2.2436	2.0969	1.9996	2.4779	3.2298	1.8088	2.6665
180	6	1.5787	2.5936	2.9182	2.9233	1.8826	2.4166	2.6511	2.5706
	12	2.2815	2.9323	2.7537	3.2247	2.3189	2.8165	2.7326	3.1957
	24	2.5401	2.6637	2.7407	2.7733	2.5175	3.0296	2.5048	3.2252
	37	2.7202	2.8213	2.2611	2.2117	2.5262	2.7266	2.4222	2.8753

Table 14. Shannon-Weiner diversity indices for arcsin-transformed proportion of surface coverage on large (15 x 15 cm) plates. The diversity of fouling assemblages on plexiglass and PVC settling plates oriented horizontally and vertically are presented. Peripheral and central regions of the plates were measured separately.

		Plexiglass				PVC			
	Depth	Horizontal		Vertical		Horizontal		Vertical	
Days	(m)	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected
77 Peripheral	6	2.3194	2.2392	2.3889	2.7080	2.1626	2.7358	2.6735	2.7762
	12	2.1538	2.0801	2.4615	2.6904	2.5324	2.4954	2.4130	2.8747
	24	1.6347	2.2041	1.7126	1.8019	2.1421	1.7841	2.3771	2.3546
	37	1.9432	2.4198	2.1882	2.1284	2.6682	2.0906	1.8115	1.8401
77 Central	6	2.3898	2.3312	2.0509	2.6226	1.7944	2.8350	2.7031	2.4396
	12	1.9808	2.2188	2.1776	2.5806	2.1985	2.2161	2.2538	2.5773
	24	1.9026	1.9760	.9158	2.0670	2.2353	1.7311	1.8394	2.1361
	37	2.3000	1.8558	1.4597	1.6965	2.6225	1.1383	1.4720	1.6935
180 Peripheral	6	2.0721	2.9192	2.9605	2.8331	2.1407	3.0177	2.7002	2.7222
	12	2.1176	2.5818	2.5649	2.7824	2.2600	2.7866	2.6126	2.9966
	24	2.6060	3.1065	2.7067	2.5328	2.5966	3.0939	3.1163	3.0181
	37	2.7264	3.1075	2.1119	2.5261	2.7017	2.0814	2.1698	2.4140
180 Central	6	2.2479	3.1724	2.5011	2.5735	2.3110	3.2739	2.6377	2.4987
	12	1.8023	2.5514	1.7126	2.7911	1.7889	2.8544	2.4551	2.5758
	24	2.5060	2.3952	2.1722	2.2570	2.3405	2.8011	2.6970	2.8545
	37	2.4121	2.8237	1.3277	2.9629	2.4128	2.0529	2.0696	2.3735

Table 15. Comparison of Shannon-Weiner diversity indices for small settling plates at Luminao Reef. The effects of duration, depth, plexiglass versus PVC, exposed versus protected, and horizontal versus vertical are tested. The Wilcoxon paired-comparison signed ranks test results are given for diversity values from Tables 13 and 14.

Comparison	Greater Diversity Value	Sample Size (n)	T_s Value	Significance Level
a. Duration (Days)				
37 vs 77	77	32	80	$p < .001$
77 vs 100	100	32	96	$p < .001$
100 vs 180	180	32	152	$p < .025$
37 vs 180	180	32	15	$p < .001$
b. Depth				
6 m vs 12 m	6	32	177	ns
37 to 100 days	6	24	46	$p < .001$
180 days	12	8	2	$p < .01$
12 m vs 24 m	24	32	117	$p < .005$
24 m vs 37 m	24	32	177	ns
6 m vs 37 m	6	32	218	ns
c. Plexiglass vs PVC				
Horizontal, Exposed	PVC	16	35	$p < .05$
Vertical, Exposed	PVC	16	43	ns
Horizontal, Protected	PVC	16	47	ns
Vertical, Protected	PVC	16	36	$p < .0523$
d. Exposed vs Protected				
Horizontal	Protected	32	151	$p < .025$
Vertical	Protected	32	150	$p < .025$
e. Horizontal vs Vertical				
Plexiglass	Vertical	32	235	ns
PVC	Vertical	32	199	ns

The diversity values were greater at 6 m from 37 to 100 days, and greater at 12 m from 100 to 180 days. The fouling assemblages at 24 m were found to be more diverse than those at 12 m and 37 m. When the data from the two extreme depths, 6 and 37 m, were compared, the fouling assemblages at 6 m were more diverse. The highest community diversity occurred at 6 and 24 m.

From the combined results of the tests in Tables 15 and 16 it can be concluded that substrate type (plexiglass or PVC) does not significantly influence the diversity of organisms recruiting to settling plates. There was a tendency for PVC plates to have higher diversities than did plexiglass plates.

Visual inspection and statistical analyses of the plate surfaces indicated that exposed surfaces had more abundant algal coverage while protected surfaces had more invertebrates. Diversity values for both horizontal and vertical orientations on small plates indicated that protected surfaces were more diverse than were exposed surfaces (Table 15d).

Large plates were subdivided into two regions, central and peripheral, for determination of surface coverage and diversity. This was done to test if an "edge effect" exists in the patterns of settling of organisms. Since the protected surfaces on small plates were more diverse than were the exposed surfaces, it was useful to test the horizontal versus vertical protected surfaces for both central and peripheral regions (Table 17a and b). It was found that no significant difference existed between the protected surfaces of either orientation. The protected surfaces of vertical plates tended to have more diverse fouling assemblages than did protected

Table 16. Effect of substrate type on the Shannon-Weiner diversity indices for small settling plates at Luminao Reef. To test plexiglass versus PVC for 37 days and 6, 12, 24, and 37 m a Mann-Whitney U-test was used.

Comparison	Greater Diversity Value	Total Sample Size (n)	U_s Value	Significance Level
Plexiglass vs PVC				
37 days	PVC	8	9	ns
6 m	PVC	8	12	ns
12 m	Plexiglass	8	9	ns
24 m	PVC	8	11	ns
37 m	PVC	8	10	ns
All depths	PVC	16	153	ns

Table 17. A comparison of peripheral with central regions by the Shannon-Weiner diversity indices of large plates. The Wilcoxon paired-comparison signed ranks test was used while combining depths and durations.

Comparison	Greater Diversity Value	Sample Size (n)	T_s Value	Significance Level
a. Horizontal vs Vertical				
Protected, Peripheral	Vertical	16	66	ns
Protected, Central	Vertical	16	58	ns
b. Peripheral vs Central				
Horizontal				
Plexiglass, Exposed	Equal	8	18	ns
Plexiglass, Protected	Peripheral	8	10	ns
PVC, Exposed	Peripheral	8	5	$p < .005$
PVC, Protected	Peripheral	8	12	ns
Vertical				
Plexiglass, Exposed	Peripheral	8	0	$p < .005$
Plexiglass, Protected	Peripheral	8	14	ns
PVC, Exposed	Peripheral	8	1	$p < .01$
PVC, Protected	Peripheral	8	0	$p < .005$

horizontal surfaces (Table 17a). The diversity of fouling organisms in central and peripheral regions for horizontally-oriented plates was not significantly different; however, for vertically oriented plates, the peripheral region had significantly more diverse fouling assemblages than did the central region (Table 17b).

Since large plates show a difference in diversity of fouling organisms between central and peripheral regions for horizontal and vertical orientations (Table 17b), small plexiglass and PVC plates in horizontal and vertical orientations were compared. There was no significant difference between the community diversity values on horizontally or vertically oriented plates, regardless of substrate type (Table 15e). Vertical plates had predominately higher community diversity values even though they were not statistically significant.

Fish Grazing

Out of a total of 4938 herbivorous fish tooth scrapes, 4588 were on exposed surfaces, while 350 occurred on protected surfaces (Table 18). Exposed surfaces had significantly more scrapes for all the time durations, except 37-day small plates (Table 19). Exposed surfaces of large plates for both 77 and 180 days had significantly more scrapes than did protected surfaces (Table 19).

When the total number of scrapes on each of the two substrate types were compared, PVC plates had four times as many scrapes as did plexiglass plates (3988 and 950, respectfully). PVC plates were found to have significantly more scrapes than did plexiglass plates on both small and large exposed surfaces (Table 19).

The effect of exposure on the intensity of grazing was shown by the results obtained by tallying fish scrapes for 37, 77, 100 and 180

Table 18. Total number of herbivorous fish tooth scrapes on small and large plexiglass and PVC plates at Luminao Reef. Total counts for exposed and protected surfaces, for the various exposure durations, depths, and plate orientations are presented.

Plate Type, Depth and Orientation	DURATIONS 37 Days Exposed	 Protected	 77 Days Exposed	 Protected	 100 Days Exposed	 Protected	 180 Days Exposed	 Protected
Small								
Plexiglass								
6 m Horizontal	–	–	86	–	9	–	–	–
Vertical	–	–	8	–	10	–	–	–
Shaded	6	–			3	–		
12 m Horizontal	–	–	13	–	36	–	9	–
Vertical	–	–	–	–	13	–	34	–
Shaded	–	–			–	–		
24 m Horizontal	14	–	18	–	–	–	12	2
Vertical	9	–	4	–	1	–	6	–
Shaded	–	–			–	–		
37 m Horizontal	6	–	166	–	18	–	4	–
Vertical	–	–	5	–	9	–	17	–
Shaded	–	–			–	–		
PVC								
6 m Horizontal	–	–	136	–	18	–	–	–
Vertical	4	–	–	–	13	–	–	–
12 m Horizontal	–	7	52	–	29	–	51	–
Vertical	–	–	8	–	8	–	25	1
24 m Horizontal	4	–	123	–	2	–	212	–
Vertical	–	–	4	–	1	–	164	–
37 m Horizontal	–	–	188	–	78	–	18	–
Vertical	–	–	207	–	10	–	104	7
TOTAL:	43	7	1018	0	258	0	656	10

Table 18 (Continued).

Plate Type, Depth and Orientation	DURATIONS							
	37 Days		77 Days		100 Days		180 Days	
	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected
Large								
Plexiglass								
6 m Horizontal			9	10			19	6
Vertical			16	6			13	13
12 m Horizontal			106	1			6	-
Vertical			23	22			26	8
24 m Horizontal			25	-			2	-
Vertical			-	4			4	-
37 m Horizontal			75	-			6	-
Vertical			13	-			19	-
PVC								
6 m Horizontal			31	-			91	5
Vertical			40	2			53	4
12 m Horizontal			200	155			160	50
Vertical			28	11			89	10
24 m Horizontal			64	4			121	-
Vertical			90	6			133	4
37 m Horizontal			248	7			141	-
Vertical			299	5			463	-
TOTAL:			1267	233			1346	100

Table 19. Comparison of the number of herbivorous fish tooth scrapes on exposed versus protected surfaces and plexiglass versus PVC substrates for large settling plates. The Wilcoxon paired-comparisons signed ranks test was used while all other factors were combined.

Comparison	Greater Number of Scrapes	Sample Size (n)	T_s Value	Significance Level
Exposed vs Protected				
Small plates				
37 days	Exposed	7	5	ns
77 days	Exposed	14	0	$p < .005$
100 days	Exposed	16	0	$p < .005$
180 days	Exposed	12	0	$p < .005$
Exposed vs Protected				
Large plates				
77 days	Exposed	16	4.5	$p < .005$
180 days	Exposed	16	0	$p < .005$
Plexiglass vs PVC				
Small plates	PVC	26	79	$p < .01$
Large plates	PVC	16	0	$p < .005$

days (Table 18). For small plates, 77 days had the most scrapes, followed by 180, 100, and 37 days. There were 20.4 times as many fish scrapes on small plates at the 77-day exposure duration than on plates at the 37-day duration. There was a 4-fold decrease in the number of scrapes from 77 to 100 days. From 100 to 180 days the amount of grazing increased 6 times. The plates exposed for 77 days had significantly more fish scrapes than plates exposed for 37 days (Table 20). When plates from other durations were compared, no significant differences in numbers of fish scrapes occurred for either small or large plates (Table 20). The plates exposed for 77 days had the most intense grazing for both small and large plates. Plates exposed for 180 days had the second highest amount of grazing.

The surface orientations were compared for the intensity of fish grazing at the various exposure durations. Horizontal plates at 77 days had significantly greater numbers of scrapes than did vertical plates. At 180 days, horizontal and vertical plates were grazed with equal intensity (Table 21).

When the four exposure depths were compared, plates at 37 m had the greatest number of scrapes (2113); plates at 12 m and 24 m had approximately the same number of scrapes (1181 and 1033, respectively); and plates at 6 m had the fewest (611).

Table 20. Comparison of number of herbivorous fish tooth scrapes per duration of exposure for exposed surfaces of settling plates. The Mann-Whitney U-test was used while all other factors were combined.

Comparison	Greater Number of Scrapes	Total Sample Size (n)	U_s Value	Significance Level
Small Plates				
37 vs 77 days	77	34	231	$p < .005$
77 vs 100 days	77	34	169.5	ns
100 vs 180 days	180	34	150.5	ns
77 vs 180 days	77	34	164	ns
Large Plates				
77 vs 180 days	77	16	135.5	ns

Table 21. Comparison of number of herbivorous fish tooth scrapes on exposed surfaces of horizontally versus vertically oriented plates for 77- and 180-day durations. Small and large plate data are combined for the Wilcoxon paired-comparison signed ranks test.

Comparison	Greater Number of Fish Scrapes	Sample Size (n)	T_s Value	Significance Level
Horizontal versus Vertical				
77 days	Horizontal	16	24	$p < .01$
180 days	Equivalent	16	62	ns

DISCUSSION

Biomass Accumulation

Birkeland (1977) determined the rates of dry weight accumulation of fouling communities during the wet and dry seasons off the Caribbean and Pacific coasts of Panama. Rates of increase were calculated by regression on plates exposed for 27 to 148 days at 5 m. To make his weight values comparable to the present study, the time durations 37, 77, 100, and 180 days were substituted into his regression formulas. The resulting numbers were normalized to grams per 150 cm^2. The calculated biomass values were plotted in Figure 14 along with the 6-m dry weights from Luminao Reef. Settling plates set off Guam and the Caribbean have similar fouling rates for the first 77 days. After 180 days, the fouling rate off Guam exceeds that of the Caribbean by 1.7 times. The Pacific side of Panama is subject to upwelling and the increased supply of nutrients that accompany the cold water. This phenomenon supports increased biomass accumulations in Panama, nearly 7 times that of Guam during the dry season and 4 times greater fouling during the wet season.

The change in biomass accumulation with duration of exposure for Guam was compared to Long's (1974) Hawaiian data (Figs. 15 and 16). Long's large (15 x 30 cm) plates were made of asbestos and secured in vertical arrays at 15 and 30 m. Long (1974) placed settling panels at two offshore sites: Site 1 was 2.1 km off Ewa Beach at 31 m and Site 2 was 1.3 km off Barbers Point at 33 m. Long found that dark-smooth

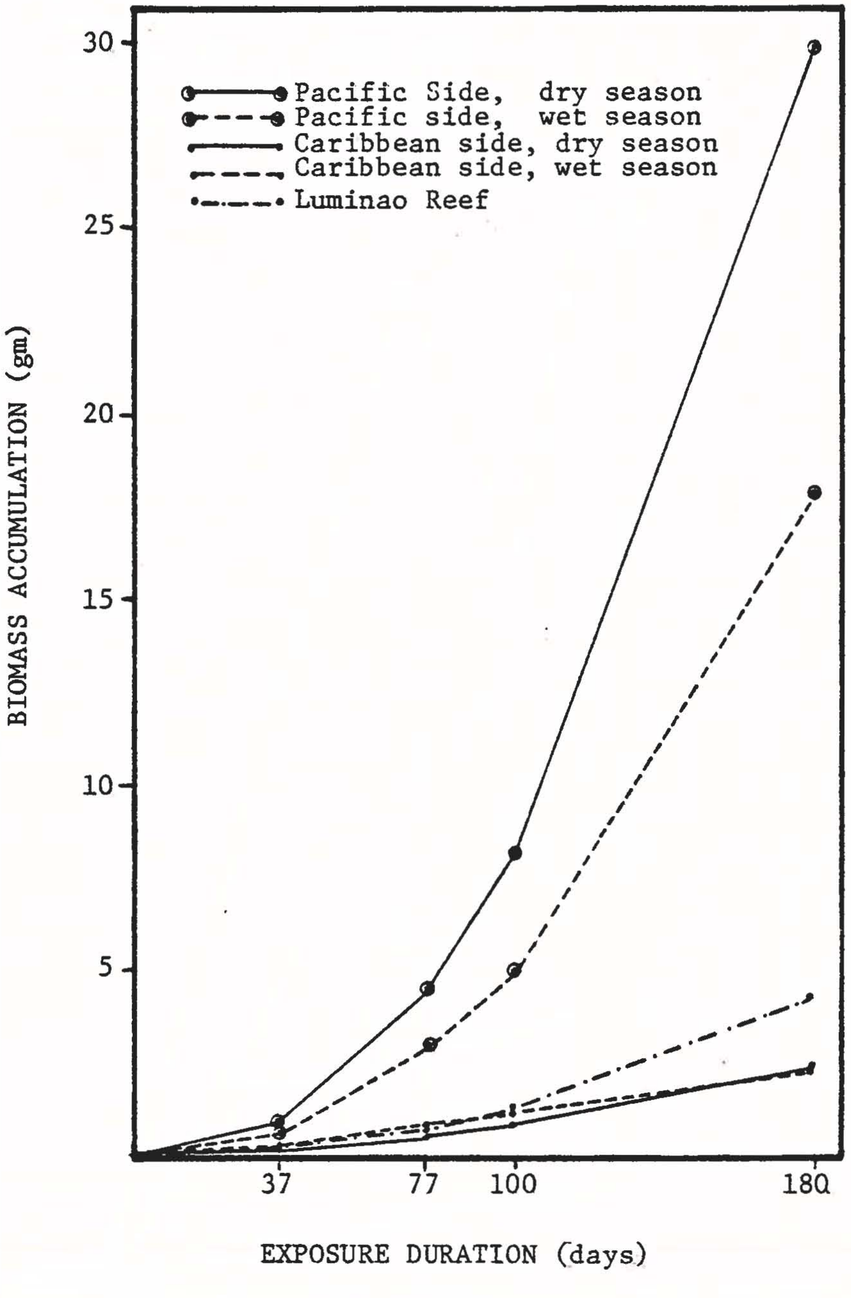


Fig. 14. Comparison of biomass accumulation with time on small (5 x 15 cm) plexiglass plates oriented horizontally at 5 m, at the Pacific and Caribbean sides of Panama (Birkeland, 1977) with plates of similar construction placed at 6 m at Luminao Reef, Guam.

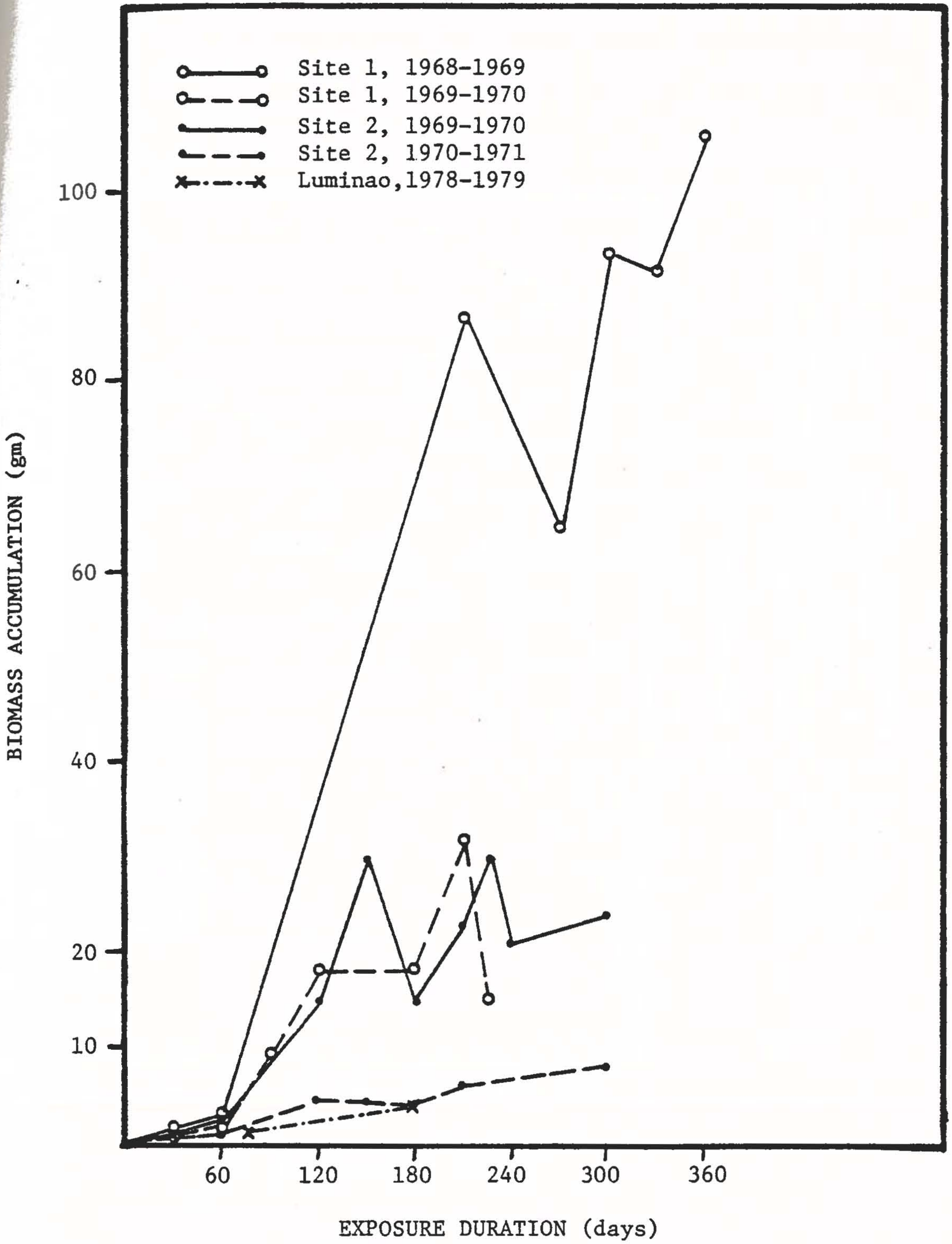


Fig. 15. Comparison of biomass accumulation with time on vertical (15 x 30 cm, one surface) asbestos plates placed at 15 m at Sites 1 and 2, offshore Oahu, Hawaii (Long, 1974) with vertical (15 x 15 cm, two surfaces) PVC plates placed at 12 m at Luminao Reef, Guam.

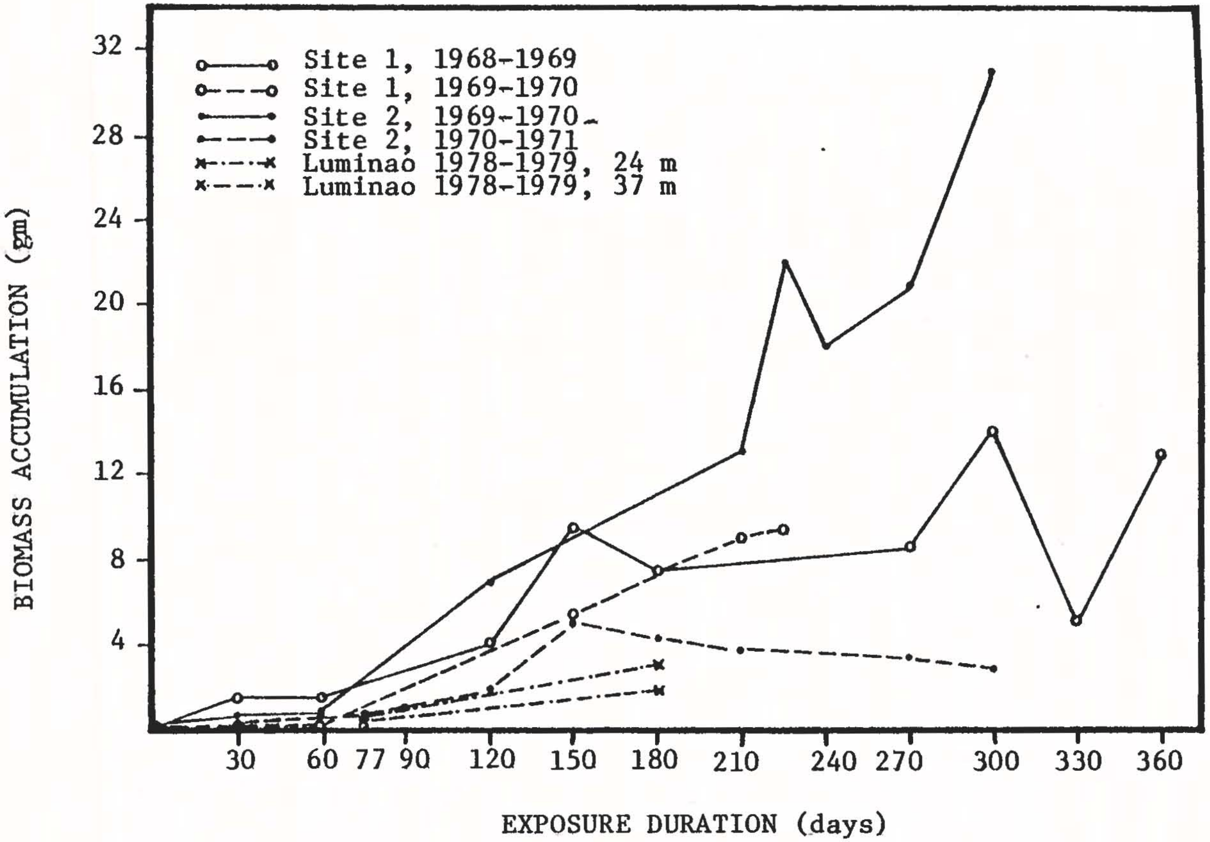
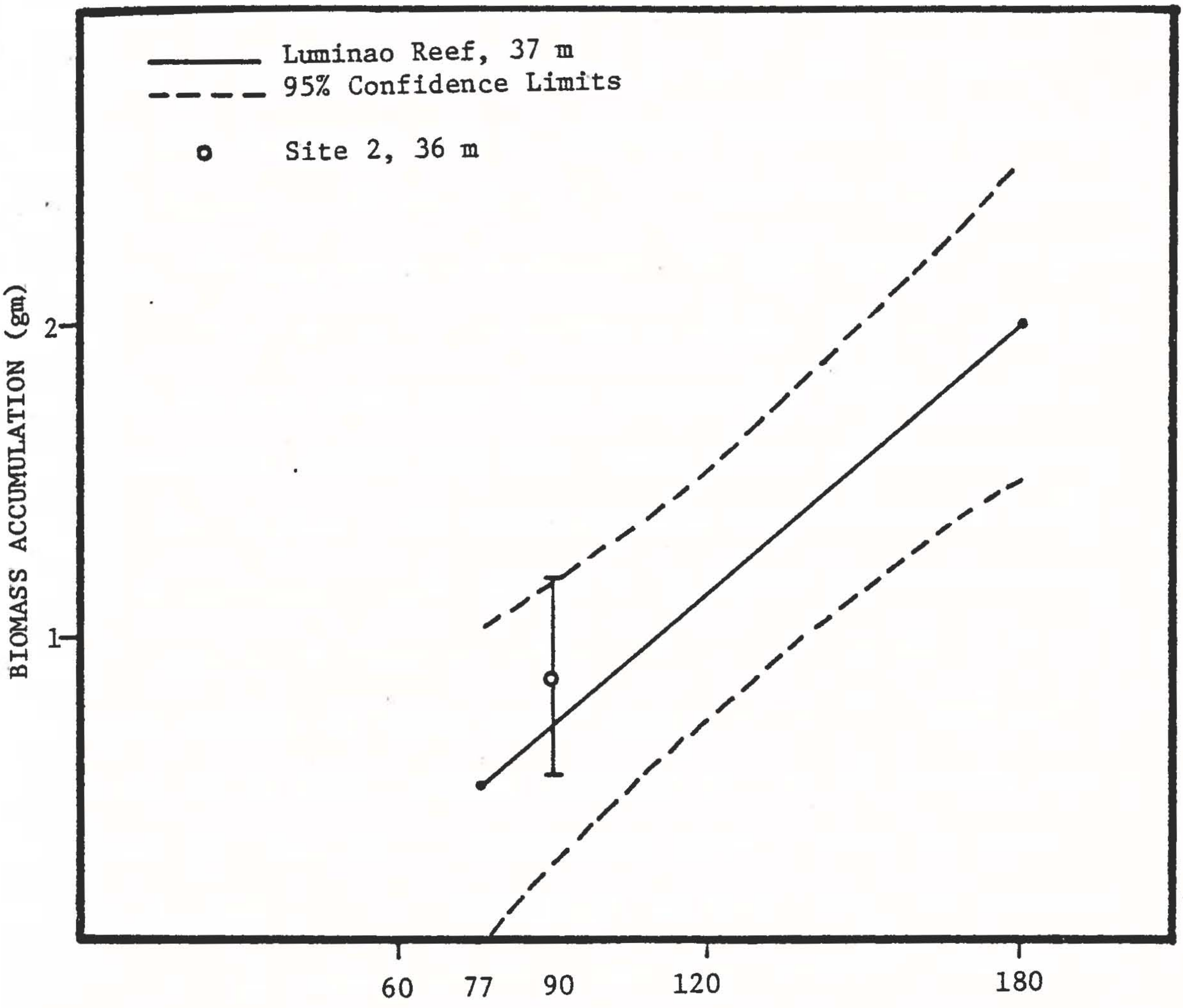


Fig. 16. Comparison of biomass accumulation with time on vertical (15 x 30 cm, one surface) asbestos plates placed at 30 m at Sites 1 and 2, offshore Oahu, Hawaii (Long, 1974) with vertical (15 x 15 cm, two surfaces) PVC plates placed at 24 and 37 m at Luminao Reef, Guam.

materials such as PVC did not accumulate fewer organisms than dark-porous materials such as asbestos. He found that plexiglass consistently accumulated fewer fouling organisms than did PVC or asbestos. Since there was no significant difference between the two substrates, the Luminao (15 x 15 cm) PVC plates were considered comparable to the Hawaii asbestos plates. Although Long's plates were twice as large as those of the present study, they collected fouling organisms on only one surface because they were mounted flush against wood blocks. Figure 15 compares Hawaii's 15-m and Luminao's 12-m plates. This comparison should not produce a bias towards the Hawaii data since the plates off Guam were placed at a shallower depth and would comparatively accumulate more organisms if exposed at the same site. Large plexiglass and PVC plates from Luminao accumulated less biomass than Long's asbestos plates for 77 days. At 180 days the biomass accumulation off Guam was less than Hawaii. When biomass data from Long's settling plates at 30 m were compared with the data from the 24- and 37-m settling plates from Luminao, it was found that fouling accumulation off Guam was less than the fouling off the Hawaii site (Fig. 16).

The biomass dry weights from 77 to 180 days at Luminao were plotted in Figure 17 with the 95% mean confidence levels. The average of Long's Hawaiian 90 day PVC plates (.8620 ± .3172) was plotted in Figure 17 and was found to lie within the 95% confidence levels of PVC weight values from Guam. The trends in Figures 15 and 16 show that the 77-day PVC values lie within the Hawaii range for early biomass accumulation, but after about 4.5 months the fouling at Hawaii increases rapidly and exceeds that at Guam.



EXPOSURE DURATION (days)

Fig. 17. Comparison of biomass accumulation at 77 and 180 days on large (15 x 15 cm) PVC plates at Luminao Reef, Guam with 95% confidence levels of the mean values, with large (15 x 30 cm) PVC plates exposed for 90 days at Site 2, Oahu (Long, 1974).

For our review, Joseph G. Grovhoug sent biomass data obtained from scrapings off plexiglass plates exposed at 5 m for 12 months at Kaneohe Bay and Pearl Harbor, Hawaii. Biomass accumulation on 6-m plexiglass plates exposed at Luminao Reef for 77 and 180 days were compared with Grovhoug's data for 12 months in Kaneohe Bay (110.51 gms) and Pearl Harbor (27.79 gms) (Fig. 18). A projected 12 month estimate of biomass off Guam was made by extrapolating from the data for exposure periods of 77 to 180 days. The estimated biomass for the Luminao Barrier Reef was 16.0 grams/year. The nutrient-rich Kaneohe Bay had seven times more fouling than Guam. Pearl Harbor had 1.7 times more fouling than did Guam. The average biomass from Neudecker's (1978) 5 x 15 cm plexiglass plates exposed for 12 months were multiplied by three to give an estimate of biomass for 15 x 15 cm plates. The estimated biomass for Tanguisson Fringing Reef was 19.6 grams/year.

The use of cages excludes predators such as echinoderms, gastropods, and most importantly, herbivorous fishes. Paine and Vadas (1969), Neushul et al., (1976), Tsuda and Kami (1973), and Birkeland (1977) found that the exclusion or removal of predators affected the algal population growth, distribution, surface coverage, and biomass accumulation in an enclosed area as long as adequate amounts of light were available. Neudecker's plates at Tanguisson were mounted inside predator-exclusion cages, therefore potentially having more biofouling than uncaged plates at Luminao.

Neudecker (1978) followed the changes in biomass accumulation from 118 days (almost 4 months) to 364 days (12 months). The biomass from upper and lower surfaces were scraped and separately weighed. These data were combined to make comparisons with the Luminao plates.

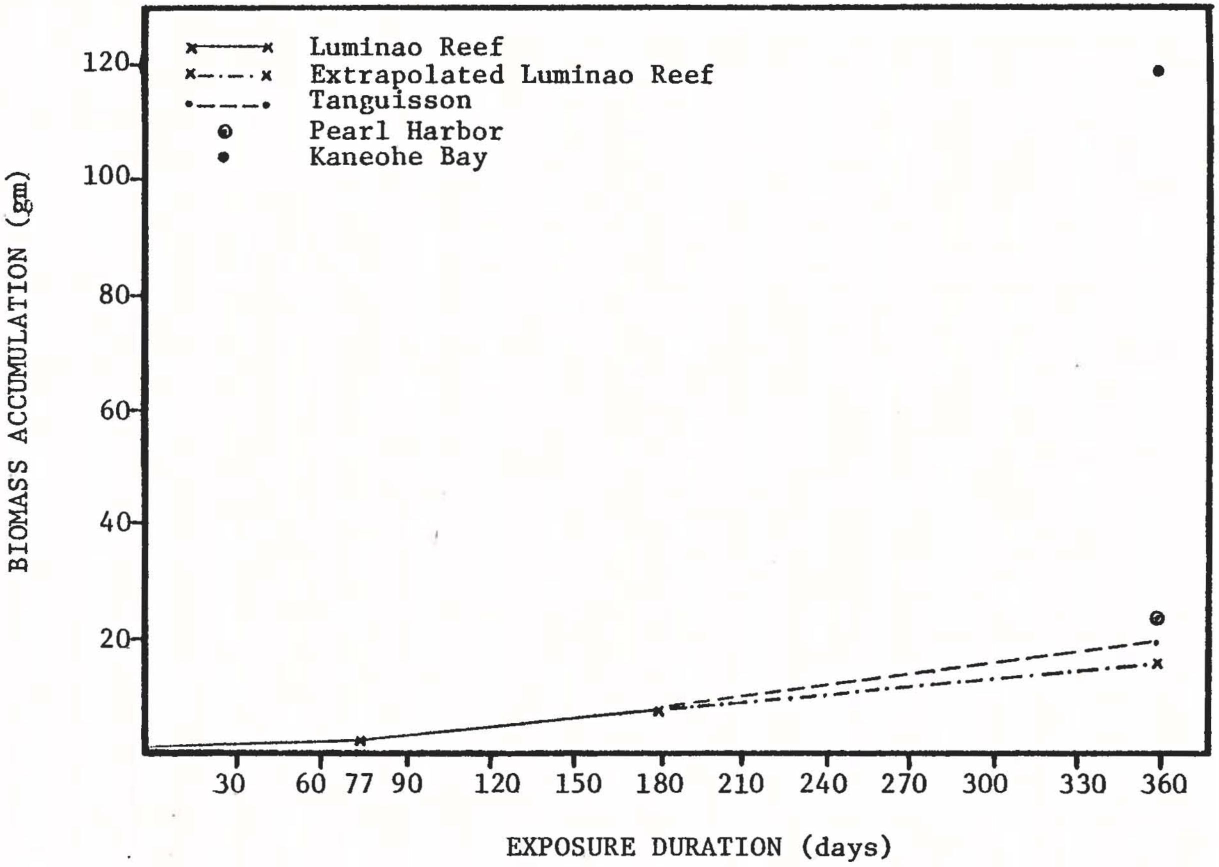


Fig. 18. Comparison of biomass accumulation on large (15 x 15 cm) plexiglass plates after 12 months exposure at 5 m at Pearl Harbor and Kaneohe Bay, Hawaii (Grovhoug) with 12-month extrapolated values from 77 and 180 days at 6 m at Luminao Reef, and at 5 m at Tanguisson Reef (Neudecker, 1978).

Neudecker's biomass values were plotted to show the trends in accumulation from 4 to 12 months for 5, 10, 15, and 30 m (Fig. 19). The biomass values increased to 141 days, decreased to 308 days, and increased again to 364 days. These fluctuations might be a result of changes in algal abundances of ephemeral species that do not persist over one year's time (Tsuda and Kami, 1973). According to counts of numbers of species on submerged artificial tire reefs in Cocos lagoon, a leveling off or climax occurred after 10 and 11 months (Tsuda and Kami, 1973). Although the major constituents in Neudecker's surface coverage data were algae, no observed climax state occurred as indicated by the fluctuations in biomass with time. The fouling community on settling plates exposed off Guam was in a nonequilibrium state when biomass accumulation data was used as an indicator of stability.

Birkeland (1977), in his study of Caribbean and eastern Pacific fouling communities, found that as levels of light and nutrients decreased, the rate of biomass accumulation decreased. Determination of fouling rates by measuring slopes of plotted biomass values from Luminao Reef per duration of exposure, demonstrated that shallower depths had faster rates of accumulation than did deeper depths.

The decrease in dry weight with increased depth is related to the attenuation of light which directly affects the zonation of subtidal algal (Hanson and Bell, 1976). Biomass accumulation was found to decrease with increased depth on settling plates submerged at Luminao Reef. Biomass accumulation was less on shaded plates than on exposed plates. There was a higher proportion of algae on the exposed surfaces in comparison with protected and shaded surfaces. The differences in algal coverage on protected surfaces of plexiglass and PVC plates were

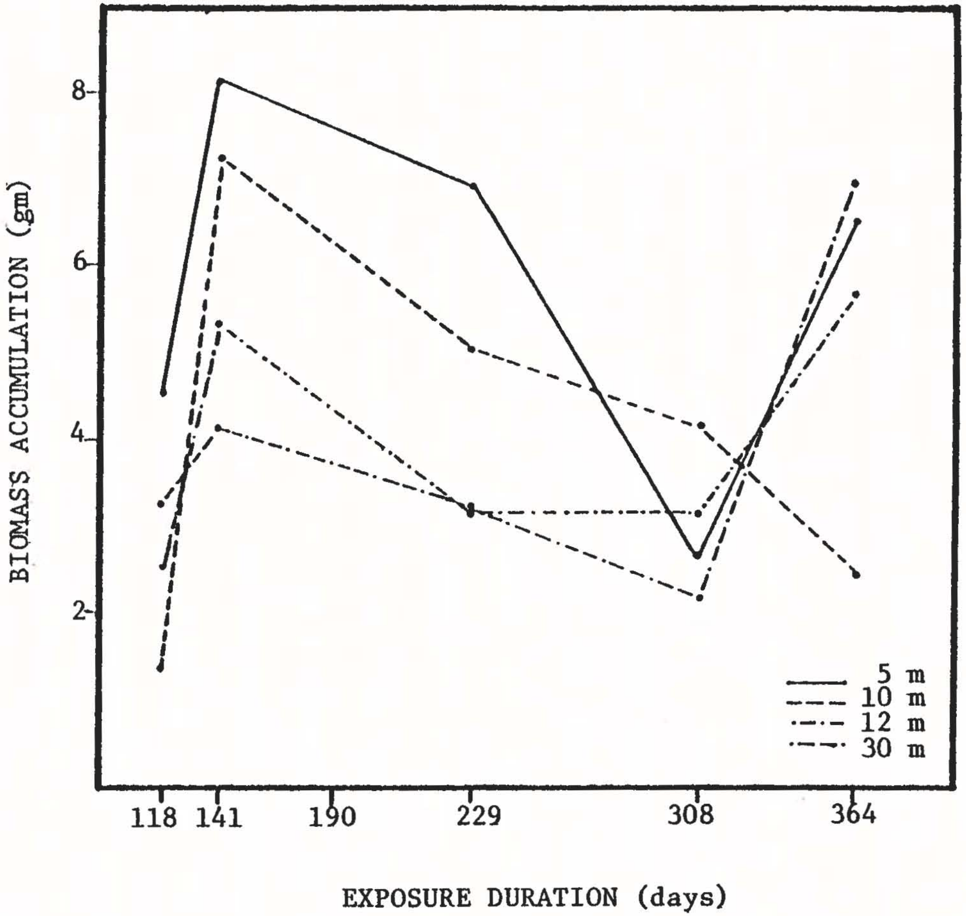


Fig. 19. Changes in biomass accumulation with time on small (5 x 15 cm) plexiglass plates placed inside predator exclusion cages at Tanguisson Fringing Reef, Guam (Neudecker, 1978).

the result of light penetration through the plexiglass plates and not through the PVC plates. The degree of illumination influences the development of the fouling communities. Fleshy and calcareous algae are important components of the exposed fouling community and their surface coverage directly affects the community structure. Protected and shaded surfaces with low illumination were dominated by non-algal components.

An estimate of the effect of season and exposure period on fouling was done with asbestos plates submerged at 5 m by Grovhoug (personal communication) in Hawaii. These biomass were data compared with data from plexiglass and PVC plates of equivalent size set at the 6-m Luminao site (Fig. 20). The data from Hawaii were collected from May 1976 to April 1977, while the data from Guam were collected from March to May 1979. The biomass accumulation on settling plates from Hawaii fluctuated with exposure period. Biofouling in waters at the Luminao site did not exhibit much variation during the months investigated.

Comparisons of Panama, Hawaii, and Guam indicate that the overall production of an area affects the biomass accumulation on artificial substrates. The upwelling of nutrients on the Pacific side of Panama was responsible for the greater rates of biomass accumulation in that area compared to the accumulation off the Caribbean side of Panama and off Guam. Guam and Hawaii are not affected by nutrient upwelling.

The differences between Hawaii and Guam are more difficult to explain. Differences in the faunal elements between Hawaii and Guam may influence biomass accumulation. Hawaii has predominantly central zone faunal representatives while Guam has equatorial faunal representatives (McGowan, 1974). There is some overlapping of faunal elements

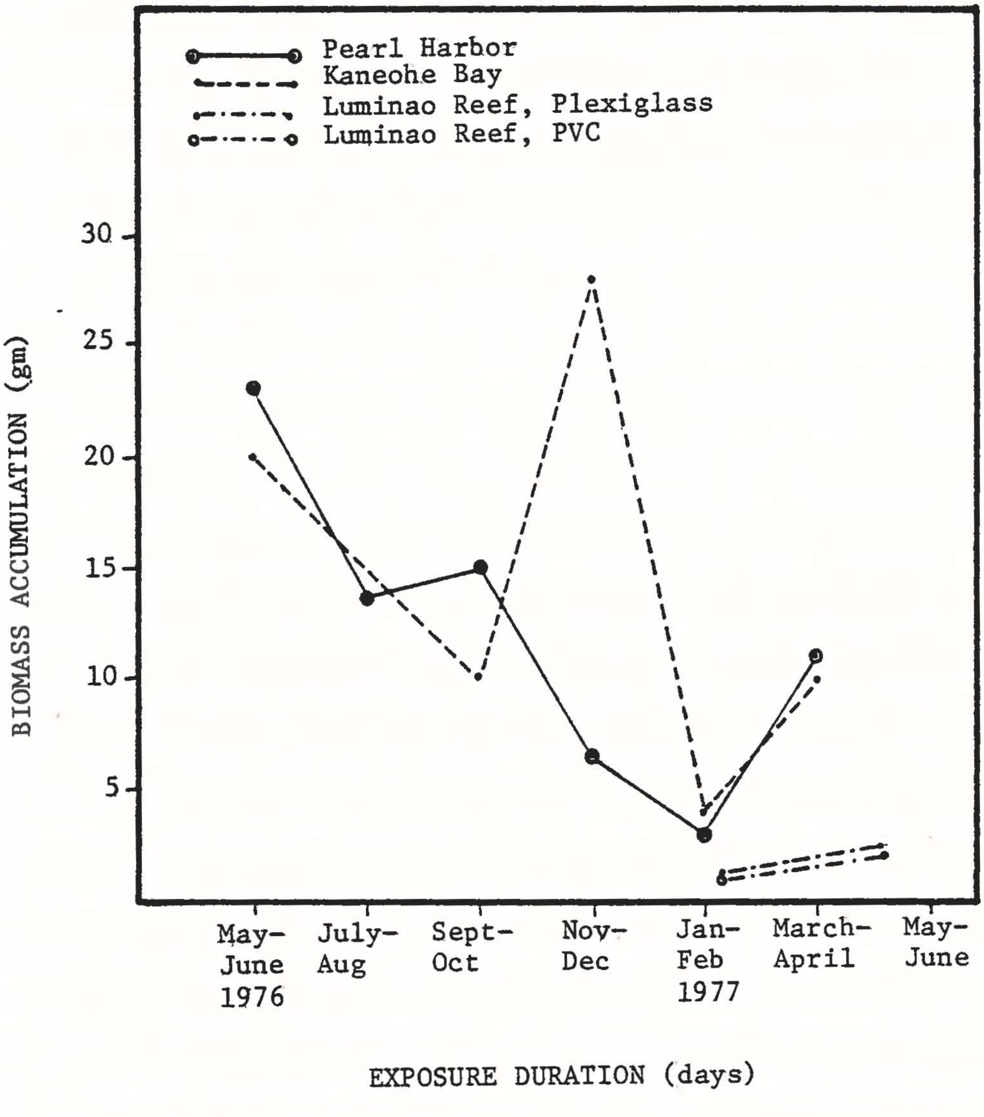


Fig. 20. Comparison of biomass accumulation on large (15 x 15 cm) asbestos plates set at 5 m at Pearl Harbor and Kaneohe Bay (Grovhoug) from May 1976 to June 1977 with large (15 x 15 cm) plexiglass and PVC plates set at 6 m at Luminao Reef, Guam from March to May 1979.

between these zones. Panama is in the eastern faunal zone which is isolated from the other zones. The type of organisms present contributes to the biomass accumulation of the respective areas. Hawaii has a higher proportion of invertebrates such as barnacles, tube worms, bivalves, and bryozoans on fouling surfaces as compared with Guam. These organisms all have calcareous exoskeletons which could account for the difference in the biofouling weights.

Hawaii, in a higher latitude than Guam, has cooler oceanic temperatures and is classified as subtropical. The difference in water temperature between Guam and Hawaii probably affects the fouling community constituents. The additional nutrient run-off associated with larger island chains could also be responsible for increased biofouling production in Hawaii. These differences are expressed in the biomass accumulation rates in the respective geographical regions.

The biomass accumulation study at Luminao Reef suggests that the warm-water intake pipe should be placed in water deeper than 12 m. This takes advantage of the decreased fouling at deeper depths, but will not change the efficiency of the OTEC power plant because the temperature only changes .18°C (.32°F) for the first 50 meters (Lassuy, 1979). Deeper placement of the intake pipe would also minimize potential pipe damage resulting from large waves associated with storms and typhoons. From the biomass accumulation data gathered from one to six months, it is evident that fouling was the least during the first 37 days. The fouling increased in intensity from 77 to 180 days. The most significant change in the rate of fouling occurred at 6 m from 100 to 180 days. It is therefore suggested that fouling accumulation on the warm-water intake pipe be removed monthly.

Community Structure

The distribution of biofouling components on settling plates was a complex interaction of many factors. Sutherland (1974) found that fish predation influenced the hierarchical patterns of community structure and the occurrence of dominant organisms. Sutherland and Karlson (1977) showed that bare space produced by the sloughing off of fouling organisms is generally recruited to by species different than the previous occupant. These two factors explain the complementary patterns of increases and decreases in the proportion of surface coverage by the major fouling groups inhabiting settling plates from Luminao Reef.

Sutherland and Karlson (1977) showed a general trend of bare space rapidly decreasing during the first month of exposure and then fluctuating thereafter. This was the result of the unpredictability of larval recruitment to unoccupied substrate and the variability in recruitment patterns both within and between years (Sutherland and Karlson, 1977). This variability was probably responsible for the inconsistant patterns of bare space on settling plates off the Luminao site.

Changes in the proportion of surface coverage during the early periods of submergence was a reflection of the intensity of grazing pressure. Following the period of heavy grazing of filamentous and mat algae from 37 to 77 days, the crustose corallines became established and then became the target for grazing. These shifts in the proportions of filamentous and mat-type algae to crustose coralline algae caused the fluctuating successional stages that were apparent in the surface coverage results.

Paine and Vadas (1969), Dayton (1971), and Brock (1979) showed that diversity increased at first in structurally simple environments because of predation. As the intensity of grazing increased, diversity tended to decrease. Apparently grazing pressures at Luminao did not reach such levels and no decrease in diversity was noted.

Fish grazing may affect diversity by having a compensatory effect on mortality as described in Connell (1978). The filamentous and mat algae maintained a high competitive rank until grazing reduced their surface coverage. At this time, space was yielded to competitors such as crustose corallines and animals. Brock (1979) found that parrotfish grazing reduced filamentous algal populations, thus enabling coralline algae to become competitively superior. The diversity of fouling assemblages on settling plates at Luminao was influenced by these competitive interactions.

Fouling communities at Luminao and Tanguisson (Neudecker, 1978) had higher diversities on the lower or protected surfaces of the settling plates. Buss and Jackson (1979) presented a model of diversity in space-limited systems without high predation pressures and physical disturbance. They proposed that a competitive network existed in cryptic environments which increased in complexity with increased numbers of species. This eliminated dominant exclusion and maintained high diversities. This principle may be working on the protected surfaces of plates submerged at Luminao.

The water currents and movements around large vertical plates might affect the development of certain organisms and is expressed as an "edge effect" which caused increased diversity on the outer zones of settling plates. Large vertical plates showed a difference in diversity between the peripheral and central zones. No "edge effect" was observed for large horizontal plates.

The effect of herbivorous grazing activities on algal growth can be demonstrated with the use of cage experiments (Randall, 1961; Tsuda and Kami, 1973; Vine, 1974; Sutherland, 1974; Birkeland, 1977). Randall (1961) found that algae outside cages averaged 1 mm in height while algae protected from fish predation varied with the normal morphological size of the species. The algae at Luminao rarely exceeded 2 mm. Vine (1974) conducted a study of algal biomass accumulation in protected and unprotected plates placed at the surface to 20 m for a period of 30 days. He found that the dry weight of algae on protected plates was significantly greater. Vine found that algal biomass from protected plates decreased with depth. Biomass on unprotected plates remained approximately the same from the surface to 15 m with the lowest value at 20 m. Vine's results indicated that the fastest growth was at the shallowest depth. Birkeland (1977) also found that fish grazing affected the biomass accumulation of fouling organisms. He found that caged plates accumulated significantly more fouling that did uncaged plates for both the Caribbean and the eastern Pacific.

Henderson et al. (1976) found that the grazing of fish was important in determining overall community structure in microcosm experimental tanks. They found that grazing provided free, hard substrate which is preferred by settling larvae. Brock (1979) tested the effects of intensity of parrotfish grazing on the percent coverage of calcareous and filamentous algae and the biomass of benthic organisms. He found that as the total number of fish increased from

0 to 4 individuals, the percent coverage of algae increased. When 5 to 8 fish were present, crustose corallines increased and filamentous algae disappeared. The benthic biomass was drastically reduced with the introduction of one fish.

The changes in surface coverage on settling plates at Luminao were the result of the intensity of fish grazing. The greatest numbers of fish tooth scrapes were found at 77 days and 37 m. At the early temporal stages of development, the horizontal surfaces supported the most abundant algal populations. Both horizontal and vertical exposed surfaces had abundant algal growth during the later exposure durations. The patterns of grazing reflected this increased growth, as there was a shift from 77 to 180 days from predominantly horizontal surface grazing to equal predation on both horizontal and vertical surfaces.

Fish grazing was identified as being important in modifying the development of the fouling community. Disturbance and the creation of small patches brought about by herbivorous fishes affected the patterns of space occupation. This was observed in the changes of surface coverage and diversity with time.

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APPENDIX A

TABLE A

Table A. Chronological exposure dates and durations for small and large plexiglass and PVC settling plates from Luminao Reef and Western Shoals.

			NUMBER OF RECOVERED SETTLING PLATES OUT OF A PLACEMENT OF FOUR								
Location	Size	Depth (Meters)	Plexiglass Horizontal	Plexiglass Vertical	PVC Horizontal	PVC Vertical	Plexiglass Shade	Total Recovered	Duration (Days)	Placement Date	Recovery Date
Luminao	Small (5 x 15 cm)	6	4	4	4	4		16	77	19 XII 78	6 III 79
		12	4	4	4	4		16			
		24	4	4	4	3		15		20 XII 78	9 III 79
		37	4	4	4	4		16			
	Large (15 x 15 cm)	6	4	3	3	4		14	77	19 XII 78	6 III 79
		12	4	4	4	4		16			
		24	4	4	4	4		16		20 XII 78	9 III 79
		37	4	4	4	4		16			
Luminao	Small	6	3	3	4	3		13	180	8 II 79	7 IIX 79
		12	4	4	4	4		16			
		24	4	4	4	4		16		12 II 79	7 IIX 79
		37	4	4	4	4		16			
	Large	6	4	4	4	4		16	180	8 II 79	7 IIX 79
		12	4	4	4	4		16			
		24	4	3	4	3		14		12 II 79	7 IIX 79
		37	4	3	4	4		15			
Luminao	Small	6	2	1	2	1	4	10	37	26 II 79	4 IV 79
		12	4	4	4	4	4	20			
		24	4	4	4	4	1	17		27 II 79	5 IV 79
		37	4	4	4	4	4	20			

Table A (Continued).

			NUMBER OF RECOVERED SETTLING PLATES OUT OF A PLACEMENT OF FOUR								
Location	Size	Depth (Meters)	Plexiglass Horizontal	Plexiglass Vertical	PVC Horizontal	PVC Vertical	Plexiglass Shade	Total Recovered	Duration (Days)	Placement Date	Recovery Date
	Small	6	4	4	4	4	4	20	100	26 II 79	6 IV 79
		12	4	4	4	4	4	20			
		24	4	4	4	4	4	20		27 II 79	7 IV 79
		37	4	4	4	4	4	20			
Western Shoals	Small	6	4	2				6	77	2 III 79	18 V 79
		12	4	4				9			
		24	4	4				8			
Luminao	Small replacements	6	6**	7**				13	77	6 III 79	22 V 79
		12	8**	8**				16			
	Large replacements	6	3	3	3	3		12	77	6 III 79	22 V 79
		12	4	4	4	4		16			
Luminao	Small replacements	6	8**	7**			4	19	37	4 IV 79	10 V 79
		12	8**	8**			4	20			
Luminao	Small										
	Brushed	12	4	4			2*	10	37	22 V 79	28 VI 79
	Unbrushed	12	4	4			2*	10			
	New Block	12	4	3			2*	9			

*Sample size equals two plates exposed.

**Sample size equals eight plates exposed.

APPENDIX B

TABLES A, B, C, D, E, F,

Table A. Average proportion of surface coverage by the major fouling groups on exposed and protected surfaces of small plexiglass horizontal settling plates.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Other Algae	Animals	Sediment
6 m	37	.7969/.3854	.1510/.0000	.0468/.6146	.0052/.0000	.0000/.0000
	77	.3177/.0938	.5052/.3047	.1771/.6016	.0000/.0000	.0000/.0000
	100	.1510/.1667	.3333/.2370	.4686/.5833	.0026/.0130	.0443/.0000
	180	.0486/.0139	.0347/.2987	.8889/.6771	.0139/.0104	.0139/.0000
12 m	37	.4297/.0547	.0286/.0000	.4791/.9374	.0026/.0078	.0599/.0000
	77	.7580/.0521	.1823/.0937	.0546/.8464	.0052/.0078	.0000/.0000
	100	.3698/.2969	.1588/.0599	.4635/.6356	.0000/.0078	.0078/.0000
	180	.0703/.1354	.2995/.1849	.6042/.5990	.0260/.0807	.0000/.0000
24 m	37	.3264/.7083	.0347/.0000	.5417/.2639	.0382/.0278	.0590/.0000
	77	.3151/.3099	.3906/.0703	.2552/.5547	.0390/.0651	.0000/.0000
	100	.1849/.2344	.2083/.0703	.5365/.6484	.0286/.0469	.0417/.0000
	180	.1927/.0807	.3177/.2963	.3359/.5911	.1302/.0312	.0234/.0000
37 m	37	.6406/.3750	.0156/.0052	.3281/.5833	.0156/.0365	.0000/.0000
	77	.2630/.3125	.1615/.1536	.4167/.3932	.1146/.1406	.0443/.0000
	100	.1198/.1172	.3724/.1015	.4714/.6667	.0364/.1145	.0000/.0000
	180	.1146/.1563	.2604/.2240	.4895/.3671	.1146/.2526	.0208/.0000

Table B. Average proportion of surface coverage by the major fouling groups on exposed and protected surfaces of small plexiglass vertical settling plates.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Other Algae	Animals	Sediment
6 m	37	.8125/.2813	.0521/.0104	.1355/.7083	.0000/.0000	.0000/.0000
	77	.3307/.2188	.4271/.4167	.2422/.3437	.0000/.0208	.0000/.0000
	100	.1510/.1380	.4166/.4896	.4089/.3672	.0234/.0052	.0000/.0000
	180	.0278/.0000	.3610/.5695	.5624/.4063	.0208/.0243	.0278/.0000
12 m	37	.2630/.0807	.0026/.0000	.7318/.8906	.0026/.0286	.0000/.0000
	77	.5807/.1563	.1172/.2083	.2969/.5964	.0052/.0391	.0000/.0000
	100	.4401/.1615	.2396/.3594	.3047/.4584	.0156/.0208	.0000/.0000
	180	.0990/.1016	.2734/.2891	.5729/.5365	.0547/.0729	.0000/.0000
24 m	37	.5234/.5365	.1380/.0052	.3255/.4401	.0130/.0182	.0000/.0000
	77	.3307/.1875	.1380/.1250	.5234/.5703	.0078/.1171	.0000/.0000
	100	.2005/.0990	.2109/.2239	.5209/.6068	.0677/.0703	.0000/.0000
	180	.1042/.0521	.4661/.5729	.3281/.2786	.1015/.0963	.0000/.0000
37 m	37	.6458/.3672	.0078/.0312	.3463/.5703	.0000/.0312	.0000/.0000
	77	.2526/.3229	.1406/.2682	.5573/.3671	.0469/.0364	.0026/.0052
	100	.2422/.1224	.2474/.1875	.4635/.6067	.0469/.0833	.0000/.0000
	180	.2005/.1927	.3776/.5026	.3126/.1927	.1093/.1119	.0000/.0000

Table C. Average proportion of surface coverage by the major fouling groups on exposed and protected surfaces of small PVC horizontal settling plates.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Algae	Animals	Sediment
6 m	37	.2361/.1285	.0035/.0104	.7534/.7153	.0069/.1458	.0000/.0000
	77	.2161/.0677	.2318/.3229	.5443/.5129	.0078/.0886	.0000/.0078
	100	.0495/.0052	.0834/.3099	.8281/.6771	.0156/.0078	.0234/.0000
	180	.0026/.0026	.0937/.3620	.8801/.5496	.0000/.0807	.0234/.0052
12 m	37	.0677/.2995	.0026/.0000	.9010/.6353	.0104/.0651	.0182/.0000
	77	.2370/.0677	.0547/.0234	.6979/.8855	.0104/.0234	.0000/.0000
	100	.1068/.0573	.1094/.1614	.7682/.7214	.0156/.0599	.0000/.0000
	180	.0549/.0208	.1432/.0286	.7839/.6094	.0182/.3412	.0000/.0000
24 m	37	.2370/.5417	.0130/.0026	.6458/.4141	.0729/.0416	.0313/.0000
	77	.1016/.3073	.1067/.0026	.7396/.6146	.0443/.0754	.0078/.0000
	100	.0043/.2188	.0833/.1094	.8464/.5104	.0208/.1616	.0052/.0000
	180	.1068/.0990	.2994/.1953	.5079/.1953	.0807/.5103	.0052/.0000
37 m	37	.4193/.5479	.0078/.0000	.5260/.4062	.0156/.0468	.0313/.0000
	77	.1458/.4609	.0781/.0000	.6120/.2735	.1276/.2656	.0364/.0000
	100	.1146/.2266	.0651/.0547	.7110/.3047	.1094/.4145	.0000/.0000
	180	.1536/.0938	.2500/.0782	.4792/.1328	.1172/.6954	.0000/.0000

Table D. Average proportion of surface coverage by the major fouling groups on exposed and protected surfaces of small PVC vertical settling plates.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Other Algae	Animals	Sediment
6 m	37	.3698/.3698	.0104/.0208	.5208/.5313	.1006/.0677	.0000/.0104
	77	.2500/.1510	.3047/.4271	.3933/.3801	.0521/.0417	.0000/.0000
	100	.0781/.0286	.2213/.3256	.6824/.6224	.0182/.0234	.0000/.0000
	180	.0174/.0000	.2292/.3924	.6875/.5765	.0659/.0174	.0000/.0139
12 m	37	.1536/.1901	.0000/.0000	.8255/.7709	.0208/.0391	.0000/.0000
	77	.3880/.0990	.0807/.0416	.4506/.8282	.0807/.0312	.0000/.0000
	100	.1380/.0443	.1329/.0937	.6510/.7109	.0781/.1510	.0000/.0000
	180	.0234/.0729	.3125/.2447	.6016/.4166	.0625/.2654	.0000/.0000
24 m	37	.5000/.4010	.0000/.0130	.4609/.5729	.0390/.0078	.0000/.0052
	77	.3125/.3385	.0468/.1067	.5053/.3412	.1354/.2136	.0000/.0000
	100	.0495/.1068	.0859/.0859	.7942/.7265	.0703/.0807	.0000/.0000
	180	.0755/.0964	.2552/.3437	.5625/.3073	.1068/.2526	.0000/.0000
37 m	37	.3880/.2839	.0000/.0052	.5963/.6771	.0156/.0338	.0000/.0000
	77	.3021/.4375	.0781/.0547	.5600/.4453	.0599/.0442	.0000/.0182
	100	.0833/.2135	.0390/.1823	.7891/.4271	.0885/.1771	.0000/.0000
	180	.1458/.1719	.1640/.2292	.5286/.3020	.1614/.2968	.0000/.0000

Table E. Average proportion of surface coverage by the major fouling groups on exposed and protected surfaces located in the peripheral region of large plexiglass, horizontal and vertical, settling plates.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Other Algae	Animals	Sediment
			HORIZONTAL			
6 m	77	.1250/.2604	.3334/.3907	.5129/.3384	.0234/.0104	.0052/.0000
	180	.0417/.0938	.2735/.5496	.6589/.3177	.0104/.0390	.0156/.0000
12 m	77	.2969/.2344	.2891/.0313	.3724/.6979	.0260/.0364	.0156/.0000
	180	.2500/.1276	.5234/.1016	.2057/.7422	.0208/.0286	.0000/.0000
24 m	77	.2057/.4245	.6120/.1146	.1511/.4244	.0313/.0365	.0000/.0000
	180	.0860/.1120	.4870/.3621	.3282/.3959	.0989/.1301	.0000/.0000
37 m	77	.2943/.4479	.5078/.1380	.1302/.3672	.0573/.0468	.0104/.0000
	180	.1582/.1146	.4271/.3646	.2630/.3620	.1510/.1588	.0000/.0000
			VERTICAL			
6 m	77	.2500/.1354	.3785/.5000	.3610/.3612	.0104/.0035	.0000/.0000
	180	.1146/.0729	.5651/.6240	.2865/.2631	.0338/.0390	.0000/.0000
12 m	77	.3203/.1641	.1927/.2370	.4531/.5468	.0339/.0521	.0000/.0000
	180	.2266/.0573	.4193/.2682	.2969/.6197	.0573/.0442	.0000/.0104
24 m	77	.5260/.2083	.3099/.3516	.1536/.4167	.0104/.0234	.0000/.0000
	180	.1388/.0382	.3403/.5451	.4583/.3750	.0625/.0416	.0000/.0000
37 m	77	.4167/.2839	.2344/.3854	.3021/.2891	.0468/.0417	.0000/.0000
	180	.2396/.1458	.3646/.5664	.3194/.1250	.0763/.1633	.0000/.0000

Table F. Average proportion of surface coverage by the major fouling groups of exposed and protected surfaces located in the peripheral region of large PVC, horizontal and vertical, settling plants.

Depth	Duration (Days)	Bare Substratum	Crustose Coralline Algae	Other Algae	Animals	Sediment
			HORIZONTAL			
6 m	77	.0521/.0347	.0833/.4202	.8228/.2847	.0417/.2603	.0000/.0000
	180	.0365/.0104	.2266/.2552	.7318/.6198	.0052/.1145	.0000/.0000
12 m	77	.2734/.3203	.1510/.1068	.5052/.4037	.0703/.1692	.0000/.0000
	180	.1224/.1224	.3229/.2396	.5260/.1797	.0286/.4584	.0000/.0000
24 m	77	.0938/.4245	.2682/.0052	.5625/.3100	.0755/.2604	.0000/.0000
	180	.0521/.1198	.3255/.2266	.5494/.1771	.0729/.0476	.0000/.0000
37 m	77	.1667/.5026	.1953/.0052	.5105/.2266	.0990/.2956	.0286/.0000
	180	.0755/.1146	.2786/.0469	.4765/.0234	.1693/.8152	.0000/.0000
			VERTICAL			
6 m	77	.1563/.1224	.3150/.4557	.4532/.2500	.0755/.1718	.0000/.0000
	180	.0130/.0182	.2371/.6041	.7395/.2682	.0104/.0937	.0000/.0000
12 m	77	.2396/.2083	.1354/.1067	.5287/.5338	.0964/.1505	.0000/.0000
	180	.0990/.0495	.2448/.1797	.6250/.6616	.0312/.1094	.0000/.0000
24 m	77	.2552/.3672	.0860/.0989	.6145/.4583	.0443/.0755	.0000/.0000
	180	.0573/.0313	.3246/.3880	.5052/.4349	.1119/.1458	.0000/.0000
37 m	77	.2656/.5625	.1640/.1016	.4974/.2214	.0729/.1146	.0000/.0000
	180	.1354/.2005	.1198/.1771	.6640/.4791	.0807/.1431	.0000/.0000