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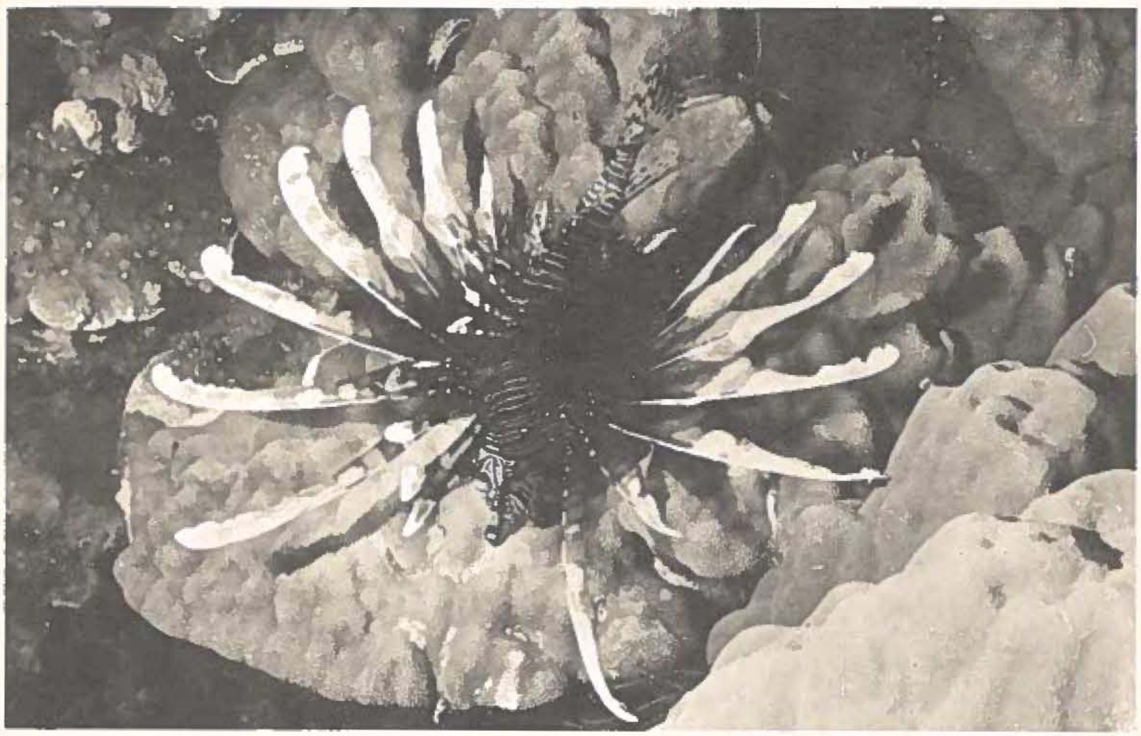

UNIVERSITY OF GUAM MARINE LABORATORY

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OF A PROPOSED SEWER OUTFALL SITE
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By

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INTRODUCTION

Palau is the westernmost group of the Caroline Islands. The islands of Palau extend in a north-south direction from 8°12' north to 6°57' north latitude and from 135°08' east longitude to 134°43' east. By far the largest island in the group is Babelthuap (Babeldaob) which is over 396 km^2 (over 153 square miles) and thus comprises about 33% of all land in the Caroline Islands. Immediately south of Babelthuap is a group of three conneeted islands on which most of the present day population of Palau is concentrated (Fig. 1). These are: Koror, which is largely a residential and commercial district with hotel and resort facilities, Malákal, which is largely occupied by maritime industry such as fishing, boat repair facilities and warehouses, and Arakabesang where the District Administration Center is located.

During the Second World War, the population in the southern half of Palau was about 19,000 (in 1943). At that time many people were located on Babelthuap and Pelelieu, but the Japanese left and by 1952 the population dropped to about 2,000 people who were mostly concentrated around Koror.

By early 1966, the population in Koror and vicinity had risen to 4,975 and raw sewage from homes along the shore began to become a hazard to the health of the residents. Many of the latrines were situated over the water. These are called benjos. Water-borne diseases from raw sewage water could be conveyed to the local population through the consumption of oysters which had taken up bacteria or even pathogens through the gills. Scylla serrata, the mangrove crab, is considered a delicacy by Palauans and may also take up bacteria and pathogens from the raw sewage water. The terrestrial latrines located on high land may drain down over patches of tapioca or taro. This potentially could result in severe intestinal disorders such as amoebic dysentery, infectious hepatitis or typhoid fever. Wastes from the industrial complexes on Malakal Island also pour directly into the harbor without treatment. Public Health Department surveys showed fecal coliform contamination near the docking facilities and fishery center to reach 11,000,000 per 100 ml. After the Trust Territory Pacific Islands Health Services report was printed, certain areas were posted as off limits, but the signs were temporary and soon disappeared (Garner, 1972). In lagoon waters near the outfall from a hospital in Koror, fecal coliform levels reached 34,000,000 per 100 ml (Hardy and Hardy, 1972). Because the organic wastes had become too concentrated for the natural cleansing capacity of the local marine communities, the Public Health Department recommended the installation of a secondary sewage treatment plant for both the industrial area and the local residences.

Several sites were considered as possible locations for the secondary sewage treatment plant and sewage outfall site. Koror Harbor was soon

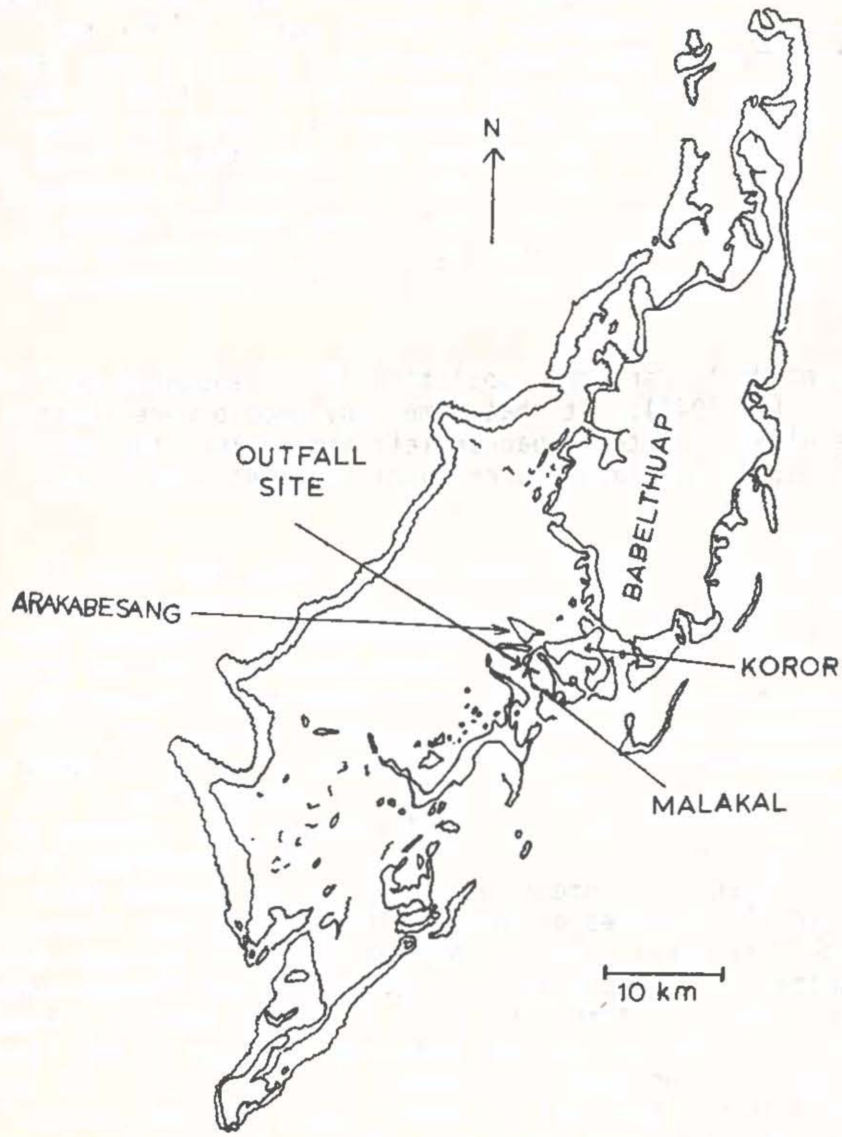

Fig. 1. Map of Palau showing location of proposed sewer outfall.

rejected. Although centrally located, the relatively shallow harbor with slow-moving water circulation would have required an extremely long pipeline to the outfall. The treated sewage would not have dispersed rapidly and would have passed over the oyster beds of Koror Harbor.

Toagel Mid-Channel site had several advantages as an outfall site. This is the channel between Babelthuap and Koror across which a bridge is being built and thus further construction would not add as much additional impact to the local ecology as would construction in a more pristine area. Of even greater importance were the very strong currents through the channel and the open bays at either end. These provided an effective mechanism for rapid dispersion of the treated waste water. The drawback of the Toagel Mid-Channel site was that its distance from the population centers of Koror, Malakal and Arakabesang would require a large financial investment to pipe the sewage over the long distance.

The site initially selected was in Lebugol Channel between Koror and Auluptagel Island (an island between Koror and Malakal). The site had the advantages of close proximity to the population centers and strong currents for rapid dispersion and mixing of the treated sewage water. However, despite the currents of 2 to 3 knots, the sewage water would eventually meander among the Rock Islands in Iwayama Bay and wastes would begin to accumulate there. Because of strong feelings of nearby residents against the construction of the secondary sewage treatment plant being built in this location, the District Legislature and members of the Congress of Micronesia stated these objections and the sewage treatment plant was relocated to its present site on Malakal Island.

Description of the Site

The final location of the secondary treatment sewage plant was at the south end of Malakal Island, by the park and recreation area which is used for picnics and swimming, about 180 m southeast of the Micronesian Mariculture Demonstration Center. The sewage treatment plant sits a few meters above sea level on a flat land fill area enclosed by a sea wall at the base of a very steep hill, which rises 38 m above the sea. The southern point of Malakal Island extends about 413 m further south below tide level as a reef flat at a depth of 2 to 4 m, then abruptly drops at an angle of about 40° to a depth of 26 m where the coral reef ends but the soft sediment bottom continues to descend deeper. A channel marker stands at the southern tip of the reef flat (Fig. 2). According to present plans, the sewage outfall pipeline will extend from shore to just before the navigation marker where it will turn east and then branch into a "Y" over the steep slope of the reef. A causeway, along which the outfall pipe will be laid, is being constructed from shore towards the channel marker. The causeway was 213 m long at the time of our study. It measured 9 m wide. The dredging of material for this causeway created a region of bare sand 34 m wide to the west and another 21 m wide to the east of the causeway.

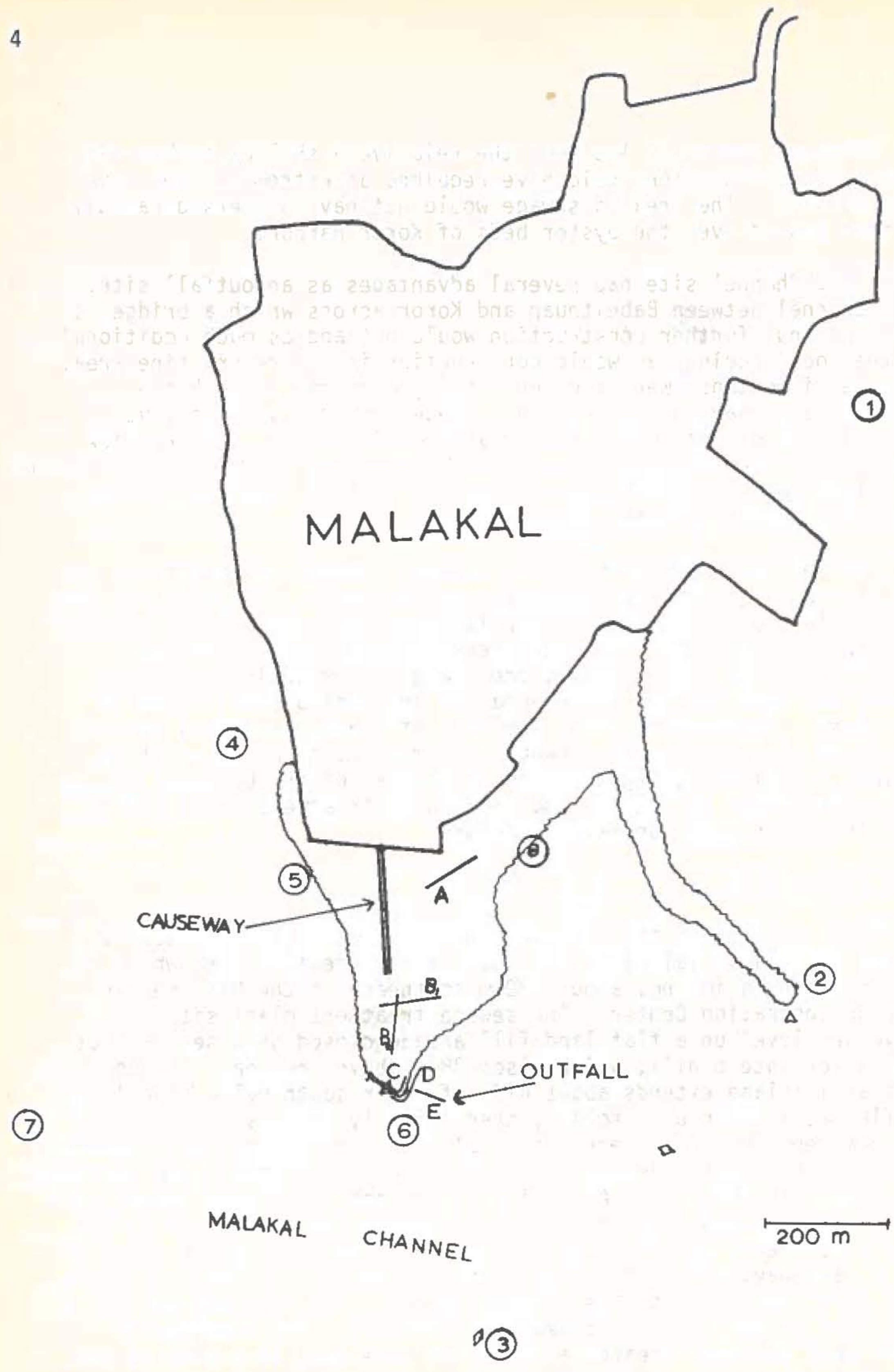

Fig. 2. Drawing of proposed sewer outfall site off Malakal Island with location of sampling sites (1-8) for physical, chemical and microbiological characteristics of the water. Location of transects A-E also shown. The triangle through which transect C runs marks the location of the channel marker.

The lagoon fringing reef which extends for over 400 m south from the southern point of Malakal Island (Fig. 2) consists of three physiographic regions: the flat, the margin and the slope. The lagoon fringing reef flat is subdivided into four biotic zones. An intertidal region of rubble and sand extends about 6.5 m out from the seawall at the southern tip of land. At the beginning of the subtidal region, a narrow (2.5 m) band of seagrass Enhalus acoroides lies between the intertidal rubble and the inner border of a zone of ramose Montipora at a depth of 0.6 meters MLLW. Twenty-five meters out from shore, Lobophora variegata became prevalent. The Montipora-Lobophora zone was 48 m in width. Transect A in Figure 2 is within the Montipora-Lobophora zone.

Fifty-seven meters from shore, the zone of ramose Montipora is bordered by a region of sand with isolated, scattered, mounds of coral. Flat mounds of Pocillopora meandrina, hemispherical mounds of Millepora tenera, mixed coral patches with Porites lutea as a predominant structural component but with alcyonaceans of the genera Sarcophyton and Sinularia especially prevalent in biomass, and scattered clumps of Acropora of several species were widely dispersed over the extensive sandy region of the lagoon fringing reef flat. Since the large coral mounds varied so greatly in the species which predominated, the region was called the Coral Patch and Sand Zone. The two transects labeled B in Figure 2 were both located within the Coral Patch and Sand Zone. The sand substratum in this zone varied in depth from 1.2 to 3 meters MLLW.

A dense and diverse community of scleractinians begins at the lagoon reef margin about 400 m from shore. The reef margin rises about 2.5 m from the reef flat to a depth of about 0.5 m MLLW. Transect C (Fig. 2) runs along the reef margin which is about 11 meters wide near the channel marker.

Beyond the lagoon reef margin, the lagoon reef slope descended along Transect E (Fig. 2) for 67 m to a depth of 26 m where the encrustate reef structure and scleractinian coral fauna ended. Beyond the lagoon reef slope, the silt and sand substratum continued to descend to greater depths.

Scope of Work

The biotic community around Malakal Harbor is extremely rich in coral and fish diversity. Because the sewage outfall line has not yet been completed, the marine community is still in a relatively unmolested state. To document the present conditions to serve as baselines for possible future investigations, the Trust Territory Environmental Protection Board asked the University of Guam Marine Laboratory to obtain the following information.

1. The extent and magnitude of surface and sub-surface currents at the proposed outfall diffuser site were to be determined so that reliable predictions on plume dispersion and dilution could be developed.

2. The species composition and the relative abundance and distribution of component species of algae, fish, hermatypic corals and other macro-invertebrates were to be documented so that future comparisons of the biota can be made to assess the impact of the sewage plant on the biota.

3. Water chemistry (NO_3-N, PO_4-P), physical characteristics (temperature, salinity and dissolved oxygen) and coliform bacterial analyses were to be measured so that the effects of the sewage plant on water quality could be evaluated.

Personnel

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Roy T. Tsuda, Ph.D., Director, Marine Laboratory, University of Guam (Marine plants).

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METHODS

Study Site

The field work was performed at the outfall site off the south end of Malakal Island from 8 January to 11 January 1976. The physical description of the site including the reef's biotic zones, physical morphology, depth gradients, and the locations of the sewage treatment plant, causeway and channel marker are given on page 2. The locations of transects along which data on benthic biota were taken are shown in Figure 2. Current studies were made by releasing drogues from about 10 m offshore from the channel marker (Fig. 2). Plankton samples were taken between the channel marker and the lighthouse about 670 m towards the east. Water samples for the determination of temperature, salinity, dissolved oxygen, NO_3-N, PO_4-P, and coliform counts were taken at the locations indicated in Figure 2.

Water Chemistry and Microbiology

Offshore water samples at 8 stations (Fig. 2) were taken with a Van Dorn sampler lowered to predetermined depths and triggered by a messenger. Temperature and salinity were measured with a YSI S-C-T meter. Oxygen was measured with a YSI oxygen meter. Subsamples were taken from the Van Dorn sampler and frozen for later analyses of NO_3-N and PO_4-P. The NO_3-N and PO_4-P samples were taken to Guam frozen and were analyzed at the University of Guam Water Resource Research Center according to the methods of Strickland and Parsons (1968). Subsamples were also obtained from the Van Dorn sampler for coliform analysis. The coliform analyses were performed using the membrane filter method (A.P.H.A. 1971). Fecal coliforms were cultured on Difco M-FC medium at 44.5±0.5°C; total coliforms were cultured on Difco M-Endo medium at 35.0±0.5°C.

Water Circulation

At one hour intervals, on the half-hour, from 0830 January 8 to 0730 January 9, pairs of drogues were released from about 10 m offshore of the channel marker (the triangle below C in Figure 2) and picked up one hour later. When picked up, the positions to which they had drifted during the hour were determined by triangulation from three landmarks with a hand-bearing compass. The position was plotted on a chart. Wind speed and direction were determined with a Belfort anemometer so that the possible influence of wind on the movements of the current-measuring drogues could be assessed.

Relative tide levels were obtained from readings on a board painted with lines at 6 inch depth intervals and tied to the channel marker. These observed tide levels were then compared to the readings in the tables of predicted tide levels for Koror, Palau, Western Caroline Islands, put out by the Office of the District Administrator, Trust Territory of the Pacific Islands.

The pair of drogues consisted of one with the vane 1 meter deep and the other with the vane 5 meters deep. The channel marker by which they were released was within a few meters of the proposed location of the sewer outfall diffusers.

Biota

Transects--Five transects were each run along lines 67 to 100 m long and marked in 1 m intervals. The locations of the transects are given in Figure 2. Transect A (100 m long) lies entirely within the *Montipora-Lobophora* zone, transects B_1 and B_2 (each 100 m long) entirely within the Coral Patch and Sand Zone, transect C (100 m long for corals, 82 m long for other taxa) along the reef margin and transect D (100 m long) along the 4.6 m isobath in the upper lagoon fringing reef slope. A sixth transect, Transect E, extends from the lagoon reef margin down the face of the lagoon reef slope for a distance of 67 meters along the transect line where the reef gives way to a sand and silt substratum at a depth of 26 m.

Algae--The algal community in each of the five zones was analyzed by placing a small gridded quadrat (25 cm x 25 cm) at 5-meter intervals on the 100 m line transect. The quadrat frame consisted of 25 squares and, thus, provided 16 interior "points" where the grid line intersected. Each species was recorded at every "point" at which it occurred. If no alga was found under the points, then whatever was present, e.g., sand, dead coral, live coral, was recorded. In many cases, the fine filamentous-like algae were difficult to identify in the field. In such cases, specimens were collected and later identified in the laboratory. Percent cover was obtained by dividing the number of points at which the species was recorded as a percent of the total number of points per transect, i.e., 16 x Number of Tosses = Total Number of Points. A checklist of algae was also made in each transect area.

Corals--Alcyonacean and scleractinian coral communities were analyzed independently, both using line transect sampling techniques. The alcyonaceans along transects A, B_2, C and D and the scleractinians along transects B_1 and D were sampled using the point-centered quarter or point-quarter technique (Cottam et al., 1953). Ten points at 10 m intervals along each 100 m transect line were used as the sample points in the alcyonacean survey while a hammer was tossed 2 to 5 meters to the left (when facing lagoonward) of each 10 m interval for the sample points in the scleractinian survey. The axes of the quadrants in the scleractinian survey were determined by the orientation of the handle of the hammer and a line perpendicular to the handle at the sample point.

The alcyonacean or scleractinian nearest the sample point in each quadrant was located and the specific name, diameter of the colony, and the distance from the center of the colony to the sample point was recorded. If no colony was observed within a maximum distance of 5 m for alcyonaceans or 2 m for scleractinians, the quadrant was recorded as having no colony with a diameter of zero and a sample point to colony distance of 5 m or 2 m, respectively. Therefore, the unit area of the alcyonacean survey quadrant was 19.6 m^2 and the unit area of the scleractinian survey quadrant was π m^2.

The average dominance value for each species is defined as the average areal coverage of individuals of the species encountered in the sampling. The following calculations were used to estimate the population and community parameters:

$$\text{total density of all species} = \frac{\text{unit area}}{(\text{mean point-to-point distance})^2}$$

$$\text{relative density} = \frac{\text{individuals of species}}{\text{total individuals of all species}} \times 100$$

$$\text{density} = \frac{\text{relative density of species}}{100} \times \text{total density of all species}$$

$$\text{percent coverage} = \text{density of species} \times \text{average dominance value for species}$$

$$\text{relative percent coverage} = \frac{\text{percent coverage for species}}{\text{total coverage for all species}}$$

$$\text{frequency} = \frac{\text{number of points at which species occurs}}{\text{total number of points}}$$

$$\text{relative frequency} = \frac{\text{frequency value for species}}{\text{total frequency values for all species}} \times 100$$

$$\text{importance value} = \text{relative density} + \text{relative percent coverage} + \text{relative frequency}$$

A more detailed analysis of the overall species diversity was achieved by making a collection in the general area on both sides of the transect line.

Scleractinian coral communities along transects A, B_2, and C were sampled using the line-intercept technique (Strong, 1966; Cox, 1972). The specific names and the lengths of the intervals intercepted were recorded for each colony lying beneath each 100 m transect line. The population and community parameters were estimated with calculations similar to those made with data from the point-centered quarter technique (cf. Cox, 1972) except that the number of intervals in which the species occurred divided by the total number of transect intervals was used in place of frequency and we have termed this measure "occurrence." Relative occurrence is used in place of relative frequency in the calculation of importance value from line-intercept sampling data.

The presence of additional coral species not encountered in the transect samples and an estimation of their relative abundances were determined for each reef zone from observations made along the transects themselves and from the general area located between the shoreline at Transect A and the lagoon slope at Transect E. Estimation of species abundance was made by using the following scale and symbols: D = dominant - the predominant coral within a reef zone, A = abundant - a species generally distributed throughout a reef zone, C = common - a species generally present but with a patchy distribution pattern within a reef zone, O = occasional - a species with only localized distribution within a reef zone, and R = rare - a species represented by only one or two occurrences within a reef zone.

Echinoderms--The abundances of large echinoderms and other macroinvertebrates were quantified by swimming the length of the transect and counting the number of invertebrates within one meter of the line to either side. A meter stick was held perpendicularly to the line with one end touching the line as the observer swam along the transect. Areas of ten square meters were examined by counting the animals along one side of the line for intervals of 10 m. The animals in a similar 10 meter long rectangular area were then counted along the other side of the transect line. This process was repeated along the entire length of the transect and data were recorded separately for the different zones.

Fishes--A diver swimming a transect line counted fishes within a meter of either side of the line. Some specimens were collected with microspears to verify identifications. The transect locations and distances were the same as those listed above, with some differences. Fishes along Transect A were only enumerated along the first 46 m of the transect. At this point, there was a shift in the substratum from dominance of Montipora to dominance of Lobophora and, rather than mix the two faunas in the counts, the count was stopped. Thus, the data from this transect reflect the fish fauna only of the Montipora-dominated area. Separate fish counts were made at Transect E from the reef crest to a depth of 18 m and from 18 m to a depth of 26 m.

Plankton--One daytime plankton tow and one nighttime plankton tow were each made beginning a few meters off the channel marker (the triangle below C in Figure 2) and running to within a few meters of a light house to the east in Malakal Harbor. Each tow took about 15 minutes and ran for about 660 m. Tows were taken just below the surface with a conical net which had an opening 45 cm in diameter and a mesh aperture size of 0.2 mm.

Samples were preserved with 10% formalin in sea water. Subsample counts on 1/20 or 1/25 of the entire sample were made in the laboratory with a binocular microscope.

RESULTS AND DISCUSSION

Physico-Chemical Characteristics of the Water

Data on the physical and chemical characteristics of the waters in the area of the sewer outfall are presented in Table 1. These data give the impression that temperature declines with depth and salinity increases with depth at all stations and this is indeed the case. The data are summarized with respect to depth in Table 2. The water temperatures at a depth of 1 meter are significantly warmer than the temperatures at 5 meters depth ($t_{[11]} = 3.29$, $p < .01$) and the salinity at 1 meter is significantly less than at 5 meters ($t_{[11]} = 3.5$, $p < .01$). The apparent increase in concentration of dissolved oxygen with depth could be due to chance ($F_{[2,16]} = 0.388$). As would be expected, temperature, salinity and dissolved oxygen concentration are far more variable within 1 meter of the surface than at greater depths as indicated by the coefficients of variation calculated in Table 2.

Since temperatures and salinities vary significantly with depth (Table 2), we compare the data from different stations at given depths (Table 1) and by doing so we can now see that the offshore stations (3 and 7) have higher temperatures and lower salinities at depths of 1 and 3 meters (Table 3) than do the nearshore and Malakal Harbor stations (1, 2, 4, 5, 6 and 8). Differences are significant at the 10% level; we need more samples to demonstrate a difference at the 5% significance level. At a depth of 5 meters, the characteristics of the water are more uniform from station to station than at shallower depths.

The phosphate levels were low at all 8 stations (Table 1). In Table 4 the phosphate levels in the waters surrounding the south end of Malakal are compared with levels in samples taken in a similar manner near other Micronesian islands of Moen (Truk), Ebeye (Kwajalein) and Dalap (Majuro). No samples taken at sewer outfalls in operation were included in Table 4. The phosphate levels in the waters around Moen, Ebeye and Majuro did not differ significantly from each other ($F_{[2,15]} = 0.81$, $.5 > p > .25$), but the phosphate levels in the samples around Malakal were very significantly lower ($t_{[24]} = 7.047$, $p << .001$).

The average nitrate level was also lower at Koror (Table 4), but a wide range of nitrate levels was recorded at Koror and the difference in mean nitrate level did not differ significantly from the other island groups listed in Table 4 ($F_{[3, 22]} = 1.31$, $.5 > p > .25$).

Microbiological Characteristics of the Water

The waters around the south end of Malakal Island were very clean of fecal and total coliform bacteria concentrations (Table 1). The only

Table 1. Physical, chemical and microbiological characteristics of the lagoon water at and adjacent to the proposed outfall site. Malakal, Palau. January 9, 1976.

Station	Depth (m)	Temp. (°C)	Sal. ($^o/_{oo}$)	D.O. (ppm)	NO_3-N (μg-at/l)	PO_4-P (μg-at/l)	FC (per 100 ml)	TC (per 100 ml)
1	1	30.1	31.4	5.0	.09	.18	110	140
	3	29.6	32.3	5.4	.33	.18	0	20
2	1	29.9	32.6	5.2	--	.14	0	0
	3	29.1	32.6	5.2				
	5	29.0	32.6	5.4				
3	1	30.8	31.6	5.3	.15	.14	0	0
	3	29.9	32.0	5.2				
	5	29.1	32.7	5.3				
4	1	29.4	32.5	5.4	.32	.15	0	0
	3	29.3	32.8	5.4				
	5	29.3	32.8	5.5				
5	1	30.5	32.0	5.3	.20	.10	0	0
6	1	30.4	31.9	5.4	.31	.14	0	0
	3	29.9	32.8	5.6				
	5	29.3	33.0	5.3				
	10	29.5	32.9	5.6				
7	1	32.0	31.1	5.0	.17	.10	0	0
	3	30.1	31.9	5.4				
	5	30.0	32.2	5.6				
8	1	29.9	32.1	5.9	.08	.15	0	0

Table 2. Change in physical characteristics of the lagoon water with depth from the data in Table 1. Coefficient of variation (CV)=(s/$\bar{Y}$) 100.

Depth (m)	n	Temperature (°C) $\bar{Y} \pm s$	CV	Salinity (°/oo) $\bar{Y} \pm s$	CV	Dissolved oxygen (ppm) $\bar{Y} \pm s$	CV
1	8	30.4 ± 0.8	2.58	31.9 ± 0.5	1.62	5.31 ± 0.28	5.37
3	6	29.6 ± 0.4	1.31	32.4 ± 0.4	1.21	5.37 ± 0.15	2.81
5	5	29.3 ± 0.4	1.33	32.7 ± 0.3	0.91	5.42 ± 0.13	2.40

Table 3. Temperature and salinity of offshore waters (Stations 3 and 7, Figure 2) and nearshore and harbor waters (Stations 1, 2, 4, 5, 6 and 8) compared at 3 depths.

Depth (m)	Offshore $\bar{Y}$ s	Nearshore $\bar{Y}$ s	df	t_s	p
TEMPERATURE (°C)					
1	31.4 ± 0.8	30.0 ± 0.4	6	2.25	$.05 < p < .1$
3	30.0 ± 0.1	29.5 ± 0.4	4	2.48	$.05 < p < .1$
5	29.6 ± 0.6	29.2 ± 0.2	3	2.76	n.s.
SALINITY (°/oo)					
1	31.4 ± 0.4	32.0 ± 0.4	6	2.32	$.05 < p < .1$
3	32.0 ± 0.1	32.6 ± 0.2	4	5.26	$.05 < p < .1$
5	32.4 ± 0.4	32.8 ± 0.2	3	1.27	n.s.

Table 4. A comparison of nitrate and phosphate levels in waters surrounding the south tip of Malakal Island with the levels in waters around some other Micronesian islands.

Island	NO_3 - N (µg-at/l) $\bar{Y} \pm s$, w, n	PO_4 - P (µg-at/l) $\bar{Y} \pm s$, w, n
Koror, Palau[a]	.206 ± .102, .08-.33, 8	.142 ± .029, .10-.18, 9
Moen, Truk[b]	.270 ± .019, .25-.29, 5	.230 ± .012, .22-.25, 5
Ebeye, Kwajalein[c]	.271 ± .076, .2-.4, 7	.214 ± .038, .2-.3, 7
Dalap, Majuro[d]	.233 ± .052, .2-.3, 6	.233 ± .082, .2-.4, 6

a. Data from Table 1 of this report.

b. Data from Table 1 in Tsuda et al., 1975. The data from Station 1, at the part of a sewer outfall in operation, were excluded.

c. Data from Table 1 in Amesbury et al., 1975a. The data from Station 6, at the end of a sewer outfall in operation, were excluded.

d. Data from offshore Stations 9-14 in Table 1 in Amesbury et al., 1975b.

coliform bacteria recorded at all were at Station 1 near the major port facilities of Palau, where the warehouse, docking and fishing industry facilities are located. Even at Station 1, the coliform counts lie within the U. S. Public Health Service water quality standards for fecal coliform concentrations set at 200 per 100 ml. This is at a much lower level than the readings taken several years ago by the U. S. Public Health Service near the docks and fishing industry center (page 1), but they may have taken their samples directly off the piers.

Water Circulation

Malakal Island is oriented in a north-south direction and extends into the center of Malakal Harbor which is a wide channel running in a northwest-southeast direction (Fig. 1). During flood tide, the water moves past Malakal Island in a northwest direction towards the narrow entrance to the harbor between Ngargol Island to the north and Urukthapel Island to the south. During ebb tide, the water moves in a southeast direction towards Ngadarak Reef, probably flowing out of Malakal Harbor through Ngell Channel to the north of the reef or through Malakal Pass to the south.

The direction and distance travelled by drift drogues in one-hour periods are plotted for 1-meter drogues in Figure 3 and for 5-meter drogues in Figure 4. The label numbers of the drogues in Figures 2 and 3 correspond to the numbers in Table 5 where the time the drogue was in the water is given along with a quantified presentation of distance moved and speed for both the 1-meter and 5-meter drogues. The direction and speed of the wind are given for each hour in Table 5 and the wind vectors are plotted in Figure 3. We could find no correlation between wind speed or direction and the direction of water movement.

The direction of water movement correlates well with the stage in the tidal cycle. The tides are graphed in Figure 3. The solid lines connecting the predicted tide levels are from the January 1976 Tide Table distributed by the Office of the District Administrator, Trust Territory of the Pacific Islands, Koror, Palau and the dots are the actual tide readings from the measuring board we attached to the Channel Marker. The dots represent the actual tide levels at the times we picked up drogue numbers 2 through 23, in order. Drogues 9-12 and 21-23 were set out during flood tides (Table 1; tide chart in Fig. 3) and all these drogues were carried in a northwest direction (Figs. 3 and 4). Drogues 3-6 and 14-19 were set out during ebb tides and all but 3 and 4 were carried to the southeast. Drogues 3 and 4 were found essentially directly off Malakal Island, neither to the northwest or southeast, and were probably retrieved during the period of change in direction of water movement.

Drogues were set out in pairs, one with a vane at a depth of 1 meter, the other with a vane at 5 meters. Twenty-one out of twenty-three pairs moved in the same direction (the exceptions being numbers 5 and 13) so the

Table 5. Distance and speed of 1-meter and 5-meter drift drogues, and direction and speed of wind, Malakal, Palau. January 8-9, 1976.

			1 METER		5 METER			
Drogue	Start	ΔT (hrs.)	Dist. (NM)	Speed (Kts)	Dist. (NM)	Speed (Kts)	Wind Dir.	Wind Kts
Jan. 8								
1	0830	1	.29	.29	.33	.33	106	6.0
2	0930	1	.20	.20	.20	.20	151	10.0
3	1030	1	.16	.16	.14	.14	098	8.5
4	1130	1	.05	.05	.09	.09	105	8.5
5	1230	1	.22	.22	.29	.29	060	6.0
6	1330	1	.38	.38	.36	.36	095	9.5
7	1430	1	.31	.31	.25	.25	090	9.0
8	1530	1	.21	.21	.13	.13	087	4.5
9	1630	1	.37	.37	.32	.32	110	10.0
10	1730	1	.24	.24	.23	.23	110	6.5
11	1830	1	.09	.09	.09	.09	102	8.0
12	1930	1	.08	.08	.04	.04	097	8.5
13	2030	1	.05	.05	.05	.05	100	5.0
14	2130	1	.26	.26	.22	.22	100	11.0
15	2230	1	.58	.58	.40	.40	040	3.5
16	2330	1	.40	.40	.40	.40	066	4.0
Jan. 9								
17	2430	1	.38	.38	.40	.40	095	5.0
18	0130	1	.27	.27	.25	.25	130	12.0
19	0230	1	.05	.05	.07	.07	100	5.0
20	0330	1	.09	.09	.06	.06	103	6.0
21	0430	2	.23	.12	.18	.09	150	7.5
22	0630	1	.28	.28	.36	.36	125	10.0
23	0730	1	.21	.21	.24	.24	124	11.5

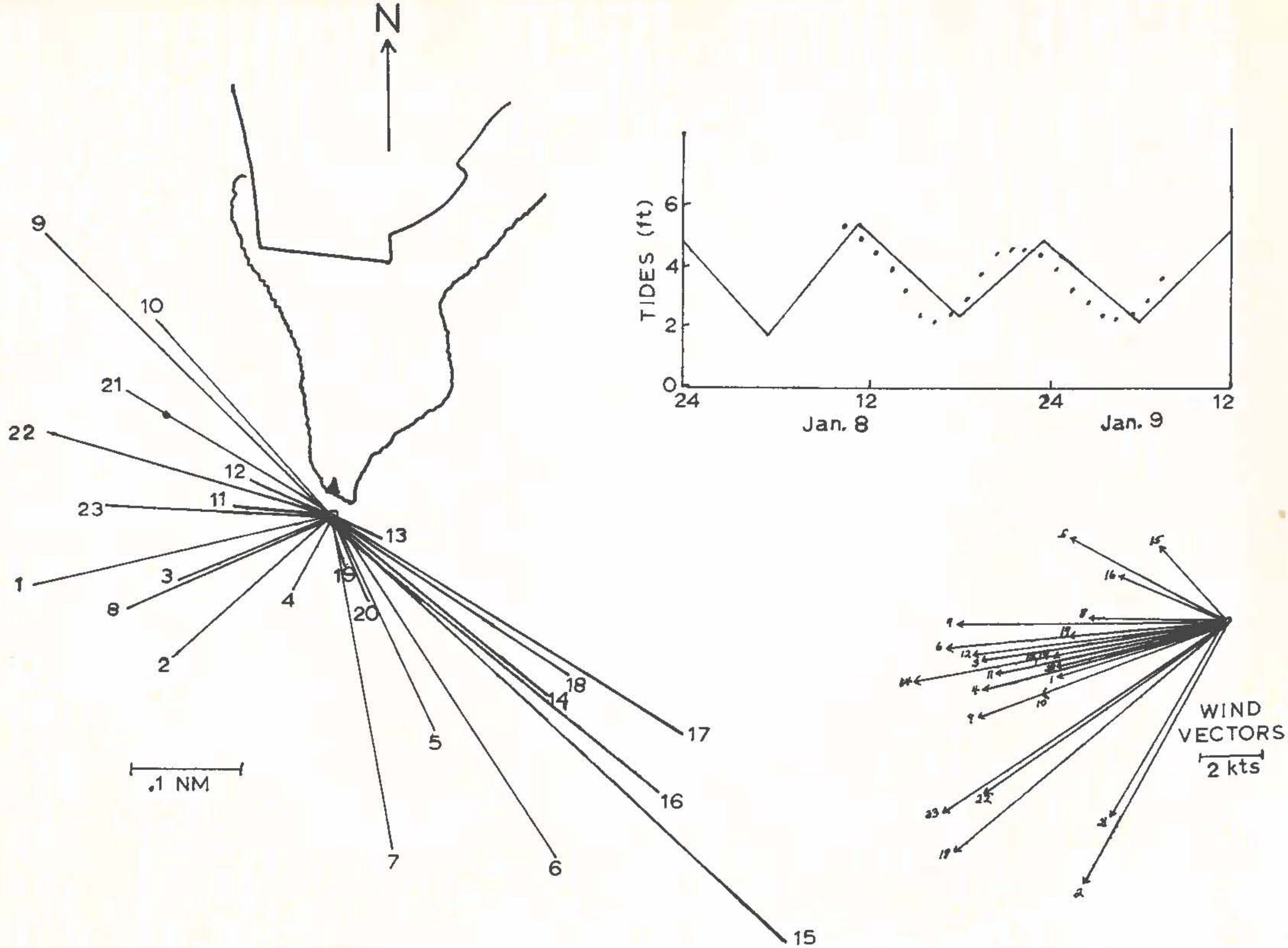

Fig. 3. Direction and distance of 1-meter drift drogues. Wind vectors and tidal range also shown. Malakal, Palau. January 8-9, 1976.

Fig. 3. Direction and distance of 1-meter drift drogues. Wind vectors and tidal range also shown. Malakal, Palau. January 8-9, 1976.

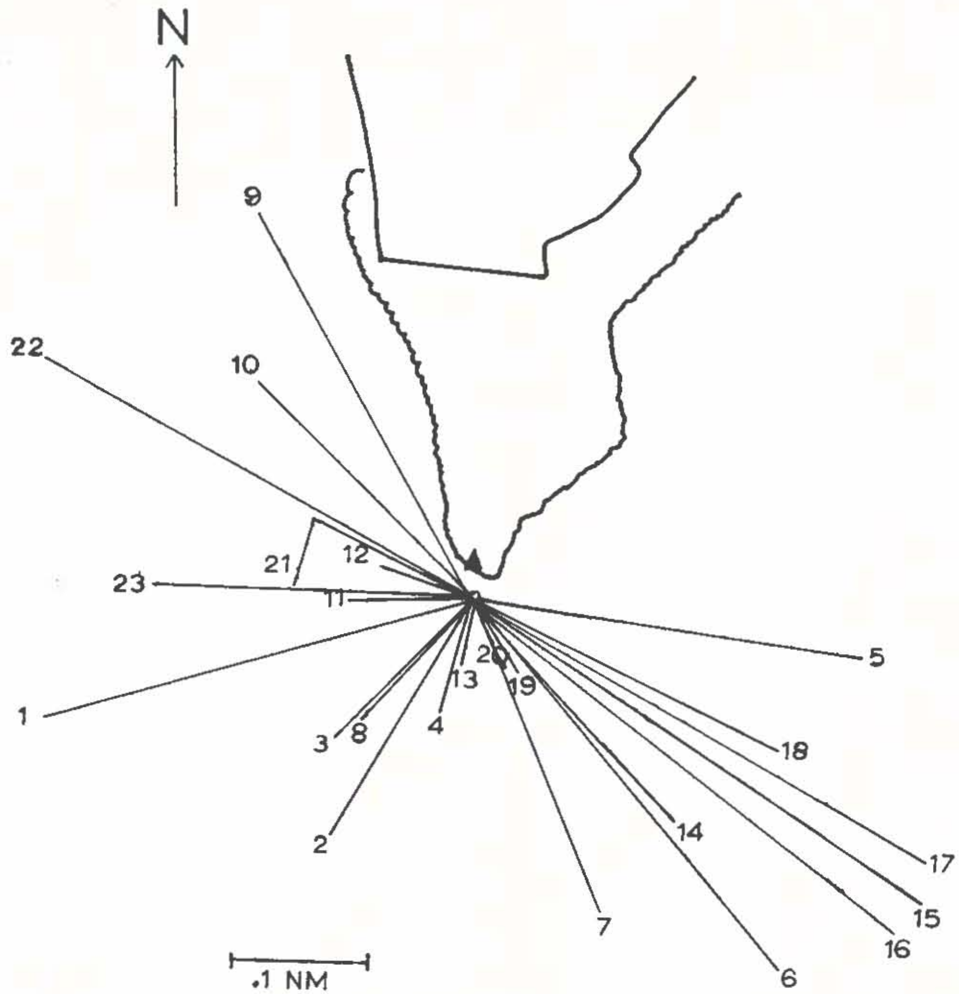

Fig. 4. Direction and distance of 5-meter drift drogues. Malakal, Palau. January 8-9, 1976.

data for drogues at the two depths were not taken independently. Therefore we compared the speed of water movement at the two depths with paired comparisons tests. Both the t-test for paired comparisons ($t_{[22]} = 1.08$, n.s.) and randomized block anova for paired comparisons ($F_{[1, 22]} = 1.17$, n.s.) showed there was no significant difference in speed of water movement between 1 and 5 meters depth. However, the speed of water movement at 1 and 5 meters varied together very significantly with time ($F_{[22,22]} = 22.42$, $p \ll .001$).

Since the speed of water movement varied significantly with time, we compared the speed of water movement during the flooding tides (drogues number 9-12 and 21-23) with the speed of water movement during the ebbing tides (drogues number 3-6 and 14-19). During flood tide the water movement appeared to be slightly slower (.20 ± .11 knots) than during ebb tide (.27 ± .14 knots), but the difference was not significant ($t_{[34]} = 1.74$).

Since our study was made during neap tides with a tidal range of 3.7 ft on 8 January and 3.2 ft on 9 January, the speed of water movement was probably less than during spring tides when the tidal range is 6 ft (19 January).

Additional Observations on the Construction of the Sewer Line

In order to lay the outfall pipe from the secondary treatment sewage plant to the outfall near the channel marker (the triangle near "C" in Fig. 2), a causeway was being constructed by dredging with a crane. At the time of our study, the causeway was 213 m long (Fig. 2). The dredging operation was causing a great deal of siltation by loosening the substratum in the areas of reef from which material was taken along the sides of the causeway. The width of this band was 21 m to the east and 34 m to the west. The causeway itself was 9 m wide and an additional source of siltation material came from the loose and fine-grained portion of the dredged material that was piled onto the causeway to construct it. At the time of our survey, 13,632 m^2 of the lagoon fringing reef flat was either dredged or covered by the causeway. If the causeway is eventually extended to near the end of the outfall pipe, the causeway and dredged areas will occupy approximately 26,432 m^2 of the lagoon fringing reef flat.

A lot of the fine-grained loose material was being stirred up and carried away from the base of the causeway and from the dredged areas, to the east or to the west depending on the tidal state. The horizontal visibility in the water away from the influence of siltation was 15 to 18 meters. When the water carried silt over the area, visibility dropped to between 1 and 2 meters.

Reef-building corals were clearly under stress in areas of siltation, although many were able to remove silt with a ciliary-mucus method. The production of mucus in large quantities is a very expensive physiological process for marine invertebrates. The ability of some hermatypic corals to cope with this stress from siltation was remarkable. Some corals such as Pocillopora damicornis were killed.

Biota

Algae--A total of 32 species of algae and one sea grass were observed in the vicinity of the proposed sewer outfall. Table 6 presents a check-list of the algae and sea grass, as well as the percent cover of the dominant algae on each of the five transects.

The Lagoon Fringing Reef Flat was divided into two zones - the Montipora-Lobophora zone and the Coral Patch and Sand zone. Algal cover in the Montipora-Lobophora zone (Transect A) was about 93 percent. Lobophora variegata (24%) and Padina tenuis (21%) were the most conspicuous foliose algae covering the bottom. The low-lying Jania capillacea and Sphacelaria tribuloides, although not conspicuous, were very abundant on the fragmented dead Montipora branches. Bornetella sphaerica was common under the loose dead Montipora branches.

The Coral Patch and Sand zone (Transect B_1) was occupied by a different algal community. The majority of the algae (49% algal cover) on the coral patches consisted of very short turfs, usually less than 1 cm high. Gelidiopsis intricata (9%), Polysiphonia sp. (17%) and Calothrix crustacea (6%) were the predominant algae composing the turf community. Schizothrix calcicola was the only alga found on the sand and appeared as a reddish film.

The Lagoon Fringing Reef Margin (Transect C) was rich in terms of coral cover. Algal cover was only 28 percent. Twenty-four species of algae were present in this zone with most of the algae occurring as a low-lying turf. Halimeda macrophysa was conspicuous in the crevices and covered about 3 percent of the transect.

Algae covered about 36 percent of the lagoon reef slope (Transects D and E). The algal species in this zone were very similar to those present on the reef margin. A red and a purple unidentified crustose coralline algae were the most conspicuous algae in water below 20 feet. Calothrix crustacea, Lobophora variegata, and Jania capillacea were much more abundant on the slope than on the margin. Algae were absent on the sandy slope below the depth of 26 meters.

Octocorals--Transects in four zones of the reef off the south end of Malakal Island were sampled using the point-centered sampling technique. The abundances, size distributions and percent cover by alcyonaceans in these zones are given in Table 7. As we move from shore to the lagoon fringing reef slope the number of species, species diversity, number of genera, and number of families of octocoral increase. However, we find that average colony size decreased with distance from shore (Table 8). Along the same gradient that average colony size (surface area in dm^2)

Table 6. Presence of marine plants (X), and percent cover of the dominant species on the five transects at the proposed sewer outfall site off Malakal, Palau. January, 1976.

SPECIES	TRANSECT A (N=20)	B_1 (N=20)	C (N=17)	D (N=20)	E (N=12)
CYANOPHYTA					
Calothrix crustacea Thuret		6	2	8	
Hormothamnion enteromorphoides B. & Fl.				X	
Microcoleus lyngbyaceus (Kutz.) Crouan	X	X	2		
Schizothrix calcicola (Ag.) Gomont	X	11	X	X	
CHLOROPHYTA					
Bornetella sphaerica (Zanardini) Solms-Laubach	X				
Caulerpa racemosa (Forskal) J. Ag.			X		
Chlorodesmis fastigiata (C. Ag.) Ducker			X	X	
Dictyosphaeria cavernosa (Forskal) Boerg.	X		X		
Dictyosphaeria versluysii W. v. Bosse	X				
Halimeda macrophysa Askenasy			3	X	
Halimeda opuntia (L.) Lamx.	1	X	1	X	
Neomeris vanbosseae Howe	X				
Udotea javensis (Montagne) A. & E.S. Gepp	X		X		
Valonia fastigiata Harvey	X		X		
Valonia ventricosa J. Ag.	1		X		
PHAEOPHYTA					
Dictyota friabilis Setchell	1		4	X	1
Lobophora variegata (Lamx.) Womersley	24	1	3	9	14
Padina jonesii Tsuda			X		
Padina tenuis Bory	10				
Sphacelaria tribuloides Meneghini	21		4	4	
RHODOPHYTA					
Actinotrichia fragilis (Forskal) Boerg.	X		X	X	
Amphiroa foliacea Lamx.	2			X	
Amphiroa fragilissima (L.) Lamx.			X		
Centroceras apiculata Yamada			4	4	
Gelidiopsis intricata (Ag.) Vickers		9			
Gelidium pusillum (Stackh.) Le Jolis		2	3		
Hypnea pannosa J. Ag.		3	X	X	
Jania capillacea Harvey	35	X	X	8	
Jania tenella Kutz.				X	
Laurencia paniculata (Ag.) J. Ag.	X		X	X	
Polysiphonia sp.	X	17	2	4	
Porolithon onkodes Foslie			X	X	
Unidentified crustose corallines					21
SEA GRASS					
Enhalus acoroides (L.f.) Royle	X				
Number of Algal Species Per Zone	19	10	24	18	3

decreased, the abundance of octocoral colonies per 100 m^2 was increasing significantly (Table 9). The total percent of substrata occupied by octocorals did not change significantly (Table 9); the increase in abundance of octocoral colonies along the gradient was offset by the decrease in average colony size.

The size distributions of octocoral colonies were significantly less variable on the lagoon fringing reef slope than were those on the reef margin and reef flat (Table 9, compiled from data in Table 7). Some colonies on the shallow reef flat grew far larger than any on the reef slope and the recruitment was also more prevalent on the shallow reef flat, yet colonies were more abundant on the reef slope. Mortality, recruitment and rate of turnover must be greater on the reef flat. Conditions may be more crowded for settling planulae on the lagoon fringing reef slope because of the greater amount of space occupied by hermatypic corals (Table 8). However, much of the space not occupied by corals on the reef flat is bare sand and therefore not suitable for settling planulae either.

Despite the more crowded conditions on the reef slope and the greater uniformity in colony size, the species diversity, number of species and number of higher taxa of octocorals increases greatly on the lagoon fringing reef slope (Table 8). In addition to the alcyonaceans listed in Table 7, a number of gorgonaceans were also observed but they were too widely scattered to be contacted in the point-quarter sampling program. They were listed when observed and counted along with alcyonaceans for the tally of octocoral taxa in Table 8. Gorgonaceans observed on Malakal included the scleraxonian Melithaea sp. (Melithaeidae) and the holaxonians Acalycigorgia sp. (Acanthogorgiidae) and Rumphella sp. (Plexauridae). All were observed on the reef slope. Rumphella was also observed on the reef margin.

One of the most striking differences between Atlantic and Pacific reef communities is the prevalence of gorgonaceans in the Atlantic and alcyonaceans in the Pacific. Because gorgonaceans are usually tall (up to 2 m tall) and branching, bushy, or fan-shaped, while alcyonaceans are usually low and massive (often over 1 m in diameter), mushroom-shaped or carpet-like (PlateI), the whole reef community gives a different impression of life form in the Atlantic when compared with the Pacific. However, when listing the species of octocorals on the south end of Malakal Island we found a difference in the nature of the variety of octocorals. In the Caribbean, there is a greater variety of closely related species of octocorals within an area; in Micronesia there is a greater variety of higher taxa of octocorals in an area. In the Caribbean, one could possibly observe up to 20 to 38 species of gorgonaceans in a single dive, but these species would all be within 4 or 5 families and one order (Gorgonacea) or possibly two (if we include Telestacea). Near the Malakal Sewer outfall one would observe only 18 species (or 19 if we include the octocoral Heliopora which is included with the reef-building corals in this report). However, these species are distributed among 7 families (or 8 if we include Helioporidae) and four orders are commonly represented in the area (Alcyonacea, Gorgonacea,

Table 7. Abundance, size distributions and percent cover by alcyonaceans in four areas of the lagoon fringing reef at Malakal. The procedures for calculating the statistics in the columns from data obtained by the point-quarter sampling technique are explained in the Methods section. When a species was observed in a zone but did not appear in samples, the observed presence is indicated by "+" in the first column. The standard symbols are used for the number of data (n), arithmetic mean ($\bar{Y}$), standard deviation (s) and range (w).

	n	No./100 m^2	Relative Density (%)	Size Distribution of Colonies in Terms of Areal Coverage (100 cm^2 Units) $\bar{Y}$	s	w	Percent Coverage	Relative Predominance in Surface Cover (%)	Importance Value
Lagoon Fringing Reef Flat									
Montipora-Lobophora Zone									
Sinularia sp. A.	2	0.25	100	19.0	±15.1	8.3 - 29.6	0.05	100	300
Coral Patch and Sand Zone									
Sarcophyton sp. A.	7	2.4	24	42.8	±44.5	0.9 - 119	1.0	65.6	122.7
Sinularia sp. A	14	4.9	48	8.7	±11.3	0.3 - 33.4	0.4	27.2	115.6
Sinularia sp. B	+								
Alcyoniid sp. A	7	2.4	24	4.7	± 5.6	0.3 - 16.5	0.1	7.2	51.1
Nephtheid sp. C	1	0.35	3	0.1			$4X10^{-4}$	$3X10^{-2}$	9.6

Total abundance of all species = 10/100 m^2
Percent coverage by all species = 1.56%

	n	No./100 m^2	Relative Density (%)	$\bar{Y}$	s	w	Percent Coverage	Relative Predominance in Surface Cover (%)	Importance Value
Lagoon Fringing Reef Margin									
Sarcophyton sp. A	15	8.9	55.6	9.7	± 8.1	0.6 - 30.0	0.9	72.1	174.4
Sinularia sp. A	2	1.1	6.9	13.0	±15.4	2.1 - 24.0	0.1	11.9	32.1
Sinularia sp. B	2	1.1	6.9	0.8	± 0.7	0.3 - 1.3	9X10	0.7	14.3
Sinularia sp. C	+								
Alcyoniid sp. A	7	3.9	24.1	4.6	± 6.4	1.1 - 18.6	0.2	15.0	65.8
Nephtheid sp. A	1	0.5	3.4	0.5			$2X10^{-3}$	0.2	10.3
Nephtheid sp. C	+								
Nephtheid sp. D	+								

Total abundance of all species = 16/100 m^2
Percent coverage by all species = 1.56%

	n
Nephtheid sp. C	+
Nephtheid sp. D	+

Total abundance of all species = 16/100 m^2

Percent coverage by all species = 1.56%

Table 7. (continued)

	n	No./100 m^2	Relative Density (%)	Size Distribution of Colonies in Terms of Algal Coverage (100 cm^2 Units) $\bar{Y}$	s	w	Percent Coverage	Relative Predominance in Surface Cover (%)	Importance Value
Lagoon Fringing Reef Slope									
Upper Slope (4.6 m depth)									
Sarcophyton sp. A	5	10.2	17.2	1.9	±1.3	0.6 - 4.0	0.2	9.9	46.2
Sarcophyton sp. B	5	10.2	17.2	2.3	±1.1	1.3 - 4.2			
Sarcophyton sp. C	+								
Sinularia sp. A	6	12.2	20.7	2.9	±1.5	1.0 - 4.8	0.4	18.0	57.8
Sinularia sp. B	1	2.0	3.4	14.7			0.3	15.0	23.2
Sinularia sp. C	2	4.1	6.9	1.7	±1.3	0.8 - 2.6	0.1	3.5	19.9
Sinularia sp. D	+								
Alcyoniid sp. A	7	14.2	24.1	4.7	3.4	0.7 - 8.4	0.7	34.0	81.9
Alcyoniid sp. B	1	2.0	3.4	1.3			$3X10^{-2}$	1.3	9.5
Nephtheid sp. A	1	2.0	3.4	1.1			$2X10^{-2}$	1.1	9.3
Nephtheid sp. B	1	2.0	3.4	5.2			0.1	5.3	13.5
Nephtheid sp. C	+								
Nephtheid sp. E	+								
Siphonogorgiid sp.	+								
Xeniid sp.	+								

Total abundance of all species = 59/100 m^2

Percent coverage by all species = 1.97%

Table 8. A comparison of four zones of the reef of the south end of Malakal Island in terms of numbers of taxa, proportions of surface areas occupied by different taxa, and species diversities.

	Montipora-Lobophora Zone	Coral Patch and Sand Zone	Lagoon Fringing Reef Margin	Lagoon Fringing Reef Slope
Percent cover of substrata				
algae	93	49	28	36
octocorals	0.05	1.6	1.2	2.0
stony corals	4.4	13.9	60.3	73.6
Number of families				
octocorals	1	2	3	7
stony corals	8	11	12	16
Number of genera				
algae	17	10	22	17
octocorals	1	3	5	8
stony corals	14	24	25	40
Number of species				
algae	19	10	24	19
octocorals	1	5	9	18
stony corals	33	74	90	92
fish	18	21	31	38
Species diversity (Shannon-Wiener index, $H' = -\Sigma p_i \log_2 p_i$				
algae	2.180	2.383	3.226	2.515
octocorals	-	1.652	1.659	2.825
stony corals	1.340	3.118	3.620	3.607
fish	2.982	3.010	2.590	3.896

Table 9. Aspects of the size distributions of alcyonacean colonies on a gradient from the lagoon fringing reef flat to the lagoon fringing reef slope.

	Coral Patch and Sand Zone	Lagoon Fringing Reef Margin	Lagoon Fringing Reef Slope
All alcyonacean species			
Colony areas in dm^2 ($\bar{Y} \pm s$)	5.5 ± 27.7	7.6 ± 8.2*	3.3 ± 3.1
Coefficient of variation of areas[a]	117.7 ± 13.0	107.2 ± 26.4*	63.4 ± 12.8
No./100 m^2	3.5 ± 1.4**	4.1 ± 4.4**	10.5 ± 4.0
Percent cover of substrata	1.56	1.20	1.97
<u>Sarcophyton</u> sp. A			
Colony areas in dm^2 ($\bar{Y} \pm s$)	42.8 ± 44.5	9.7 ± 8.1*	1.9 ± 1.3
Coefficient of variation of areas	104.0 ± 49.5	83.5 ± 23.6	68.4 ± 30.1
No./100 m^2	2.4	8.9	10.2
Percent cover of substrata	1.0	0.9	0.2
<u>Sinularia</u> sp. A			
Colony areas in dm^2 ($\bar{Y} \pm s$)	8.7 ± 11.3	13.0 ± 15.4	2.9 ± 1.5
Coefficient of variation of areas	129.9 ± 51.3	118.5 ±115.6	51.7 ± 18.5
No./100 m^2	4.9	1.1	12.2
Percent cover of substrata	0.4	0.1	0.4

* $p < .02$, by t - test, for the two statistics separated by the asterisk.
** $p < .001$, by t - test, for the two statistics separated by the asterisks.

a. Mean and standard deviation of the coefficient of variation $[(s/\bar{Y})100]$ of each species weighted for the sample size.

Coenothecalia and Stolonifera). Micronesia does not lack gorgonaceans but Caribbean reefs are essentially devoid of alcyonaceans, coenothecalians and stoloniferans.

A number of species of octocorals were probably overlooked because of our brief survey of many physical and biological aspects of the environment near the sewer outfall site. It should be noted that other tall arborescent or whiplike anthozoans of the genera Antipathes and Cirripathes were prevalent on the reef slope near the proposed sewer outfall site. One large bronze-colored Antipathes at a depth of 9 meters was 1.7 meters tall.

Reef-building corals--Malakal Island consists of both volcanic rocks and raised limestone deposits and is bordered at the study site by a well developed lagoon fringing reef. The reef is rather broad where it abutts against the island and tapers to a somewhat irregular blunt point in a southerly direction (Fig. 2). The overall shape of the reef is probably reflective of the underlying volcanic basement rocks and older reef development.

Structurally,the lagoon fringing reef can be broadly divided into a shallow reef-flat platform with relatively little surface relief that extends outward from the shore, a peripheral outer platform margin with a more pronounced and irregular surface relief, and a steep lagoon slope which dips downward to the flattened lagoon floor (Fig. 5). A preliminary snorkeling reconnaissance of the study area revealed a rather conspicuous zonation pattern of the corals which is reflective of the differences in environmental factors or gradients of such factors acting upon various parts of the reef as a whole.

The reef flat can be divided into an inner region about 48 meters wide called the Montipora-Lobophora zone and an outer Coral Patch and Sand zone. The Montipora-Lobophora zone is characterized by the predominance of ramose clusters of Montipora digitata and a brown alga, Lobophora variegata, growing on a substrate composed mostly of stick-like coral rubble. This zone is slightly shallower than the wider Coral Patch and Sand zone and this is subject to greater environmental stress, particularly from emersion during low spring tides (Fig. 5). Although Table 10 lists a fewer known number of species for the lower lagoon slope, which is probably due to incomplete collecting in the latter because the coral authority on this trip could not use scuba (for medical reasons), the Montipora-Lobophora zone is actually more depauperate in number of coral species than any other. Many of the species listed here are occasional and rare observations, represented only by one or two sightings in the entire zone. The ramose Montipora clumps and thickets are mostly dead with living patches and fragments scattered here and there which accounts for the relatively high coral density and low percentage of substratum covered values recorded there (Table 11a).

The Montipora-Lobophora zone grades irregularly into a broad Coral Patch and Sand zone about 340 meters wide. The substratum here consists

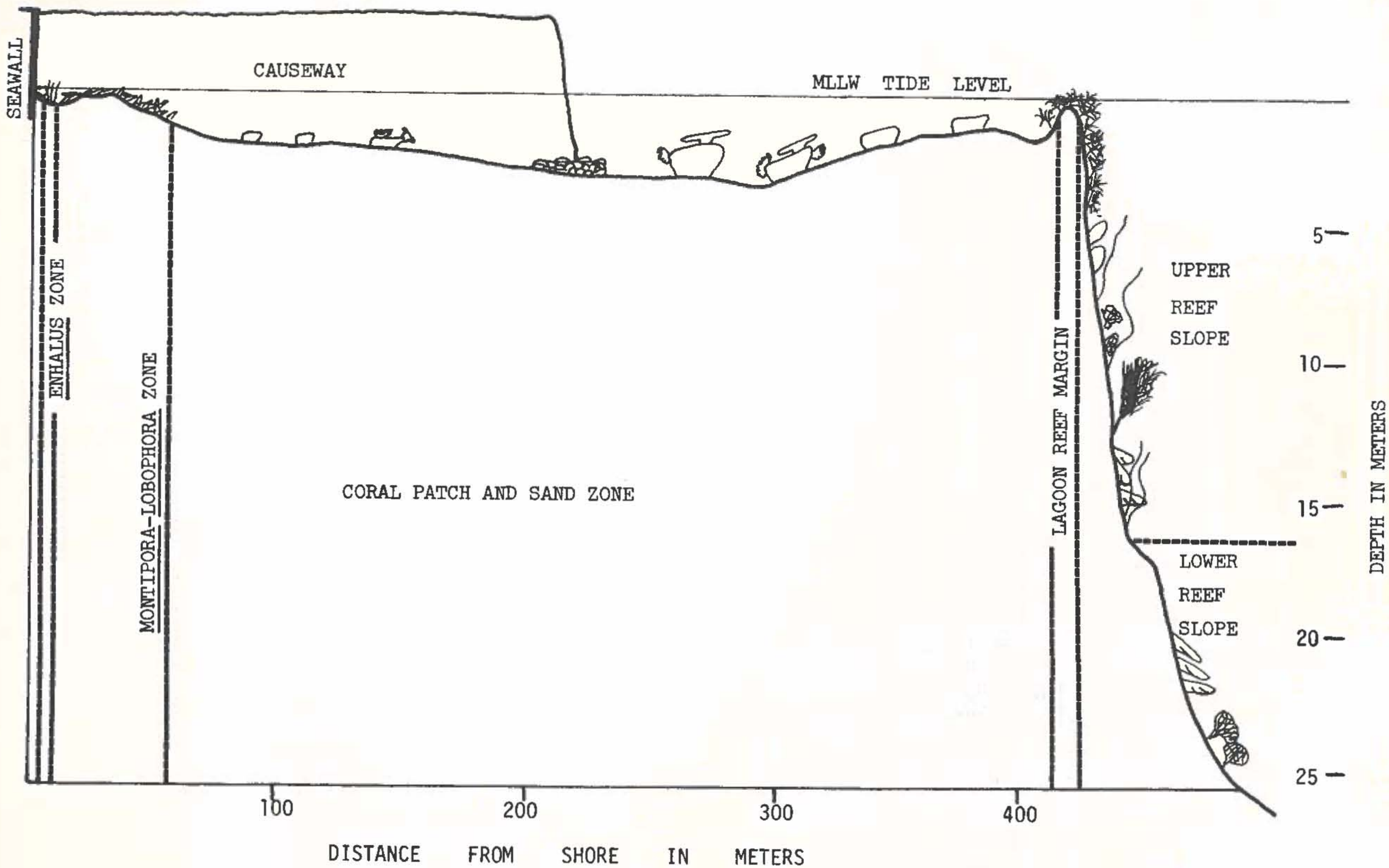

Figure 5. Vertical profile of the reef under the route of the proposed sewer outfall pipeline. Vertical exaggeration X 10.95.

Table 10. List of corals observed within the study area. Symbols indicate their relative abundance within the various reef zones: D = dominant, A = abundance, C = common, 0 = occasional, and R = rare.

	LAGOON FRINGING REEF				
	REEF FLAT		REEF MARGIN	LAGOON REEF SLOPE	
	MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE		UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
CLASS - ANTHOZOA					
ORDER - SCLERACTINIA					
FAMILY-ASTROCOENIIDAE					
<u>Styocoeniella</u> <u>ormata</u> (Ehrenberg)		0	0	0	
FAMILY-THAMNASTERIIDAE					
<u>Psammocora</u> <u>contigua</u> (Esper)			R	R	
<u>Psammocora</u> <u>contigua</u> var. <u>tutuilensis</u> Hoffmeister	0	0	0		
<u>Psammocora</u> <u>nierstraszi</u> van der Horst			0	0	
<u>Psammocora</u> <u>samoensis</u> Hoffmeister		0	0	0	
<u>Psammocora</u> <u>verrilli</u> Vaughan			0		
<u>Psammocora</u> <u>(Plesioseris)</u> <u>haimeana</u> Milne-Edwards and Haime			R		
<u>Psammocora</u> (<u>Stephanaria</u>) <u>togianensis</u> Umbgrove		0		0	
FAMILY-POCILLOPORIDAE					
<u>Stylophora</u> <u>mordax</u> (Dana)				R	
<u>Stylophora</u> <u>pistillata</u> (Esper)		R			
<u>Seriatopora</u> <u>hystrix</u> Dana			0	R	
<u>Pocillopora</u> <u>damicornis</u> (Linnaeus		C	C	0	
<u>Pocillopora</u> <u>danae</u> Verrill	0	0	0		
<u>Pocillopora</u> <u>eydouxi</u> <u>Milne</u>-Edwards and Haime				R	
<u>Pocillopora</u> <u>meandrina</u> Dana		A	0	0	
<u>Pocillopora</u> <u>verrucosa</u> (Ellis and Solander)				R	

Pocillopora meandrina Dana				R	
Pocillopora verrucosa (Ellis and Solander)					

	LAGOON FRINGING REEF				
	REEF FLAT		REEF MARGIN	REEF SLOPE	
	MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE		UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
FAMILY-ACROPORIDAE					
Acropora acuminata Verrill		O	O		
Acropora affinis (Brook)				O	
Acropora arbuscula (Dana)		O			
Acropora aspera (Dana)	O				
Acropora clathrata (Brook)		O	O	O	O
Acropora complanata (Brook)				O	
Acropora corymbosa (Lamarck)				O	
Acropora cymbicyathus (Brook)	R				
Acropora delicatula (Brook)				O	
Acropora echinata (Dana)		O	A	A	O
Acropora formosa (Dana)	O	C	A	C	C
Acropora hebes (Dana)	O	R			
Acropora humilis (Dana)		O	O	O	
Acropora hyacinthus (Dana)		O		O	
Acropora sp. cf. *A. kenti* (Brook)			O		
Acropora nassuta (Dana)		R			
Acropora procumbens (Brook)					C
Acropora sp. cf. *A. prolixa* Verrill		O	A	C	
Acropora reticulata (Brook)		C	C	C	O
Acropora samoensis (Brook)			O		
Acropora squarrosa (Ehrenberg)			O	O	
Acropora sp. cf. *A. tenella* (Brook)					O
Acropora teres Verrill			R		
Acropora vaughani Wells			O	O	
Acropora sp. 1 (Corymbose-Arborescent)		O	C	C	
Acropora sp. 2 (Cespitose)			R		
Acropora sp. 3 (Arborescent)			R		
Acropora sp. 4 (Arborescent)		O	O		
Acropora sp. 5 (Arborescent)			O		
Acropora sp. 6 (Arborescent-Cespitose)			O	O	
Acropora sp. 7 (Corymbose)			R		
Astreopora gracilis Bernard		R			
Astreopora myriophthalma (Lamarck)		O	O	O	

	LAGOON FRINGING REEF				
	REEF FLAT			LAGOON REEF SLOPE	
	MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE	REEF MARGIN	UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
Astreopora ocellata Bernard	R	R			
Montipora acanthella Bernard	R		R	0	
Montipora composita Crossland				R	
Montipora sp. cf. M. danae Milne-Edwards and Haime		0	0		
Montipora digitata (Dana)	D	0			
Montipora divaricata Brueggemann	0		0		
Montipora sp. cf. M. ehrenbergii Verrill			0		
Montipora elschneri Vaughan		0	0		
Montipora sp. cf. M. fragilis Quelch	R	R			
Montipora foveolata (Dana)		0	0		
Montipora granulosa Bernard			0		
Montipora hoffmeisteri Wells			0		
Montipora sp. cf. M. informis Bernard		R	0		
Montipora lobulata Bernard	0	C	0	0	
Montipora prolifera Bernard			0		
Montipora sinensis Bernard	R				
Montipora socialis Bernard			0	0	
Montipora strigosa Nemenzo		0	0		
Montipora trabeculata Bernard		0	0	0	
Montipora tuberculosa (Lamarck)		0	0	0	
Montipora verrilli Vaughan		0	C	0	
Montipora verrucosa (Lamarck)				0	
Montipora sp. 1 (Tuberculate)			0	0	
Montipora sp. 2 (Papillate)				R	R
SUBORDER - FUNGIINA					
FAMILY-AGARICIIDAE					
Pavona decussata Dana	R				
Pavona frondifera Lamarck	0	0			
Pavona praetorta (Dana)				0	
Pavona varians Verrill			R		
Pavona (Polyastra) obtusata (Quelch)		R	0		

Pavona praetorta (Dana)				0	
Pavona varians Verrill		R	R		
Pavona (Polyastra) obtusata (Quelch)			0		

	LAGOON FRINGING REEF				
	REEF FLAT			LAGOON REEF SLOPE	
	MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE	REEF MARGIN	UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
Pavona (Polyastra) venosa Ehrenberg	R	R	R		
Leptoseris solida (Quelch)				R	
Coeloseris mayeri Vaughan			R		
Pachyseris rugosa (Lamarck)			0	0	
Pachyseris speciosa (Dana)				0	0
FAMILY-FUNGIIDAE					
Fungia (Verrillofungia) concinna Verrill		0			
Fungia (Ctenactis) echinata (Pallas)	0	0			
Fungia (Fungia) fungites (Linnaeus)	0	0			
Fungia (Pleractis) paumotuensis Stutchbury	0	0			
Herpolitha limax (Esper)		0		0	
Herpentoglossa simplex (Gardiner)			0	0	
Polyphyllia talpina (Lamarck)		0			
Parahalomitra robusta (Quelch)		0			
FAMILY-PORITIDAE					
Goniopora arbuscula Umbgrove				R	
Goniopora lobata Milne-Edwards and Haime		0			
Goniopora tenuidens (Quelch)			R		
Porites andrewsi Vaughan	0	0	A	D	
Porites australiensis Vaughan	R		0	0	0
Porites compressa Dana			R	R	
Porites lichen Dana				0	
Porites lobata Dana		0	0	0	
Porites lutea Milne-Edwards and Haime	C	D	D	A	0
Porites nigrescens Dana			0	0	
Porites sp. 1 (Massive)			0		
Porites (Synaraea) convexa Verrill	0	0	C	C	0
Porites (Synaraea) hawaiinsis Vaughan				0	
Porites (Synaraea) horizontalata Hoffmeister				0	
Porites (Synaraea) iwayamaensis Eguchi	0	C	A	A	
Porites (Synaraea) sp. 1 (Fine-Branched)			0		
Alveopora allingi Hoffmeister			R		0

	LAGOON FRINGING REEF				
	REEF FLAT			LAGOON REEF SLOPE	
	MONTIPPRA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL SLOPE	REEF MARGIN	UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
SUBORDER - FAVIINA					
FAMILY-FAVIIDAE					
Favia danae Verrill	R	0	0	0	
Favia laxa (Klunzinger)			R		
Favia pallida	R				
Favia speciosa		0	0	0	
Favia sp. 1 (Massive)		R	R		
Favites acuticollis (Ortman)	R				
Favites complanata (Ehrenberg)				0	
Favites flexuosa (Dana)		0			
Favites melicerum (Ehrenberg)		0	0	0	
Favites palauensis (Yabe and Sugiyama)	0	0	0		
Favites virens (Dana)		0			
Goniastrea australiensis (Milne-Edwards and Haime				R	
Goniastrea favulus (Dana)		R			
Goniastrea parvistella (Dana)	0	0	0	0	
Goniastrea pectinata	0	0	0	0	
Goniastrea retiformis (Lamarck)		0	0		
Platygyra daedalea (Ellis and Solander)		0	0	0	
Platygyra lamellina (Ehrenberg)		0	0	0	
Leptoria phrygia (Ellis and Solander)			R		
Hydnophora exesa (Pallas)				R	
Hydnophora microconos (Lamarck)		0	0		
Hydnophora rigida (Dana)			0	0	
Diploastrea heliopora (Lamarck)				R	
Leptastrea purpurea (Dana)	0	C	C	0	
Cyphastrea chalcidicum Klunzinger		0	0		
Cyphastrea microphthalma (Lamarck)	0		0		
Cyphastrea serailia (Forskaal)		0	0		
Cyphastrea sp. 1 (Nodular)		R			
Echinopora lamellosa (Esper)				0	
Plesiastrea versipora (Lamarck)				0	

Cyphastrea sp. 1 (Nodular)		R			
Echinopora lamellosa (Esper)				0	
Plesiastrea versipora (Lamarck)				0	

	LAGOON FRINGING REEF				
	REEF FLAT		REEF MARGIN	LAGOON REEF SLOPE	
	MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE		UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
FAMILY-OCULINIDAE					
Galaxea clavus (Dana)		0			
Galaxea fascicularis (Linnaeus)				0	
Galaxea sp.1 (Explannate)					0
Acrhelia horrescens (Dana)				0	0
FAMILY-MERULINIDAE					
Merulina ampliata (Ellis and Solander)					0
Merulina vaughani van der Horst			0	0	
Clavarina scrabicula Dana					0
FAMILY-MUSSIDAE					
Lobophyllia corymbosa (Forskaal)				R	
Lobophyllia costata (Dana)				0	
Lobophyllia hemprichii (Ehrenberg)					0
Symphyllia agaricia Milne-Edwards and Haime					0
FAMILY-PECTINIIDAE					
Echinophyllia aspera (Ellis and Solander)				R	0
Mycedium elephantotus (Pallas)					0
Pectinia lactuca (Pallas)					0
SUBORDER - CARYOPHYLLIINA					
FAMILY-CARYOPHYLLIIDAE					
Euphyllia glabrescens Chamisso and Eysenhardt		0			
Plerogyra sinuosa (Dana)				R	
Physogyra lichtensteini Milne-Edwards and Haime				R	

		LAGOON FRINGING REEF				
		REEF FLAT			LAGOON REEF SLOPE	
		MONTIPORA-LOBOPHORA ZONE	CORAL PATCH AND SAND CORAL ZONE	REEF MARGIN	UPPER SLOPE	LOWER SLOPE (>10 m DEPTH)
SUBORDER - DENDROPHYLLIINA						
FAMILY-DENDROPHYLLIIDAE						
Dendrophyllia micranthus (Ehrenberg)						O
Tubastraea aurea (Quoy and Gaimard)						O
ORDER - COENOTHECALIA						
FAMILY-HELIOPORIDAE						
Heliopora coerulea (Pallas)				R		
CLASS - HYDROZOA						
ORDER - MILLEPORINA						
FAMILY-MILLEPORIDAE						
Millepora exaesa Forskaal			O	O		
Millepora intricata Milne-Edwards and Haime			O	O		
Millepora platyphylla Hemprich and Ehrenberg				R		
Millepora tenera Boschma		O	A	A	A	
ORDER - STYLASTERINA						
FAMILY-STYLASTERIDAE						
Stylaster sp.						O
TOTAL GENERA	48	14	24	25	32	17
TOTAL SPECIES	163	33	75	91	79	24

TOTAL GENERA	48	14	24	25	32	17
TOTAL SPECIES	163	33	75	91	79	24

Table 11. Size distribution, frequency, density and percent of substratum covered by stony corals in four zones of the fringing reef on the south end of Malakal Island. Relative values of frequency, density and percent of substratum covered are also given and an importance value is calculated from the sum of these three relative values. The procedures for calculating the statistics in the column from the data obtained by the point-quarter sampling technique or the line-intercept sampling technique are explained in the Methods section. The standard symbols are used for the number of data (n), arithmetic mean ($\bar{Y}$), standard deviation (s), and range (w). Since the point-quarter sampling technique was used on transects B_1 and D (Coral Patch and Sand zone and lagoon fringing reef slope zone) and the line-intercept sampling technique was used on transects A, B_2 and C (*Montipora*-*Lobophora* zone, Coral Patch and Sand zone and lagoon fringing reef margin zone), the data from the five transects will be presented in separate tables.

Table 11a. *Montipora*-*Lobophora* zone. Transect A. Line-intercept sampling method.

	n	Size Distribution of Colonies Diameters in cm $\bar{Y}$	s	w	Relative Occurrence	Density/100 m^2	Relative Density	Percent Coverage	Relative Percent Coverage	Importance Value
Montipora digitata	44	7.2	7.1	1-35	74.6	997	78.8	3.20	72.6	226.0
Porites lutea	8	8.5	6.9	4-25	13.6	128	10.1	.70	15.0	39.6
Montipora divaricata	2	4.5	3.5	2-7	3.4	64	5.1	.09	2.0	10.5
Pocillopora danae	1	13.0			1.7	8	.6	.12	2.7	5.0
Porites andrewsi	1	12.0			1.7	8	.6	.12	2.7	5.0
Porites (S.) iwayamaensis	1	3.0			1.7	33	2.6	.03	.7	5.0
Pavona frondifera	1	9.0			1.7	11	.9	.09	2.0	4.6
Favia danae	1	6.0			1.7	17	1.3	.06	1.4	4.4

Overall Density 12.66 per m^2

Overall Percent of Substratum Coverage 4.4%

Table 11b. Coral Patch and Sand Zone. Transect B_1. Point-centered quarter sampling method.

Corals	Size Distribution of Colonies Diameters in cm: n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density per 100 m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Porites lutea	14	17.7	12.0	6-43	.9	31.0	106	36.8	3.7	28.0	95.8
Acropora sp. 1	1	90.0			.1	3.4	7	2.6	4.5	34.1	40.1
Acropora formosa	5	10.2	5.1	7-19	.2	6.8	38	13.2	.4	3.0	23.0
Leptastrea purpurea	3	14.0	3.5	10-16	.2	6.8	23	7.9	.4	3.0	17.7
Acropora acuminata	1	50.0			.1	3.4	7	2.6	1.4	10.6	16.6
Pocillopora meandrina	2	14.5	3.5	12-17	.2	6.8	15	5.3	.3	2.3	14.4
Porites australiensis	2	4.0	2.8	2-6	.2	6.8	15	5.3	.1	.8	12.9
Acropora hyacinthus	1	38.0			.1	3.4	7	2.6	.8	6.1	12.1
Montipora verrilli	1	33.0			.1	3.4	7	2.6	.6	4.6	10.6
Montipora elschneri	1	22.0			.1	3.4	7	2.6	.3	2.3	8.3
Montipora lobulata	1	18.0			.1	3.4	7	2.6	.2	1.5	7.5
Acropora sp.3	1	7.0			.1	3.4	7	2.6	.1	.8	6.8
Acropora echinata	1	6.0			.1	3.4	7	2.6	.1	.8	6.8
Cyphastrea serailia	1	11.0			.1	3.4	7	2.6	.1	.8	6.8
Goniastrea parvistella	1	9.0			.1	3.4	7	2.6	.1	.8	6.8
Millepora tenera	1	8.0			.1	3.4	7	2.6	.1	.8	6.8
Pocillopora danae	1	9.0			.1	3.4	7	2.6	.1	.8	6.8

Overall Density 2.87 per m^2

Percent of Substratum coverage 13.2

Table 11c. Coral Patch and Sand zone. Transect B_2. Line-intercept sampling method.

		Size Distribution of Colonies Diameter in cm			Relative Occurrence	Density/100 m^2	Relative Density	Percent Coverage	Relative Percent Coverage	Importance Value
	n	$\bar{Y}$	s	w						
<u>Porites lutea</u>	19	21.7	19.97	3-70	43.2	188	53.3	4.13	28.3	124.8
<u>Pocillopora meandrina</u>	9	75.8	82.46	5-210	20.5	48	13.6	6.82	46.7	80.8
<u>Montipora verrilli</u>	2	21.0	1.41	20-22	4.5	9	2.5	.42	2.9	9.9
<u>Acropora</u> sp. 1	1	95.0			2.3	1	.3	.95	6.5	9.1
<u>Acropora arbuscula</u>	1	6.0			2.3	17	4.8	.06	.4	7.5
<u>Fungia echinata</u>	1	7.0			2.3	14	4.0	.07	.5	6.8
<u>Acropora nassuta</u>	1	8.0			2.3	13	3.7	.08	.5	6.5
<u>Acropora formosa</u>	1	47.0			2.3	2	.6	.47	3.2	6.1
<u>Astreopora myriophthalma</u>	1	9.0			2.3	11	3.1	.09	.6	6.0
<u>Cyphastrea microphthalma</u>	1	12.0			2.3	10	2.8	.12	.8	5.9
<u>Pavona (P.) venosa</u>	1	10.0			2.3	10	2.8	.10	.7	5.8
<u>Montipora lobulata</u>	1	15.0			2.3	7	2.0	.15	1.0	5.3
<u>Leptastrea purpurea</u>	1	22.0			2.3	5	1.4	.22	1.5	5.2
<u>Montipora tuberculosa</u>	1	17.0			2.3	6	1.7	.17	1.2	5.2
<u>Montipora verrucosa</u>	1	30.0			2.3	3	.8	.30	2.1	5.2
<u>Porites lobata</u>	1	30.0			2.3	3	.8	.30	2.1	5.2
<u>Montipora fragilis</u>	1	16.0			2.3	6	1.7	.16	1.1	5.1

Overall Density 3.53 per m

Overall Percent of Substratum Coverage 14.61%

Table 11d. Lagoon fringing reef margin. Transect C. Line-intercept sampling method.

	n	Size Distribution of Colonies Diameters in cm			Relative Occurrence	Density/100 m^2	Relative Density	Percent Coverage	Relative Percent Coverage	Importance Value
		Y	s	w						
Acropora formosa	35	40.3	48.7	3-175	17.5	309	14.63	14.11	23.4	55.5
Porites lutea	34	15.2	11.1	4-50	17.0	342	16.19	5.13	8.5	41.7
Porites andrewsi	29	21.6	22.8	2-100	14.5	320	15.15	6.25	10.4	40.1
Porites (S.) convexa	19	51.2	95.7	3-425	9.5	154	7.29	9.73	16.1	32.9
Porites (S.) iwayamaensis	20	31.1	73.7	4-328	10.0	230	10.89	6.22	10.3	31.2
Acropora acuminata	14	9.8	8.5	2-35	7.0	233	11.03	1.37	2.3	20.3
Acropora sp. 6	7	43.6	56.3	3-165	3.5	56	2.65	3.50	5.8	11.9
Acropora sp. 1	4	131.8	120.2	15-300	2.0	9	0.43	5.27	8.7	11.1
Acropora echinata	8	11.5	7.5	3-25	4.0	109	5.16	.92	1.5	10.7
Millepora tenera	6	47.2	51.8	10-140	3.0	39	1.85	2.83	4.7	9.5
Acropora samoensis	4	6.8	2.8	4-10	2.0	68	3.22	.27	.4	5.6
Acropora sp. 4	3	60.0	40.0	20-100	1.5	8	0.38	1.80	3.0	4.9
Pocillopora damicornis	3	9.3	7.5	5-18	1.5	46	2.18	.28	.4	4.1
Montipora granulosa	2	16.0	19.8	2-30	1.0	53	2.51	.32	.5	4.0
Porites compressa	2	4.0	1.4	3-5	1.0	53	2.51	.08	.1	3.6
Acropora humilis	3	22.3	10.8	10-30	1.5	17	0.80	.67	1.1	3.4
Goniopora tenuidens	2	42.5	3.5	40-45	1.0	5	0.24	.85	1.4	2.6
Montipora divaricata	2	7.5	3.5	5-10	1.0	30	1.42	.15	.2	2.6
Montipora lobulata	1	7.0			.5	14	0.66	.07	.1	1.3
Acropora kenti	1	35.0			.5	3	0.14	.35	.6	1.2

Overall Density 21.12 per m^2

Overall Percent of Substratum Coverage 60.3

Table 11e. Lagoon fringing reef slope along the 4.6 meter isobath. Transect D. Point-centered quarter sampling method.

Corals	Size Distribution of Colonies Diameters in cm				Frequency	Relative Frequency	Density per 100 m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	n	$\bar{Y}$	s	w							
Acropora formosa	4	73.3	43.1	12-110	.4	12.1	49	10.0	26.0	35.2	57.3
Porites lutea	9	25.2	22.4	5-70	.6	18.2	111	22.5	9.4	12.7	53.4
Acropora sp. 1	2	88.0	36.8	62-114	.1	3.0	25	5.0	16.5	22.3	30.3
Porites (*S.*) *convexa*	4	31.3	31.1	11-55	.3	9.1	49	10.0	4.9	6.6	25.7
Porites (*S.*) *iwayamaensis*	3	45.0	34.6	25-85	.2	6.1	32	7.5	8.2	11.1	24.7
Acropora prolixa	3	23.3	20.6	10-47	.3	9.1	37	7.5	2.4	3.2	19.8
Porites australiensis	2	30.0	31.1	8-52	.2	6.1	25	5.0	2.7	3.7	14.8
Montipora tuberculosa	2	12.5	10.6	5-20	.2	6.1	25	5.0	.4	.5	11.6
Astreopora myriophthalma	2	12.0	1.4	11-13	.2	6.1	25	5.0	.3	.4	11.5
Porites andrewsi	2	19.5	3.5	17-22	.1	3.0	25	5.0	.8	1.1	9.1
Acropora echinata	1	30.0			.1	3.0	12	2.5	.8	1.1	6.6
Montipora verrilli	1	20.0			.1	3.0	12	2.5	.4	.5	6.0
Herpentoglossa simplex	1	16.0			.1	3.0	12	2.5	.3	.4	5.9
Psammocora samoensis	1	17.0			.1	3.0	12	2.5	.3	.4	5.9
Montipora lobulata	1	16.0			.1	3.0	12	2.5	.2	.3	5.8
Psammocora contigua	1	16.0			.1	3.0	12	2.5	.2	.3	5.8
Favites complanata	1	10.0			.1	3.0	12	2.5	.1	.1	5.6

Overall Density 4.92 Corals Per m^2

Percent of Substratum coverage 73.6%

mostly of a thin veneer of bioclastic sand and coral-algal-mollusk rubble covering a somewhat poorly consolidated reef rock platform. Scattered here and there, but becoming more abundant towards the reef margin are living patches of coral and large individual coral heads (Plate I). Examination of the deposits being dredged from this part of the reef platform show them to be composed mostly of detrital lagoon deposits interspersed with local patches of coral growth and large individual coralla, indicating a paleoecological environment much like the setting now observed on the platform surface. At the present time the surface and scattered coral patches platform in this zone are completely covered during low tides indicating that its upward development with respect to tidal equilibrium has not been achieved. Considering the above tide relation and the rich coral development and substratum coverage found on the adjacent but slightly shallower lagoon reef margin, it is difficult to explain the relatively low coral coverage in this zone (Tables 8, 11b and 11c). Possibly the predominance of a depositional environment of reef detrital material provides a mobile substratum on which it is difficult for newly settled coral planulae to become established. The scattered locations where a few corals have become established provides a nucleus for the development of the diverse coral patches observed.

The scattered coral patches vary considerably in size, diversity, and developmental origin. Some consist of a single colony, commonly of massive Porites lutea or ramose Millepora tenera colonies; an aggregation of a number of large massive or ramose colonies, predominately of a single species; or a patch consisting of a diverse assemblage of coral species and growth forms. Coral patch size ranged from single coralla a meter or less in diameter to large aggredations of Pocillopora meandrina up to ten meters in diameter (Plate I).

Although the total number of species recorded from the coral patch and sand zone was not significantly lower than that of the adjacent reef margin zone (Table 10), it was conspicuously delimited from it by its lower percent of coral coverage. Physiographically and developmentally it differed in being predominately a zone of detrital deposition whereas the lagoon reef margin was predominately a zone of in situ reef framework deposition.

The lagoon reef margin consists of the extreme outer edge of the shallow fringing reef platform. In the vicinity of the proposed outfall it is about 11 meters wide and easily differentiated from the shoreward Coral Patch and Sand zone by reasons given above, but is poorly separated from the upper lagoon slope below. At best the differences between the reef margin and upper lagoon slope are gradational, consisting mostly of differences in species composition (Table 10). Environmental conditions for coral growth appear to be optimum (Plate II) at the reef margin and upper lagoon slope where plenty of light is available and greater water agitation from lagoon waves prevents sediments from accumulating. Although the reef margin has a lower value for percent of coral coverage than the upper lagoon slope (Table 8), the number of species occurring there is nearly as large and the species diversity is higher. This higher species diversity is partly due to the intergrading pressure of some predominant reef flat species on its shallow shoreward margin and some predominant lagoon slope species on its deeper lagoonward border. Community structure is somewhat different in that colony size tends to be smaller and more fragmentary on the reef margin whereas larger colonies, particularly of Porites lutea and Porites andrewsi, are more commonly encountered on the upper lagoon slope.

Lagoon slope depths greater than ten meters were arbitrarily established as the lower lagoon slope zone. Like the boundary between the reef margin and the upper lagoon slope, the distinction between the upper and lower lagoon slopes is gradational. Fewer species which were more typical of deeper water habitats were encountered here and the substratum was characterized by the presence of more unconsolidated detrital material. Although no quantitative data were collected in this lower zone, it was fairly obvious that species diversity and abundance and percentage of substratum covered was considerably lower than that on the upper slope and reef margin zones.

As we moved along a gradient from the lagoon fringing reef flat to the upper lagoon fringing reef slope, the living scleractinian corals covered more of the substratum, individual colonies averaged larger in diameter, and increasing numbers of taxa were present including species, genera or families (Tables 8 and 12). This general trend of corals as a group was also followed by the predominant species of branching coral, Acropora formosa, and the predominant species of massive coral, Porites lutea, which were prevalent on the lagoon fringing reef flat, margin and slope (Table 12). As we followed a gradient from the reef flat to the reef slope, these species became larger in average colony size and covered more surface area.

However, despite the general increase in colony size, space occupied and number of species and other taxa on the upper reef slope, the greatest abundance of colonies and the greatest species diversity of corals was on the lagoon fringing reef margin. This was also the case for Acropora formosa and Porites lutea which were more numerous per unit area on the reef margin but occupied a greater percent of the space on the reef slope.

Of particular interest was the observation that the variation in colony size was greatest on the reef margin. In order to compare the variation in size of different species which have different mean diameters, we standardized the variances by dividing the standard deviations by their respective means to obtain a coefficient of variation [$CV = (s/\bar{Y})\ 100$]. The mean of the coefficients of variation for diameters of coral species on transects B_1 and B_2 did not differ significantly so the data from those transects were combined to represent the Coral Patch and Sand zone in Table 12. The mean of the coefficients of variation for each species

Table 12. Aspects of size distributions of hermatypic corals as a group of species, of a predominant arborescent species and of a predominant massive species along a gradient from the lagoon fringing reef flat to the lagoon fringing reef slope.

	Coral Patch and Sand Zone	Lagoon Fringing Reef Margin	Lagoon Fringing Reef Slope
All species of hermatypic corals together			
Colony diameters in cm ($\bar{Y}$±s)	26.1 ± 22.4 *ns*	29.9 ± 20.7***	32.5 ± 21.3
Coefficient of variation of diameters	75.0 ± 27.5***	116.3 ± 54.5***	74.2 ± 27.5
No./100 m^2	320	2112	492
Percent cover of substrata	13.9	60.3	73.6
<u>Acropora formosa</u> (arborescent)			
Colony diameters in cm ($\bar{Y}$±s)	16.3 ± 14.5*	40.3 ± 48.7 *ns*	73.3 ± 43.1
Coefficient of variation of diameters	50.0 ± 19.4***	120.8 ± 40.4***	58.8 ± 27.0
No./100 m^2	20	309	49
Percent cover of substrata	0.4	14.1	26.0
<u>Porites lutea</u> (Massive)			
Colony diameters in cm ($\bar{Y}$±s)	19.7 ± 16.8 *ns*	15.2 ± 11.1 *ns*	25.2 ± 22.4
Coefficient of variation of diameters	83.3 ± 16.4**	73.0 ± 12.7 *ns*	88.9 ± 33.7
No./100 m^2	147	342	111
Percent cover of substrata	3.9	5.1	9.4

ns means not significant by *t*-test for the two statistics separated by the letters

* $p < .05$, by *t*-test for the two statistics separated by the asterisk

** $p < .01$, by *t*-test for the two statistics separated by the asterisks

*** $p < .001$, by *t*-test for the two statistics separated by the asterisks weighted for the numbers in the samples was significantly greater for coral populations on the lagoon fringing reef margin than for coral populations on the lagoon fringing reef flat or the lagoon fringing reef slope. The coefficients of variation for diameters of corals on the reef flat did not differ from the coefficients of variation for diameters of corals on the reef slope. Although the mean of the coefficients of variation was significantly greater for diameter of corals on the reef margin, the mean diameter itself of corals on the reef margin was significantly less than the mean diameters of corals on the reef slope and not significantly different from corals on the reef flat.

For reef-building corals in general, the colonies are more numerous, average smaller in diameter, and have more variance in their size distribution on the reef margin than on the reef slope. On the reef slope, the reef-building corals average larger in diameter, are less numerous, cover a greater portion of the substrata, and the size distributions are less variable. From this we would speculate that the lagoon fringing reef slope (ca. 4.6 m depth) is a more stable environment for corals than is the lagoon reef margin. Despite some signs of slumping, siltation and biogenic erosion of corals on the upper slope, it appears that corals tend to live longer on the reef slope as evidenced by their larger average size and lower variation in size. Since more of the space is occupied by living corals, recruitment may be more difficult because of less available space for planulae to settle. Although corals are less numerous on the reef slope, the number of species and especially the numbers of higher taxa are greater in this more stable environment. However, many of the additional species found on the reef slope but not on the reef margin were rare and so the species diversity was greater on the reef margin.

The reef margin may be a more unstable habitat for reef-building corals than the reef slope, as indicated by the greater variances in size distributions and smaller mean colony sizes. In addition to biogenic erosion (by burrowing sponges, bivalves and algae) and slumping, the coral community on the reef margin is more severely affected by wave damage during occasional storms than is the coral community on the deeper reef slope. Despite the apparently greater mortality of corals on the reef margin, the action of coral recruitment and growth appears to be greatest in this zone and therefore the reef margin may be the most productive part of the lagoon fringing reef in terms of reef growth.

A predominant species of arborescent coral, Acropora formosa, had a size distribution that conformed to the typical pattern set by the majority of coral species: the mean colony size increased along a gradient from the lagoon reef flat to the lagoon reef slope, the coefficient of variation in colony diameters was significantly greater for populations on the lagoon reef margin than for those in the other zones, the abundance of colonies was greatest on the lagoon reef margin and the amount of substrata occupied was greatest on the lagoon reef slope (Table 12). This was not surprising since Acropora is the most abundant and diverse genus of hermatypic corals on the reef (Table 10).

In shallow waters of the reef margin and upper reef slope where the rate of coral growth is greatest, the arborescent corals such as Acropora spp. and Hydnophora spp. either overgrow or shade the more massive corals such as Porites lutea (Plate II a-d). Perhaps because of this, the massive Porites lutea does not conform the usual pattern for the more diverse arborescent species. Although Porites lutea is also most abundant on the reef margin, the colonies are not significantly larger in diameter than on the reef flat (smaller, if different at all), and the population averages larger in colony diameter in deeper water where it occupies a larger proportion of the substratum space. Our observations and data indicate that the faster growing, more delicate arborescent corals are more successful in shallow water (where wave action has its greatest influence) than they are in deeper water. This is probably due to the greater rate of growth of arborescent corals in shallow waters.

Echinoderms--The echinoderm fauna on the fringing reef of Malakal was impressive for echinoderms in the number of species in the small area. However, no species was abundant. The results of counts from 102 ten m^2 quadrats are given in Table 13. Seven species of asteroids were observed. This was a large number of species of asteroids for a small area on a coral reef. The most common asteroid was Linckia laevigata which was found in densities as high as one per 40 m^2 on the reef margin. To obtain adequate data for statistical analysis of the asteroid community we would need to have taken 300 ten m^2 quadrats in both the Coral Patch and Sand zone and on the reef margin. Six hundred 10 m^2 quadrats would be necessary for the reef slope. However, the species list is probably nearly complete.

Five species of holothurians were observed, but none were abundant. About 120 ten m^2 quadrats should have been taken in the Coral Patch and Sand zone and about 600 quadrats should have been taken on both the reef margin and the reef slope. Holothurians are far more prevalent on reef flats with sea grass beds (cf. Amesbury et al., 1976).

Many of the crinoids were difficult to find because they hid away under overhangs and in holes and crevices. To adequately sample crinoids, a night dive should be made because some species come out at night to feed. The abundances in Table 13 are probably conservative estimates.

Fishes--The Malakal site supports a rich fish fauna (Table 14). The reef crest and upper lagoon slope zones contain especially dense assemblages of fishes of many species. The positioning of the transect lines within physical/biological zones tends to underestimate the real diversity of this area as species occupying areas of contact between zones are not observed. Also, fish are quite motile and non-territorial fish are likely to be outside the two meter wide transect at the time the count is being made but inside the area at other times. A number of species were observed in the area at times when the counts were not being made. Among these were the lutjanid Symphorichthys spilurus (Günther), the scorpaenid Pterois volitans (Linnaeus) (cover photograph) and the chaetodontids Pygoplites

Table 13. Frequencies and abundances of large echinoderms on the Lagoon Fringing Reef at the southern tip of Malakal Island. Frequency is the proportion of 10 m^2 quadrats in which the species was observed. The average abundances in 10 m^2 quadrats are given in terms of mean and standard deviation. When a species was observed in a zone but was not found in any of the quadrats, its observed presence is indicated by "+".

	Reef Flat: Montipora-Lobophora Zone	Reef Flat: Coral Patch and Sand Zone		Reef Margin		Reef Slope	
	F	F	(No./100 m^2)	F	(No./100 m^2)	F	(No./100 m^2)
Crinoid spp.		8/42	0.4 ± 1.04	13/20	1.75 ± 2.53	6/20	0.9 ± 2.15
Culcita novaeguineae Müller & Troschel		1/42	0.02			+	
Linckia laevigata (Linnaeus)		3/42	0.07 ± 0.26	4/20	0.25 ± 0.55		
Linckia multifora (Lamarck)		5/42	0.12 ± 0.33				
Acanthaster planci (Linnaeus)		4/42	0.1 ± 0.3	1/20	0.1	1/20	0.05
Echinaster luzonicus (Gray)		1/42	0.05				
Fromia monilis Perrier		2/42	0.05				
Nardoa tuberculata Gray	+					+	
Bohadschia argus Jaeger				1/20	0.05		
Bohadschia vivittata (Mitsukuri)		3/42	0.07 ± 0.26			1/20	0.05
Holothuria atra Jaeger	+	10/42	0.48 ± 1.02				
Holothuria edulis Lesson		8/42	0.24 ± 0.53			1/20	0.15
Stichopus chloronotus Brandt	+	7/42	0.21 ± 0.56	2/20	0.1	2/20	0.15

Table 14. Transect counts of fishes observed at the Malakal outfall site, Koror, Palau. Transect designations: A - *Montipora-Lobophora* zone, 46 m long; B - Coral Patch and Sand zone, 100 m long: C - Reef Margin zone, 82 m long; D - Lagoon Slope zone, at a depth of 4.6 m, 100 m long; E1 - Lagoon Slope, crest to 18 m deep, 27 m long; E2 - Lagoon Slope, 18 m to 26 m deep, 40 m long.

SPECIES	TRANSECTS A	B	C	D	E1	E2
Acanthuridae						
Acanthurus nigrofuscus Forskal						
A. triostegus (Linnaeus)	1			2		
Ctenochaetus striatus (Quoy & Gaimard)		2	2	5	1	
Zebrasoma veliferum (Bloch)			1			
juvenile and unident. acanthurids	6		2			
Apogonidae						
Apogon aroubiensis Hombron & Jacquinot	1		15	41		
Apogon compressus (Smith & Radcliffe)			8	15	2	
Archamia zosterophora (Bleeker)			100		50	
Paramia quinquelineata (Cuvier & Valenciennes)		2	4			
Blenniidae						
unident. blennids	2		5			
Chaetodontidae						
Centropyge tibicen Cuvier			2			
Chaetodon auriga Forskal		1				
C. ephippium Cuvier	2	1				
C. kleinii Bloch			1	2		
C. lunula (Lacepede)				1		
C. melannotus Schneider				6		
C. trifascialis Quoy & Gaimard			1	2		
C. trifasciatus Mungo Park		5	7	5	3	
Gobiidae						
Amblygobius albimaculatus (Rüppell)	2	2				
unident. gobiids		5				
Holocentridae						
Adioryx sp.			1			
Myripristis sp.			10			
Labridae						
Cheilinus fasciatus (Bloch)				1		
Cheilinus undulatus Rüppell						1
Cheilinus sp.					2	
Gomphosus varius Lacepede				1		
Halichoeres cf. *argus* (Bloch & Schneider)		4				
H. hoeveni (Bleeker)	24	32	16	14	2	
Hemigymnus melapterus (Bloch)				1		
Labrichthys unilineata (Guichenot)			2			

SPECIES	A	B	C	D	E1	E2
	TRANSECTS					
Labroides dimidiatus (Cuvier & Valenciennes)			6	5	2	
Thalassoma lutescens (Lay & Bennett)		1				
unident. labrids	3			4	2	
Lutjanidae						
Caesio sp.						50
Monotaxis grandoculis (Forskal)				4		
Scolopsis bilineata (Bloch)						1
Mullidae						
Parupeneus multifasciatus (Quoy & Gaimard)					1	
Pomacentridae						
Amblyglyphidodon curacao (Bloch)		43	46	96	17	
Amphiprion melanopus Bleeker			18	3	2	
Chromis caerulea (Cuvier)		235	727		6	
C. margaritifer Fowler			5			
C. ternatensis (Bleeker)			20	10		
Dascyllus aruanus (Linnaeus)		45	10	42	9	
D. reticulatus (Richardson)				2		
Dischistodus chrysopoecilus (Schlegel & Müller)	4					
D. perspicillatus (Cuvier)	5	8				
Eupomacentrus lividus (Bloch & Schneider)	61					
Glyphidodontops azurepunctatus (Flower & Bean)	3			30		
G. leucopomus (Lesson)		14				
Neopomacentrus sp.		96	118	126	8	
?Paraglyphidodon behni (Bleeker)		11		12		
Plectroglyphidodon lachrymatus (Quoy & Gaimard)			8			
Pomacentrus alexanderae (Evermann & Seale)				29	37	12
?P. grammorhynchus Fowler	6					
P. moluccensis Bleeker	38			30	3	
P. pavo (Bloch)		48	1			
P. popei Jordan & Seale		12	272	139	28	
P. taeniometopon Bleeker	65	93	61	10	3	
unidentified sp. A				1		
unidentified sp. B	2					
unidentified sp. C					3	
unidentified sp. D						3
juveniles	16					
Scaridae						
Scarus sodidus Forskal			2			
juvenile scarids	1					
Serranidae						
Cephalopholis argus (Bloch & Schneider)			1			
No. of fish	242	660	1472	639	181	67
No. of fish/m^2	2.6	3.3	9.0	3.1	3.4	.8
No. of species	18	20	30	29	19	5
Total No. of fishes = 3251						
Total No. of species = 66						

diacanthus (Boddaert) and Pomacanthus imperator (Bloch).

An especially diverse assemblage of pomacentrids (damselfishes) was seen: some 25 species out of a total of 77 recorded for all of the Palau archipelago (Allen, 1975). A comparison with a similar study performed in Tomil Harbor in Yap (Amesbury et al., 1976) might suggest that the Malakal fish fauna was less diverse: nearly the same number of species were observed in both areas, although almost four times as many fishes were counted at Malakal. These results were greatly influenced by the methods used: at Malakal, transects were parallel to the zonation and at Tomil, the transects run perpendicular to the zonation, cutting across several zones. That the fish fauna is zoned, as well as the corals and algae, is indicated by these results.

Plankton--Plankton was in rather low abundance in Malakal Harbor (Table 15). Plankton tows performed in an almost identical fashion in Tomil Harbor in Yap captured more than ten times as much plankton during the day and nearly eighteen times as much plankton at night (Amesbury et al., 1976). The greater abundance of plankton at night indicates that certain species are migrating into the surface waters at this time. These migrating species are primarily copepods and certain crustacean larvae. Ostracods and zoea larvae, which made up a large proportion of the night-time surface plankton at Tomil Harbor were only poorly represented in Malakal Harbor waters.

Table 15. Abundance of planktonic organisms collected in the area of the proposed Malakal sewer outfall, Palau. Abundances in number per m^3; percent of total catch in parentheses.

Plankton organisms	Daytime Tow	Nighttime Tow
diatoms	< 0.1 (0.1)	0.1 (0.3)
foraminifera	< 0.1 (0.1)	
radiolarians	0.1 (0.4)	
tintinnids	0.3 (0.9)	< 0.1 (0.1)
siphonophores	0.3 (1.0)	0.2 (0.5)
gymnosomes		< 0.1 (0.1)
other gastropods (incl. larvae)	< 0.1 (0.1)	0.2 (0.4)
pelecypod larvae		0.2 (0.4)
polychaetes		< 0.1 (0.1)
copepods (incl. copepodites)	26.3 (80.3)	35.8 (78.4)
ostracods		0.1 (0.3)
mysids		< 0.1 (0.1)
sergestids (Lucifer)		< 0.1 (0.1)
crustacean larvae:		
nauplius	0.9 (2.6)	1.5 (3.3)
zoea	0.2 (0.6)	3.6 (8.0)
alima (stomatopod)		<0.1 (0.1)
cryptoniscid (isopod)	0.1 (0.3)	<0.1 (0.1)
chaetognaths	0.6 (1.9)	0.9 (2.0)
larvaceans	2.8 (8.4)	2.1 (4.7)
echinoderm larvae	0.1 (0.4)	< 0.1 (0.1)
fish eggs	0.9 (2.6)	0.3 (0.7)
fish larvae		0.1 (0.3)
TOTAL	32.7 (100.0)	45.7 (100.0)

CONCLUSIONS

The proposed location of the sewer outfall at the southern tip of the reef which extends south from Malakal Island is a reasonable site for efficient dispersion and dilution of the effluent. The sewer outfall will be located near the center of Malakal Harbor on a tip of reef bordered by deep water for approximately 250° and bordered by the reef flat for approximately 110°. Malakal Harbor is open at both ends and the water movement changes direction with the tide, flowing northwest towards Ngell Channel during flood tides and southeast towards Malakal Pass during ebb tides.

The tidal current speed averaged about .23 knots during our study and the movements of drogues indicated that the sewer effluent would be dispersed into the center of Malakal Harbor and diluted rapidly by the changes in current direction. The treated effluent will be of low salinity and so should tend to rise to the surface and remain there until mixed with sea water. There was no significant difference in the speed or the direction of movements of water between the depths of one meter and five meters.

The increased siltation, erosion and turbidity caused by the dredging and piling of loose sediment during construction of the causeway over the reef flat will probably cause more harm to the reef biota than will the sewer effluent itself. Some corals have been killed by the sedimentation and many are enduring a great deal of stress, removing the silt by producing mucus and sloughing it off with the silt. The causeway will also have a strong influence on the hydrographic features of the reef and the southern end of Malakal Island. The coral reef community will be affected by this in addition to the direct effects of sediments. The causeway constructed to lay the sewer pipe will probably have a greater effect on the region than the treated sewage effluent.

The coral reef community at Malakal Island is very rich and diverse. During our brief survey at the sewer outfall site where one of us (RHR) surveyed the corals by snorkeling, without scuba, 48 genera and 163 species were observed. To put this in perspective, 64 species have been recorded after searching around the large island of Jamaica to depths of 100 m over a number of years by several scientists (Wells and Lang, 1973). There may be more species of scleractinian corals near the sewer outfall site on Malakal Island than could be listed for the entire tropical Atlantic to depths of 100 m.

It is particularly interesting to note that the coral fauna at Malakal Island is the richest in species diversity of any of the sites surveyed by the University of Guam Marine Laboratory for the Trust Territory Environmental Protection Board while the waters around Malakal Island appear to be lowest in nutrients of any of these sites. The level of phosphate in the open waters around Malakal Island (Palau) were significantly lower than the levels in the open waters around Moen (Truk), Ebeye (Kwajalein) or Dalap (Majuro). The concentration of plankton in the waters around the outfall in Tomil Harbor, Yap, was ten times as high as in Malakal Harbor during the day and nearly eighteen times as high during the night. This seems to reinforce the general impression of coral reefs as "oases in the desert," with the richness of the coral fauna being inversely related to the productivity of the plankton in the area. The sewer outfall may provide an experiment on this topic because the treated effluent will probably contain dissolved organic material and inorganic nutrients, phosphates and nitrates. This could possibly result in a significant increase in the nutrient contents of the waters around the reef without a significant change in water temperature.

The increase in nutrient concentration of waters around a coral reef without a decrease in temperature would be a very interesting experiment and the changes in the coral community should be followed over a long period of time, referring to this report for baseline data for comparisons. Corals have long been known to do well in tropical waters with warm temperatures and with low levels of nutrients and productivity. Corals have been known to be disfavored by upwelling of cold waters rich in nutrients. The coral fauna appears to do well in areas in which the upwelling waters are cold but low in nutrients (Birkeland et al., 1975). The forthcoming situation near the Malakal Island sewer outfall may present the fourth combination of factors, warm water with added nutrients. The result of this environmental change should be observed about a year after the sewer outfall becomes operational.

There would becomplications and confounding factors in interpreting results from a return trip because this is not a controlled experiment. The negative effects of high nutrient levels on coral reef formation might be most influential during the early stages of succession. An increased growth rate of algae and encrusting bryozoans or tunicates due to increased nutrients or increased plankton productivity might be detrimental to recently settled corals but not dangerous to large coral colonies. Although high nutrient levels could prevent a reef from forming, an increase in nutrient levels might not have a major effect on a reef that is already established. If this is the case, however, it is still worth knowing in order to predict the effects of other sewer outfalls.

In addition to phosphates and nitrates, the treated effluent will contain other chemicals such as chlorine which may have a toxic influence on the biota. However, we should be able to observe a difference in symptoms between toxic effects and nutrient enrichment.

Although our stay was limited to a four day period in which several subjects were surveyed by each investigator, a cross-comparison of our results implies that the data are reliable enough to serve as a baseline for future comparisons on return trips. Considering that algae, octocorals and stony corals were each sampled by different investigators using different sampling techniques, the results on percent of area occupied by these different groups are in remarkably close agreement. When sampling stony corals in the Coral Reef and Patch zone with the line-intercept sampling technique, the octocorals were estimated by calculations from the resulting data to occupy 1.69% of the substratum. When sampling octocorals in the same zone by the point-quarter technique, octocorals were calculated to occupy 1.59% of the substratum. There are many other examples of this general agreement between results. A comparison of these baseline data with the future condition of the reef community after the sewer outfall has been in operation for a year would be valuable.

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PLATE I

CORAL PATCH AND SAND ZONE

a. A single colony of _Psammocora_ (_Stephanaria_) _togianensis_ Umbgrove, 1.2 meters wide. The damselfishes (Pomacentridae) associated with the colony include _Chromis caerulea_ (Cuvier) and _Dascyllus trimaculatus_ (Rüppell).

b. A patch of corals including the scleractinian _Pocillopora meandrina_ Dana, .75 m across (to the left), and the alcyonaceans _Sarcophyton_ sp., over 1 m in diameter (background to the right), and _Sinularia_ sp. (foreground to the right).

c. A patch of _Pocillopora meandrina_ 4 meters wide. A patch 10 meters wide was nearby. It was too large to photograph.

d. Transect line B_2 passing near a colony of _Millepora tenera_ Boschma (left center), _Sinularia_ sp. (center, 25 cm in diameter), and _Sarcophyton_ sp. (to the right, 50 cm in diameter). Note the _Tridacna maxima_ (Röding) imbedded in the substratum to the right of the _Sinularia_ and the _Acanthaster planci_ (Linnaeus) partially hidden beneath. The sand substratum is only a thin veneer over a basement of reef limestone.

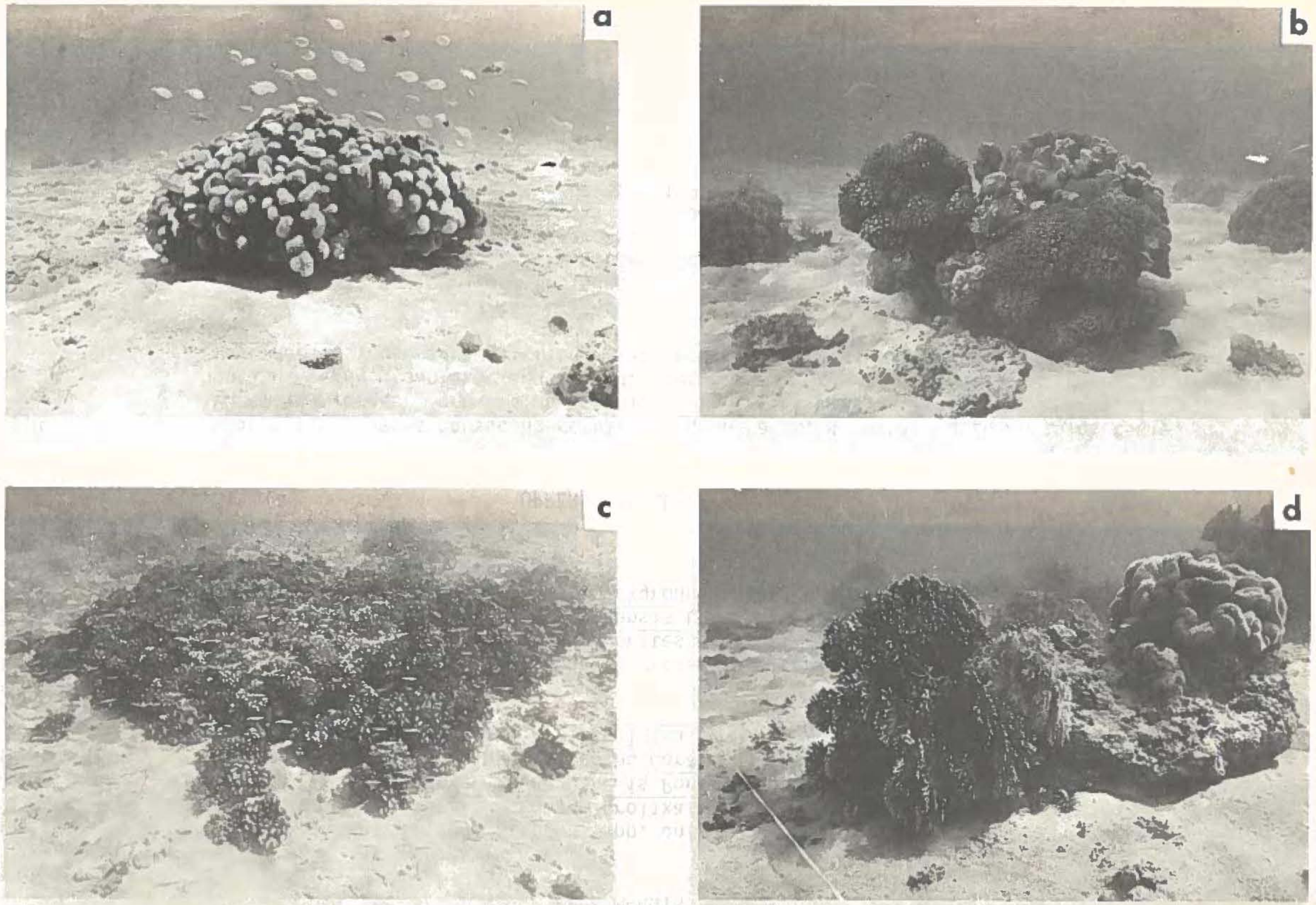
a
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PLATE II

REEF MARGIN

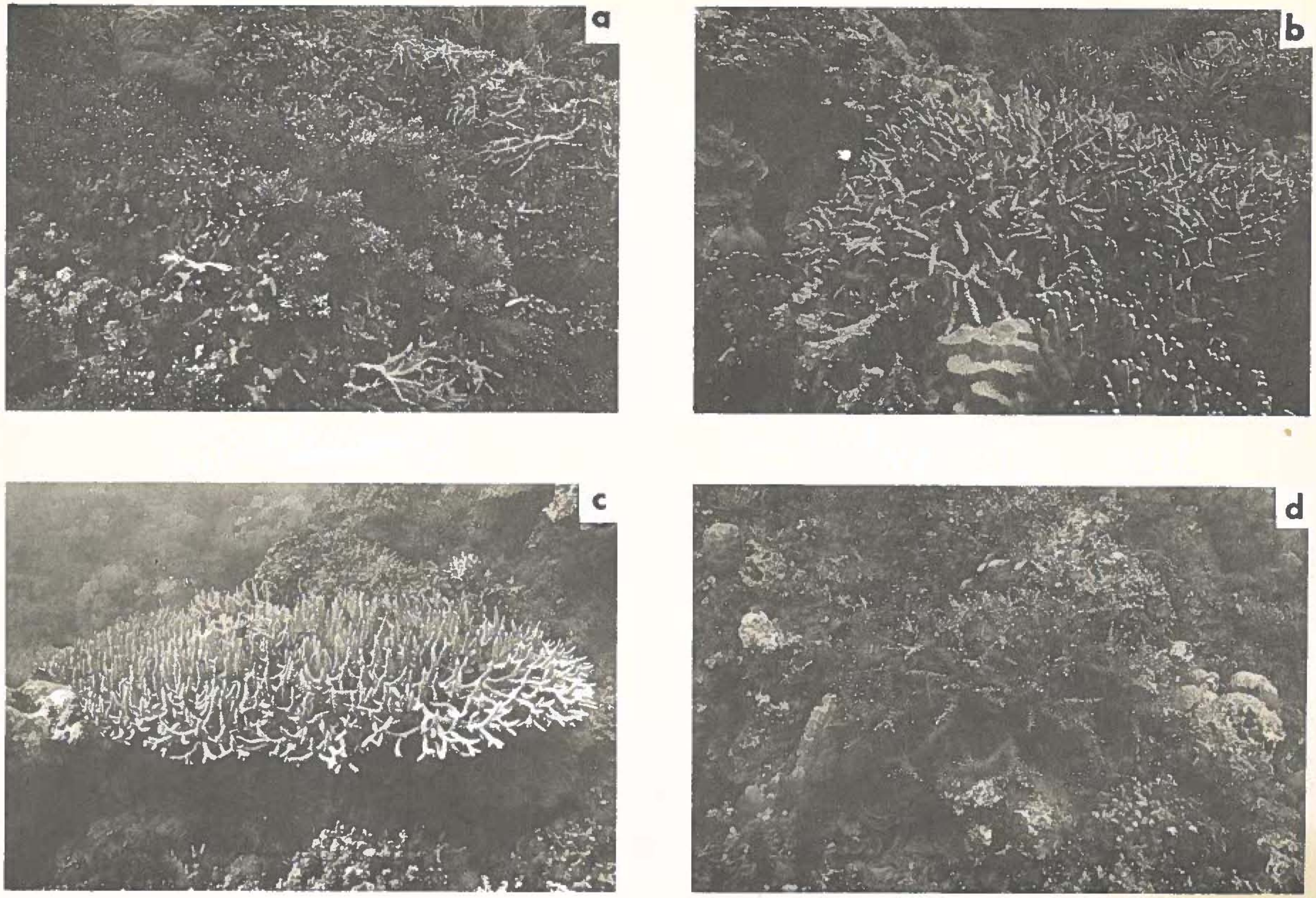
a. A variety of arborescent *Acropora* spp. on the reef margin. The finely branched species in the center is *Acropora prolixa* Verrill. The relatively smooth finger-like coral in the center foreground is *Porites andrewsi* Vaughan. Notice the prevalence of fast-growing, branching corals on the shallow reef margin swamping the slower-growing, massive *Porites lutea* Milne-Edwards and Haime in the background.

b. Branching *Hydnophora rigida* (Dana) 1 m diameter (center); a massive *Porites* sp. in center foreground; finger-like *Porites andrewsi* in right foreground; explanate shelving *Porites* (*Synaraea*) *iwayamaensis* Eguchi to the left; a variety of arborescent *Acropora* spp. in the background. Notice the massive *Porites* being overgrown by branching corals.

UPPER REEF SLOPE

c. A large corymbose-arborescent-renniform *Acropora* sp. 1 forming a 20 cm thick table, 190 cm in diameter, growing on a pedicel. Note the massive *Porites* to the right, beneath, being grown over and shaded. Depth 4 m. Columnar *Porites* (*Synaraea*) *iwayamaensis* in foreground; finger-like *Porites andrewsi* in background.

d. A variety of life forms of corals at a depth of 3 m on the upper reef slope. Note the small massive *Porites* (left center) being overgrown by the branching arborescent *Acropora echinata* (Dana), 1 m across. In foreground are columnar and explanate forms of *Porites* (*Synaraea*) *iwayamaensis*. In background are ramose *Porites andrewsi*, small massive *Porites*, and several arborescent *Acropora* species.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