LIMITED CURRENT AND UNDERWATER BIOLOGICAL SURVEY OF THE DONITSCH ISLAND SEWER OUTFALL SITE, YAP, WESTERN CAROLINE ISLANDS

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UNIVERSITY OF GUAM MARINE LABORATORY

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Prepared For

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TABLE OF CONTENTS

INTRODUCTION

Description of Yap

Yap consists of four closely approximated islands which are surrounded by an extensive fringing reef (Figure 1). Its total land area of 37 square miles makes it one of the largest land masses in the Trust Territory. Yap's climate is appropriate to its tropical location (9°33'N latitude, 138°08'W longitude): monthly average temperatures vary from 80-82°F (27-28°C) and monthly average humidity varies from 75-81%. Average yearly rainfall is 122 inches, falling primarily in the months of July to October. From January to April is the dry season when rainfall averages only 6 inches per month. Tradewinds from the northeast and east predominate from November to June; summer winds are weaker and more variable and blow from the south and southwest (Lyon Associates, Inc., 1975).

The most recent census figures (September 1973) set the resident population of Yap at 5,139 (Anon., 1974), which is distributed among almost 130 villages throughout the islands.

The main commercial and administrative center is Colonia, located on the Tomil Harbor. Because of the maintenance of traditional patterns of land ownership and residence, Colonia has a rather small resident population (approximately 600 in 1968; Hawaii Architects and Engineers, 1968). This figure is considerably below the actual number of people who reside in Colonia during the workweek, however, as many Yapese work in Colonia and return to their villages of residence on the weekends.

Most of Colonia's population, as well as its two hotels and housing for Trust Territory personnel, are located along Chamorro Bay (Colonia Lagoon), and this bay is the recipient of raw sewage from these sources. Circulation within Chamorro Bay is weak and its condition has been described as grossly polluted by both Austin, Smith and Associates (1967) and Hawaii Architects and Engineers (1968).

The need for sewage treatment has been recognized, and two sites for treatment plants have been suggested. Austin, Smith and Associates (1967) have suggested Donitsch Island as an ideal location for the plant inasmuch as it is adjacent to Colonia in Tomil Harbor and connected to the main island by a causeway and is "... judged to be too small and low to be of much use for any commercial venture." Circulation studies performed in this area in August 1967 indicated that the effluent would be carried away from Colonia and Chamorro Bay. Hawaii Architects and Engineers (1968) proposed to use Donitsch Island for a civic center and recreational park and suggested that a better location for the treatment plant and outfall would be at the southern end of Balabat Village south of Colonia.

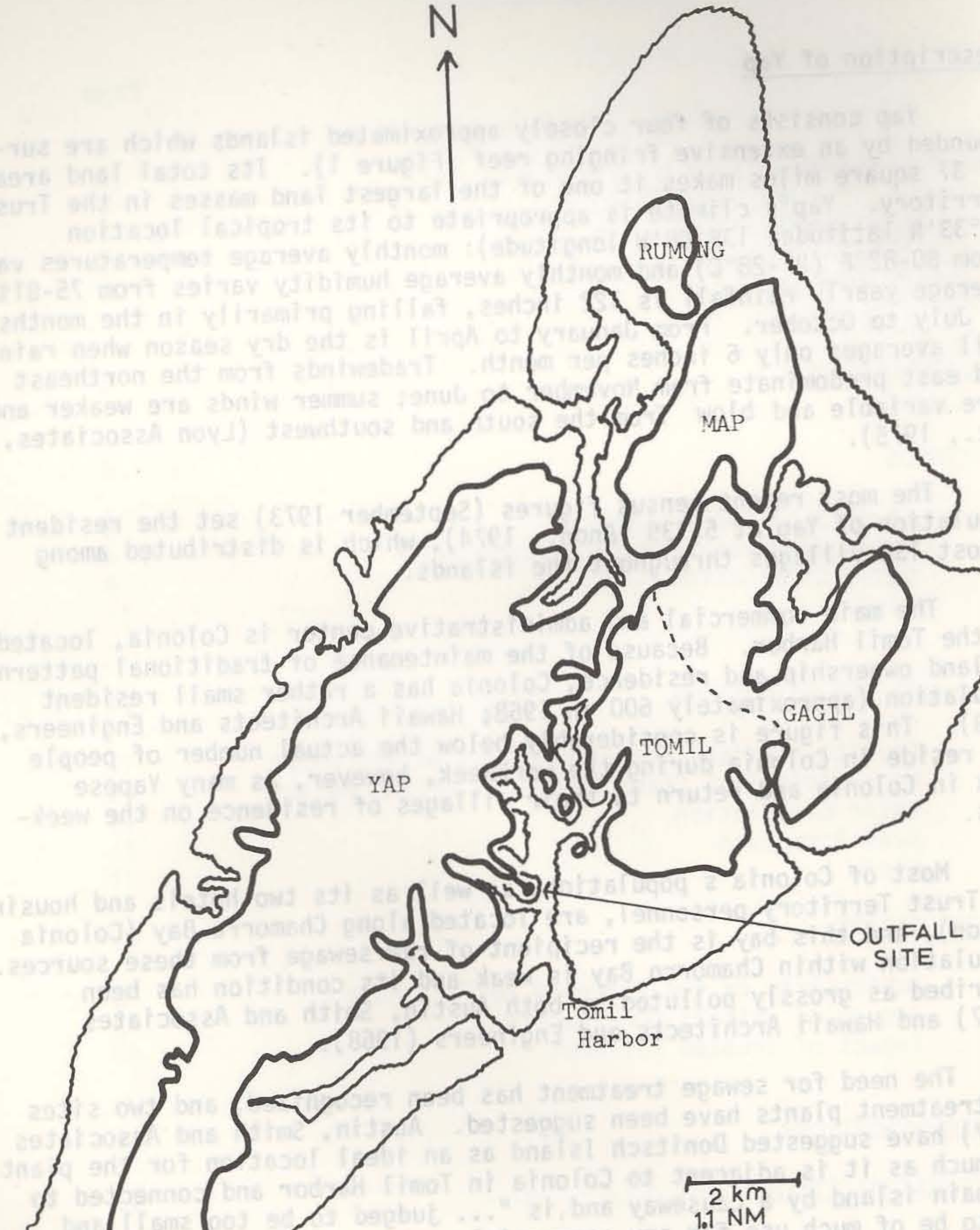

Fig. 1. The central Yap Islands and the location of the outfall.

The Donitsch Island site has been selected (Department of Public Works, TTPI, 1971, 1972) and construction has begun. The facility is to be an Imhoff tank with sludge drying beds and a chlorinator (William A. Brewer, pers. comm.), and the cement portions of these structures have already been poured. The outfall pipe has been laid, though not anchored down, and extends approximately 140 m out to the reef margin and then down to a depth of approximately 6 m. The initial design is for an average flow of 0.17 million gallons per day (MGD) with a peak capacity of 1.20 MGD, which will be able to accommodate a population of 2150.

Scope of Work

The proposed wastewater outfall at Yap will discharge treated effluent into nearshore waters of the Yap lagoon in an area believed to be under considerable environmental stress from untreated sewage discharges and construction activities.

The University of Guam Marine Laboratory biologists were to address themselves to the following questions:

- What effect, if any, the discharge of treated effluents will have on the ecological condition and water quality at the proposed outfall sites.

- The extent and magnitude of surface and sub-surface currents at the proposed outfall diffuser sites, so that reliable predictions on plume dispersion and dilution can be developed.

- Define potential alternate sites for outfall/diffuser location, should currents/tidal flushing at the proposed sites be found inadequate, or result in excessive biological impact.

- Baseline ecological data that can be utilized for future comparison, evaluation and determination of deleterious effects or impacts on biota and water quality.

Personnel

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ACKNOWLEDGEMENTS

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METHODS

Study Site and Transects

The Donitsch Island outfall site was visited on January 2-6, 1976. Donitsch Island lies in Tomil Harbor, approximately 230 meters from the easternmost extension of Colonia and can be reached by a narrow causeway. Surrounding the island is a shallow reef flat which extends 100 to 275 m to the east and south of the island where the bottom drops off to approximately 27.4 m into the Tomil channel. Three transects were established across the reef flat (Figure 2). Transect A followed the existing sewer pipe across the reef flat and was extended down the slope to a depth of 24.4 m. Transect B extended from Donitsch Island 293 m to the south, terminating at marker #11. Transect C extended to the northeast 171 m and terminated at marker #13. The depth profiles of the three transects are shown in Figures 3a, 3b, and 3c. See also Figure 4 for zone boundaries.

Water Chemistry and Microbiology

Offshore water samples at Stations 1-6 (Figure 2) were collected with a Van Dorn sampler lowered to predetermined depths and triggered by a messenger. Subsamples were frozen for later analyses of NO_3-N and PO_4-P (Strickland and Parsons, 1968) on Guam. Temperature and salinity were measured with a YSI S-C-T meter and oxygen with a YSI oxygen meter. Subsamples were obtained for coliform analysis. Shoreline samples at Stations 7-12 were also collected and analyzed for temperature, salinity, oxygen, and coliforms. 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-FC medium at 35.0 ± 0.5°C.

Water Circulation

Periodically, during rising and falling tides, pairs of drogues, 1 m and 5 m deep, were released from a point above the existing diffuser and from a point in the center of the channel approximately 150 m beyond the end of the outfall pipe. After appropriate time intervals, the positions of the drogues were determined and plotted. Wind speed and direction were recorded during the current studies to assess the possible effects of the wind on the movement of the drogues. Additional studies of water movement were made by releasing fluorescein dye, dissolved in freshwater to simulate the expected salinity of the sewage effluent, at a point immediately above the diffuser at a depth of 2 to 3 meters. The dye studies were performed at times of high and low tides.

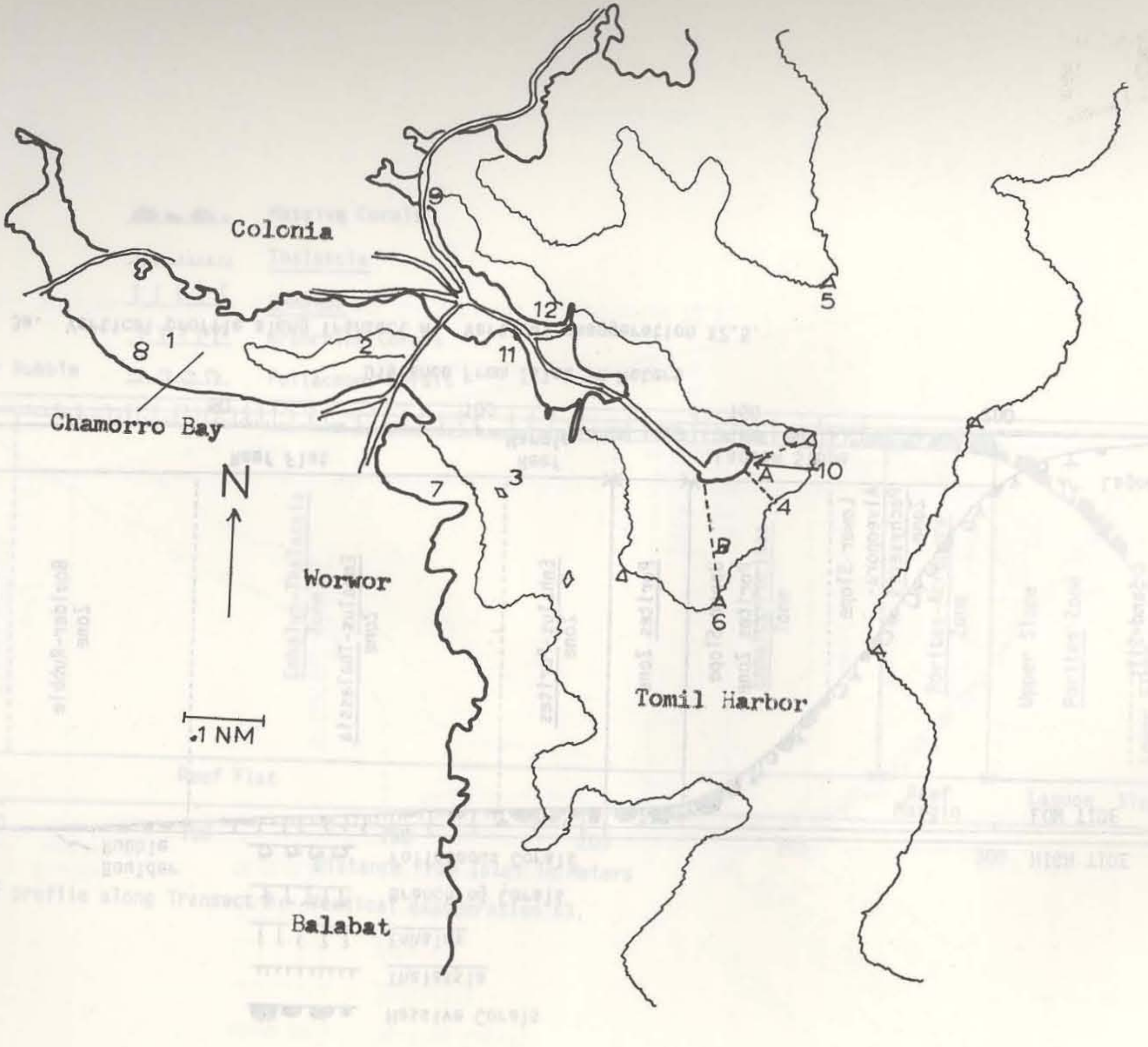

Fig. 2. Transects (A, B, and C) and water sampling stations (1-12) in the area of the outfall site.

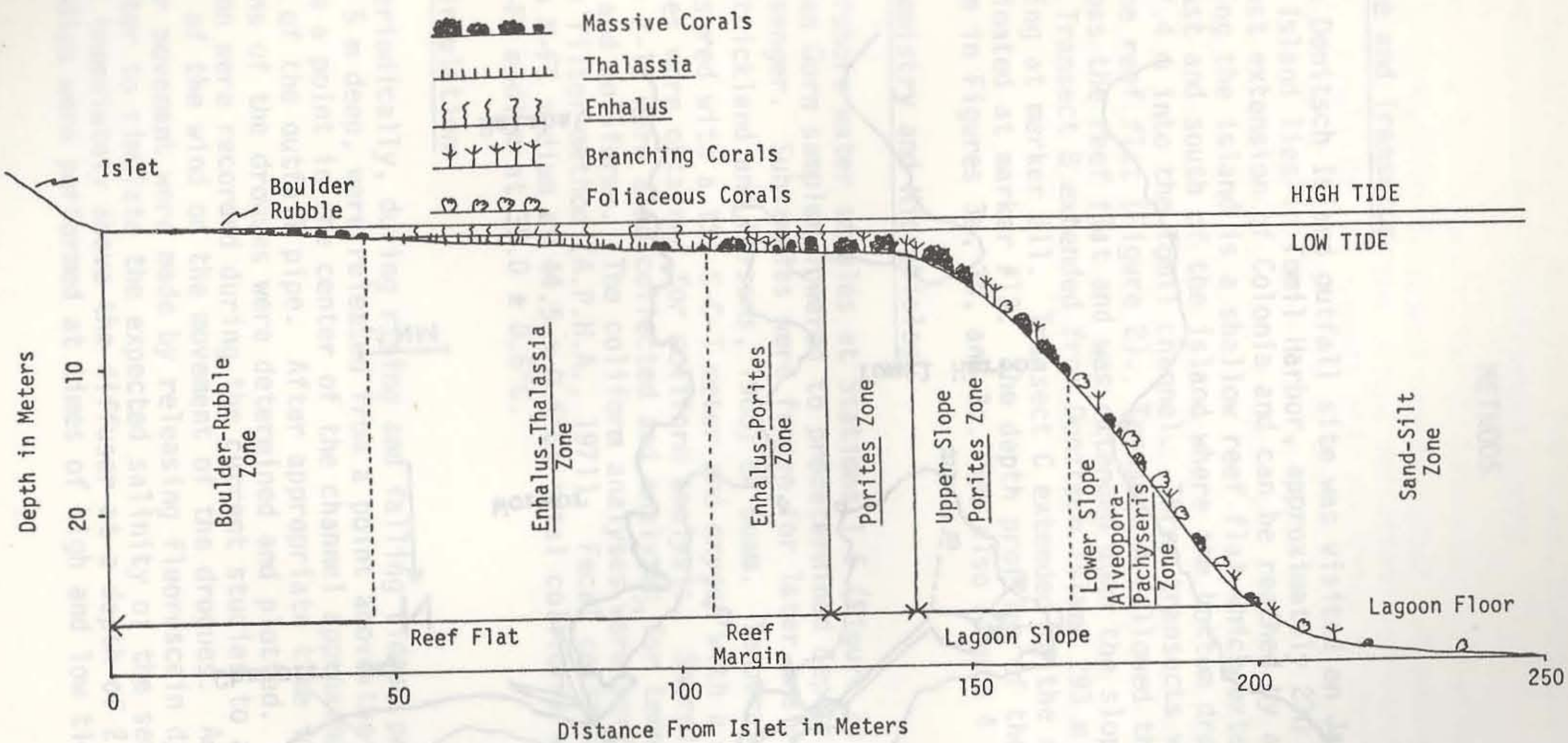

Fig. 3a. Vertical profile along Transect A. Vertical exaggeration X2.5.

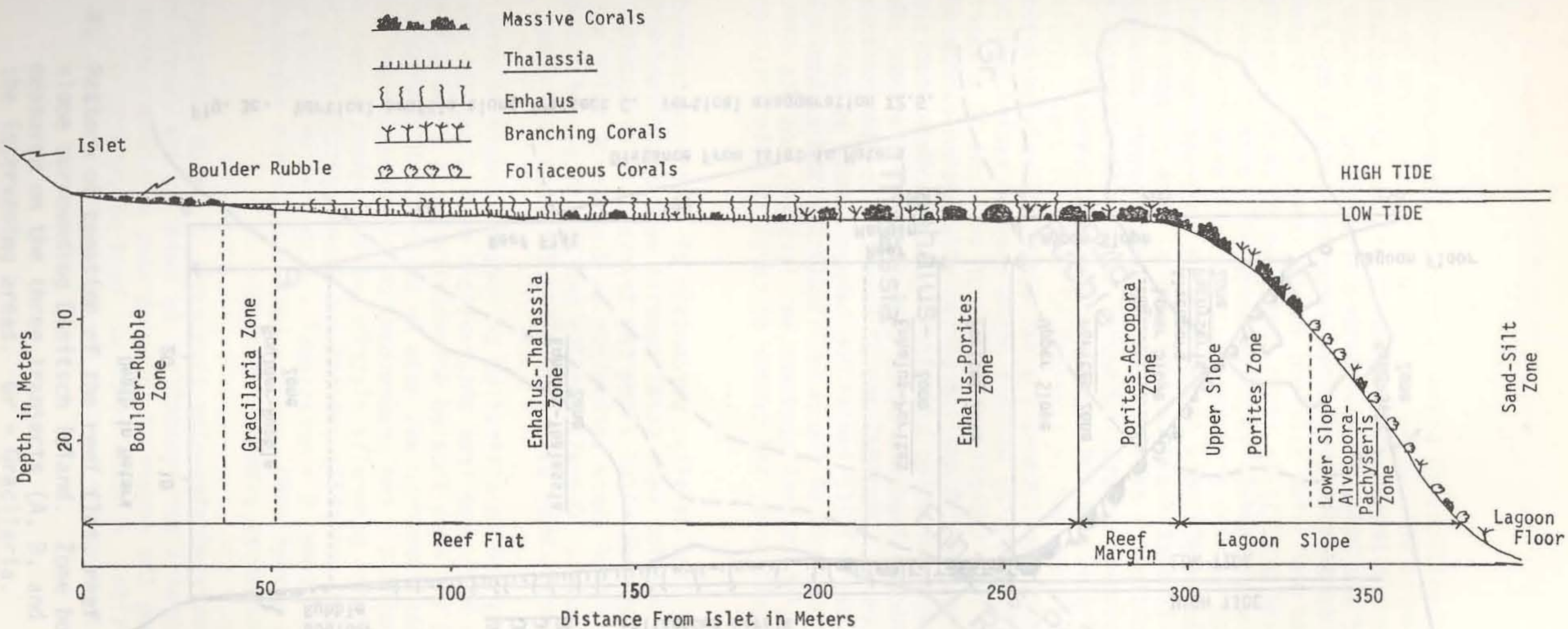

Fig. 3b. Vertical profile along Transect B. Vertical exaggeration X3.

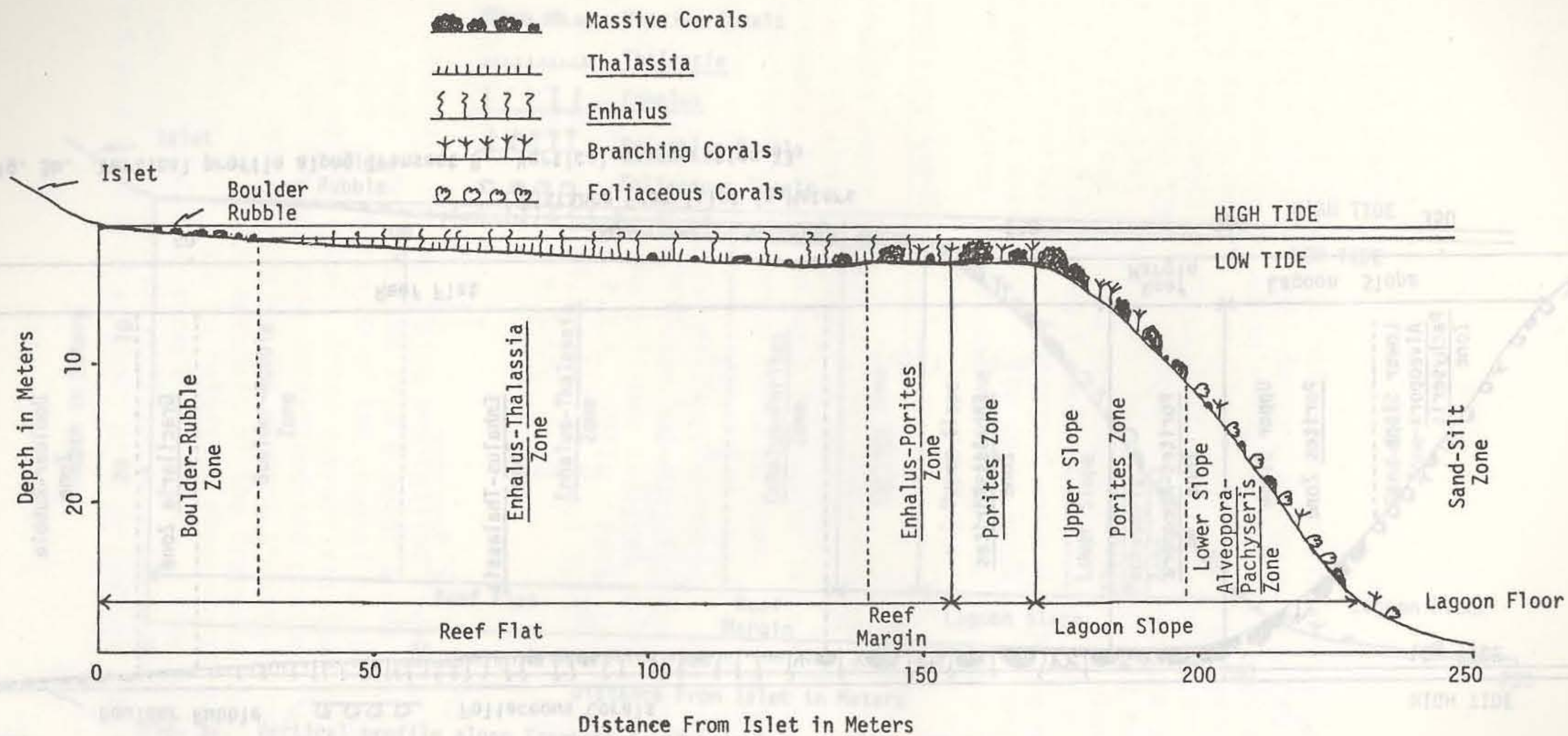

Fig. 3c. Vertical profile along Transect C. Vertical exaggeration X2.5.

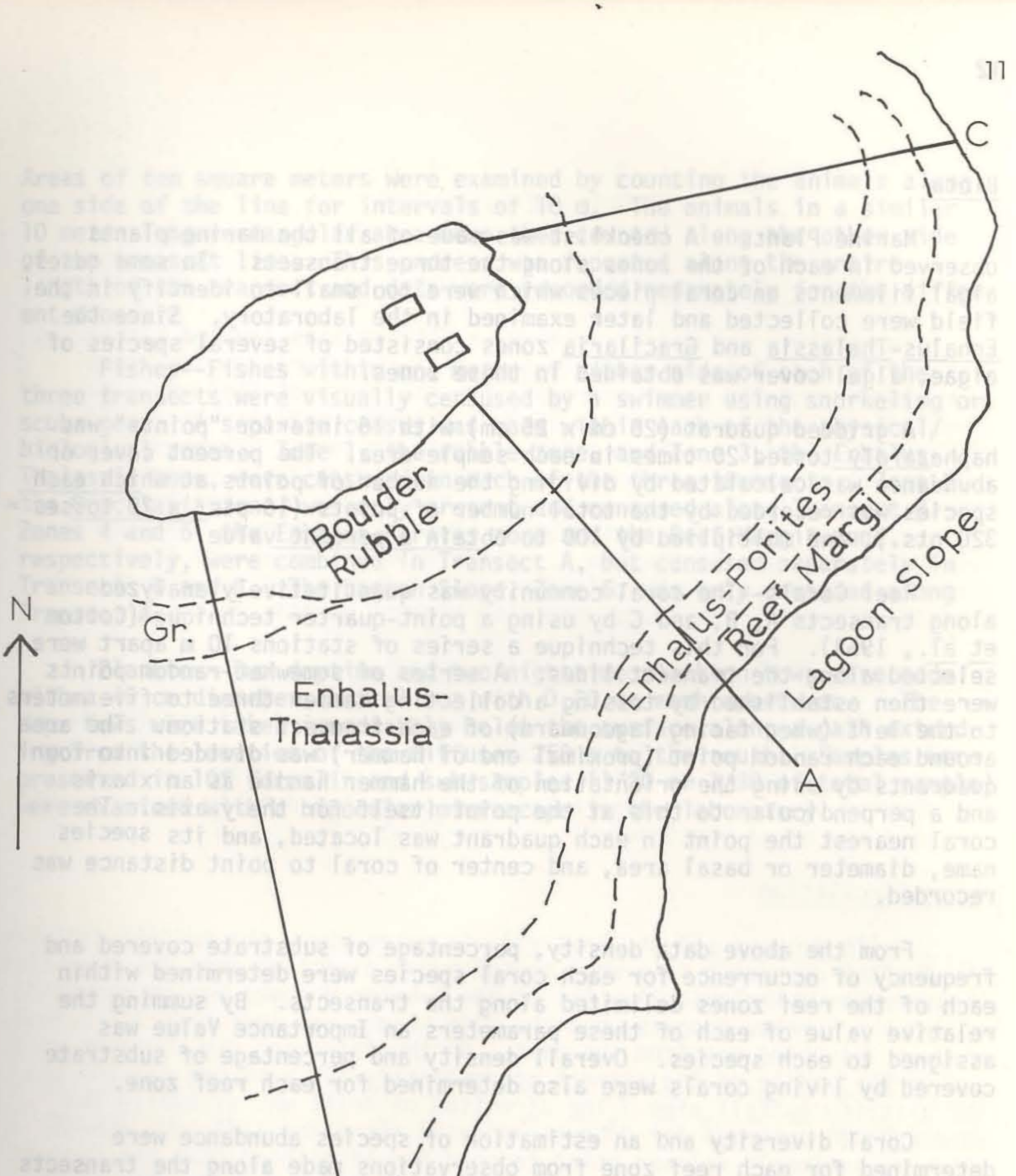

Fig. 4. Pattern of zonation of the reef flat, reef margin, and lagoon slope surrounding Donitsch Island. Zone boundaries were measured on the three transects (A, B, and C) and estimated in the intervening areas. Gr = Gracilaria.

Biota

Marine Plants - A checklist was made of all the marine plants observed in each of the zones along the three transects. In some cases, algal filaments on coral pieces which were too small to identify in the field were collected and later examined in the laboratory. Since the Enhalus-Thalassia and Gracilaria zones consisted of several species of algae, algal cover was obtained in these zones.

A gridded quadrat (25 cm x 25 cm) with 16 interior "points" was haphazardly tossed 20 times in each sample area. The percent cover or abundance was calculated by dividing the number of points at which each species was recorded by the total number of points (16 pts. x 20 tosses = 320 pts.), and multiplied by 100 to obtain a percent value.

Reef Corals--The coral community was quantitatively analyzed along transects A, B, and C by using a point-quarter technique (Cottom et al., 1953). For this technique a series of stations 10 m apart were selected along the transect lines. A series of somewhat random points were then established by tossing a collecting hammer three to five meters to the left (when facing lagoonward) of each transect station. The area around each random point (proximal end of hammer) was divided into four quadrants by using the orientation of the hammer handle as an x axis and a perpendicular to this at the point itself for the y axis. The coral nearest the point in each quadrant was located, and its species name, diameter or basal area, and center of coral to point distance was recorded.

From the above data density, percentage of substrate covered and frequency of occurrence for each coral species were determined within each of the reef zones delimited along the transects. By summing the relative value of each of these parameters an Importance Value was assigned to each species. Overall density and percentage of substrate covered by living corals were also determined for each reef zone.

Coral diversity and an estimation of species abundance were determined for each reef zone from observations made along the transects themselves and from the area located between Transects B and C (Fig. 4). 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.

Other Macro-invertebrates--The abundances of large echinoderms and other macro-invertebrates 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--Fishes within one meter of either side of each of the three transects were visually censused by a swimmer using snorkeling or scuba gear. A separate census was made within each of the physical/biological zones. Zone 1, the rubble zone, and Zone 3, the Enhalus-Thalassia zone, were censused in each of the three transects. Zone 2, the Gracilaria zone, was only present and censused along Transect B. Zones 4 and 5, the Enhalus-Porites zone and the Reef Margin zone, respectively, were combined in Transect A, but censused separately in Transects B and C. The Lagoon Slope, Zone 6, was only censused along Transect A.

Plankton--Two daytime and two nighttime plankton tows were made with a 45 cm diameter conical net with 0.20 mm mesh apertures. The four tows were taken immediately below the surface along a path extending from the location of the diffuser 250 m to the south. Samples were preserved in 10% formalin and sub-samples (1/20 or 1/30 of total sample) were examined with a binocular microscope in the laboratory.

RESULTS AND DISCUSSION

Physico-Chemical Characteristics of the Water

Temperature was fairly uniform at all stations sampled (Table 1), although it tended to be slightly higher at the shoreline locations where warming of the water overlying the shallow reef flat would be expected. Salinity varied from 29.2 °/oo in Chamorro Bay to >33 °/oo at Stations 5 and 6 on the margins of Tomil Channel. Oxygen was in no area depleted, even in Chamorro Bay where circulation is sluggish. Lowest dissolved oxygen was measured at the highly polluted inshore Station 7, but was highest at Station 12 which had almost the same coliform counts as did Station 7. Nitrates were low except for two high measurements at Station 4, the site of the as yet non-functioning outfall diffuser. Phosphates are also highest at this location.

Microbiological Characteristics of the Water

With the exception of a total coliform count of 100 per 100 ml at Station 2 (Table 1), coliform contamination was found only at the shoreline locations (Stations 7-12). Station 7, near the Ulithian village, and Station 12, near the Health Services Dock, had notably higher counts than did the other stations.

Water Circulation

Drift drogues set on January 3, in water above the outfall diffuser, all drifted generally in a west to southwest direction onto the reef flat (Figures 5a and 5b; Table 2). All of the 5-meter drogues became grounded, as did the 1-meter drogues when the tide height was less than 3 1/2 feet. Wind at this time was from the east. On the following day, drogues were set in the middle of the channel approximately 150 m beyond the end of the existing outfall pipe. The direction of drift was virtually the same as that recorded for drogues released above the diffuser, though the more southerly release point reduced the likelihood that the drogues would drift onto the reef flat surrounding Donitsch Island. The paths taken by the drogues, however, indicate that, given long enough drift time, they would drift onto the reef flat area between Worwor and Balabat.

Our drogue studies did not show a reversal of current flow with the change of tides as reported by Austin, Smith and Associates (1967) and Lyon Associates, Inc. (1975). During both ebb and flood tides, the direction of flow was generally the same although there appears to be a relationship between tide cycle and current speed (Figure 6). Greatest speed occurred approximately 4-5 hours following high tide, after which speeds decreased reaching minimal speed 4-5 hours after low tide.

Dye studies on January 5 were performed in the immediate area of the diffuser. Fluorescein dye released at the joint of the T-shaped

Table 1. Physical, chemical, and microbiological characteristics of the water in the area of the Donitsch Island outfall and Colonia, Yap. Station locations are shown in Figure 2.

Station No.	Depth (m)	Temperature (°C)	Salinity (°/oo)	D.O (ppm)	NO_3-N (hg-at/l)	PO_4-P (mg-at/l)	Total Coliform (per 100 ml)	Fecal Coliform (per 100 ml)
1	1	29.9	29.2	5.19	.044	0.16	0	0
2	1	29.0	33.1	5.59	.038	0.20	100	0
	3	29.0	32.8	6.45				
3	1	29.5	32.9	6.08	.077	0.23	0	0
	5	29.0	32.9	6.10				
4	1	29.0	32.8	6.41	.763	0.46	0	0
	3	28.8	32.8	6.44	.044	0.19	0	0
	5	29.5	32.5	6.58	.402	0.19	0	0
5	1	28.6	33.2	5.95	.033	0.10	0	0
	3	28.9	33.4	6.91				
	5	29.0	33.2	7.20				
6	1	29.3	33.2	5.40	.077	0.10	0	0
	3	28.8	33.0	6.20				
	5	28.8	33.2	6.38				
7	<1	30.1	31.4	4.90			1,000	200
8	<1	30.1	31.9	5.40			100	100
9	<1	30.0	32.0	6.58			170	60
10	<1	30.0	32.0	7.00			30	0
11	<1	29.9	31.9	6.60			100	0
12	<1	30.2	32.0	7.21			880	220

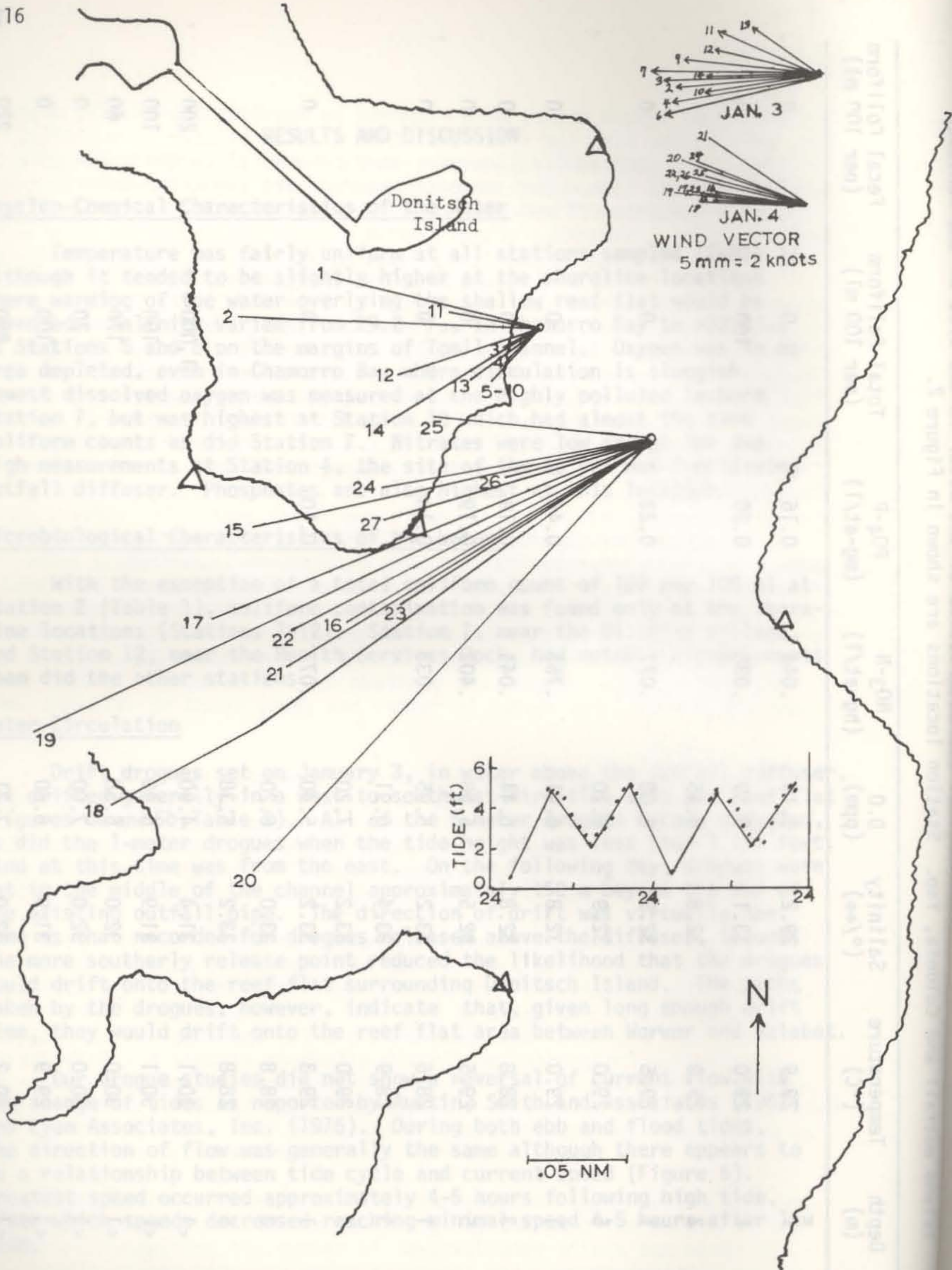

Fig. 5a. Drift patterns of 1-m drogues. Also shown are wind vectors and tidal fluctuations for January 3 and 4, 1976. Numbers on drift drogue and wind vector patterns are drogue numbers (see Table 2). Solid lines on tide chart are predicted tides; points are tide heights measured during current study.

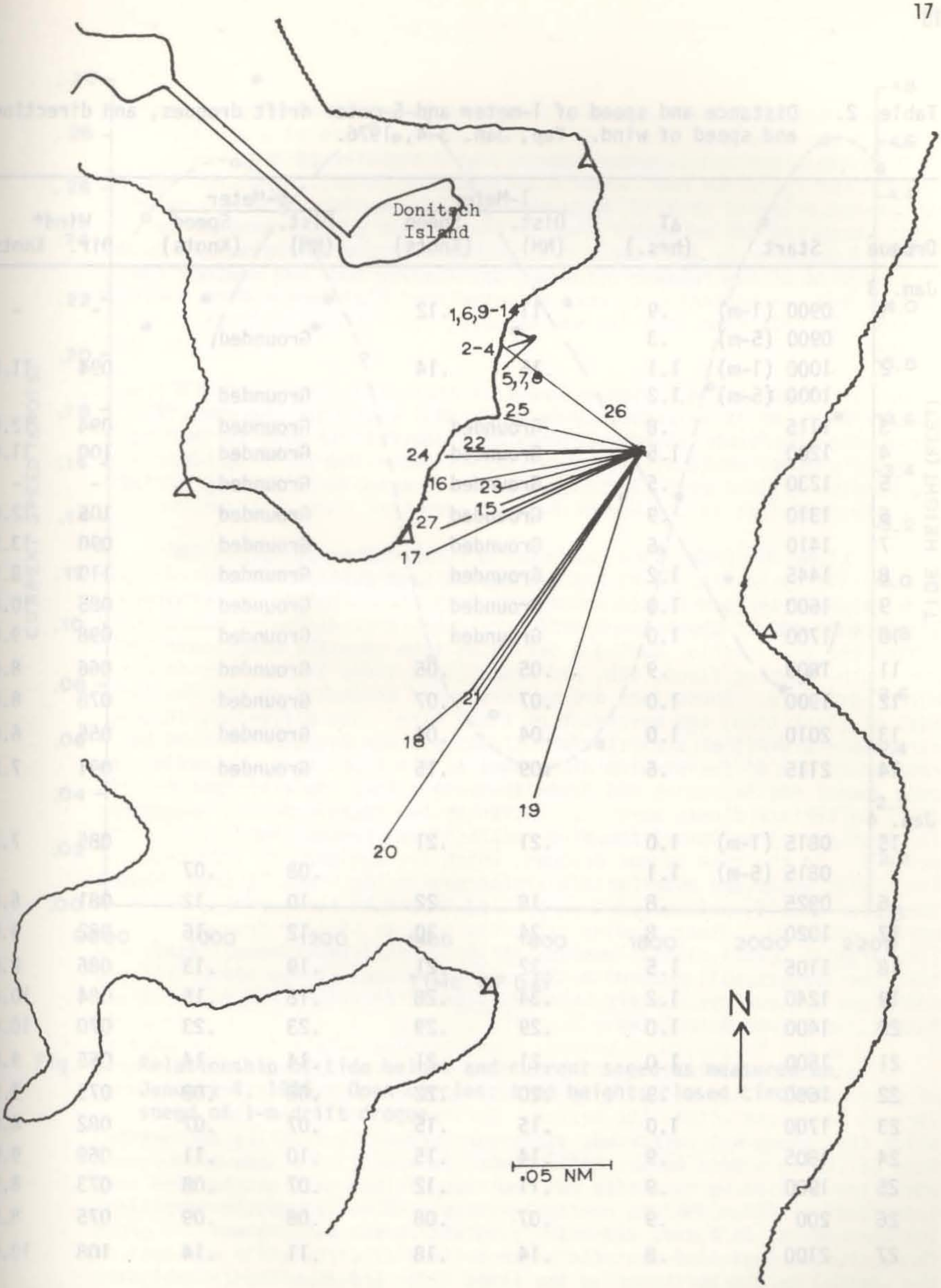

Fig. 5b. Drift patterns of 5-m drogues. Numbers are drogue numbers (see Table 2).

Table 2. Distance and speed of 1-meter and 5-meter drift drogues, and direction and speed of wind. Yap, Jan. 3-4, 1976.

			1-Meter		5-Meter		Wind*	
Drogue	Start	ΔT (hrs.)	Dist. (NM)	Speed (Knots)	Dist. (NM)	Speed (Knots)	Dir.	Knots
Jan. 3								
1	0900 (1-m)	.9	.11	.12			-	-
	0900 (5-m)	.3			Grounded			
2	1000 (1-m)	1.1	.15	.14			094	11.0
	1000 (5-m)	1.2			Grounded			
3	1115	.8	Grounded		Grounded		094	12.0
4	1200	1.5	Grounded		Grounded		100	11.0
5	1230	.5	Grounded		Grounded		-	-
6	1310	.9	Grounded		Grounded		105	12.0
7	1410	.6	Grounded		Grounded		090	13.5
8	1445	1.2	Grounded		Grounded		110	8.5
9	1600	1.0	Grounded		Grounded		085	10.0
10	1700	1.0	Grounded		Grounded		098	9.0
11	1800	.9	.05	.05	Grounded		066	8.0
12	1900	1.0	.07	.07	Grounded		078	8.0
13	2010	1.0	.04	.04	Grounded		055	6.0
14	2115	.6	.09	.15	Grounded		091	7.5
Jan. 4								
15	0815 (1-m)	1.0	.21	.21			085	7.5
	0815 (5-m)	1.1			.08	.07		
16	0925	.8	.18	.22	.10	.12	081	6.8
17	1020	.8	.24	.30	.12	.15	082	9.0
18	1105	1.5	.32	.21	.19	.13	086	8.0
19	1240	1.2	.34	.28	.18	.15	084	10.4
20	1400	1.0	.29	.29	.23	.23	070	10.0
21	1500	1.0	.21	.21	.14	.14	055	9.0
22	1600	.9	.20	.22	.08	.08	075	9.5
23	1700	1.0	.15	.15	.07	.07	082	8.0
24	1805	.9	.14	.15	.10	.11	069	9.0
25	1900	.9	.11	.12	.07	.08	073	8.0
26	200	.9	.07	.08	.08	.09	075	8.5
27	2100	.8	.14	.18	.11	.14	108	10.0

*Readings obtained ± 10 minutes of drogue release.

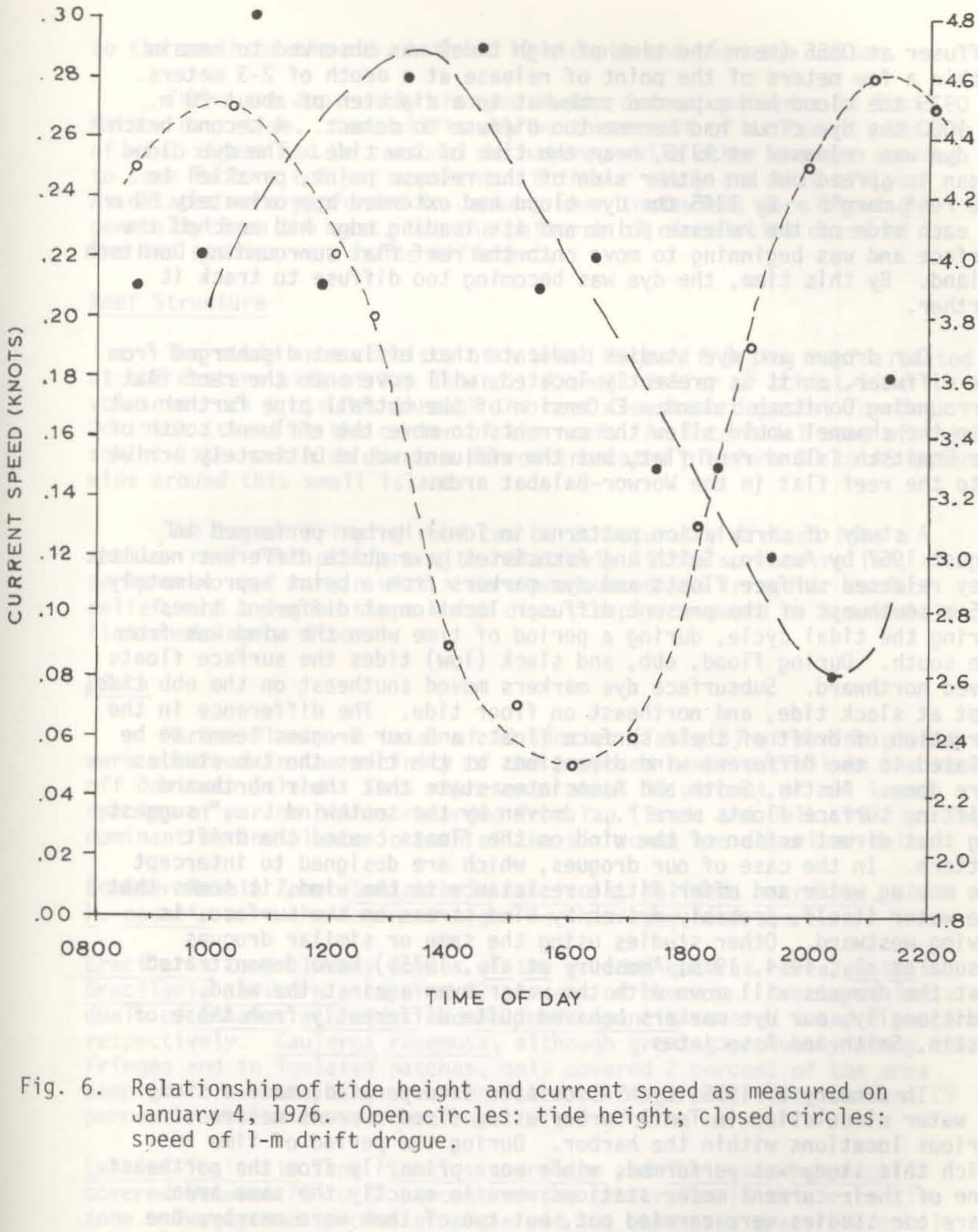

Fig. 6. Relationship of tide height and current speed as measured on January 4, 1976. Open circles: tide height; closed circles: speed of 1-m drift drogue.

diffuser at 0855 (near the time of high tide) was observed to remain within a few meters of the point of release at a depth of 2-3 meters. By 0935 the cloud had expanded somewhat to a diameter of about 20 m. By 1050 the dye cloud had become too diffuse to detect. A second batch of dye was released at 1315, near the time of low tide. The dye cloud began to spread out on either side of the release point, parallel to the reef margin. By 1345 the dye cloud had extended approximately 50 m to each side of the release point and its leading edge had reached the surface and was beginning to move onto the reef flat surrounding Donitsch Island. By this time, the dye was becoming too diffuse to track it further.

Our drogue and dye studies indicate that effluent discharged from the diffuser, as it is presently located, will move onto the reef flat surrounding Donitsch Island. Extension of the outfall pipe further out into the channel would allow the currents to move the effluent south of the Donitsch Island reef flat, but the effluent would ultimately arrive onto the reef flat in the Worwor-Balabat area.

A study of circulation patterns in Tomil Harbor performed in August 1967 by Austin, Smith and Associates gave quite different results. They released surface floats and dye markers from a point approximately 225 m southwest of the present diffuser location at different times during the tidal cycle, during a period of time when the wind was from the south. During flood, ebb, and slack (low) tides the surface floats moved northward. Subsurface dye markers moved southeast on the ebb tide, east at slack tide, and northeast on floor tide. The difference in the direction of drift of their surface floats and our drogues seems to be related to the different wind directions at the times the two studies were done. Austin, Smith and Associates state that their northward drifting surface floats were "... driven by the southwind ...," suggesting that direct action of the wind on the floats caused the drift pattern. In the case of our drogues, which are designed to intercept the moving water and offer little resistance to the wind, it seems that the water itself, probably driven by wind stress on the surface, is moving westward. Other studies using the same or similar drogues (Tsuda et al., 1974, 1975; Amesbury et al., 1975b) have demonstrated that the drogues will move with the water even against the wind. Additionally, our dye markers behaved quite differently from those of Austin, Smith and Associates.

In January of 1975, Lyon Associates Incorporated, made a study of water circulation in Tomil Harbor using fixed current meters at various locations within the harbor. During the period of time in which this study was performed, winds were primarily from the northeast. None of their current meter stations were in exactly the same area where our studies were carried out, but two of them were nearby, one approximately 450 m NNE and one approximately 400 m SSE of the proposed location of the diffuser, and both lying within the main channel. These studies indicated that the major pattern of circulation was up the channel to the north during the flood tide, and down the channel to the south on the ebb, both at 10 m depth and near the bottom.

There are apparently changes in the current patterns in Tomil Harbor over time. Some shifts may be the result of different patterns of wind stress and be seasonal in nature, while other changes are due to some factors not yet apparent. Both our study and that of Lyon Associates were performed in January when tradewinds were blowing generally from the east, but the patterns of circulation measured in the two studies were quite different.

Reef Structure

The study area consists of a broad lagoon fringing reef situated at the eastern side of Yap Island. A small inlier of schist-like volcanic rock protrudes through the reef limestone deposts, forming Donitsch Island at the center of the reef. An intertidal zone of this schist-like rock also forms a narrow truncated platform 30 to 45 meters wide around this small island.

The lagoon fringing reef can be structurally divided into a shallow reef-flat platform with relatively little surface relief, a peripheral reef margin with a more pronounced and irregular surface relief, and a lagoon slope which dips steeply downward to a somewhat flattened lagoon floor.

Biota

Marine Plants--A total of 40 species (Table 3) of marine plants were observed in the vicinity of the proposed sewer outfall on the reef off Donitsch Island. This represents about 38 percent of all known species of marine plants recorded from Yap (Tsuda and Belk, 1972). The dominant marine plants in each of the six zones are described below.

Boulder Rubble Zone: Schizothrix calcicola, Halimeda macroloba, and H. opuntia were the dominant algae in this zone near shore.

Gracilaria Zone: Twenty tosses of the gridded quadrat revealed that Gracilaria salicornia covered 42 percent of the area. Scattered individuals of Enhalus acoroides and Halimeda opuntia covered 3 and 2 percent, respectively. Caulerpa racemosa, although growing profusely along the fringes and in isolated patches, only covered 2 percent of the area sampled. The remaining area consisted of 24 percent silt-sand and 25 percent rubble with no conspicuous algae growing here.

Enhalus-Thalassia Zone: Enhalus acoroides and Thalassia hemprichii covered between 70 to 77 percent of the substratum in this extensive zone. Twenty-one species of algae and one other sea grass (Halophila ovalis) were observed in this zone. The five dominant algae growing among the sea grasses along the three transects were similar as shown in Table 4. An area, within 5 m south of the sewer pipe, was obviously damaged during the laying of the pipe and was quantified also. Four species of algae covered 27 percent of the sandy bottom - Caulerpa

Table 3. Checklist of marine plants along three transects at the proposed sewer outfall site off Donitsch Island, Yap. January, 1976. The locations of the three transects are shown in Figure 4. The zone designations are as follows: 1-Boulder Rubble Zone, 2-*Gracilaria* Zone, 3-*Enhalus*-*Thalassia* Zone, 4-*Enhalus*-*Porites* Zone, 5-Reef Margin, 6-Lagoon Slope

Species	Transect A				Transect B				Transect C			
	1	3	4/5	6	1	2	3	4/5	1	3	4/5	6
CYANOPHYTA (blue-greens)												
Calothrix crustacea Thuret								X				
Microcoleus lyngbyaceus (Kutz.) Crouan		X					X	X				
Schizothrix calciola (Ag.) Gomont	X	X			X				X			
CHLOROPHYTA (greens)												
Anadyomene wrightii Gray										X		
Avrainvillea obscura J. Ag.		X										
Boodlea composita (Harv.) Brand		X				X	X			X		
Caulerpa filicoides Yamada							X					
Caulerpa racemosa (Forsk.) J. Ag.	X	X				X	X			X		
Caulerpa sertularioides (Gmel.) Howe						X						
Caulerpa webbiana Montagne												X
Dictyosphaeria cavernosa (Forsk.) Boerg.						X	X	X				
Halimeda discoidea Decaisne				X		X				X		
Halimeda incrassata (Ellis) Lamx.		X					X			X		
Halimeda macroloba Decaisne	X	X			X	X	X			X		
Halimeda macrophysa Askenasy			X				X					
Halimeda opuntia (L.) Lamx.	X	X				X	X	X		X		
Neomeris annulata Dickie										X		
Rhipilia orientalis A. & E. S. Gepp				X								X
Tydemannia expeditionis W. v. Bosse			X	X				X			X	X
Valonia ventricosa J. Ag.			X					X				
PHAEOPHYTA (browns)												
Dictyota apiculata J. Ag.											X	
Dictyota cervicornis Kutz.		X					X			X		

Table 3. Continued.

Species	Transect A				Transect B				Transect C			
	1	3	4/5	6	1	2	3	4/5	1	3	4/5	6
PHAEOPHYTA (browns) (continued)												
Dictyota friabilis Setchell								X				
Feldmannia indica (Sonder) Womersley & Bailey								X				
Hydroclathrus clathratus C. Ag.		X					X			X		
Lobophora variegata (Lamx.) Womersley			X								X	
Padina tenuis Bory		X			X	X	X		X	X		
Rosenvingea intricata (J. Ag.) Boerg.							X			X		
Sphacelaria tribuloides Meneghini								X				
RHODOPHYTA (reds)												
Acanthophora spicifera (Vahl) Boerg.		X					X					
Amphiroa foliacea Lamx.								X				
Amphiroa fragilissima (L.) Lamx.								X		X		
Gracilaria crassa Harvey							X			X		
Gracilaria salicornia (Mert.) Grev.	X					X	X		X			
Hemitrema fragilis (Harvey) Dawson												X
Metagoniolithon charoides (Lamx.) W. v. Bosse					X							
Polysiphonia tepida Hollenberg			X					X				
Spyridia filamentosa (Wulf.) Harvey		X					X			X		
SEA GRASS												
Enhalus acoroides (L.f.) Royle		X			X	X	X			X	X	
Halophila ovalis (R.Br.) Hook.										X		
Thalassia hemprichii (Ehrenb.) Aschers.		X				X	X			X	X	
	5	15	5	3	5	11	19	12	3	18	5	4

Table 4. Percent cover of algae in Enhalus-Thalassia beds (Zone 3) along the three transects off Donitsch Island, Yap. January, 1976.

Species	Transects A (n = 20)	B (n = 20)	C (n = 20)
Sand	4	9	11
Enhalus acoroides-Thalassia hemprichii	70	77	74
Dictyota cervicornis	15	2	7
Caulerpa racemosa	5	9	5
Microcoleus lyngbyaceus	1	1	-
Padina tenuis	3	3	<1
Halimeda opuntia	2	<1	2

racemosa (14%), Microcoleus lyngbyaceus (6%), Dictyota cervicornis (6%), and Schizothrix calcicola (1%). Except for S. calcicola, the other three species are identical to those found in the adjacent sea grass beds.

Enhalus-Porites and Reef Margin Zones: These zones, predominantly with live corals, possessed algal tufts on dead corals. At times, up to five species of algae were intermixed on a one cm^2 coral surface.

Lagoon Slope: Tydemannia expeditionis and Rhipilia orientalis were the most conspicuous algae on the reef front.

Reef Corals--Observations along the three transects revealed a rather conspicuous zonation pattern of the corals as indicated in Figures 3 and 4.

Reef-Flat Platform Zones: The innermost Boulder-Rubble zone is exposed at all three transects during low spring tides and thus lacks coral growth. Corals were also absent in the Gracilaria zone at Transect B and the inner part of the Enhalus-Thalassia zones at all the transects. A few widely scattered corals were present in the outer part of this wide seagrass dominated zone. It is suspected that during extreme low spring tides much of the Enhalus-Thalassia zone is irregularly exposed which limits coral growth to patchy depressed areas retaining water. A few small Porites lutea colonies constituted the predominant corals observed, with the remaining four species listed in Table 5 being encountered only rarely.

Along the outer part of the reef-flat platform, the water is deeper and more uniformly retained during low spring tides and corals become more predominant, forming the Enhalus-Porites zone. Coinciding with an increase in coral growth in this zone was a decrease in the abundance of seagrasses, particularly Thalassia. The number of coral species observed ranged from a high of 26 at Transect A to a low of 17 at Transect B. Overall, Porites lutea was the predominant coral, forming large subhemispherical and flat-topped colonies up to a meter in diameter (Fig. 3). Localized areas of this zone on Transect A were dominated by thickets of a large blue-colored arborescent Acropora species, giving Transect A significantly higher values for coral density and percentage of substratum covered than at Transects B and C (Table 5).

Lagoon Fringing Reef Margin Zone: Except for Transect A, the overall species diversity, percentage of substratum covered, and coral development was greater in this zone than at any other (Tables 5 and 6). The low percentage of coral substratum coverage recorded for Transect A was a reflection of the presence of a wide area of construction damage to corals at the reef margin, through which the transect line passed. Large colonies of Porites lutea and Porites andrewsi were the predominate corals in this zone and are primarily responsible for the irregular topographic relief found there (Fig. 3). Corals of the family Fungiidae were locally abundant on the uppermost part of the reef margin

Table 5. Living coral density, percent of substratum coverage, and frequency of occurrence. Relative values of these three measures are summed to give an importance value. Overall density and per cent of substratum covered are given for each transect zone where corals occurred. Species are arranged in order of their importance value.

TRANSECT A	Frequency	Relative Frequency	Density	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Lagoon Fringing Reef Flat							
Boulder Rubble Zone - 0 to 46 meters (no corals encountered)							
Enhalus-Thalassia Zone - 46 to 105 meters (no corals encountered)							
Enhalus-Porites Zone - 105 to 125 meters							
Acropora (blue)	0.5	25	2.1	25.0	22.8	82.6	132.6
Porites lutea	1.0	50	5.2	62.5	2.7	9.9	122.4
Pocillopora damicornis	0.5	25	1.0	12.5	2.1	7.5	45.0
Overall density 8.3 corals/m^2							
Overall per cent of cover 27.6%							
Lagoon Fringing Reef Margin							
Porites Zone - 125 to 140 meters							
Porites lutea	0.9	64.3	4.1	78.1	16.9	96.0	238.4
Porites andrewsi	0.1	7.1	0.5	9.4	0.2	1.1	17.6
Millepora exaesa	0.1	7.1	0.2	3.1	0.2	1.1	11.3
Favites melicerum	0.1	7.1	0.2	3.1	0.1	0.6	10.8
Fungia fungites	0.1	7.1	0.2	3.1	0.1	0.6	10.8
Pocillopora damicornis	0.1	7.1	0.2	3.1	0.1	0.6	10.8
Overall density 5.3 corals/m^2							
Overall per cent of cover 17.6%							

Overall per cent of cover 17.6%

Table 5. (continued)

TRANSECT B	Frequency	Relative Frequency	Density	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Lagoon Fringing Reef Flat							
Boulder Rubble Zone - 0 to 32 meters (no corals encountered)							
<u>Gracilaria</u> Zone - 32 to 50 meters (no corals encountered)							
<u>Enhalus-Thalassia</u> Zone - 50 to 205 meters (no corals encountered)							
<u>Enhalus-Porites</u> Zone - 205 to 270 meters							
<u>Porites lutea</u>	1.0	71.4	2.9	91.7	8.2	95.3	258.4
<u>Montipora ehrenbergii</u>	0.2	14.3	0.1	4.2	0.3	3.5	22.0
<u>Montipora verrilli</u>	0.2	14.3	0.1	4.2	0.1	1.2	19.7
Overall density 3.2 corals/m^2							
Overall per cent of cover 8.7%							
Lagoon Fringing Reef Margin							
<u>Porites-Acropora</u> Zone - 270 to 293 meters							
<u>Porites lutea</u>	0.8	26.7	2.7	25.0	39.2	67.0	118.7
<u>Pavona praetorta</u>	0.5	16.7	3.4	31.3	4.9	8.4	56.4
<u>Acropora formosa</u>	0.3	10.0	0.7	6.3	11.1	19.0	35.3
<u>Montipora lobulata</u>	0.5	16.7	1.4	12.5	1.8	3.1	32.3
<u>Porites andrewsi</u>	0.3	10.0	1.4	12.5	0.4	0.7	23.2
<u>Montipora ehrenbergii</u>	0.3	10.0	0.7	6.3	0.6	1.0	17.3
<u>Millepora exaesa</u>	0.3	10.0	0.7	6.3	0.6	1.0	17.3
Overall density 10.9 corals/m^2							
Overall per cent of cover 58.5%							

Table 5. (continued)

TRANSECT C	Frequency	Relative Frequency	Density	Relative Density	Percent Cover	Relative Percent Cover	Importance Value
Lagoon Fringing Reef Flat							
Boulder Rubble Zone - 0 to 30 meters (no corals encountered)							
Enhalus-Thalassia Zone - 30 to 140 meters (no corals encountered)							
Enhalus-Porites Zone - 140 to 155 meters							
Porites lutea	1.0	66.7	2.4	87.5	2.5	55.6	209.8
Montipora divaricata	0.5	33.3	0.4	12.5	2.0	44.4	90.2
Overall density	2.8 corals/m^2						
Overall per cent of cover	4.5%						
Lagoon Fringing Reef Margin							
Porites Zone - 155 to 171 meters							
Porites lutea	0.5	20.0	3.4	25.0	29.3	44.5	89.5
Porites andrewsi	0.5	20.0	3.4	25.0	16.8	25.5	70.5
Montipora lobulata	0.5	20.0	3.4	25.0	11.5	17.5	62.5
Montipora ehrenbergii	0.5	20.0	1.7	12.5	5.6	8.5	41.0
Montipora venosa	0.5	20.0	1.7	12.5	2.6	4.0	36.5
Overall density	13.5 corals/m^2						
Overall per cent of cover	65.7%						

Table 6. List of corals observed along the transects of the study area. Symbols indicate their relative abundance within the various reef zones: D = dominant, A = abundant, C = common, O = occasional, R = rare.

CORALS	TRANSECT A							TRANSECT B								TRANSECT C						
	REEF FLAT			REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR	REEF FLAT				REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR	REEF FLAT			REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR
	Boulder Rubble Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone	Boulder Rubble Zone	Gracilaria Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites-Acropora Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone	Boulder Rubble Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone
CLASS ANTHOZA																						
ORDER-SCLERACTINIA																						
SUBORDER-ASTROCOENIINA																						
Family -ASTROCOENIIDAE																						
Stylocoeniella armata (Ehrenberg)			R	O	O							O	O					R	O	O		
Family-THAMNASTERIIDAE																						
Psammocora contigua (Esper)				O								O						R	O			
Psammocora obtusangula (Lamarck)																		R				
Psammocora (Stephanaria) togianensis Umbgrove																				O		
Family-POCILLOPORIDAE																						
Seriatopora hystrix Dana					R														R			
Pocillopora damicornis (Linnaeus)		R	O	C	O					R	C	C	O				R	O	C	O		
Family-ACROPORIDAE																						
Acropora exigua (Dana)											O											
Acropora formosa (Dana)			C	O	O					R	C	C	O					O	O	R		
Acropora hebes (Dana)			R																			
Acropora humilus (Dana)			R																			
Acropora palifera (Lamarck)													O									
Acropora (Blue)			C	R							O		R					O	R			
Astreopora myriophthalma (Lamarck)			R	R																R		
Montipora acanthella Bernard				R																		
Montipora annularis Bernard						R																
Montipora berryi Hoffmeister			O	O							O	O							O			
Montipora carinata Nemenzo				O								O							R			
Montipora circumuallata (Ehrenberg)			R															R				
Montipora divaricata Brueggemann			C	O						R	O	O						O				
Montipora sp. cf. M. ehrenbergii Verrill			O	O														R	O			
Montipora foveolata (Dana)				O																		
Montipora lobulata Bernard			O	C	O						O	O						O	O	R		
Montipora turgescens Bernard			O	O								O						O	R			
Montipora verrilli Vaughan				O																R		
Montipora sp. 1 (Papillate)				R																		
SUBORDER-FUNGIINA																						
Family-AGARICIIDAE																						
Pavona frondifera Lamarck				R																		
Pavona praetorta (Dana)						O							O	O								
Pavona varians Verrill			R																R			
Pavona (Polyastra) venosa (Ehrenberg)			O	C							O	O							O			
Pavona sp. 1														O	O							
Leptoseris scabra Vaughan																					O	
Leptoseris solida (Quelch)						C														O	C	
Leptoseris sp. 1														O	O						C	
Pachyseris levicollis (Dana)						O															O	
Pachyseris rugosa (Lamarck)				O	O							O	O						O	O		
Pachyseris speciosa (Dana)				O	O	C							O	C					O	C	A	
Family-FUNGIIDAE																						
Fungia (Heliofungia) actiniformis Quoy and Gaimard				R																		
Fungia (Verrillofungia) concinna Verrill				O								O										
Fungia (Fungia) fungites (Linnaeus)			O	A	O						O	O						O	O	O		
Fungia (Ctenactis) echinata (Pallas)			R	O								R							O			

Table 6. Continued.

	TRANSECT A							TRANSECT B								TRANSECT C						
	REEF FLAT			REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR	REEF FLAT				REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR	REEF FLAT			REEF MARGIN	LAGOON SLOPE UPPER	LAGOON SLOPE LOWER	LAGOON FLOOR
CORALS	Boulder Rubble Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone	Boulder Rubble Zone	Gracilaria Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites-Acropora Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone	Boulder Rubble Zone	Enhalus-Thalassia Zone	Enhalus-Porites Zone	Porites Zone	Porites Zone	Alveopora-Pachyseris Zone	Sand-Silt Zone
Fungia (Pleuractis) paumotuensis Stutchbury					R																	
Fungia (Pleuractis) scutaria Lamarck				O															R			
Family-PORITIDAE																						
Goniopora arbuscula Umbgrove																						
Goniopora Singapore 1 Bernard											R							R				
Goniopora sp. 1				O																		
Porites andrewsi Vaughan			O	A	D	C					O	A	D					O	A	D		
Porites cocosensis Wells			R																			
Porites lobata Dana				O																		
Porites lutea Milne-Edwards and Haime		O	D	D	A					O	D	D	A	O			O	D	D	C		
Porites (Synaraea) convexa Verrill				O	O							O	O						O	O	O	
Porites (Synaraea) horizontalata Hoffmeister														O								
Porites (Synaraea) iwayamaensis Equchi				O	O							O	O						O	O		
Porites (Synaraea) monticulosa (Dana)														O								
Alveopora allingi Hoffmeister					R									O								
Alveopora sp.1						C								C							C	
SUBORDER-FAVIINA																						
Family-FAVIIDAE																						
Favia danae Verrill					O						R											
Favia pallida (Dana)				R	O								R								R	
Favia rotumana (Gardiner)												R										
Favia speciosa (Dana)												R	O							O		
Favites acuticollis (Ortmann)												R										
Favites melicerum (Ehrenberg)			O	O							R	O						O	O	R		
Favites sp. 1											R											
Goniastrea parvistella (Dana)																				R		
Goniastrea pectinata (Ehrenberg)				O								O										
Platygyra lamellina (Ehrenberg)			R	R																R		
Diploastrea heliopora (Lamarck)				R														R				
Leptastrea purpurea (Dana)		R	O	O	O					R	O	O	O				R	O	O	O		
Cyphastrea microphthalma (Lamarck)			R																			
Family-OCULINIDAE																						
Galaxea fascicularis (Linnaeus)																				R		
Acrhelia horrescens (Dana)				R	R	O								O								
Family-MUSSIDAE																						
Lobphyllia costata (Dana)												R	O	O					O	O	O	
Lobophyllia (Palauphyllia) hataii Yabe, Sugiyama, and Eguchi														O					O			
Family-PECTINIIDAE																						
Echinophyllia aspera (Ellis and Solander)																				R		
Mycedium elephantotus (Pallas)						C								O	O						C	
Pectinata lactvca (Pallas)																			R			
Pectinata sp. 1						O																

Table 6. Continued.

CORALS		TRANSECT A REEF FLAT: Boulder Rubble Zone	TRANSECT A REEF FLAT: Enhalus-Thalassia Zone	TRANSECT A REEF FLAT: Enhalus-Porites Zone	TRANSECT A REEF MARGIN: Porites Zone	TRANSECT A LAGOON SLOPE UPPER: Porites Zone	TRANSECT A LAGOON SLOPE LOWER: Alveopora-Pachyseris Zone	TRANSECT A LAGOON FLOOR: Sand-Silt Zone	TRANSECT B REEF FLAT: Boulder Rubble Zone	TRANSECT B REEF FLAT: Gracilaria Zone	TRANSECT B REEF FLAT: Enhalus-Thalassia Zone	TRANSECT B REEF FLAT: Enhalus-Porites Zone	TRANSECT B REEF MARGIN: Porites-Acropora Zone	TRANSECT B LAGOON SLOPE UPPER: Porites Zone	TRANSECT B LAGOON SLOPE LOWER: Alveopora-Pachyseris Zone	TRANSECT B LAGOON FLOOR: Sand-Silt Zone	TRANSECT C REEF FLAT: Boulder Rubble Zone	TRANSECT C REEF FLAT: Enhalus-Thalassia Zone	TRANSECT C REEF FLAT: Enhalus-Porites Zone	TRANSECT C REEF MARGIN: Porites Zone	TRANSECT C LAGOON SLOPE UPPER: Porites Zone	TRANSECT C LAGOON SLOPE LOWER: Alveopora-Pachyseris Zone	TRANSECT C LAGOON FLOOR: Sand-Silt Zone
SUBORDER-CAROPHYLLIINA																							
Family-CAROPHYLLIIDAE																							
Euphyllia glabrescens Chamisso and Eysenhardt																				R			
Physogyra lichtensteini Milne-Edwards and Haime							O								O								
SUBORDER-DENDROPHYLLINA																							
Family-DENDROPHYLLIIDAE																							
Dendrophyllia micranthus (Ehrenberg)																							R
CLASS HYDROZOA																							
ORDER-MILLEPORINA																							
Family-MILLEPORIDAE																							
Millepora exaesa Forskaal				O	C								O										
Millepora intricata Milne-Edwards and Haime				P									O										
TOTAL GENERA	31	0	3	13	18	12	10	0	0	0	5	10	15	9	9	3	0	3	11	15	18	7	1
TOTAL SPECIES	81	0	3	26	39	18	11	0	0	0	5	17	27	16	14	3	0	3	18	20	23	10	1

crest at Transect A and a local patch of delicately branched Pavona frondifera completely dominated the same location at Transect B.

Lagoon Slope Zones: The lagoon slope can be divided into two zones (Fig. 3) consisting of an upper Porites zone to 10 meters depth, dominated by large hemispherial colonies of Porites lutea and Porites andrewsi and a lower Alveopora and Pachyseris zone characterized by the presence of scattered to locally abundant ramose clumps of Alveopora allingi and foliaceous whorls of Pachyseris speciosa and Mycedium elephantotus. The lower slope has considerably more area covered by unconsolidated sand and coral-algal rubble than the upper slope. Although the lagoon slope was not quantitatively analyzed, the upper part is very similar to the reef margin in percentage of substratum covered and the lower part has much less coral cover.

Lagoon Floor Zone: This region is primarily a zone of silt and sand accumulation. Corals are for the most part lacking, except where local slumping of reef material from the reef margin and lagoon slope have occurred providing a solid substrate for coral growth to develop upon. The few corals observed or collected from this zone are listed in Table 6.

Other Macro-invertebrates--Aspidochirote holothurians, the large deposit-feeding holothurians, were the prevalent macro-invertebrates on the reef flat (Table 7). Five genera of holothurians were present with the genus Holothuria containing five species. Holothuria atra was the predominant holothurian in the sand bottom areas of Enhalus and Caulerpa for the first 20 m out from the intertidal rubble along transects B and C. Beyond the first 20 m in the Enhalus-Thalassia zone, Holothuria edulis outnumbered all the other species of holothurians combined. Holothuria leucospilota was found in the area of transition from Enhalus and sand habitat on the reef flat to coral habitat on the reef margin. Holothuria moebii was the prevalent holothurian on the reef margins and lagoon slopes on all the transects.

Actinopyga echinites was common in the Enhalus-Thalassia zone of Transect B but very clumped in dispersion. For example, eight were found in a "pile," all in close contact. Morisita's index of dispersion* is an appropriate measure of dispersion for field biology because it is relatively independent of the number of samples, the sample sizes and the type of probability distribution the samples tend to fit (Southwood 1966). If the index reads greater than 1, the dispersion pattern is tending towards a clumped pattern; less than 1 indicates a tendency

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*$I = N \frac{\Sigma X_1^2 - \Sigma X_1}{(\Sigma X_1)^2 - \Sigma X_1}$ where N is the number of samples and X_1's are the data.

Table 7. Macro-invertebrates along Transects B and C. Units of measure are 10 m^2 quadrats as explained in Methods section. In columns under the heading "F" are frequencies of occurrence, the number of 10 m^2 quadrats in which the species occurred as a ratio to the number of quadrats examined. Under "No./10 m^2" are the means and standard deviations of the counts in the quadrats. In parenthesis in the row with the name of the zone is the size of the total area carefully surveyed.

	TRANSECTS			
	B		C	
REEF FLAT	F	(No./10 m^2)	F	(No./10 m^2)
Boulder Rubble Zone		(60 m^2)		(60 m^2)
		No MACRO-INVERTEBRATES		
Gracilaria Zone		(40 m^2)		(40 m^2)*
Protoreaster nodosus (Linnaeus)			2/4	0.5
Bohadschia bivittata (Mitsukuri)			1/4	0.2
Holothuria atra Jaeger	1/4	0.2	4/4	1.5 ± 0.6
Holothuria hilla Lesson	1/4	0.2	1/4	0.2
Stichopus chloronotus Brandt			1/4	0.2
Enhalus-Thalassia Zone		(260 m^2)		(60 m^2)
Cassiopea (cf. medusa Light)	6/26	0.3 ± .6		
Protoreaster nodosus (Linnaeus)			2/6	0.3
Actinopyga echinites (Jaeger)	19/26	4.08 ± 5.11	1/6	0.2
Bohadschia bivitatta (Mitsukuri)			1/6	0.2
Holothuria atra Jaeger	20/26	1.42 ± 1.10	5/6	2 ± 2.2
Holothuria edulis Lesson	25/26	11.7 ± 5.8	6/6	4.67 ± 3.88
Holothuria hilla Lesson	1/26	0.04		
Stichopus chloronotus Brandt	13/26	0.65 ± 0.80	5/6	1.2 ± 0.45
synaptid sp. (with brown blotches)	1/26	0.04		
Enhalus-Porites Zone	(Observations; No Quadrats)			(50 m^2)
Protoreaster nodosus (Linnaeus)			5/5	1.4 ± 0.5
Actinopyga echinites (Jaeger)			1/5	0.4
Holothuria edulis Lesson			5/5	2.6 ± 2.5
Holothuria leucospilota Brandt		+	1/5	0.2
Stichopus chloronotus Brandt			2/5	0.4

*In Transect C, the 20 m wide band was predominantly occupied by Enhalus, not Caulerpa and Gracilaria. This 20 m wide band is still considered a "Zone" because of the distribution of holothurians as explained in the text.

Table 7. (continued)

	TRANSECTS			
	B		C	
REEF MARGIN	F	(No./10 m^2) (60 m^2)	F	(No./10 m^2) (60 m^2)
Actinopyga echinites (Jaeger)	1/6	0.2		
Holothuria edulis Lesson	5/6	2.7 ± 4.2		+
Holothuria leucospilota Brandt			2/2	2.0
Holothuria moebii Ludwig	3/6	3.7 ± 2.8		
Stichopus chloronotus Brandt	3/6	0.5	1/2	0.5

towards an even pattern. The significance of departure from randomness (I=1) can be tested by the variance ratio, F_o^{**} (cf. Southwood 1966). Actinopyga echinites in the Enhalus-Thalassia zone of Transect B showed a dispersion index of I=2.28 [F=6.4 with (25,∞) d.f., $p << .001$].

Holothuria edulis, the most abundant holothurian, showed a significantly clumped pattern of dispersion in the Enhalus-Thalassia zone along Transect B [I=1.15, F_o=2.84, $p < .001$] and along Transect C [I=1.41, F_o=3.23, $p < .01$] and in the Enhalus-Porites zone along Transect C [I=1.47, F_o=9.69, $p << .001$]. In contrast, data for the holothurians Holothuria atra and Stichopus chloronotus along both transects in the Enhalus-Thalassia zone produced dispersion pattern indices that did not differ significantly from randomness. Similarly, the asteroid Protoreaster nodosus in the Enhalus-Porites zone along Transect C [I=0.48, F=.143] and the scyphozoan medusa Cassiopea (medusa?) in the Enhalus-Thalassia zone along Transect B [I=0.43, F=.2] showed a tendency towards an even dispersion pattern but this did not differ significantly from randomness.

As might have been expected, the holothurians showing a clumped dispersion pattern differed significantly in abundance between Transects B and C when the data were compared by the Mann-Whitney U-test. Both Holothuria edulis and Actinopyga echinites differed with $p < .01$. In contrast, the differences in ranking of data from the two transects could have been due to chance for Holothuria atra ($.90 > p > .50$) and Stichopus chloronotus ($.6 > p > .2$), two species which tended to be randomly dispersed.

A single 100 m quadrat was taken along Transect A and the following were counted in the quadrat: 116 Holothuria edulis, 6 Holothuria moebii, 4 Holothuria atra, 5 Stichopus chloronotus, 1 Actinopyga echinites, 1 Protoreaster nodosus and 5 Cassiopea (medusa?). Because only a single datum from Transect A was available for each species, the simple observations were compared with the means of samples from Transects B and C separately by t-tests for each of the species Holothuria edulis, Holothuria atra, Stichopus chloronotus and Actinopyga echinites. In no case was the abundance of a species in Transect A found to differ significantly from the abundances in Transects B or C.

As can be seen in Table 7, the variances of the samples were large when compared with the means. We learned that when counting macroinvertebrates, such as holothurians, asteroids or scyphozoans, we should use quadrats at least 25 m^2 in size (J. Doty, pers. comm.) and a total area of at least 500 m^2 should be covered.

** $F_o = \frac{I\,(\Sigma X-1) + N-\Sigma X}{N-1}$ with degrees of freedom taken as (N-1,∞)

Fishes--Eight hundred seventy-seven fishes of 63 species were enumerated along the three transects (Table 8). In general the number of species and the density of individuals increases with greater distance from shore. The exceptions to these generalizations are 1) the high fish density in the Boulder Rubble zone on Transect B, wherein all but six of the fishes censused were the single goby species Obortiophagus kousmani, a species which lives in burrows in the sand (in a commensal relationship with a shrimp) and 2) the relatively high diversity and density of fishes in the Boulder Rubble and Enhalus-Thalassia zones along Transect A, coupled with the relatively low diversity and density of fishes on this transect in the Enhalus-Porites and Reef Margin zones (Table 9). It seems fairly clear that the enhancement of the abundance of fishes and the number of species in the rubble and seagrass dominated zones along Transect A is the result of the presence of the outfall pipe which provides cover and habitat for a number of fish species that would not ordinarily occur in these zones. It may well be that the opposite effect occurs in the coral-dominated zones where the pipe provides less cover and a less diverse habitat than did the original coral assemblages which were destroyed during the laying of the pipe. Recovery of the fish community to levels of abundance and diversity comparable to those observed on Transects B and C will depend upon the re-establishment of complex coral assemblages.

Plankton--Copepods are by far the most numerous component of the daytime plankton community sampled by our nets (Table 10). At night, the abundance of the surface plankton is approximately doubled, primarily through the addition of large numbers of crustacean zoea larvae and ostracods, the copepod density remaining more or less the same as that during the daytime. Crustacean nauplii, the second most abundant component of the daytime plankton community are considerably less abundant at night.

Although differences in the mesh size of the nets used precludes precise comparisons, some general features of the surface plankton community as sampled at Yap can be compared to previous work elsewhere. The pattern of vertical migration observed at the Yap site is very similar to that observed for ostracods and total zooplankton by Johnson (1954) in Bikini Lagoon in the Marshall Islands. Johnson also found considerably more individuals of the copepod Undinula vulgaris in surface waters at night than during the day. Specific identification of copepods was not made with the Yap samples, but for copepods as a whole there was no significant difference between daytime and nighttime abundance in the surface waters. Surface collections made by Hobson and Chess (1973) in Majuro lagoon, Marshall Islands, also show a predominance of zooplankton in the surface waters at night.

Daytime zooplankton abundance at the Yap site is greater than in oceanic waters off Majuro (Amesbury et al., 1975b) where fewer organisms/m^3 were collected with a finer mesh net and was less than that collected in Kwajalein Atoll near Ebeye (Amesbury et al., 1975a) where larger numbers were collected with a coarser mesh net.

Table 8. Counts of fishes observed along each of the three transects at the Donitsch Island sewer outfall site. Counts are tabulated within each zone (see Table 3 for zone designations).

	TRANSECTS												
	A				B					C			
	1	3	4+5	6	1	2	3	4	5	1	3	4	5
Acanthuridae													
Acanthurus lineatus (Linnaeus)									1				
A. nigrofuscus Forskal								6	10				
A. triostegus (Linnaeus)	3		1			1							
A. xanthopterus Cuvier & Valenciennes	2	5	11										
Ctenochaetus striatus (Quoy & Gaimard)			2	2				2					7
Zebrasoma scopas (Cuvier)				1									1
Apogonidae													
Apogon cf. _lateralis_ Valenciennes	80	110				3	1						
Balistidae													
Sufflamen chrysoptera (Bloch & Schneider)				2									
Blenniidae													
Unidentified blenniids		4											
Callionymidae													
Amora sp.						1							
Chaetodontidae													
Centropyge bicolor (Bloch)				1									
C. tibicen (Cuvier & Valenciennes)									3				2
Chaetodon auriga Forskal			1	1									
C. citrinellus Cuvier								1					
C. kleinii Bloch				1				1					
C. trifasciatus Mungo Park				2					8				1
C. ulietensis Cuvier				1									
Forcipiger sp.				3									
Heniochus permutatus Cuvier				1									
Pygoplites diacanthus (Boddaert)				1									

Table 8. (continued)

	TRANSECTS												
	A				B					C			
	1	3	4+5	6	1	2	3	4	5	1	3	4	5
Gobiidae													
Amblygobius albimaculatus (Ruppell)		2			est. 100	2							
Obortiophagus kousmani Whitley													
Unidentified gobiids						4				2		1	
Holocentridae													
Adioryx sp.				3									
Labridae													
Cheilinus sp.				2									
Epibulus insidiator (Pallas)				2									
Halichoeres hoeveni (Bleeker)				2									1
H. trimaculatus (Quoy & Gaimard)		4	4				1					2	
Stethojulis bandanensis (Bleeker)		5											1
Thalassoma hardwickei (Bennett)									1				1
T. lutescens (Lay & Bennett)				1									
Unidentified labrids		6					8	2			7		
Lutjanidae													
Caesio xanthonotus Bleeker				est. 100									
Lethrinus sp. (juveniles)						9	12				5		
Lutjanus monostigmus (Cuvier & Valenciennes)	3	1	1			1	1						
L. vaigiensis (Quoy & Gaimard)	1												
Monotaxis grandoculis (Forskal)		3											
Scolopsis cancellatus (Cuvier & Valenciennes)	5	1			1			2			3	2	
Monacanthidae													
Paramonacanthus sp.					5								
Mullidae													
Mulloidichthys samoensis (Gunther)	1												
Parupeneus barberinus (Lacepede)							1						
P. trifasciatus (Lacepede)											5		

Parupeneus barberinus (Lacepede) 1 5
P. trifasciatus (Lacepede)

	TRANSECTS A 1	A 3	A 4+5	A 6	B 1	B 2	B 3	B 4	B 5	C 1	C 3	C 4	C 5
Pomacentridae													
Abudefduf septemfasciatus (Cuvier)	6												
A. sordidus (Forskal)	2												
Amblyglyphidodon curacao (Bloch)				9									8
Chromis caerulea (Cuvier)									21				3
Dascyllus aruanus (Linnaeus)								3	53				4
D. trimaculatus (Ruppell)				1									
Dischistodus perspicillatus (Cuvier)		3	2					17				9	
Eupomacentrus lividus (Bloch & Schneider)								5	1				
Glyphidodontops leucopomus (Lesson)								1					
Plectroglyphidodon dickii (Lienard)									15				
P. lachrymatus (Quoy & Gaimard)									1				
P. leucozona (Bleeker)		4					3	2				5	
Pomacentrus pavo (Bloch)			9						7				2
Scaridae													
Scarus sordidus Forskal			1										
Scarid juveniles	1		8										
Unidentified scarids				1									
Serranidae													
Epinephelus sp.				1									
Siganidae													
Siganus canaliculatus (Park)	1					6							
S. puellus (Schlegel)		4							1				
S. spinus (Linnaeus)	8	34											
Syngnathidae													
Corythoichthys intestinalis (Jordan & Seale)			3										
# Fishes	113	186	43	138	106	26	29	42	122	2	20	21	29
# Species	12	14	11	21	3	7	9	11	12	1	4	6	10
# Fish/m^2	1.23	1.58	0.61	1.86	1.66	0.72	0.09	0.32	2.65	0.03	0.09	0.70	0.91

Total # Fishes = 877
Total # Species = 63

Table 9. Fish density and number of species in physical/biological zones along the three transects.

Transect		Rubble/Seagrass Dominated Zones (Zones 1 and 3)	Coral Dominated Zones (Zones 4 & 5)
A	No. Species	21	11
	No. Fish/m^2	1.42	0.61
B	No. Species	11	20
	No. Fish/m^2	0.36	0.93
C	No. Species	5	16
	No. Fish/m^2	0.08	0.81

Table 10. Abundance of planktonic organisms collected in area of sewer outfall site, Yap. Abundances in number per m^3.

Plankton Organisms	Daytime Tow #1	Daytime Tow #2	Nighttime Tow #1	Nighttime Tow #2
diatoms	17.0	11.5	-	-
dinoflagellates	-	0.5	-	-
foraminifera	3.0	1.5	1.5	1.0
radiolarians	0.5	-	-	-
tintinnids	-	1.0	-	0.5
medusae	-	-	1.5	-
gastropods (including larvae)	-	0.5	11.3	9.5
pelecypod larvae	-	-	-	4.0
copepods	327.0	240.5	344.3	160.5
ostracods	-	2.5	153.8	103.0
mysids	-	-	2.3	-
cumaceans	-	-	1.5	-
sergestids (<u>Lucifer</u>)	-	-	0.8	-
crustacean larvae:				
nauplius	38.0	57.0	2.3	8.0
zoea	7.0	21.5	368.3	387.5
alima (stomatopod)	-	-	-	1.5
cryptoniscid (isopod)	-	-	-	2.5
megalops	-	-	-	2.0
unidentified crustacean	-	-	0.8	-
acarina (mites)	-	-	-	0.5
chaetognaths	1.0	2.0	3.8	6.5
larvaceans	0.5	1.5	1.5	2.5
cephalochordates (amphioxides)	-	-	1.5	5.0
fish eggs	7.5	8.0	3.8	9.0
fish larvae	-	0.5	1.5	10.0
TOTAL	401.5	348.5	900.5	713.5

CONCLUSIONS

Suitability of the Proposed Outfall Site

The polluted conditon of Chamorro Bay indicates the need for effective sewage treatment and disposal for the Colonia area. The Donitsch Island site has the advantage of nearness to Colonia which reduces the difficulty and cost of providing the additional piping and pumping stations that would be needed for a more distantly located facility. This site does have some disadvantages, however, which will be pointed out, although this may be purely academic at this point as the treatment plant is partially constructed and the outfall pipe and diffuser are already in place.

Donitsch Island is to the east of Colonia, and so is upwind during the tradewind season. The proposed facility is to be an Imhoff tank which is typically designed to allow accumulation and anaerobic decomposition of sludge in its lower compartment (Metcalf and Eddy, Inc., 1972). The gases of decomposition, H_2S, CO_2, CH_4, and NH_3, are released into the air; thus there is a potential odor problem in the area to the west of the Donitsch Island (which includes, among other buildings, the hospital) during at least part of the year.

In addition, the results of the current studies presented in this report indicate that effluent released at the present site of the diffuser will be carried back onto the reef flat. There is apparently some variability in the circulation patterns in this area as circulation studies done by Austin, Smith, and Associates in August 1967 and Lyon Associates in January 1975 gave somewhat different results. Extension of the outfall pipe further into the channel might prevent the effluent from drifting onto the Donitsch Island reef flat, but our studies suggest that it would eventually wash onto the Worwor-Balabat reef flat. This might be more desirable, however, as this reef flat is considerably further away from the diffuser and the effluent should be much more diluted and dispersed by the time it arrives there.

Impact of Outfall Construction

The laying of the outfall pipe has left a damaged area approximately 5 m wide along the length of the pipe on its south side. At the reef margin, this damaged zone extends 7-10 m on either side of the pipe. In the *Enhalus*-*Thalassia* zone, *Enhalus*, which can reproduce vegetatively by runners, seems to be repopulating this damaged area. Coral damage was most extensive in the *Enhalus*-*Porites* zone, the Reef Margin, and the upper Lagoon Slope, but coral in these areas is becoming re-established through growth of colonies and fragments remaining in the area and through recruitment of new corals. There was no significant difference in the abundances of the two most abundant holothurians in the damaged areas on Transect A and the undamaged areas of Transects B and C.

The laying of the outfall pipe seems to have increased environmental heterogeneity in the rubble and seagrass zones, and more fish species are found in these zones associated with the pipe than are found in these zones on the undisturbed transects. On the other hand, environmental heterogeneity has been reduced in the coral dominated zones, and fewer fish are found in the damaged part of these zones than are found in the same zones on the undisturbed transects. As corals recolonize the damaged areas, the fish fauna is expected to return to something approaching its original state.

Impact of Treated Effluent

The Imhoff tank acts primarily to digest settleable solids; dissolved organic material and nutrients (e.g. nitrates and phosphates) should not be greatly affected by the treatment. Chlorination will destroy most of the coliforms and potentially pathogenic microorganisms. The treated effluent will then probably contain dissolved organics, inorganic nutrients, and chlorine, and be of low salinity. The low salinity should cause the effluent to rise to the surface of the water, and, if this water moves onto reef flat areas, the various constituents may be expected to influence the biological communities found there. The decomposition of dissolved organic material will take up some of the dissolved oxygen in the water; nutrients may stimulate the growth of certain marine plant species, possibly to the detriment of other community members; chlorine is toxic to many marine organisms, especially to young or larval stages. The magnitude of any of these effects depends upon the concentrations of the various effluent constituents and the length of time to which the organisms are exposed to them.

The proposed treatment facility on Donitsch Island, once it is in operation and the residential, commercial, and administrative buildings of Colonia are joined to it, offers considerable advantages over the status quo; settleable materials will be removed from the sewage, potential pathogens will be killed by chlorination, and the effluent will be discharged in an area with much better circulation than that which exists in Chamorro Bay. The disadvantages have been discussed above. Should future population growth in this area require the construction of additional treatment facilities, it would be worthwhile considering locations further removed from Colonia and not to the windward of any population centers.

RECOMMENDATIONS

If it becomes apparent, once the Donitsch Island treatment plant is in operation, that the effluent is being carried back onto the reef flat, the possibility of extending the outfall pipe further into Tomil Channel, placing the diffuser further to the southeast, should be considered. Under the current regime measured during the present study, this would prolong the time taken for the effluent to reach reef flat areas and would allow it to become more diluted.

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PLATE I

a. Boulder Rubble zone along the inner part of Transect A. The floor here consists of a truncated platform of a schist-like non-limestone rock which is exposed during low spring tides.

b. Inner part of the *Enhalus*-*Thalassia* zone on Transect B. The sea cucumber *Holothuria edulis* is at center.

c. Outer part of the *Enhalus*-*Thalassia* zone along Transect B. A few scattered heads of *Porites lutea* and some dark-colored sponges are intermixed with the seagrass along the outer part of this zone.

d. *Enhalus*-*Porites* zone along Transect B. The abundance of seagrass is somewhat reduced and larger *Porites* colonies and other coral species are more commonly encountered. A black, columnar sponge is at center.

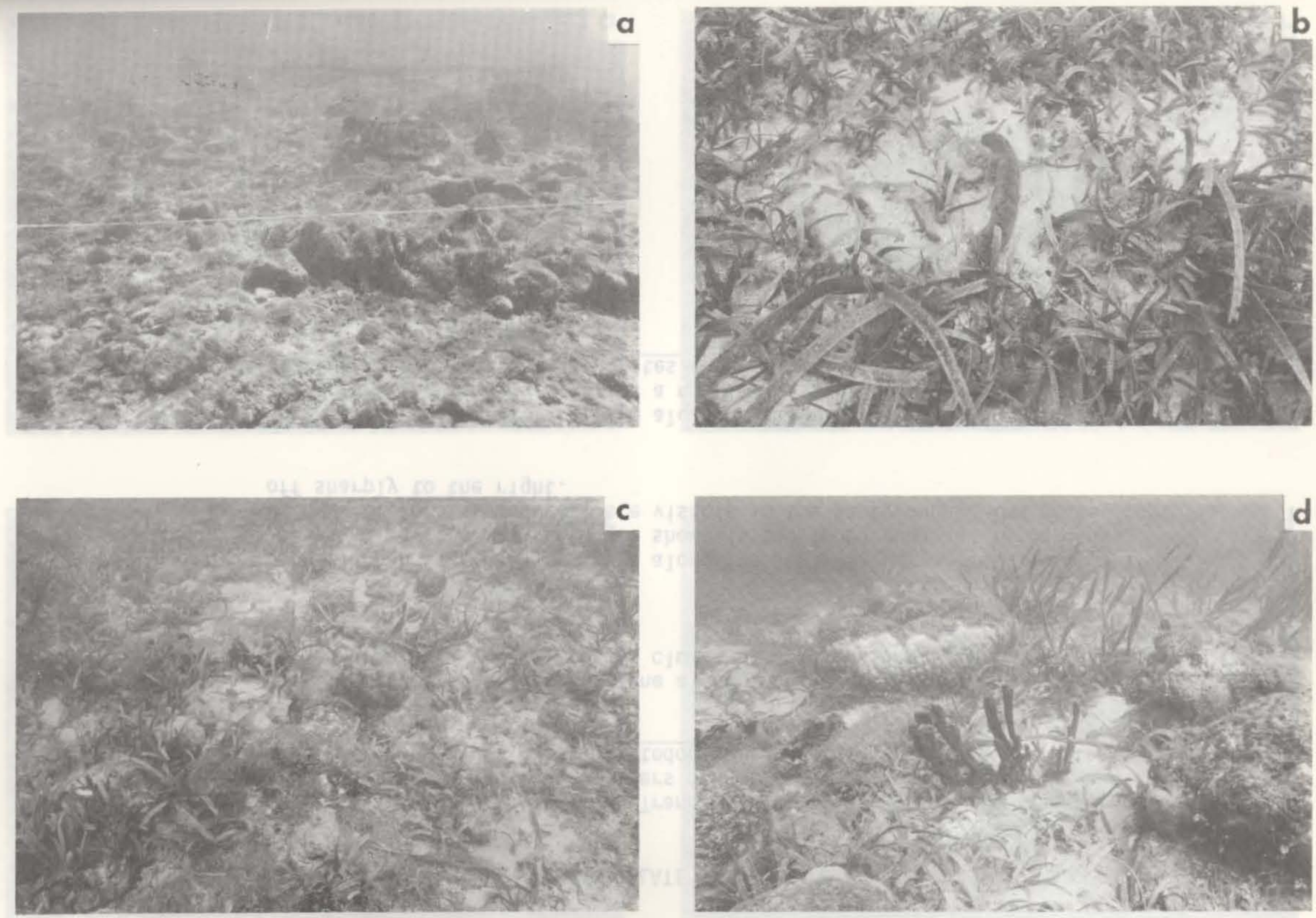

a
b
c
d

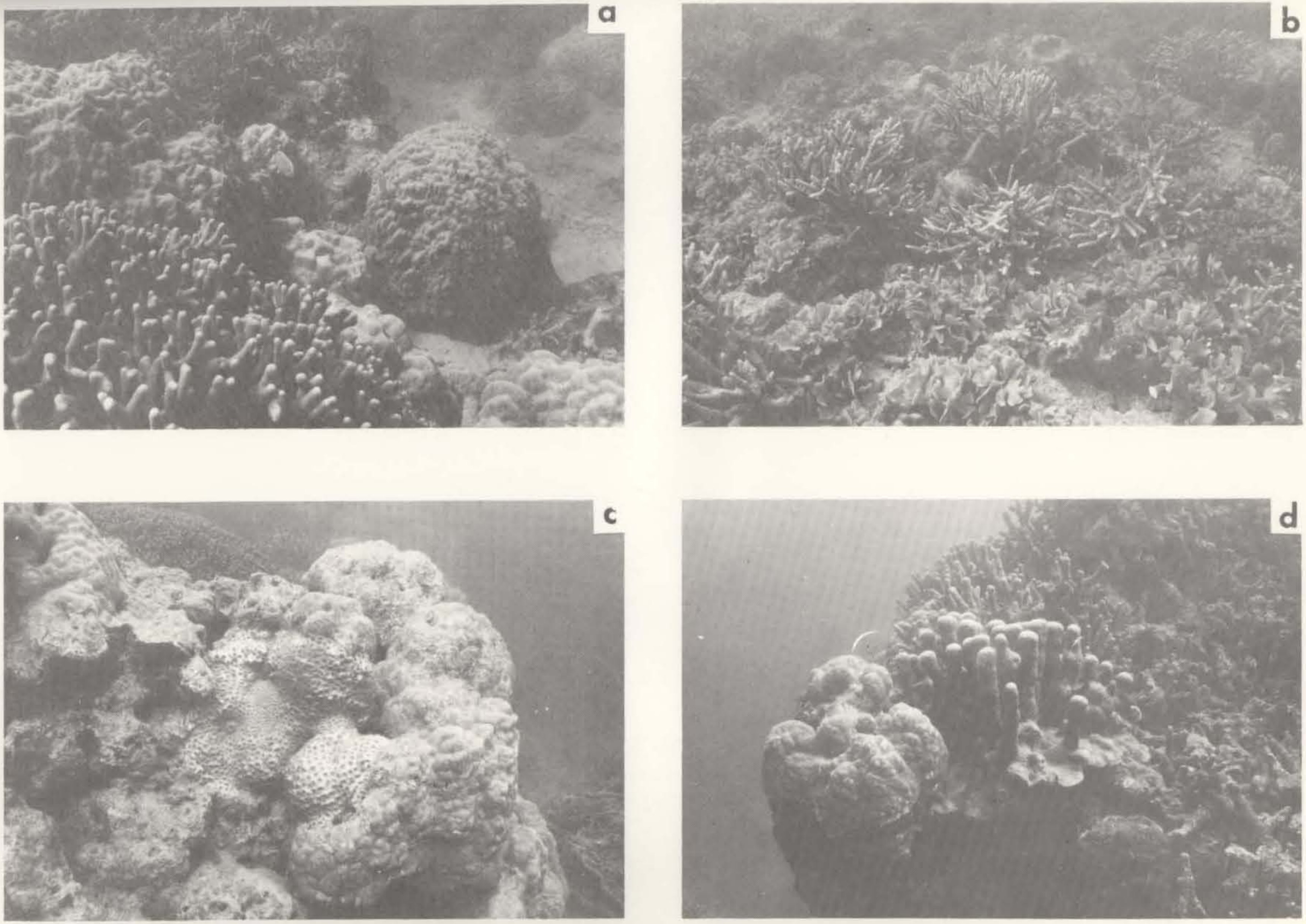
PLATE II

a. Reef margin *Porites* zone along Transect A. Large, nodulated, massive *Porites lutea* colonies and ramose clusters of *Porites andrewsi* dominate the reef margin. The butterflyfish *Chaetodon trifasciatus* is visible at center.

b. Reef margin *Porites-Acropora* zone along Transect B. Arborescent clumps of *Acropora formosa* and foliaceous clumps of *Pavona frondifera* are intermixed with massive *Porites* colonies.

c. Upper lagoon slope *Porites* zone along Transect A. Large massive *Porites lutea* and *Favites melicerum* are shown in the foreground and large convex columns of *Porites andrewsi* are visible in the background. The slope drops off sharply to the right.

d. Upper lagoon slope *Porites* zone along Transect C. A columnar colony of *Psammocora (S.) togianensis* and a nodular mass of *Porites lutea* are shown in the foreground, and ramose *Porites andrewsi* are visible in the background.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