MARINE SURVEY OF A PROPOSED RESORT SITE AT ARAKABESAN ISLAND, PALAU

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INTRODUCTION

PURPOSE

The Pacific Islands Development Corporation has proposed a project to build a resort complex in the Palau (Belau) Islands. site selected for the resort project is located at a small embayment on The west side of Arakabesan Island (Fig. 1). As proposed in the Pacific Islands Development Corporation Perspective (Palau Resort Town Plan, 1976), the project will proceed by phases, the first of which includes improving the adjacent beach area and possibly importing sand to the shoreline region. These proposed activities require an environmental assessment for permit application in order to comply with the intent of the National Environmental Policy Act of 1969 (NEPA, approved January 1, 1970). The intended goal of the environmental assessment procedure is to gain foresight into the consequences of the proposed project, to illustrate preventative measures which could mitigate environmental degradation in the area, and to determine the significance of the proposed project in terms of its effect on the quality of the human environment.

Since part of the environmental assessment for the project requires an investigation of adjacent marine habitats, the Pacific Islands Development Corporation submitted a request to the University of Guam, Marine Laboratory, to perform a marine survey at the project site. A "Memorandum of Understanding and Agreement" was made and entered into by and between the Pacific Islands Development Corporation and the University of Guam on the 8th day of October, 1977, to perform the marine survey. The results and findings submitted in this report relate only to the marine habitats and may not constitute a complete environmental assessment for the project, but may be used partly or in its entirety for the preparation of such a document.

SCOPE OF WORK

The primary objectives of the marine survey are to determine and map the major current patterns and biological and physical characteristics in the bay area of the project site. Specifically the scope of work involved the following:

1. Assessment of the flora and fauna.
2. Assessment of the water circulation patterns.
3. Assessment of sedimentation rates
4. Assessment of sediments and sediment transport at several stations along the shoreline.
5. Assessment of water chemistry of marine waters in the bay and at a station in a small fresh water impoundment within the project site.

PERSONNEL

The following personnel, listing their major scope of work responsibilities, performed the field work and jointly prepared this report.

1. Richard H. Randall, Assistant Professor, Marine Laboratory, University of Guam (Organization of the study and physiographic description and sediment, coral, and current analysis).
2. Charles Birkeland, Association Professor, Marine Laboratory, University of Guam (Macroinvertebrate, sedimentation rate, and water chemistry analysis).
3. Steve S. Amesbury, Assistant Professor, Marine Laboratory, University of Guam (Fish and plankton analysis).
4. Dennis Lassuy, Graduate Student, Marine Laboratory, University of Guam (Algal and plankton analysis).
5. John R. Eads, Marine Technician, Marine Laboratory, University of Guam (Field support, water and sediment sampling, and field current study).

ACKNOWLEDGEMENTS

This project was supported by the Pacific Island Development Corporation, and we wish to thank the President, Mr. Thomas H. Yamamoto, and the Vice President of the Koror Development Corporation, Mr. Katsumi Inabo, for the fine logistic support they provided. This support was especially helpful during the 24 hour current study by providing two survey crews to man the triangulation base stations. The success and smooth operation of our field work was made possible because of the efficient and punctual assistance given by the local Paluan support personnel. Our appreciation goes to a number of local residents of Arakabesan Island who were helpful in providing historical background information about the study area. We also want to thank the many other Palauan residents we met during this study for their assistance and hospitality.

Thanks goes to Mr. David Gardner, our student photo-laboratory manager at the Marine Laboratory, for his help in developing and printing our film. We thank William Zolan, of the Water Resources Research Center, for performing chemical analyses of the water samples. Last but not least, we extend our appreciation to the Marine Laboratory's Administrative Secretary, Mrs. Teresita Balajadia, who typed the report and cheerfully put up with our many changes in preparing the manuscript.

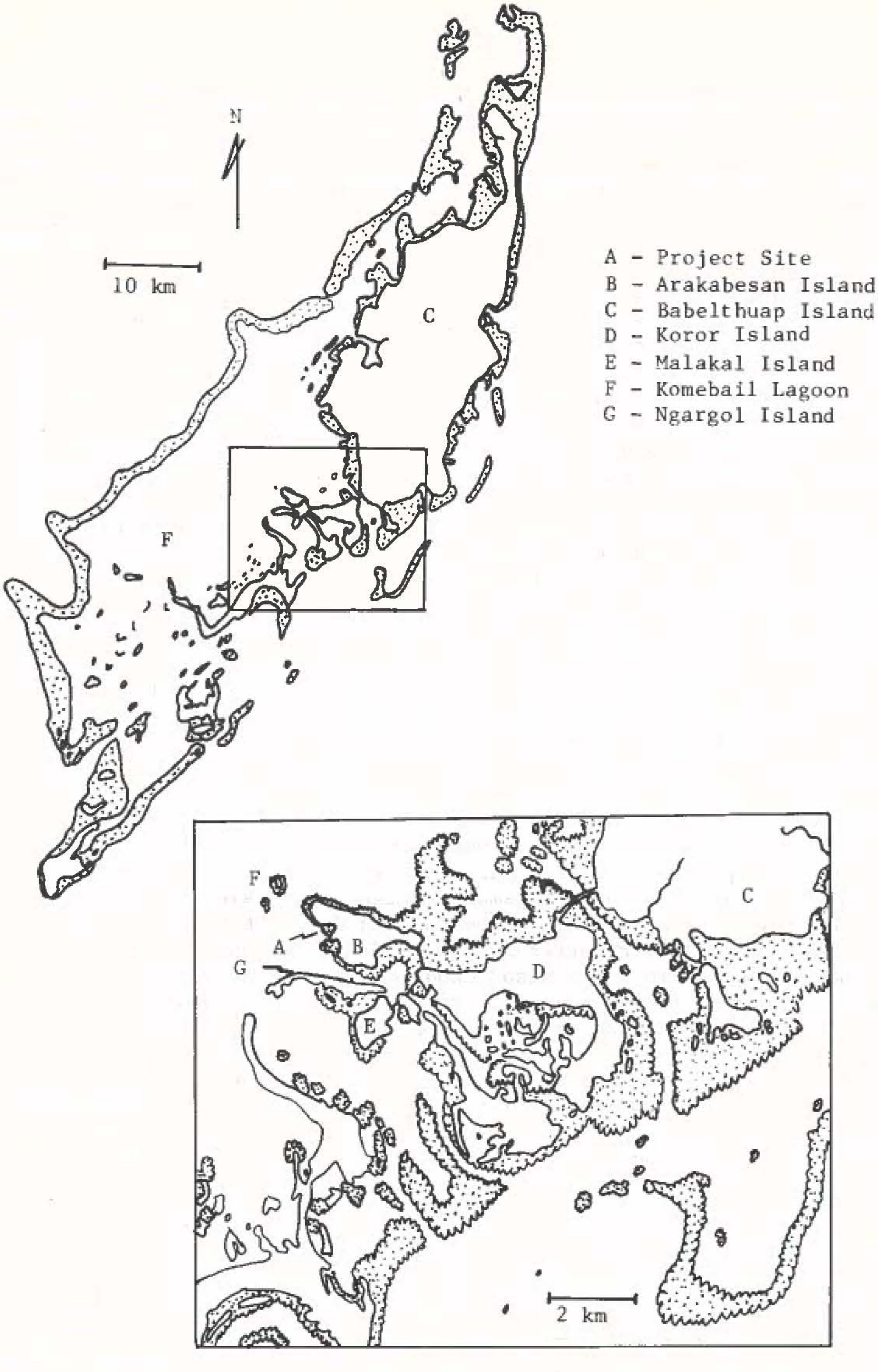

Figure 1. Location of the proposed project in relation to the entire Palau Islands group. Fringing and barrier reef areas are stippled.

GENERAL SETTING AND PHYSIOGRAPHIC DESCRIPTION OF THE STUDY SITE

GENERAL SETTING

The Palau (Belau) Islands are the westernmost group of the Caroline Islands. The islands trend in a north-south direction from 8°12' north to 6°57' north latitude and from 135°08' east to 134°43' east longitude. The largest island in the group is Babelthuap (Babeldaob) which is over 396 km^2 and comprises about 33 percent of all land in the Caroline Islands. Immediately south of Babelthuap is a group of three 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, Malakal, which is largely occupied by maritime and other industries such as fishing, boat repair facilities, warehouses, and copra processing and aggregate plants, and Arakabesan where the District Administration Center and additional residential areas are located.

Physically Palau consists of a group of high volcanic and raised limestone islands surrounded for the most part by an outer barrier reef which is interrupted at intervals by deep passes (Fig. 1). The larger volcanicislands are drained by a pattern of rivers and streams except where porous limestone is exposed at the surface. Anguar, the most southern island, is surrounded by fringing reefs and Kayangel Atoll at the northern end of the group both lies outside the barrier reef. In the lagoon between the barrier reef and the main islands are isolated and clustered groups of smaller high rocky islets. Many of these small islets are haystack-shaped with a deep notch cut at their bases and are popularly referred to as the "Rock Islands." Low limestone and mangrove islets are also found at places in the lagoon and around the larger volcanic islands. Fringing reefs and shallow sandy terraces border most of the larger and many of the smaller lagoon islands. Mangrove swamp, volcanic rocks, or raised limestone forms the shoreline at most places. Shorelines with well-developed beach deposits are found on some limestone islands, but are mostly lacking or poorly developed and patchy in distribution on the larger islands. Beaches are particularly poorly developed on the three centrally located islands of Koror, Malakal, and Arakabesan. In the lagoon itself, numerous patch reefs reach the surface. These patch reefs range from small isolated pinnacles, a few tens of meters across, to linear or intricately curved and branched reefs, several kilometers or more in length. At places the curved and branched reefs enclose both shallow and deep secondary lagoons.

A complex variety of marine habitats are found on the seaward and lagoon barrier reef slopes and terraces, reef-flat platforms, deep reef passes, fringing island reefs, lagoon patch and linear reefs, coral knolls and banks, deep and shallow lagoon basins, shallow lagoon terraces, enclosed secondary lagoons, river estuaries, and mangrove swamps.

ARAKABESAN ISLAND

The setting of Arakabesan Island in relation to the entire Palau Island group is shown in Figure 1. The wide Komebail Lagoon faces the northern and eastern sides of the island and a narrow channel and reef complex separates it from the long raised barrier reef island of Ngargol to the south and Koror Island to the southeast. The proposed resort complex is located on the eastern side of the island at the head of a small embayment. At the present time the embayment is approximately 530 meters across at its widest point and 425 meters in maximum length.

Arakabesan Island is of volcanic origin consisting for the most part of steep dissected hills with a maximum elevation of about 114 meters. The coastal area is mostly steep and rocky and flanked by low narrow terraces and mangrove swamps at places. At the study site dark colored flow conglomerate and breccia form low rocky cliffs and steep slopes at the shoreline along the north side of the bay and at Karuchisu Island on the south side of the bay, which is now connected to Arakabesan Island by a short causeway (Fig. 2). A similar rocky shoreline bordered by a low narrow terrace at places originally formed the shoreline along the head of the bay. The head of the bay has been subject to considerable disturbance and alteration in the past by land filling and construction of seawalls, a seaplane ramp, a causeway, and other related support facilities. Prior to the land-filling, an old map (HO-6077, Malakal Harbor) compiled from Japanese surveys between 1916 and 1936, indicates that the bay was originally about 175 meters longer than at present.

The present configuration of the bay and shoreline features are shown in Figure 2 which was drawn from orthophoto maps compiled from aerial photography taken on February 24, 1976.

FRINGING REEF

A lagoon fringing reef has developed in the embayment that ranges from about 300 meters wide at the head of the bay to a narrow fringe 30 to 50 meters wide along the north and south sides near the mouth. Narrow intertidal platforms are cut into the volcanic rocks along the north side of the bay and along Karuchisu Island at the south side of the bay. The fringing reef can be divided into a number of divisions (Figs. 2, 3A and 3B) that are reflective of both physiographic and community structure, the latter of which will be discussed in more detail in the Results Section.

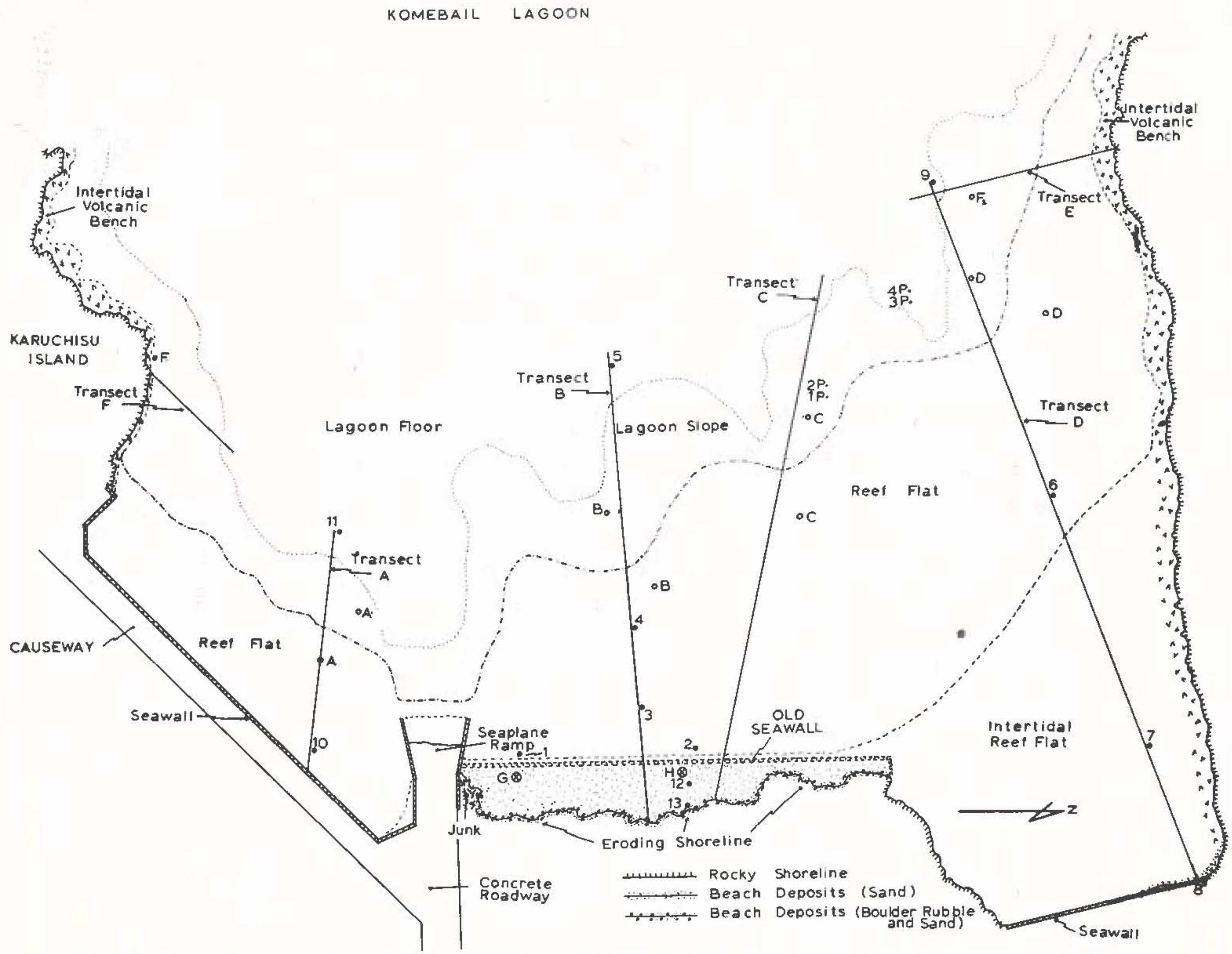

Figure 2. Map of study area on the east side of Arakabesan Island showing the locations of Transects A-F, physiographic divisions of the fringing lagoon reef, sediment trap stations A-F (open circles), sediment sample stations 1-13 (blackened circles), dermersal plankton trap stations 1P-4P, marked grain sediment release stations G and H (encircled X), and other shoreline features. Stippled area adjacent to broken seawall indicates extent of former fill area and location of proposed beach development.

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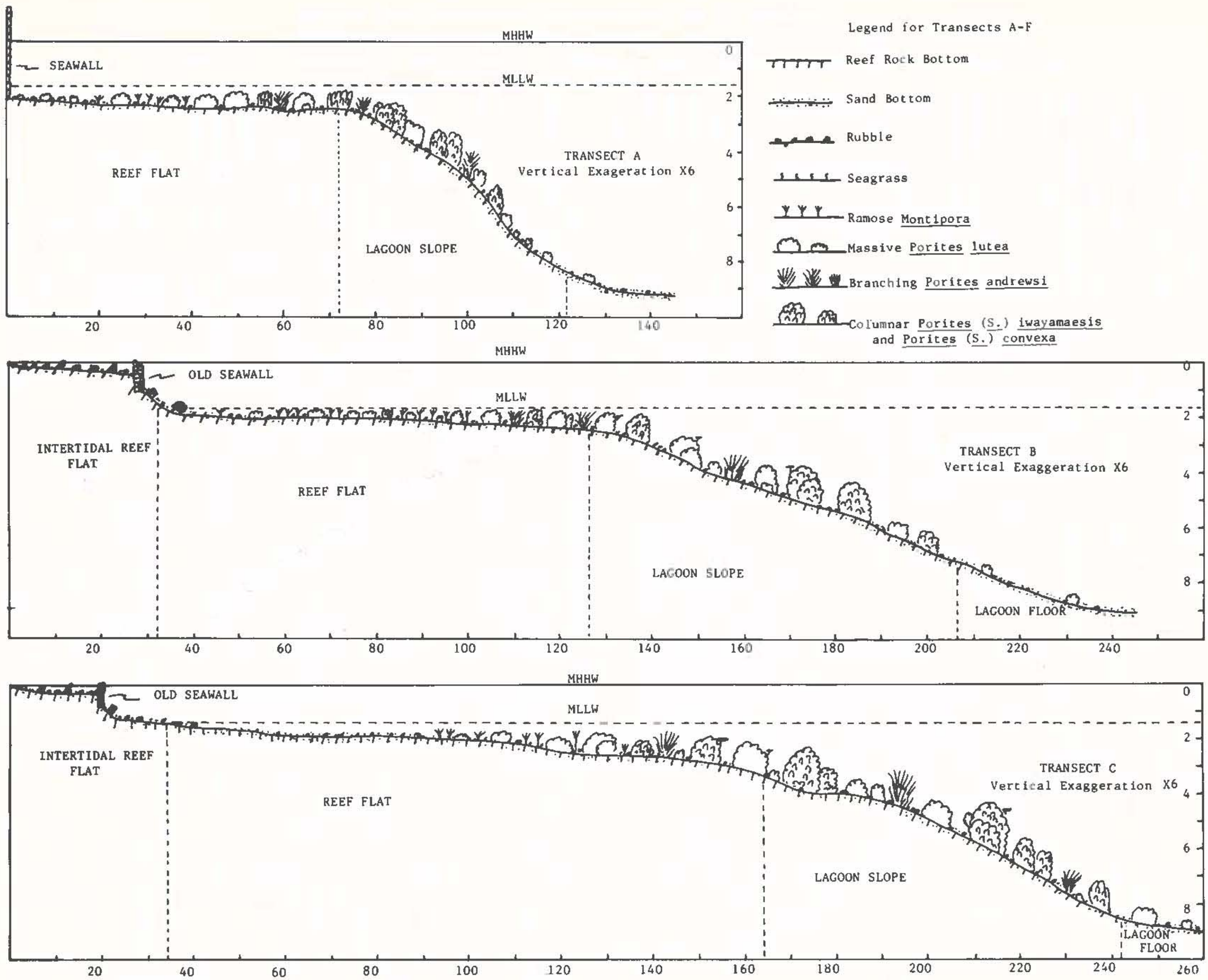
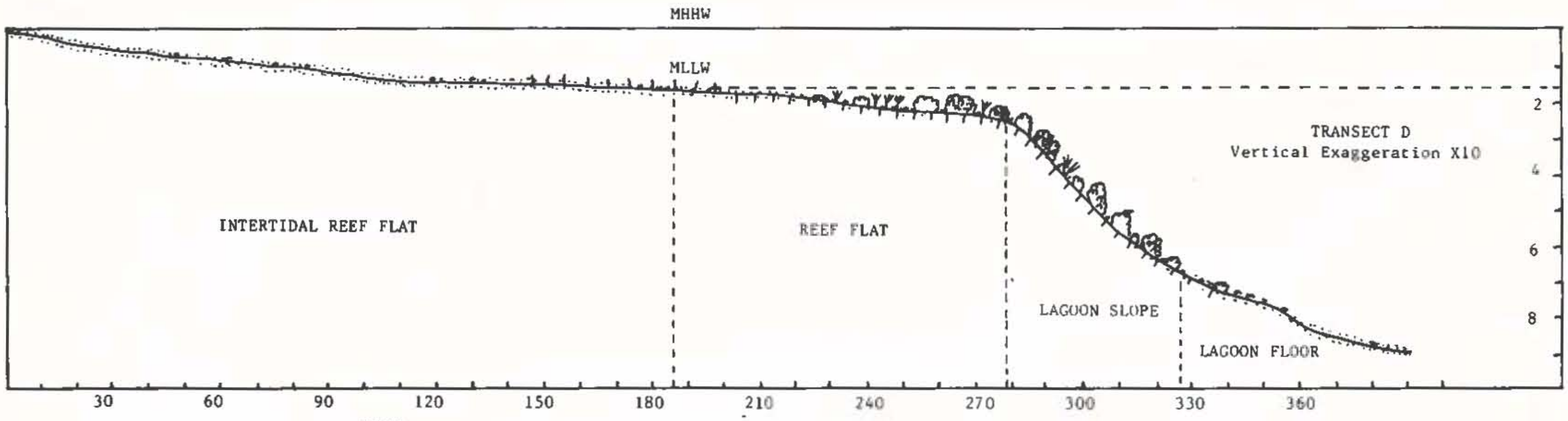
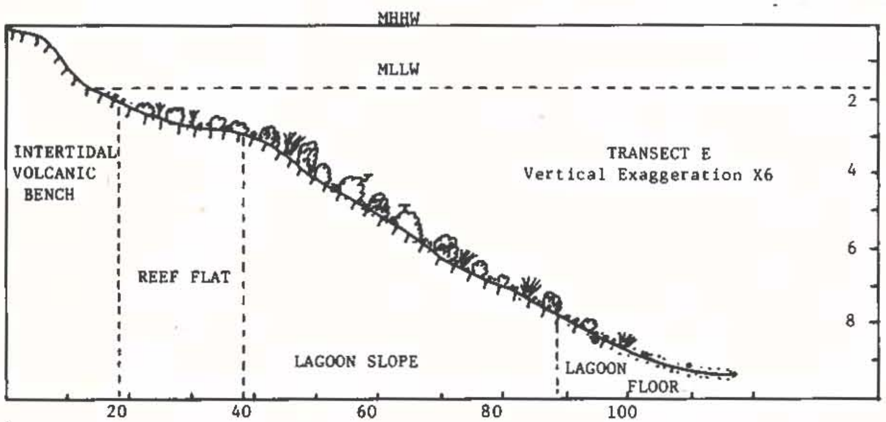


Figure 3A. Vertical profiles of Transects A-C, showing various reef divisions, distribution of dominant corals, and substrate characteristics. All depths and horizontal distances are in meters.





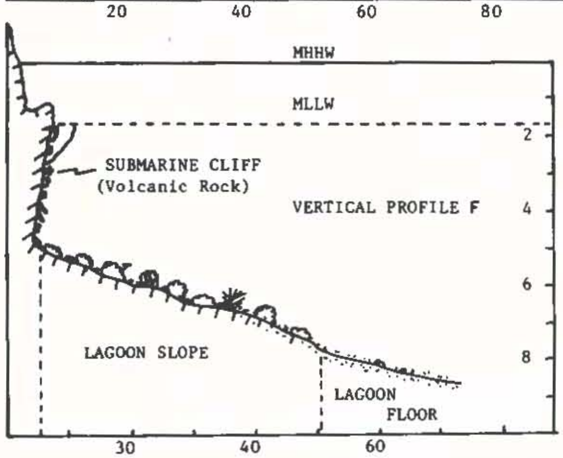


Figure 3B. Vertical profiles of Transects D-F, showing various reef divisions, distribution of dominant corals, and substrate characteristics. All depths and horizontal distances are in meters.

The most extensive of these physiographic divisions is the reef-flat platform. At the northeast corner of the bay an extensive rather barren sand-floored part of the reef flat exposes during low tides and a small sandy beach has developed in front of a seawall there. The only other extensive part of the reef flat that exposes during low tide is found immediately north of the seaplane ramp, between an old broken down seawall and the shoreline. It is at this location where the proposed beach is to be developed by importing sand. Originally this intertidal area was occupied by a seawall and land fill. Damage to this part of the seawall complex along the head of the bay during WW II and subsequent erosion by waves has eroded the land fill and extended the shoreline up to 34 meters inland at places. The surface of this intertidal region is covered with a mixture of mostly boulders and rubble, and some sand, gravel, and mud derived predominately from the original volcanic fill material. A pile of scrap iron has been dumped upon the platform surface where it abutts against the seaplane ramp. The remaining subtidal parts of the reef-flat platform are covered on the inner half by sediments consisting mostly of sand, coral-algal-mollusc rubble, and some silt and clay; scattered corals which gives the surface most of its topographic relief; and algae and minor amounts of seagrass. The outer half is similar to the inner half, but seagrasses are absent, corals are much more abundant and of greater size, and less sand and more coral-algal-mollusc rubble is present. Along Karuchisu Island the reef-flat platform is absent and a submarine cliff borders the volcanic platform there.

At about two meters depth the reef surface dips downward forming the lagoon reef slope. Corals grow to large size here and along with coral-algal-mollusc rubble dominate much of the surface along the upper part. Farther downslope corals become more scattered, smaller in size, and sand sized sediments more abundant.

The lagoon floor begins at about 10 meters depth where the lagoon slope flattens out somewhat, and is covered predominantely by sand sized sediments. Corals are widely scattered forming an occasional knob, knoll, or mound here and there which gives the floor its only significant relief except for the low cone-and-funnel topography produced in fine sand areas by some unidentified burrowing organisms. Except for a scuba dive at the outer southeast corner of the bay, 10 meters was the deepest depth investigated. Table 1 gives the depths and nature of the substrate along Transects A-F and Figures 3A and 3B show the various fringing reef divisions, distribution of dominant corals, and other substrate characteristics in vertical profile sections.

Recent orthophoto maps (Feb. 1976) show evidence of previous dredging in the bay, especially in the approach area to the seaplane ramp (Fig. 2). Possibly some other areas were dredged as well, but no positive evidence was found during our study.

Table 1. Depth of water along Transects A-E. Depths corrected to mean high water spring tide level. General composition of the bottom is given by the following symbols: R=rock, R+S=rock and sand, C=coral, C+S=coral and sand, and S=sand.

METERS FROM SHORELINE	TRANSECT (Depth in Meters)									
	A		B		C		D		E	
0	2.1[a]	R	0.0	R+S	0.0	R+S	0.0	S	0.0	R
10	2.2	R	0.2	R+S	0.3	R+S	0.2	S	1.1	R
20	2.3	C	0.4	R+S	1.3	R	0.2	S	2.0	C
30	2.3	C	1.1	R+S	1.3	S	0.3	S	2.6	C
40	2.5	C	1.8	R+S	1.6	S	0.4	S	2.9	C
50	2.3	C	1.9	S	1.7	S	0.6	S	4.1	C
60	2.6	C	2.0	S	1.9	S	0.7	S	5.0	C
70	2.4	C	1.9	C+S	1.9	S	0.9	S	6.3	C
80	2.8	C	1.9	C	1.7	S	1.1	S	6.9	C+S
90	3.8	C	2.1	C	2.0	C+S	1.2	S	7.8	S
100	4.8	C	2.2	C	2.1	C+S	1.3	S	8.7	S
110	7.0	C+S	2.3	C	2.2	C	1.3	S		
120	8.3	S	2.4	C	2.5	C	1.3	S		
130			2.5	C	2.7	C	1.4	S		
140			3.1	C	2.6	C	1.4	S		
150			3.9	C	2.9	C	1.5	S		
160			4.3	C	3.2	C	1.5	S		
170			5.0	C	3.9	C	1.5	S		
180			5.4	C	3.9	C	1.6	S		
190			6.0	C	4.3	C	1.6	S		
200			6.8	C+S	4.9	C	1.7	S		
210			7.4	C+S	5.7	C	1.8	S+C		
220			8.4	S	6.7	C	1.7	S+C		
230					7.6	C+S	1.8	C		
240					8.5	S	1.9	C		
250					8.7	S	2.0	C		
260							2.1	C		
270							2.3	C		
280							2.5	C		
290							3.5	C		
300							4.7	C+S		
310							5.7	C+S		
320							6.4	S		
330							7.1	S		
340							7.4	S		
350							7.7	S		
360							8.5	S		

a - Transect A begins at a seawall.

CONCLUSIONS

Even though the bay at the proposed resort site has been subject to considerable disturbance by land filling and construction activities in the past, it presently supports a rich and diverse community of corals and other associated reef flora and fauna. Structural reef development is also relatively well developed for a shallow lagoon embayment reef, especially on the outer part of the reef-flat platform and lagoon slope where numerous coral mounds, knobs, pillars, and knolls give the reef its irregular surface topography and relief. Some of the larger individual coral colonies measured on the lagoon slope were four meters or more across and high. Although the overall reef is dominated by Porites species, many of the other less common species have a widespread distribution in all the reef zones. The colorful stony reef-building and soft corals, fishes, sponges, other associated reef organisms, and marine plants, along with the varied reef topography, give this reef embayment area considerable aesthetic appeal. For the proposed resort complex, that hopes to cater to a tourist clientele, it is important to keep the adjacent embayment region in the relatively pristine condition as described in this report.

The general concept of tourists, that tropical resort areas have green forests bordered by white sandy beaches and blue lagoon waters, is for the most part a reality at the proposed resort complex. At the study area the only part of this concept missing is the presence of well-developed sandy beach areas, although at the north end of the bay a small beach has developed along part of an old seawall. This beach area is relatively small and is adjacent to an extensive intertidal sand flat that is considerably exposed during low spring tides and is relatively shallow during other stages of the tide. The developers propose to alliviate this lack of an extensive beach area adjacent to deeper parts of the bay by importing sand to a part of the present shoreline and building up a beach.

From the assessment of flora and fauna, water circulation patterns, sedimentation rates, sediments and sediment transport, and water chemistry, we conclude that such a proposed beach be built up in the intertidal region immediately north of the sea plane ramp (stippled intertidal region shown in Figure 2) by importing sand from some other location.

The environmental impact of building up such a beach in the proposed area would be the modification of about 5300 m^2 of the present intertidal platform. Modificaion would be in the form of changing the present 100 percent intertidal area to a ratio of about 50 percent intertidal area to 50 percent supratidal beach area. This would result in a loss of about 2650 m^2 of intertidal marine habitat and a gain of 2650 m^2 beach area. Also modified would be the nature and composition of the present intertidal surface which now consists mostly of volcanic boulders, rubble, gravel, sand, and mud to one composed of mostly sand-size bioclastic deposits of reef or lagoon origin.

The source of these imported beach sediments at the present time is not known, but if they are to be supplied from the marine environment within the study area, additional impact will be caused by dredging and the generation of a dredge spoil which may be carried to other locations by currents. Some turbid water will also be generated at the beach site when beach deposits are freshly dumped upon the intertidal platform.

An alternate location for the proposed beach site would be at the northeast corner of the bay near Sediment Station No. 7 (Fig. 2).

The proposed location for the beach site (north of the seaplane ramp) was based upon the following considerations:

1. The most objectionable characteristic of the embayment region at the present time, in relation to developing a resort complex, is the presence of the eroding land-filled shoreline and adjacent rubble and mud intertidal zone and metal junk pile at the head of the bay.

2. The greatly weathered fill materials in proposed beach region are presently the major source of terrestrial sediments to the adjacent reef flat and nearby shoreline regions within the bay area. Building up a beach in this region would stop or greatly reduce the present shoreline erosion and transport of eroded fill material to the adjacent marine environment.

3. Sediment transport studies indicate that beach deposits would be fairly stable at the proposed beach site, but the effect of large waves generated by storms blowing from a westerly direction are not known. The present distribution pattern of sediments indicate that some fine particles are carried some distance from the eroding fill material source, but that larger sand and gravel sized sediments are more stable and are carried for the most part to the immediate reef flat area along the broken down seawall. The imported bioclastic sand would be composed of less fine-grained material subject to wave transport. In the event that large storm waves do transport the new beach deposits, they would most likely be moved toward the north around the rocky point at the end of the old seawall and into the same location were beach deposits are presently being deposited near Sediment Station No. 7 (Fig. 2). This region is our choice for an alternative location for the beach site.

The above proposed beach site location and other suggestions are subject to the following recommendations:

1. In the event beach deposits are to be obtained from the study area, we recommend that they not be dredged from the reef-flat or lagoon slope zones. These two zones are areas of rich coral development. The lagoon floor, away from peripheral border where it grades into the lagoon slope zone, would be the preferred dredging location in the study area as it is a zone that for the most part lacks corals and reef development and a rich diversity of other associated flora and fauna. Current patterns in this part of the bay are also more favorable for dredge plume dispersal away from reef areas located farther in toward the head of the bay. The sediments found in the bay would also be of a more desirable size class for beach development than the rubbly deposits generally found in reef areas.

2. It is recommended that sand be placed on the proposed beach site during low tide when the platform is exposed. This would reduce plume generation and sedimentation on the adjacent reef-flat platform.

3. It is recommended that shoreline erosion at the proposed beach site be brought under control by constructing a rock or concrete wall at the existing shoreline. Large boulders and pieces of the old seawall that are near or above the high tide level should be removed prior to bringing in new beach deposits. A significant deepening of the platform in the vicinity of the old seawall (Figs. 2 and 3A and 3B) possess somewhat of a problem in that the freshly deposited beach sand will have a tendency to migrate lagoonward during high tide onto the adjacent reef flat until a new beach slope is attained that is in equilibrium with the grain size of the fresh beach deposits and the hydrologic characteristics of the bay. For a solution to this problem the old seawall could be restored to approximately mean low tide level. This would established a seaward boundary for the beach and help stabilize the new deposits. It would also require less sand to establish the beach as it would reduce the amount lost by emigration in establishing the new beach slope. During high tide water would then cover the wall and outer half or so of the new beach.

4. The abundance and variety of fishes in the survey area are a valuable resource which could be utilized in a number of ways. For tourists, the bay is a natural aquarium, in which snorkelers and scuba divers can see a tremendous variety of fish they may have only seen in

books before. Many relatively large food fishes are available for the recreational and artisanal spearfisherman. The sardines and silversides may provide baitfish for commercial tuna fisherman. As long as excessive harvesting is avoided, there appears to be no reason why all these potential uses of the fish resources could not coexist.

5. One of the most valuable assets to any resort area in this bay area is the presence of the rich and diverse coral reef community. Because of the physical location of the bay on the leeward side of the Palau Island group, it enjoys relatively calm seas most of the time throughout the year. The currents are also relatively weak and the coral reef community is situated in relatively shallow water for the most part. About 70 to 80 percent of the reef area is less than two meters deep and the adjacent lagoon slopes grade into the relatively barren lagoon floor at ten meters depth or less. All these factors contribute to making this region very accessable to snorkelers and scuba divers. The reef area in this bay is a tremendous natural asset and utmost care should be used in maintaining it in its present pristine condition.

METHODS

GENERAL OPERATIONS

The field work was conducted at the project site, located on the east side of Arakabesan Island, from November 19 to November 26, 1977. The study area was limited to the marine environment of the embayment area around the project site itself and the adjacent intertidal area and shoreline (Figs. 1 and 2).

A field reconnaissance trip was made to the site on November 19 to plan a schedule of general operations for the field work. Transect and sand transport stations locations, sediment and demersal plankton trap stations, and two triangulation base stations for use in plotting drift drogues during the current study were determined from observations made at this time. Preliminary observations revealed that a lagoon fringing reef system formed a number of physiographic zones arranged in a parallel pattern around the perimeter of the bay. With such a reef zonation pattern present, quantitative assessment of the bay flor and fauna could best be achieved by running transects at right angles across these parallel zones (Fig. 2). Five transect locations (A-E, Fig. 2) were selected on the basis of being a representative sampling of the of the habitat diversity in the area as well as areas where proposed work will definitely alter the marine environment and where potential impact on the marine environment may be expected.

WATER CIRCULATION

Water circulation studies were confined to the bay area on the east side of Arakabesan Island. Drift drogues were released in ten casts,one to four at a time, at various locations and times within the bay from 0827, November 20, to 0726, November 21, 1977. The positions of the drogues in each cast were determined by triangulation with surveying transits from two base stations (TS1C and TS2A, Fig. 2) at the point where they were placed in and taken out of the water, and at hourly intervals during their drift time. The drift track of each drogue was plotted on a 1:1200 scale map.

The drift drogues consist of a flattened float from which a metal vane in the shape of a cross is suspended by a variable length of rope. Because of shallow water present over the fringing reef-flat platform and scattered large coral knolls that extended upward to within one meter of the surface on the lagoon slope, the vane depth of the drogues was maintained at one meter.

Wind speed and direction were determined at hourly intervals at Base Station TS1C with a Belfort anemometer so that the possible influence of the wind on the movements of the drift drogues could be assessed. Influence of the tides on current patterns within the bay were obtained at hourly intervals by taking water level readings on a Philadelphia rod located at Base Station TS1C. These observed tide levels were then compared to the predicted tide levels for Malakal Harbor, Koror, Palau.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE WATER

Water samples were taken in polyethylene bottles by opening them underwater at the given location and depth. The water samples were then placed in an ice chest. The ice chest was stored in the freezer at the Fishermen's Co-op until the morning of our flight back to Guam. The samples stayed frozen during our return trip and they were placed in the freezer of the Water Resources Research Center upon our arrival. The samples were analyzed at the University of Guam Water Resources Research Center for NO_3-N, NO_2-N, PO_4-P, and turbidity according to the methods of Strickland and Parsons (1968).

Water Temperature was measured with a protected field thermometer which was taken underwater to the given depth and allowed at least two minutes to equilibrate. Salinity was measured in samples brought to the surface in a plastic freezer jar. An American Optical Corp. refractometer was used.

SEDIMENTS AND SAND TRANSPORT

Beach and marine sediments were collected from 13 stations as shown in Figure 2. Grain size and composition analyses were made.

Grain size was determined by sieving the samples for 15 minutes on a Tyler Portable Sieve Shaker. From these screen fractions cumulative grain size curves and histograms of grain sizes were constructed and Trask sorting coefficients ($So = \sqrt{Q25/Q75}$, Trask, 1932, p. 67-76) calculated.

The percentage of volcanic material in the 13 samples was determined by digesting a sample portion in cold dilute hydrochloric acid. The weight loss after decantation of the spent acid is considered to be the bioclastic fraction and insoluble fraction the volcanic detrital fraction. Insoluble bioclastic debris such as siliceous sponge spicules and other soluble detrital material are minor and have a negligible effect on the percentages.

The organic carbonate fraction of the sediment samples was composed principally of the hard parts of reef plants and animals. The most abundant constituent groups were identified as coral, calcareous red algae, mollusc shells, Foraminifera, _Halimeda_ segments, sand, echinoid spines, soft coral sclerites, and a minor amount of other unidentifiable hard parts. The percentage that each of the above groups contributed to the carbonate sediment fraction was analyzed by making frequency estimates with a binocular microscope.

Estimations on the stability of the imported sand that is to be placed along part of the shoreline at the head of the bay to build up a beach zone (Fig. 2) was made by using marked sand grain recovery techniques, and by analyzing the movement of sediments presently found in the proposed beach zone to other parts of the bay.

The first of these methods was initiated by placing 500 ml samples of marked calcareous sand grains at two stations within the proposed beach area (Stations G and H, Fig. 2) on November 19, 1977. The marked sand grains were selected from a low energy beach environment, similar to that found in the proposed beach zone. They were washed and dried and then soaked in an indelible black dye. The black calcareous sand grains are unlike any others found in the study area and they can be identified, if present, in other sediment samples found in the bay.

No marked grains were recovered in sediment sample Stations 1-13 except for No. 12 which is located at release Station H. Not enough time has elapsed since the release of the marked grains to show evidence of any sediment transport at the proposed beach site by using this method. Arrangements have been made for sediment samples to be collected and analyzed at a later data to determine whether or not the marked grains are being transported to other parts of the bay.

An analysis of present sediments being transported from the proposed beach site is possible because of the presence of unique yellow-brown volcanic detrital grains which are eroding from an adjacent land-filled shoreline. The presence of these unique grains in sediment sample Stations 1-13 was used to analyze the movement of sand-sized sediments from the proposed beach site.

SEDIMENTATION RATES

Plastic tubes with inner diameters of 2.25 centimeters, aperture areas of 4 cm^2, and lengths of 41 centimeters were strapped to rebar rods and hammered into the reef to stand upright at the sampling stations (Fig. 4). Six of the stations were at depths of 4 meters near the six transects or vertical profiles. The other four stations were at depths of 1.5 meters near the central four transects.

The tubes were left out for five days. When the tubes were collected, the sediment was emptied and rinsed into plastic bags and preserved with formalin for shipment back to the Marine Laboratory. At the Marine Laboratory, the sediment was then rinsed into clean beakers that had been previously weighed and labeled. Distilled water was

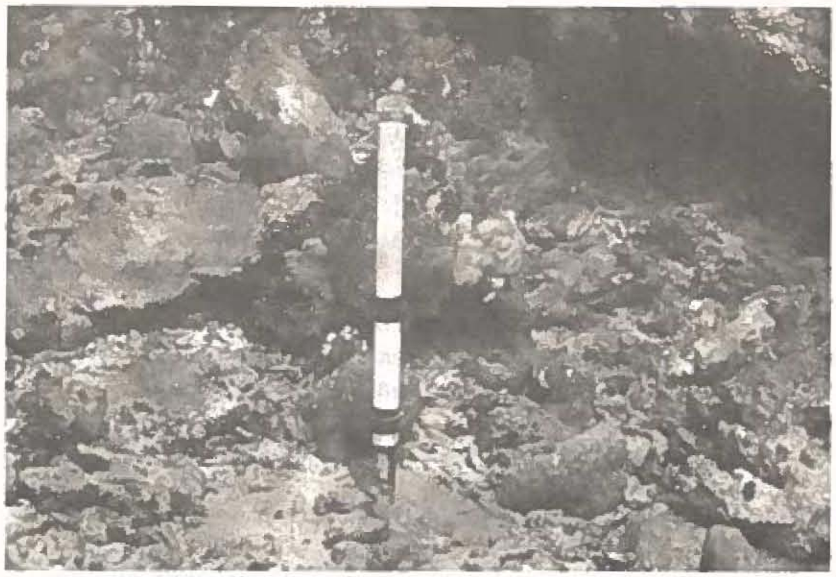


Figure 4. Sediment collecting tubes at a station on the lagoon slope. Depth about 4 m.

Figure 5. Demersal plankton trap in position on the lagoon slope.

poured into the beaker, the sediment was allowed 24 hours to settle, then the water was decanted. This rinsing procedure was continued for four days to get rid of the salts from the seawater. Then, after the fifth decanting, the beakers with the sediment were placed in drying oven at 80°C for four days. On the fifth day, the beakers were placed in a desiccator and allowed to reach room temperature overnight beside the microbalance. The beaker with dried sediment was then weighed and the weight of the empty beaker was substrated.

BIOTA

Marine Plants

The point-quadrat method was used for the quantification of marine benthic plants. The quadrat used was 25 cm x 25 cm with 16 internal points. The quadrat was placed at each meter-mark along the transect line and each algal species was recorded at every point it occurred. If no algal species occurred beneath a point then whatever was present, i. e., live coral, sand, reef pavement, was recorded. The percent cover was calculated by dividing the number of points at which a plant species occurred by the total number of points sampled. The number of points sampled per transect, then, was dependent upon transect length and varied from 1600 (Transect E) to 5280 (Transect D), totalling 16816 points sampled for the study site. Relative abundances for the major contributors to the plant cover were calculated by dividing the number of points recorded for each by the total number of points at which plants occurred.

Occasional random swims were also made throughout the study site recording the names of those species which had not been encountered on the transects, thus enabling a more comprehensive species list to be compiled. Specimens not readily identifiable in the field were brought to the University of Guam Marine Laboratory for positive identification.

Corals

Coral communities were analyzed along Transects A-E by using the point-centered or point-quarter technique (Cottam et al., 1953). The transects were established by placing a plastic surveyors tape along the bottom at the locations indicated in Figure 2. Points established at ten meter intervals along the line were used as sample points. A line bisecting the sample point at right angles to the transect line established four quadrants around the point. The coral nearest the sample point in each quadrant was located and the specific name, diameter of the colony (or width and length measurement), and the distance from the center of the colony to the sample point was recorded. If no colony was observed within the maximum distance of one meter from the sample point, the quadrant was recorded as having no colony with a diameter of zero and a sample point to colony distance of one meter. Therefore, the unit area of the survey quadrant was .785 m^2.

From the point-quarter data the following calculations were used to estimate the population and community parameters:

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

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

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

total percent coverage = total density of all species X average coverage value for all species

percent coverage = density of a species X average coverage value for the species

$$\text{relative percent coverage} = \frac{\text{percent coverage for a species}}{\text{total coverage for all species}} \times 100$$

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

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

importance value = relative density + relative percent coverage + relative frequency

The presence of additional coral species not encountered in the transect samples were determined for each transect by making 10 minutes observations along each side of the transect line for each 100 meters of transect length. The number of coral species and an estimation of their relative abundances were determined for each physiographic reef zone mapped in Figure 2. 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.

For each species encountered on the transects or physiographic reef zones, one or more representative colonies or parts of colonies were collected for positive identification.

A vertical Profile F no quantitative data was collected, but species occurrence was recorded along the region indicated in Figure 2 and relative abundance was recorded along the submarine cliff which occurred there.

Macroinvertebrates

The abundances of octocorals, anemones, Tridacna (giant clams) and echinoderms were quantified by swimming the lengths of the transects and counting the number of invertebrates within one meter of the line to either side. A meter stick was held perpendicular 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 ten meters. The animals in a similar ten meter long rectanglular area were then counted along the other side of the transect line. This process was repeated along the entire lengths of the transects and the data were recorded separately for the different zones.

The small cerithiid snails that were abundant in the rock rubble intertidal zone were sampled by counting the number that were found in each 10 x 10 cm division of a 0.25 m^2 quadrat.

The suspension-feeding bivalves found living embedded in living coral heads were sampled by counting those occurring within 40 x 40 cm quadrats that were placed on heads of Porites lutea. Forty such samples were taken.

Zooplankton

Zooplankton was sampled with two different methods. Plankton in the water column during the day was sampled by making five tows with a plankton net, four running perpendicular to the shoreline and one running across the mouth of the bay. A 50 centimeter diameter plankton net with mesh apertures of 0.40 mm was used. The nets were towed for five minutes at an approximate speed of 1 m/sec.

Demersal plankton, those planktonic organisms which reside within the substrate for periods of time during the 24-hour day, were sampled using demersal plankton traps built according to the design of Porter and Porter (1977) (Fig. 5). These traps are designed to capture planktonic organisms as they emerge from the sediment to occupy the water column. Pairs of traps were secured to the bottom on each of two different substrate types: coral and sand. Traps were harvested twice a day, at approximately 0800 and 1700. Each day the traps were moved to an immediately adjacent area of the same substrate type so that planktonic organisms would not be prevented from entering the substrate beneath the trap. Each trap covered an area of 0.21 m^2.

All plankton samples were preserved in the field in 5% formalin, and identifications and counts of organisms were done in the laboratory with a binocular microscope. A one-seventh subsample of the total collection was counted for the tow net samples. The entire demersal trap sample was counted except for some very numerous groups that were subsampled.

Fishes

Five transect lines were established which ran generally perpendicular to the pattern of reef zonation (Fig. 2). A diver swam the transect lines, using scuba or snorkeling gear, and enumerated the fishes observed within one meter to either side of the transect line. Separate enumerations were made for each ten meters interval along the transect line. Censuses were analyzed by combining all ten meter interval counts which lay within each of the reef zones. Random surveys were made at various locations throughout the study area to compile a more complete species list than was provided by the transect censuses.

RESULTS AND DISCUSSION

WATER CIRCULATION

Current patterns within the bay are complex, depending upon the tides, wind, wave and swell conditions, and currents in the nearby Komebail Lagoon (Figs. 6 and 7 and Table 2). The effect of various sea surface conditions upon the currents could only be determined for waves and swell amplitudes of about 5-15 centimeters, which prevailed throughout the current monitoring period, except for 30 minutes from 0100 to 0130, November 21, 1977, when a rain squally passed over the area creating short period waves about 30 centimeters high within the bay. Wind is important in that it may generate a surface current and its speed and direction determine the height and direction of waves within the bay and in the adjacent Komebail Lagoon. Large swells were generally of little significance since the barrier reef to the west protects the area from the open sea, although low short period swells about 15 centimeters high were detectable within bay as they broke on the seaplane ramp at Base Station TS1C. This low swell probably originated from breaking waves on the distant barrier reef to the west.

The measurement of currents in the nearby Komebail Lagoon was beyond the scope of work for this project but the effect of such currents would probably have some effect on the currents within the bay. During the period of our study no clear pattern of currents could be established by assessing the movement of drogues after they drifted past the mouth of the bay and into the Komebail Lagoon. Drift drogue Cast 1B indicated a northerly flowing current at the mouth of the bay during a low water slack tide period but was taken out during the early part of the flood tide cycle (Table 2 and Fig. 7). Drift drogue Cast 1D followed the same drift pattern as 1B, except that it was left in the water for an additional 65 minutes. During this latter part of the drift it abruptly changed direction and began drifting in a southerly direction. This abrupt change in direction was probably a tidal influence as the effects of the approaching flood tide cycle become more pronounced. Drift drogue Cast 5A was the only other drogue that drifted out to the mouth of the bay, and it followed a somewhat similar track during a later flood and early ebb tide cycle at the latter part of its drift as did Cast 1D. Although this meager evidence is not conclusive it does indicate that tides influence the current movements in the nearby Komebail Lagoon. Complex eddy systems may be present in the lagoon as well which may modify the current patterns in the study area as they sweep by the mouth of the bay.

There appears to be two somewhat variable but distinct net current patterns within the bay; one that flows from near the head to the mouth of the bay in a southwestern direction in the southern half of the bay and another one that flows from the head to the mouth of the bay in a

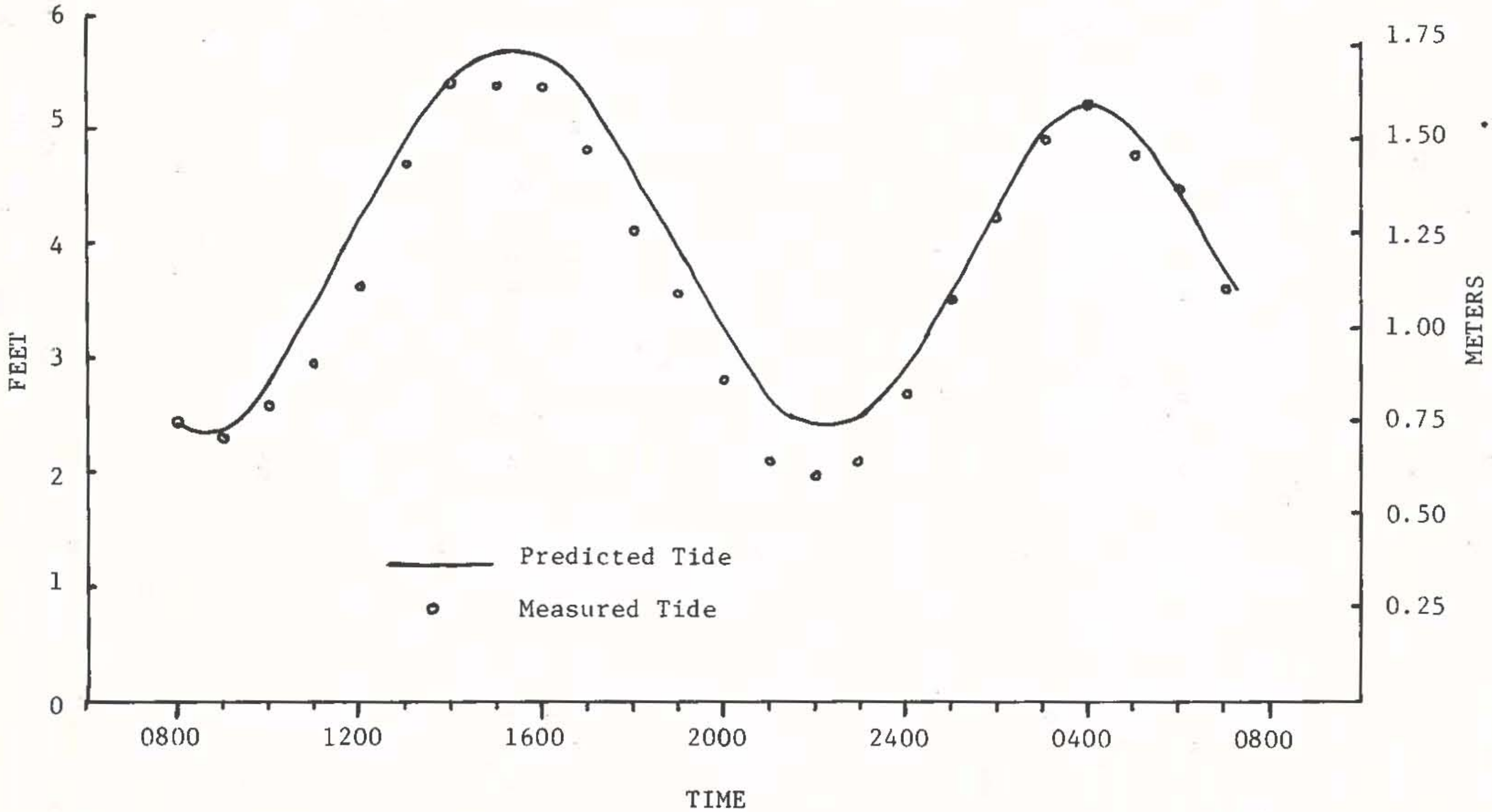


Figure 6. Tide curves generated from predicted tides at Malakal Harbor, Palau, 0800, November 20, 1977, to 0700, November 21, 1977.

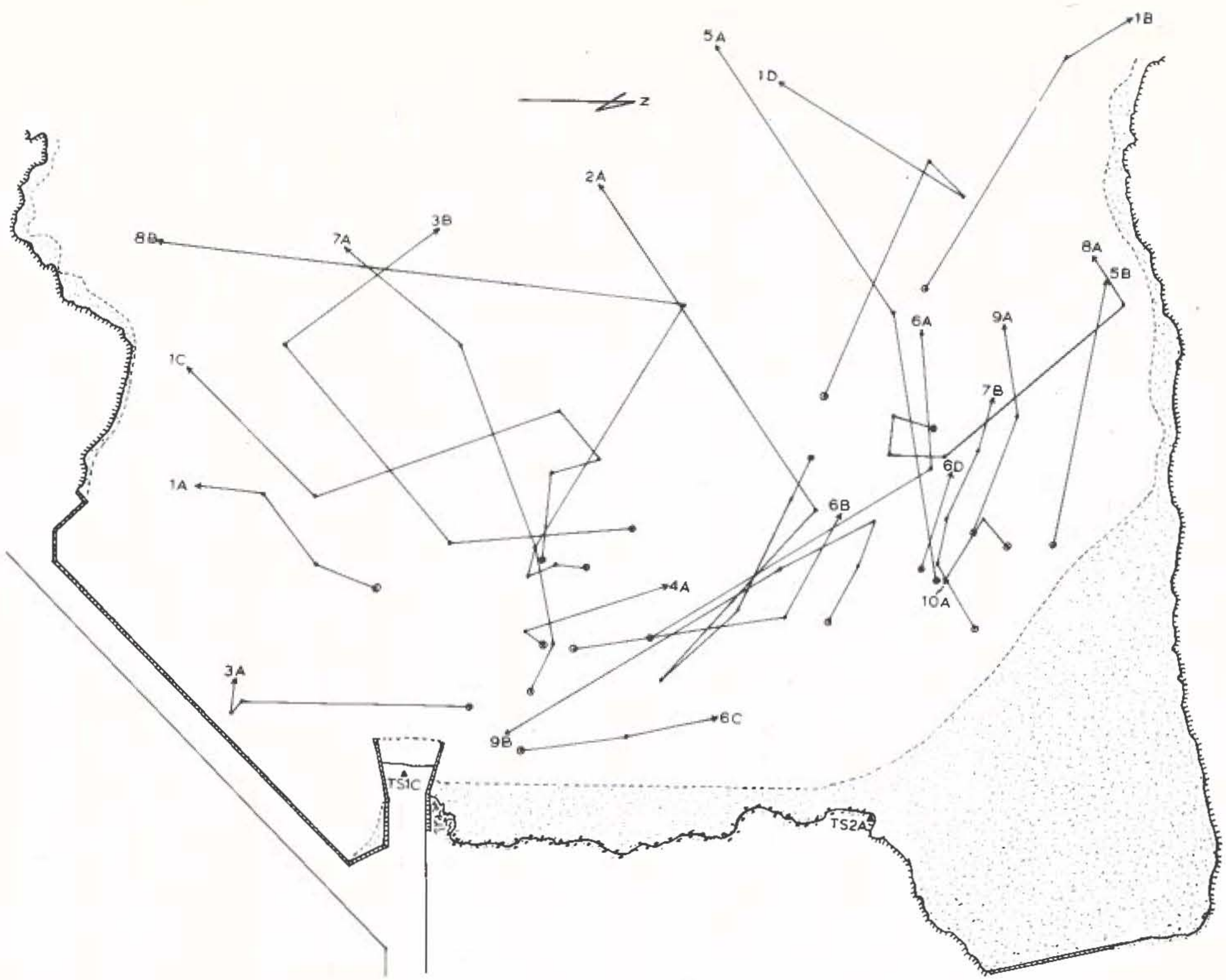


Figure 7. Drift tracts of 1-meter drogues. Drogues were released in ten casts ranging from one to four drogues (A-D) per cast. Tracts were determined by triangulation from base stations TSIC and TS2A. Dots within circles indicate the locations where drogues were released and the terminal arrow where they were retrieved. Black dots between the drogue release and retrieval points indicate intervening triangulation positions. Intertidal areas are indicated by stippling. See Figure 2 for legend of shoreline features.

Table 2. Drift distance, time, and speed of current drogues, and direction and speed of wind during time of drogue drift from 0827, November 20, to 0726, November 21, 1977.

DROGUE CAST NO.	TIME IN	TIME OUT	DRIFT TIME HRS.	DRIFT TIME MIN.	DRIFT DISTANCE (NM)	SPEED (KTs)	WIND DIRECTION TIME IN	WIND DIRECTION MID DRIFT	WIND DIRECTION TIME OUT	WIND SPEED (KTs) TIME IN	WIND SPEED (KTs) MID DRIFT	WIND SPEED (KTs) TIME OUT	TIDE	REMARKS
1A	0827	1125	2	58	.055	.019	063	090	309	2.0	2.5	5.5	early-flood	
1B	0835	1031	1	56	.089	.046	063	107	090	2.0	3.7	2.5	early-flood	
1C	0829	1328	4	59	.163	.033	063	309	358	2.0	5.5	2.5	mid-flood	
1D	0832	1136	3	4	.133	.043	063	090	220	2.0	2.5	1.5	early-flood	
2A	1035	1538	5	3	.227	.045	309	358	030	5.5	2.5	3.5	late-flood	
3A	1128	1429	3	1	.070	.023	220	358	030	1.5	2.5	3.5	late-flood	
3B	1144	1425	2	41	.159	.059	220	358	030	1.5	2.5	3.5	late-flood	
4A	1334	1535	2	1	.044	.022	087	030	calm	3.0	3.5	0.0	late-flood	
5A	1435	1627	1	52	.150	.080	030	calm	104	3.5	0.0	4.0	early-ebb	
5B	1436	1542	1	6	.069	.043	030	–	calm	3.5	–	0.0	early-ebb	
6A	1544	1729	1	45	.119	.068	calm	104	calm	0.0	4.0	0.0	mid-ebb	
6B	1546	1733	1	47	.084	.047	calm	104	calm	0.0	4.0	0.0	mid-ebb	
6C	1547	1735	1	48	.051	.028	calm	104	calm	–	4.0	–	mid-ebb	
6C	1631	1731	1	0	.026	.026	104	–	calm	4.0	–	0.0	mid-ebb	
7A	1755	2200	4	5	.132	.032	calm	calm	calm	0.0	0.0	0.0	late-ebb	
7B	1800	2202	4	2	.064	.016	calm	calm	calm	0.0	0.0	0.0	late-ebb	
8A	2216	0326	5	10	.110	.021	calm	180	calm	0.0	18.0	0.0	mid-flood	rain squall
8B	2233	0228	3	45	.172	.046	calm	180	calm	0.0	18.0	0.0	mid-flood	rain squall
9A	0330	0534	2	4	.056	.027	calm	090	040	0.0	2.0	2.5	early-ebb	
9B	0333	0725	3	52	.135	.035	calm	050	300	0.0	2.5	7.5	early-ebb	
10A	0538	0726	1	48	.029	.016	050	040	300	2.5	2.0	7.5	mid-ebb	

northwestern direction in the northern half of the bay (Fig. 7). The principal factor influencing water circulation in the bay appears to be from tide flushing and filling, although the effect of variable winds, both in direction and speed, attribute a considerable amount of complexity to the drogue drift patterns shown in Figure 7.

Correlation of the drift drogue tracks at hourly intervals with wind speed and direction and state of the tide yielded some distinct water circulation patterns. In general, the currents are weaker and more variable at low slack tide and the drogues are thus more responsive to wind influences. Although the wind was not strong during this part of the study period, it was quite variable both in direction and speed (Table 2).

During flood tide (0930 to 1430), the bay was filling, and the drogue tracks had strong southerly components at the south end of the bay and northwesterly and southwesterly components at the north end. Current speed at this time was greater than at low slack tide. Wind was variable in speed and direction with calm periods intersperced.

During high slack tide (about 1430 to 1530) the drogue tracks were once again variable but with an overall more westerly and northwesterly components present than during the earlier low slack tide period.

During ebb tide (1530 to 2100) the bay is emptying and the drogue tracks had strong westerly components. Current speeds were on the average higher during this period than at any other time.

During the second low slack tide period (2100 to 2230), currents were again weak and variable, with most having southerly or southwesterly drogue track components.

During the second flood tide period (2230 to 0300) the drogue tracks had strong southerly components at the south end of the bay, changing to a northern track because of strong southerly winds during a passing rain squall. From 2216 to 1245 there was little movement of the drogues.

Drogue tracks during the last ebb tide period (0400 to 0726) had strong westerly components similar to the previous ebb period, but abruptly changed to a southeasterly track because of a moderately strong westerly wind.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE WATER

The results of the survey of physical and chemical characteristics of the seawater in the bay and the freshwater in the pond and stream are given in Table 3. The mean concentration of nitrates in the water samples (.65 ± .06 μg-at/l) was about three times higher than concentrations found in our previous surveys around coral reefs in Micronesia (cf. Table 4 in Birkeland et al. 1976). The phosphates, however, were in rather low concentration (0.15 ± .06 μg-at/l). A low amount of phosphates was also found in our previous study at Koror, Pálau, in comparison with other sites around Micronesia (cf. Table 4 in Birkeland et al. 1976).

Table 3. Physical and chemical characteristics of the lagoon water of the bay, the higher freshwater pond, and the mouth of the small freshwater stream at the north end of the sandy beach. November 24, 1977.

STATION	Depth (m)	Temp. (°C)	Sal. (°/₀₀)	NO_3-N (µg-at/l)	PO_4-P (µg-at/l)	Turbidity (NTU)
Freshwater pond	.3	26.8	0	1.12	1.12	1.7
Freshwater stream mouth	0	27.6	0	.45	.02	2.8
Near vertical profile F	.3	29.7	33	1.16	.32	.34
	4	29.7	32	1.20	.23	.32
Near Transect A	.3	29.8	34	.69	.13	.26
	4	29.7	32	.62	.17	.68
Near Transect B	.3	29.8	33	.54	.16	.33
	4	29.7	33	.58	.09	.52
Near Transect C	.3	29.8	32	.98	.14	.38
	4	29.8	32	.83	.10	.35
Near Transect D	.3	29.9	34	.40	.23	.48
	4	29.8	34	.34	.12	.40
Near Transect E	.3	30.0	33	.31	.11	.37
	4	30.0	34	.65	.13	.27
Open water at mouth of bay	.3	29.8	33	.89	.12	.30
	4	29.7	33	.22	.10	.22
Sandy beach	.6	31.0	33	.40	.10	.38

The water temperatures ranged between 29.7°C at the south end of the bay to 30.0°C at the north end of the bay. (We do not include the 31.0°C temperature recorded near low tide on the shallow sand flat near Transect C.) Although this 0.3°C difference is very small, the water at the north half of the bay is significantly warmer than the water at the south half (P=.04, median test). The difference is statistically significant, but probably not important to the biology of the region.

The water temperatures were recorded on the outgoing tide (1100 to 1230) and on the incoming tide (1600 to 1700). The order in which the stations were sampled was reversed on the second run, but the same results were obtained.

SEDIMENTS AND SAND TRANSPORT STUDIES

Proposed development plans call for importing sand to build up a beach along a portion of the present shoreline. The proposed beach site is located at the head of the bay between an old broken and partly disintegrated seawall and the shore (Fig. 2). The shoreline itself consists of a mixture of intensely weathered volcanic rock and earth fill. Originally this fill material extended outward to the old seawall, but has since been eroded shoreward forming an intertidal platform up to 34 meters wide as shown in Figure 2. Shoreline erosion is continuing and is the source of the yellow-brown colored mud, sand, gravel, and boulder deposits presently found on the surface of the intertidal platform and area adjacent to the old seawall. These weathered yellow-brown detrital sediments are unlike those found in other parts of the bay and can be used as natural marker grains. Identification of these yellow-brown grains in other sediment samples taken around the bay will give some indication as to the direction and amount of transport of the eroded fill material from its original location, and will also give some indication as to the stability of the imported sand to the proposed beach site.

Sediment samples were collected from beach deposits at Stations 7 and 13, the proposed beach site at Stations 1, 2, and 3, the intertidal sand flat at the southeast corner of the bay at Station 8, the reef-flat platform at Stations 3, 4, 6, and 10; and the lagoon floor at Stations 5, 9, and 11 (Fig. 2). Histograms of grain size and cumulative screen analysis graphs were constructed for each sample as shown in Figures 8A and 8B. Trask sorting coefficients ($So = \sqrt{Q1/Q3}$) were computed (Figs. 8A and 8B) and percentage of insoluble volcanic material present and composition analysis of the carbonate fractions are given in Table 4.

Volcanic detrital grains ranged from 4 to 94 percent and were found in all the samples. These volcanic grains are derived from three principle sources. Most widespread are those brought to the bay by several small steams that drain the adjacent island slopes and those

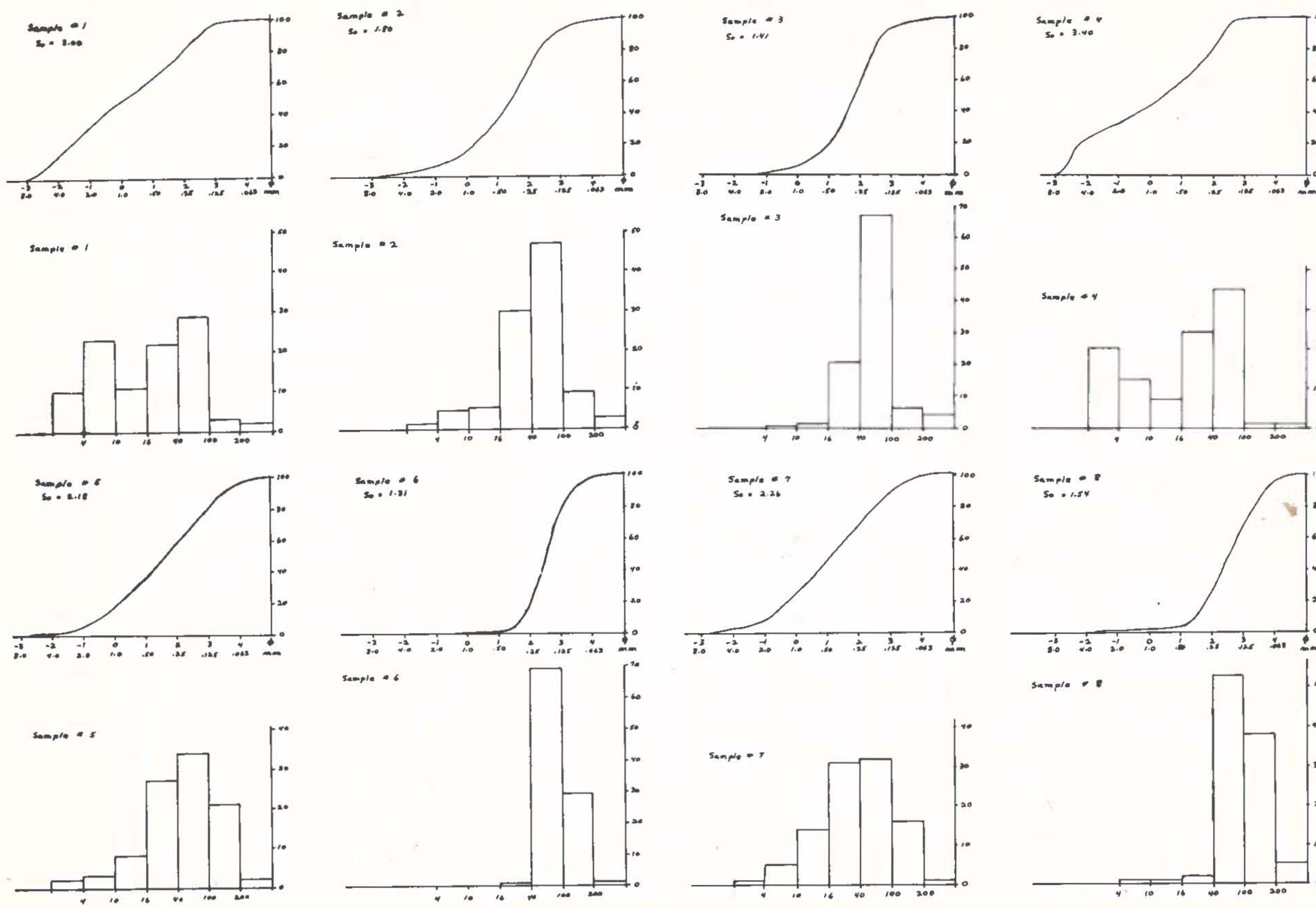


Figure 8A. Histograms of grain size, cumulative screen analysis graphs, and trask sorting coefficients for sediment Samples 1-8.

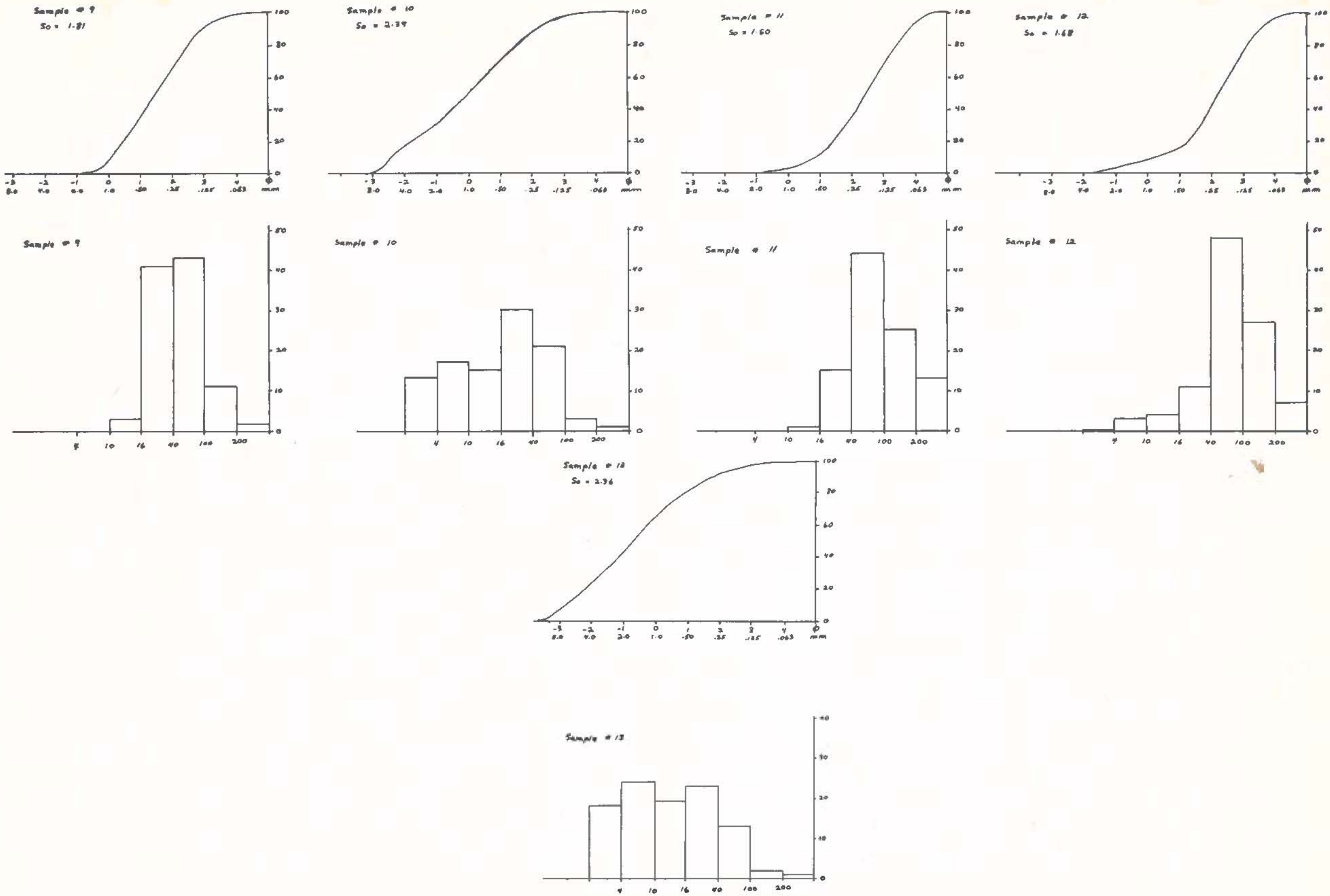


Figure 8B. Histograms of grain size, cumulative screen analysis graphs, and trask sorting coefficients for sediment Samples 9-13.

Table 4. Composition of beach sands and reef sediments, in percent.

	1	2	3	4	5	6	7	8	9	10	11	12	13
A-Organic Carbonate	47	33	69	96	94	72	66	70	95	94	85	13	6
Calcareous algae(Red)	3	3	9	9	10	12	8	3	5	10	6	8	-
Halimeda fragments	-	-	-	-	3	3	3	2	10	3	2	-	-
Foraminifera	8	3	6	15	9	12	12	3	8	6	8	8	-
Coral	17	14	22	29	13	23	11	2	17	33	5	23	31
Shells	14	12	14	8	7	11	12	6	5	14	5	23	22
Soft coral sclerites	3	3	-	3	2	-	-	-	1	2	2	-	-
Echinoid spines	3	-	2	5	2	3	2	1	-	-	3	-	-
Sand	45	59	44	28	44	28	45	78	51	27	66	37	44
Miscellaneous	7	6	3	3	10	8	7	5	3	5	3	1	3
B-Inorganic Volcanics (insoluble residue)	53	67	31	4	6	18	34	30	5	6	15	87	94

which are washed into the bay by erosion of the exposed volcanic rocks along the intertidal shoreline at the north and south ends of the bay. The third source is derived from shoreline erosion of the weathered volcanic fill along the head of the bay at the proposed beach site. Volcanic rocks exposed on the island slopes and shoreline at the north and south ends of the bay are relatively fresh and unweathered and the eroded grains transported into the bay are for the most part dark colored. In contrast, the grains eroded from the fill material at the proposed beach site are greatly weathered and mostly of a yellow-brown color.

Although some volcanic detrital grains of the yellow-brown weathered variety were found at in all samples, the majority were found in samples close to the source (Samples 1, 2, 3, 12, and 13). The only exception to this was the beach sample at the northernend of the bay (Sample 7) which had significant amounts of both weathered and fresh volcanic material present. The small amount of yellow-brown material in samples more distant from the source were mostly clay or very fine sand sized grains, whereas the material in samples near the source ranged from gravel to clay sized particles with most being in the fine to coarse sand and gravel sized fractions (Figs. 8A and 8B). The fresher dark colored volcanic grains were most abundant at the north end of the bay (Samples 6, 7, 8, and 9), moderately abundant at the south end of the bay (Sample 11), and least abundant from the middle part of the bay (Samples 4 and 5).

The distribution pattern of yellow-brown grains indicates that very little of the sand or larger sized grain fractions are being transported any great distance from their source. Sample 4, collected immediately lagoonward of the eroding shoreline and platform, contained only 4 percent volcanic detridal grains and 96 percent carbonate material of reef origin. Because of the physical setting of the project site on the leeward side of the island group there is little wave activity in the bay. This low wave assault plus the absence of strong currents in the bay account for relative stability of the sand and larger sized grain fractions at the proposed beach site. Apparently though, the minor wave activity and weak currents present in the bay are of sufficient magnitude to transport a small amount of the very fine sand and clay sized fractions greater distances, which accounts for their presence in stations move distant from their source. Although calm conditions generally prevailed during the study period, a minor amount of turbidity was noticed in the vicinity of the eroded seawall. It is suspected that most of the sediment transport, of all size fractions, from the eroding shoreline and adjacent intertidal platform occurs during relatively rare weather conditions when strong winds are blowing from a westerly component.

The presence of some coarse sand and larger sized yellow-brown grains in the beach deposits at the north end of the bay (Sample 7) indicates a minor amount of sediment transport from the beach site northward along the shoreline. Since it was mostly coarse sediments found in this beach sample, they were probably transported at infrequent times during storms or when strong west winds were blowing. This evidence indicates that it might be reasonable to expect some movement of coarse grained material from proposed beach site to the northeast corner of the bay during tropical storms and typhoons, or when strong winds blowing from the west generate larger waves and stronger currents within the bay.

Sediments were most poorly sorted (So 3.40 - 2.26) in regions of active coral growth (Samples 4, 5, and 10) and in beach environments (Samples 7 and 13), best sorted (So 1.31 - 1.81) on the extensive intertidal sand platform at the northeast corner of the bay and lagoon floor, and variably sorted (So 3.00 - 1.41) on or near the intertidal platform at the proposed beach site.

Organic carbonate fractions of the samples were highest in regions of reef development and lowest in the vicinity of the proposed beach site. These materials were all of reef origin as no other limestone source rocks are present within the drainage basin area of the bay to provide detrital cardonate grains. The most abundant constituent in most samples was comminuted skeletal material in the form of sand that was unidentifiable as to origin. Of the identifiable constituents coral, shell, red calcareous algae fragments, and Foraminifera were the most abundant, and *Halimeda* segments, soft coral sclerites, and echinoid spines the least abundant. Miscellaneous materials included crustacean parts, sponge spicules, and other large unidentifiable fragments.

SEDIMENTATION RATES

The amounts of sediment (dry weight in mg) that accumulated over a 5-day period in each of ten sediment tubes (Fig. 4) are given in Table 5. There was no significant difference between rates of sedimentation along any of the transects, nor was there a significant difference between the sediment accumulations measured at 1.5 meters and those measured at 4 meters. If we lump the data, then extrapolate to estimate the amount of sediment settling per m^2 per week on the reef, we calculate about 40 grams settles per m^2 per week.

Although the differences in sediment accumulation along the transects and between the 1.5 meter and 4 meter stations were not statistically significant, there does seem to be a tendency for more sediment to accumulate at the 4 meter stations. The 5-day period was too short to give us satisfactory data for statistical analysis.

Table 5. Dry weight (mg) of sediment collected over a 5-day period in tubes with a 4 cm^2 aperture.

Depth	STATION Near Vertical Profile F	Near Transect A	Near Transect B	Near Transect C	Near Transect D	Near Transect E
1.5 m	---	10.85	11.37	8.05	10.95	---
4 m	8.75	15.4	11.1	21.5	27.0	4.85

BIOTA

Marine Plants

A total of 53 species of marine benthic plants were identified from the study site, including 49 species of algae and 4 species of seagrasses (Table 6). This represents approximately 42 percent of the total recorded species for Palau and is of comparable diversity to similar studies done in Palau and throughout the Trust Territory (Amesbury, et al., 1976, Amesbury, et al., 1977, Birkeland, et al., 1976). This total includes those sampled on transects(37 spp.) as well as those observed during random swims (an additional 16 spp.). Although certain areas were predominated by one or a few species, (Table 7), no distinct zonation patterns occurred. Therefore, the data will be discussed primarily in terms of topographical zones, i.e., intertidal, reef flat, lagoon slope and lagoon floor (Fig. 2).

Table 8 summarizes the percent cover of marine benthic plants for the intertidal reef flat and lagoon slope zones, of each transect. Table 7 summarizes relative abundances of the major components of the plant communities in these same zones. Since the transects extended only a few meters across the lagoon floor the data for this zone are incomplete and therefore are not shown in these tables.

Intertidal zones within the study site varied in plant cover from 1 percent (Transect D) to 88 percent (Transect E), reflecting the variation in substrates. Approximately the first 200 meters of Transect D was sand, providing no suitable substrate for attachment. The only recorded plant cover was restricted to the surfaces of very occasional boulders and to a sparsely developed seagrass bed of juvenile _Halodule uninervis_ in the extreme lower intertidal. The intertidal zones of Transects B and C were composed of the boulder-rubble remains of an old seawall and showed essentially identical plant growth. A rust colored turf composed primarily of _Enteromorpha clathrata_ and _Gelidopsis intricata_ overgrown with _Calthrix confervicola_ and, in the lower intertidal, _Padina tenuis_ were the dominant species. The smooth volcanic substrate forming the intertidal bench of Transect E was dominated on its upper third by a very slippery black film of the blue-green alga _Entophysalis deusta_. The mid and lower intertidal was dominated by a turf of _Microcoleus lyngbyaceus_, _Sphacelaria tribuloides_ and _Gelidiopsis intricata_. With only a few feet of the vertical surface of a seawall as the intertidal zone at Transect A, no quantification of the marine plants was done.

Far less variable than the intertidal zones, the reef flats of all transects showed a consistent pattern of dominance by a low-lying turf of _Sphacelaria tribuloides_, _Gelidiopsis intricata_ and juvenile _Neomeris_, only varying in relative abundance from 54 to 57 percent. With the exception of Transect D, _Lobophora variegata_ showed the second highest relative abundance, varying between 20 and 31 percent. An extension on

Table 6. Checklist of marine plants observed at the study site. The topographic zones in which each species occurred on the five transects are given. (1=intertidal, 2=reef flat, 3=lagoon slope, 4=lagoon floor).

SPECIES	TRANSECTS A	B	C	D	E
CYANOPHYTA					
Calothrix confervicola Ag.		1	1		
Entophysalis deusta (Menegh.) Dr. & Daily					1
Hormothamnion enteromorphoides B. & Fl.			2		
Microcoleus lyngbyaceus (Kutz.) Crouan		2		2	1,4
Schizothrix calcicola (Ag.) Gomont		1,2	1		3
S. mexicana Gomont*					
CHLOROPHYTA					
Acetabularia exigua Solms-Laubach*					
Avrainvillea obscura J. Ag. *					
Bornetella oligospora Solms-Laubach				2	
B. sphaerica (Zanard.) Solms-Laubach		2		2	1
Caulerpa serrulata (Forsk.) J. Ag.*					
Chaetomorpha cf. indica Kutz.				1	
Enteromorpha clathrata (Roth) J. Ag.		1	1	1	
Halimeda opuntia (L.) Lamx.				2	
H. simulans Howe		2			
Neomeris sp.	2,3	1,2,3	1,2,3	1,2,3	2,3,4
Udotea javensis (Mont.) A. & E. S. Gepp*					
Valonia ventricosa J. Ag.	3				
PHAEOPHYTA					
Dictyota bartayresii Lamx.			2	2	4
D. friabilis Setchell		3			1,3
Lobophora variegata (Lamx.) Womersley	2,3	2,3	2,3,4	2,3	1,2,3
Padina jonesii Tsuda*					
P. tenuis Bory	2	1,2	1,2	2	1
Sargassum cristaefolium C. Ag.*					
S. oligocystum Mont.	2	2	2	2	1
Sphacelaria tribuloides Menghini	2,3	2,3	2,3	1,2,3	1,2,3
Turbinaria decurrens Bory*					
T. ornata (Trun.) J. Ag.	2	2,3		3	1,2
RHODOPHYTA					
Actinotrichia fragilis Boerg.	2	2,3	2,3		2
Amphiroa foliacea Lamx.	2,3	2	2		2
A. fragilissima Lamx.		2	2	2	
Ceramium mazatlanense Dawson	2	2,3			3,4

*Not observed on transect

Table 6. continued

SPECIES	A	B	C	D	E
Champia parvula (Ag.) J. Ag.*					
Galaxaura fasciculata Kjellman			3		
G. fastigiata Decaisne				2	
Gelidiopsis intricata (Ag.) Vickers	2,3	1,2,3	1,2,3	1,2,3	1,2,3,4
Gelidium divaricatum Martens*					
Gracilaria sp.*					
Hypnea pannosa J. Ag.	3				
Jania capillacea Harvey	2,3	2,3			3,4
J. decussato-dichotoma (Yendo) Yendo*					
Laurencia papilosa (Forssk.) Grev.	3				
Laurencia sp.*					
Polysiphonia scopulorum Harvey	2	2,3			3,4
Rhodymenia sp.*					
Tolypiocladia glomerulata (Ag.) Schmidt*					
Corallinaceae sp. 1	2,3	3	2,3		2,3
Corallinaceae sp. 2	2,3	2,3	2,3	2	1,2,3,4
Coraliinaceae sp. 3*					
SEAGRASS					
Cymodocea rotundata Ehrenb. & Hempr.		2			
Enhalus acoroides (L.F.) Royle			2		
Halodule uninervis (Forssk.) Ascherson			1,2		
Thalassia hemprichii (Ehrenb.) Aschers.*					
No. of Species per transect	17	23	17	19	20

*Not observed on transect

Table 7. Relative abundances of the major contributors to plant cover in the intertidal zones, reef flats and lagoon slopes of the five transects.

ZONE	TRANSECTS A	B	C	D	E
Intertidal:					
Low-lying turfs		89	89	7	52
Padina tenuis		9	9		7
Entophysalis deusta					32
Halodule uninervis				86	
	—	98	98	93	91
Reef Flat:					
Low-lying turfs	67	54	60	65	59
Lobophora variegata	26	31	20	9	30
Padina Sargassum stands		9	17	9	
Halodule uninervis				13	
Corallinaeae sp. 1					6
	93	94	97	96	95
Lagoon Slope:					
Low-lying turfs	9	8	24	49	3
Lobophora variegata	79	86	68	50	72
Polysiphonia-turf					9
	88	94	92	99	84

Table 8. Percent cover of marine benthic plants in the intertidal zones, reef flats and lagoon slopes of the five transects.

ZONE	TRANSECTS A	B	C	D	E
Intertidal	--	33	33	1	88
Reef Flat	42	31	27	43	26
Lagoon Slope	42	25	37	30	22
Entire Transect	41	25	28	16	35

to the reef flat of the seagrass bed on Transect D gave Halodule uninervis a slightly higher relative abundance value than Lobophora variegata. Other species contributing significantly to the plant cover on the reef flat were Padina tenuis, Sargassum oligocystum and a species of crustose coralline red algae, listed in tables as Corallinaceae sp. 1.

Lobophora variegata was the dominant species on the lagoon slopes of every transect, varying in relative abundance between 50 and 86 percent. In all cases except Transect E, the low-lying Sphacelaria-Gelidiopsis-Neomeris turf was second, varying between 8 and 49 percent. A more developed turf of Polysiphonia scopulorum, Gelidiopsis intricata and Ceramium mazatlanense occurred on the lower slope of Transect E and showed a relative abundance of 9 percent, somewhat higher than the low-lying turf.

Since the transects extended only a short distance across the lagoon floor, the data are very incomplete and definitive conclusions should not be drawn. In general, however, the floor was predominantly sand and loose coral rubble with few conspicuous marine plants. Crustose coralline red algae, the Polysiphonia turf and Lobophora variegata were the most commonly observed species on the lagoon floor.

Species diversities for the five transects were quite similar, varying from 17 species on Transects A and C to 23 species on Transect B.

Corals

The lagoon fringing reef at the study site supports a moderately diverse coral community consisting of 40 genera and 117 species (Table 9). Similar fringing reefs investigated in Palau, Yap, and Truk have coral communities consisting of 48 genera and 163 species, (Birkeland et al., 1976), 31 genera and 81 species (Amesbury et al., 1976), and 35 genera and 102 species (Amesbury et al., 1977) respectively. All four of these study sites represent regions of previous disturbance and the total species diversity at all four locations would probably be higher in nearby more pristine habitats.

Coral size, density, percentage of substrate covered, and species diversity vary considerably from transect to transect (Tables 9 and 10). These differences, however, are reflective for the most part of actual variation observed in coral community structure and development from place to place within the study area. Because of the near absence of corals on the lagoon floor, except for a few colonies where it grades rather indistinctly into the lagoon slope, the quantitative data for the two zones were combined in Table 10.

Coral diversity ranges from 33 genera and 84 species on the lagoon slope (36 genera and 92 species when combined with the lagoon floor) to 19 genera and 29 species on the vertical to overhanging face of the

Table 9. List of corals observed within the study area by Transects A-F and physiographic zones. Symbols indicate their relative abundance within the various physiographic zones: D=dominant, A=abundant, C=common, O=occasional, R=rare.

CORALS	PHYSIOGRAPHIC ZONES				TRANSECTS					
	Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	A	B	C	D	E	F
CLASS - ANTHOZOA										
ORDER - SCLERACTINIA										
SUBORDER - ASTROCOENIINA										
FAMILY - ASTROCOENIIDAE										
<u>Stylocoeniella armada</u> (Ehrenberg)	O	O	O		x	x	x		x	x
<u>Stylocoeniella guentheri</u> (Bassett-Smith)				R						x
FAMILY - THAMNASTERIIDAE										
<u>Psammocora contigua</u> (Esper)	O	O			x	x	x	x	x	
<u>Psammocora digitata</u> Milne-Edwards and Haime	O	R						x	x	
<u>Psammocora profundacella</u> Gardiner		R		R					x	x
<u>Psammocora samoensis</u> Hoffmeister		R			x					
<u>Psammocora superficialis</u> Gardiner		O		R		x				x
<u>Psammocora</u> sp. (Ramose)	O				x	x	x	x	x	
FAMILY - POCILLOPORIDAE										
<u>Stylophora mordax</u> (Dana)		R			x				x	
<u>Seriatopora hystrix</u> Dana		R							x	
<u>Pocillopora damicornis</u> (Linnaeus)	A	C	C	O	x	x	x	x	x	x
<u>Pocillopora danae</u> Verrill		O			x			x		x
<u>Pocillopora meandrina</u> Dana		R					x			
<u>Pocillopora</u> sp. (Ramose)		O		R	x					x

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
FAMILY - ACROPORIDAE										
Acropora cymbicyathus (Brook)	R	R			x			x		
Acropora echinata (Dana)		R	R		x	x	x	x		
Acropora formosa (Dana)	O				x			x		
Acropora humilis (Dana)		R					x			
Acropora hyacinthus (Dana)		R		R	x				x	x
Acropora kenti (Brook)			R		x	x	x			
Acropora procumbens (Brook)		R				x	x	x		
Acropora sp. cf. *A. squamosa* (Brook)	R	D			x	x	x		x	
Acropora teres Verrill			R				x	x		
Acropora vaughani Wells		R	R		x			x		
Acropora sp. 1 (Arborescent)	R							x	x	
Acropora sp. 2 (Corymbose)		R			x					
Acropora sp. 3 (Corymbose-Cespitose)		R					x			
Anacropora spinosa Rehberg	O				x	x			x	
Astreopora myriophthalma (Lamarck)	R					x				
Montipora acanthella Bernard		R					x			
Montipora cocosensis Vaughan	R					x				
Montipora digitata (Dana)	C				x	x	x	x		
Montipora divaricata Brueggemann	A				x	x	x	x		
Montipora ehrenbergii Verrill	O	R				x				
Montipora sp. cf. *M. fragilis* Quelch	O				x					
Montipora sp. cf. *M. informis* Bernard	R				x					
Montipora lobulata Bernard	O	O	R		x	x	x	x	x	x
Montipora patula Verrill	R	R						x	x	
Montipora prolifera Bernard	R	O			x	x	x	x	x	x

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
Montipora trabeculata Bernard	R					x				
Montipora tuberculosa (Lamarck)	O	O		R	x	x		x		x
Montipora turgescens Bernard	R	R	R		x	x		x		
Montipora venosa (Ehrenberg)	R					x				
Montipora verrilli Vaughan	O				x	x				
Montipora verrucosa (Lamarck)		R						x		
Montipora sp. 1 (Ramose)	O				x	x	x			
Montipora sp. 2 (Ramose)	O				x	x		x		
SUBORDER - FUNGIINA										
FAMILY - AGARICIIDAE										
Pavona frondifera Lamarck	O				x	x				
Pavona sp. (Foliaceous)			R	R	x					x
Pavona (Polyastra) obtusata (Quelch)	O	O		R		x		x		
Pachyseris rugosa (Lamarck)		O	O		x		x	x	x	
Pachyseris speciosa (Dana)		O	R	R	x	x				
FAMILY - FUNGIIDAE										
Fungia (Verrillofungia) concinna Verrill	C	C	C		x	x	x	x	x	x
Fungia (Ctenactis) echinata (Pallas)	O	D			x	x	x	x	x	
Fungia (Fungia) fungites (Linnaeus)	C	C	O		x	x	x	x	x	x
Fungia (Pleractis) paumotuensis Stutchbury	R	R				x		x		
Herpolitha limax (Esper)		O				x	x		x	x
Herpentoglossa simplex (Gardiner)		O				x	x	x	x	
Parahalomitra robusta (Quelch)		C	C		x	x	x	x	x	x

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
FAMILY - PORITIDAE										
Goniopora arbuscula Umbgrove		O				x			x	
Goniopora columna Dana		O					x			
Goniopora lobata Milne-Edwards and Haime		C			x		x			
Goniopora tenuidens (Quelch)		R					x			
Porites andrewsi Vaughan	C	A	C	O	x	x	x	x	x	x
Porites australiensis Vaughan	O	O				x			x	
Porites lichen Dana	O	C	O	O	x	x	x	x	x	x
Porites Lutea Milne-Edwards and Haime	D	D	D	C	x	x	x	x	x	x
Porites murrayensis Vaughan	O	O	R			x	x	x	x	
Porites sp. (massive)	R	R				x			x	
Porites (Synaraea) convexa Verrill	A	A	A	O	x	x	x	x	x	x
Porites (Synaraea) iwayamaensis Eguchi										
Alveopora allingi Hoffmeister			R		x					
SUBORDER - FAVIINA										
FAMILY - FAVIIDAE										
Favia laxa (Klunzinger)	C				x		x	x	x	
Favia matthai Vaughan	C	C		O	x	x	x	x	x	x
Favia pallida (Dana)	O	O		O		x		x		x
Favia rotulosa (Ellis and Solander)	C	O			x	x	x	x	x	
Favia rotumana (Gardiner)	C	C		O		x	x	x	x	x
Favia speciosa (Dana)		O	O	C	x		x		x	
Favites acuticollis (Ortmann)	C	O			x	x	x	x	x	x

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
Favites chinensis (Ehrenberg)	R					x				
Favites flexuosa (Dana)		R						x	x	
Favites melicerum (Ehrenberg)	C	C	O	O	x	x	x	x	x	x
Favites virens (Dana)		R						x		
Goniastrea australensis (Milne-Edwards and Haime)	R					x				
Goniastrea edwardsi Chevalier		O						x	x	
Goniastrea favulus (Dana)	C	O			x	x	x	x	x	x
Goniastrea retiformis (Lamarck)	R							x		
Platygyra daedalea (Ellis and Solander)	C	C			x	x	x	x	x	
Platygyra lamellina (Ehrenberg)	C	C	C	O	x	x	x	x	x	x
Diploastrea heliopora (Lamarck)		O			x				x	
Leptastrea bottae (Milne-Edwards and Haime)	R							x		
Leptastrea pruinosa Crossland	O	R			x	x			x	x
Leptastrea purpurea (Dana)	O	R			x	x			x	x
Cyphastrea serailia (Forskaal)	R	O		R		x	x	x	x	x
Echinopora lamellosa (Esper)		R		R		x			x	x
Oulophyllia crispa (Lamarck)		R						x		
FAMILY - OCULINIDAE										
Galaxea fascicularis (Linnaeus)	O	R			x	x	x			
Galaxea sp.				O						x
FAMILY - MERULINIDAE										
Merulina ampliata (Ellis and Solander)	R	O			x	x	x	x		
Merulina laxa (Dana)	O	O	O		x	x			x	x

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
FAMILY - MUSSIDAE										
Lobophyllia corymbosa (Forskaal)		O				x		x		
Lobophyllia costata (Dana)	O	O	O		x	x	x	x	x	x
Lobophyllia hemprichii (Ehrenberg)			R		x					
Symphyllia nobilis (Dana)		R	R			x			x	x
Symphyllia valenciennesii Milne-Edwards and Haime	R	R			x	x				
FAMILY - PECTINIIDAE										
Echinophyllia aspera (Ellis and Solander)		R					x			
Pectinia lactuca (Pallas)		R	R		x					
Pectinia paeonia (Dana)			R		x					
Oxopora lacera (Verrill)			R	R	x					x
SUBORDER - CARYOPHYLLIINA										
FAMILY - CARYOPHYLLIIDAE										
Physogyra lichtensiteini Milne-Edwards and Haime		R		O	x					x
SUBORDER - DENDROPHYLLIINA										
FAMILY - DENDROPHYLLIIDAE										
Dendrophyllia micranthus (Ehrenberg)				R						x
Balanophyllia sp.				R						x
Turbinaria sp.			R		x					

Table 9. continued

CORALS	PHYSIOGRAPHIC ZONES: Reef Flat	Lagoon Slope	Lagoon Floor	Submarine Cliff	TRANSECTS: A	B	C	D	E	F
ORDER - COENOTHECALIA										
FAMILY - HELIOPORIDAE										
Heliopora coerulea (Pallas)		R			x					
CLASS - HYDROZOA										
ORDER - MILLEPORINA										
FAMILY - MILLEPORIDAE										
Millepora dichotoma Forskaal	0	0			x	x	x	x		
Millepora intricata Milne-Edwards and Haime	0	0	R	R	x	x	x	x	x	x
Millepora platyphylla Hemprich and Ehrenberg		R		R					x	x
TOTAL GENERA	21	33	19	19	30	27	22	20	27	26
TOTAL SPECIES	65	84	32	29	70	66	52	57	53	42

Total Genera for Study Site 40

Total Species for Study Site 117

Table 10. Size distribution, frequency, density, and percent of substrate covered by corals on the reef flat and lagoon slope and floor zones of the fringing reef at the study site. Relative values of frequency, density, and percent of substrate covered are also given and an importance value is calculated from the sum of these three relative values. The procedures for calculating the statistics from the data obtained by the point-quarter sampling technique are explained in the Methods section.

CORALS	Size Distribution of Colonies Diameters (cm)				Frequency	Relative Frequency	Density per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	n	$\bar{Y}$	s	w							
TRANSECTS A*											
Reef Flat - 0 to 72 meters											
Porites lutea	9	38.0	24.9	4-13	.7	35.0	3.3	32.1	52.0	75.9	143.0
Montipora divaricata	10	13.7	7.5	6-33	.6	30.0	3.7	35.7	7.5	10.9	76.6
Porites (S.) iwayamaensis	3	24.0	21.7	11-49	.3	15.0	1.1	10.7	7.6	11.2	36.9
Pocillopora damicornis	3	7.7	4.7	4-13	.1	5.0	1.1	10.7	.6	.9	16.6
Montipora sp. 1	1	10.0	-	-	.1	5.0	.4	3.6	.3	.4	9.0
Porites andrewsi	1	9.0	-	-	.1	5.0	.4	3.6	.3	.4	9.0
Montipora lobulata	1	8.0	-	-	.1	5.0	.4	3.6	.2	.3	8.9
Overall Density 10.4 per m^2											
Percent Substrate Coverage 68.5											
*No Intertidal Reef Flat											
Lagoon Slope and Floor - 72 to 100 meters											
Porites lutea	3	59.7	31.5	29-92	.5	22.7	.7	25.0	23.2	73.2	120.9
Porites (S.) convexa	4	15.5	9.2	7-24	.6	27.4	1.0	33.3	2.5	7.9	68.6
Porites andrewsi	3	18.3	18.3	4-39	.5	22.7	.7	25.0	3.1	9.8	57.5
Fungia (C.) echinata	1	21.0	-	-	.3	13.6	.2	8.3	.7	2.2	24.1
Lobophyllia costata	1	87.0	-	-	.3	13.6	.2	8.3	2.2	6.9	28.8
Overall Density 2.8 per m^2											
Percent Substrate Coverage 31.7											

Table 10. continued

CORALS	Size Distribution of Colonies Diameters (cm) n	Ȳ	s	w	Frequency	Relative Frequency	Density per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT B											
Intertidal Reef Flat - 0 to 31 meters											
(No Corals Present)											
Reef Flat - 31 to 126 meters											
Porites lutea	15	18.0	13.5	4-4	.7	46.7	1.7	50.0	6.6	37.9	134.6
Montipora divaricata	10	18.0	23.4	3-80	.4	26.7	1.1	33.3	7.0	40.2	100.2
Montipora sp. 2	1	61.0	-	-	.1	6.6	.1	3.3	2.9	16.7	26.6
Porites (S.) convexa	2	19.0	8.5	13-25	.1	6.6	.2	6.7	.6	3.4	16.7
Favites acuticollis	1	14.0	-	-	.1	6.6	.1	3.3	.2	1.1	11.0
Montipora sp. 1	1	10.0	-	-	.1	6.6	.1	3.3	.1	.7	10.6
Overall Density 3.3 per m^2											
Percent of Substrate Coverage 17.4											
Lagoon Slope and Floor - 126 to 230 meters											
Porites lutea	16	39.5	39.5	8-124	.6	26.2	1.9	47.2	36.4	77.9	151.3
Porites (S.) iwayamaensis	6	21.8	10.5	10-37	.5	21.8	.8	17.7	3.1	6.7	46.2
Porites andrewsi	3	26.3	15.1	9-37	.3	13.1	.4	8.8	2.6	5.7	27.6
Porites (S.) convexa	2	33.5	29.0	13-54	.2	8.8	.3	6.0	3.7	7.9	22.7
Favites chinensis	1	11.0	-	-	.1	4.3	.1	2.9	.1	.2	7.4
Porites murrayensis	1	12.0	-	-	.1	4.3	.1	2.9	.1	.2	7.4
Psammocora contigua	1	13.0	-	-	.1	4.3	.1	2.9	.1	.2	7.4
Fungia (C.) echinata	1	10.1	-	-	.1	4.3	.1	2.9	.1	.2	7.4
Cyphastrea sp. 1	1	5.0	-	-	.1	4.3	.1	2.9	< .1	< .1	7.3
Fungia (P.) paumotuensis	1	7.0	-	-	.1	4.3	.1	2.9	< .1	< .1	7.3
Porites lichen	1	5.0	-	-	.1	4.3	.1	2.9	< .1	< .1	7.3

Overal Density 4.1 per m^2
Percent of Substrate Coverage 47.2

Table 10. continued

CORALS	Size Distribution of Colonies Diameters (cm) n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Values
TRANSECT C											
Intertidal Reef Flat - 0 to 34 meters (No Corals Present)											
Reef Flat -34 to 162 meters											
Porites (S.) convexa	4	37.8	30.9	15-82	.3	14.3	1.6	14.3	27.0	70.7	99.3
Porites lutea	7	11.0	5.0	5-18	.7	33.2	2.8	25.0	3.1	8.1	66.3
Montipora divaricata	7	14.7	8.4	5-26	.4	19.0	2.8	25.0	6.1	16.1	60.0
Porites (S.) iwayamaensis	5	9.8	3.4	6-15	.3	14.3	2.0	17.9	1.5	3.8	36.0
Pocillopora damicornis	2	3.0	0.0	3-3	.1	4.8	.8	7.0	.1	.3	12.1
Goniastrea favulus	1	8.0	-	-	.1	4.8	.4	3.6	.2	.5	8.9
Porites andrewsi	1	8.0	-	-	.1	4.8	.4	3.6	.2	.5	8.9
Favia matthai	1	3.0	-	-	.1	4.8	.4	3.6	<.1	.1	8.5
Overal Density 11.2 per m^2 Percent of Substrate Coverage 38.2											
Lagoon Slope and Floor - 162 to 260 meters											
Porites lutea	13	31.1	32.0	4-92	.7	31.8	1.7	37.2	24.2	58.0	127.0
Porites (S.) iwayamaensis	6	34.2	33.2	6-86	.4	18.3	.7	17.1	11.4	27.3	62.7
Porites (S.) convexa	5	27.0	19.5	6-52	.4	18.2	.6	14.3	4.8	11.5	44.0
Porites andrewsi	6	9.2	11.3	2-32	.3	13.6	.7	17.1	1.0	2.4	33.1
Porites murrayensis	2	11.5	.7	11-12	.2	9.1	.2	5.7	.2	.5	15.3
Goniopora sp. 1	2	7.0	1.4	6-8	.1	4.5	.2	5.7	.1	.2	10.4
Merulina ampliata	1	7.0	-	-	.1	4.5	.1	2.9	<.1	.1	7.5
Overall Density 4.2 per m^2 Percent of Substrate Coverage 41.7											

Table 10. continued

CORALS	Size Distribution of Colonies Diameters (cm) n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Values
TRANSECTS D											
Intertidal Reef Flat - 0 to 187 meters											
(No Corals Present)											
Reef Flat - 187 to 278 meters											
Porites lutea	11	11.1	7.6	5-29	.5	55.6	1.0	73.2	1.4	60.3	189.1
Acropora formosa	1	33.0	-	-	.1	11.1	.1	6.7	.8	34.8	52.6
Montipora divaricata	1	11.0	-	-	.1	11.1	.1	6.7	.1	4.3	22.1
Leptastrea bottae	1	3.0	-	-	.1	11.1	.1	6.7	< .1	.3	18.1
Pocillopora damicornis	1	3.0	-	-	.1	11.1	.1	6.7	< .1	.3	18.1
Overall Density 1.4 per m^2											
Percent of Substrate Coverage 2.3											
Lagoon Slope and Floor - 278 to 330 meters											
Porites lutea	9	21.7	18.3	3-57	.7	36.8	1.8	40.9	10.9	74.7	152.4
Porites (S.) convexa	8	12.0	7.3	5-26	.7	36.8	1.6	36.4	2.5	17.1	90.3
Porites andrewsi	4	10.3	6.8	5-20	.3	15.9	.9	18.2	1.0	6.8	40.9
Montipora divaricata	1	11.0	-	-	.2	10.5	.2	4.5	.2	1.4	16.4
Overall Density 4.5 per m^2											
Percent of Substrate Coverage 14.6											

Table 10. continued

CORALS	Size Distribution of Colonies Diameters (cm) n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Values
TRANSECT E											
Intertidal Reef Flat - 0 to 19 meters											
(No Corals Present)											
Reef Flat - 19 to 39 meters											
Porites lutea	7	29.1	32.7	6-98	1.0	66.7	5.6	87.5	78.3	96.2	250.4
Montipora lobulata	1	22.0	-	-	.5	33.3	.8	12.5	3.1	3.8	49.6
Overall Density 6.4 per m^2											
Percent of Substrate Coverage 81.4											
Lagoon Slope and Floor - 19 to 100 meters											
Porites lutea	7	20.9	25.2	5-76	.6	37.4	1.0	36.8	7.7	81.8	156.0
Porites (S.) convexa	5	11.0	3.1	6-14	.3	18.7	.7	26.3	.8	8.5	53.5
Porites andrewsi	2	10.0	5.7	6-14	.3	18.7	.4	10.5	.4	4.2	33.4
Porites (S.) iwayamaensis	2	9.5	4.9	6-13	.1	6.3	.4	10.5	.3	3.2	20.0
Favia speciosa	1	11.0	-	-	.1	6.3	.1	5.3	.1	1.1	12.7
Platygyra lamellina	1	9.0	-	-	.1	6.3	.1	5.3	.1	1.1	12.7
Goniastrea edwardsi	1	3.0	-	-	.1	6.3	.1	5.3	<.1	.1	11.7
Overall Density 2.8 per m^2											
Percent of Substrate Coverage 9.4											

submarine cliff at Transect F. Although there was no significant difference in the number of genera between the submarine cliff at Transect F and the reef flat, the number of species recorded at the latter was considerably greater. The submarine cliff is an environment of reduced available light which probably accounts for the reduced species diversity observed, although four species recorded there were unique for the study site as a whole, and it was the only location where the ahermatypic genera Balanophyllia and Dendrophyllia were found. On the transects proper (Fig. 2) the highest species diversity was found at A and B (70 and 66 species respectively) near the south end of the bay and the lowest at C, D, and E (ranging from 57 to 53 species) at the north end of the bay. This slightly higher species diversity found at the south end of the bay appears to be reflective of the steeper lagoon slope and slightly deeper water found there, since no significant differences in sedimentation rates, temperature, and current patterns were found between the two parts of the bay.

Although species diversity is fairly high for all the transect reef zones, relative abundance data from Table 9, show that on the reef flat 1 species is dominant, 4 are abundant, 11 are common, and the remaining 47 are observed occasionally or rarely; on the lagoon slope 1 species is dominant, 3 are abundant, 11 are common, and 39 are observed occasionally or rarely; and on the lagoon floor 1 species is dominant, 2 are abundant, 5 are common, and 24 are observed occasionally or rarely. A further comparison of relative abundance data in Table 9 shows that Porites lutea is dominant all three zones, Porites (S.) convexa and Porites (S.) iwayamaensis are abundant in all three reef zones;and Pocillopora damicornis, Fungia (V.) concinna, Porites andrewsi, and Platygyra lamellina are common or abundant in all three zones. Fungia (F.) fungites, Favia matthai, Favia rotumana, Favites melicerum, and Platygyra daedalea are common species found both in the reef flat and lagoon slope zones and Parahalomitra robusta is a common species found in the lagoon slope and lagoon floor zones. The only common or abundant species found in a single zone are Montipora divaricata and Montipora digitata, which are ramose colony forms that are mostly restricted to shallow reef flat habitats. The high abundance and wide distribution of the above coral species throughout the various reef zones imparts a considerable degree of species homgeniety and similarity of reef development and community structure from one part of the study area to another.

Coral density and percent of substrate coverage are considerably more variable than species diversity from one transect reef zone to another (Tables 9 and 10). Variation in coral density and percentage of substrate coverage is considerably greater on the reef flat (1.4 to 11.2 corals per m^2 and 2.3 to 81.4% coverage) than on the lagoon slope (2.8 to 4.5 corals per m^2 and 9.4 to 47.7% coverage). There is greater variance in size distributions and larger mean colony sizes on the lagoon slope. Such patterns of variation in density, substrate coverage, and size distribution indicate that the reef flat is a more unstable habitat for reef corals than the lagoon slope. Greater habitat stability on the lagoon slope may be due in part to the presence of deeper water allowing colonies to attain a larger size, more stable water temperatures, better water circulation, and possibly more available plankton for food. The high substrate coverage on the reef flat at Transect A is partly due to the absence of an intertidal zone at its seaward end which allows corals to colonize the entire inner part of the platform to a greater extent. Substantially lower coral coverage is found at Transect A, B, and C where the subtidal portion of the reef flat grades gradually into the intertidal zone. This transitional effect is especially significant at Transect D which has an extensive shallow sandy zone where corals are small in size, widely scattered, and patchy in distribution. The highest substrate coverage recorded is found at Transect E where a short steeply dipping reef flat platform, dominated by large Porites lutea colonies, grades somewhat indistinctly into the lagoon slope (Fig. 3B).

In a gradient from the shore to the lagoon slope the mean colony size, variance in size distribution, and species diversity all increase slightly. Porites species overhelmingly predominate in all the reef zones (Tables 9, 10, and 11) and from a mean total coverage value of 35.2 percent (mean of total coverage of Transects A-E), have a relative percent coverage value of 90.6. Massive Porites lutea colonies are especially abundant and from the mean total coverage value of 35.2 percent have a relative percent coverage value of 69.3. Massive Porites lutea and submassive columnar Porites (S.) convexa and Porites (S.) iwayamaensis colonies form knobs, knolls, and pinnacles in all reef zones and are responsible for most of the irregular topographic relief observed. Colonies up to four meters across and high were measured on the lagoon slope. Occasional ramose mounds of Porites andrewi were also present intermixed among the other Porites species. Although 13 species of Acropora and 18 species of Montipora were recorded from various reef zones, most were relatively rare or occasional occurrences (Table 9), except for scattered arborescent clusters of Acropora formosa and ramose patches of Montipora divaricata and Montipora digitata on the inner part of the reef flat. The general aspects of the coral community on the reef flat and lagoon slope, and predominance of Porites species are shown in Figures 9-12.

Macroinvertebrates

The diversity of macroinvertebrates in the bay was impressive, but few of the species were abundant enough to sample with 1 m^2 quadrats. Therefore, 10 m^2 quadrats were used along the five transect lines as described in the Methods section. A total of 820 m^2 was surveyed on the reef flat for macroinvertebrates, 620 m^2 was surveyed on the lagoon floor, and 140 m^2 was surveyed on the lagoon floor. The abundances and distributions of octocorals, Tridacna spp. (Fig. 13), asteroids (eight species) and holothuroids (nine species) are given in Table 12.

Table 11. List of coral species arranged in order by the sum of their Importance Values. Relative frequency + relative density + relative percent of coverage = Importance Value. Data from Table 10.

	Reef Flat	Lagoon Slope and Floor	Total for all Zones
Porites lutea	783.4	707.6	1491.0
Porites (S.) convexa	116.0	279.1	359.1
Montipora divaricata	258.9	16.4	275.3
Porites andrewsi	17.9	192.5	210.4
Porites (S.) iwayamaensis	72.9	133.9	206.8
Montipora lobulata	58.5		58.5
Acropora formosa	52.6		52.6
Pocillopora damicornis	40.8		40.8
Fungia (C.) echinata		31.5	31.5
Lobophyllia costata		28.8	28.8
Montipora sp. 1	26.6		26.6
Porites murrayensis		22.4	22.4
Montipora digitata	19.6		19.6
Leptastrea bottae	18.1		18.1
Favia speciosa		12.7	12.7
Platygyra lamellina		12.7	12.7
Goniastrea edwardsi		11.7	11.7
Goniopora lobata		10.4	10.4
Favia matthai	8.9		8.9
Goniastrea favulus	8.9		8.9
Merulina ampliata		7.5	7.5
Favites chinensis		7.4	7.4
Psammocora contigua		7.4	7.4
Cyphastrea serailia		7.3	7.3
Fungia (P.) paumotuensis		7.3	7.3
Porites lichen		7.3	7.3

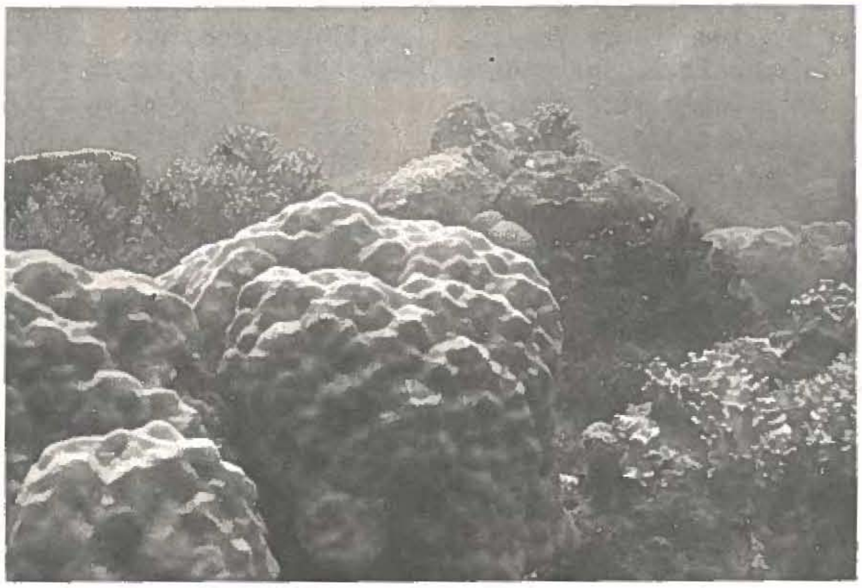


Figure 9. Massive Porites lutea colonies and soft corals on the reef-flat platform.

Figure 10. Outer part of the reef-flat platform dominated by ramose colonies of Porites andrewsi. Several massive Porites lutea, columnar Porites (S.) convexa, and soft coral colonies are visible in the foreground.

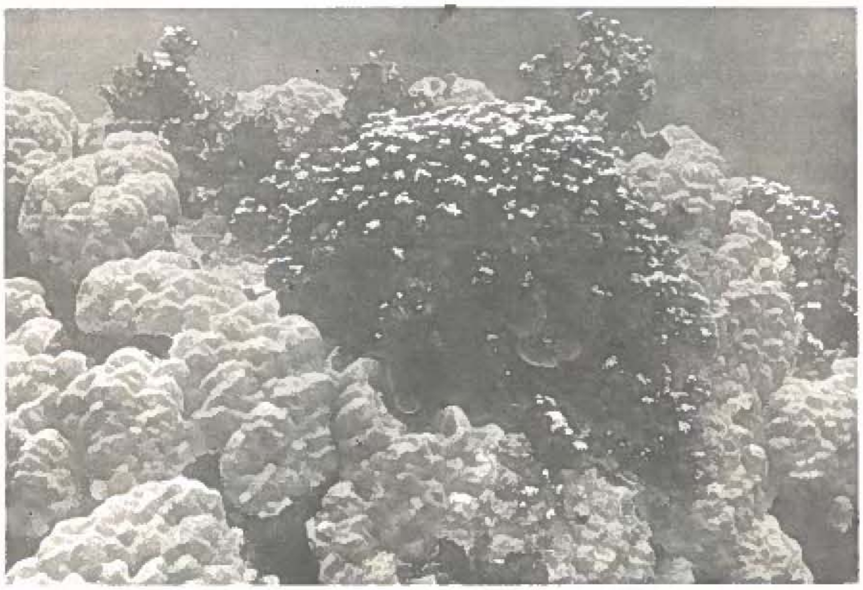


Figure 11. Upper lagoon slope dominated by massive Porites lutea and columnar Porites (S.) convexa colonies.

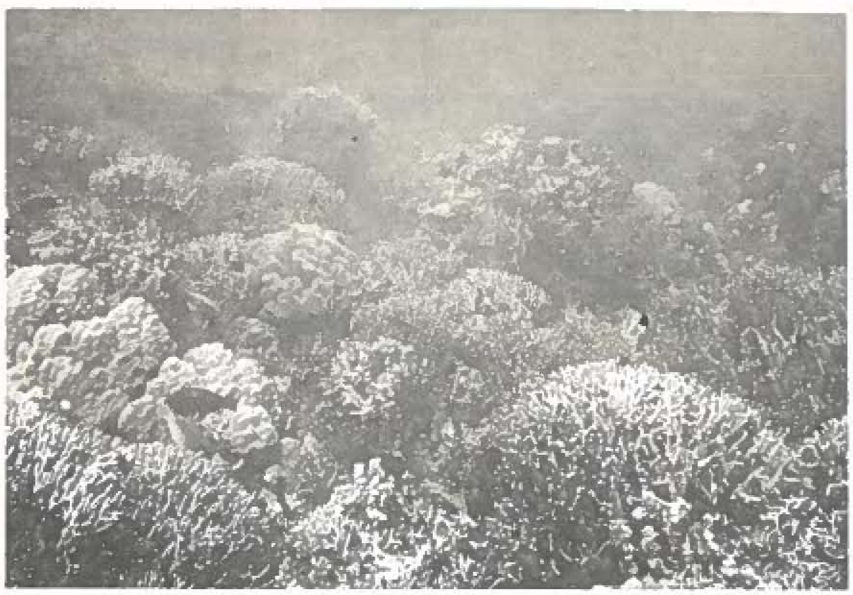


Figure 12. Upper lagoon slope dominated by ramose Porites andrewsi, scattered Porites lutea, and soft colonies.

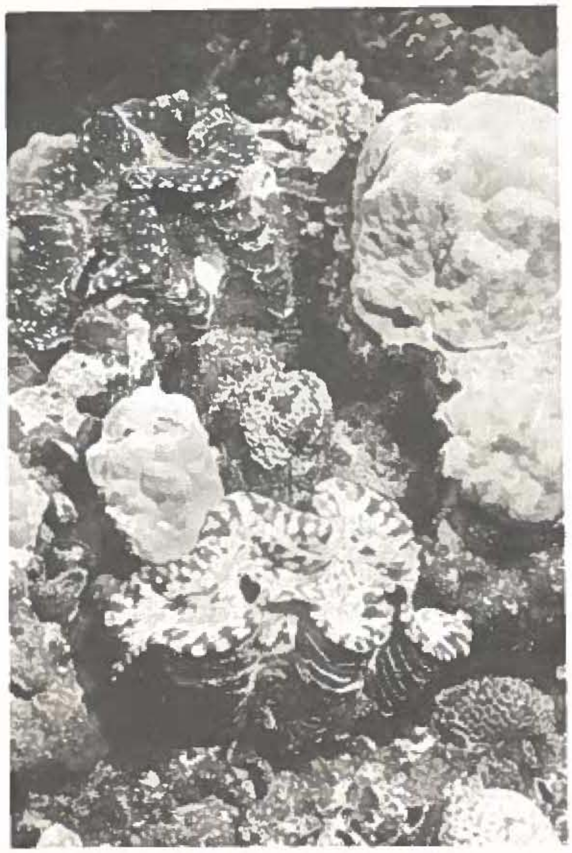


Figure 13. Tridacna squamosa on the lagoon slope.

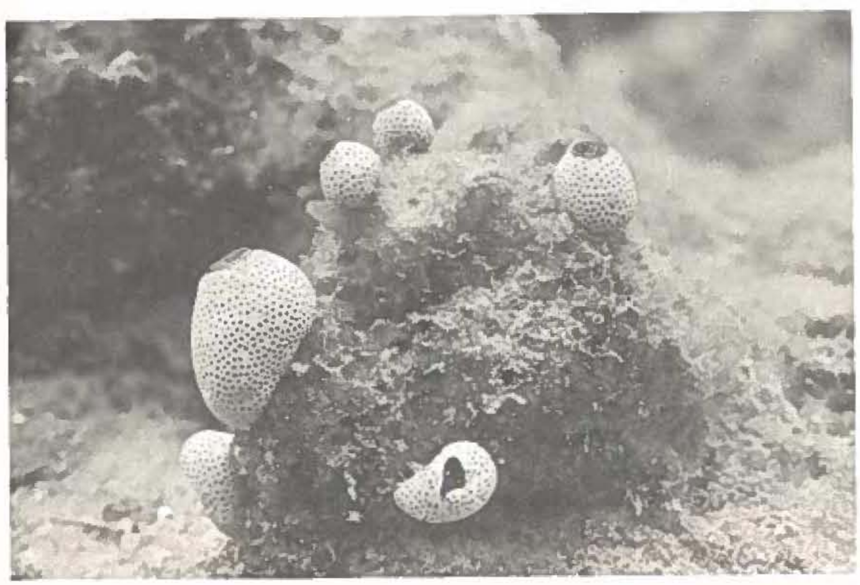


Figure 14. The prevalent ascidian tunicate Didemnum ternatanum.

Table 12. Macroinvertebrates found along the five transects in this study. The frequency (f) is the number of 10 m^2 quadrats in which the species or group was observed. The total number of 10 m^2 quadrats examined (n) within each reef area with the data from the five transects combined is given at the heads of the columns. The means and standard errors of the means are of the number of individuals per 10 m^2 quadrat. The "+" means the species was observed near, but not in, the transects.

Reef Area	REEF FLAT		LAGOON SLOPE		LAGOON FLOOR	
Sample Size	n=82		n=62		n=14	
Statistic	f	$\bar{Y}\pm S_{\bar{y}}$	f	$\bar{Y}\pm S_{\bar{y}}$	f	$\bar{Y}\pm S_{\bar{y}}$
Taxa						
Octocorallia						
Sinularia spp.	8	3.4 ±1.3	24	4.6 ±1.5	2	.21±.16
Sarcophyton spp.	5	.16± .10	12	1.7 ± .90		
Lobophyton spp.	10	.27± .10			2	.14±.10
Stereonephthya spp.	1	.01± .01	2	.05± .04		
Dendronephthya sp.			1	.02± .02		
Xenia sp.					1	.07±.07
alcyonacean spp.			2	.03± .02		
gorgonacean spp.			3	.05± .03		
stoloniferan sp.			+			
Hexacorallia						
Physobrachia douglasi Kent			1	.02 .02		
Bivalvia						
Tridacna crocea Lamarck	48	1.6 ± .84	48	9.1 ±1.3	3	.21±.11
Tridacna squamosa Lamarck	6	.10± .04	21	1.3 ± .30		
Asteroidea						
Culcita novaeguineae Müller & Troschel	+		+			
?*Ophidiaster trychnus* Fisher	2	.02± .02				
Fromia monilis Perrier	2	.02± .02	1	.02± .02		
Linckia laevigata (Linnaeus)	2	.02± .02	1	.02± .02		
Linckia multifora (Lamarck)	11	.17± .05	5	.08± .03	2	.14±.10
ophidiasterid sp.[1/]	4	.05± .02	5	.08± .03		
Acanthaster planci (Linnaeus)	3	.04± .02	2	.03± .02		
Echinaster luzonicus (Gray)	2	.02± .02			2	.14±.10
Ophiuroidea						
Ophiothrix sp.	4	.07 .04	15	.40 .11	1	.07 .07
Echinoidea						
Echinometra mathaei (de Blainville)	35	2.5 ± .59	31	2.8 ± .78	1	.21±.21
Diadema sp.	10	.34± .13	20	.87± .27	1	.14±.14
Echinothrix diadema (Linnaeus)			1	.13± .13		

[1/] A new genus and species with the description by F. W. E. Rowe in press at this time.

Table 12. continued

Reef Area Sample Size Statistic	REEF FLAT n=82 f	 $\bar{Y}\pm S_{\bar{y}}$	LAGOON SLOPE n=62 f	 $\bar{Y}\pm S_{\bar{y}}$	LAGOON FLOOR n=14 f	 $\bar{Y}\pm S_{\bar{y}}$
Holothuroidea						
Stichopus chloronotus Brandt	13	.17±.05	15	.32±.08	4	.50±.30
Stichopus horrens Selenka	+					
Stichopus variegatus Semper			+			
Holothuria (Halodeima) atra Jaeger	34	.16±.51	20	.61±.15	4	.50±.30
Holothuria (Halodeima) edulis Lesson	9	.15±.05	26	2.6 ±.27	8	2.2 ±.71
Holothuria (Thymiosycia) hilla Lesson	5	.11±.06	1	.02±.02	1	.07±.07
Holothuria (Selenkothuria) moebii Ludwig	1	.01±.01				
holothurian sp.					2	.14±.10
synaptid sp.			1	.02±.02		

One group of macroinvertebrates was too abundant to survey efficiently with 10 m^2 quadrats. This was the group of bivalve species (other than the giant clams, Tridacna spp.) that live as suspension-feeders imbedded in the coral framework. In fact, these bivalves are found almost entirely in heads of the coral Porites lutea, so we only sampled the space on heads of Porites lutea for these species. A total of forty 0.16 m^2 quadrats on Porites lutea were examined for bivalves. The mussel, Septifer bilocularis (Linnaeus) was found in 29 of the 40 quadrats; a total of 211 Septifer were found in the quadrats for a mean and standard error of 5.3 ± 1.03 per 0.16 m^2 or 33 Septifer per square meter of Porites lutea surface area. To estimate the number of Septifer in terms of absolute area, we would multiply the percent of area occupied by P. lutea by a factor of 33.

Similar calculations for the bivalve Pedum spondyloideum (Gmelin), found in 25 of the 40 quadrats, provided an estimated abundance of 2.0 ± 0.35 per 0.16 m^2 or 12.5 per m^2 of Porites lutea. Isognomon isognomon (Linnaeus) was found in six of the quadrats with an abundance of 0.25 ± 0.11 per 0.16 m^2 or 1.6 per m^2. Tridacna crocea Lamarck was found twice in the samples for an average abundance of 0.05 ± 0.22 per 0.16 m^2 or 0.3 per m^2. Forty Pedum were found on a single Porites lutea head that was 50 cm tall and 40 cm by 40 cm in diameter.

The cerithiid snails that occupy the intertidal reef flat also required special samples because of their relatively great abundance and restricted distribution. Therefore, the snails were counted in 0.01 m^2 quadrats in the intertidal reef flat on Transect B. In the higher intertidal of small rock rubble, the cerithiid snails were found in all ten 0.01 m^2 quadrats with a mean and standard error of 4.2 ± 0.77 per 0.01 m^2. In the lower intertidal area of large rock rubble, the cerithiid snails were found in 12 of 40 quadrats with 0.36 ± .16 per 0.01 m^2. To put these estimates on a comparable scale with those in Table 12, you multiply the means listed earlier in this paragraph by 1000.

Edible oysters, Saxostrea mordax (Gould), were also abundant in the intertidal areas all around the bay. There were 9.7 oysters per m^2 found on the intertidal volcanic beach at the landward end of Transect E. All isolated rocks on the extensive sand flat at the landward end of Transect D were also covered with oysters.

Smaller oysters with jagged apertures, Lopha cristagalli (Linnaeus), and very large oysters with spiny projections from the shell, Spondylus aurantius Lamarck, were found near, but not in, the transects. The featherduster worm, Sabellastarte indica (Savigny), and other species of sabellid worms were seen in the study area. Nudibranchs, Pteraeolidia ianthina Angus and Phyllidia sp., were also observed.

Didemnid tunicates (Didemnum candidum Savigny and D. nekozita Tokioka) were abundant and nearly ubiquitous, but inconspicuously located on the undersides of rubble. Tunicate larvae were found in the demersal plankton trap collections and these larvae are most likely from these abundant didemnid tunciates. The more obviously exposed didemnid tunicates, Didemnum ternatanum (Gottschaldt), were especially abundant. Didemnids of this species looked like small white vases with green linings, the color resulting from algae in the tissues (Fig. 14). The yellow tunicate, Phallusia julinea Sluiter, was also common.

The antipatharian (black coral), Cirripathes anguina Dana, was found to extend its depth range into remarkably shallow water within the study area. Certain individual colonies had dead tips which may have been killed by desiccation during very low tides.

Lambis lambis (Linnaeus) the spider conch, Cypraea tigris Linnaeus (the tiger cowry, Cypraea moneta Linnaeus the money cowry, and Conus spp. showed up in the quadrats. However, too many were probably missed to allow a reasonably accurate estimate of abundance. At least four species of crinoids were present, but their cryptic or nocturnal habits prevented an accurate survey.

Colonies of Pavona, Psammocora and Sinularia were occasionally infested by large aggregations of polyclad flatworms.

The macroinvertebrates of most interest to those concerned with the condition of the coral reef community are the two species of asteroids that feed on coral, the crown-of-thorns seastar Acanthaster planci (Linnaeus) and the cushion-star Culcita novaeguineae Müller and Troschel. Although one frequently observes Acanthaster feeding on corals (Fig. 15) in the bay, the actual abundance of Acanthaster is very low (Table 12). If we accept Glynn's (1973) data on rates of feeding of Acanthaster as 0.45 m^2 area of living reef surface per month, or 5.4 m^2 per year, then the Acanthaster population in the bay (Table 12) would be consuming about 0.2 m^2 per year per 10 m^2 on the reef flat and about 0.17 m^2 per year per 10 m^2 on the lagoon slope. If we prefer to accept Chesher's (1969) estimates of feeding rates (1 m^2 area of living reef surface per month, or 12 m^2 per year), then the Acanthaster population would be consuming about 0.44 m^2 per year per 10 m^2 on the reef flat and about 0.38 m^2 per year per 10 m^2 on the lagoon slope. In either case, this rate of feeding by Acanthaster does not appear to be a major threat to the survival of the reefs in the bay.

Culcita novaeguineae probably poses even less of a threat than Acanthaster for two reasons. First, Culcita feeds only on small corals, and many corals can essentially reach a refuge in size from Culcita. Second, Culcita is relatively scarce in the bay. Since none were encountered in the transects (although they were observed nearby), this implies that there is less than 0.0006 Culcita per m^2 in the bay under study. In all four feeding observations, Culcita fed upon small heads of Pocillopora.

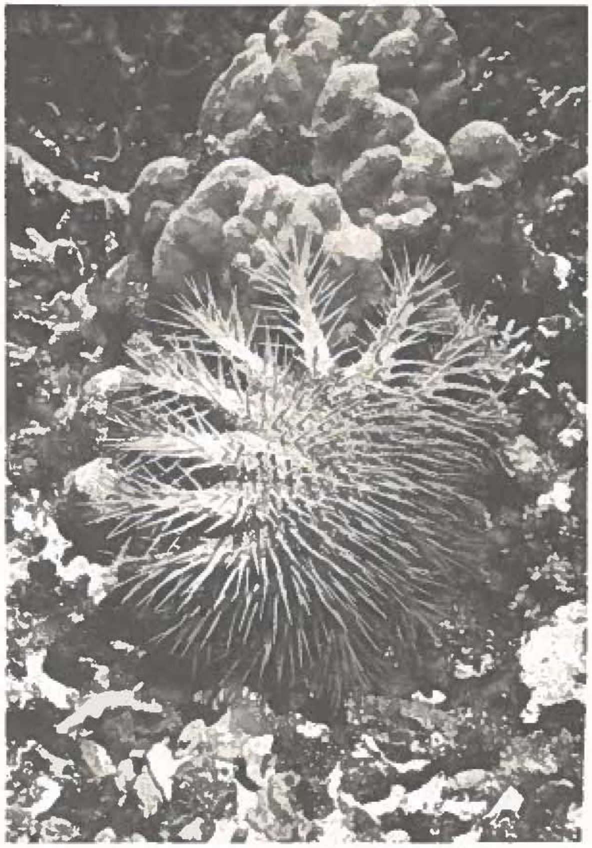


Figure 15. The crown-of-thorns seastar Acanthaster planci.

Figure 16. A diver collecting a sample from a demersal plankton trap on the lagoon slope.

Zooplankton

Zooplankton abundance was not especially great in the study area, based on net tows (Table 13). Density was comparable to that measured off Malakal Island in January 1976 (Birkeland et al., 1976) and was less than that measured in Truk lagoon in April 1977 (Amesbury et al., 1977) and considerably less than that measured in Tanapag Harbor, Saipan in June 1976 (Amesbury and Doty, 1977). In view of the large numbers of plankton-feeding atherinid and clupeid fishes observed at the Arakabesan study site, it is surprising that zooplankton density did not appear greater. Zooplankton often occurs in dense patches, rather than being evenly distributed throughout the water body. Visually-feeding fishes are able to seek out these patches which the plankton net may have missed.

The demersal plankton traps (Fig. 16) indicated that a considerable variety of planktonic organisms spend part of their time within the substrate from which they emerge at different times of the day (Table 14). Some of the organisms appearing in the demersal trap collections probably do not ordinarily inhabit the substrate as free living planktonic forms (e.g. siphonophores, crustacean and fish eggs, fish larvae), but either swam (or were carried) under the base of the trap from the open water, or, in the case of eggs and larvae, were just rleased by spawning adults during the time the trap was in place. In the case of crab zoeae, very few occurred in any of the demersal traps except on one night set over the coral substrate where the two replicate traps collected large numbers of these larval forms (approximately 1120 and 250). Presumably on this night, a large number of crab eggs hatched under the trap and the released zoea larvae were caught.

In general, more plankters were caught over the coral substrate than over the sand, and over both substrates, nighttime emergence was greater than daytime. The preponderance of nighttime emergence is presumably an adaptation to avoid predation by planktivorous fish which are primarily daytime feeders. The two types of organisms which were most abundant during the day (Foraminifera and nauplius larvae) are both probably too small to be effectively preyed upon by fish. They most likely predators, larger planktonic crustaceans, are considerably less abundant during the daytime.

Fishes

The study area contains a very rich fish fauna of more than 125 conspicuous species (Table 15); there are undoubtedly more species of secretive, crytically colored, and nocturnal fishes which were not observed. The transect censuses (Table 16) indicate a pattern of increasing fish abundance from the intertidal reef flat out to the lagoon slope, then a drop in abundance on the lagoon floor. Fish abundance on the lagoon floor is lower than the transect results indicate as the transects extended only a short distance out onto the lagoon floor, and most of the fishes seen here were in loose association with the base of the lagoon slope. Further out onto the lagoon floor, the resident fish fauna is very sparse, although schools of roving fishes, such as goat fishes and surgeon fishes, probably move across this area occasionally.

At various times during this study, immense shoals of clupeid fishes (sardines) were seen in the bay. Very large schools of atherinids (silversides) were also observed. These two species no doubt provide forage for larger food fishes such as carangids (jacks) and tuna. The presence of such large concentrations of these fishes within the bay indicate that it is a very productive environment.

Table 13. Zooplankton abundance (no. organisms per m^3 of water) based on daytime plankton tows at Arakabesan study site.

Organism	Tow A	Tow B	Tow C	Tow D	Tow E
dinoflagellates	.23	.70	.23	.35	.82
foraminifera	.12	0	0	0	0
medusae	.23	.47	.23	0	.82
siphonophores	2.45	.23	1.98	0	.35
polychaetes	0	0	.12	0	0
larval gastropods	0	0	0	0	.12
pteropods	1.75	.12	.12	0	0
misc. mollusks	.12	0	0	0	0
crustacean eggs	.58	2.33	2.22	4.67	1.98
nauplii	.23	.12	.12	.12	0
brachyuran zoeae	.23	.23	.35	.35	1.75
anomuran zoeae	.12	0	0	0	0
"shrimp" zoeae	0	.23	.82	0	0
ostracods	0	0	.12	0	0
copepods	8.87	3.15	2.33	3.03	2.33
mysids	.23	0	.23	0	.12
larval brachiopods	.12	0	.12	0	.12
chaetognaths	.93	.12	0	0	.12
larval echinoderms	1.98	.82	1.28	.70	.47
thaliaceans	0	0	.23	0	0
larvaceans	6.53	6.88	1.40	1.63	2.33
fish eggs	.35	.23	1.05	.58	1.63
larval fishes	.12	0	.58	.35	.58
misc.	.47	.12	0	0	.12
Total	25.67	15.75	13.53	11.78	13.65

Table 14. Mean abundance (no. per m^2 per hr) of planktonic organisms collected in demersal plankton traps at Arakabesan study site.

ORGANISMS	SAND SUBSTRATE day (n=8)	SAND SUBSTRATE night (n=7)	CORAL SUBSTRATE day (n=10)	CORAL SUBSTRATE night (n=8)
dinoflagellates	0	0	.05	0
foraminifera	1.39	1.54	17.78	10.12
medusae	0	.05	.05	.04
siphonophores	0	0	0	.04
flatworms	0	0	0	.09
nudibranchs	.07	0	0	0
pteropods	0	0	0	.04
gastropods	.07	.27	.05	.04
polychaetes (larval + adult)	.20	.67	.95	8.41
crustacean eggs	1.79	.09	.53	.56
nauplii	.73	.54	37.67	1.79
"shrimp" zoeae	0	.05	0	.52
crab zoeae	0	1.18	.21	54.49
crab megalops and juv.	0	.05	.05	.04
cumaceans (?)	0	.05	0	.75
ostracods	.13	1.13	0	4.29
copepods	14.49	19.64	3.44	39.21
mysids	.20	1.95	.11	3.93
amphipods	.66	.82	.69	6.55
isopods	.13	.64	.05	2.05
euphausiids	0	.18	0	.04
misc. crustaceans	.13	0	0	.09
mites	0	0	0	.20
larval brachiopods	0	0	.05	0
chaetognaths	.32	0	0	.20
larval echinoderms	.66	.04	.42	0
thaliaceans	.07	0	0	.04
larval ascidians	.20	.14	1.43	2.38
larvaceans	.66	.64	.90	1.03
fish eggs	.07	.18	.11	.12
fish larvae	0	0	0	.04
unidentified	.07	.36	.21	.16
Total	22.04	30.21	64.75	137.27

Table 15. Fishes at the Arakabesan survey site.

ACANTHURIDAE - Acanthurus glaucopareius Cuvier, A. lineatus (Linnaeus), A. nigrofuscus Forskal, A. triostegus (Linnaeus), A. xanthopterus Cuvier and Valenciennes, Ctenochaetus striatus (Quoy and Gaimard), Naso literatus Bloch and Schneider, N. unicornis (Forskal), Zebrasoma veliferum (Bloch)

APOGONIDAE - Apogon compressus (Smith and Radcliffe), A. orbicularis Cuvier and Valenciennes, Cheilodipterus quinquelineatus Cuvier and Valenciennes

ATHERINIDAE - unidentified atherinids

BALISTIDAE - Pseudobalistes flavomarginatus (Ruppell), Rhinecanthus aculeatus (Linnaeus), R. verrucosus (Linnaeus)

BLENNIIDAE - Meiacanthus grammistes (Valenciennes), unidentified blenniids

CANTHIGASTERIDAE - Canthigaster valentini (Bleeker)

CARANGIDAE - Caranx melampygus Cuvier, Trachurops crumenopthalmus Jordan and Evermann

CENTRISCIDAE - Aeoliscus strigatus (Gunther)

CHAETODONTIDAE - Chaetodon auriga Forskal, C. citrinellus Cuvier, C. ephippium Cuvier, C. kleinii Bloch, C. lineolatus Cuvier, C. lunula (Lacepede), C. melannotus Schneider, C. octofasciatus Bloch, C. rafflesi Bennett, C. semeion Bleeker, C. trifasciatus Mungo Park, C. ulietensis Cuvier, C. unimaculatus Bloch, C. vagabundus Linnaeus, Euxiphipops sexstriatus Cuvier and Valenciennes, Heniochus acuminatus (Linnaeus), H. chrysostomus Cuvier

CLUPEIDAE - unidentifed clupeids

ELEOTRIDAE - Ptereleotris microlepis Bleeker

EPHIPPIDAE - Platax tiera Forskal

FISTULARIIDAE - Fistularia petimba Lacepede

GOBIIDAE - Amblygobius albimaculatus (Ruppell), unidentified gobies

HOLOCENTRIDAE - Adioryx spinifer (Forskal), Flammeo sammara (Forskal), Myripristis sp.

KYPHOSIDAE - Kyphosus sp.

LABRIDAE - Cheilinus fasciatus (Bloch), Choerodon anchorago (Bloch), Epibulus insidiator (Pallas), Halichoeres hoeveni (Bleeker), H. cf. kawarin Bleeker, H. margaritaceous (Cuvier and Valenciennes), H. trimaculatus (Quoy and Gaimard), Hemigymnus melapterus (Bloch),

Table 15. continued

Labroides dimidiatus (Cuvier and Valenciennes), Stethojulis bandanensis Bleeker, Thalassoma hardwicki (Bennett), unidentified labrids

LEIOGNATHIDAE - Gerres argyreus Cuvier and Valenciennes, Gerres sp.

LUTJANIDAE - Caesio xanthonotus Bleeker, Ctenoscolopsis ciliatus (Lacepede), Gaterin chaetodonoides (Lacepede), G. orientalis (Bloch), Lutjanus fulviflamma (Forskal), L. fulvus (Bleeker), L. monostigmus (Cuvier and Valenciennes), Monotaxis grandoculis (Forskal), Pentapodus caninus (Cuvier), Scolopsis cancellatus (Cuvier and Valenciennes), S. margaritifer (Cuvier)

MUGILIDAE - Chelon vaigensis (Quoy and Gaimard)

MUGILOIDIDAE - Parapercis sp.

MULLIDAE - Mulloidichthys samoensis (Gunther), Parupeneus barberinus (Lacepede), P. trifasciatus (Lacepede), Upeneus tragula Richardson

MYLIOBATIDAE - Aetobatus narinari (Euphrasen)

PLOTOSIDAE - Plotosus anguillaris (Bloch)

POMACENTRIDAE - Abudefduf coelestinus (Cuvier), A. sordidus (Forskal), Abudefduf sp., Amblyglyphidodon curacao (Bloch), A. ternatensis (Bleeker), Amphiprion melanopus Bleeker, Chromis caerulea (Cuvier), Dascyllus aruanus (Linnaeus), Dischistodus chrysopoecilus (Schlegel and Muller), D. notopthalmus (Bleeker), D. perspicillatus (Cuvier), Eupomacentrus lividus (Bloch and Schneider), Glyphidodontops cyaneus (Quoy and Gaimard), G. uniocellatus (Quoy and Gaimard), Neopomacentrus sp., Paraglyphidodon melanopus (Bleeker), Plectroglyphidodon dickii (Lienard), P. lachrymatus (Quoy and Gaimard), P. leucozona (Bleeker), Pomacentrus alexanderae Evermann and Seale, P. moluccensis Bleeker, P. pavo (Bloch), P. popei Jordan and Seale, P. taeniometopon Bleeker, P. tripunctatus Cuvier, unidentified pomacentrids

PSEUDOCHROMIDAE - Pseudochnomis sp.

SCARIDAE - Scarus chlorodon Jenyns, S. dimidiatus Bleeker, S. ghobban Forskal, S. scaber Cuvier and Valenciennes, S. sordidus Forskal, S. venosus Cuvier and Valenciennes

SERRANDIDAE - Epinephelus merra Bloch, Plectropomus sp.

SIGANIDAE - Siganus canaliculatus (Park), S. lineatus (Cuvier and Valenciennes), S. virgatus (Cuvier and Valenciennes), S. vulpinus (Schlegel and Muller)

SYNGNATHIDAE - unidentified syngnathid

Table 15. continued

TETRAODONTIDAE - *Arothron nigropunctatus* (Bloch and Schneider)

THERAPONIDAE - *Therapon jarbua* (Forskal)

ZANCLIDAE - *Zanclus cornutus* (Linnaeus)

Table 16. Distribution of fish species among reef zones at Arakabesan survey site, based on transect counts. Figures represent mean abundance (no. per 100 m^2) within given zones. Area surveyed within each zone is indicated below zone designation.

	Intertidal Reef Flat (540 m^2)	Subtidal Reef Flat (820 m^2)	Lagoon Slope (600 m^2)	Lagoon Floor (80 m^2)
ACANTHURIDAE				
Acanthurus lineatus		0.12		
A. triostegus	0.37	0.24		
A. xanthopterus		1.10		
Ctenochaetus striatus		4.63	6.33	1.25
juvenile acanthurids		0.85		
APOGONIDAE				
Cheilodipterus quinquelineatus		0.49	3.67	
ATHERINIDAE				
unidentified atherinids	hundreds	hundreds		
BALISTIDAE				
Rhinecanthus aculeatus		0.37	0.17	
R. verrucosus		0.12		
BLENNIIDAE				
Meiacanthus grammistes		0.37	0.17	
blenniid sp. A		0.61	0.83	1.25
other blenniids			0.17	
CHAETODONTIDAE				
Chaetodon auriga		0.24	0.33	
C. kleinii			0.17	
C. semeion		0.12		
C. trifasciatus		0.12	0.33	1.25
C. ulietensis			0.33	
C. vagabundus	0.19	0.12	0.67	
Heniochus chrysostomus		0.12		
ELEOTRIDAE				
Ptereleotris microlepis			2.83	
GOBIIDAE				
Amblygobius albimaculatus		0.49	0.33	1.25
unidentified gobies	0.56	4.02	6.17	2.50
HOLOCENTRIDAE				
Myripristis sp.			0.17	

Table 16. continued

	Intertidal Reef Flat (540 m^2)	Subtidal Reef Flat (820 m^2)	Lagoon Slope (600 m^2)	Lagoon Floor (80 m^2)
LABRIDAE				
Epibulus insidiator			0.17	
Halichoeres hoeveni	0.19	8.29	8.50	10.00
H. cf. *kawarin*	0.37	0.49		
H. margaritaceous	0.19			
H. trimaculatus		0.12	0.17	
Hemigymnus melapterus			0.17	
Labroides dimidiatus			0.83	
Stethojulis bandanensis	0.74	0.49	0.17	
juv. *Stethojulis*		0.61		
Thalassoma hardwicki			0.17	
labrid sp. A		0.24	0.33	
labrid sp. B			0.50	1.25
labrid sp. C		1.22	0.50	1.25
unidentified labrids	0.37	6.71	1.83	5.00
juv. labrids	0.56	2.44	2.50	1.25
LUTJANIDAE				
Lutjanus fulvus	0.93	0.24		
Monotaxis grandoculis		0.12		
Scolopsis cancellatus		0.12		
S. margaritifer		0.49	0.67	1.25
MUGILOIDIDAE				
Parapercis sp.			0.17	
MULLIDAE				
Parupeneus barberinus		0.12		2.50
P. trifasciatus		0.12	0.50	
Upeneus tragula			0.17	
POMACENTRIDAE				
Abudefduf coelestinus		0.73		
Abudefduf sp.	0.19			
Amblyglyphidodon curacao		2.32	1.50	
A. ternatensis	3.70	1.34	12.83	1.25
Amphiprion melanopus			0.50	
Chromis caerulea		2.44		
Dascyllus aruanus		0.49	0.50	
Dischistodus chrysopoecilus		0.24		
D. notophthalmus		0.12		
D. perspicillatus		2.32	7.67	13.75
Eupomacentrus lividus		0.49		
Glyphidodontops cyaneus	1.11	0.49	0.17	
G. uniocellatus	0.19			
Neopomacentrus sp.	0.19	15.00	118.00	
Plectroglyphidodon lachrymatus		0.12		
P. leucozona	0.37			
Pomacentrus alexanderae			4.50	48.75

Table 16. continued

	Intertidal Reef Flat (540 m^2)	Subtidal Reef Flat (320 m^2)	Lagoon Slope (600 m^2)	Lagoon Floor (80 m^2)
P. molluccensis	0.19	9.27	15.83	5.00
P. popei		0.24	1.33	
P. taeniometopon		9.02	9.83	1.25
P. tripunctatus		0.12	1.59	6.25
unidentified pomacentrids		0.73	0.67	2.50
juvenile pomacentrids			0.83	1.25
PSEUDOCHROMIDAE				
Pseudochromis sp.		0.24	0.67	
SERRANIDAE				
Epinephelus merra	0.19	0.49	0.67	
SIGANIDAE				
Siganus virgatus		0.49		
SYNGNATHIDAE				
unidentified syngnathid			0.33	
THERADONIDAE				
Therapon jarbua	0.19			
TOTAL (Mean abundance of fish per 100 m^2, excluding schooling atherinids)	10.79	82.65	217.44	110.00

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