ASSESSMENT OF THE SHOALWATER ENVIRONMENTS IN THE VICINITY OF THE PROPOSED OTEC DEVELOPMENT AT CABRAS ISLAND, GUAM

Edited by

Richard H. Randall and Lucius G. Eldredge

Participating Authors

Bruce R. Best, Russell N. Clayshulte, Ann Hillman-Kitalong
Roy K. Kropp, and Robert F. Myers

Government of Guam
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University of Guam Marine Laboratory

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Cover photo - Luminao Barrier Reef and Glass Breakwater in foreground and Cabras Island in background, view toward the east (Photo: L. G. Eldredge).

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INTRODUCTION

by

Richard H. Randall, Lucius G. Eldredge
and Roy K. Kropp

Background

The tropical setting of Guam in the western Pacific Ocean coupled with its steep offshore submarine topography makes the island a potential site for development of an alternate energy resource by utilizing Ocean Thermal Energy Conversion (OTEC) technology. In a study funded by the Government of Guam Energy Office, the University of Guam Marine Laboratory conducted an annual study of the oceanographic conditions in the vicinity of Cabras Island and Luminao Barrier Reef for the potential development of OTEC on Guam (Lassuy, 1979). The results of Lassuy's study have shown that Guam is indeed an ideal site for OTEC development, and in terms of physical parameters the island is perhaps better suited than any other location under the United States political umbrella. Lassuy's work demonstrated the consistent presence of an annual mean temperature difference (ΔT) of 23.4°C (42.2°F) between the surface water and that at a depth range of 854 to 915 m (2800 to 3000 ft.). Off the western tip of Luminao Barrier Reef the above temperature difference and depth range is reached at a distance of only 1.75 km (1.1 miles) from the Glass Breakwater.

Based upon the demonstrated potential for OTEC development on the island the Government of Guam Energy Office has proceeded with plans to develop this potential alternate energy resource. In consideration of the ideal oceanographic parameters found in the vicinity of Cabras Island (Fig. 1), and the present location of the major electric power generating facilities, a site on the seaward side of the eastern end of Cabras Island has been selected for OTEC development by the Guam Energy Office. The Guam Energy Ofice is presently conducting in-depth feasibility studies for OTEC development at the Cabras Island site. Part of these feasibility studies includes an assessment of the environmental impact of OTEC development in the adjacent marine waters. An overall environmental impact report addressing projected OTEC development on Guam was prepared by Dames and Moore in 1979. In May 1980 the Guam Energy Office requested the University of Guam Marine Laboratory to submit a proposal to provide a more detailed analysis of the environmental impact of OTEC development on the seaward side of Cabras Island and Luminao Barrier Reef than was provided in the Dames and Moore (1979) study. The Marine Laboratory submitted the requested proposal to the Guam Energy Office and a memorandum of understanding and agreement was signed on June 18, 1980. On August 1, 1980 the Marine Laboratory received a notice to proceed with the proposed work from the Guam Energy Office.

Objectives and Scope of Work

The study area consists of the reef-flat platform, reef margin, and reef front slope zones along the seaward side of Cabras Island and the portion of the Luminao Barrier Reef that lies on the north side of the Glass Breakwater (Fig. 1). The major objective of the study is to determine the environmental impact of a proposed 40 megawatt OTEC facility, located on the seaward side of the eastern end of Cabras Island, on the marine habitats within the above study area. As a secondary objective the results of the study are also to be used to assist the Guam Energy Office and the Bureau of Planning's Guam Coastal Management Program in maintaining their energy facility impact planning process and further effective management of pristine marine areas. Specifically the work items included in the study include the following: 1) provide a description of the study area that includes the general submrine topography and general ecology, 2) prepare an inventory of organisms (macroalgae, corals, other invertebrates, fishes, and planktonic organisms) inhabiting the study area, 3) assess the currents on the reef-flat platforms (dye injection method) and inshore water mass (drift drouge method) during ebb and flood tide conditions at monthly intervals (6 month period), 4) determine water quality in the study area by measuring salinity, phosphate, nitrate, and oxygen levels at monthly intervals (6 month period), 5) determine sediment distribution in the study area, 6) identify and evaluate anticipated environmental impacts within the study area from the proposed OTEC development during construction and operation and provide recommendations for mitigation or avoidance of these impacts, and 7) discuss the value of the study area as a pristine marine community and as a recreational area.

Work Schedule

Originally, the field work for this study was to be completed within seven months and a final copy of the report submitted within a nine-month period. This schedule was thought to be reasonable if field work could be started early in the summer to take advantage of the few calms and reduced NE Tradewind speeds which normally occur during that season. The platforms along the seaward side of Cabras Island and Luminao Barrier Reef normally receive constant wave assault because of their northerly exposure. Quantitative or qualitative work in the reef margin and upper reef front slope zones was found to be impossible during normal sea conditons. Because of our late notice to proceed work on the study (August 1980) we were not able to complete the proposed investigations in the reef margin and reef front zones during the few days of calm that occurred between August 1980 and April 1981. A no-cost extention of the study period was asked to complete the quantitative and qualitative work in the reef margin and reef front slope zones. The Guam Energy Office extended the study period and the final field data was collected from the reef front zone along Cabras Island in September 1981. Because of the difficulty encountered in collecting good quantitative data in the wave-assaulted reef zones of the study area we considerably underestimated the length of time required to complete this project.

Previous Work in the Study Area

Little previous work has been conducted in the marine environment along the seaward side of Cabras Island and the Glass Breakwater. Marsh and Wilkins (1980a and 1980b) reviewed the information available. In conjunction with studies of the Piti Power Plant, J. A. Marsh, Jr. surveyed Piti Bay and Piti Channel, the results of which appeared in six technical reports published between 1972 and 1977. A summary of these Piti Power Plant studies is provided by Marsh et al. (1977). During the preparation of an atlas of the reefs and beaches of Guam, Randall and Eldredge (1976) briefly described the coastal regions and reef-flat platforms and mapped the distribution of seagrasses, corals, and marine sediments of the Cabras Island - Luminao Barrier Reef area. Offshore studies to provide baseline data for an OTEC plant were conducted by Lassuy (1979). General marine studies in the area of the GORCO deballast discharge facility were initiated by Rupp and Larson (1972) and further studied by Neudecker et al. (1978). The first report concerning the Luminao Barrier Reef was that of Stojkovich (1977) who studied the seaward portion of the reef platform as a pristine community and recommended that the area be established as a "natural sanctuary in which no coral harvesting, net fishing, or other such activity be permitted." More recently Rowley (1980) analyzed the biofouling community on the Calalan Bank near the west end of Luminao Barrier Reef, and Clayshulte (1981) studied foraminiferan settlement and distribution in the same area.

LITERATURE CITED

Clayshulte, R. N. 1981. Distribution and recruitment of foraminifera in the families Acervulinidae and Homotrematidae in shallow coral environments on Guam. Master of Science Thesis, Univ. Guam. 78p.

Dames and Moore. 1979. Environmental impact report projected OTEC development for the Territory of Guam. Guam Coastal Management Program, Bureau of Planning, Govt. Guam. 73p.

Lassuy, D. R. 1979. Oceanographic conditions in the vicinity of Cabras Island and Glass Breakwater for the potential development of ocean thermal energy conversion on Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 53. 30p.

Marsh, J. A., Jr., M. I. Chernin, and J. E. Doty. 1977. Power Plants and the marine environment in Piti Bay and Piti Channel, Guam: 1976-1977 observations and general summary. Univ. Guam Mar. Lab. Tech. Rept. No. 38. 93 p.

Marsh, J. A., Jr., and S. C. Wilkins. 1980a. Review of information on the marine ecosystem in Piti Channel and Apra Harbor, Guam. Rept. submitted to R.W. Beck and Associates, Univ. Guam Mar. Lab. 33p.

______________. 1980b. Review of information on the marine ecosystem of the Cabras Island Reef. Rept. submitted to R.W. Beck and Associates, Univ. Guam Mar. Lab. 10p.

Neudecker, S., D. M. Rowley, and R. F. Myers. 1978. Marine environmental survey of the GORCO deballast discharge, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 19. 24p.

Randall, R. H., and L. G. Eldredge. 1976. Atlas of the reefs and beaches of Guam. Coastal Zone Management, Bureau of Planning, Govt. of Guam. 191p.

Rowley, D. M. 1980. Analysis of biofouling communities on settling plates at the proposed ocean thermal energy conversion site off Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 64. 89p.

Rupp, J. H., and H. K. Larson. 1972. A marine environmental survey for the GORCO deballasting facility outfall, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 2. 17p.

Stojkovich, J. O. 1977. Survey and species inventory of representative pristine marine communities on Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 40. 183p.

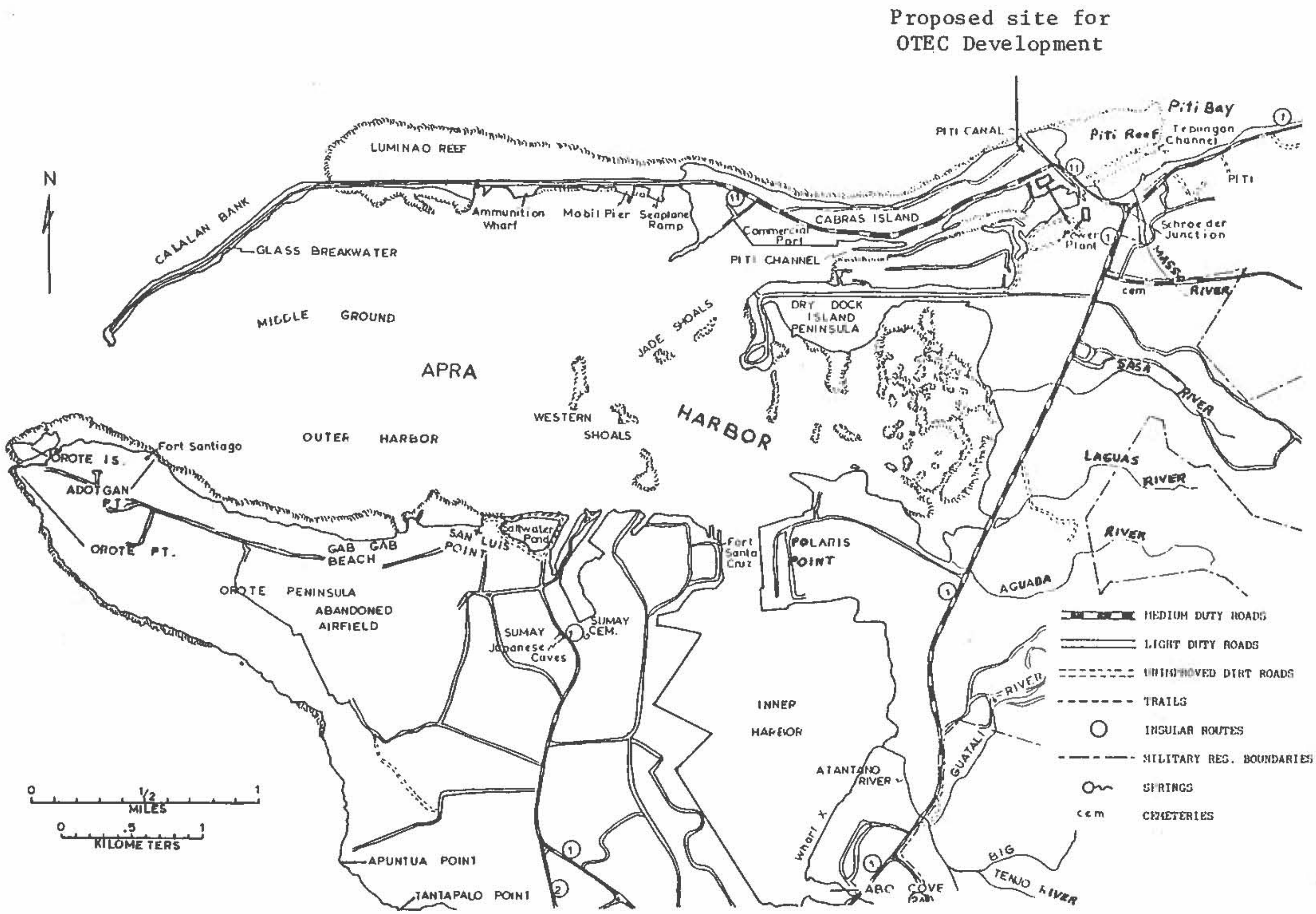


Figure 1. General map of the study area (Map modified from Randall and Holloman, 1974).

DESCRIPTION OF THE STUDY AREA

by

Richard H. Randall

Introduction

The general study area includes the shoalwater regions along the seaward side of Cabras Island, Piti Reef that extends east of Cabras Island, and the portion of the Luminao Barrier Reef situated on the north side of the Glass Breakwater (Figs. 1 and 2). Cabras Island, Piti Reef, and Luminao Barrier Reef, along with Calalan Bank located somewhat to the west of the study region, form the northern margin of the Apra Harbor Lagoon on the west side of Guam (Fig. 1).

Marsh and Wilkins (1980) reviewed the available information on the marine ecosystem of the Cabras Island Reef. They reported that only a few studies have been made along the seaward side of Cabras Island, and that most of these investigations focused on the submarine terrace or areas further seaward.

Randall and Eldredge (1976) briefly described and mapped the physiographic features of the Luminao-Cabras-Piti reef platforms and coastal region along the seaward side of Cabras Island in an atlas of Guam's reefs and beaches. On their maps of the present study area they classified the coastal features of Cabras Island and mapped the relative abundance and distribution patterns of sediments and corals on the shallow reef platforms.

General Geographical Setting

Cabras Island is a raised barrier reef of Mariana Limestone that has been extensively altered by quarrying, dock and port construction, and other commercial development. Unaltered coastal regions of Cabras Island are found at the extreme eastern tip and along a short stretch located on the seaward-facing side near the western end. The island is elongate in an east-west direction and slightly curved with its concave side facing the sea. It is 2.9 kilometers long and ranges in width from 250 to 470 meters. The altered shoreline along the seaward side of the island mostly consists of quarried limestone blocks and boulder riprap or bare exposed rock. At the two unaltered coastal locations the shoreline consists of steep rocky slopes and cliffs buttressed at places with large limestone blocks and boulders. At most places well-developed concave indentations called nips are cut into the base of the unaltered rocky cliffs and slopes. Beach deposits are absent along the seaward side of Cabras Island except for isolated pockets of a few meters extent found at the eastern and western ends. Originally Cabras Island was separated from the main island of Guam by Tepungan Channel, but it is now connected at its eastern end by a causeway. Before construction of the causeway Tepungan Channel connected the northeastern corner of Apra Harbor Lagoon to the open sea via Piti Bay. Now the only circulation through this once natural waterway is from thermal effluent discharged into Apra Harbor from the Piti-Cabras power plants that is drawn in from the ocean via Piti Canal and Tepungan Channel. Within the study area a narrow fringing reef platform 10 to 45 meters wide fringes the entire seaward side of Cabras Island. To the east of Cabras Island the fringing reef platform abruptly widens and is here called the Piti Reef (Fig. 2). The lobate-shaped Piti Reef platform extends 625 meters eastward from the eastern tip of Cabras Island to Piti Bay. The reef platform is 446 meters wide near its western end and is bisected by the much-altered Tepungan Channel. For this study only the portion of the reef seaward of Tepungan Channel was studied.

Luminao Barrier Reef extends westward from Cabras Island to the submerged Calalan Bank (Fig. 2). The barrier reef platform is 2.5 kilometers long and ranges in width from 240 meters at its eastern end to 620 meters at its westend end. A one-mile long breakwater, 36 feet (11 meters) wide and 5 feet (1.5 meters) above sea level was constructed on the eastern end of the barrier reef before late 1941 (U.S. Navy Joint Intelligence Center, 1944). The present 17,000-foot (2.5 kilometers) Glass Breakwater, elevated along the older portion west of Cabras Island and extended to the western end of Calalan Bank, was completed in July 1947 (Tudor Engineering Company, 1964). The Glass Breakwater was built upon the lagoon fringe of Luminao Barrier Reef which leaves the major part of the shallow reef-flat platform situated on the exposed seaward side of the structure. Since construction of the breakwater this wide seaward portion of the platform has had little man-influenced disturbance. In contrast the narrow platform fringe located on the lagoon side of the breakwater has been altered considerably by dredging, land filling, and construction of docks and piers.

Description of the Marine Environment

The portion of the Luminao Barrier Reef along the seaward side of Glass Breakwater, the fringing reef along the seaward side of Cabras Island, and the fringing Piti Reef east of Cabras Island consist of two principal morphologic regions -- a rather flat, shallow reef platform that extends outward from the shore or breakwater and an outer forereef slope that dips downward to the dwindle point of coral growth and reef development. Both the shallow reef platform and deeper forereef slope can be subdivided into a number of conspicuous physiographic zones. The various physiographic zones discriminated, water depth, and sediment and coral distribution patterns are shown in the vertical profiles of Figures 3-A through 3-E for Luminao Barrier Reef, Figures 3-F through

3-I for the fringing reef along Cabras Island, and Figure 3-J for Piti Reef. Figure 2 shows the locations of the various representative vertical profiles.

Fringing Reef Along The Seaward Side of Cabras Island

The fringing reef along the entire seaward side of Cabras Island forms a shallow reef platform 10 to 45 meters wide. Vertical profiles F through I (Figs. 3F-3I) show the zonation patterns, general physiographic features, and sediment and coral distribution patterns for the fringing reef along the seaward side of Cabras Island.

The narrow platform can be divided into an inner limestone pavement zone 10 to 20 meters wide that sometimes exposes during low spring tides and an outer wave-washed reef margin zone 10 to 20 meters wide. During normal NE Tradewind seas both the inner pavement and reef margin are zones of agitated water and rolling surf. The reef surface in the pavement zone is relatively flat with the only relief features being widely scattered holes, troughs, and depressions generally less than 30 cm deep. Other relief features consist of a few large blocks and boulders that have been transported onto the platform by storm waves. Except for a few boulders, cobbles, and gravel-sized sediments trapped in some of the deeper holes and troughs, the pavement surface is generally swept free of loose sediments by strong water movement.

At the outer edge of the reef platform the surface slopes gently downward forming the wave-washed reef margin zone. Although the reef margin is nearly always awash from breaking waves and swell there is no algal ridge development along the length of Cabras Island. There is though, a short stretch of shoreline along the western end of the island where a supratidal bench is being cut into the coastal cliffs that somewhat resembles an elevated algae ridge. Low knobs, mounds, ridges, and shallow holes, all of which generally express less than 50 cm of relief, impart a rough irregular surface to the reef margin zone. Elongate troughs or surge channels that cut across the reef margin zone are characteristic features of many fringing reefs around the island, but here along Cabras Island they are poorly developed, irregularly distributed, and generally less than a meter deep. At places a few of the larger surge channels extend into the inner pavement zone of the reef platform as shallow troughs or fissures. Except for a few boulders and cobbles on the floors of surge channels and deeper holes, loose sediments are absent in this wave-washed zone.

Seaward of the reef margin the reef surface abruptly dips downward forming the forereef slope. Along Cabras Island the forereef slope can be divided into three conspicuous physiographic zones. The uppermost zone of this seaward dipping surface, which is under the influence of strong oscillatory currents and wave surge, is the reef front slope. The most characteristic feature of this zone is the presence of channels or fissures, one to three meters wide and five to seven meters deep, that cut across the slope normal to the fringing reef axis. Apparently the lower parts of these channels are maintained principally by erosion, judging from the occurrence of large rounded boulders, cobbles, and coarse gravel scattered along their floors and the presence of smooth scoured lower wall and floor surfaces. In contrast much of the upper wall surfaces are dominated by corals and encrusting red algae, and reef accretion appears to be taking place. Vigorous growth commonly produces projecting shelves along the upper channel walls that at some locations completely roof over the lower parts of the channel. At places the reef front channels are somewhat uniformly spaced 10 to 20 meters apart with intervening areas developed into lobate-shaped buttresses or ridges which dip gently downward in a seaward direction. At other places the channels are poorly developed and irregularly spaced much farther apart. Buttresses and ridges tend to be very hummocky and uneven on their upper surfaces because of localized reef growth. Knobs, pinnacles, and mounds of coral growth up to several meters in height are also common physiographic relief features of the reef front slope. Occasionally some of the channels widen into large boulder-strewn holes ten or more meters across. Potholes up to several meters across and deep, with large rounded boulders on their floors, are also encountered on the buttress slopes or seaward terminus of some channels. Minor relief features consisting of echinoid grooves are sometimes abundant and conspicuous on the reef front slope, particularly where channels are poorly developed and irregularly spaced.

Although the forereef zones seaward of the reef front slope were not directly studied for this report, a brief physiographic description of the reef to about 30 meters depth will be given. Between five and seven meters depth the downward dip of the reef front slope decreases and the channel and buttress topography grades into a hummocky surface traversed by shallow or poorly defined troughs. This flattened region of the forereef slope is commonly refered to as the submarine terrace zone; and along Cabras Island it generally extends in a seaward direction for 20 to 100 meters. Although the topographic relief on the submarine terrace is generally less than that of the reef front slope, occasional knobs, pinnacles, or mounds will extend upward to five or more meters above the surrounding reef surface. The deeper and less agitated water of the submarine terrace allows more sand-sized sediments to accumulate in holes and troughs than on the shallow wave-swept reef platform and reef front slope zones, but evenso, much of the loose material of this size is gradually transported downslope. In 1972 Rupp and Larson conducted a marine survey of the submarine terrace zone at the western end of Cabras Island. They described the terrace as having a gentle seaward dipping surface cut by shallow grooves that extend into the reef front zone at the shallower shoreward part, and with scattered dead coral knobs on the deeper seaward part. At 15 to 20 meters depth the gentle downward slope of the submarine terrace increases abruptly which marks the beginning of the seaward reef slope zone. The seaward reef slope along Cabras Island is quite steep and at places forms local submarine cliffs. Surface topography is similar to that found on the shallower submarine terrace, but occasional deeper channels, fissures, and troughs cut across its surface. Although this steep zone extends downward to the dwindle point of hermatypic coral growth (about 100 meters), it is commonly interrupted at places by deeper terraces where considerable amounts of sediment accumulate.In 1978 Neudecker et al., resurveyed the Rupp and Larson study area. They described the seaward reef slope zone as dropping precipitously from 18 meters depth at the seaward edge of the submarine terrace to a deeper submarine terrace at 40 meters depth.

Luminao Barrier Reef Seaward of The Glass Breakwater

This lobate-shaped barrier reef platform can be divided into four distinct physiographic zones. In a seaward direction from the breakwater these are the inner and outer moat zones that retain water during low spring tides, an outer limestone pavement zone which exposes during low spring tides, and the wave-washed reef margin zone at the seaward edge of the platform. Seaward of the reef margin the forereef slope can be divided into three distinct physiographic regions consisting of the reef front slope that extends downward from the reef margin to a depth of 5 to 7 meters, an intermediate submarine terrace zone of reduced slope that gently dips downward to a depth of 15 to 20 meters, and the outer seaward reef slope zone that dips steeply downward to the lower limits of hermatypic coral growth and reef development. Vertical Profiles A through E (Figs. 3A-3E) show the zonation patterns, general physiographic features, and sediment and coral distribution patterns for Luminao Barrier Reef. A brief description of the physiographic features of the above reef zones follows.

The inner moat zone ranges in width from 121 meters at Profile A to 22 meters at Profile D. During low spring tides this part of the reef platform retains 50 to 100 centimeters of water. Although the general reef floor of the inner moat zone is relatively flat, numerous to somewhat scattered knolls, pinnacles, and mounds of living and dead corals give the surface an irregular topography. Many of the topographic features appear truncated or flat-topped as a result of upward coral growth being limited to the mean low tide level of the water in the moat. Rubble- to sand-sized sediments thinly veneer most of the reef platform surfaces between the coral knolls and pinnacles, but some bare rock patches also occur, particularly where the inner moat zone grades into the outer moat zone.

The outer moat zone ranges in width form 68 meters at Profile A to 13 meters at Profile D. Water depth in this zone during low spring tides ranges from 50 centimeters on the inner part to just a few centimeters where it grades into the exposed outer pavement zone. Numerous knobs, pinnacles, and mounds of living and dead coral give this part of the reef platform a very irregular topography. Many of the individual coral heads as well as knobs and pinnacles are flat-topped or develop microatoll shapes as a result of their upward growth being restricted to the mean low tide level of the moat. Between the various topographic relief features the reef floor consists mostly of bare reef rock and scattered patches of rubbly sediments. Much of the finer-sized sediments are carried into the inner moat zone by currents.

The outer pavement zone ranges in width from 49 meters at Profile A to 15 meters at Profiles D and E. During low spring tides the zone is exposed. Because of this periodic low tide exposure corals and many other reef organisms are absent or restricted to scattered shallow holes and depressions which retain a few centimers of water during such times. The reef surface is pavement-like with little relief and at most places is swept free of loose sediment by strong currents. The most prominent relief feature on the pavement surface is an occasional block or boulder that has been dislodged from the adjacent reef margin or forereef slope zones and carried onto the reef platform by storm waves. At the extreme western tip of Luminao Barrier Reef the outer pavement zone is somewhat depressed, and thus remains covered during low spring tides. Strong currents are generated in this depressed region when water transported onto the reef platform by normal NE Tradewind seas returns to the open ocean through it.

The reef margin, reef front, submarine terrace, and seaward reef slope zones situated on the seaward side of the outer pavement zone of Luminao Barrier Reef are in most respects very similar in physiographic structure and reef development to that described for the same zones along the seaward side of Cabras Island, and thus need not be repeated.

Piti Fringing Reef

In the vicinity of Profile J (Fig. 3-J) the shallow reef platform and forereef slope zones of Piti Fringing Reef are very similar in physiographic structure and reef development to that described for the platform zones of Luminao Barrier Reef and the forereef zones described along the seaward side of Cabras Island. Some minor differences include the following: 1) an expansion of the outer pavement zone across the entire eastern end of Piti Reef, 2) extensive boulder and rubble accumulation along the seaward edge of the pavement zone at Piti Reef, particularly at the eastern end, 3) a thicker veneer of loose rubble on the reef platform of Piti Reef in the inner moat zone, and 4) the presence of extensive echinoid grooves in the outer pavement zone along the western part of Piti Reef. Marsh (1974) conducted productivity studies on the Piti reef in the vicinity of Profile J and described the reef platform in a seaward to shore direction as having an outer surf zone occupied by a poorly developed coral-algal community, an algal zone dominated by seasonal brown algae, zones of smaller and larger coral heads, and a back reef zone of sand and rubble.

Literature Cited

Marsh, J. A., Jr. 1974. Preliminary observations on the productivity of a Guam reef flat community. Proc. of 2nd Intern. Coral Reef Symp., Great Barrier Reef Committee, Brisbane, 139-145.

Marsh, J.A., Jr., and S. C. Wilkins. 1980. Review of information on the marine ecosystem of the Cabras Island Reef. Rept. submitted to R.W. Beck and Associates, Univ. Guam Mar. Lab. 10p.

Neudecker, S., D. M. Rowley, and R. F. Myers. 1978. Marine environmental survey of the GORCO deballast discharge Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 19. 24p.

Randall, R. H., and L. G. Eldredge. 1976. Atlas of the reefs and beaches of Guam. Coastal Zone Management, Bureau of Planning, Govt. of Guam. 191p.

Rupp, J. H., and H. K. Larson. 1972. A marine environmental survey for the GORCO deballasting facility outfall Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 2. 17p.

Tudor Engineering Company. 1964. Apra Harbor. Apra Harbor Military Reservation Guam, M.I.

U.S. Navy Joint Intelligence Center, Pacific Ocean Areas. 1944. Marianas. JICPOA Bulletin No.7-44. 78p.

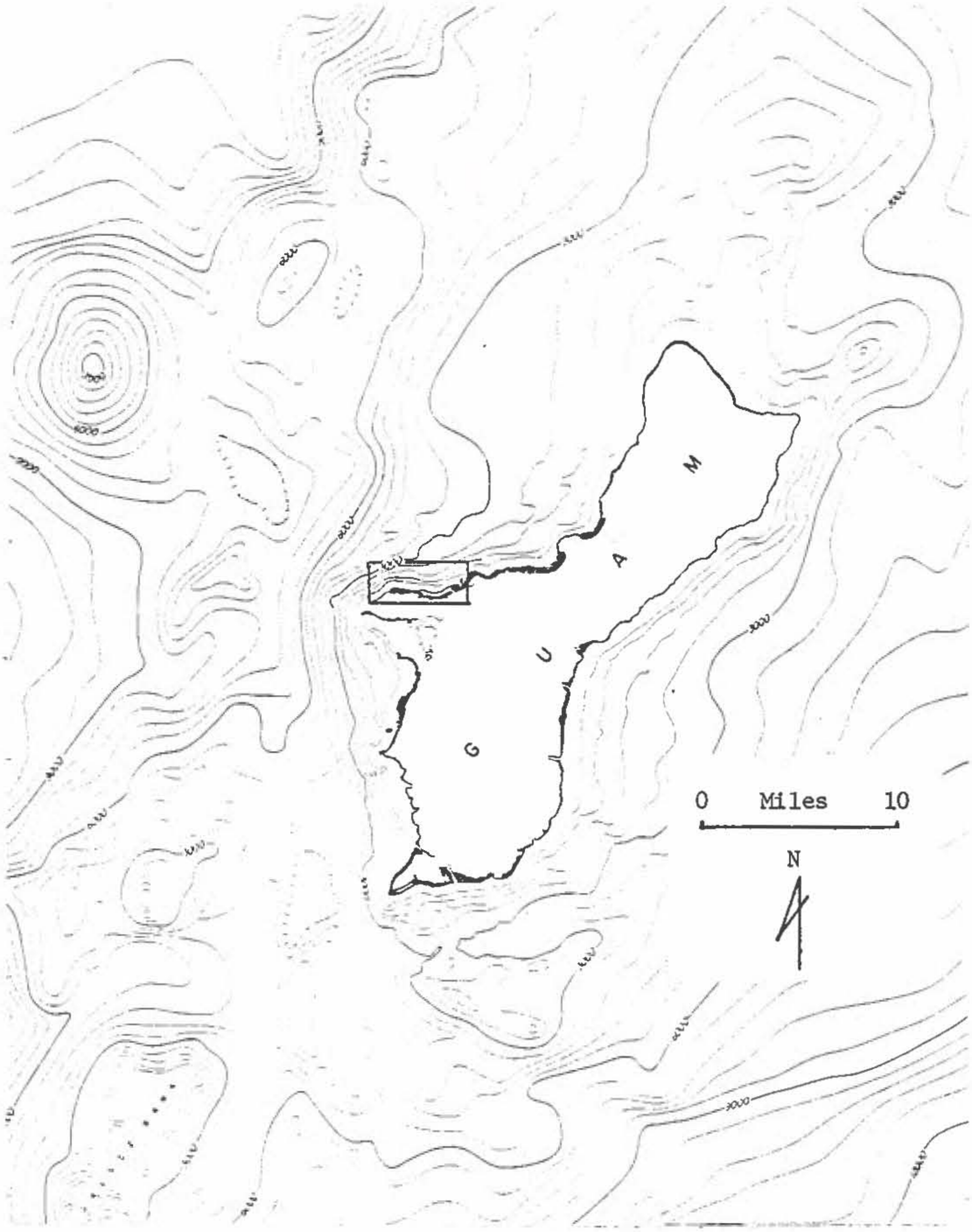


Figure 1. Map of Guam showing the study area location (area in rectangle) and the general bathymetry in the vicinity. Reef areas are shown in black and the submarine contour interval is 100 fathoms. Map modified from Emery, 1962.

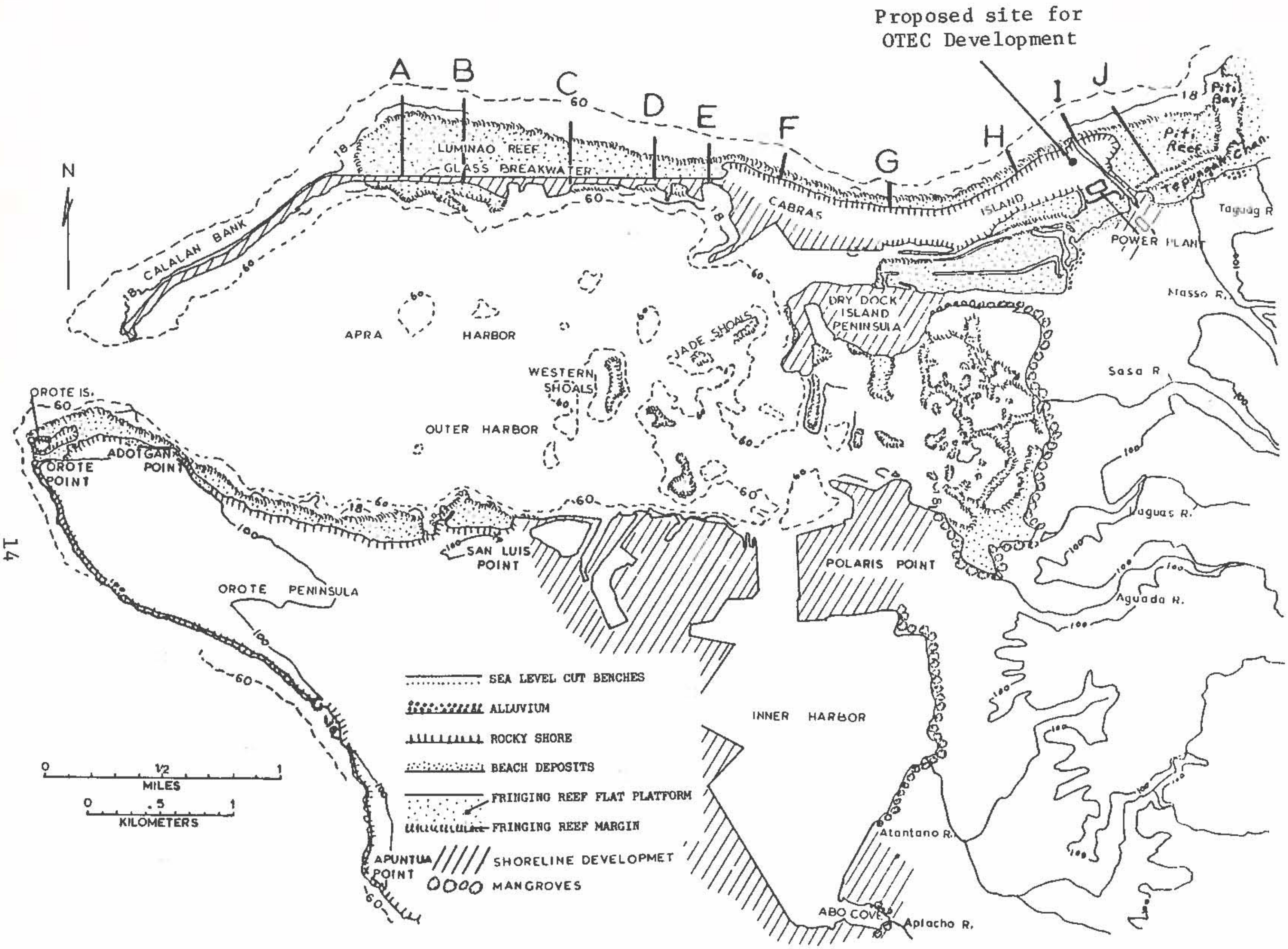
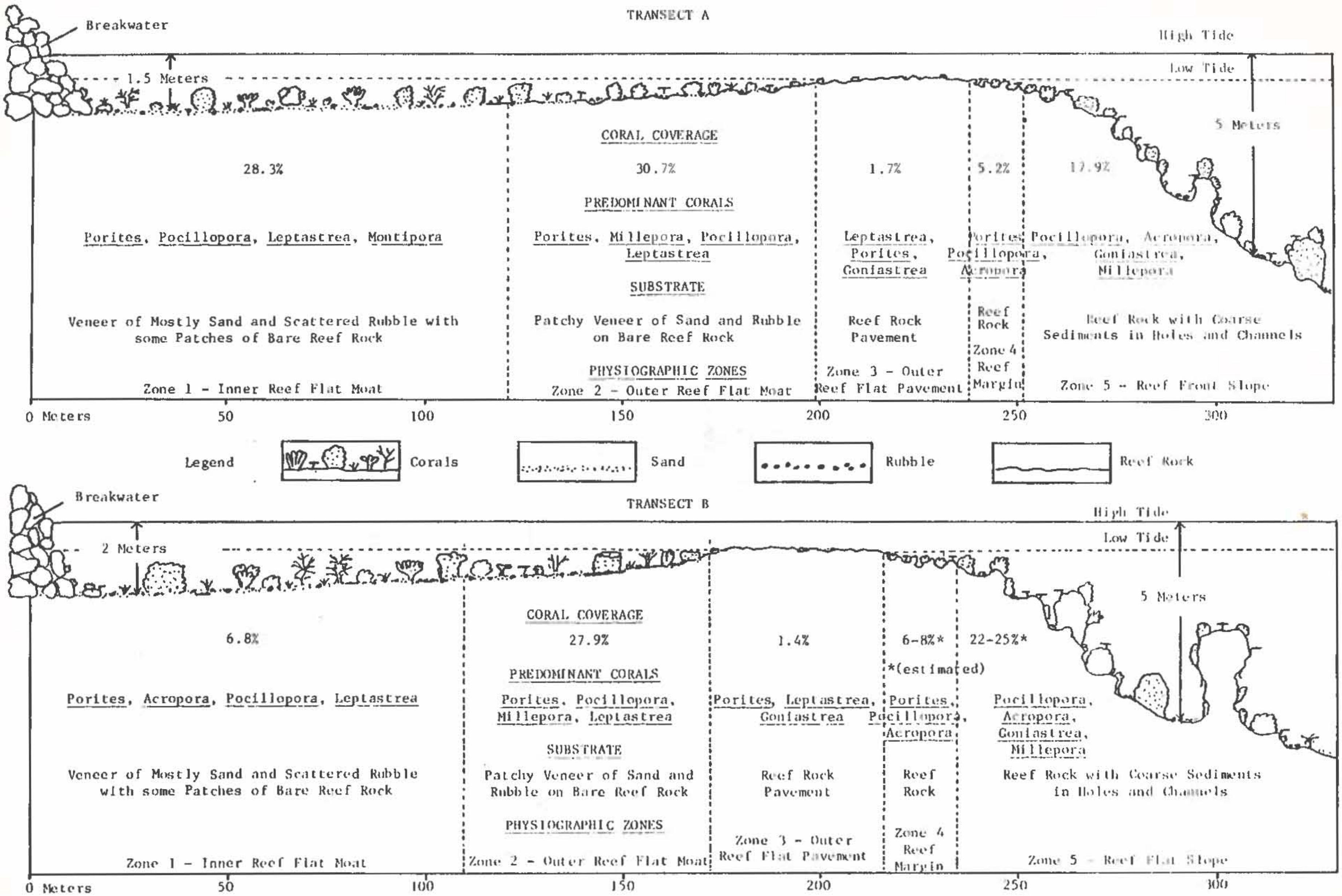
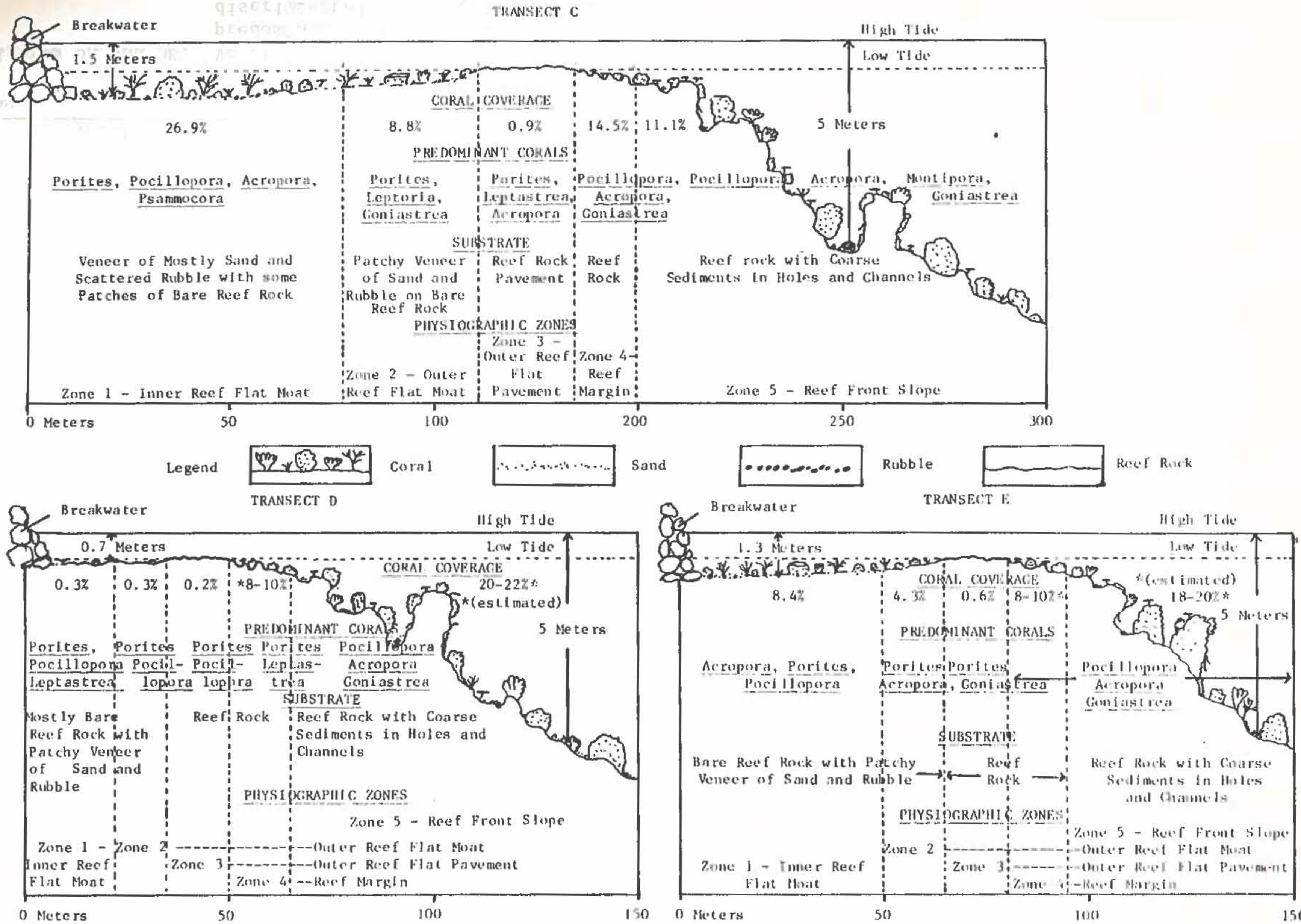


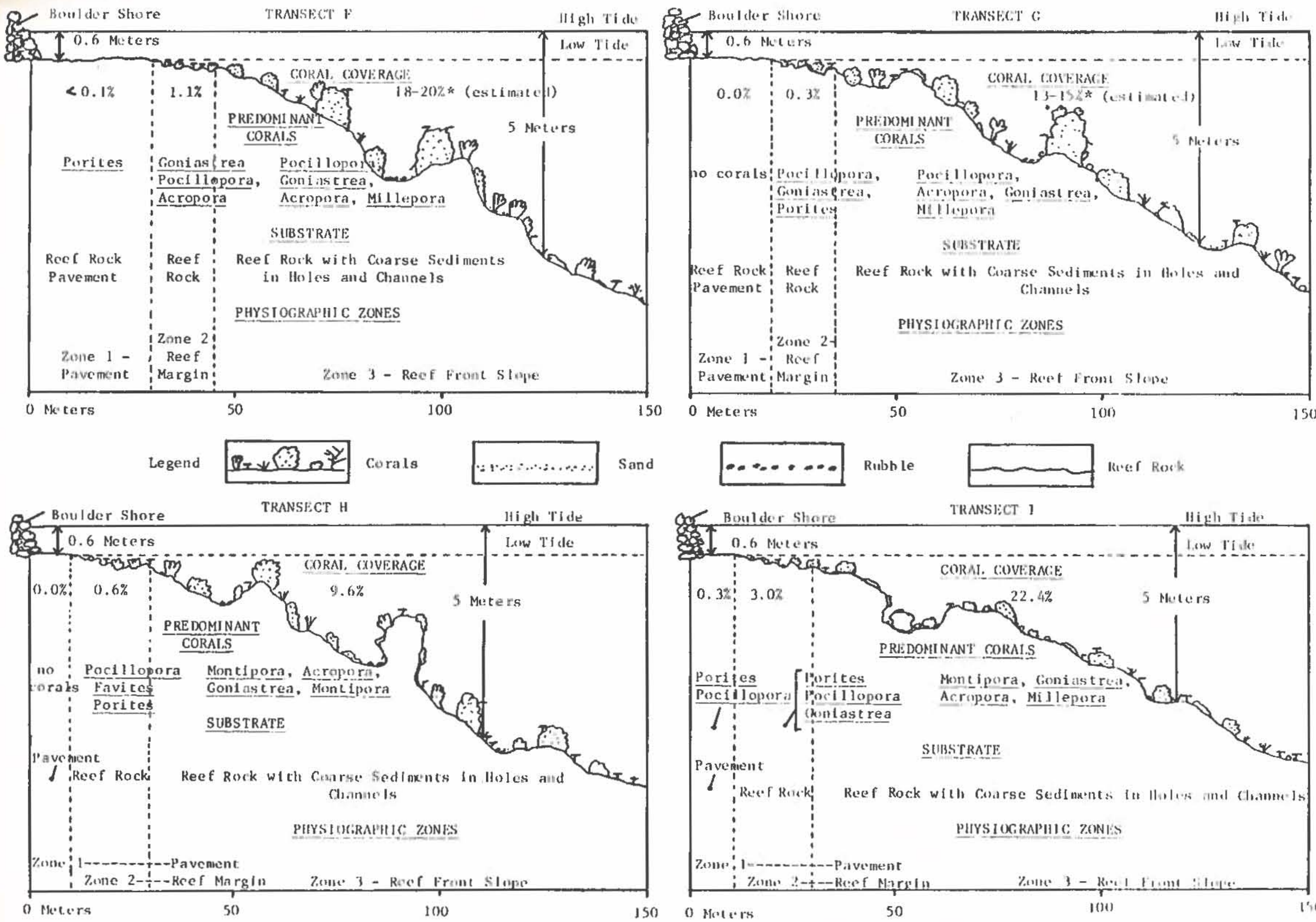
Figure 2. Map of the Apra Harbor area showing the study site and locations of Transects A-J (Map modified from Randall and Holloman, 1974).



Figures 3A and 3B. Vertical profiles of Transects A and B showing water depth, percentage of coral coverage, predominant coral genera, and nature of the substrate for the various physiographic zones discriminated. Vertical exaggeration X10.



Figures 3C, 3D, and 3E. Vertical profiles of Transects C, D, and E showing water depth, percentage of coral coverage, predominant coral genera, and nature of the substrate for the various physiographic zones discriminated. Vertical exaggeration X10.



Figures 3F, 3G, 3H, and 3I. Vertical profiles of Transects F, G, H, and I showing water depth, percentage of coral coverage, predominant coral genera, and nature of the substrate for the various physiographic zones discriminated. Vertical exaggeration X10.

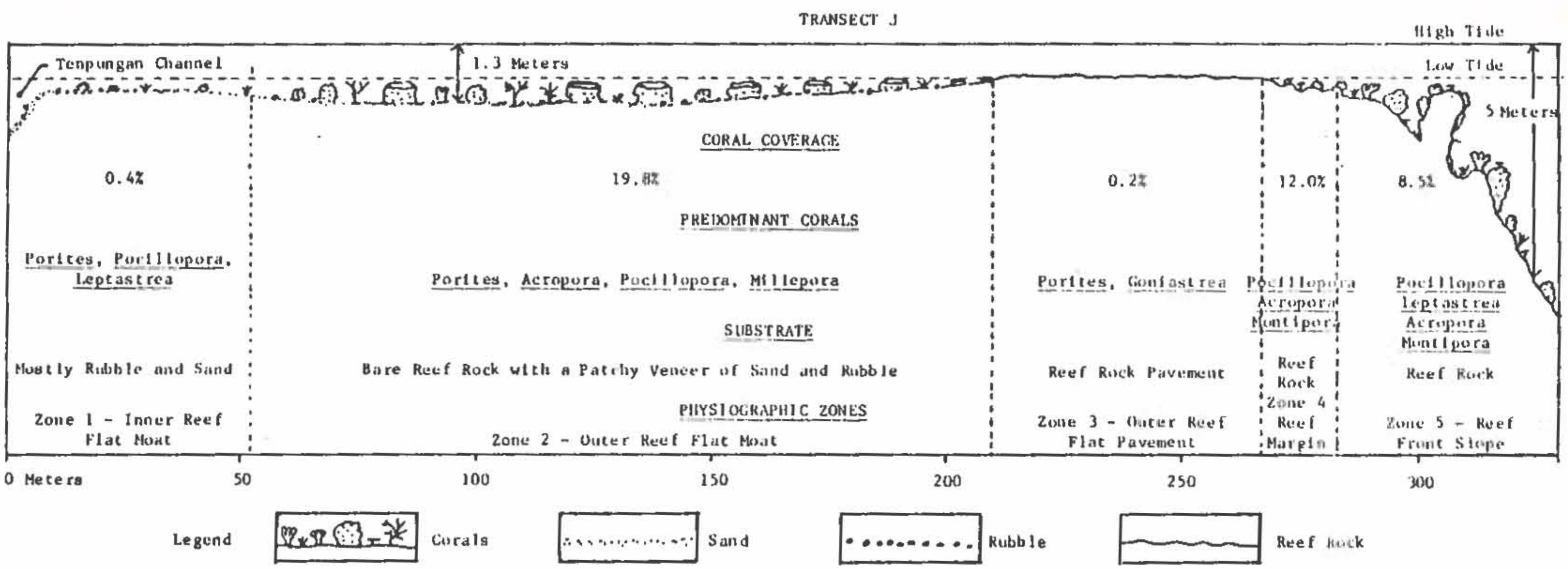


Figure 3J. Vertical profile of Transect J showing water depth, percentage of coral coverage, predominant coral genera, and nature of the substrate for the various physiographic zones discriminated. Vertical exaggeration X10.

A QUANTITATIVE ASSESSMENT OF THE MARINE ALGAE AND OTHER COMMON BIOTIC AND ABIOTIC BENTHIC CONSTITUENTS OF THE LUMINAO-CABRAS-PITI REEFS

by

Bruce R. Best

Introduction

This qualitative and quantitative assessment of the shallow benthic biota of the Luminao-Cabras-Piti Reefs was requested and funded by the Guam Energy Office to provide environmental information for a possible OTEC installation.

The physiography of the Luminao-Cabras-Piti Reefs has been described by Randall and Holloman (1974) and recent vertical reef profiles are presented in the this report (see Figs. 3A-3J, p. 15-18). The area, one of two barrier reef systems on Guam, is well used by snorkelers and fishermen, and, indeed, has been defined as a pristine marine community (Stojkovich 1977).

Marine algae from the unique and diverse Luminao-Cabras Island Barrier Reef community have been previously reported by Stojkovich (1977), Neudecker et al. (1978), and Rupp and Larson (1972). The purpose of the 1972 and 1978 studies was to evaluate the environmental impact of a deballasting facility on the reef slope off Cabras Island. Both studies were confined to a small area on the reef terrace. The Stojkovich (1977) survey provided checklists of the reef-flat fauna and flora. Therefore, this study represents the first extensive qualitative and quantitative analysis of both the shallow reef slope and reef-flat platform along the Luminao-Cabras-Piti Reef System.

Methods

The marine plants and other benthic constituents were quantified by a point-quadrat method. This method generates data from which a rapid general assessment of the percent cover and frequency of occurrence of any benthic algal species or group of benthic macro-invertebrates. From these data, distributional patterns, such as evenness or patchiness of biota can be easily be recognized.

The point-quadrat method consisted of haphazardly tossing or dropping a 25 x 25-cm gridded quadrat, with 16 internal cross-points, every 10 m along 100-m transects. The substrate cover directly under each point was recorded. A total of over 2,700 points were sampled along the 17 transects depicted in Figure 1. Reef-terrace (5-10 m depth) field work incorporated the use of a UOGML boat and scuba equipment.

Percent cover for each transect was calculated by taking the total points at which a constituent occurred, divided by the total points per transect. Similarly, frequency of occurrence was calculated by taking the number of quadrat tosses in which a benthic constituent occurred, divided by the number of tosses per transect. Both cover and frequency values were converted to percentages by multiplying by 100. Additional algal species along the transects were also recorded.

Results and Discussion

Marine plants were typically the most predominate biotic group on the Luminao-Cabras-Piti Reefs. Results of the benthic surveys are presented in Table 1. Percent cover by algae was generally greater than 50% for all transects except those over large sand or coral zones (see profiles in this report). Overall mean percent cover for the algal community along the 17 transects was 59.5 (n = 17, s.d. = 19.6). Coralline algae was the most predominate algal group especially on the reef-slope transects. No seagrasses were found. Forty species from 33 genera of marine plants were recorded from the transects. Littoral populations of Chlorodesmis, Ectocarpus, and Udotea were observed on the Cabras platform.

The Luminao-Cabras-Piti Reefs are presently subjected to harsh natural and man-induced pressures. During the course of the study (1 year), over 30 field visits were made to the study area during which seasonal, man, and storm induced changes were recorded. Storm waves scoured the narrow bench areas and moved large boulders, exposing new substrates and destroying established benthic biota. Temperatures exceeding 33°C were often recorded in bench pools. The effect of an oil spill was witnessed in the area. The effect of suspected poison dumping from the adjacent cliff area (Site H-I) was noted by the presence of a heavy infestation of Microcoleus growing on recently and abruptly killed macro-thalli. The benthic biota along the narrow bench--the most favored site for an OTEC development--reflects these stresses by the abundance of low, tenacious turf-algae and macrofauna. No exotic or endangered algal populations were noted along the Luminao-Cabras-Piti Reefs and, in general, algae abundance and diversity was much lower than that found on the Cocos Barrier Reef System.

It is the view of this author that the designation of the Luminao Barrier Reef as a pristine marine community (Stojkovich 1977) should apply to the northwest portion of the reef-flat platform only. This section, along the Glass Breakwater, has a wide reef flat which protects the inner-moat areas from wave action. This semi-isolated area possibly could be assessed as successfully reestablishing their "natural character" even though reef-flat flushing has been restricted by the man-made breakwater. Certainly, the narrow bench area adjacent to Cabras Island should not be designated as part of the Luminao pristine community.

Literature Cited

Neudecker, S., D. M. Rowley, and R. F. Myers. 1978. Marine environmental survey of the GORCO deballast discharge, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. 19. 24p.

Randall, R. H., and J. Holloman. 1974. Coastal survey of Guam. Univ. Guam Mar. Lab. Tech. Rept. 14. 404p.

Rupp, J. H., and H. K. Larson. 1972. A marine environmental survey for the GORCO deballasting facility outfall, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. 2. 17p.

Stojkovich, J. O. 1977. Survey and species inventory of representative pristine marine communities on Guam. Univ. Guam Mar. Lab. Tech. Rept. 40. 183p.

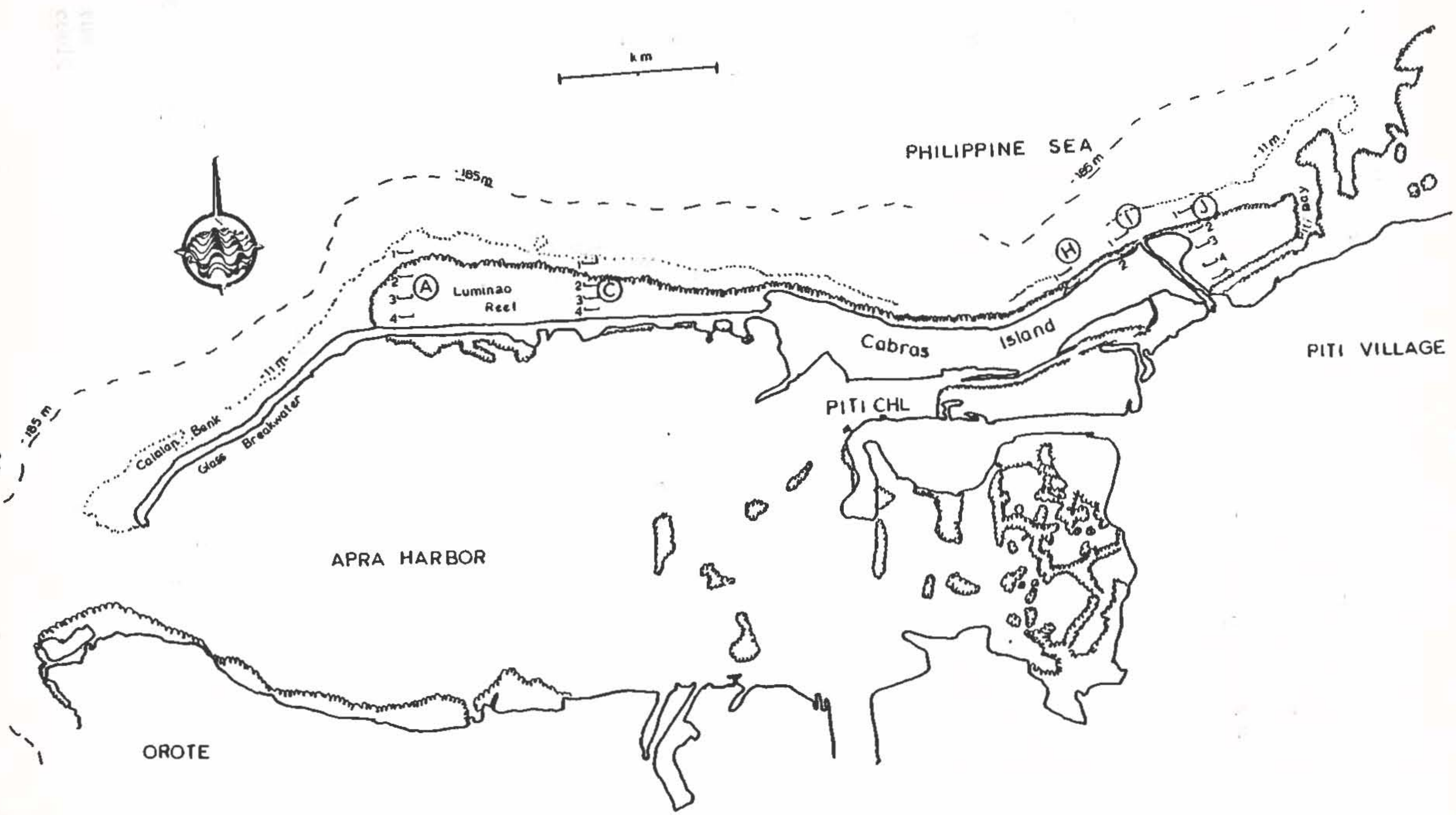


Figure 1. Luminao Barrier Reef System. Numbered transects are depicted in each study area (circled letters). The depth of the reef-slope transects, designated as number 1 in each study area, was approximately -5 m. Depth of the reef-flat transects was -1.5 to 0 m.

Table 1. Frequency and percent cover of benthic fauna and flora along Luminao Reef, Guam. Plain numbers indicate percent cover, numbers in parenthesis indicate frequency of occurrence converted to percent (see Algae Methods in text). Example: 9.8(10) = 9.8% cover, while only found at 10% of the sample sites, indicating a patchy distribution. A 9.1(90) notation suggest an even, sparse distribution. Biota occurring in the vicinity of transects are marked with an X. Transect notations concur with those located on Figure 1.

	TRANSECT																
	A-1 Over Margin	A-2 R-F Margin	A-3 R-F Moat	A-4 R-F Inner	C-1 Over Margin	C-2 R-F Margin	C-3 R-F Mid	C-4 R-F Inner	H-1 Over Margin	H-2 R-F	I-1 Over Margin	I-2 R-F Margin	J-1 Over Margin	J-2 R-F Margin	J-3 R-F Outer Moat	J-4*** R-F Inner Moat	J-5 R-F Channel Margin
Cyanophyta (blue-greens)																	
Hormothamnion enteromorphoides Bornet & Thuret																0.7 (11)	
Microcoleus lyngbyaceus (Kütz) Crouan	4.4 (20)		1.3 (20)	3.3(20)	5.6 (30)	30.0 (100)	X	2.5 (30)	1.3 (10)		1.2 (20)		3.1 (10)		0.6 (10)	2.8 (22)	2.5 (30)
Schizothrix calcicola (Ag.) Gomont	4.4 (20)		X	X		X	X		2.5 (20)		3.8 (10)						1.3 (10)
Schizothrix mexicana Gomont					0.6 (10)	0.6 (10)	0.6 (10)	0.6 (10)									
Undifferentiated scum	25.0 (80)		X	X		3.1 (10)	X		11.2 (20)	X	3.1 (20)		35.6 (80)				
Chlorophyta (greens)																	
Boergesenia forbesii (Harv.) Feldmann							1.8 (20)										
Boodlea composita (Harv.) Brand		4.4 (40)	X				6.3 (30)	0.6 (10)									
Caulerpa racemosa (Forsk.) J. Ag.			X	X		1.3 (10)									0.6 (10)		
Caulerpa sertularioides (Gmel.) Howe			1.3 (20)			0.6 (10)	X										
Caulerpa webbiana Montagne						0.6 (10)											
Caulerpa sp.	1.9 (10)				1.3 (20)												
Cladophoropsis sp.														2.5 (10)			
Codium sp.		0.6 (10)															
Dictyosphaeria cavernosa W.v. Bosse		1.3 (20)				0.6 (10)	0.6 (10)			0.6 (10)							
Halimeda micrloba Decaisne							X	1.3 (10)									0.6 (10)
Halimeda opuntia (L.) Lamx.	0.6 (10)					0.6 (10)	0.6 (10)								2.5 (40)		
Halimeda sp.	0.6 (10)																
Neomeris sp.							X										0.6 (10)
Udotea sp.										****							
Valonia ventricosa J. Ag.							0.6 (10)										
Phaeophyta (browns)																	
Dictyota sp.		5.0 (30)	5.6 (50)	20 (60)			38.8 (100)	18.8 (80)									0.6 (10)
Hydroclathrus clathratus (Bory) Howe		0.6 (10)															
Lobophora variegata (Lamx.) Womersley	X	0.6 (10)	21.9 (70)	9.4 (70)	5.0 (30)	X	3.8 (50)	5.0 (40)	X		1.3 (10)			1.3 (10)	0.6 (10)	0.7 (11)	1.3 (20)
Padina minor Yamada		10.6 (90)															
Padina tenuis Bory			7.5 (20)			13.8 (90)		3.1 (30)		8.8 (60)		1.3 (10)			1.8 (30)	4.2 (22)	8.1 (50)
Sargassum cristaefolium C. Ag.		1.9 (20)				X								75.6	33.8 (50)		
Sphacelaria sp.																0.7 (11)	
Turbinaria ornata (Turner) J. Ag.		0.6 (10)	0.6 (10)			3.8 (30)	0.6 (10)			58.8 (100)		65.6 (100)		0.6 (10)	4.4 (20)		
Unidentified turf		X	X	X		X				2.5 (10)		4.4 (20)		X	X	X	X
Rhodophyta																	
Actinotrichia fragilis Boerg.		3.1 (20)				1.3 (10)											
Amphiroa sp.	2.5 (20)	3.1 (10)	X	X	4.4 (20)	0.6 (10)	4.4 (40)	0.6 (10)	0.6 (10)	0.6 (10)	X	1.9 (20)	X	1.3 (70)	X	X	X
Asparagopsis taxiformis (Delile) Collins & Hervey	X												3.8 (20)				
Ceramium sp.									0.6 (10)	X							
Gelidium sp.			0.6 (10)								1.3 (10)						
Gelidiella acerosa (Forsk.) Feldmann & Hamel														3.1 (10)			
Hypnea sp.		3.8 (20)	0.6 (10)									0.6 (10)					
Jania sp.	4.4 (20)	11.3 (50)	X	X	3.8 (20)	1.3 (20)	0.6 (10)	X	X	X	3.8 (30)	11.3 (40)	X	X	X	X	X
Laurencia sp.		3.8 (30)								X							
Leveillea jungermannioides (Her. & Mart.) Harv.					1.9 (10)												
Mastophora rosea (C. Ag.) Setch.		5.6 (50)				1.9 (30)				1.9 (10)		5.0 (60)					
Pesophyllum sp	0.6 (10)																
Porolithon onkodes (Heydrich) Foslie	10.6 (50)	16.3 (80)	7.5 (60)	2.5 (30)	10.0 (5)	1.3 (20)	6.3 (60)	1.9 (30)	21.3 (90)	3.1 (20)	14.4 (70)	0.6 (10)	13.8 (80)	4.4 (30)	4.4 (20)		
Unidentified turf (red or blue-green)	X	X	X	X	16.3 (40)	X	6.3 (40)	8.8 (20)	19.4 (30)	23.2 (30)	26.3 (70)	0.6 (10)	0.6 (10)	X	7.5 (30)	20.8 (56)	29.4 (70)
Macroinvertebrates																	
Arthropoda																	
Crustacean	0.6 (10)	X	X	X	X	X	X	X	X	X	X	X	0.6 (10)	X		0.7 (11)	
Cnidaria																	
live stone coral	28.8 (90)	5.0 (30)	8.1 (30)	13.1 (30)	23.1 (80)	0.6 (10)	10.0 (20)	8.1 (20)	24.4 (90)	X	35.0 (100)	X	36.9 (80)	X	X	18.5 (22)	X
soft coral														2.5 (20)			
Anemone													0.6 (10)				
Echinodermata																	
Holothuroids	X	4.4 (40)	X	X	X	X	X	X	X	X				0.6 (10)	3.1 (30)		
Asteroids, Echinoids and Ophiuroids	X	X	X	X	X	1.35 (20)	X	X	0.6 (10)	X	1.3 (20)	X	1.9 (30)	X		0.7 (11)	
Mollusca																	
Gastropods and Bivalves	1.9 (20)	1.9 (20)	X	X	1.9 (10)	X	1.3 (10)	X	0.6 (10)	0.6 (10)	2.5 (40)	0.6 (10)	0.6 (10) a	X	1.3 (10)		
Porifera	2.5 (10)		X	X			X		0.6 (10)				1.3 (20)	X	X	X	X
Vertebrates																	
Fish**	X		X	X	X		X		0.6 (10)	X	X	X	X	X	X	X	X
*Detritus				1.9 (10)	6.2 (20)			11.9 (30)									
Pavement	7.5 (30)	2.5 (10)	35.0 (50)	8.8 (20)	8.8 (20)	5.6 (30)	5.0 (20)		16.3 (40)		6.3 (50)		1.3 (10)	1.3 (10)	21.9 (40)	6.9 (33)	16.9 (30)
Rubble	X	2.5 (10)	8.7 (30)	14.8 (40)	X	1.9 (10)	X	6.9 (20)	X	X	X	X	X	X	3.8 (70)	35.4 (78)	35.6 (60)
Sand	2.5 (10)	13.8 (40)	1.2 (10)	25.6 (70)	10.0 (10)	26.9 (80)	9.4 (50)	30.0 (70)	X	X	X	7.5 (40)	X	8.9 (20)	13.1 (50)	6.3 (22)	3.1 (10)
Number of Plant Genera/Transect	10	16	13	8	8	14	15	10	7	9	7	7	5	8	9	6	7
Number of Plant Species/Transect	11	16	14	8	8	17	17	10	7	9	7	7	5	8	5	6	8
Overall Percent Plant Cover/Transect	55.0	72.6	46.9	33.7	48.9	61.4	71.3	43.2	56.7	99.5	55.2	81.3	56.9	88.4	56.2	29.9	44.4

Total Number Plant Genera	33
Total Number Plant Species	40

* Defined as holothurian feces or decaying organism
** Tube dwelling or stationary gobiods or blennies
*** Transect J4 had 144 points
**** It was noted that Udotea "fields" were present during June, 1981. The distribution was very even and monospecific along the bench just south of area H.

RECENT FORAMINIFERA

by

Russell N. Clayshulte

Introduction

There is a conspicuous foraminifera component in sediment deposits and adhering to the reef framework at the Luminao and Piti Reefs. Benthonic foraminifera are the dominate species associated with shallow water and intertidal sediment deposits with only rare occurrences of planktonic species. Adherent foraminifera readily occur on natural substrates at Luminao Barrier Reef. There are a minimum of 150 species of living foramifera, representing three suborders and 28 families, which can be found on the reef-flats and upper reef slopes (<60 m) at Luminao and Piti Reefs (Clayshulte, 1981a).

Few foraminifera studies have been conducted on Guam's reefs and off-shore areas. A review of off-shore dredging activities prior to 1952 was presented by Emery (1962). The foraminiferal component of sediments dredged near the Apra Harbor entrance (Emery, 1962) at depths to 3,000 ft. (914 m) was not specifically determined, although foraminifera were identified as a major sediment constituent. The Tertiary larger foraminifera were determined by Cole (1963). There were no samples taken from the vicinity of Luminao or Piti Reefs, since Cole (1963) dealt only with fossil species. Foraminifera were recorded in a 21-fathom (60 m) sample collected at a Guam anchorage of the "Albatross" expedition (Cushman and Todd, 1972). Todd (1966) examined the smaller foraminifera from Guam and reported over 400 species, ranging in geologic time from upper Eocene to Recent. The distribution and recruitment of sedentary foraminifera in the families Homotrematinidae and Acervulinidae were studied at Luminao Barrier Reef (Clayshulte, 1981b).

Benthonic Foraminifera

The dominate benthonic foraminifera associated with the Luminao and Piti Reefs are *Baculogypsina*, *Marginopora*, *Heterostegina*, *Amphistegina* and *Elphidium*. These genera are typical reef-flat forms or very shallow water forms (Cushman et al., 1954; Emery, 1962; Todd, 1966; Tracey et al., 1964). Living specimens of *Marginopora vertebralis* are uncommon on the outer reef-flat platform at Luminao Reef. Specimens, when observed, are firmly cemented to the reef pavement or to solid massive corals with their flat surface oriented toward the oncoming current. Specimens have not been observed on the inner reef-flat platform. Marginopora vertebralis was abundnat at the western end of Luminao Reef between the 17 m and 32 m terraces. Specimens are firmly attached to the reef framework with their flat surface oriented parallel to the surface. Amphistegina lessonii is rare in reef-flat sediment deposits. Specimens are relatively common in the sediment deposits below 15 m. Elphidium advena and Heterostegina depressa are relatively uncommon in sediments from Luminao Reef but were common in a mud sample collected at a depth of 300 m off Luminao and Piti Reefs.

The benthonic foraminifera Baculogypsina sphaerulata is a species common to dominant in the foraminifera assemblage of some Indo-Pacific reef-flat environments (Boltovskoy and Wright, 1976). On Guam, B. sphaerulata can be a major contributor of sand-sized particles to beach sediments. It is characteristic of high energy reef-flat environments and generally shows the greatest abundance in the outer reef-flat zone. Luminao Reef is a high energy reef, which has good to excellent water exchange in the outer reef-flat zone. As a result, B. sphaerulata is locally abundant across the outer reef platform. Dead tests of B. sphaerulata are an important source of medium sand-sized bioclastic sediments which are usually deposited in the beach and intertidal areas. The midwater and highwater beach samples are composed of about 60% B. sphaerulata tests.

Sedentary Foraminifera

Characteristic components of the cryptofaunal assemblage residing in cavities and interstices of the reef framework are foraminifera. These framework-associated species can be significant contributors to bioclastic sediments and important cementing agents (Hanzawa, 1957; Loeblich and Tappan, 1964). Recent foraminifera from the families Acervulinidae and Homotrematinidae characteristically attach themselves permanently to reef-associted substrates by means of a cement which persists after death of the animal. As a result of this attachment, species from these families are conspicuous components of the cryptofaunal assemblage of Cenozoic reef systems.

In particular, adherent foraminifera are an important component of the cryptofaunal communities on hard substrates in different reef zones around Guam. They are found in fringing reef, barrier reef, lagoon and coral community environments. Previous records (Brady, 1884; Cole, 1963; Cushman and Todd, 1972; Todd, 1966) and personal investigations indicate that the adherent foraminifera associated with Guam's reefs re Homotrema rubrum (Lamarck), Gypsina globula (Reuss), G. vesicularis (Parker and Jones), G. plana (Carter), Miniacina miniacea (Pallas), Sporadotrema cylindricum (Carter), S. rubrum (d'Orbigny), Carpenteria proteiformis (Göes), C. utricularis (Carter), C. monticularis (Carter), Acervulina inhaerens (Schultze), Planogypsina squamiformis (Chapman), and Sphaerogypsina globulus (Reuss).

Methods

Hard substrate was quantitatively sampled at Luminao Barrier Reef. Transected substrates were subdivided into five basic habitat categories: living coral, dead coral, rubble, cavity and exposed knob. The coral habitats had natural distinguishable subunits: branching, tabulate and massive forms of living coral and branching and tabulate forms of dead coral. The cavity habitat was subdivided into exposed and cryptic (<10 cm opening) cavities. The exosed knob was generally a low-relief solid topographic feature (i.e., eroded massive or branching coral). Branching calcareous algae, important habitats types in some reef zones, were not encountered on the transects. The habitats generally represented the major types of topographic relief features found in the reef zones. Substrate was characterized along transects at Luminao Reef in three zones with the point-centered or point-quarter technique (Cox, 1967). A 50-m transect was established parallel to the reef margin in each zone: the reef flat, upper reef slope (ca. 6 m), and reef slope (ca. 12 m). Ten substrate collection points were randomly selected along each transect line. A line bisecting the point at right angles to the line established four quadrants around a point. Substrate types from each quadrant were quantified.

Adherent foraminifera species composition, density and surface coverage were analyzed on samples collected from each transected habitat type. The substrate samples were mini-transected by using a modified point-quarter technique (Clayshulte, 1981b). This technique is a reproducible method for quantifying foraminifera community structure on substrates with intricate relief (e.g. knobs and cavities).

Results

Total species densities on natural substrates and biofouling collectors in the different reef zones were generally less than 1 specimen/cm^2 with incidences as great as 1.08/cm^2 on transected substrates (Table 1) and 3.75/cm^2 on bulk substrates (Table 2). Most substrates examined had adherent foraminifera with higher overall densities on the 12-m terrace. The foraminifera density, surface coverage, frequency of occurrence and relative ranking were determined for each transected habitat type (Table 1).

The most conspicuous adherent foraminifera species in the cryptic interstices of the reef-flat complex was _Homotrema rubrum_. Specimens of living _H. rubrum_ occurred on upper littoral reef zone substrates and on material dredged from a depth of 300 m. Additional foraminiferal species which were equally conspicuous components of the Luminao Barrier Reef cyrptofaunal assemblage were _M. miniacea_, _C. utricularis_ and _S. cylindricum_. These species were particularly common on reef slope substrates as compared with cryptic surfaces of reef-flat substrates. Specimens were observed on most substrate types with relatively high densities on shaded and cryptic cavity surfaces and occasionally on exposed surfaces of reef margin substrates.

Gypsina spp. were common on exposed and shaded surfaces of natural substrates from reef-flat and reef-slope environments with a few small encrustations on dredged substrates (150-400 m).

The less frequent species were Planogypsina squamiformis, Acervulina inhaerens, Sporadotrema rubrum and Sphaerogypsina globulus. Sporadotrema rubrum and A. inhaerens occurred on exposed and shaded surfaces of natural substrates from reef-flats to depths of 50 m. Small specimens of S. globulus (75 to 500μ diameter) were occasionally found on natural substrates, but no attached specimens were found.

Foraminifera colonizing natural barrier reef substrates were similar in species composition and density to those of fringing reef substrates. The average densities of M. miniacea and H. rubrum were similar at a given depth from 7 to 20 m, with increased densities and decreased surface coverage at the deeper depths. At 27 and 55 m there were higher densities of M. miniacea (0.123 and 0.210/cm^2) than H. rubrum (0.015 and 0.035/cm^2). External test variations and coloration of M. miniacea and H. rubrum varied consistently within two general deep zones: specimens from the reef margin to 9 m had robust or globose tests and darker red hues, whereas specimens from 12 m to 55 m generally had branching tests with light red to white hues. Sporadotrema cylindricum was uncommon on all natural substrates. Carpenteria monticularis occurred in low densities on sub- strates from 12 to 55 m.

Discussion

Adherent foraminifera species are a conspicuous component of the cryptofaunal community on substrates from the reef environments at Luminao Barrier Reef. Species recruited to most habitat types, with densities generally less than 1 specimen/cm^2 (10,000/m^2). The total surface coverage by foraminifera was usually about 1%. The species occurrence, surface coverage and frequencies of occurrence on natural substrates varied between reef-flat and seaward slope zones and between habitat types. Exposed and cryptic cavities and dead branching corals provided more surface area for attachment and subsequently had higher species recruitment and densities. The principal species, H. rubrum, M. miniacea and C. utricularis, were found in all the reef environments. Variation in recruitment patterns were found in minor species, A. inhaerens, P. squamiformis, C. monticularis, S. rubrum and S. cylindricum.

Although adherent foraminifera occupy only about 1% of substrate surface area, they are important biofoulers. On reef-flat and reef margin substrates they can be the major cryptofaunal component and occupy as much as 50% of cryptic surface areas. Since foraminifera tests remain attached to reef substrates after the animals die, adherent foraminifera do make a small contribution to the overall coral reef carbonate accretion.

Literature Cited

Boltovskoy, E., and R. Wright. 1976. Recent foraminifera. Dr. W. Junk b.v., The Hague. 515 p.

Brady, H. B. 1884. Report on the foraminifera dredged by H. M. S. Challenger, during the years 1873-76. Rept. Voy. Challenger, Zool., 9:1-814. 115 pls.

Clayshulte, R. N. 1981a. Preliminary checklist of living foraminifera from Guam. In A working list of marine organisms from Guam. Univ. Guam Mar. Tech. Rept. No. 70:16-21.

_________. 1981b. Distribution and recruitment of foraminifera in the families Acervulinidae and Homotrematinidae in shallow coral reef environments on Guam. Univ. Guam, M.S. Thesis Biology. 79 p.

Cole, W. S. 1963. Tertiary larger foraminifera from Guam. U.S. Geol. Survey. Prof. Paper 403-E:1-28.

Cox, G. W. 1967. Laboratory manual of general ecology. W. M. C. Brown Co., Inc., Iowa. p. 33-37.

Cushman, J. A., and R. Todd. 1972. The foraminifera of the tropical Pacific collections of the "Albatross", 1899-1900 Part 4: Rotiliform families and planktonic families. Antiquariaat Junk, Netherlands. 139 p.

Cushman, J. A., R. Todd, and R. J. Post. 1954. Recent foraminifera of the Marshall Islands. U.S. Geol. Survey Prof. Paper 260-H:319-384.

Emery, K. O. 1962. Marine geology of Guam. U.S. Geol. Survey Prof. Paper 403-B:1-76.

Hanzawa, S. 1957. Cenozoic foraminifera of Micronesia. Geol. Soc. Amer. Memori 66. 163 p.

Loeblich, A. R., and H. Tappan. 1964. Part C, Protista 2. In Moore, R. C. (ed.), Treatise on invertebrate paleontology. Geo. Soc. Amer., Univ. Kansas Press. p. 55-900.

Todd, R. 1966. Smaller foraminifera from Guam. U.S. Geol. Survey Prof. Paper 403-I:1-41.

Tracey, J. I., Jr., S. O. Schlanger, J. T. Stark, D. B. Doan, and H. G. May. 1964. General geology of Guam. U.S. Geol. Survey Prof. Paper 403-A:1-104

Table 1. Average species density, coverage, frequency of occurrence and relative ranking for transected habitat substrates from Luminao barrier reef. The species abbreviations are as follows: Mm, M. miniacea; Hr, H. rubrum; Cu, C. utricularis; Cm, C. monticularis; Sc, S. cylindricum; Sr, S. rubrum. The symbol RF is the abbreviation for reef flat. The habitat abbreviations are as follows: LCB, branching living coral; LCM, massive living coral; DCB, dead branching coral; DCT, dead tabulate coral; EXK, exposed knob; R, rubble; CAEX, exposed cavity; CAL, shaded or cryptic cavity.

Habitat	Species	Species Density (no./cm^2)			Species Coverage (%)			Frequency of Species Occurrence			Relative Species Ranking		
		RF	6m	12m	RF	6m	12m	RF	6m	12m	RF	6m	12m
LCB	Mm	.006	.073	.073	.005	.098	.094	.110	.105	.170	13.4	177.0	178.9
	Hr	.090	.096	.072	.438	.121	.114	.155	.070	.160	201.0	93.5	96.2
	Cu	.025	.011	.006	.041	.170	.128	.020	.030	.020	85.6	29.5	24.9
LCM	Mm		.121	.083		.115	.059		.225	.190		159.7	101.8
	Hr	.103	.008	.090	.429	.008	.188	.190	.025	.200	203.6	12.2	150.8
	Cu	.047	.057	.028	.301	.177	.064	.110	.150	.070	83.8	128.1	47.4
	Cm	.003			.013			.010			12.6		
DCB	Mm	.087	.197		.356	.269		.100	.400		104.0	276.3	
	Hr	.173	.016		1.370	.016		.100	.050		196.0	23.7	
DCT	Mm	.008		.462	.004		.252	.025		.600	12.6		122.2
	Hr	.145		.292	.471		.193	.175		.550	258.6		93.7
	Cu	.017		.194	.121		.382	.025		.250	28.8		84.1
EXK	Mm		.122	.074		.258	.040		.220	.150		172.9	83.8
	Hr		.177	.102		.280	.154		.250	.180		73.1	151.4
	Cu		.049	.034		.337	.062		.100	.100		46.0	64.8
	Sr		.022			.061			.030			8.0	
R	Mm	.028	.058	.211	.051	.101	.195	.090	100	.340	23.9	121.2	98.9
	Hr	.277	.022	.221	1.398	.032	.264	.410	.045	.360	161.6	35.9	108.8
	Cu	.148	.005	.141	1.591	.056	.492	.275	.010	.240	104.3	20.8	78.8
	Cm	.004		.024	.245		.075	.010		.050	8.2		13.5
	Sc		.003			.007			.010			5.0	
	Sr		.022			.044			.060			117.1	
CAEX	Mm		.202	.100		.396	.068		.350	.200		142.0	74.0
	Hr		.037	.220		.476	.540		.100	.285		62.0	163.4
	Cu		.037	.047		.118	.224		.050	.110		27.1	43.2
	Cm		.018	.012		.238	.122		.050	.025		30.9	19.4
	Sr		.055			.090			.100			38.0	
CAL	Mm	.019	.273	.111	.017	.399	.159	.050	.365	.220	10.4	161.9	66.3
	Hr	.328	.090	.180	1.217	.292	.575	.350	.200	.315	176.4	74.6	122.0
	Cu	.118	.072	.123	1.246	.248	.418	.240	.120	.230	99.5	57.8	85.7
	Cm	.003	.003	.026	.016	.005	.332	.005	.005	.050	1.3	1.6	18.3
	Sc	.004		.003	.279		.282	.010		.005	12.5		7.7
	Sr		.006			.018			.005			4.1	

Table 2. Average species recruitment on bulk substrates from Luminao barrier reef. The species abbreviations are as follows: Mm, M. miniacea; Hr, H. rubrum; Cu, C. utricularis; Cm, C. monticularis; Sc, S. cylindricum.

Location	Depth (m)	Species	Density (no./cm^2)	Coverage (%)	Frequency of occurrence	Relative importance	Average no. of specimens
Luminao (barrier reef)	7	Mm	0.071	0.253	0.150	200.0	6
		Hr	0.052	0.014	0.070	48.0	2
		Cu	0.015	0.084	0.040	51.8	1
	Total		0.138	0.351	0.260	300.0	9
	9	Mm	0.117	0.097	0.250	129.9	7
		Hr	0.099	0.129	0.220	98.0	6
		Cu	0.033	0.064	0.080	45.1	2
		Sc	0.007	0.351	0.020	27.0	2
	Total		0.256	0.641	0.570	300.0	17
	12	Mm	0.212	0.227	0.380	100.6	11
		Hr	0.247	0.907	0.380	119.4	12
		Cu	0.073	0.306	0.160	46.7	4
		Cm	0.013	0.236	0.030	13.0	1
		Sc	0.004	0.312	0.010	20.3	1
	Total		0.549	1.988	0.960	300.0	29
	12	Mm	0.381	0.162	0.340	58.1	10
		Hr	0.358	0.624	0.460	120.1	13
		Cu	0.255	0.608	0.280	66.0	7
		Cm	0.038	0.060	0.060	13.7	1
		Sc	0.061	2.684	0.080	42.1	2
	Total		1.093	4.138	1.220	300.0	33
	26	Mm	0.318	0.191	0.500	130.0	14
		Hr	0.227	0.199	0.400	110.0	10
		Cu	0.113	0.086	0.150	46.3	5
		Cm	0.023	0.032	0.050	13.7	1
	Total		0.681	0.508	1.100	300.0	30
	27	Mm	0.123	0.092	0.200	252.6	8
		Hr	0.015	0.012	0.050	42.4	1
	Total		0.138	0.105	0.250	300.0	9
	55	Mm	0.210	0.353	0.300	213.7	12
		Hr	0.035	0.011	0.100	34.8	2
		Cu	0.017	0.034	0.050	23.5	1
		Cm	0.017	0.053	0.050	28.0	1
	Total		0.280	0.451	0.500	300.0	16

SURFACE PLANKTON

by

Ann Hillmann-Kitalong

A quantitative and semi-qualitative plankton survey was conducted over a six month period starting September 1980. This survey was part of a study, sponsored by the Guam Energy Office and the Guam Office of Coastal Zone Management, to assess the environmental impact of the construction of an OTEC energy facility off Cabras-Piti Reef.

No plankton survey had been previously conducted at Cabras-Piti Reef, however the Piti Canal and Channel to the immediate east of the study site and Apra Harbor on the opposite side of the breakwater have been surveyed (Tseng, 1971; Grovhoug, 1977; Marsh et al., 1980). Apra Harbor had the higher mean numbers of organisms and a richer diversity of organisms than the other areas studied. No seasonal trends were found due to monthly variations. But specific groups had peak abundances on given months.

For this survey, two study sites were established, one inshore (0.5 km x 0.2 km) and one offshore (0.3 km x 0.3 km) of Cabras-Piti Reef (Fig. 1). These sites were surveyed on a biweekly basis day (1500-1700) and night (1800-2000). A plankton net with a 0.5 m diameter and a 0.35 mesh size was used for all the tows. The net was towed approximately ten meters behind the boat about 0.1 m below the surface. Replicate tows were conducted at each station. Volume transport was calculated by timing triplicate fluoresceine dye patches over a known distance. Time (ten minutes) and speed (0.65 m/sec) were maintained as closely as possible. The zooplankton was immediately preserved in 5% neutral formalin for later identification. Subsamples were taken with a Folsom splitter and counted on a plastic petri dish with a grid (see Table 2).

A third plankton sample was collected at each station from October 9 to January 22. This sample was kept in an ice chest in the field. Dry weights were determined by filtering the sample for excess preserving fluid and placing them onto plastic petri dishes. These samples were then left 48 hours to dry out excess water and then placed in plastic weighing dishes and dried in an oven for 48 hours at 50°C.

A four-way ANOVA (SPSS computer program package) was used to test for significant differences and interactions between eight predominant groups of plankton, offshore and inshore transects, day and night samples, and the dates of the sampling (see Tables 1a, 1b, and 2). Significan differences were found between the groups, the day of sampling, and day and night tows. No significant difference was found between transects. Significant 2-way interactions were found for groups and the date, and for groups and the day and night tows. No significant interaction was found between the date and the transects or the transects and the day and night samples.

A one-way ANOVA showed significant differences between the ten predominant groups of zooplankton but not between months. The calanoid group of copepods, representing at least ten different species, was the most abundant group of organisms and accounted for the differences found between species. The one-way ANOVA for dates showed that December 9 and 23 had the highest mean number of the ten predominant/m^3 groups of plankton. December 23 and March 5 had the highest total number of organisms for the six month period (1000 org/m^3); February 5, October 9, January 7, and December 10 all had about 500 organisms/m^3; and February 19 and January 21 had about 300 organisms/m^3. Night tows were always higher in total number of organisms than day tows for all the predominant groups. Bivalve larvae and barnacle larvae were only found at night. All other groups were found day and night. Total dry weights were highest for December 23 (2.6728 g); high for October 9 (2.0110 g); January 7 (1.4900 g) and December 10 (1.366 g); and low for January 21 (0.4497 g). These values correlate well with the total number of organisms collected on each date. Patchiness between replicate tows was found especially for mysids (Dec. 23), calanoid copepods (Dec. 9, 10, and Oct. 9), and radiolaria (Oct. 9). All the latter patches were found inshore at night except the radiolaria which was offshore during the day. This patchiness causes great variance between tows.

The composition of organisms found at Cabras-Piti Reef was similar to the previous surveys of adjacent areas. Radiolarians, the diatom Coscinodiscus, siphonophores, and salps were only found at Cabras-Piti Reef and not in adjacent areas. These groups are commonly found offshore.

The significance of these findings in respect to the construction of an OTEC plant can only be speculative. This survey was only for surface plankton, whereas plankton at deeper depth would also be affected by the OTEC plant. The thermal nutrient rich waters processed by the plant may cause a change in the plankton community. Organisms more tolerant physiologically to temperature change may predominant. When temperature increases, metabolic activity will increase according to the van't Hoff principle (Swartzman and Adams, 1979) and favor smaller sized organisms. An increase in nutrients will increase the number of smaller sized plankton also. Survival of larvae depends on predation and the availability of food which is probably microcopepods. Larval fish seem to have a limit to the amount of feeding they can do above a certain density of microcopepods. Chaetognaths a known predator on fish may increase disproportionately when microcopepods numbers increase, whereas fish larvae could not feed above a certain density of microcopepods. Thus fish larvae would be at a disadvantage and chaetognath predation would limit the numbers of larvae (Clutter, 1969).

Literature Cited

Clutter, R. I. 1969. Plankton ecology. Univ. of Hawaii Water Resources Res. Center Tech. Dept. 31:267-323.

Grovhoug, J. G. 1978. Piti power plant intake survey November 1977. Naval Ocean System Center, Hawaii Lab. Tech. Rept. 288. 58 p.

Marsh, J. A., Jr., M. I. Chernin, and J. E. Doty. Power plants and the marine environment in Piti Bay and Piti Channel, Guam 1976-1977. Observations and general summary. Univ. Guam Mar. Lab. Tech. Rept. 38. 93 p.

Marsh, J. A., Jr., S. de Wilkins, D. E. Pendleton, and A. Hillmann-Kitalong. 1980. Cabras Seawater Scrubber Project: Phase II. Ecological studies progress report submitted to R.W. Beck and Associates. 102 p.

Swartzman, G. L., and V. D. Adams. 1979. Simultating the effects of increased temperature to a plankton ecosystem. Center for quantitative Science. Univ. of Wash. Tech. Rept. 0974. 50 p.

Tseng, W.-Y. 1971. A preliminary study of zooplankton in the waters of Guam. Univ. Guam Mar. Lab unpublished report.

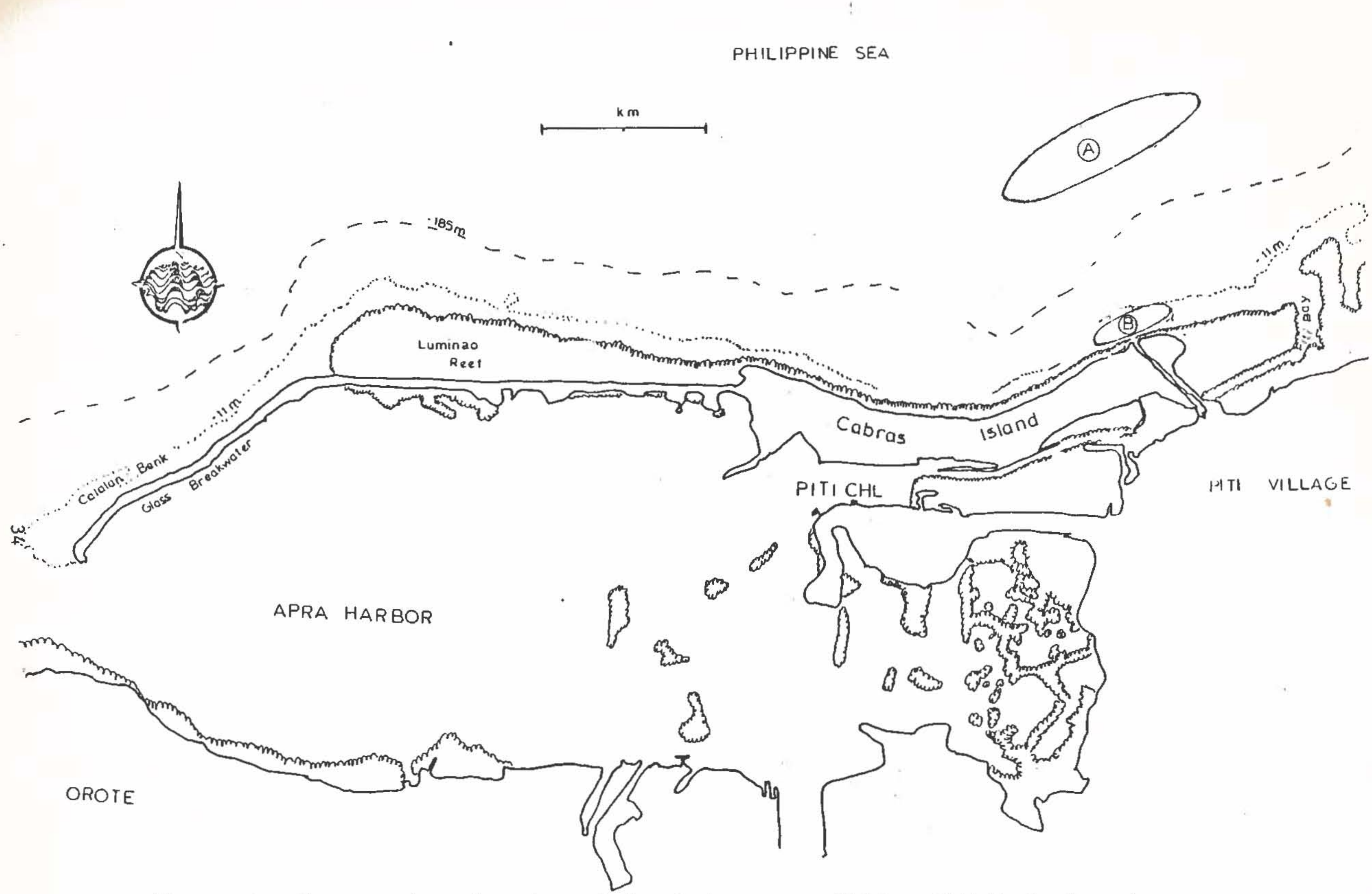


Figure 1. The approximate locations of the plankton tows off Cabras-Piti Reef. Legend: (A) = offshore, (B) = inshore.

Table 1 a. Mean counts with the 95% confidence interval and sample size for the ten most predominant plankton categories. The data were analyzed using a one-way ANOVA. Significance levels: NS <.05, * ≥.05, ** ≥.01, *** ≥.001.

Table 1 b. Mean counts with the 95% confidence interval and sample size for the nine dates plankton were collected.

Table 1a

Copepods/Calanoid	8.97±0.78(31)
Shrimp Zoeae	6.31±1.13(31)
Crab Zoeae	6.30±1.02(32)
Fish Eggs "Round"	5.95±1.14(31)
Veliger Capsules	5.86±1.23(31)
Fish Larvae	5.47±0.82(30)
Foraminifera*	4.57±0.97(31)
Larvacea**	3.85±0.96(31)
Siphonophores	3.24±0.09(30)
Copepods/Harpacticoids	2.84±0.77(31)

Source of Variation	DF	Mean Square
Between groups	9	99.95***
Within groups	299	7.2351

Table 1b

Dec. 9	6.71±1.29(20)
Oct. 9	6.41±1.12(30)
Mar. 5	5.54±1.22(40)
Dec. 10	5.49±1.06(39)
Dec. 23	5.41±1.02(40)
Feb. 5	4.99±1.10(20)
Jan. 23	4.98±1.10(20)
Feb. 19	4.72±0.99(40)
Jan. 7	4.62±0.97(40)

DF	Mean Square
8	14.79^{NS}
300	9.81

Table 2 . The degrees of freedom (DF), the mean sums of squares, and the significance levels for eight predominant groups of plankton [calanoid and harpaticoid copepods, shrimp and crab zoeae, fish eggs and larvae, foraminifera (*Orbulina universa*), larvacea (*Oikopleura* sp. A), and unidentified veliger capsules], the seven dates of completed eight tows (excluding Oct. 9 and Feb. 5), the day-night tows, and offshore inshore transects. The data were analyzed using a four way ANOVA.

Source of Variation	DF	Mean Square
Main effects	5	65.79***
Groups	7	121.34***
Day	6	14.43**
Transect	1	2.91
Day-Night Tows	1	22.29*
2-way Interactions	69	11.11***
Groups Day	42	8.51**
Groups Transect	77	9.62
Groups Day-Night Tows	7	25.84***
Day Transect	6	9.55
Day Day-Night Tows	6	14.71***
Transect Day-Night Tows	1	2.44

* The Foraminifera group was represented by *Orbulina universa*.
** The Larvacea group was represented by *Oikopleura* sp. A.

Table 3. Quantitative checklist of plankton collected off Luminao Reef. Numbers in parentheses equal standard deviation. Location legend: IS = inshore, OS = offshore.

Date: October 9 / Taxa	Location / Sampling Number	IS 1	OS 4	OS 5	IS 7	IS 8	OS 10	OS 11
Chrysophyta								
Bacillariophyceae (Diatoms)								
Centrales								
Coscinodiscus sp. A		0.58	9.90	6.07			1.99(2.81)	4.75
Protozoa								
Foraminifera								
Orbulina universa					0.19(0.27)	0.91(0.27)	0.38(0.28)	
Globigerina sp. B				0.49				
Radiolaria								
Species A		87.39					3.88(2.74)	
Cnidaria								
Siphonophora		0.10		0.19	0.19		0.19(0.27)	
Medusae					0.58(0.55)	0.29(0.14)	0.24(0.34)	0.19
Annelida								
Polycheate larvae				0.10	4.66(2.19)	5.05(2.20)	0.24(0.07)	
Arthropoda/Crustacea								
Cladocera								
Evadne sp. A								
Ostracoda		6.12			1.65(0.14)	1.36(0.82)	1.16(0.41)	
Unidentified sp. A								
Euconchoecia sp. A								
Conchoecia sp. A								
Copepoda/Calanoida		3.49	3.98	3.06	95.84(12.62)	19.79(4.66)	119.21(0)	9.02
Oithona sp. A			0.97					
Oithona sp. B					0.10(0.14)	0.10(0.14)		
Unidentified sp. A						0.10(0.14)		

Table 3 Continued.

Date: October 9	Location	IS	OS	OS	IS	IS	OS	OS
Taxa	Sampling Number	1	4	5	7	8	10	11
Copepoda/Harpacticoida								
Unidentified harpaticoids							0.24(0.21)	
Copepoda/Unidentified Order sp. A								
Copepoda/Unidentified Order sp. B					0.39(0.27)			
Cirripedia								
Nauplii sp. A					0.78(0.27)	3.59(0.69)	0.10(0.03)	
Malacostraca								
Mysidacea sp. A			0.10		1.26(0.96)	1.65(0.69)	3.01(1.92)	12.33
Mysidacea sp. B			0.39		1.84(0.69)	6.12(2.88)	9.12(1.23)	12.12
Cumacea sp. A					0.10(0.14)			
Isopoda sp. A				0.15	0.10(0.14)	0.10(0.14)	0.10(0)	
Amphipoda sp. A							0.48(0.69)	
Decapoda/Shrimp mysis sp.		0.19	0.58		13.87(5.88)	43.07(11.80)	4.03(2.13)	2.81
Decapoda/Crab zoeae sp.		1.16	0.97	3.40	0.48(0.14)	29.52(15.65)	1.50(0.75)	0.97
Decapoda/Crab megalops sp.					22.79(2.61)	17.85(7.28)	4.61(3.09)	2.04
Mollusca								
Gastropoda								
Gastropod veliger larvae			0.19	0.05		0.68(0.14)	0.29(0.14)	0.48
Pteropoda								
<u>Cresius acicula</u>		0.58	0.10	0.48	0.29(0.14)		0.10(0)	
Unidentified sp. A								
Bivalvia								
Bivalve veliger larvae								
Unidentified veliger capsules		6.12	14.56		3.30(2.19)	0.19(0)	3.21(3.98)	2.81
Echinodermata								
Echinoderm larvae								
Chaetognatha								
<u>Sagitta enflata</u>				0.05	0.39(0)			0.10
<u>Sagitta</u> sp. A				0.24			0.29(0.14)	0.29

Table 3 Continued.

Date: October 9 — Location	IS	OS	OS	IS	IS	OS	OS
Taxa — Sampling Number	1	4	5	7	8	10	11
Chordata							
Urochordata							
Larvacea							
Oikopleura sp. A		0.78	0.48				0.97
Oikopleura sp. B				1.45(2.06)		0.24(0.21)	
Fritillaria borealis							
Thaliacea (Salpa)							
Salpa sp. A		0.19		0.97(0.14)	0.39(0.27)	0.05(0.07)	
Vertebrata							
Osteichthyes							
Fish larvae		0.29	0.24	1.45(0.41)	0.39(0)	0.39(0.27)	0.10
Fish eggs "oval"	0.68	0.78	0.86		0.97(0.55)	3.93(5.42)	
Fish eggs "round"		0.10	2.57	40.74(10.97)	0.58(0.55)	0.49(0.70)	0.68
Miscellaneous		0.39					0.58
Individual/Cubic meter	106.41	34.18	18.43	193.41	132.7	155.44	40.24
Settled Vol. (ml/cubic meter)	0.02	0.02	0.40	0.49	0.39	0.21	0.20
Aliquots counted	1/8	1/8	1/4	1/16 1/16	1/16 1/16	1/8 1/8	1/8
Dry weight (g)	0.0703	0.1096		1.4459		0.3153	

Table 3 Continued.

Date: December 9 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5
Chrysophyta					
Bacillariophyceae (Diatoms)					
Centrales					
Coscinodiscus sp. A		0.78(0.06)	0.07(0.01)	1.06(0.14)	
Protozoa					
Foraminifera					
<u>Orbulina</u> <u>universa</u>			0.02(0)		
Globigerina sp. B		0.49(0.12)	0.01(0.01)		
Radiolaria					
Species A					
Cnidaria					
Siphonophora		0.43(0.03)	0.07(0.03)	0.64(0.63)	
Medusae		0.10(0.09)	0.19(0.08)		
Annelida					
Polycheate larvae		0.04(.06)		1.06(0.68)	0.05(0.07)
Arthropoda/Crustacea					
Cladocera					
Evadne sp. A			0.03(0.01)		
Ostracoda			0.19(0)		
Unidentified sp. A					
Euconchoecia sp. A					
Conchoecia sp. A					
Copepoda/Calanoida					
Unidentified species		8.29(2.87)	7.50(0.42)	105.72(10.35)	14.90(11.88)
Copepoda/Cylcopoida					
Oithona sp. A				0.19(0.27)	
Oithona sp. B				0.10(0.14)	
Unidentified sp. A				0.48(0.14)	

Table 3 Continued.

Date: December 9 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5
Copepoda/Harpacticoida					
Unidentified harpaticoids			0.25(0.21)	0.96(0.27)	
Copepoda/Unidentified Order sp. A		0.12(0.06)	0.01(0)	0.19(0.27)	0.10(0.14)
Copepoda/Unidentified Order sp. B				0.10(0.14)	
Cirripedia					
Nauplii sp. A				0.19(0)	
Malacostraca					
Mysidacea sp. A		0.06(0.03)			0.78(0.10)
Mysidacea sp. B					
Cumacea sp. A			0.02(0.01)	0.19(0.27)	
Isopoda sp. A					
Amphipoda sp. A			0.01(0.01)		
Decapoda/Shrimp mysis sp.		1.02(0.42)	0.13(0.04)	0.57(0.13)	
Decapoda/Crab zoeae sp.		0.23(0.03)	1.17(1.17)	0.77(0.27)	0.25(0.22)
Decapoda/Crab megalops sp.		0.04(0.05)			
Mollusca					
Gastropoda					
Gastropod veliger larvae			0.01(0.01)		
Pteroda					
<u>Cresius acicula</u>		0.06(0.03)			
Unidentified sp. A			0.01(0.01)		
Bivlavia					
Bivalve veliger larvae					
Unidentified veliger capsules		2.90	1.15(0.22)	16.46(1.22)	4.47(0.82)
Echinodermata					
Echinoderm larvae					
Chaetognatha					
<u>Sagitta enflata</u>			0.01(0.01)	0.58(0.27)	
<u>Sagitta</u> sp. A		0.19(0.20)	0.01(0.01)		0.10(0)

Table 3 Continued.

Date: December 9	Location	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5
Chordata					
Urochordata					
Larvacea					
Oikopleura sp. A		0.15(0.21)		2.21(0.41)	0.73(0.34)
Oikopleura sp. B			0.19(0.21)	7.51(1.36)	
Fritillaria borealis		2.44(0.29)			
Thaliacea (Salpa)					
Salpa sp. A			0.19(0.08)		
Vertebrate					
Osteichthyes					
Fish larvae		0.04(0.06)	0.80(1.13)	0.39(0.27)	0.15(0.07)
Fish eggs "oval"		0.05(0.02)	0.02(0)	0.19(0.27)	
Fish eggs "round"		0.52(0.07)	0.30(0.01)	4.60(0.02)	2.18(0.21)
Miscellaneous					
#Individiduals/cubic meter		17.95	12.17	144.35	23.71
Settled Vol. (ml/cubic meter)		0.08	0.06	0.18	0.12
Aliquots counted		1/4 1/8	1/8 1/8	1/16 1/16	1/8 1/8
Dry weight (g)		0.0874		.0567	

Table 3 Continued.

Date: December 10 Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa Sampling Number	1	2	4	5	7	8	10	11
Chrysophyta								
Bacillariophyceae (Diatoms)								
Centrales								
Coscinodiscus sp. A	0.05	1.35(0.33)	0.05(0.06)		0.19(0)			
Protozoa								
Foraminifera								
Orbulina universa		0.05(0.05)				5.09(1.36)	5.10(0.41)	1.06(0.14)
Globigerina sp. B		0.19(0.13)						
Radiolaria								
Species A								
Cnidaria								
Siphonophora			0.05(0.07)		0.10(0.13)	0.05(0.07)		
Medusae					0.09(0.13)			
Annelida								
Polycheate larvae	0.01			0.13(0.19)			1.06(0.14)	0.38(0.42)
Arthropoda/Crustacea								
Cladocera								
Evadne sp. A		0.19(0)	0.05(0)					
Ostracoda					1.02(0.39)	0.64(0)		
Unidentified sp. A								
Euconchoecia sp. A				0.04(0)		0.10(0.14)	9.82(5.17)	4.52(2.86)
Conchoecia sp. A								
Copepoda/Calanoida								
Unidentified species	0.10		12.55(0.53)	7.62(1.17)	9.16(0.13)	7.70(2.31)	31.58(2.18)	125.84(8.03)
Copepoda/Cylcopoida								
Oithona sp. A			0.05(0.07)	0.54(1.03)	0.18(0.26)	0.10(0.14)		0.19(0.27)
Oithona sp. B								

Table 3 Continued.

Date: December 10 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Unidertified sp. A									
Copepoda/Harpacticoida									
Unidentified harpaticoids					0.04(0.06)	0.09(0.13)	0.10(0.14)	0.19(0)	0.10(0.14)
Copepoda/Unidentified Order sp. A									
Copepoda/Unidentified Order sp. B									
Cirripedia									
Nauplii sp. A									
Malacostraca									
Mysidacea sp. A				0.23(0.20)	0.78(0.35)				
Mysidacea sp. B						19.13(3.15)	7.85(0.20)	23.01(3.95)	30.71(7.50)
Cumacea sp. A							0.14(0.20)		
Isopoda sp. A				0.05(0.07)	0.02(0.03)	0.09(0.14)	0.10(0.14)		
Amphipoda sp. A								1.44(0.68)	3.37(0.68)
Decapoda/Shrimp mysis sp.		0.04	0.23(0.07)	0.14(0.20)		8.69(0)	7.61(0.54)	12.71(1.36)	5.96(0.57)
Decapoda/Crab zoeae sp.		0.12				1.11(1.05)	0.36(0.44)		1.06(0.14)
Decapoda/Crab megalops sp.							0.34(0.07)	8.86(5.99)	6.45(0.68)
Mollusca									
Gastropoda									
Gastropod veliger larvae							0.10(0.14)	1.44(0.68)	0.58(0)
Pteropoda									
Cresius acicula			0.05(0.06)				0.14(0.07)	0.19(0.27)	
Unidentified sp. A		0.14	0.05(0.06)						
Bivalvia									
Bivalve veliger larvae							0.05(0.07)	0.30(0.14)	
Unidentified veliger capsules		0.78	2.05(1.05)	5.16(1.64)	3.48(1.39)	14.77(3.55)	7.54(1.70)	5.10(0.41)	0.67(0.14)
Echinodermata									
Echinoderm larvae		0.05	0.19(0.26)		0.22(0.03)			0.48(0.41)	0.19(0)

Table 3 Continued.

Date: December 10	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Chaetognatha									
Sagitta enflata				0.05(0.07)					
Sagitta sp. A						0.09(0.13)	0.14(0.07)	0.42(0.49)	0.99(0.59)
Chordata									
Urochordata									
Larvacea									
Oikopleura sp. A		0.144	0.33(0.20)	1.72(0.33)	0.29(0.22)		0.14(0.07)	13.09(0)	4.65(0.86)
Oikopleura sp. B									
Fritillaria borealis		0.24	2.88(1.45)	0.06(0.92)			0.05(0.07)		
Thaliacea (Salpa)									
Salpa sp. A		0.024	0.49(0.53)			0.09(0.52)	0.29(0.14)		
Vertebrata									
Osteichthyes									
Fish larvae		0.012			0.18(0.13)	0.37(0.26)	0.29(0.14)	2.40(0.14)	0.19(0)
Fish eggs "oval"			0.98(0.72)	1.26(0.33)		1.20(0.39)	0.72(0.34)		
Fish eggs "round"		0.012	0.51(0.33)	10.32(4.08)	1.81(0.98)	1.02(0.65)		10.29(0.97)	13.38(16.48)
Miscellaneous			0.17(0.24)						
#Individuals/cubic meter		17.34	11.44	31.68	15.15	57.37	39.64	127.48	199.75
Settled Vol. (ml/cubic meter)		0.02	0.02	0.09	0.11	0.29	0.26		0.36
Aliquots counted		ALL	1/8 1/8	1/8 1/8	1/4 1/4	1/16 1/16	1/8 1/8	1/16 1/32	1/16 1/16
Dry weight (g)		0.0084		0.1226		0.3040		0.9323	

Table 3 Continued.

Date: December 23	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Chrysophyta									
Bacillariophyceae (Diatoms)									
Centrales									
Coscinodiscus sp. A		0.36(0.36)	0.67(0.22)	1.59(0.56)	3.70(0)	1.60(2.26)	0.14(0.20)	0.55(0.07)	
Protozoa									
Foraminifera									
Orbulina universa					0.41(0.58)			0.10(0.14)	1.54(1.09)
Globigerina sp. B		0.15(0.07)	0.15(0.07)			2.00(5.66)	0.14(0.20)	1.50(2.83)	
Radiolaria									
Species A		0.15(0.07)				4.98(7.05)		30.0(0)	
Cnidaria									
Siphonophora			1.86(0.15)	5.18(0.56)	1.86(0.88)	4.80(4.52)	0.74(0.39)	3.15(2.12)	0.19(0.27)
Medusae		0.05(0.07)	0.05(0.07)			0.80(1.13)	0.09(0.13)		0.19(0.27)
Annelida									
Polycheate larvae		0.21(0)	0.05(0.07)	1.79(0.28)	5.98(2.04)	2.80(3.96)	0.09(0)	0.15(0.07)	1.92(0.54)
Arthropoda/Crustacea									
Cladocera									
Evadne sp. A		0.41(0.15)		23.53(1.13)	3.07(2.63)		0.56(0.79)	0.85(0.71)	1.54(0.54)
Ostracoda									12.13(3.54)
Unidentified sp. A									
Euconchoecia sp. A			0.10(0)		7.84(3.50)	28.40(17.54)			2.12(0.27)
Conchoecia sp. A							0.05(0.07)		
Copepoda/Calanoida									
Unidentified species		1.65(1.61)	4.64(1.75)	14.35(6.20)	280.01(11.38)	18.24(1.55)	23.25(6.58)	6.60(2.54)	46.58(1.63)
Copepoda/Cylcopoida									
Oithona sp. A				0.60(0.28)	0.41(0.58)		0.05(0.07)		0.38(0)
Oithona sp. B				0.60(0.28)	21.88(7.59)	1.60(1.13)	0.05(0.07)	0.10(0)	2.50(1.36)
Unidentified sp. A				7.18(1.13)					

Table 3 Continued.

Date: December 23 — Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa — Sampling Number	1	2	4	5	7	8	10	11
Copepoda/Harpacticoida								
Unidentified harpaticoids	0.10(0)		7.38(0.28)	14.03(0.58)		0.05(0.07)	0.10(0)	5.20(2.99)
Copepoda/Unidentified Order sp. A	0.10(0)	0.21(0)	2.39(0.56)	5.98(0.87)	0.80(1.13)	0.09(0)	0.20(1.41)	0.19(0.27)
Copepoda/Unidentified Order sp. B	0.05(0.07)	0.05(0.07)		0.62(0.29)	0.20(0.14)		0.10(0)	
Cirripedia								
Nauplii sp. A								0.19(0.27)
Malacostraca								
Mysidacea sp. A	0.26(0.36)				0.40(0.57)		0.05(0.07)	1.54(0.54)
Mysidacea sp. B					52.00(5.66)	5.11(2.24)		122.24(1.36)
Cumacea sp. A							0.05(0.07)	0.19(0.27)
Isopoda sp. A	0.05(0.07)				1.20(1.70)			
Amphipoda sp. A					0.10(0)			1.15(0.54)
Decapoda/Shrimp mysis sp.		1.91(0.51)	0.40(0)	0.86(0)	4.09(0.28)	3.72(0.53)	0.75(0.71)	11.43(8.12)
Decapoda/Crab zoeae sp.	0.82(0.87)	1.86(4.24)	2.59(0.28)	0.41(0.58)	3.20(4.51)	0.42(0.59)	1.95(0.92)	1.54(0.54)
Decapoda/Crab megalops sp.				0.21(0.29)	3.20(4.53)	0.14(0.20)		1.35(1.36)
Mollusca								
Gastropoda								
Gastropod veliger larvae	0.05(0.07)				6.80(5.09)	0.37(0.26)	0.55(0.35)	1.73(1.91)
Pteropoda								
Cresius acicula				1.44(0.88)	2.80(1.70)	0.37(0.53)		
Unidentified sp. A	0.05(0.07)	0.15(0.07)	2.19(0.85)				0.15(0.07)	0.38(0)
Bivalvia								
Bivalve veliger larvae					1.20(0.57)	0.05(0.07)		
Unidentified veliger capsules	3.91(3.64)	11.28(4.30)		8.05(1.46)	62.85(2.76)	5.58(2.90)	32.0(8.48)	6.16(1.63)
Echinodermata								
Echinoderm larvae					2.40(3.39)			
Chaetognatha								
Sagitta enflata			1.00(1.41)	2.27(0.88)	8.40(2.83)	0.93(0)	0.10(0)	1.35(0.82)
Sagitta sp. A		0.05(0.07)	6.18(3.10)	7.43(1.17)	3.20(2.26)		0.20(0.14)	1.15(1.63)

Table 3 Continued.

Date: December 23	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Chordata									
Urochordata									
Larvacea									
Oikopleura sp. A			0.10(0.15)	0.80(0)	0.83(0)	9.60(13.58)	1.02(0.13)	0.50(0.28)	0.29(0.14)
Oikopleura sp. B					0.41(0)				
<u>Fritillaria borealis</u>						10.80(2.83)			
Thaliacea (Salpa)									
Salpa sp. A			0.15(0.07)			3.60(5.66)	0.14(0.20)	0.30(0.28)	0.19(0.27)
Vertebrata									
Osteichthyes									
Fish larvae			0.46(0.07)	13.56(1.69)	10.73(0.58)	10.80(1.70)	0.60(0.01)	0.20(0.14)	5.00(1.63)
Fish eggs "oval"			0.31(0.29)	0.79(0)	2.27(0.29)	1.60(1.13)	0.05(0.07)	0.07(0.04)	1.15(0)
Fish eggs "round"		1.29(0.95)	0.41(1.41)		2.89(3.30)		0.05(0.07)	0.50(0)	
Miscellaneous			0.05(0.07)				0.23(0.33)	0.05(0.07)	
#Inidividuals/cubic meter		9.66	24.51	92.28	383.59	256.46	40.74	80.82	231.42
Settled Vol. (ml/cubic meter)		0.02	0.02	0.02	0.05	0.12	0.17	0.06	0.48
Aliquots counted		1/8 1/8	1/8 1/8	1/32 1/32	1/32 1/32	1/8 1/8	1/8 1/8	1/8 1/8	1/32 1/32
Dry weight (g)		0.0463		1.3325		0.2781		1.0159	

Table 3 Continued.

Date: January 7 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Chrysophyta									
Bacillariophyceae (Diatoms)									
Centrales									
Coscinodiscus sp. A		0.62(0)	0.38(0.21)			0.23(0.34)			
Protozoa									
Foraminifera									
<u>Orbulina universa</u>				0.11(0.09)	0.89(1.26)	0.47(0)	0.50(0.35)	2.11(0.33)	1.41(0.66)
Globigerina sp. B		0.40(0.04)							
Radiolaria									
Species A						9.41(3.33)			
Cnidaria									
Siphonophora		1.33(0.48)	1.09(0.46)			1.35(0.91)	0.37(0.17)		
Medusae						0.23(0.33)			
Annelida									
Polycheate larvae				0.39(0.08)	0.33(0)	0.06(0.08)		0.70(1.00)	0.35(0.50)
Arthropoda/Crustacea									
Cladocera									
Evadne sp. A					0.11(0.16)				
Ostracoda									
Unidentified sp. A								15.98(1.99)	8.70(2.98)
Euconchoecia sp. A									
Conchoecia sp. A									
Copepoda/Calanoida									
Unidentified species		3.09(0.44)	5.11(2.66)	4.73(0.87)	4.65(0.08)	10.58(1.50)	30.26(5.06)	41.15(24.28)	44.09(41.07)
Copepoda/Cylcopoida									
Oithona sp. A				0.11(0.16)	0.33(0.47)			0.23(0.33)	0.11(0.17)
Oithona sp. B									
Unidentified sp. A		0.19(0)		0.05(0.08)					

Table 3 Continued.

Date: January 7 / Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa / Sampling Number	1	2	4	5	7	8	10	11
Copepoda/Harpacticoida								
Unidentified harpaticoids				0.17(0.08)	0.23(0.17)	0.59(0)	0.94(0.66)	0.35(0.50)
Copepoda/Unidentified Order sp. A							0.23(0.33)	
Copepoda/Unidentified Order sp. B	0.03(0.04)				0.06(0.08)	0.37(0.17)		
Cirripedia								
Nauplii sp. A				0.06(0.08)				
Malacostraca								
Mysidacea sp. A			2.00(0.47)	1.85(0.08)	7.17(3.66)	3.70(1.74)	11.74(4.65)	7.52(0)
Mysidacea sp. B			0.44(0.63)		2.70(2.16)	9.63(0.70)	48.64(2.33)	79.72(1.33)
Cumacea sp. A	0.06(0.09)							
Isopoda sp. A								
Amphipoda sp. A					0.12(0.17)		0.47(0)	1.41(0)
Decapoda/Shrimp mysis sp.	2.20(0.13)	4.09(1.95)	0.78(0.16)	0.06(0.08)	5.76(1.83)	15.44(3.67)	23.03(7.31)	10.82(0)
Decapoda/Crab zoeae sp.	5.16(0.39)	11.29(3.33)	3.12(0.89)	1.73(0.87)	0.53(0.75)	2.72(1.05)		
Decapoda/Crab megalops sp.	0.09(0.04)					0.25(0)	18.58(2.12)	21.40(10.97)
Mollusca								
Gastropoda								
Gastropod veliger larvae				0.11(0.16)	0.47(0.17)			
Pteropoda								
Cresius acicula					0.06(0.08)			
Unidentified sp. A					0.06(0.08)			
Bivalvia								
Bivalve veliger larvae							0.23(0.33)	
Unidentified veliger capsules	7.73(1.31)	2.35(0)	0.72(0.39)	1.17(0.24)	4.09(1.70)	7.29(3.69)		
Echinodermata								
Echinoderm larvae								
Chaetognatha								
Sagitta enflata					0.29(0.08)		0.12(0.17)	
Sagitta sp. A	0.09(0.04)	0.06(0.08)			0.06(0.08)	0.74(0)	0.12(0.17)	

Table 3 Continued.

Date: January 7 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Chordata									
Urochordata									
Larvacea									
Oikopleura sp. A		0.06(0.09)		0.11(0.09)	0.02(0)			0.70(1.00)	
Oikopleura sp. B					0.06(0.08)	0.12(0.17)	0.25(0.35)		
Fritillaria borealis									
Thaliacea (Salpa)									
Salpa sp. A		0.37(0.17)	0.21(0.04)	0.06(0.08)		0.12(0)	0.25(0)		
Vertebrate									
Osteichthyes									
Fish larvae		0.25(0.28)	0.62(0.21)	0.44(0.16)	0.06(0.08)	0.41(0.42)	0.59(0)	0.47(0)	1.53(0.17)
Fish eggs "oval"		0.12(0)	0.23(0.17)	0.11(0)	0.02(0)	0.41(0.08)	0.12(0.17)		
Fish eggs "round"		0.62(0)		0.95(0.24)	0.38(3.14)			1.17(0.33)	
Miscellaneous						0.29(0.25)			
#Individuals/cubic meter		46.12	25.23	14.12	11.15	51.03	72.99	166.62	177.41
Settled Vol. (ml/cubic meter)		0.03	0.07	0.03	0.14	0.18	0.31	0.37	0.44
Aliquots counted		1/4 1/4	1/4 1/4	1/8 1/8	1/8 1/8	1/8 1/8	1/16 1/16	1/32 1/32	1/16 1/16
Dry weight (g)		0.1513		0.0721		0.2424		1.0242	

Table 3 Continued.

Date: January 22 — Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa — Sampling Number	1	2	4	5	7	9	10	11
Chrysophyta								
Bacillariophyceae (Diatoms)								
Centrales								
Coscinodiscus sp. A	0.62(0)	0.39(0.19)	0.62(0.87)	0.26(0.07)		0.12(0.17)		
Protozoa								
Foraminifera								
<u>Orbulina universa</u>	1.39(1.50)	0.03(0.04)				0.80(0.44)	1.00(0.23)	6.92(0.70)
Globigerina sp. B			0.31(0.26)	0.37(0.07)	0.68(0.61)		0.49(0.12)	0.72(0)
Radiolaria								
Species A								
Cnidaria								
Siphonophora	0.17(0.08)	0.34(0.26)	0.06(0.09)		0.40(0.31)	0.68(0.26)	0.25(0)	
Medusae		0.11(0)				0.25(0.17)		0.36(0.51)
Annelida								
Polycheate larvae	0.06(0.08)						0.25(0.35)	
Arthropoda/Crustacea								
Cladocera								
Evadne sp. A								
Ostracoda								
Unidentified sp. A							1.48(0)	0.25(0)
Euconchoecia sp. A								
Conchoecia sp. A						0.06(0.09)	0.12(0.17)	
Copepoda/Calanoida								
Unidentified species	0.22(0.16)	0.31(0.22)	6.49(1.66)	19.32(3.56)	3.94(2.24)	5.69(0.35)	48.37(6.12)	31.79(6.12)
Copepoda/Cylcopoida								
Oithona sp. A				0.05(0.07)			0.12(0.17)	
Oithona sp. B				0.05(0.07)				
Unidentified sp. A	0.17(0.08)							

Table 3 Continued.

Date: January 22 Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa Sampling Number	1	2	4	5	7	9	10	11
Copepoda/Harpacticoida								
Unidentified harpaticoids		0.03(0.04)	0.62(0.17)				0.12(0.17)	1.36(0.87)
Copepoda/Unidentified Order sp. A	0.06(0.08)						0.12(0.17)	0.74(0)
Copepoda/Unidentified Order sp. B								
Cirripedia								
Nauplii sp. A								
Malacostraca								
Mysidacea sp. A		0.03(0.04)						
Mysidacea sp. B			0.56(0.26)					
Cumacea sp. A			0.06(0.09)					
Isopoda sp. A				0.10(0.15)	0.03(0.04)	0.12(0.17)	0.12(0.17)	
Amphipoda sp. A	0.17(0.24)	0.03(0.04)			0.03(0.04)		0.62(0.17)	2.88(0.34)
Decapoda/Shrimp mysis sp.		0.21(0.07)		0.10(0)	10.17(1.05)	9.77(1.57)	17.20(0.52)	15.19(4.02)
Decapoda/Crab zoeae sp.	0.73(0.08)	0.18(0.11)	0.25(0)	6.30(0.15)	5.73(2.41)	8.10(5.34)	2.96(0)	2.40(0.34)
Decapoda/Crab megalops sp.	0.11(0.16)		0.12(0.17)		0.59(0.44)	0.62(0.35)	2.35(0.52)	1.56(1.314)
Mollusca								
Gastropoda								
Gastropod veliger larvae							0.62(0.52)	0.72(1.02)
Pteropoda								
<u>Cresius acicula</u>				0.05(0.07)		0.12(0.17)		
Unidentified sp. A								
Bivalvia								
Bivalve veliger larvae								
Unidentified veliger capsules	3.90(1.42)		0.95(0.46)	0.52(0)	1.80(1.67)		1.85(0.87)	0.96(1.36)
Echinodermata								
Echinoderm larvae		0.08(0.11)						
Chaetognatha								
<u>Sagitta enflata</u>								
<u>Sagitta</u> sp. A								

Table 3 Continued.

Date: January 22 — Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 9	IS 10	IS 11
Chordata									
Uorchordata									
Larvacea									
Oikopleura sp. A				0.06(0.08)	0.26(0.07)		0.37(0.17)	2.84(0.52)	1.25(0.71)
Oikopleura sp. B				0.19(0.09)					1.00(1.06)
Fritillaria borealis		0.28(0.08)	0.47(0.30)		0.21(0.30)				
Thaliacea (Salpa)									
Salpa sp. A			0.89(0.15)			3.94(0.48)	2.54(0.61)		
Vertebrata									
Osteichthyes									
Fish larvae		0.06(0.08)	0.079(0.04)	0.19(0.09)	0.10(0)	1.39(0.13)	1.05(0.61)	4.82(0.17)	6.42(0)
Fish eggs "oval"		6.18(1.65)	0.40(0.03)	0.06(0.09)		0.31(0.08)	0.19(0.26)		
Fish eggs "round"		4.96(2.44)	6.71(0.52)	0.62(0.87)	0.47(0.07)	0.62(0.17)	0.37(0.52)	1.61(0.17)	3.83(0.71)
Miscellaneous		0.06(0.08)						0.12(0.17)	
#Individuals/cubic meter		40.92	11.00	11.16	28.16	29.63	30.85	87.43	78.35
Settled Vol. (ml/cubic meter)		0.03	0.02	0.08	0.13	0.31	0.15	0.31	0.15
Aliquots counted		1/4 1/4	1/4 1/4	1/8 1/8	1/8 1/8	1/4 1/4	1/8 1/8	1/16 1/16	1/16 1/16
Dry weight (g)		0.0496		0.0373		0.2232		0.1896	

Table 3 Continued.

Date: February 5 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4
Chrysophyta				
Bacillariophyceae (Diatoms)				
Centrales				
Coscinodiscus sp. A				
Protozoa				
Foraminifera				
Orbulina universa		0.51(0.24)	0.39(0.24)	0.17(0.08)
Globigerina sp. B		0.51(0.24)	5.73(7.62)	
Radiolaria				
Species A				
Cnidaria				
Siphonophora		0.28(0.24)	0.46(0.48)	0.03(0)
Medusae				
Annelida				
Polycheate larvae				
Arthropoda/Crustacea				
Cladocera				
Evadne sp. A				
Ostracoda				
Unidentified sp. A				
Euconchoecia sp. A				
Conchoecia sp. A				
Copepoda/Calanoida				
Unidentified species		0.51(0.24)	0.40(0.08)	1.30(0.08)
Copepoda/Cylcopoida				
Oithona sp. A				
Oithona sp. B				

Table 3 Continued.

Date: February 5 — Location	OS	OS	IS
Taxa — Sampling Number	1	2	4
Unidentified sp. A			
Copepoda/Harpacticoida			
Unidentified harpaticoids	0.06(0.08)	0.11(0.16)	0.03(0.04)
Copepoda/Unidentified Order sp. A			
Copepoda/Unidentified Order sp. B			
Cirripedia			
Nauplii sp. A			
Malacostraca			
Mysidacea sp. A			
Mysidacea sp. B			
Cumacea sp. A			
Isopoda sp. A			
Amphipoda sp. A			
Decapoda/Shrimp mysis sp.	0.34(0.16)	0.40(0)	
Decapoda/Crab zoeae sp.	25.65(6.71)	20.85(1.20)	0.06(0)
Decapoda/Crab megalops sp.	0.06(0.08)		
Mollusca			
Gastropoda			
Gastropod veliger larvae			
Pteropoda			
Cresius acicula			
Unidentified sp. A			
Bivalvia			
Bivalve veliger larvae	0.06(0.08)		
Unidentified veliger capsules	1.30(0.56)	1.24(0.32)	
Echinodermata			
Echinoderm larvae			
Chaetognatha			
Sagitta enflata			
Sagitta sp. A			

Table 3 Continued.

Date: February 5	Location	OS	OS	IS
Taxa	Sampling Number	1	2	4
Chordata				
Urochordata				
Larvacea				
Oikopleura sp. A				
Oikopleura sp. B				
Fritillaria borealis				
Thaliacea (Salpa)				
Salpa sp. A		0.73(0.72)	0.85(0.24)	
Vertebrata				
Osteichthyes				
Fish larvae		0.28(0.08)	0.23(0)	0.03(0.04)
Fish eggs "oval"		0.79(0)	0.056(0)	0.68(0.48)
Fish eggs "round"		0.11(0.16)	0.056(0)	0.28(0.24)
Miscellaneous				
#Individuals/cubic meter		30.06	30.772	2.58
Settled Vol. (ml/cubic meter)		0.07	0.07	0.03
Aliquots counted		1/8 1/8	1/8 1/8	1/8 1/8

Table 3 Continued.

Date: February 19 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Chrysophyta									
Bacillariophyceae (Diatoms)									
Centrales									
Coscinodiscus sp. A			0.96(0.10)		0.05(0.07)	0.16(0.22)	0.84(0.30)		0.05(0.07)
Protozoa									
Foraminifera									
Orbulina universa			3.02(0.28)					1.26(0.31)	7.03(1.93)
Globigerina sp. B				2.89(0.37)	2.15(0.87)	4.15(0.82)	7.78(4.31)	0.46(0.13)	2.99(0.52)
Radiolaria									
Species A		7.88	1.86(0.87)	0.10(0.15)					
Cnidaria									
Siphonophora		0.01		0.10(0.15)	0.05(0.07)	0.05(0.07)	0.26(0.22)		
Medusae					0.05(0.07)	0.05(0.07)		0.09(0.13)	0.10(0)
Annelida									
Polycheate larvae				0.16(0.07)				0.28(0.13)	0.10(0)
Arthropoda/Crustacea									
Cladocera									
Evadne sp. A		0.08	0.05(0.07)				0.05(0.07)		
Ostracoda									
Unidentified sp. A									
Euconchoecia sp. A				0.58(0.07)	0.16(0.22)			1.21(0.92)	1.05(0.30)
Conchoecia sp. A							0.37(0.22)		0.21(0.15)
Copepoda/Calanoida									
Unidentified species		1.04	0.51	13.07(5.27)	6.88(1.86)	12.30(1.19)	9.45(2.38)	4.65(0.53)	11.81(1.11)
Copepoda/Cylcopoida									
Oithona sp. A			0.02(0.03)	1.21(0.71)			0.05(0.07)	0.09(0.13)	
Oithona sp. B				1.21(0.07)					
Unidentified sp. A									

Table 3 Continued.

Date: February 19 / Taxa — Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Copepoda/Harpacticoida								
Unidentified harpaticoids	0.10	0.02(0.03)		0.16(0.22)		1.21(0.52)	0.28(0.13)	0.10(0.15)
Copepoda/Unidentified Order sp. A	0.01			0.05(0.07)		0.10(0.15)	0.28(0.13)	0.05(0.07)
Copepoda/Unidentified Order sp. B							0.19(0)	
Cirripedia								
Nauplii sp. A						0.05(0.07)		
Malacostraca								
Mysidacea sp. A			1.16(1.04)				2.60(0)	1.26(0)
Mysidacea sp. B			0.16(0.22)		0.16(0.22)		1.76(0.39)	4.25(0.96)
Cumacea sp. A		0.02(0.03)						0.10(0)
Isopoda sp. A			0.05(0.07)				0.09(0.13)	1.99(0)
Amphipoda sp. A							0.74(0.26)	
Decapoda/Shrimp mysis sp.	0.39		0.26(0.37)	0.16(0.22)	3.26(1.04)	3.52(0.52)	11.72(5.67)	5.72(4.53)
Decapoda/Crab zoeae sp.	0.13		0.53(0)	2.26(0.52)	14.46(16.73)	14.87(0.82)	3.71(1.05)	2.31(0)
Decapoda/Crab megalops sp.	0.03	0.10(0)	0.05(0.07)				0.28(0.13)	0.47(0.22)
Mollusca								
Gastropoda								
Gastropod veliger larvae	0.01	0.05(0.07)	0.10(0.15)	0.05(0.07)	0.05(0.07)	0.05(0.07)		0.52(0.15)
Pteropoda								
Cresius acicula			0.05(0.07)			0.05(0.07)	0.09(0.13)	
Unidentified sp. A					0.05(0.07)			0.05(0.07)
Bivalvia								
Bivalve veliger larvae								
Unidentified veliger capsules	3.00	4.03(1.29)		1.68(0.89)		2.68(0.22)		0.63(0)
Echinodermata								
Echinoderm larvae			0.05(0.07)					
Chaetognatha								
Sagitta enflata			0.10(0)		2.62(0.07)	0.26(0.07)		0.16(0.22)
Sagitta sp. A					0.31(0.15)	0.31(0)	0.56(0)	

Table 3 Continued.

Date: February 19	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Chordata									
Urochordata									
Larvacea									
Oikopleura sp. A				0.10(0.15)	0.58(0.71)	0.31(0.15)	1.00(0.07)	0.19(0)	0.10(0)
Oikopleura sp. B									
Fritillaria borealis		0.21	0.30(0)	0.10(0.15)	0.42(0.15)				
Thaliacea (Salpa)									
Salpa sp. A		0.01				0.53(0.45)	1.47(0.59)		
Vertebrata									
Osteichthyes									
Fish larvae		0.12	0.05(0.07)	1.16(0.15)	2.41(0.30)	1.05(5.66)	3.68(0.12)	5.39(1.05)	9.20(0.37)
Fish eggs "oval"			0.12(0.11)	0.10(0.15)	1.26	0.74(0)	0.84(0.59)	0.19(0)	0.42(0.15)
Fish eggs "round"		0.14	0.12(0.11)	3.13(0.11)	6.88(0.67)		0.10(0.15)	14.58(1.71)	35.33(1.26)
Miscellaneous			0.02(0.03)				0.05(0.07)		0.31(0.15)
#Individuals/cubic meter		13.16	12.20	26.32	25.25	40.20	49.04	50.60	88.31
Settled Vol. (ml/cubic meter)		0.02	0.01	0.10	0.07	0.13	0.13	0.15	
Aliquots counted		ALL	1/4 1/4	1/8 1/8	1/8 1/8	1/8 1/8	1/8 1/8	1/16 1/16	1/8 1/8
Dry weight (g)		1.9374		1.9552		1.8694		2.2813	

Table 3 Continued.

Date: March 3 / Taxa	Location / Sampling Number	OS 1	OS 2	IS 4	IS 5	OS 7	OS 8	IS 10	IS 11
Chrysophyta									
Bacillariophyceae (Diatoms)									
Centrales									
Coscinodiscus sp. A		0.06(0.08)	0.11(0)			0.11(0.16)		0.22(0.32)	
Protozoa									
Foraminifera									
Orbulina universa		1.13(0.16)		0.34(0.16)	1.69(0.64)	2.25(1.27)	2.42(0.08)	25.25(14.02)	16.00(3.53)
Globigerina sp. B			1.13(0.16)			0.22(0)			
Radiolaria									
Species A									
Cnidaria									
Siphonophora		1.24(0.32)	1.58(0.32)			2.14(0.16)	0.73(0.40)		0.56(0.16)
Medusae		0.28(0.08)					0.11(0.16)		0.22(0.32)
Annelida									
Polycheate larvae				0.28(0.08)		0.79(0.16)	0.06(0.08	0.45(0.59)	
Arthropoda/Crustacea									
Cladocera									
Evadne sp. A									
Ostracoda									
Unidentified sp. A		0.06(0.08)					0.11(0)		4.84(2.98)
Euconchoecia sp. A									
Conchoecia sp. A									
Copepoda/Calanoida									
Unidentified species		1.41(0.72)		18.81(0.88)	21.24(1.83)	23.33(9.72)	8.51(5.18)	15.33(0.64)	36.08(3.19)
Copepoda/Cylcopoida									
Oithona sp. A			0.34(0.16)			0.56(0.79)	0.11(0.16)		0.11(0.16)
Oithona sp. B		0.11(0.16)			0.06(0.08)	0.11(0)			
Unidentified sp. A		0.057(0.08)		2.43(0.56)					

Table 3 Continued.

Date: March 3	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Copepoda/Harpacticoida									
Unidentified harpaticoids			0.06(0.08)		3.10(0.40)	0.34(0.16)	0.17(0.08)	0.90(0)	1.13(1.60)
Copepoda/Unidentified Order sp. A							0.17(0.09)	0.22(0.32)	0.11(0)
Copepoda/Unidentified Order sp. B									
Cirripedia									
Nauplii sp. A						0.22(0)			
Malacostraca									
Mysidacea sp. A				4.12(0.08)				13.75(6.06)	17.13(13.41)
Mysidacea sp. B							0.06(0.08)	9.92(0.63)	44.96(25.7)
Cumacea sp. A									
Isopoda sp. A									
Amphipoda sp. A		0.06(0.08)				0.45(0.32)	0.39(0.16)	5.86(0.64)	3.27(2.39)
Decapoda/Shrimp mysis sp.		1.47(0.64)		0.11(0)		36.79(16.70)	14.60(2.31)	37.20(6.36	44.61(12.17)
Decapoda/Crab zoeae sp.		1.64(0.56)	1.75(0.08)		3.38(0.64)	9.67(3.18)	3.78(3.11)	202.9(1.90)	173.51(86.28)
Decapoda/Crab megalops sp.						0.22(0)	0.06(0.08)	0.68(0.32)	0.34(0.48)
Mollusca									
Gastropoda									
Gastropod veliger larvae					0.62(0.56)	0.68(0.32)	0.22(0)	6.31(0.64)	8.78(2.22)
Pteropoda									
<u>Cresius acicula</u>		0.06(0.08)	0.11(0)	0.34(0.16)					
Unidentified sp. A							0.11(0)		0.11(0.16)
Bivalvia									
Bivalve veliger larvae							0.06(0.08)		0.45(0.64)
Unidentified veliger capsules		1.02(0.96)		0.28(0.40)	0.06(0.08)				1.32(1.59)
Echinodermata									
Echinoderm larvae		0.06(0.08)							
Chaetognatha									
<u>Sagitta enflata</u>						1.24(0.80)	0.34(0.16)	2.03(0.32)	3.38(4.78)
<u>Sagitta</u> sp. A		0.06(0.08)			0.17(0.24)	2.82(0.16)	1.35(1.43)	1.13(0.32)	2.03(2.87)

Table 3 Continued.

Date: March 3	Location	OS	OS	IS	IS	OS	OS	IS	IS
Taxa	Sampling Number	1	2	4	5	7	8	10	11
Chordata									
Uorchordata									
Larvacea									
Oikopleura sp. A									0.56(0.79)
Oikopleura sp. B									
Fritillaria borealis		0.68(0.48)			0.39(0.56)	3.49(1.11)	0.79(0.48)	16.23(2.55)	8.77(12.41)
Thaliacea (Salpa)									
Salpa sp. A		0.28(0.08)	0.06(0.08)			1.01(0.16)	0.99(0.68)	0.22(0.32)	
Vertebrata									
Osteichthyes									
Fish larvae		0.23(0)		3.39(0)	3.27(0.48)	0.45(0.32)	0.67(0.32)	4.28(1.59)	20.28(14.05)
Fish eggs "oval"		1.81(0.64)	0.56(0.16)		0.11(0)	1.58(0.96)	0.84(0.24)		
Fish eggs "round"			1.02(0.32)	4.24(0.40)	10.42(1.19)	65.72(35.86)	22.55(1.75)	25.93(3.51)	77.44(7.94)
Miscellaneous		0.17(0.24)		0.11(0.16)		0.11(0.16)	0.06(0.08)		
#Individuals/cubic meter		11.71	6.72	34.45	44.51	154.30	69.26	230.40	465.79
Settled Vol. (ml/cubic meter)		0.07	0.14	0.14	0.21	0.35	0.42	0.50	0.49
Aliquots counted		1/8 1/8	1/8 1/8	1/8 1/8	1/8 1/8	1/16 1/16	1/8 1/8	1/32 1/32	1/32 1/16

CORALS

by

Richard H. Randall

Introduction

Reef-building scleractinian, octocorallian, and hydrozoan corals are sessile invertebrates with potentially long life spans and distribution patterns that depend upon the particular environmental setting found from one habitat to another. Their stony calcium carbonate skeletons are major contributors to both in situ framework and detrital reef development in the shoal-water environments around Guam. Characteristic coral communities develop in response to the variable environmental conditions found from one habitat to another, ranging from conditions completely unfavorable for corals to optimum conditions where corals are the dominant organisms in the community. Corals are sensitive to many environmental variables; particularly suspended materials in the water column, sediment accumulation on the substrate upon which they grow, water currents, sea water dilution from surface drainage and groundwater discharge, temperature fluctuations, emersion on shallow platforms during low tides, and various forms of pollution from toxic substances and thermal, storm drain, and sewage discharges. Because of their sensitivity to such factors, corals can be useful as indicator organisms which reflect the quality of the environment. Assessment of the present coral communities on the Cabras-Piti-Luminao Reef systems will establish baseline data from which changes in the quality of the reef environment can be determined or predicted. This data will be useful in establishing sound planning practices and management of these reef areas in relation to future OTEC development.

The principal objectives of this part of the study are to determine the distribution and community structure of corals within the study area described in the "Description of the Study Area" section.

Methods

Coral communities were analyzed along transects by using the point-centered or point-quarter technique of Cottam et al. (1953).

Transects A-J were established by placing a plastic surveyors tape along the reef surface at the locations shown in Figure 2 of the "Description of the Study Area" (p. 14). These transect locations are the same as those from which the vertical profile sections in the "Description of the Study Area" were constructed (Figs. 3-A - 3-J, pp. 15-18). Points were established at 2.5 meter intervals along the transect line. A line bisecting the sample point at right angles to the transect line extablished 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 maximum width and length measurements), and the distance from the center of the colony to the sample point was recorded.

From the above point-quarter data the following calculations were used to estimate community structure of the corals:

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

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

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

$$\text{Total percent coverage} = \text{total density of all species} \times \text{average coverage value for all species}$$

$$\text{Percent coverage} = \text{density of a species} \times \text{average coverage value for the species}$$

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

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

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

Colony size distribution data (n = number of data, $\bar{Y}$ = arithmetic mean, s = standard deviation, and w = size range) were also calculated from the point-quarter data.

The coral species encountered during the point-quarter analysis indicate the predominate and common species along the transects. The presence of uncommon and rare species, not encountered during the point-quarter analysis, were determined for each transect by making ten-minute snorkel observations along each side of the transect line for each 100 meters of transect length. An overall list of species is compiled for each transect by combining those encountered during the point-quarter analysis and those from snorkel observations in Table 1. Quantitative data of the predominate and common species encountered from the point-quarter analysis are presented in Table 2. Table 3 shows the number of species found within the zones of each transect.

Vertical profile sections along each transect, shown in Figures 3-A - 3-J in the "Description of the Study Area" section, indicate the zones discriminated, water depth, sediment distribution, and the relative abundance of corals along the transects.

Results and Discussion

Zonation

One of the most noticeable aspects of the coral communities studied on the Cabras-Luminao-Piti Reefs is their unequal distribution along the transects from the shoreline to lower reef front slope. Some reef areas are without corals at all, while other areas support communities ranging from a few widely scattered colonies and species to regions where the surface is dominated by a relatively rich diversity of species. Although less noticeable, considerable community variation also occurs along the reef axis parallel to the shoreline. Because of this variation in coral distribution it was necessary to divide the reef into a number of zones in order to make a realistic quantitative assessment of the coral community. While collecting data and making observations along the transects it was quite obvious that distinctive coral communities were associated with the same physiographic reef zonation distinctions described earlier in the "Description of the Study Area" section. Lateral variation in the coral community along the reefs, as well as the long length of the study area, necessitated the establishment of ten transect areas as shown in Figure 2 (p. 14). Transects A, C, H, I, and J were considered primary study areas in which the coral communities were analyzed from the shoreline or edge of the breakwater (Tepungan Channel at Transect J) to five meters depth on the reef front slope. Transects B, D, E, F, and G were considered secondary study areas in which the coral communities were analyzed on the reef platform zones (inner and outer moat and pavement zones along Luminao Barrier Reef, and pavement and reef margin zones along Cabras Island).

Coral Distribution

A combined total of 160 species of corals representing 45 genera were recorded from the transects along the Luminao-Cabras-Piti Reefs (Table 1). Considerable variation occurred in species richness, size distribution, frequency of occurrence, density, and percentage of substrate coverage between the three reef areas (Luminao, Cabras, and Piti Reefs), between most transects within a reef area, and among the various zones discriminated along the length of each transect (Tables 1-3).

Much of the regional variation found in the community structure of corals on the reef platform zones is attributable to the fact that different parts of the platform are exposed during low spring tides. Corals are unable to survive long periods of emergence, particularly when low spring tides coincide with the drying effects of the mid-day sun, and are thus restricted to parts of the reef platforms that retain water during such time. Low tide exposure accounts for the few species and general low density and percentage of substrate coverage recorded for the reef platform pavement zones along the Luminao-Cabras-Piti Reef system. The few species of corals that were recorded (Tables 1-2) on these periodically exposed pavement zones were confined to small scattered holes that retain some water during low tides. In contrast species richness, and particularly the percentage of substrate coverage, greatly increases in the inner and outer moat zones of Luminao and Piti Reefs that retain water during low spring tides. Species richness and percentage of substrate coverage in the moat zones of Transects A, B, and C on the Luminao Barrier Reef are higher than for any other reef platform studied on Guam. Percentage of substrate coverage in the outer moat zone of Piti Reef was also quite high, but species richness was considerably lower than that of comparable zones on the Luminao reef platform. At Transects D and E on Luminao Reef the general elevation of the reef platform is slightly higher than that at Transects A, B, and C, resulting in reduced water depth in the moat zones during low spring tides and a corresponding reduction in species abundance and percentage of substrate coverage (Tables 1-3). Although emergence is generally not an important factor in the outer part of the reef margin zone because of wave wash, corals in the inner part of the zone are periodically subjected to exposure, particularly if calms accompany low spring tides and waves fail to wash over the surface. Along Cabras Island the reef platform appears to be slightly elevated and has less surge channel development, resulting in greater surface exposure when calms accompany low spring tides and a corresponding reduction in species richness, coral density, and percentage of substrate coverage (Tables 1-3). In contrast there is a marked increase in most of these parameters in the reef margin zones along Luminao and Piti Reefs. In general the shallow reef platform corals are restricted in their upward growth to few centimers above or below the mean low tide water level, and upon reaching this height can then grow only horizontally. Such growth restrictions explains the presence of the many flat-topped corals of massive or compact branching forms called microatolls and the truncated thickets of arborescent growth forms in the shallower moat zones of the reef platforms.

Substrate composition is another important factor that influences community structure of corals across the reef platforms. Most corals require a hard rocky surface or relatively stable unconsolidated substrate to settle upon and successfully grow. Although strong currents keep the narrow Cabras reef platforms swept nearly free of sediment and the outer parts of the Luminao and Piti reef platforms relatively free, the inner zones at places accumulate a thin patchy veneer of sand-sized sediments intermixed with rubble, particularly in holes and depressions. Where sediments tend to accumulate on the inner part of the reef platform coral distribution becomes somewhat patchy with a resulting reduction in density and percentage of substrate coverage. Increased sediment accumulation in the deeper inner moat zone of Transect B appears to be partly responsible for the low coral density and percentage of substrate coverage found there (Table 2). Similarly, the low species richness, density, and percentage of substrate coverage found in the inner moat zone of Transect J, appears to be caused by the presence of an unstable veneer of gravel-sized sediments intermixed with rubble on the platform surface. Marsh (1974) also reported that the reef community in the inner moat zone at Transect J was damaged by bulldozing during dredging operations to widen and deepen Tepungan Channel, which also may be a factor in the poorly developed coral community found there.

Although considerable suspended sediment was observed in the water column, both on the shallow reef platform and forereef slope zones during periods of normal NE Tradewind seas, it did not appear to affect the coral community very much or accumulate on the living coral tissues because of strong currents and water agitation present during such times. Suspended sediment was particularly noticeable where water transported onto the reef platform by waves and swell returns to the open sea via the depressed pavement zone at the western end of Luminao Reef. Evenso, a thriving coral community is found in the above depressed platform zone.

Although minor freshwater lens discharge was noted at places along the seaward side of Cabras Island, it does not lower seawater salinity to a level that affects coral distribution. Even in Piti Canal (Fig. 1, p. 14), where greatest lens discharge was noted, there was no noticeable effect on the corals. Freshwater discharge and influx of terrestrial sediments from the Masso River undoubtedly affects coral development in the immediate vicinity of its mouth, but the Tepungan Channel tends to act as a barrier which prevents these factors from influencing coral distribution on the western side of the Piti reef platform. Because of its distance from river mouths or freshwater lens discharge the Luminao Barrier Reef is little influenced by the effects of reduced salinity. A minor effect may occur, though, when sea water trapped in isolated small pools in the outer pavement zone during low spring tides may be reduced in salinity during periods of intense rainfall.

The minor annual and diurnal seawater temperature fluctuations observed in the reef margin and reef front slope zones has little to no affect on the coral communities growing there. On the reef platform lethal or sublethal elevated temperatures may be reached for some corals when exposure occurs during midday hours. A few corals may also be restricted from the reef platform moat zones during low spring tides when water temperatures there become elevated because of poor water circulation or isolation from the open sea.

Although no storm drains or thermal and sewer outfall facilities discharge within the study area, there is a possibility that toxic materials could periodically be released from the GORCO deballast facility outfall located on the forereef slope at the western end of Cabras Island. On Nov. 11, 1980, approximately 16,800 gallons of deballast oil was discharged through the GORCO deballast facility outfall. The offshore plume of oil moved westerly to the end of Cabras Island where it then moved across the reef margin onto the Luminao reef platform to the Glass Breakwater. The plume continued to more westward along the breakwater and then exited back into the offshore waters through the depressed region at the western end of Luminao Barrier reef platform. Within a two-week period the coral communities were investigated along the route of the oil plume, and interestingly no obvious effects from the oil spill were observed.

Specific Distribution Patterns of Coral

Stylocoeniella armata is an inconspicuous species that forms small encrusting patches a few centimers across in cryptic habitats. It was found in nearly all the reef zones, but was most commonly observed in the cryptic regions of the reef margin and reef front slope zones.

In the genus *Psammocora*, seven of the eight species were observed in the inner and outer moat zones of the reef platform. Most abundant of these were ramose clumps of *Psammocora contigua*, *P. obtusangulata*, and *P. stellata*. These ramose *Psammocroa* species fragment easily during storms, during which times many of the living pieces are transported to other parts of the reef platform by currents where they establish new colonies. Because of their much larger initial size, than newly settled planulae, these fragments have a greater chance of survival, particularly on unstable substrates which accounts for their common occurrence on the sand-veneered surfaces of the inner and outer moat zones. Large encrusting patches of *Psammocora superficiales* and *Psammocora* (encrusting sp. 1) were most commonly found in the reef margin and reef front slope zones.

In the family Pocilloporidae, *Stylophora mordax* and *Seriatopora hystrix* were most commonly found in the reef margin and reef front slope zones, but they were also occasionally observed in the moat of the reef platform where good water circulation was present. *Pocillopora damicornis* is the most common pocilloporid species in the inner and outer moat and pavement zones of the reef platform, but it was rarely observed in the reef margin and reef front slope zones. Although *P. setchelli* was occasionally found in the inner and outer moat zones, it was most conspicuous and abundant in the wave-washed reef margin zone. *Pocillopora ankeli* and *P. woodjonesi* are uncommon species that were found only in the reef margin and reef front slope zones. Large arborescent colonies of *Pocillopora eydouxi* are normally found in the reef margin and deeper forereef slope zones, but on the Luminao Barrier Reef they are also locally common in the moat zones of the reef platform, particularly at Transect A where strong currents are present. Most of the remaining *Pocillopora* species were more commonly found in the reef margin and reef front slope zones, but occasionally they were also observed in the inner and outer moat zones as well, particularly where good water circulation was present.

Although *Acropora* was the most diverse genus of corals (30 species) represented on the Luminao-Cabras-Piti reef system, the only species found in great abundance were *Acropora aspera* and *Acropora formosa*. At places in the inner and outer moat zones these two species form arborescent thickets up to 5 or more meters across. Like the ramose *Psammocora* species, they also fragment easily during storms and various sized pieces of branches become established on unconsolidated sand and rubble substrates. *Acropora aculeus* is a rare species on Guam that was found only in the outer moat zone of Transect B. Although *Acropora monticulosa*, *A. smithi*, *A. irregularis*, and *A. ocellata* are species mostly restricted to the wave-assaulted reef margin and upper reef front slope zones, they were also occasionally observed in the reef platform moat zones where good water circulation was present. The remaining *Acropora* species were occasionally found or locally common at places in the inner and outer moat zones and common to locally abundant at places in the reef margin and reef front slope zones.

A few small rounded colonies of *Astropora* were observed in the moat zones on the reef platform and in the lower part of the reef front slope zone.

Montipora was the second most diverse genus with 22 species recorded from the study area. Encrusting and irregular shaped submassive colonies were commonly observed in all but the reef pavement zone. Of these, *Montipora berryi*, *M. danae*, *M. monasteriata*, *M. planiuscula*, and *M. venosa* were restricted to the shallow moat zones of the reef platform and *M. floweri* and *M. socialis* were restricted to the deeper reef front slope zone on the forereef slope. Colonies of *M. ehrenbergii*, *M. elschneri*, and *M. verrilli* were the most abundant and widely distributed species.

In the family Agariciidae 11 species of *Pavona* and one species each in the genera *Gardineroseris*, *Leptoseris*, and *Pachyseris* were recorded from the study area. Although *Leptoseris incrustans* and *Pachyseris speciosa* are common in deeper forereef zones, they were rare species recorded only once each in cryptic habitats of the reef front slope within the study area. Of the eleven *Pavona* species, *P. decussata*, *P.* cf. *diffluens*, and *P.* (foliate sp. 1) were restricted to the reef platform zones and *P. maldivensis* and *P.* (encrusting sp. 2) were found only in the forereef slope zones. None of the *Pavona* species were abundant in any one zone, but in the inner and outer moat zone *P. decussata* was occasionally found in small patches consisting of 10 to 15 colonies. *Pavona dicussata* is fragile foliate species, and apparently many of the colonies within a clump are clones that arose by fragmentation from a proginator colony.

Coscinaraea columna is a rare species in the family Siderastreidae that was observed only three times, once in the outer moat zone and once in the reef front slope zone of Luminao and Cabras Reefs.

The family Fungiidae was poorly represented in the study area, both in abundance and number of species, as only three solitary species in the genus *Fungia* were found in the moat zones of Luminao Reef. Apparently these free living solitary fungiid species do not survive in the zones of strong water movement and breaking surf.

In the family Poritidae, Porites species were the most widespread group within the study area. In the reef platform zones Porites lutea, P. andrewsi, and several species in the subgenus Synaraea were generally the most important corals in terms of frequency, density, and percentage of substrate coverage. The above Porites species were also the largest colonies encountered, with some being in excess of three meters in diameter. Porites andrewsi is also a ramose species which fragments easily, and is thus widespread on unconsolidated substrates in the inner moat zones of the Luminao reef platform. The four species in the genus Goniopora were for the most part restricted to the moat zones of Luminao Reef. Ramose colonies of Goniopora arbuscula were particularly abundant in the moat zones of Transect A. Alveopora (sp. 1) was an uncommon species restricted to the forereef slopes along the study area. Although the inconspicuous pea-sized Stylaraea punctata colonies are difficult to observe, they were fairly common on pieces of rubble in the inner moat zone of the reef platform at Luminao and Piti Reefs.

The diverse family Faviidae is represented by 13 genera within the study area. Of these faviid genera Goniastrea, Leptastrea, and Favia were both abundant and widely distributed within the overall study area. Goniastrea retiformis was especially common in the reef front zones, where it is one of the major reef-building species, and in the outer moat zone of Luminao Reef. Small encrusting patches of Leptastrea were common corals in small pools and depressions in the outer pavement zone of the Luminao Reef platform. Other widely distributed but less abundant genera were Favites, Leptoria, Platygyra, Cyphastrea, Hydnophora, and Montastrea. Monotypic rare genera with restricted distribution were Oulophyllia, Plesiastrea, Diploastrea, and Echinopora.

In the family Oculinidae, Galaxea fascicularis was most commonly found in the reef margin and reef front zones where it forms small clumps 5 to 10 cm across, and less commonly in the moat zones of Luminao Reef. Acrhelia horrescens was a rare species observed only once in the inner moat zone at Transect C.

In the family Merulinidae only two species were found in the study area. Merulina ampliata was observed several times in the outer moat zone at Luminao Reef and once in the reef front zone at Transect I. Scapophyllia cylindrica was observed only twice in the reef front zone within the entire study area.

Of the mussid species, Acanthastrea echinata was the most widespread. It was especially common on the upper walls of reef margin and reef front channels where it forms small drab-colored encrusting patches. Large rounded colonies of Lobophyllia corymbosa and L. hemprichii were most commonly observed in the reef front slope zone, but smaller colonies were also occasionally observed in the outer moat zone of Luminao Reef as well. Lobophyllia costata was a relatively rare species restricted to the reef front slope zone.

Although species of the Pectiniidae family are generally found in deeper zones of the forereef slope on Guam, small encrusting patches of *Echinohyllia aspera* were occasionally observed in the reef front slope zone and once in the outer moat zone on the shallow reef platform at Luminao Reef. *Mycedium elephantotus*, also a deep-water species, was found on two occasions in cavernous regions of the reef front slope at the western end of Luminao Reef.

The suborder Caryophylliina was represented by several ramose clumps of *Euphyllia glabrescens* in the outer moat zone, and in the suborder Dendophylliina two species of *Turbinaria* were observed at widely scattered locations in the reef front slope zone.

The blue coral *Heliopora coerulea* was fairly common and widely distributed in the moat zones of Luminao Reef. Widely scattered colonies up to 50 or more centimers in diameter were also growing in the reef front slope zone along the eastern end of Cabras Island and Piti Reefs.

The red colored pipe organ coral, *Tubipora*, was encountered only once in the reef front slope zone at Transect J.

Hydrozoan corals in the genus *Millepora* were widely distributed in all but the pavement zones within the study area. Although *Millepora latifolia* is a rather uncommon species at most reef localities on Guam, it was quite common in the outer moat zone on the Luminao reef platform. Large truncated colonies of *Millepora dichotoma* were also abundant where the outer moat grades into the pavement zone. The plate-forming species *Millepora platyphylla* is an important reef builder in the reef margin and reef front slope zones where many colonies were observed covering two or more square meters of reef surface.

Stylaster gracilis is a small branching ahermatypic hydrozoan coral that was observed on cavernous channel walls and ledges in the reef margin and reef front slope zones.

Summary

A diverse community of corals consisting of 160 species, representing 45 genera, was found within the shallow reef platform and upper forereef slope zones of the study area. The reef platform coral community (inner and outer moat and pavement zones) growing on the western end of Luminao Barrier Reef (Transects A-C) is better developed, in respect to species richness (134 species) and percentage of surface coverage (30.7 percent), than any other similar reef zone investigated to date on Guam. The above species richness is considerably higher than the 58 species listed by Stojkovich (1977) from the same area.

On shallow reef platforms coral distribution and community structural patterns are largely controlled by low tide emersion of reef surfaces, distribution of sediments, current patterns, and solar heating of water trapped during low tides in small holes and depressions on exposed pavement surfaces. Infrequent disturbance, but with possible long-lasting effects, also occurs during storms when large waves and strong currents are generated on the shallow platform surfaces. In respect to corals, environmental conditions range from very unstable and harsh in platform zones that expose during low tides to moderately stable and more favorable in deeper parts of the platform moat zones. The low species richness, density, and surface coverage values and small mean colony size found in exposed pavement zones indicate high mortality rates where few corals grow to large size. More favorable environmental conditions are reflected in the higher species richness, density, and surface coverage values and greater mean colony size found in the moat zones where many corals grow to large size. Cloning by fragmentation in some fragile ramose species of *Acropora*, *Porites*, and *Psammocora* is an important mode of propagation, as well as an effective means of colonizing unstable substrates on the shallow reef platforms. Except for the reef margin zone, *Porites* species dominate the coral communities at most locations on the reef platform. Massive and ramose *Porites* species form large hemispherical and microatoll shaped colonies that give the reef platform much of its irregular topographic relief. At some places thickets of aborescent *Acropora* species replace *Porites* as the dominant element in the coral community.

Although species richness was high in the reef margin and reef front slope zones at most transect locations (21 to 50 species), the percentage of substrate coverage (<1.0 to 14.5 percent in the reef margin and 8.5 to 17.9 percent in the reef front) is lower than that found at most other locations along the western coast of Guam.

The coral community in the reef front slope zone along the entire study area was severely damaged by heavy predaton from *Acanthaster planci* between 1969 and 1971 (Neudecker et al., 1978). Soon after the predation by *A. planci*, Rupp and Larson (1972) surveyed the submarine terrace zone near the western end of Cabras Island where they reported less than six percent of the substrate covered by living corals. Six years later Neudecker et al. (1978) resurveyed the same region and listed 90 species of corals and a mean surface coverage by corals of 37.5 percent. Although about the same number of coral species (81-101) are reported in this study from the reef front slope zone, the substrate coverage values reported by Neudecker et al. (1978) are probably higher because their study included the deeper forereef zones where a better developed coral community was observed.

Literature Cited

Cottam, G., J. T. Curtis, and B. W. Hale. 1953. Some sampling characteristics of a population of randomly dispersed individuals. Ecology 34:731-757.

Marsh, J. A., Jr. 1974. Preliminary observations on the productivity of a Guam reef flat community. Proc. of 2nd Internat. Coral Reef Symp., Great Barrier Reef Committee, Brisbane, 139-145.

Neudecker, S., D. M. Rowley, and R. F. Myers. 1978. Marine environmental survey of the GORCO deballast discharge, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 19. 24p.

Rupp, J. H., and H. K. Larson. 1972. A marine environmental survey for the GORCO deballasting facility outfall, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 2. 17p.

Stojkovich, J. O. 1977. Survey and species inventory of representative pristine marine communities on Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 40. 183p.

Table 1. Species list of corals by transects. List includes corals recorded on the transects (A-J) and those observed within a 20 meter band on each side of the transects. Each coral species is recorded by a number or series of numbers which corresponds to the transect physiographic zonation patterns shown in Figures 3A through 3J in the "Description of the Study Area" section (pp. 15-18).

TRANSECT	A	B	C	D	E	F	G	H	I	J
CLASS-ANTHOZOA										
ORDER-SCLERACTINIA										
SUBORDER-ASTROCOENIINA										
FAMILY-ASTROCOENIIDAE										
Stylocoeniella armada (Ehrenberg)	1-2-3-5	1-3	1-5	2	2	2	2	2-3	2-3	2-5
FAMILY-THAMNASTERIIDAE										
Psammocora contigua (Esper)	1-2	1-2	1-2-4		2				3	2-5
Psammocora digitata Milne-Edwards and Haime			1-5						3	
Psammocora haimeana Milne-Edwards and Haime		1	5					3		
Psammocora obtusangulata (Lamarck)	1-2	1-2	1-2-5		1-2			2		
Psammocora profundacella Gardiner	2-5	1-2-3	1-2-5		2		2	2-3	3	5
Psammocora stellata (Verrill)	2	2	2							
Psammocora superficialis Gardiner	2-4-5	2-3	4-5						3	5
Psammocora (Encrusting sp. 1)	5		5							
FAMILY-POCILLOPORIDAE										
Stylophora mordax (Dana)	1-2-4-5	1-2	2-4-5	1	1-2	2	2	3	3	2-4-5
Seriatopora hystrix Dana			2					3	3	5

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-POCILLOPORIDAE (cont'd)										
Pocillopora ankeli Scheer and Pillai	5		5					3	3	4-5
Pocillopora damicornis (Linnaeus)	1-2-3	1-2-3	1-2	1-2	1-2-3				3	1-2
Pocillopora danae Verrill	1-2	1	1-2-4							5
Pocillopora elegans Dana	2-3-4-5	2	2-4-5			2		2-3	3	5
Pocillopora eydouxi Milne-Edwards and Haime	2-5	2	2-4-5	1	2	2	2	2-3	3	4-5
Pocillopora ligulata Dana	5	2	2	1		2			3	5
Pocillopora cf. *P. meandrina* Dana	1-2-5	2	2-5						3	5
Pocillopora setchelli Hoffmeister	1-2-3-4-5	1-2-3	1-2-3-4-5	2	1-2	1-2	1-2	2-3	2-3	4-5
Pocillopora verrucosa (Ellis and Solander)	4-5	2	2-4-5	2	2	2		2-3	3	4-5
Pocillopora woodjonesi Vaughan	5									
Pocillopora (Meandroid sp. 1)	4		4-5		2			3		5
FAMILY-ACROPORIDAE										
Acropora abrotanoides (Lamarck)	2-5		2-5							5
Acropora aculeus (Dana)		2								
Acropora acuminata Verrill	1	1-2	2							
Acropora arbuscula (Dana)	1	1-2	2							
Acropora aspera (Dana)	1-2-3	1-2	1-2		1-2					2
Acropora cerealis (Dana)	2-4-5	2	2-4-5	1				3	2-3	4-5
Acropora delicatula (Brook)	2-5	2	2-5						3	5
Acropora diversa (Brook)	5	2	5						3	5
Acropora formosa (Dana)	1-2	1-2	1-2							
Acropora humilis (Dana)	1-2-4-5	2	1-2-4-5		2	2	2	2-3	3	2-4-5
Acropora irregularis (Brook)	2-5	2	2-4-5				2	2-3	3	4-5
Acropora monticulosa (Brüggemann)	4-5		4-5	2	2	2		2-3	2-3	4-5

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-ACROPORIDAE (cont'd)										
Acropora nasuta (Dana)	2-4-5	2	1-2-3-4-5		1-2	1-2	2	2-3	3	4-5
Acropora ocellata (Klunzinger)	4-5		4-5			2	1-2	2-3	2-3	4-5
Acropora palifera (Lamarck)	1-2	1-2	2		2					
Acropora pyramidalis (Klunzinger)	2-5		5		2		2	3	3	5
Acropora quelchi (Brook)	2-4		5						3	5
Acropora rambleri (Bassett-Smith)								3		
Acropora smithi (Brook)	2-4-5	2	2-4-5		2		2	3	2-3	4-5
Acropora squarrosa (Ehrenberg)	2-4-5	2-3	2-4-5		2	2		2-3	2-3	4-5
Acropora striata Verrill	2									
Acropora surculosa (Dana)	2-4-5	3	2-4-5	2	1-2		2	2-3	2-3	4-5
Acropora tenuis (Dana)	2-5	2	2-5						3	5
Acropora teres (Verrill)	1									
Acropora valida (Dana)	4-5		4-5		2			2-3	3	4-5
Acropora variabilis (Klunzinger)	2-4-5	3	2-3-4-5	2	1-2	2	2	2-3	2-3	4-5
Acropora wardi Verrill	2-5	2	4-5		2	2		2	3	5
Acropora sp. 1	2-5	2	2-5					3	3	5
Acropora sp. 2	2	2	2-5	2						5
Acropora sp. 3	4-5	2	5				2	3		4
Astreopora eliptica Yabe and Sugiyama	5		1							
Astreopora gracilis Bernard	5	1	2-5						3	5
Astreopora myriophthalma (Lamarck)	1-2-5	1-2	1-2-5		1-2			3	3	5
Montipora acanthella Bernard	1-2	2	2-5						3	
Montipora berryi Hoffmeister	2		2							
Montipora colei Wells	1	2	5						3	
Montipora conicula Wells	1-4		5			2				
Montipora cf. M. danae Milne-Edwards and Haime	1-2	1	1-2							

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-ACROPORIDAE (cont'd)										
Montipora cf. *M. ehrenbergii* Verrill	1-2-4-5	1-2-3	1-2-3-5					3	3	4-5
Montipora elschneri Vaughan	1-2-4-5	1-2	1-2-4-5		2			2-3	2-3	4-5
Montipora floweri Wells			5					3		
Montipora foveolata (Dana)	1-5	2	2-5					3	3	5
Montipora hoffmeisteri Wells	1-2-5	1-2	1-2-5					3	3	4-5
Montipora lobulata Bernard	1-2	1-2	1-2-5	1	2				3	2
Montipora monasteriata (Forskål)	1	2								
Montipora planiuscula (Dana)	1-2	1-2	1-2							
Montipora socialis Bernard									3	
Montipora tuberculosa (Lamarck)	4-5		1-5			2		3	3	
Montipora venosa (Ehrenberg)	2		2							
Montipora verrilli Vaughan	1-4-5	1-2	2-4-5	2	2	2		2-3	2-3	2-4-5
Montipora verrucosa (Lamarck)	1	1	1-2					2-3	3	5
Montipora (Tuberculate sp. 1)	1-2	1-2	1-2-5					3	3	5
Montipora (Tuberculate sp. 2)	1-2-5	1-2	1-2-5					3	3	5
Montipora (Tuberculate sp. 3)	1-2-5	1-2	2-4-5					3	3	4-5
Montipora (Foveolate sp. 1)	2-4-5	2	2-4-5		2			3	3	4-5
SUBORDER-FUNGIINA										
FAMILY-AGARICIIDAE										
Pavona decussata (Dana)	2	2	1-2		1-2					
Pavona divaricata (Lamarck)	1	1	2		1				3	2
Pavona cf. *P. diffluens* (Lamarck)	2	1								
Pavona duerdeni Vaughan	2-5	2	2-5						3	5
Pavona varians Verrill	1-5	1-2	1-5					3	3	5
Pavona venosa (Ehrenberg)	1-4-5	2	2-5					3	3	
Pavona maldivensis (Gardiner)	5		4-5							5
Pavona (Foliate sp. 1)		2								
Pavona (Encrusting sp. 1)	4-5	2	1-2-4-5					3	3	4-5

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-AGARICIIDAE (cont'd)										
Pavona (Encrusting sp. 2)									3	5
Pavona (Encrusting sp. 3)	2	1-2	2		1-2					2-5
Cardineroseris planulata (Dana)		1	5					3		5
Leptoseris incrustans (Quelch)								3		
Pachyseris speciosa (Dana)								3		
FAMILY-SIDERASTREIDAE										
Coscinaraea columna (Dana)		2	5					3		
FAMILY-FUNGIIDAE										
Fungia fungites (Linnaeus)		1	2							
Fungia paumotuensis Stutchbury			2							
Fungia scutaria (Lamarck)		2								
FAMILY-PORITIDAE										
Goniopora arbuscula Umbgrove	1-2	1-2	1-2							5
Goniopora lobulata Milne-Edwards and Haime	1									
Goniopora tenuidens (Quelch)	1	1	1							
Goniopora (Columnar sp. 1)	1		2							
Porites andrewsi Vaughan	1-2	1-2	1-2		1					2
Porites annae Crossland	2	1-2	1-2		1					
Porites australiensis Vaughan	1-2-3-4-5	1-2-3	1-2-3-4-5	2-3	1-2-3	1	1	2-3	1-2-3	2-5

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-PORITIDAE (cont'd)										
Porites lichen Dana	2-5	2	2-5					3	3	2-5
Porites lobata Dana	1-5	2	2-5					3	3	5
Porites lutea Milne-Edwards and Haime	1-2-3-4-5	1-2-3	1-2-3-4-5	1-2-3	1-2-3	1-2	1-2	2-3	1-2-3	1-2-3-4-5
Porites murrayensis Vaughan	2-3	1-2	1-2-5	1				3	3	2-5
Porites superfusa Gardiner	4-5		4-5			2	2	2-3	2-3	4-5
Porites (S.) convexa Verrill	1-2	1	1-2		2			3		5
Porites (S.) iwayamaensis Eguchi	1-2	1-2	1-2		1			3	3	2-5
Porites (S.) vaughani Crossland	4-5		4-5					3	3	4-5
Porites (Massive sp. 1)	1-2-5	1-2	1-2-5		2				3	5
Porites (Massive sp. 2)	1-2	1-2	1-2							
Porites (Columnar sp. 1)	2								3	5
Stylaraea punctata Klunzinger	1	1	1							1
Alveopora (sp. 1)	5		5					3	3	5
SUBORDER-FAVIINA										
FAMILY-FAVIIDAE										
Favia favus (Forskål)	1-5	1-2	1-2-3-5		1			3	3	2-5
Favia matthai Vaughan	1-4-5	2	2-4-5			2	1	3	3	4-5
Favia pallida (Dana)	2-3-5	2-3	2-4-5		1-3	2		3	3	2-5
Favia stelligera (Dana)	1-2-4-5	1-2	1-2-4-5		1-2	2	2	2-3	2-3	2-4-5
Favites abdita (Ellis and Solander)	4	3	4	2-3	2	2	1	2-3	3	2-5
Favites flexuosa (Dana)	2		5						3	
Favites russelli (Wells)	5	2	4-5					3	2	5
Oulophyllia crispa (Lamarck)			5							

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-FAVIIDAE (cont'd)										
Goniastrea edwardsi Chevalier	1-2-5	1-2	2-5		1-2			3	3	2-5
Goniastrea pectinata (Ehrenberg)	1	2	2-5							
Goniastrea retiformis (Lamarck)	1-2-3-4-5	1-2-3	1-2-3-4-5	1-2-3	1-2-3	1-2	1-2	1-2-3	2-3	2-3-4-5
Platygyra daedalea (Ellis and Solander)	2-5	1-2	2-4-5		2			2-3	3	5
Platygyra pini Chevalier	2-4-5	1-2-3	2-4-5			2		3	3	4-5
Leptoria phrygia (Ellis and Solander)	2-3-4-5	1-2-3	1-2-4-5		2	1-2	2	2-3	2-3	4-5
Hydnophora microconos (Lamarck)	2-5	1-2	2-4-5		1				3	5
Montastrea curta (Dana)	2-4-5	2	2-3-4-5	2	1-2	1-2	2	2-3	2-3	4-5
Plesiastrea versipora (Lamarck)	5									5
Diploastrea heliopora (Lamarck)			2	3						
Leptastrea bottae (Milne-Edwards and Haime)	2-3	1-2-3	1-2-3	1-3	2-3					5
Leptastrea purpurea (Dana)	1-2-3-4-5	1-2-3	1-2-3-4-5	1-2-3	1-2-3	2	2	2-3	2-3	1-2-5
Leptastrea transversa Klunzinger	1-2-5	2	2-4-5					2-3	3	5
Cyphastrea chalcidicum (Forskål)			1					3	3	5
Cyphastrea microphthalma (Lamarck)	4-5	3	1-5							
Cyphastrea serailia (Forskål)	1-2-4-5	2	2-5			2				5
Echinopora lamellosa (Esper)	1-4		5					3		

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
FAMILY-OCULINIDAE										
Galaxea fascicularis (Linnaeus)	2-4-5	1-2	2-4-5		2	2	2	2-3	3	4-5
Acrhelia horrescens (Dana)			1							
FAMILY-MERULINIDAE										
Merulina ampliata (Ellis and Solander	2		2						3	
Scapophyllia cylindrica Milne-Edwards and Haime	5									5
FAMILY-MUSSIDAE										
Acanthastrea echinata (Dana)	3-4-5	2-3	2-4-5			2		2-3	3	4-5
Lobophyllia corymbosa (Forskål)	2-5	2	2-5							5
Lobophyllia costata (Dana)			5							
Lobophyllia hemprichii (Ehrenberg)	2-5	2	2-5					3	3	5
FAMILY-PECTINIIDAE										
Echinophyllia aspera (Ellis and Solander)	2-5		5					3	3	5
Mycedium elephantotus (Pallas)	5		5							
SUBORDER-CARYOPHYLLIINA										
FAMILY-CARYOPHYLLIIDAE										
Euphyllia glabrescens (Chamisso and Eysenhardt)	2		2							

Table 1 Continued.

TRANSECT	A	B	C	D	E	F	G	H	I	J
SUBORDER-DENDROPHYLLIINA										
FAMILY-DENDROPHYLLIIDAE										
Turbinaria cf. *T. reniformis* Bernard			5							
Turbinaria stellulata (Lamarck)	5							3		5
ORDER-STOLONIFERA										
FAMILY-TUBIPORIDAE										
Tubipora musica Linnaeus										5
ORDER-COENOTHECALIA										
FAMILY-HELIOPORIDAE										
Heliopora coerulea (Pallas)	1-2-5	1-2	1-2-5					3	3	5
CLASS-HYDROZOA										
ORDER-MILLEPORINA										
FAMILY-MILLEPORIDAE										
Millepora dichotoma Forskål	2-4-5	1-2	1-2-4-5		1-2			3	3	2-5
Millepora latifolia Boschma	2	1-2	1-2				2		3	
Millepora platyphylla Hemprich and Ehrenberg	1-2-4-5	1-2	1-2-4-5		2	2	1-2	2-3	2-3	2-4-5
Millepora tuberosa Boschma	2-4-5	1	2-4-5		2		2	3	3	2-5
ORDER-STYLASTERINA										
FAMILY-STYLASTERIDAE										
Stylaster gracilis Milne-Edwards and Haime	5		4							

Table 2. Coral size distribution, frequency and relative frequency, density and relative density, percent cover and relative cover, and importance value for coral species at Transects A through J. Species are listed in order of their importance values.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT A Zone 1 - Inner Moat (0-121 Meters)											
<u>Porites</u> <u>andrewsi</u>	52	35.9	47.2	1-207	.29	9.57	.29	15.94	8.22	29.03	54.54
<u>Porites</u> (S.) <u>iwayamaensis</u>	10	110.0	132.0	4-376	.09	2.97	.06	3.13	12.59	44.56	50.56
<u>Pocillopora</u> <u>damicornis</u>	52	12.2	6.5	2-24	.44	14.52	.30	16.25	.46	1.62	32.39
<u>Porites</u> <u>lutea</u>	28	46.0	32.2	8-119	.29	9.57	.16	8.75	3.49	12.33	30.65
<u>Leptastrea</u> <u>purpurea</u>	32	4.4	3.7	1-19	.34	11.22	.19	10.00	.06	.21	21.43
<u>Montipora</u> <u>verrilli</u>	20	20.9	15.0	5-56	.19	6.27	.12	6.25	.58	2.05	14.57
<u>Montipora</u> <u>lobulata</u>	18	19.0	6.5	8-30	.19	6.27	.10	5.63	.33	1.17	13.07
<u>Heliopora</u> <u>coerulea</u>	14	6.1	4.5	2-20	.18	5.94	.08	4.38	.04	.14	10.46
<u>Psammocora</u> <u>contigua</u>	15	8.8	4.0	3-17	.16	5.28	.09	4.69	.06	.21	10.18
<u>Montipora</u> <u>ehrenbergii</u>	9	22.1	15.9	6-58	.10	3.30	.05	2.81	.29	1.02	7.13
<u>Montipora</u> <u>conicula</u>	7	17.6	8.9	9-34	.08	2.64	.04	2.19	.09	.32	5.15
<u>Acropora</u> <u>aspera</u>	6	22.3	9.4	6-33	.06	1.98	.03	1.56	.12	.42	4.28
<u>Montipora</u> <u>planiuscula</u>	5	29.2	10.0	14-40	.06	1.98	.03	1.56	.21	.74	4.28
<u>Montipora</u> (tuberculate sp. 2)	3	32.3	28.4	13-65	.04	1.32	.02	.94	.22	.78	3.04
<u>Pocillopora</u> <u>setchelli</u>	5	4.0	1.7	3-7	.04	1.32	.03	1.56	.005	.02	2.90
<u>Montipora</u> (tuberculate sp. 3)	4	16.0	6.7	8-24	.03	.99	.02	.94	.11	.39	2.63
<u>Montipora</u> (tuberculate sp. 1)	3	24.7	12.5	16-39	.04	1.32	.02	.94	.10	.35	2.61
<u>Goniopora</u> <u>arbuscula</u>	3	28.3	27.4	12-60	.03	.99	.02	.94	.18	.64	2.57
<u>Pavona</u> <u>varians</u>	3	22.3	8.0	14-30	.03	.99	.02	.94	.07	.25	2.18
<u>Acropora</u> <u>palifera</u>	2	33.5	20.5	19-48	.03	.99	.01	.63	.12	.42	2.04
<u>Porites</u> (S.) <u>convexa</u>	2	64.5	23.3	48-81	.03	.99	.01	.63	.41	1.44	2.03

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Montipora colei	2	28.0	8.5	22-34	.03	.99	.01	.63	.08	.28	1.90
Montipora elschneri	2	26.5	0.7	26-27	.03	.99	.01	.63	.07	.25	1.87
Cyphastrea microphthalma	2	13.0	12.7	4-22	.03	.99	.01	.63	.03	.11	1.73
Goniastrea edwardsi	2	15.5	10.6	8-23	.03	.99	.01	.63	.03	.11	1.73
Porites (massive sp. 1)	2	9.5	6.4	5-14	.03	.99	.01	.63	.01	.04	1.66
Montipora monasteriata	3	17.3	10.6	6-27	.01	.33	.02	.94	.05	.18	1.45
Echinopora lamellosa	2	15.5	2.1	14-17	.01	.33	.01	.63	.02	.07	1.03
Astreopora myriophthalma	1	43.0	-	-	.01	.33	.006	.31	.08	.28	.92
Favia stelligera	1	36.0	-	-	.01	.33	.006	.31	.06	.21	.85
Montipora hoffmeisteri	1	27.0	-	-	.01	.33	.006	.31	.03	.11	.75
Acropora (sp. 1)	1	22.0	-	-	.01	.33	.006	.31	.02	.07	.71
Pocillopora danae	1	19.0	-	-	.01	.33	.006	.31	.02	.07	.71
Porites lobata	1	15.0	-	-	.01	.33	.006	.31	.01	.04	.68
Favia favus	1	12.0	-	-	.01	.33	.006	.31	.006	.02	.66
Pavona venosa	1	11.0	-	-	.01	.33	.006	.31	.006	.02	.66
Goniastrea retiformis	1	9.0	-	-	.01	.33	.006	.31	.004	.01	.65
Goniopora tenuidens	1	7.0	-	-	.01	.33	.006	.31	.003	.01	.65
Leptoria phrygia	1	8.0	-	-	.01	.33	.006	.31	.003	.01	.65
Porites (massive sp. 2)	1	3.0	-	-	.01	.33	.006	.31	.001	.004	.64
TOTALS	320	24.0	37.4	1-376			1.82		28.29		
TRANSECT A Zone 2 - Outer Moat (121-189 Meters)											
Porites lutea	25	31.7	23.2	1-101	.48	14.86	.80	15.63	9.61	31.26	61.75
Millepora dichotoma	12	38.6	49.6	2-168	.25	7.74	.38	7.50	11.34	36.89	52.13

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Pocillopora damicornis	28	8.3	5.6	1-18	.53	16.41	.90	17.50	.71	2.31	36.22
Leptastrea purpurea	27	5.0	4.1	1-20	.43	13.31	.87	16.88	.32	1.04	31.23
Psammocora contigua	11	8.7	3.4	1-14	.23	7.12	.35	6.88	.23	.75	14.75
Heliopora coerulea	4	39.0	39.3	5-76	.10	3.10	.13	2.50	2.73	8.88	14.48
Montipora planiuscula	5	36.2	17.0	15-57	.13	4.02	.16	3.13	1.94	6.31	13.46
Pocillopora setchelli	8	7.3	4.6	3-17	.13	4.02	.26	5.00	.14	.46	9.48
Porites murrayensis	3	32.3	26.7	2-52	.08	2.48	.10	1.88	1.15	3.74	8.10
Goniastrea retiformis	6	8.2	7.8	1-22	.10	3.10	.19	3.75	.18	.59	7.44
Porites australiensis	6	9.5	5.2	5-19	.10	3.10	.19	3.75	.17	.55	7.40
Psammocora stellata	5	6.0	1.9	4-9	.13	4.02	.16	3.13	.05	.16	7.31
Porites (S.) convexa	2	26.5	14.8	16-37	.05	1.55	.06	1.25	.41	1.33	4.13
Porites (massive sp. 2)	1	46.0	-	-	.03	.93	.03	.63	.55	1.79	3.35
Leptoria phrygia	2	14.0	7.1	9-19	.05	1.55	.06	1.25	.12	.39	3.19
Porites annae	2	6.0	5.7	2-10	.05	1.55	.06	1.25	.03	.10	2.90
Millepora platyphylla	2	17.5	2.1	16-19	.03	.93	.06	1.25	.16	.52	2.70
Porites (massive sp. 1)	1	26.0	-	-	.03	.93	.03	.63	.17	.55	2.11
Goniastrea edwardsi	1	23.0	-	-	.03	.93	.03	.63	.14	.46	2.01
Pocillopora elegans	1	21.0	-	-	.03	.93	.03	.63	.11	.36	1.92
Acropora surculosa	1	19.0	-	-	.03	.93	.03	.63	.10	.33	1.89
Favia pallida	1	18.0	-	-	.03	.93	.03	.63	.08	.26	1.82
Favia stelligera	1	17.0	-	-	.03	.93	.03	.63	.08	.26	1.82
Montipora ehrenbergii	1	15.0	-	-	.03	.93	.03	.63	.06	.20	1.76
Montipora hoffmeisteri	1	15.0	-	-	.03	.93	.03	.63	.06	.20	1.76
Montipora monasteriata	1	15.0	-	-	.03	.93	.03	.63	.06	.20	1.76
Pavona venosa	1	11.0	-	-	.03	.93	.03	.63	.03	.10	1.66
Montipora lobulata	1	6.0	-	-	.03	.93	.03	.63	.01	.03	1.59
TOTALS	160	17.1	21.8	1.168			5.09		30.74		

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	Ȳ	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT A Zone 3 - Outer Pavement (189-238 Meters)											
<u>Leptastrea purpurea</u>	53	3.3	2.6	1-13	.62	33.51	1.32	45.69	.20	11.90	91.10
<u>Porites lutea</u>	35	7.0	5.2	1-20	.52	28.11	.87	30.17	.55	32.74	91.02
<u>Goniastrea retiformis</u>	7	7.1	5.9	8-20	.17	9.19	.17	6.03	.11	6.55	21.77
<u>Favia pallida</u>	4	14.0	9.4	4-26	.10	5.41	.10	3.45	.21	12.50	21.36
<u>Porites murrayensis</u>	3	28.3	25.4	6-56	.07	3.78	.07	2.59	.23	13.69	20.06
<u>Leptastrea bottae</u>	4	11.8	9.0	3-20	.07	3.78	.10	3.45	.16	9.52	16.75
<u>Pocillopora setchelli</u>	4	7.3	6.8	2-17	.14	7.57	.10	3.45	.07	4.17	15.19
<u>Leptoria phrygia</u>	1	20.0	-	-	.03	1.62	.02	.86	.08	4.76	7.24
<u>Pocillopora elegans</u>	2	12.0	4.2	9-15	.03	1.62	.05	1.72	.06	3.57	6.91
<u>Pocillopora damicornis</u>	2	4.5	3.5	2-7	.07	3.78	.05	1.72	.01	.60	6.10
<u>Acanthastrea echinata</u>	1	16.0	-	-	.03	1.62	.02	.86	.004	.24	2.72
TOTALS	116	6.6	7.3	1-56			2.87		1.68		
TRANSECT A Zone 4 - Reef Margin (238-251 Meters)											
<u>Porites lutea</u>	7	10.9	8.1	2-21	.43	15.09	.92	25.00	1.27	24.56	64.65
<u>Pocillopora setchelli</u>	8	7.0	3.8	4-13	.71	24.91	1.05	28.57	.55	10.64	64.12
<u>Acropora variabilis</u>	4	9.5	5.8	4-21	.43	15.09	.53	14.29	.48	9.28	38.66
<u>Acropora ocellata</u>	1	31.0	-	-	.14	4.91	.13	3.57	.99	19.15	27.63
<u>Goniastrea retiformis</u>	2	11.5	2.1	10-13	.29	10.18	.26	7.14	.27	5.22	22.74
<u>Monastrea curta</u>	2	9.5	2.1	8-11	.29	10.18	.26	7.14	.20	3.87	21.19

Table 2 Continued.

Transect Reef-Zone Species	n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
		Size Distribution Colony Diameters in cm									
Acropora valida	1	24.0	-	-	.14	4.91	.13	3.57	.58	11.22	19.70
Acropora cerealis	1	23.0	-	-	.14	4.91	.13	3.57	.57	11.03	19.51
Pavona (sp. 2)	1	15.0	-	-	.14	4.91	.13	3.57	.23	4.45	12.93
Acropora nasuta	1	5.0			.14	4.91	.13	3.57	.03	.58	9.06
TOTALS	28	11.1	7.7	2-31			3.67		5.17		
TRANSECT A Zone 5 - Reef Front Slope (251-286 Meters)											
Pocillopora setchelli	40	10.1	4.7	2-25	1.0	43.86	4.55	66.77	4.50	25.17	135.70
Acropora monticulosa	6	32.2	36.3	5-76	.33	14.47	.68	10.00	8.64	48.32	72.79
Pocillopora eydouxi	1	43.0	-	-	.07	3.07	.11	1.67	1.64	9.17	13.99
Acropora valida	2	15.5	12.0	7-24	.13	5.70	.23	3.33	.57	3.19	12.22
Goniastrea retiformis	2	9.5	0.7	9-10	.13	5.70	.23	3.33	.17	.95	9.98
Pocillopora elegans	1	31.0	-	-	.07	3.07	.11	1.67	.84	4.70	9.44
Acropora variabilis	2	6.0	0.0	6-6	.13	5.70	.23	3.33	.06	.34	9.37
Acropora smithi	1	75.0	-	-	.07	3.07	.11	1.67	.51	2.85	7.59
Acropora ocellata	1	22.0	-	-	.07	3.07	.11	1.67	.42	2.35	7.09
Millepora platyphylla	1	20.0	-	-	.07	3.07	.11	1.67	.34	1.90	6.64
Acropora surculosa	1	10.0	-	-	.07	3.07	.11	1.67	.09	.50	5.24
Acropora humilis	1	8.0	-	-	.07	3.07	.11	1.67	.06	.34	5.08
Pavona duerdeni	1	6.0	-	-	.07	3.07	.11	1.67	.04	.22	4.96
TOTALS	60	14.5	14.4	2-76			6.80		17.88		

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in 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											
Zone 1 - Inner Moat Zone											
(0-110 Meters)											
Porites lutea	44	34.6	25.9	3-86	.49	17.25	.14	15.94	2.03	29.87	63.06
Porites andrewsi	61	15.4	22.2	1-93	.51	17.96	.19	22.10	1.10	16.18	56.24
Acropora aspera	39	32.4	25.9	4-100	.39	13.73	.12	14.13	1.58	23.25	51.11
Pocillopora damicornis	41	11.3	6.2	1-26	.42	14.79	.13	14.86	.16	2.35	32.00
Acropora formosa	27	21.6	19.5	2-62	.22	7.75	.09	9.78	.61	8.97	26.50
Lepastrea purpurea	11	4.3	3.4	2-14	.16	5.63	.03	3.99	.01	.15	9.77
Porites murrayensis	5	34.2	34.6	2-73	.07	2.46	.016	1.81	.26	3.83	8.10
Porites (*S.*) *iwayamaensis*	3	63.3	81.8	6-157	.03	1.06	.006	.72	.42	6.18	7.96
Heliopora coerulea	8	8.5	9.5	3-31	.12	4.23	.025	2.90	.03	.44	7.57
Psammocora contigua	6	8.2	8.7	1-24	.09	3.17	.02	2.17	.02	.29	5.63
Porites (*S.*) *convexa*	4	28.3	22.1	6-58	.04	1.41	.01	1.45	.12	1.77	4.63
Montipora verrilli	5	20.8	11.8	8-38	.04	1.41	.016	1.81	.07	1.03	4.25
Montipora (tuberculate sp. 1)	2	49.0	9.9	42-56	.103	1.06	.006	.72	.12	1.77	3.55
Montipora lobulata	3	21.0	5.2	18-27	.04	1.41	.009	1.09	.03	.44	2.94
Psammocora (ramose sp. 1)	3	10.0	2.6	7-12	.04	1.41	.009	1.09	.01	.15	2.65
Millepora dichotoma	2	23.0	25.5	5-41	.03	1.06	.006	.72	.04	.59	2.36
Montipora planiuscula	2	16.5	4.9	13-20	.03	1.06	.006	.72	.01	.15	1.93
Goniopora arbuscula	1	56.0	-	-	.01	.35	.003	.36	.08	1.18	1.89
Montipora elschneri	1	45.0	-	-	.01	.35	.003	.36	.05	.74	1.45
Pavona varians	1	32.0	-	-	.01	.35	.003	.36	.03	.44	1.15
Stylocoeniella armata	2	2.5	.7	2-3	.01	.35	.006	.72	.001	.01	1.08
Pavona (foliate sp. 1)	1	17.0	-	-	.01	.35	.003	.36	.01	.15	.86
Hydnophora microconos	1	11.0	-	-	.01	.35	.003	.36	.003	.04	.75
Leptastrea bottae	1	4.0	-	-	.01	.35	.003	.36	.001	.01	.72

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
<u>Millepora platyphylla</u>	1	11.0	-	-	.01	.35	.003	.36	.001	.01	.72
<u>Pocillopora setchelli</u>	1	7.0	-	-	.01	.35	.003	.36	.001	.01	.72
TOTALS	276	21.4	23.4	1-157			.86		6.80		
TRANSECT B Zone 2 - Outer Moat Zone (10-172 Meters)											
<u>Porites lutea</u>	29	38.6	28.9	4-127	.53	15.36	.66	18.13	11.89	42.68	76.17
<u>Pocillopora damicornis</u>	26	9.9	6.4	1-25	.43	12.46	.59	16.25	.67	2.41	31.12
<u>Millepora dichotoma</u>	13	29.9	27.1	6-98	.30	8.70	.30	8.13	3.65	13.10	29.93
<u>Leptastrea purpurea</u>	13	5.6	4.2	1-15	.28	8.12	.30	8.13	.11	.39	16.64
<u>Heliopora coerulea</u>	8	13.3	17.0	3-53	.18	5.22	.18	5.00	.62	2.23	12.45
<u>Acropora aspera</u>	6	33.7	17.6	6-57	.08	2.32	.14	3.75	1.49	5.35	11.42
<u>Goniastrea retiformis</u>	6	27.8	13.8	11-48	.13	3.77	.14	3.75	1.00	3.58	11.10
<u>Porites</u> (massive sp. 1)	3	40.7	47.5	3-94	.08	2.32	.07	1.88	1.68	6.03	10.23
<u>Montipora lobulata</u>	5	20.2	7.3	15-33	.13	3.77	.11	3.13	.40	1.44	8.34
<u>Porites</u> (massive sp. 2)	4	22.3	25.7	3-59	.10	2.90	.09	2.50	.72	2.58	7.98
<u>Montipora verrilli</u>	3	30.7	20.6	7-45	.08	2.32	.07	1.88	.66	2.37	6.57
<u>Goniastrea edwardsi</u>	3	29.0	15.4	12-42	.08	2.32	.07	1.88	.54	1.94	6.14
<u>Leptastrea bottae</u>	5	5.4	3.0	2-9	.10	2.90	.11	3.13	.03	.11	6.14
<u>Leptoria phyrgia</u>	3	24.0	8.7	14-29	.08	2.32	.07	1.88	.34	1.22	5.42
<u>Pocillopora eydouxi</u>	1	76.0	-	-	.03	.87	.02	.63	1.04	3.73	5.23
<u>Psammocora profundacella</u>	3	16.3	11.8	7-29	.08	2.32	.07	1.88	.19	.68	4.88
<u>Platygyra pini</u>	3	12.7	4.2	8-16	.08	2.32	.07	1.88	.10	.36	4.56
<u>Porites annae</u>	3	8.3	3.1	5-11	.08	2.32	.07	1.88	.04	.14	4.34
<u>Hydrophora microconos</u>	2	31.5	20.5	17-46	.05	1.45	.05	1.25	.43	1.54	4.24

Table 2 Continued.

Transcect Reef-Zone Species	n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	Size Distribution Colony Diameters in cm										
Millepora latifolia	2	32.0	12.7	23-41	.05	1.45	.05	1.25	.40	1.44	4.14
Montipora acanthella	2	28.5	31.8	6-51	.03	.87	.05	1.25	.47	1.69	3.81
Porites (S.) convexa	2	24.5	14.8	14-35	.05	1.45	.05	1.25	.25	.90	3.60
Montipora colei	2	18.5	7.8	13-24	.05	1.45	.05	1.25	.13	.47	3.17
Favia stelligera	1	51.0	-	-	.03	.87	.02	.63	.46	1.65	3.15
Pavona varians	2	17.0	5.7	13-21	.05	1.45	.05	1.25	.11	.39	3.09
Psammocora contigua	2	7.0	1.4	6-8	.05	1.45	.05	1.25	.02	.07	2.77
Acropora smithi	1	29.0	-	-	.03	.87	.02	.63	.16	.57	2.07
Porites (S.) iwayamaensis	1	23.0	-	-	.03	.87	.02	.63	.10	.36	1.86
Porites andrewsi	1	18.0	-	-	.03	.87	.02	.63	.06	.22	1.72
Pocillopora setchelli	1	14.0	-	-	.03	.87	.02	.63	.03	.11	1.61
Pocillopora danae	1	12.0	-	-	.03	.87	.02	.63	.03	.11	1.61
Montipora hoffmeisteri	1	10.0	-	-	.03	.87	.02	.63	.02	.07	1.57
Montipora (tuberculate sp. 3)	1	8.0	-	-	.03	.87	.02	.63	.01	.04	1.54
Astreopora gracilis	1	6.0	-	-	.03	.87	.02	.63	.006	.02	1.52
TOTALS	160	22.7	21.9	1-157			3.66		27.86		
TRANSECT B Zone 3 - Pavement Zone (172-216 Meters)											
Porites lutea	22	7.0	4.8	2-19	.69	29.87	.75	34.38	.43	29.97	94.22
Leptastrea purpurea	28	2.3	.9	1-4	.81	35.06	.95	43.75	.06	4.18	82.99
Goniastrea retiformis	3	22.3	21.7	6-47	.19	8.23	.10	4.69	.65	45.30	58.22
Pocillopora damicornis	4	13.0	5.0	8-20	.25	10.82	.14	6.25	.21	14.63	31.70
Leptastrea bottae	5	6.8	2.8	4-11	.25	10.82	.17	7.81	.07	4.88	23.51
Psammocora profundacella	1	6.0	-	-	.06	2.60	.03	1.56	.008	.56	4.72

Table 2 Continued.

Transect Reef-Zone Species	n	$\overline{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
		Size Distribution Colony Diameters in cm									
Acropora variabilis	1	5.0	-	-	.06	2.60	.03	1.56	.007	.49	4.65
TOTALS	64	6.0	6.8	1-47			2.17		1.44		
TRANSECT C Zone 1 - Inner Moat Zone (0-78 Meters)											
Porites andrewsi	70	28.5	39.8	2-197	.67	25.87	.74	36.46	13.85	51.47	113.80
Porites lutea	26	52.2	34.2	3-108	.42	16.22	.28	13.54	8.37	31.11	60.87
Pocillopora damicornis	31	11.8	5.0	3-26	.44	16.99	.33	16.15	.36	1.34	34.48
Porites (S.) iwayamaensis	10	31.3	37.4	5-99	.17	6.56	.11	5.21	1.86	6.91	13.63
Acropora aspera	9	9.7	8.1	3-28	.15	5.79	.10	4.69	.12	.45	10.91
Psammocora contigua	7	14.4	13.5	3-43	.10	3.86	.07	3.65	.21	.78	8.29
Millepora dichotoma	5	13.0	5.8	7-21	.08	3.09	.05	2.60	.08	.30	5.99
Heliopora coerulea	5	7.4	5.7	2-17	.06	2.32	.05	2.60	.03	.11	5.03
Montipora planiuscula	3	25.7	12.5	17-40	.06	2.32	.03	1.56	.19	.71	4.59
Porites (S.) convexa	4	10.0	2.6	7-13	.06	2.32	.04	2.08	.04	.15	4.55
Psammocora digitata	1	87.0	-	-	.02	.77	.01	.52	.63	2.34	3.63
Porites (massive sp. 1)	1	83.0	-	-	.02	.77	.01	.52	.57	2.12	3.41
Porites (massive sp. 2)	2	28.5	23.3	12-45	.04	1.54	.02	1.04	.18	.67	3.25
Pavona varians	2	18.0	7.1	13-23	.04	1.54	.02	1.04	.06	.22	2.80
Leptastrea bottae	2	13.0	7.1	8-13	.04	1.54	.02	1.04	.03	.11	2.69
Leptastrea purpurea	2	4.5	.7	4-5	.04	1.54	.02	1.04	.004	.01	2.59
Leptoria phrygia	2	24.5	4.9	21-28	.02	.77	.02	1.04	.10	.37	2.18
Montipora lobulata	2	21.5	16.3	10-33	.02	.77	.02	1.04	.10	.37	2.18
Acorpora nasuta	2	15.0	9.9	8-22	.02	.77	.02	1.04	.05	.19	2.00

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Pavona (encrusting sp. 1)	1	22.0	-	-	.02	.77	.01	.52	.04	.15	1.44
Montipora ehrenbergii	1	15.0	-	-	.02	.77	.01	.52	.02	.07	1.36
Montipora tuberculosa	1	11.0	-	-	.02	.77	.01	.52	.01	.04	1.33
Cyphastrea microphthalma	1	5.0	-	-	.02	.77	.01	.52	.002	.007	1.30
Psammocora profundacella	1	3.0	-	-	.02	.77	.01	.52	.001	.003	1.29
Stylocoeniella armata	1	2.0	-	-	.02	.77	.01	.52	.001	.001	1.29
TOTALS	192	25.6	32.1	2-197			2.02		26.91		
TRANSECT C Zone 2 - Outer Moat Zone (78-111 Meters)											
Porites lutea	9	17.4	28.8	4-85	.71	24.91	.51	32.14	3.57	40.63	97.68
Leptoria phrygia	3	51.0	4.4	48-56	.43	15.09	.17	10.71	3.47	39.49	65.29
Goniastrea retiformis	6	20.0	11.2	7-36	.57	20.00	.34	21.43	1.35	15.36	56.79
Leptastrea purpurea	4	6.0	2.9	3-9	.57	20.00	.23	14.29	.08	.91	35.20
Pocillopora damicornis	4	10.8	5.6	3-16	.29	10.18	.23	14.29	.26	2.96	27.43
Millepora platyphylla	1	11.0	-	-	.14	4.91	.06	3.57	.05	.57	9.05
Leptastrea bottae	1	4.0	-	-	.14	4.91	.06	3.57	.007	.08	8.56
TOTALS	28	18.29	19.66	3-85			1.60		8.79		
TRANSECT C Zone 3 - Pavement Zone (111-135 Meters)											
Porites lutea	12	6.3	3.9	2-14	1.00	57.14	1.80	75.00	.77	91.12	223.26

Table 2 Continued.

Transcect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Leptastrea purpurea	2	4.0	0.0	4-4	.25	14.29	.30	12.50	.04	4.73	31.52
Acropora nasuta	1	5.0	-	-	.25	14.29	.15	6.25	.03	3.55	24.09
Acropora variabilis	1	2.0	-	-	.25	14.29	.15	6.25	.005	.59	21.13
TOTALS	16	5.6	3.6	2-14			2.40		.85		
TRANSECT C Zone 4 - Reef Margin Zone (135-149 Meters)											
Pocillopora setchelli	7	14.7	4.8	9-23	.67	19.94	1.03	29.17	1.93	13.28	62.39
Acropora monticulosa	2	49.5	26.2	31-68	.33	9.82	.29	8.33	6.39	43.98	62.13
Goniastrea retiformis	5	8.4	5.3	4-17	.67	19.94	.73	20.83	.54	3.72	44.49
Millepora platyphylla	1	62.0	-	-	.17	5.06	.15	4.17	4.43	30.49	39.72
Favites abdita	2	9.5	3.5	7-12	.33	9.82	.29	8.33	.23	1.58	19.73
Pocillopora (sp. 1)	1	18.0	-	-	.17	5.06	.15	4.17	.39	2.68	11.91
Acropora valida	1	16.0	-	-	.17	5.06	.15	4.17	.30	2.06	11.29
Montipora verrilli	1	9.0	-	-	.17	5.06	.15	4.17	.10	.69	9.92
Favia pallida	1	9.0	-	-	.17	5.06	.15	4.17	.09	.62	9.85
Acropora wardi	1	7.0	-	-	.17	5.06	.15	4.17	.06	.41	9.64
Psammocora contigua	1	7.0	-	-	.17	5.06	.15	4.17	.06	.41	9.64
Porites lutea	1	3.0	-	-	.17	5.06	.15	4.17	.01	.07	9.30
TOTALS	24	16.4	16.31	3-68			3.54		14.53		

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm				Frequency	Relative Frequency	Density Per m²	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	n	$\overline{Y}$	s	w							
TRANSECT C Zone 5 - Reef Front Slope Zone (149-181 Meters)											
Pocillopora setchelli	16	9.0	4.9	3-17	.67	20.81	1.97	26.67	1.52	13.64	61.12
Acropora monticulosa	6	21.2	7.2	10-28	.33	10.25	.74	10.00	2.87	25.76	46.01
Montipora verrilli	6	12.3	5.5	6-18	.33	10.25	.74	10.00	1.02	9.16	29.41
Goniastrea retiformis	7	10.4	1.0	9-12	.33	10.25	.86	11.67	.73	6.55	28.47
Montastrea curta	4	12.3	3.0	8-15	.20	6.21	.49	6.67	.61	5.48	18.36
Acropora cerealis	4	8.0	3.4	6-13	.27	8.39	.49	6.67	.28	2.51	17.57
Acropora irregularis	1	32.0	-	-	.07	2.17	.12	1.67	.99	8.87	12.71
Acropora smithi	1	31.0	-	-	.07	2.17	.12	1.67	.93	8.35	12.19
Acropora ocellata	3	10.0	1.0	9-11	.13	4.04	.37	5.00	.28	2.51	11.55
Acropora surculosa	2	15.0	2.8	13-17	.13	4.04	.25	3.33	.32	2.87	10.24
Leptastrea purpurea	2	8.0	1.4	7-9	.13	4.04	.25	3.33	.14	1.26	8.63
Montipora foveolata	1	22.0	-	-	.07	2.17	.12	1.67	.47	4.21	8.05
Acropora humilis	1	18.0	-	-	.07	2.17	.12	1.67	.31	2.78	6.62
Platygyra daedalea	1	16.0	-	-	.07	2.17	.12	1.67	.26	2.33	6.17
Goniastrea edwardsi	1	14.0	-	-	.07	2.17	.12	1.67	.19	1.71	5.55
Millepora platyphylla	1	12.0	-	-	.07	2.17	.12	1.67	.14	1.26	5.10
Acropora vallida	1	6.0	-	-	.07	2.17	.12	1.67	.03	.27	4.11
Pavona (encrusting sp. 1)	1	6.0	-	-	.07	2.17	.12	1.67	.03	.27	4.11
Acropora variabilis	1	4.0	-	-	.07	2.17	.12	1.67	.02	.18	4.02
TOTALS	60	12.2	6.8	3-32			7.36		11.14		

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT D Zone 1 - Inner Moat Zone (0-22 Meters)											
Porites lutea	6	12.8	8.8	3-24	.50	20.00	.12	37.50	.22	71.66	139.16
Pocillopora damicornis	5	7.6	4.6	3-13	1.00	40.00	.10	31.25	.06	19.54	90.79
Leptastrea purpurea	2	3.5	.7	3-4	.50	20.00	.04	12.50	.005	1.63	34.13
Leptastrea bottae	2	2.5	.7	2-3	.25	10.00	.04	12.50	.002	.65	23.15
Porites murrayensis	1	11.0	-	-	.25	10.00	.02	6.25	.02	6.51	22.76
TOTALS	16	8.6	6.9	2-24			.32		.31		
TRANSECT D Zone 2 - Outer Moat Zone (22-35 Meters)											
Porites lutea	9	8.8	8.9	2-31	1.0	60.24	.23	75.00	.26	96.30	231.54
Pocillopora damicornis	2	4.5	2.1	3-6	.33	19.88	.05	16.67	.009	3.33	39.88
Leptastrea purpurea	1	2.0	-	-	.33	19.88	.03	8.33	.001	.37	25.58
TOTALS	12	9.8	9.6	2-31			.31		.27		
TRANSECT D Zone 3 - Pavement Zone (35-50 Meters)											
Porites lutea	4	10.8	4.3	5-15	1.0	50.00	.15	50.00	.15	94.34	194.34

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	$\overline{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Leptastrea purpurea	4	2.5	.6	2-3	1.0	50.00	.15	50.00	.009	5.66	105.66
TOTALS	8	6.6	5.3	2-15			.30		.16		
TRANSECT E Zone 1 - Inner Moat Zone (1-50 Meters)											
Acropora aspera	17	36.3	31.8	5-105	1.00	34.36	.39	53.13	7.04	83.50	170.99
Porites lutea	5	31.2	14.3	18-54	.63	21.65	.12	15.63	1.05	12.45	49.73
Pocillopora damicornis	4	13.5	2.9	10-17	.50	17.18	.09	12.50	.14	1.66	31.34
Goniastrea retiformis	1	20.0	-	-	.13	4.47	.02	3.13	.07	.83	8.43
Favia pallida	1	16.0	-	-	.13	4.47	.02	3.13	.05	.59	8.19
Hydnophora microconos	1	16.0	-	-	.13	4.47	.02	3.13	.05	.59	8.19
Millepora dichotoma	1	11.0	-	-	.13	4.47	.02	3.13	.02	.24	7.84
Leptastrea purpurea	1	7.0	-	-	.13	4.47	.02	3.13	.009	.11	7.71
Pocillopora setchelli	1	3.0	-	-	.13	4.47	.02	3.13	.002	.02	7.62
TOTALS	32	28.2	25.8	3-105			.72		8.43		
TRANSECT E Zone 2 - Outer Moat Zone (50-65 Meters)											
Porites lutea	5	15.0	8.8	7-26	.75	25.00	.95	31.25	2.14	49.65	105.90
Porites australiensis	1	28.0	-	-	.25	8.33	.19	6.25	1.16	26.91	41.49
Acropora aspera	2	10.0	1.4	9-11	.50	16.67	.38	12.50	.30	6.96	36.13

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	Y	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Leptatrea purpurea	2	4.0	2.8	2-6	.50	16.67	.38	12.50	.06	1.39	30.56
Goniastrea retiformis	2	16.0	7.1	11-21	.25	8.33	.38	12.50	.22	5.10	25.93
Pocillopora damicornis	1	14.0	-	-	.25	8.33	.19	6.25	.31	7.19	21.77
Favia pallida	2	3.5	.7	3-4	.25	8.33	.38	12.50	.03	.70	21.53
Montastrea curta	1	8.0	-	-	.25	8.33	.19	6.25	.09	2.09	16.67
TOTALS	16	12.0	8.2	2-26			3.04		4.31		
TRANSECT E Zone 3 - Pavement Zone (65-80 Meters)											
Porites lutea	9	8.2	3.7	4-14	1.00	50.25	.22	75.00	.14	22.58	147.83
Porites australiensis	1	50.0	-	-	.33	16.58	.02	8.33	.47	75.81	100.72
Goniastrea retiformis	1	7.0	-	-	.33	16.58	.02	8.33	.01	1.61	26.52
Leptastrea purpurea	1	2.0	-	-	.33	16.58	.02	8.33	.001	.16	15.07
TOTALS	12	11.1	12.79	2-50			.48		.62		
TRANSECT F Zone 1 - Pavement Zone (0-30 Meters)											
Porites lutea	2	36.0	11.3	28-44	.14	50.00	.002	50.00	.02	76.92	176.92
Porites australiensis	2	18.0	5.7	14-23	.14	50.00	.002	50.00	.006	23.08	123.08
TOTALS	4	27.0	12.7	14-44			.004		.026		

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm: n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT F Zone 2 - Reef Margin Zone (30-45 Meters)											
<u>Goniastrea retiformis</u>	3	15.0	5.0	10-20	.67	20.24	.28	25.00	.51	45.13	90.37
<u>Pocillopora setchelli</u>	2	10.0	2.8	8-12	.33	9.97	.19	16.67	.15	13.27	39.91
<u>Acropora wardi</u>	1	14.0	-	-	.33	9.97	.09	8.33	.14	12.39	30.69
<u>Montasrea curta</u>	1	12.0	-	-	.33	9.97	.09	8.33	.11	9.73	28.03
<u>Leptoria phrygia</u>	1	10.0	-	-	.33	9.97	.09	8.33	.07	6.19	24.49
<u>Favia pallida</u>	1	9.0	-	-	.33	9.97	.09	8.33	.06	5.31	23.61
<u>Acropora nasuta</u>	1	8.0	-	-	.33	9.97	.09	8.33	.05	4.42	22.72
<u>Leptastrea purpurea</u>	1	5.0	-	-	.33	9.97	.09	8.33	.02	1.77	20.07
<u>Porites lutea</u>	1	5.0	-	-	.33	9.97	.09	8.33	.02	1.77	20.07
TOTALS	12	10.7	4.3	5-20			1.10		1.13		
TRANSECT G Zone 1 - Pavement Zone (0-20 Meters) (no corals encountered)											
TRANSECT G Zone 2 - Reef Margin Zone (20-35 Meters)											
<u>Pocillopora setchelli</u>	17	4.8	1.8	2-10	1.00	54.64	.64	70.83	.17	50.00	175.47
<u>Goniastrea retiformis</u>	3	7.0	3.6	3-10	.33	18.03	.11	12.50	.15	44.12	74.65

Table 2 Continued.

Transect Reef-Zone Species	n	$\overline{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
		Size Distribution Colony Diameters in cm									
<u>Porites lutea</u>	3	3.3	2.3	2-6	.33	18.03	.11	12.50	.01	2.94	33.47
<u>Montastrea curta</u>	1	7.0	-	-	.17	9.29	.04	4.17	.01	2.94	16.40
TOTALS	24	5.0	2.2	2-10			.90		.34		
TRANSECT H Zone 1 - Pavement Zone (0-10 Meters)											
(no corals encountered)											
TRANSECT H Zone 2 - Reef Margin Zone (10-30 Meters)											
<u>Pocillopora setchelli</u>	14	7.4	3.6	3-14	1.00	39.84	.57	58.33	.29	49.15	147.32
<u>Favites abdita</u>	2	13.5	9.2	7-20	.33	13.15	.08	8.33	.14	23.73	45.21
<u>Porites lutea</u>	3	4.0	3.5	2-8	.33	13.15	.12	12.50	.03	5.08	30.73
<u>Millepora platyphylla</u>	1	12.0	-	-	.17	6.77	.04	4.17	.05	8.47	19.91
<u>Goniastrea retiformis</u>	1	10.0	-	-	.17	6.77	.04	4.17	.03	5.08	16.02
<u>Acropora squarrosa</u>	1	7.0	-	-	.17	6.77	.04	4.17	.02	3.39	14.33
<u>Acropora surculosa</u>	1	7.0	-	-	.17	6.77	.04	4.17	.02	3.39	14.33
<u>Leptoria phrygia</u>	1	5.0	-	-	.17	6.77	.04	4.17	.009	1.53	12.47
TOTALS	24	7.6	4.3	2-20			.97		.59		

Table 2 Continued.

Transect Reef-Zone Species	n	$\overline{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
TRANSECT H Zone 3 - Reef Front Zone (30-65 Meters)											
Montipora verrilli	9	17.3	11.2	5-36	.60	15.67	1.03	15.00	3.37	35.11	65.78
Goniastrea retiformis	11	8.6	4.7	2-18	.73	19.06	1.25	18.33	.93	9.69	47.08
Montipora hoffmeisteri	2	25.0	21.2	10-40	.13	3.39	.23	3.33	1.53	15.94	22.66
Acropora surculosa	3	17.3	1.5	16-19	.20	5.22	.34	5.00	.81	8.44	18.66
Favia pallida	3	9.0	3.6	6-13	.20	5.22	.34	5.00	.26	2.71	12.93
Porites lutea	3	8.0	2.6	6-11	.13	3.39	.34	5.00	.19	1.98	10.37
Pocillopora setchelli	3	2.3	0.6	2-3	.20	5.22	.34	5.00	.01	.10	10.32
Leptastrea purpurea	3	8.0	3.5	6-12	.13	3.39	.34	5.00	.18	1.88	10.27
Montastrea curta	2	10.0	0.0	10-10	.13	3.39	.23	3.33	.18	1.88	8.60
Leptoria phrygia	1	22.0	-	-	.07	1.83	.11	1.67	.42	4.38	7.88
Acropora ocellata	2	11.5	4.9	8-15	.07	1.83	.23	3.33	.26	2.71	7.87
Acropora irregularis	2	7.5	4.9	4-11	.13	3.39	.23	3.33	.11	1.15	7.87
Acropora nasuta	2	5.0	2.8	3-7	.13	3.39	.23	3.33	.05	.52	7.24
Favia stelligera	1	19.0	-	-	.07	1.83	.11	1.67	.33	3.44	6.94
Acropora humilis	1	14.0	-	-	.07	1.83	.11	1.67	.18	1.88	5.38
Montipora elschneri	1	14.0	-	-	.07	1.83	.11	1.67	.18	1.88	5.38
Platygyra pini	1	12.0	-	-	.07	1.83	.11	1.67	.13	1.35	4.85
Porites murrayensis	1	11.0	-	-	.07	1.83	.11	1.67	.11	1.15	4.65
Acropora valida	1	10.0	-	-	.07	1.83	.11	1.67	.09	.94	4.44
Favia matthai	1	9.0	-	-	.07	1.83	.11	1.67	.07	.73	4.23
Montipora tuberculosa	1	9.0	-	-	.07	1.83	.11	1.67	.07	.73	4.23
Acropora aspera	1	7.0	-	-	.07	1.83	.11	1.67	.04	.42	3.92
Acropora cerealis	1	6.0	-	-	.07	1.83	.11	1.67	.03	.31	3.81
Favia rotumana	1	6.0	-	-	.07	1.83	.11	1.67	.03	.31	3.81

Table 2 Continued.

Transcect Reef-Zone Species	Size Distribution Colony Diameters in cm: n	$\overline{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
<u>Acropora</u> (sp. 3)	1	5.0	-	-	.07	1.83	.11	1.67	.02	.21	3.71
<u>Echinophyllia</u> <u>aspera</u>	1	4.0	-	-	.07	1.83	.11	1.67	.01	.10	3.60
<u>Acropora</u> <u>wardi</u>	1	3.0	-	-	.07	1.83	.11	1.67	.008	.08	3.58
TOTALS	60	12.2	6.8	2-40			6.78		9.60		
TRANSECT I Zone 1 - Pavement Zone (1-10 Meters)											
<u>Porites</u> <u>australiensis</u>	3	17.7	7.8	9-24	.67	50.38	.04	50.00	.11	43.65	144.03
<u>Porites</u> <u>lutea</u>	2	21.5	21.9	5-36	.33	24.81	.03	33.33	.14	55.56	113.70
<u>Pocillopora</u> <u>setchelli</u>	1	4.0	-	-	.33	24.81	.01	16.67	.002	.79	42.27
TOTALS	6	16.3	12.6	4-36			.08		.25		
TRANSECT I Zone 2 - Reef Margin Zone (10-30 Meters)											
<u>Porites</u> <u>lutea</u>	4	20.8	17.7	8-47	.50	17.61	.30	16.67	1.93	64.98	99.26
<u>Pocillopora</u> <u>setchelli</u>	11	9.0	4.3	4-19	.83	29.23	.82	45.83	.64	21.55	96.61
<u>Goniastrea</u> <u>retiformis</u>	2	9.0	0.0	9-9	.33	11.62	.15	8.33	.09	3.03	22.98
<u>Acropora</u> <u>cerealis</u>	2	6.0	0.0	6-6	.33	11.62	.15	8.33	.04	1.35	21.30
<u>Millepora</u> <u>platyphylla</u>	1	13.0	-	-	.17	5.99	.07	4.17	.10	3.37	13.53
<u>Leptoria</u> <u>phrygia</u>	1	13.0	-	-	.17	5.99	.07	4.17	.09	3.03	13.19
<u>Montastrea</u> <u>curta</u>	1	8.0	-	-	.17	5.99	.07	4.17	.04	1.35	11.51

Table 2 Continued.

Transect Reef-Zone Species	Size Distribution Colony Diameters in cm n	Y	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
Acropora surculosa	1	7.0	-	-	.17	5.99	.07	4.17	.03	1.01	11.17
Acropora squarrosa	1	4.0	-	-	.17	5.99	.07	4.17	.01	.34	10.50
TOTALS	24	11.3	8.7	4-47			1.77		2.97		
TRANSECT I Zone 2 - Reef Front (30-65 Meters)											
Montipora verrilli	13	14.5	17.9	4-72	.47	16.91	1.46	21.67	7.96	38.94	78.52
Goniastrea retiformis	18	15.8	9.8	4-40	.67	24.10	2.03	30.00	5.49	26.86	56.86
Acropora surculosa	6	14.7	4.6	9-14	.27	9.71	.68	10.00	1.25	6.12	25.83
Acropora nasuta	5	10.8	6.1	4-17	.20	7.19	.56	8.33	.65	3.18	18.70
Millepora platyphylla	1	56.0	-	-	.07	2.52	.11	1.67	2.80	13.70	17.89
Pocillopora setchelli	4	11.3	10.4	3-26	.20	7.19	.45	6.67	.73	3.57	17.43
Favia stelligera	2	12.0	4.2	9-15	.13	4.68	.22	3.33	.28	1.37	8.29
Acropora humilis	1	19.0	-	-	.07	2.52	.11	1.67	.33	1.61	5.80
Pocillopora verrucosa	1	19.0	-	-	.07	2.52	.11	1.67	.31	1.52	5.71
Porites lutea	1	15.0	-	-	.07	2.52	.11	1.67	.20	.98	5.17
Leptoria phrygia	1	11.0	-	-	.07	2.52	.11	1.67	.11	.54	4.73
Porites australiensis	1	11.0	-	-	.07	2.52	.11	1.67	.11	.54	4.73
Millepora dichotoma	1	7.0	-	-	.07	2.52	.11	1.67	.05	.24	4.43
Acropora cerealis	1	7.0	-	-	.07	2.52	.11	1.67	.04	.20	4.39
Leptastrea purpurea	1	7.0	-	-	.07	2.52	.11	1.67	.04	.20	4.39
Montastrea curta	1	7.0	-	-	.07	2.52	.11	1.67	.04	.20	4.39
Porites murrayensis	1	6.0	-	-	.07	2.52	.11	1.67	.03	.15	4.34

Table 2 Continued.

Transect Reef-Zone Species	n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
		Size Distribution Colony Diameters in cm									
Favites abdita	1	5.0	-	-	.07	2.52	.11	1.67	.02	.10	4.29
TOTALS	60	14.3	11.9	3-72			6.72		22.44		
TRANSECT J Zone 1 - Inner Moat Zone (0-52 Meters)											
Porites lutea	11	9.9	9.1	2-34	.71	33.33	.14	39.29	.19	50.00	122.62
Pocillopora damicornis	7	4.3	3.6	1-9	.71	33.33	.09	25.00	.02	5.26	63.59
Leptastrea purpurea	9	3.2	1.3	2-6	.57	26.76	.12	32.14	.01	2.63	61.53
Porites australiensis	1	39.0	-	-	.14	6.57	.01	3.57	.16	42.11	52.25
TOTALS	28	7.4	9.1	1-39			.36		.38		
TRANSECT J Zone 2 - Outer Moat Zone (52-210 Meters)											
Porites lutea	60	27.1	26.0	2-112	.86	36.75	1.41	53.57	1.55	78.50	168.82
Acropora aspera	7	29.1	24.9	5-62	.21	8.97	.16	6.25	1.12	5.65	20.87
Porites (S.) iwayamaensis	5	32.4	27.8	12-68	.18	7.69	.12	4.46	1.54	7.77	19.92
Porites australiensis	6	14.2	11.3	2-31	.21	8.97	.14	5.36	.34	1.72	16.05
Pocillopora damicornis	8	6.0	4.6	1-15	.18	7.69	.19	7.14	.08	.40	15.23
Millepora dichotoma	7	25.4	10.7	6-37	.11	4.70	.16	6.25	.45	2.27	13.22
Leptastrea purpurea	4	4.0	2.8	2-8	.14	5.98	.09	3.57	.02	.10	9.65
Porites annae	3	25.0	11.8	15-38	.11	4.70	.07	2.68	.40	2.02	9.40

Table 2 Continued.

Transect Reef-Zone Species	n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	Size Distribution Colony Diameters in cm										
Pavona venosa	3	11.7	3.8	9-16	.11	4.70	.07	2.68	.08	.40	7.78
Goniastrea retiformis	5	5.0	3.2	2-10	.07	2.99	.12	4.46	.03	.15	7.60
Montipora verrilli	1	21.0	-	-	.04	1.71	.02	.89	.08	.40	3.00
Porites murrayensis	1	20.0	-	-	.04	1.71	.02	.89	.07	.35	2.95
Millepora platyphylla	1	16.0	-	-	.04	1.71	.02	.89	.04	.20	2.80
Montipora lobulata	1	7.0	-	-	.04	1.71	.02	.89	.01	.05	2.65
TOTALS	112	22.0	22.0	1-112			2.61		19.81		
TRANSECT J Zone 3 - Outer Pavement Zone (210-267 Meters)											
Porites lutea	39	5.0	3.2	2-18	1.0	90.91	.70	97.50	.20	99.01	287.42
Goniastrea retiformis	1	3.0	-	-	.10	9.09	.02	2.50	.002	.99	12.58
TOTALS	40	4.9	3.1	2-18			.72		.20		
TRANSECT J Zone 4 - Reef Margin Zone (267-282 Meters)											
Pocillopora setchelli	15	8.6	4.3	3-18	.83	41.29	8.65	6.14	62.50	51.04	154.83
Acropora monticulosa	4	14.3	9.0	5-26	.33	16.42	2.31	16.67	4.71	39.15	72.24
Montipora verrilli	1	10.0	-	-	.17	8.46	.58	4.17	.45	3.74	16.37
Acropora valida	1	8.0	-	-	.17	8.46	.58	4.17	.29	2.41	15.04
Acropora squarrosa	1	6.0	-	-	.17	8.46	.58	4.17	.19	1.58	14.21
Acropora nasuta	1	5.0	-	-	.17	8.46	.58	4.17	.17	1.41	14.04

Table 2 Continued.

Transect Reef-Zone Species	n	$\bar{Y}$	s	w	Frequency	Relative Frequency	Density Per m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
		Size Distribution Colony Diameters in cm									
Acropora cerealis	1	4.0	-	-	.17	8.46	.58	4.17	.08	.67	13.30
TOTALS	24	9.1	5.4	3-26			13.86		12.03		
TRANSECT J Zone 5 - Reef Front Zone (282-317 Meters)											
Leptastrea purpurea	9	7.3	3.2	4-13	.40	12.90	1.35	22.50	.66	7.80	43.20
Pocillopora setchelli	7	8.6	3.1	5-13	.50	16.13	1.05	17.50	.66	7.80	41.43
Acropora surculosa	4	12.0	4.7	7-16	.40	12.90	.60	10.0	.75	8.87	31.77
Acropora cerealis	4	7.2	3.3	3-11	.40	12.90	.60	10.00	.28	3.31	26.21
Montipora verrilli	3	16.3	6.1	11-23	.20	6.45	.45	7.50	1.03	12.17	26.12
Montipora hoffmeisteri	1	30.0	-	-	.10	3.23	.15	2.50	1.09	12.88	18.61
Pocillopora elegans	1	30.0	-	-	.10	3.23	.15	2.50	1.09	12.88	18.61
Leptoria phrygia	2	15.0	4.2	12-18	.20	6.45	.30	5.00	.55	6.50	17.95
Acropora humilis	2	15.5	6.4	11-20	.10	3.23	.30	5.00	.61	7.21	15.44
Millepora platyphylla	1	24.0	-	-	.10	3.23	.15	2.50	.66	7.80	13.53
Acanthastrea echinata	1	17.0	-	-	.10	3.23	.15	2.50	.34	4.02	9.75
Favia pallida	1	17.0	-	-	.10	3.23	.15	2.50	.34	4.02	9.75
Monstastrea curta	1	14.0	-	-	.10	3.23	.15	2.50	.23	2.72	8.45
Acropora variabilis	1	8.0	-	-	.10	3.23	.15	2.50	.08	.95	6.68
Millepora dichotoma	1	7.0	-	-	.10	3.23	.15	2.50	.06	.71	6.44
Acropora wardi	1	5.0	-	-	.10	3.23	.15	2.50	.03	.35	6.08
TOTALS	40	11.7	6.7	3-30			6.00		8.46		

Table 3. Number of species found on each transect (A-J) and the zones within each transect. Asterisk (*) indicates zone not investigated.

Transect	Inner Moat	Outer Moat	Outer Pavement	Reef Margin	Reef Front Slope	Total
	Reef Zones[1]					
Luminao Reef						
A	58	88	14	46	87	137
B	61	92	20	*	*	110
C	52	99	11	50	101	141
D	11	15	7	*	*	23
E	26	46	7	*	*	53
Piti Reef						
J	4	26	2	36	98	105

	Pavement	Reef Margin	Reef Front Slope	Total
Cabras Reef				
F	7	32	*	33
G	8	25	*	28
H	1	34	81	83
I	2	21	93	94
Study Area				160

[1]See Vertical Profiles 3-A - 3-J (pp. 15-18) in "Description of the Study Area" for distribution of zones.

MACROINVERTEBRATES

by

R. K. Kropp and L. G. Eldredge

Introduction

Only one detailed report concerning any invertebrates group has appeared for this extensive and rich reef area. Stojkovich (1977) carried out a pristine-site study in the area of Station B of the present study. She listed a few invertebrates other than reef corals.

This report provides the most extensive list of macroinvertebrates reported to date from any location on Guam.

Methods

Data on invertebrate abundance was gathered by a line-transect method. The transect tape was placed parallel to shore and invertebrates found within one meter on both sides of the tape were counted. Densities were expressed as mean number of individuals $\pm$ standard deviation per 10 m . In moat areas a 100-m tape was used, whereas on the outer reef flat and the reef front a 50-m tape was used. All transects were done during the day.

Also many excursions were made to the study area to conduct a general survey of the invertebrate fauna and to collect specimens for identification. Most of the molluscs reported here have been placed in the Richard "E" Dickinson Memorial Mollusk Collection at the University of Guam Marine Laboratory.

Results

Cabras Island Bench

The bench habitat along Cabras Island was separated into three zones. The landward edge is an area of large limestone blocks and boulders. This region becomes exposed at low tide and is characterized by animals typical of mid- and high rocky intertidal regions. On the exposed surfaces of blocks and boulders were limpets, (Acmaea cf. lentigenosus), nerites (Nerita plicata), and a grapsid crab (Grapsus tenuicrustatus). The predominant invertebrates underneath the boulders were xanthid crabs (Neoliomera sp., Panopeus, sp.), porcellanid crabs (Petrolisthes spp.), and hermit crabs (Calcinus elegans and C. laevimanus). A grapsid crab, Percnon planissimum, was very common here.

The principal gastropods found here were thaidids (Drupa ricinus and Morula granulata) and mitrids (Strigatella sp.).

The flat bench itself is exposed during low tides, except for several small pools scattered along it. Most of the invertebrates found here are small and hardy. Eight species of worm-eating cone shells co-occurred here and numbered 7.8 per 10 m^2. The bivalve, Modiolus auriculatus was common here. Actinopyga echinites and Holothuria cinerascens were the only sea cucumbers on the bench. A sea urchin, Echinothrix sp. was found in the bench pools.

The bench margin is subject to heavy wave action. The animals found here remain within the small caverns in low, stout corals and consolidated coralline algae. Most noticeable of this fauna were small porcellanid crabs (Petrolisthes, spp. and Pachycheles sp.) three of which occur only in this type of habitat. A medium sized xanthid crab (Daira perlata) was seen roaming among crevices.

Luminao-Cabras Island Reef Front

The reef front throughout the study area was very similar. This zone is subject to heavy wave surge, particularly during the dry season. Consequently, the region is scoured and lacks large invertebrates. The most conspicuous reef-front feature is the system of grooves created by the urchin Echinometra mathaei. Each groove held one urchin and provided shelter for several gastropods--particularly Drupa morum, D. rubusidaea, and Morula uva. One or more individuals of a sedentary bivalve, Chama sp., was found in most urchin grooves. E. mathaei occurred in every 10 m^2 quadrat on the reef front. The mean density was 17.0 $\pm$ 5.7 urchins per 10 m^2 at stations A, H, and J. Station I had much a higher density--44.3 $\pm$ 6.7 urchins per 10 m^2. E. mathaei densities were probably higher toward the reef margin which was not sampled because of wave surge. The reef-front pavement is covered with an algal scuss which entraps a layer of sandy sediment. Although this layer is only millimeters thick, it provides refuge for many gastropods. Most common were several species of thaidids--Drupa (five species), Thais spp., and Morula spp.--and costellariids, Pusia (five species). Seven species of Conus were found in this habitat. The bivalve Tridacna maxima (discussed later) was common on the reef front.

A burrowing sea urchin (Echinostrephus aciculatus) was fairly common, occurring in 31 of 40 reef-front 10 m^2 quadrats. Its mean density was 2.7 $\pm$ 2.6 per 10 m^2. The only sea cucumber seen here was Actinopyga mauritiana.

The most common crustaceans here were hermit crabs (Calcinus latens and C. gaimardi). Acroporid and pocilloporid corals collected from the reef front contained many symbiotic crustaceans, including 14 species of xanthid crabs and six species of palaemonid shrimps.

The coral-eating sea star Acanthaster planci did not occur on any transect but in late June 1981 a large aggregation of about 1000 individuals was observed in a band parallel to shore off the east end of Cabras Island (J. A. Marsh, Jr., pers. comm.). This band was observed at a depth of 10-12 m and was causing some damage to the coral community.

Luminao Barrier Reef

The inner moat sandy regions adjacent to the Glass Breakwater at stations A and B were very similar. Sea cucumbers were the most common invertebrates. Holothuria atra reached densities of 18.9 ± 6.2 per 10 m^2 and 13.7 ± 6.0 per 10 m^2 at Stations A and B respectively. Also common was H. hilla at 4.5 ± 2.5 per 10 m^2 at A and 2.4 ± 3.3 per 10 m^2 at B. Bohadschia marmorata was common at Station B where it reached 2.6 ± 2.8 per 10 m^2. Many species of sand-dwelling gastropods were found at these stations. Six species of terebrids, including the relatively uncommon Terebra undulata, as well as several cerithiids, strombids, and mitrids occurred here. Portunid crabs were the most abundant crustaceans here. Close to the Breakwater the moat is sandy with intermixed rubble. The area was fairly depauperate--H. atra, for example, occurred at a density of 1.0 ± 1.1 per 10 m^2. The inner moat region of Station E had little sand, consisting mostly of pavement, rocks, and rubble. Actinopyga echinites was the most common invertebrate, reaching 14.2 ± 5.6 per 10 m^2. H. atra and Echinothrix diadema were also common at 1.4 ± 1.5 per 10 m^2 and 1.8 ± 1.8 per 10 m^2, respectively.

The mid-moat area was a varied habitat, having large coral boulders, rubble patches, and pavement covered with a thin sand veneer. Although many invertebrate species occurred on transects, only H. atra was abundant. This sea cucumber was found at a density of 12.2 ± 7.3 per 10 m^2 at Station A and 10.0 ± 7.3 per 10 m^2 at Station B. H. hilla was locally common at Station B where in one section of the mid-moat it occurred at 5.2 ± 2.3 per 10 m^2. Station C was more depauperate than either A or B. H. atra was the most common invertebrate, but its abundance (0.9 ± 0.9 per 10 m^2) was much lower than at A or B.

Because of heavy surf action the outer moat was only sampled at Station A. This area is predominantly pavement and large coral blocks. H. atra, at 6.4 ± 2.4 per 10 m^2, was the most common invertebrate on the transect. Scattered throughout the area were Echinometra mathaei, A. echinites, and Linckia laevigata. Cerithium nodulosum and Strombus luhuanus were the most abundant gastropods here. Acanthaster planci was seen on the outer reef flat.

Piti Reef Flat

The Piti reef flat (Station J) has a diverse invertebrate fauna. The inner moat is characterized by a large rubble zone with scattered *Porites* boulders and *Acropora* patches. The area close to Tepungan Channel is relatively depauperate. *Holothuria hilla* (1.2 ± 1.2 per 10 m^2) and *H. atra* (0.9 ± 1.5 per 10 m^2) were the most abundant animals encountered on transects. The sand slope of Tepungan Channel was rich in gastropods. Ten species of terebrids and five species of mitrids were found here.

The mid-moat area has larger coral boulders and rubble blocks. Sea urchins (*Diadema savignyi* and *Echinometra mathaei*) were the most conspicuous invertebrates, occurring on 38 and 37 out of 40 10-m^2 quadrats, respectively. The density of *D. savignyi* here was 5.8 ± 5.0, whereas that of *E. mathaei* was 4.6 ± 3.7 per 10 m^2. Another sea urchin, *Echinothrix* was also common, occurring at 1.7 ± 2.1 per 10 m^2. The high variability of the densities is because of the daytime habit of these urchins to aggregate among large boulders. Although seven species of holothurians occurred in this zone, none were very abundant. *H. hilla*, at 1.0 ± 1.3 per 10^2, was the most common.

The outer moat was very diverse and also had a high density of *Echinometra mathaei* which occurred at 40.4 ± 28.1 urchins per 10 m^2. Holothurians were more abundant here than the inner moat. Five sea cucumbers species (*Actinopyga echinites*, *A. mauritiana*, *Holothuria atra*, *H. hilla*, *H. leucospilota*) occurred at densities from 1.4 to 2.6 per 10 m^2. The total density for all five was 9.0 ± 3.7 per 10 m^2. Cryptic species were probably underestimated. At night, although no transects were made, *Stichopus horrens* and *H. hilla* were much more noticeable. On a 50-m^2 area of pavement in the outer moat 17 *H. atra* were encountered. Of these, 9 were infested by parasitic eulimid gastropod, *Balcis* sp. As many as four *Balcis* were found on a single holothurian. Eulimids were also found on *A. mauritiana* but not on *H. hilla* in the area.

The outer reef flat at Piti is similar to the Cabras bench except that *A. echinites* is more common (3.8 ± 4.1 per 10 m^2) and cone shells are less common (three species: 1.2 ± 0.8 per 10 m^2).

Uncommon and New Species

Two of the mollusks listed as uncommon by Stojkovich (1977) were found within the Cabras Island-Luminao Reef study area. One living specimen of the triton's trumpet, *Charonia tritonis*, was found on the Piti reef flat near Station J. Another trumpet shell which was occupied by a hermit crab, *Dardanus megistos*, was found in the moat area near Station B. *Charonia* evidently ranges throughout the study area but is not common. The other mollusk listed by Stojkovich, as bivalve--*Tridacna maxima*, was found to be very common throughout much of the study area. *T. maxima* was most abundant on the reef front, occurring in 31 of the 40 per 10 m^2 quadrats. It was found on the reef front at a mean density of 1.85 ± 1.7 individuals per 10 m^2. The mean valve length of clams encountered on transects ranged from 2.5 to 17 cm, having a mean length of 9.3 ± 3.7 cm (n = 74). Clearly, Tridacna maxima should not be considered as uncommon.

Not listed by Stojkovich but considered uncommon on Guam is a thaidid gastropod, Purpura persica. This species, which is common in the northern Marianas was found among the intertidal boulders at Cabras Island.

One rare crustacean was found in the study area. This stenopodid shrimp, Microprosthema plumicorne was found under a small boulder on the reef front at Station C. This species was previously known only from the type specimen which was collected in Mauritius over 100 years ago (A. J. Bruce, pers. comm. to L. G. Eldredge). The Guam record represents a considerable range extension for the species.

One new species of gastropod was found at Cabras Island. This littornid (Echininus n. sp.) occurs on supratidal limestone cliffs along the island. This species, which is being described by J. Rosewater (Smithsonian Institution), is probably endemic to the southern Marianas.

Three new species of porcellanid crabs were found within the study area. All are in the genus Petrolisthes. One of these, being described by the author (RKK), is at presently known only from the intertidal boulder zone at the landward edge of the bench at Cabras Island. The other two are fairly common throughout the Indo-Pacific.

Literature Cited

Stojkovich, J. O. 1977. Survey and species inventory of representative pristine marine communities on Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 40. 183 p.

Table 1. Checklist and habitat of macroinvertebrates encountered within the study area. Habitat code: PV = on pavement; RK = under or among rocks; RB = under or among rubble; CO = on living coral; EX = exposed on intertidal rock surfaces; SN = on or in sand; EC = on echinoderms; * = collected dead.

	Luminao Barrier Reef				Cabras Island Reef			Piti Fringing Reef		
	Reef Front	Inner Moat	Outer Moat	Margin	Inner Bench	Mid Bench	Margin	Inner Moat	Outer Moat	Margin
	1	2	3	4	5	6	7	8	9	10
Polychaeta										
Phyllodocidae										
<u>Eteone</u> sp.							PV			
Polynoidae										
<u>Iphione</u> <u>murricata</u> Savigny								RK		
Hesionidae										
<u>Hesione</u> sp.								RK		
Amphinomidae										
<u>Eurythoe</u> <u>complanata</u> (Pallas)		RK		PV				RK		PV
Sabellidae										
<u>Sabellastarte</u> sp.		CO	CO					CO	CO	
Serpulidae										
<u>Spirobranchus</u> sp.		CO	CO					CO	CO	

Table 1 continued.

	1	2	3	4	5	6	7	8	9	10
Mollusca										
Polyplacophora										
Cryptoplacidae										
Cryptoplax sp.	RB									
Acmaeidae										
Acmaea cf. *lentigenosa* Reeve		EX			EX					
Trochidae										
Ethalia guamensis Quoy & Gaimard		RB	RB							
Monilea philippiana Dunker		RB						RK		
Tectus pyramis (Born)	PV	RB		RV						
Trochus intextus Kiener	PV									
T. niloticus Linnaeus	PV		PV							PV
T. ochroleucus	PV									
Turbinidae										
Astraea rhodostoma (Lamarck)	PV	RB								
Leptothyra sp.	RB		RB							
Turbo setosus Gmelin										
Turbo petholatus Linnaeus	*									
Neritopsidae										
Neritopsis radula (Linnaeus)									*	
Neritidae										
Nerita albicilla Linnaeus					RK			RK		
N. cf. *guamensis* Quoy & Gaimard					EX					
N. plicata Linnaeus		EX			EX					

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Neritidae (continued)										
Nerita polita Linnaeus					UR					
Littorinidae										
Echininus n.sp.					EX					
Architectonicidae										
Philippia radiata (Roeding)								RB		
Vermetidae										
Dendropoma maxima Sowerby	CO	CO	PV					CO	CO	
D. platypus Morch				PV			PV			PV
Petaloconchus keenae Hadfield & Kay	CO	CO	CO					CO	CO	
Planaxidae										
Planaxis cf. *lineatus*					RK					
Modulidae										
Modulus tectum (Gmelin)								*		
Cerithiidae										
Cerithium atromarginatum Dautzenberg & Bouge	RK									
C. columna Sowerby		SN								
Cerithium cf. *columna*		SN								
Cerithium echinatum (Lamarck)	*									
C. nesioticum Pilsbry & Vanatta	SN		SN					SN	SN	
C. nodulosum Bruguiere		SN	PV					SN		
Clupeomorus morus (Bruguiere)					RK					
Rhinoclavis aspera (Linnaeus)		SN						SN		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Cerithiidae (continued)										
Rhinoclavis diadema Houbrick	SN									
R. fasciata (Brugière)	*									
R. sinensis (Gmelin)	SN									
Eulimidae										
Balcis cf. thaanumi (Pilsbry)			RK							
Balcis sp.									EC	
Strombidae										
Lambis chiragra (Linnaeus)			RB							
L. lambis (Linnaeus)		RB	RB					RB		
Strombus dentatus Linnaeus								*		
S. gibberulus Linnaeus		SN						SN		
S. lentigenosus Linnaeus			PV							
S. luhuanus Linnaeus		SN	SN							
S. microurceus (Kira)	SN	SN						SN		
S. mutablis Swainson			RB						RB	
Vanikoridae										
Vanikoro cf. cancellata (Lamarck)			RK							
Vanikoro cf. plicata (Récluz)			RK							
Hipponicidae										
Sabia conica (Schumacher)										
Calyptraeidae										
Cheilea equestris (Linnaeus)								RK	RK	
Eratoidae										
Trivia sp.		RB								

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Cypraeidae										
Cypraea annulus Linnaeus				RK						
C. arabica Linnaeus			*							
C. caputserpentis Linnaeus	PV			RK						CA
C. cf. *carneola* Linnaeus			*							
C. depressa Gray		RK								
C. fimbriata Gmelin	RB									
C. helvola Linneaus								*		
C. isabella Linnaeus		RK	RK					RK		
C. limacina Lamarck	*									
C. lynx Linnaeus				RK						
C. maculifera Schilder		RK								
C. mauritiana Linnaeus					RK					
C. moneta Linnaeus	PV	RK	RK	RK				RK	RK	RK
C. poraria Linnaeus	RB									
C. punctata Linnaeus	RB	*								
C. ventriculus Lamarck			*		RK					
C. vitellus Lamarck				*						
Naticidae										
Pollinices melanostoma (Gmelin)		*								
Cassidae										
Casmaria erinaceus Linnaeus								*		
Cymatiidae										
Charonia tritonis (Linnaeus)			*					RK		
Cymatium gemmatum (Reeve)								RK		
C. hepaticum (Linnaeus)					*					
C. muricinum Roeding)				RK						
C. nicobaricum (Roeding)	PV		PV							
Distorsio anus (Linnaeus)								RB		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Bursidae										
Bursa bufonia Gmelin				PV		PV				PV
B. cruentata Sowerby	RK									PV
B. granularis (Roeding)				PV						
B. rhodostoma (Sowerby)	RB									
Tonnidae										
Malea pomum (Linnaeus)								*		
Tonna perdix (Linnaeus)		*	*					*		
Muricidae										
Chicoreus brunneus (Link)	PV		RK							
Muricodrupa funiculus (Wood)								RK		
Phyllocoma convoluta (Broderip)		*								
Thaididae										
Drupa clathrata (Lamarck)	PV									
D. grossularia (Roeding)	PV									
D. morum Roeding	PV	PV		PV						
D. ricinus (Linneaus)	PV		PV	PV	EX	PV			PV	PV
D. rubusidaeus Roeding	PV									
Drupella elata Blainville	PV									
Maculotriton bactreatus (Hinds)								RK	RK	
Morula anaxeres (Kiener)		RB								
M. granulata (Duclos)					RK					
M. uva (Roeding)	PV									
Nassa serta (Bruguiere)	RK							RK		
Purpura persica (Linnaeus)					RK					
Thais aculeata (Deshayes)					EX					
T. armigera (Link)	PV			PV						
T. tuberosa (Roeding)	PV									

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Coralliophilidae										
Coralliophila erosa (Roeding)	PV									
C. violacea (Kiener)	CO	CO	CO					CO	CO	
Magilopsis lamarckii	CO									
Quoyula madreporarum (Sowerby)	CO	CO	CO							
Buccinidae										
Cantharus fumosus (Dillwyn)								RK		
C. undosus Linnaeus					RK					
Pisania gracilis (Reeve)	PV									
Columbellidae										
Aesopus spiculum (Duclos)	RB									
Mitrella sp.	RB									
Pyrene cf. *ocellata*	RK									
P. punctata (Bruguiere)		RK								
P. turturina (Lamarck)	RB							RK		
Nassariidae										
Nassarius glans (Linnaeus)					*					
N. graniferus (Kiener)								SN		
Fasciolariidae										
Litirus nodatus (Gmelin)	PV									
L. polygonus (Gmelin)	PV		PV							
Peristernia nassatula (Lamarck)	PV		RK							
Olividae										
Oliva annulata (Gmelin)	SN							SN		
O. carneola (Gmelin)								SN		
O. miniacea (Roeding)	SN									
O. paxillus Reeve	SN									

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Vasidae										
Vasum ceramicum (Linnaeus)				PV						
V. turbinellus (Linnaeus)		RB	PV	PV				PV		
Harpidae										
Harpa amouretta Roeding		*								
Mitridae										
Cancilla filiaris (Linnaeus)		SN						SN		
Imbricaria conularis (Lamarck)								SN		
I. olivaformis (Swainson)		SN						SN		
I. punctata (Swainson)	SN							SN	SN	
Mitra cardinalis (Gmelin)			RK							
M. cucumerina Lamarck	PV	RK			RK	PV		RK	PV	PV
M. feruginea Lamarck			*							
M. mitra (Linnaeus)		SN								
M. stictica (Link)				PV						
Neocancilla papilio (Link)	SN							SN		
Scabricola casta (Gmelin)	SN									
Strigatella acuminata (Swainson)									RB	
S. decurtata (Reeve)					RK					
S. litterata (Lamarck)					RK					
S. pellisserpentis (Reeve)					RK					
Costellariidae										
Pusia amabilis (Reeve)	PV									
P. cancellarioides (Anton)	PV									
P. microzonias (Lamarck)	PV									
P. pardalis (Kuester)	PV									
P. patriarchalis (Gmelin)	PV							RK		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Costellariidae (continued)										
Vexillum cadaverosum (Reeve)	SN									
V. coronatum (Hebbling)								*		
V. crocatum (Lamarck)								*		
V. exasperatum (Gmelin)		SN						SN	RK	
V. michaui (Crosse & Fischer)		SN						SN		
V. semifasciatum (Lamarck)								SN		
Turridae										
Clavis sp.	PV									
Iredalea pygmaea (Dunker)					*					
Lienardia rubida (Hinds)					RK					
Conidae										
Conus ammiralis Linnaeus									RK	
C. arenatus Hwass								*		
C. balteatus Sowerby	PV									
C. catus Hwass					RK	PV				
C. chaldeus (Roeding)				PV		PV				
C. coronatus Gmelin				PV		PV				
C. ebraeus Linnaeus				PV		PV	PV			PV
C. eburneus Hwass		SN								
C. flavidus Lamarck						PV		RB		
C. frigidus Reeve						PV				
C. geographus Linnaeus		*								
C. leopardus (Roeding)		SN								
C. lividus Hwass	PV		PV	PV		PV		RB	PV	
C. miles Linnaeus	PV			PV						
C. miliaris Hwass				PV		PV				
C. moreleti Crosse	PV									
C. muriculatus Sowerby	PV									

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Conidae (continued)										
Conus obscurus Sowerby	RB									
C. pulicarius Hwass		SN						SN		
C. rattus Hwass			RB	PV		PV				
C. sponsalis Hwass	PV			PV		PV			PV	
C. striatus Linnaeus								*		
C. tessulatus Born	SN									
C. textile Linnaeus								*		
C. vexillum Gmelin	PV									
C. virgo Linnaeus		SN								
C. vitulinus Hwass		RB						RB		
Terebridae										
Hastula lanceata (Linnaeus)	SN									
H. solida (Deshayes)		SN						SN		
Terebra affinis Gray		SN	SN					SN		
T. argus Hinds								SN		
T. babylonia Lamarck		SN						SN		
T. cerithina Lamarck								SN		
T. dimidiata (Linnaeus)								SN		
T. felina (Dillwyn)	SN									
T. laevigata Gray								SN		
T. maculata (Linnaeus)		SN						SN		
T. pertusa (Born)								SN		
T. subulata (Linnaeus)		SN						SN		
T. undulata Gray		SN								
Terenolla pygmaea (Hinds)	SN									
Pyramidellidae										
Otopleura mitralis A. Adams		SN						SN	DN	
Pyramidella sulcata A. Adams		SN						SN		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Actaeonidae										
Pupa sp.		SN								
Aplustridae										
Hydatina amplustre (Linnaeus)					*					
Smaragdinellidae										
Smaragdinella calyculata (Brodcrip & Sowerby)					EX					
Bullidae										
Bulla ampulla Linnaeus		*								
Cuthonidae										
Phestilla sibogae Bergh								CO		
Bivalria										
Arcidae										
Area avellana Lamarck	RB	RB	RB					RB	RB	
Mytilidae										
Modiolus auriculatus Krauss						PV				
Septifer bilocularis (Linnaeus)		RB	RB							
Isognomonidae										
Isognomon		RK	RK		RK			RK	RK	
Spondylidae										
Spondylis ducalis Roeding								*		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Lumidae										
Lima sp.		RK						RK		
Lucinidae										
Codakia punctata (Linnaeus)			*							
Fimbridae										
Fimbria fimbriata (Linnaeus)								SN		
Carditidae										
Cardita variegata Brugiere						*				
Cardiidae										
Fragum fragum (Linnaeus)		SN						SN		
Tridacnidae										
Tridacna maxima (Roeding)										
Tellinidae										
Scutarcopagia scobinata (Linneaus)		*								
Veneridae										
Periglypta reticulata (Linneaus)					*					
Cephalopoda										
Loliginidae										
Sepioteuthis lessoniana Lesson										

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Crustacea										
Stomatopoda										
Gonodactylidae										
Gonodactylus micronesia Manning	RB									
G. platysoma Wood Mason			RB	PV						
Haptosquilla glyptocerus (Wood Mason)				PV						
Decapoda										
Stenopodidae										
Microprosthema plumicorne (Richters)	RK									
Stenopus hispidus (Olivier)	RK		RK					RK		
Gnathophyllidae										
Gnathophyllum americanum								RK	RK	
Alpheidae										
Alpheus frontalis H. Milne Edwards								RK		
A. funafutensis Borradaile				PV						
A. gracilipes Stimpson			RB							
A. lottini Guerin	CO	CO	CO					CO	CO	
A. pavirostris Dana			RB							
Synalpheus charon (Heller)				CO						
Palaemonidae										
Coralliocaris graminea (Dana)	CO									
C. superba (Dana)			CO							
C. venusta Kemp	CO									
Fennera chacei Holthius	CO									

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Palaemonidae (continued)										
Harpiliopsis beaupresi (Audoin)	CO									
H. depressus (Stimpson)	CO									
Jocaste lucina (Nobili)			CO							
J. japonica (Ortmann)	CO									
Periclimenes soror Nobili								EC		
Homaridae										
Enoplometopus sp.		SN	SN					SN	SN	
Galatheidae										
Coralliogalathea humilis (Nobili)			CO							
Porcellanidae										
Pachycheles garciaensis Ward			RB				RB			CA
P. pisoides (Heller)							CA			CA
Petrolisthes carinipes (Heller)			RB							
P. coccineus (Owen)					RK					
P. elegans Haig							CA			CA
P. n. sp. 2 (Haig, ms)	RK									
P. lamarckii (Leach)					RK					
P. lamarckii var. *rufescens* Borradaile					RK					
P. masakii Miyake			RB							
P. pubescens Stimpson	RK				RK					
Petrolisthes n. sp. 4 (Haig & Kropp, ms)							CA			CA
Petrolisthes n. sp. 5 (Kropp, ms)					RK					
Petrolisthes sp.			RB							
P. tomentosus (Dana)	CO	CO	RB							

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Diogenidae										
Calcinus elegans (H. Milne Edwards)					RK					
C. gaimardi (H. Milne Edwards)	PV									
C. laevimanus (Randall)					RK					
C. latens (Randall)	PV	RB	RB					RK	RB	
C. minutus Buitendijk				CO						
C. aff. *pulcher* Forest	CO									
Clibanarius humilis (Dana)					RK					
C. virescens (Krauss)					RK					
Dardanus deformis (H. Milne Edwards)								RB		
D. guttatus (Oliver)				PV						
D. lagopodes (Forskal)			PV	PV						
D. megistos (Herbst)			PV							
D. scutellatus (H. Milne Edwards)								RB		
Trizopagurus strigatus (Herbst)	PV									
Paguridae										
Paguritta harmsi (Gordon)	CO									
Calappidae										
Calappa calappa (Linnaeus)		SN						SN		
C. hepatica (Linnaeus)								SN		
Majidae										
Composia retusa Latreille	RB									
Parthenopidae										
Daldorfia horrida (Linnaeus)								RK		

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Portunidae										
Lissocarcinus orbicularis Dana								HO		
Portunus cf. *longispinosus* (Dana)		SN								
Thalamita admete (Herbst)		SN		PV						
T. danae Stimpson										PV
Thalamita cf. *malaccensis* Gordon	RK									
T. picta Stimpson						RB				
T. pyrmna (Herbst)								RB		
Thalamita cf. *spinifera* Borradaile	*									
T. spinimana Dana		SN								
T. wakensis Edmondson	RK									
Thalamitoides quadridens A. Milne Edwards			RB							
Xanthidae										
Atergatis frontalis (De Haan)		*								
A. floridus (Linnaeus)								RK	RK	
Carpilius convexus (Forskal)			RB							
C. maculatus (Linnaeus)		RB	RB							
Cymo andreossyi (Audoin)	CO									
C. cf. *deplanatus* H. Milne Edwards	CO									
C. melanodactylus (De Haan)	CO									
Daira perlate (Herbst)	PV			PV			PV			PV
Domecia hespida Eydoux & Souleyet			CO							
Etisus dentatus (Herbst)								*		
E. splendidus Rathbun			RB							
Globopilumnus cf. *globosus* (Dana)				CA						
Liomera sp.		RK								
Lydia annulipes (H. Milne Edwards)				RK						
Maldivia triunguiculata (Borradaile)	CO									
Neoliomera sp.					RK					

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Xanthidae (continued)										
Panopeus sp.					RK					
Pseudoliomera speciosa (Dana)			RB							
Tetralia glaberrima (Herbst)	CO									
T. heterodactyla Heller	CO									
Tetralia sp.	CO									
Trapezia cymodoce (Herbst)	CO	CO	CO							
T. davaoensis Ward		CO	CO							
T. digitalis Latreille	CO									
T. ferruginea Latreille	CO									
Trapezia cf. *formosa* Smith	CO									
T. maculata (Macleay)	CO									
T. rufopunctata (Herbst)	CO									
T. speciosa Dana									CO	
T. wardi Serene	CO	CO								
Xanthias lividus (Lamarck)				PV						
Grapsidae										
Grapsus tenuicrustatus (Herbst)		EX			EX			EX		
Percon affine (H. Milne Edwards)							*			
P. pilimanus (A. Milne Edwards)		RK								
P. planissimum (Herbst)	RK	RK			RK			RK		
Hapalocarcinidae										
Favicola cf. *helleri* Fize & Serene	CO									
Hapalocarcinus marsupialis Stimpson	CO	CO	CO						CO	
Pseudocryptochirus crescentus (Edmondson)			CO							
P. kahe McCain & Coles	CO									

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Echinodermata										
Oreasteridae										
Culcita novaeguineae Müller & Troschel	PV		RB						PV	
Ophidiasteridae										
Linckia laevigata (Linnaeus)		PV	RB					PV	RB	
L. multifora (Lamarck)	PV		RK						RK	
Asterinidae										
Asterina anomala H. L. Clark	RK									
Acanthasteridae										
Acanthaster planci (Linnaeus)	CO			PV						
Mithrodiidae										
Mithrodia clavigera (Lamarck)								RK		
Echinasteridae										
Echinaster luzonicus (Gray)		RK								
Ophiocomidae										
Ophiocoma brevipes Peters			RK							
O. dentata Müller & Troschel	RK		RK							
O. erinacenus Müller & Troschel			RK							
Diadematidae										
Diadema savignyi Michelin								RB	RB	
Echinothrix calamaris (Pallas)	RB	RB	RB					RB		
E. diadema (Linnaeus)		RB						RB	RB	

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Temnopleuridae										
Mespilia globulus (Linnaeus)									RB	
Toxopneustidae										
Toxoneustes pileolus (Lamarck)								RB	RB	
Tripneustes gratilla (Linnaeus)								RB	RB	
Echinometridae										
Colobocentrotus mertensi Brandt					RK					
Echinometra mathaei (deBlainville)	PV		RK	PV			PV	RB	PV	PV
Echinostrephus aciculatus A. Agassiz	PV								PV	
Brissidae										
Brissus latecarinatus (Leske)			*							
Holothuriidae										
Actinopyga echinites (Jaeger)			PV	PV		PV				
A. mauritiana (Quoy & Gaimard)	PV			PV						PV
Bohadschia argus Jaeger		SN	RB	PV				SN	RB	
B. marmorata Jaeger		SN						SN		
Holothuria atra Jaeger		SN	RB	PV				SN	RB	PV
H. axiologa H. L. Clark		SN								
H. cinerascens (Brandt)				PV		PV	PV			PV
H. hilla Lesson		RK	RK					RK	RK	
H. leucospilota (Brandt)		RK	RK					RK	RK	
H. nobilis Selenka				PV						
H. pardalis Selenka								RK	RK	
Stichopodidae										
Stichopus chloronotus Brandt			RB	PV					PV	
S. horrens Selenka			RK					RK	RK	

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10
Synaptidae										
Euapta godeffroyi (Semper)								RB		
Synapta maculata (Chamisso & Eysenhardt)		RB	RB					RB	RB	

LUMINAO PROJECT-FISHES

Robert F. Myers

Introduction

Numerous works have been published on the fishes of Guam. Only two, however, treat fishes specifically within the Luminao-Piti study area (see Myers and Shepard 1981 for further references). Gawel (In Stojkovich, 1977, Table 17) listed 92 species of fishes observed in the moat and reef flat of Luminao Barrier Reef. All were observed during the present survey. The author (Myers In Neudecker et al., 1978) conducted a brief survey of fishes of the lower reef front and submarine terraces off Cabras Island to a depth of 18 m. Those results are incorporated into the present survey (Table 1).

Methods

Resident fishes were censused primarily by means of 50 m transects in which the observer swam along a line counting all fishes seen within 1.5 m of either side and to 3 m above the line in each of 10 five-meter intervals. Each transect thus covered approximately 150 m^2 of reef surface. Transects were laid entirely within a particular habitat type, generally parallel to the shoreline and were run during tidal levels at lest 0.5 m above mean low water to insure relatively impartial observation of fishes occupying the water column. Fish species not observed along the transects but seen in the vicinity within the same habitat were listed as well. It was not possible to run transects in certain habitats because of rough conditions, inaccessability during suitable tides, or insufficient time. In these areas a subjective

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1 Some of the species names listed in Table 17 do not match the names used in this survey because of recent clarification of the nomenclature of many controversial species (Myers and Shepard, 1981). The true *Glyphidodontops cyaneus* does not occur at Guam and was probably recorded on the basis of another superficially similar pomacentrid.

assessment of fishes present was made by listing species observed during reconnaissance dives or incidentally through other projects, or collected with small mesh handnets. When possible, estimates of each species' relative abundance was noted.

From the transect data it was possible to determine relative abundances and approximate densities of the species, observed. Transect data in conjunction with results of subjective observations were used to construct a master table listing all species from all habitats investigated, (Table 1).

Results

A total of 304 species of fishes were observed or collected within the Luminao-Piti study site and the adjacent outer reef slope. Their relative abundances and ecological distributions are summarized in Table 1. Locations of transects, collection sites, and incidental observations are indicated on Figure 1.

Intertidal areas collectively contained the fewest species, whereas inner reef habitats, (i.e. those bounded by the seaward edge of the reef flat and shoreline) collectively contained 206 species of fishes. The outer reef habitats to a depth of 40 m collectively contained 200 species of fishes. The most speciose outer reef habitat was the reef front with 144 species. Diversity appeared to decrease with increasing depth, however, this could be partially a result of decreased sampling effort with depth. The moat habitats collectively contained 165 species, considerably more than the channel systems and rocky interstices of the Glass Breakwater. The staghorn Acropora zone was the most diverse moat habitat with 131 species, followed by the mixed coral zone,the Millepora zone, and the rubble-and-agal zones of the inner moat, respectively.

More detailed discussions of the ichthyofauna of each habitat follow under their respective headings.

Intertidal

Intertidal areas include the immediate shoreline of Cabras Island, the Glass Breakwater, and sides of the Piti Power Plant Intake Channel, as well as portions of the reef flats at Cabras Island and the Luminao barrier reef.

It was not possible to run quantitative visual transects in these habitats because of the physiographic conditions of the immediate shoreline or hazardous surf conditions along outer reef flats during high tides. However, qualitative observations or collections were made in the following areas: The Glass Breakwater at Stations A, B, and C and the intertidal shoreline and reef flat near Site H (Figure 1).

Intertidal areas collectively contained 28 species of fishes. The rocky shoreline fauna of the entire study area is dominated by blenniids, Alticus saliens being the most abundant, and occurring in moist shaded pockets above the water line. In the immediate vicinity of the water line Entomacrodus striatus and Istiblennius edentulus are common. The deep recesses between the boulders of the Glass Breakwater provide shelter for numerous subtidal species which will be considered elsewhere.

Twenty-five species were collected or observed during low tides on the intertidal reef flat near Station H. Most of these appeared to be quite common resident fishes and include seven blenniids and four pomacentrids. In early June 1981, several large schools of juvenile Gnathodentex aureolineatus and Kuhlia mugil were observed in surge channels encroaching the reef flat. Undoubtedly numerous transient species, mostly roving herbivorous acanthurids and scarids, move onto the flat during high tides.

While it was not possible to sample the intertidal outer reef flat of Luminao barrier reef, observations at high tides revealed the presence of the resident pomacentrids Chysiptera leucopomus and Plectroglyhidodon leucozona as well as numerous outer moat and reef front species.

Moats

The study area includes two large moats, Luminao moat bounded by the Luminao barrier reef flat and Glass Breakwater; and Piti moat located at the east end of Cabras Island.

Collectively, 165 species were observed in the moat habitat including 143 species at Luminao and 112 at the smaller Piti site, ninety of which were observed in both areas. Seven species were among the 10 most abundant at each of the two moat sites (Tables 3, 5).

Luminao Moat: The following eight transects were run into the Luminao moat. Depths refer to the approximate depth of the substrate base and are calibrated to mean low water. An effort was made to sample as many different habitats as possible.

A-1. West end of Luminao reef approximately 15 m seaward from the Glass Breakwater,--inner moat, 1.0 m, subject to strong currents and secondary wave chop; coarse sand and rubble with occasional scattered colonies of Pocillopora damicornis, Porites lutea, Platygyra daedalea, Sinularia sp., Sarcophyton trachelioforum, and clumps of the algae Dictyota sp.

C-1. East end of Luminao reef approximately 20 m seaward from the Glass Breakwater,--inner moat, 1.2 m; coarse sand and thick Dictyota sp. mat on limestone base with scattered colonies of Porites cocosensis, Pocillopora damicornis, Pavona diveracata, and Porites (Synaraea) convexus.

B-1. Central Luminao reef approximately 50 m seaward of the Glass Breakwater,--Acropora aspera zone, 1.5 m at sand base; large beds of Acropora aspera and A. formosa between tracts of coarse sand with scattered colonies of Porites cocosensis, Sinularia sp., some rubble, coralline algae, and Dictyota sp.

B-2. Central Luminao reef approximately 170 m seaward of the Glass Breakwater,--central moat, 1.0 m; thin layer of coarse sand and exposed limestone with scattered rubble between ridges of consolidated coralline algae and Dictyota on rubble base, with numerous scattered patches of Acropora aspera, Millepora dichotoma, Porites lutea, P. cocosensis, and Pocillopora damicornis.

A-2. West end of Luminao reef approximately 125 m seaward of the Glass Breakwater,--central moat, 1.3; limestone pavement with patches of lobate Porites spp., Porites (Synaraea) convexa, and colonies of Isopora palifera, and Porites cocosensis.

C-2. East end of Luminao reef approximately 90 m seaward of the Glass Break-water,--outer moat, 0.5 m; subject to secondary wave chop and strong currents; limestone pavement with patches of loose sand and algal mats with scattered colonies of Millepora dictotoma, Porites cocosensis, P. lutea, and Acropora aspera.

A-3. West end of Luminao reef approximately 180 m seaward of the Glass Breakwater,--outer moat, 1.0 m; subject to secondary wave chop; limestone with thin veneer of coarse sand and numerous large colonies of lobate Porites spp., Millepora dichotoma, Pocillopora damicornis, Lobophyllia sp. and Heliopora caerulea.

A-4. West end of Luminao reef approximately 240 m seaward from the Glass Breakwater; outer moat, 0.8 m; subject to secondary wave chop and strong currents; scoured limestone pavement with approximately 40 percent cover by Millepora dichotoma patches, dead at their centers.

Results of transect counts are presented in Table 2 and arranged approximately zonally from most offshore. The ten most abundant species on each transect are presented in Table 3.

Territorial pomacentrids and small roving labrids dominated all moat habitats, whereas scarids, acanthurids, mullids, chaetodontids, gobiids, holocentrids, and a few other families tended to be well represented, locally. Lethrinids and carangids were occasionally seen but not encountered on any transects.

Halichoeres trimaculatus was the most common and most widespread species followed by Stegates lividus, both of which were among the top ten species in all eight transects. Scarus sordidus was among the ten commonest species in seven transects, Stegates nigricans in six and Stethojulis bandanensis in five. Dascyllus aruanus, Chromis caerulea, Pomacentrus vaiuli, and Chrysiptera biocellatus tended to be locally abundant in certain habitats and among the ten most abundant species in four transects each. Scarus psittacus was among the top ten in only two transects but may have been underestimated because of the uncertain identity of many juvenile scarids.

Densities ranged from 0.89 individuals per m^2 at the relatively barren current-swept rubble area at J-1 to 2.88 individuals per m^2 in the relatively sheltered, rich area at B-2. Of the Luminao moat transects, the central moat area at A-2 contained the greatest number of species in its vicinity (70), whereas the Millepora zone of the outer moat at A-4 had the greatest number of species counted on any given transect (43).

Glass Breakwater: While no transects were run here, a listing of species observed living near or among the recesses of the breakwater itself is presented in Table 1. This structure provides shelter for at least 46 species of fishes, some of which were not observed elsewhere. The snapper Lutjanus fulvus and numerous holocentrids were often observed here.

Piti Moat: The following three transects were run in the subtidal moat of the Piti reef flat bounded by Tenpugan Channel, Cabras Island, and the Philippine Sea. Each transect was run in one of three predominating biophysiographic zones. All zones were subject to strong southeasterly flowing currents generated by a strong northwest swell during most of the fall, winter, and spring months.

J-1. Inner moat approximately 65 m from roadbed on north side of Tepungan Channel,--sand and rubble zone, 0.5 m; with abundant clumps of Halimeda macroloba, Padina tenuis, Dictyota sp., Sargassum polycystum, and occasional small colonies of Pocillopora damicornis.

J-2. Central moat approximately 130 m east of Cabras Island,--Porites lutea zone, 0.8 m; sand and rubble with numerous large colonies of Porites lutea and smaller ones of Acropora aspera; Pocillopora damicornis, Porites cocosensis, Porites (Synaraea) spp., and Sinularia sp.

J-3. Central moat approximately 220 m east of Cabras Island;--Acropora aspera zone, 0.6 m; elevated stands of Acropora aspera about 0.5 m above sandy interspaces.

Results of transect counts are presented in Table 4 and arranged approximately from most inshore to most offshore. The ten most abundant species in each transect are presented in Table 5.

Here, as the Luminao moat, territorial pomacentrids and roving labrids dominated the three habitats, whereas apogonids, holocentrids, mullids, and chaetodontids were seen in high numbers.

Dascyllus aruanus was the most abundant species with a mean density as high as 1.35 individuals per m^2 in the Acropora aspera zone of area J-3 but was all but absent in the current-swept rubble area of J-1. Halichoeres trimaculatus was the second most abundant and most widespread species, being among the ten most common species on all three transects. Chrysiptera biocellatus, Stegastes albifasciatus, S. nigricans, and Stethojulis bandanensis were among the ten most common species in two of the three transects, whereas Segastes lividus, Chromis caerule, Apogon novemfasciatus, and Flammeo sammara tended to be locally abundant, among the ten most common species in only one transect each.

Densities ranged from a low of 1.55 individuals per m^2 at the current-swept rubble zone of J-1 to 4.34 individuals per m^2 in the lush Acropora aspera zone of site J-3, which was also the richest in terms of density, species seen on a transect line (60), and species seen in the vicinity of a transect (89) for the entire study area. The Porites lutea zone of area J-2 contained a slightly higher density than area J-1, but had many more species (45 vs 21 counted on a transect, and 62 vs 31 seen in the vicinity).

Tepungan and Piti Intake Channel System

Portions of this man-altered channel system bound the southern and eastern portion of the Piti study site and bisect the eastern portion of Cabras Island. Fishes occupying the intertidal rocky sites of the Piti intake channel are covered under the heading "intertidal." This channel system provides a suitable habitat for at least 115 species of fishes, many of which were not encountered elsewhere. No transects were run here, but a list is incorporated in Table 1. Territorial pomacentrids such as Chysiptera biocellatus and wrasses like Halichoeres trimaculatus were abundant in Tepungan Channel, as well as numerous species of gobiids, apogonids, scorpaenids, mullids, acanthurids, and several other families. Gerres argyreus and Caranx melampygus were often seen here, and the seasonal atulai, Selar cumenopthalmus is occasionally caught by fishermen in large numbers.

Reef Front and Upper Submarine Terrace

The following five transects were run in the reef front and upper submarine terrace environments and represent a variety of habitats from the upper portion of a ridge-and-channel zone to the coral-rich upper terrace zone. All zones are subject to various degrees of nearly continual wave assault and surge during all but the summer months.

J-4. Piti reef approximately 220 m east northeast of Cabras Island,--upper reef front, channel, and ridge zone 1.5-3 m; rich with large mounds of Pocillopora spp., Millepora dichotoma, and Acropora spp.

I-1. Cabras Island immediately west of Piti intake channel,--reef front, 3-4 m; barren limestone between zone of deep surge channels and rich coral growth of upper terrace; numerous low stubbly corals and grooves excavated by the echinoid Echinometra mathae.

H-1. Cabras Island at Site H,--reef front, 4 m; barren limestone with scattered colonies of Pocillopora spp. and Acropora spp. and occasional deep channels extending from reef margin.

A-5. West end of Luminao reef,upper submarine terrace, 5 m; barren limestone with numerous small colonies of Pocillopora spp., Acropora spp. and Montipora spp.

J-5. Piti Reef approximately 230 m east-northeast Cabras Island,--upper submarine terrace, 4-6 m; coral rich with numerous colonies of Acropora spp., Pocillopora spp., Millepora dichotoma, Stylophora mordax, and Montipora spp.

The results of transect counts are presented in Table 6, and the ten most abundant species in each transect are listed in Table 7. It was not possible to run transects off all study sites, but qualitative surveys were made in the surge channel zone off Site I and the reef front of Site C. These results are included in Table 1.

Territorial pomacentrids and roving labrids were the most abundant and widespread species, closely followed by the blenniids Cirripectes variolosus, Istiblennius coronatus, and the gobiid Pogonuculias zebra. Large schools of scarids and acanthurids occurred throughout this habitat and cirrhitids were commonly observed on numerous coral heads. A total of 121 species were observed on reef front transects, whereas an additional 21 species were observed or collected on qualitative surveys of the surge channels zone of Site I and the reef front at C.

By far the most abundant reef-front species was Chysiptera leucopomus with an average density of 0.73 individuals per m^2 and a high of 1.35 individuals per m^2, the highest of all species surveyed in this study. It was among the ten most common species on four of the five transects, however, its relative absence from the upper terrace of J-5 may have been brought about to the late hour of this count. Thalassoma quinquevittata was the second most common species and among the ten most common in all five transects. Stegastes fasciolatus, Cirripectes variolosus, and Plectroglyphidodon imparipennis were among the ten most common species in all five transects while the third most abundant species overall, Pomachromis guamensis was among the ten most common in three transects. Dascyllus reticulatus, Plectroglyphidodon dickii, Istiblennius coronatus and Pogonuculias zebra tended to be more restricted, all among the ten most common species encountered in two transects each.

Densities ranged from a low of 1.94 individuals per m^2 at transect J-5 to a high of 3.41 individuals per m^2 at H-1. This low count may represent an underestimate of species and numbers, since the count was taken at dusk and several species seen before the start of the count were absent at the end of the count, having taken shelter for the night. Numbers of species seen on a transect ranged from 27 at I-1 to 40 at J-4, whereas the number of species seen within the vicinity ranged from 44 at I-1 to 65 at J-4.

Submarine Terrace and Outer Reef Slope

Although not directly within the study site, the reef terrace below 6 m and outer reef slope were subject to a brief previous study (Myers In Neudecker et al., 1978) as well as incidental observations made by the author while scuba diving to a depth of 40 m. Fishes observed in these habitats are incorporated into Table 1.

Literature Cited

Myers, R. F., and J. W. Shepard. 1981. New records of fishes from Guam with notes on the ichthyofauna of the southern Marianas. Micronesica 16(2):305-347.

Neudecker, S., D. M. Rowley, and R. F. Myers. 1978. Marine environmental survey of the GORCO deballast discharge, Cabras Island, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 19. 24p.

Stojkovich, J. O. 1977. Survey and species inventory of representative pristine marine communities on Guam. Univ. Guam Mar. Lab. Tech. Rept. 40. 183p.
40. pp. 60-61.

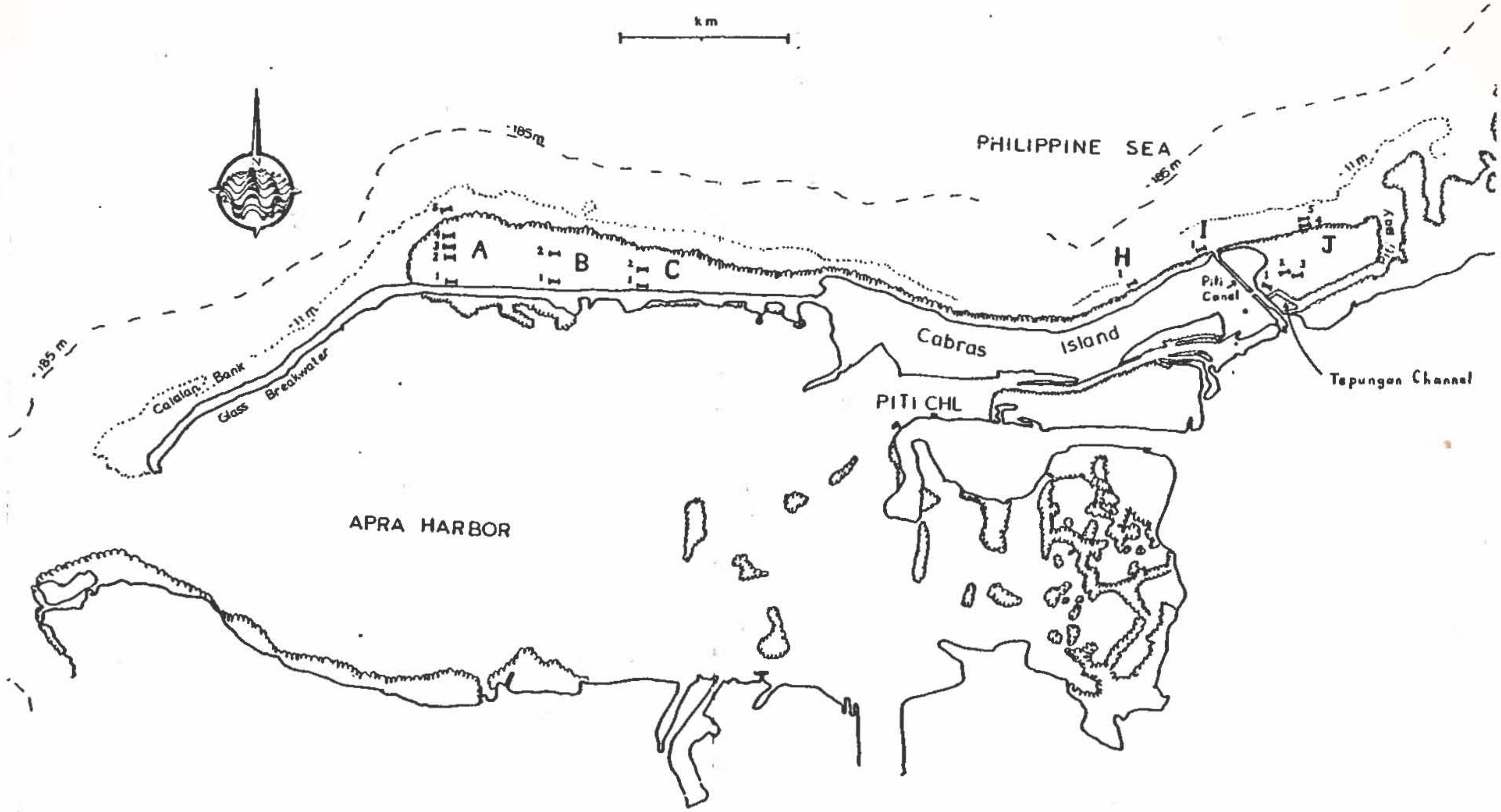

Figure 1. Map of the Luminao-Piti reef system showing locations of fish transects.

Table 1. Ecological distribution of fishes observed in the Luminao and Piti reef area with estimates of relative abundances based on transect counts and qualitative observation. (Refer to text and key below for definition of habits and explanations of symbols.)

TAXA	Intertidal shoreline and reef flats	INNER REEF HABITATS: Subtital Glass Breakwater	Tepungan and Piti intake Channel System	Inner moat - rubble and agal zones	Mid moat - mixed coral zones	Mid moat - staghorn *Acropora* zones	Outer moat - *Millepora* zones	Reef front	Submarine terrace	Outer reef slope	Approximate depth range in meters
	1	2	3	4	5	6	7	8	9	10	11
Corcharhinidae											
Carcharinus amblyrhynchos (Bleeker)[1]										R	>30
C. melanopterus (Quoy & Gaimard)[2]								R			1
Muraenidae											
Echidna nebulosa (Ahl)			R		R						0-2
Gymnothorax sp. cf. *thyrsoideus* (Richardson)			R			R					1-4
Lycodontis flavimarginatus (Rüppell)			R								1

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Muraenidae (continued)											
Lycodontis javanicus (Bleeker)						R					1
L. undulatus (Lacepede)			R	R							0-3
Uropterygius micropterus (Bleeker)	0										0-1
Ophichthidae											
Myrichthys colubrinus (Boddaert)[3]				R							0.5
Synodontidae											
Saurida gracilis (Quay & Gaimard)		0	0	0	0	0	0				1-4
Synodus binotatus Schultz								0	0		2>5
S. variegatus (Lacepede)									0	0	9≥10
Belonidae											
Belone platyura Bennett		C			0		C				Surface
Hemiramphidae											
Hemiramphus archipelagicus Collette & Parin					0	0					Surface
Atherinidae											
Atherion elymus freyi Schultz		0									Surface
Holocentridae											
Adioryx diadema (Lacepede)				0	0	0		R	R		1-6
A. caudimaculatus (Rüppell)										0	15-40
A. lacteoguttatus (Cuvier)	0				R		R	0			1-3
A. microstomus (Günther)				R	0	C	C	R			1-5
A. spinifer (Forsskal)		0	0	R	0	0	R	R	0	0	1>30
A. tiere (Cuvier)								0	0		2-4

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Holocentridae (Continued)											
Flammeo argenteus (Valenciennes)			C		0	0					1
F. sammara (Forsskål)		C	C	0		A	0	0	0	0	1-30+
Myripristis amaenus (Castlenau)		0	0	0	C	0	0	0			1-4
M. berndti Jordan & Evermann			0		0	C	0				1-4
M. violaceus Bleeker		0									1-2
Aulostomidae											
Aulostomus chinensis (Linnaeus)		C	0	0	0	0				0	1-4;>10
Fistulariidae											
Fistularia commersonii Rüppell			0		0	0	0				1-4
Syngnathidae											
Corythoichthys flavofasciatus (Rüppell)			C			0	0				1
C. intestinalis (Ramsey)		C	C	0	0	0					1
Doryhamphus melanopleura (Bleeker)		0	0	R				0			1-4
Unid sp.			R								1-4
Unid post-larval[4]											Surface
Scorpaenidae											
Dendrochirus brachypterus (Cuvier)			0								1-4
Pterois antennata (Bloch)			0						0	0	1-4;≥5
P. volitans (Linnaeus)			R								4
Scorpaena tristis (Klunzinger)			0	C	0	0					1-4
S. albobrunnea Günther								R			3-7
Scorpaenodes guamensis (Quoy & Gaimard)	0		0	0	0	0					1-4
S. parvipinnis (Garrett)						0					1
Scorpaenopsis diabolus Cuvier			R								1-2
Synanceia verrucosa (Bloch & Schneider)			R			R					1

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Scorpaenidae (continued)											
Taenionotus triacanthus Lecepede									R		5
Unid post-larval[5]											Surface
Carancanthidae											
Caracanthus maculatus (Gray)									0		5
Platycephalidae											
Platycephalus sp.			R								3
Serranidae											
Anthias pleurotaenia (Bleeker)										0	>35
Cephalopholis urodelus (Bloch & Schneider)								C	C	0	2-30+
Cephalopholis analis (Valenciennes)[6]										0	21-40
Epinephelus fasciatus (Forsskål)								R	0	0	4-40
E. hexagonatus (Bloch & Schneider)					0			0			1-5
E. tauvina (Forsskål)								R			4-6
E. merra (Bloch)				0		0					1
Pseudochromidae											
Pseudochromis tapienosoma Bleeker								C	0		4-6
Plesiopidae											
Plesiops coeruleolineatus Rüppell					0						1
Grammistidae											
Grammistes sexlineatus (Thunberg)			0					0			1-6
Kuhlidae											
Kuhlia mugil (Forster)	A										0-1

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Priacanthidae											
Priacanthus hamrur (Forsskål)										0	30
Apogonidae											
Apogon angustatus (Smith & Radcliffe)								0			4-6
A. fraenatus Valenciennes			0	0	0						1-2
A. guamensis Valenciennes			0	R	0	0					1-4
A. kallopterus Bleeker		0	C		0		0				1-4
A. nigrofasciatus Lachner						0	R				1
A. novemfasciatus Smith & Radcliffe	C	0	A	A	C	0	0	0			1-4
A. sp.[7]			A								
Apogonichthys ocellatus Weber	R			R							0.5
Cheilodipterus macrodon (Lacepede)			0							0	1;≥15
C. quinquelineatus Cuvier			A	0	0	0				0	1-4
Siphamia versicolor (Smith & Rodcliffe)			0								3-4
Carangidae											
Caranx melampygus Cuvier			0					0	0	0	1≥20
Carangoides sp.			0	0							1
Selar crumenophthalmus (Bloch)			S								--
Decapterus sp.									0		4-6
Lutjanidae											
Aphareus furcatus (Lacepede)			0					0	0		2-6
Lutjanus bohar (Forsskål)										0	>15
L. fulvus (Bloch & Schneider)		0						0			1-3
Caesionidae											
Caesio caerulaureus Lacepede								0	0		2-15
Pterocaesio chrysozona (Cuvier)										C	18-30 m

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Nemipteridae											
Scolopsis cancellatus (Cuvier)			0	0	0	C	0	C			1-4
Gerreidae											
Gerres argyreus (Bloch & Schneider)			0	0		0					1-4
Haemulidae											
Plectorhynchus orientalis (Bloch)										0	>30
Lethrinidae											
Gnathodentex aureolineatus (Lacepede)	A		C								0.5-1
Lethrinus harak (Forsskål)				0		0	0	0			1-4
L. miniatus (Bloch & Schneider)							R		R		1-7
L. sp.								R			4
Monotaxis grandoculus (Forsskål)										C	>20
Mullidae											
Mulloidichthys flavolineatus (Lacepede)			C	C	0	0	0				1-4
M. vanicolensis (Valenciennes)					R						1
Parupeneus barberinus (Lacepede)			C	C	0	0					1-4
P. bifasciatus (Lacepede)			0				0	0	0		1-10
P. chryserydros (Lacepede)			0	R	0			0	0	0	1-40
P. trifasciatus (Lacepede)			0	0	0	0	0	0	0	0	1-40
P. pleurostigma (Bennett)								0			1-3
P. pleurotaenia (Playfair)						0					1
Pempheridae											
Pempheris oualensis Cuvier			C					C			1-4
Ephippidae											
Platax orbicularis (Forsskål)			0								3-4

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Chaetodontidae											
Chaetodon auriga Forsskål		0	0	0	0	0		0	0		1-4
C. bennetti Cuvier						0					1
C. citrinellus Cuvier			0	C	C	0	C	C	C		1≥18
C. ephippium Cuvier								0	0		2>10
C. lunula (Lacepede)		0	0	0	0	R	R	C	0		1-6
C. melannotus Bloch& Schneider		0				0	0				1-2
C. mertensii Cuvier									R	0	
C. ornatissimus Cuvier						0		0	0		1>10
C. punctatofasciatus Cuvier					0			0	0	0	1>30
C. quadrimaculatus Gray					R		0	0	0		1-6
C. reticulatus Cuvier			R		R	R	0	0	0		1-6
C. trifasciatus Park				0	0	C	C	0	R		1-6
C. uleitensis Cuvier		0				R		0			1-3
C. unimaculatus Bloch					0	0		0	0		1>10
Forcipiger flavissimus Jordan & McGregor								0	0	0	2-40
Hemitaurichthys polylepis Bleeker										C	21>40
Heniochus chrysostomus Cuvier			C	0	0	0				0	1-40
H. monoceros Cuvier		0	0								1-4
H. varius (Cuvier)										0	12-18
Megaprotodon trifascialis (Quoy & Gaimard)					0	C	0	0	0		1-6
Pomacanthidae											
Apolemichthys trimaculatus (Cuvier)									0	0	4≥20
Centropyge flavissimus (Cuvier)								0	0	0	5-24
C. heraldi Woods & Schultz										0	>18
C. shepardi Randall & Yasuda					R				0	0	1.5;12-30
Pomacanthus imperator (Bloch)								0			2-3
Pygoplites diacanthus (Boddaert)										0	10-40

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Pomacentridae											
Abudefduf sordidus (Forsskål)	C	0	0								0-2
A. septemfasciatus (Cuvier)		0					0				0-2
A. sexfasciatus (Lacepede)								0			1-2
A. vaigiensis (Quoy & Gaimard)							0	C			1-3
Amblyglyphidodon curacao (Bloch)						0j	0j				1
Amphiprion chrysopterus Cuvier								0	0		2-5
A. clarckii (Bennett)								0			2-3
A. melanopus Bleeker					0	0	0				0.5-1
A. perideraion Bleeker									0		5
Chromis acares Randall & Swerdloff									C		4>18
C. agilis Smith									0	C	6-40
C. amboinensis (Bleeker)										A	>18
C. atripectoralis Welander & Schultz						0	0				1
C. caerulea (Cuvier & Valenciennes)			C	A	A	A	C				0-4
C. margaritifer Fowler								0	C	0	3>15
C. vanderbilti (Fowler)								C	C		3>15
C. sp.[8]										C	>18
Chrysiptera biocellatus Quoy & Gaimard			A	A	C	C	0				1-3
C. glaucus (Cuvier)	A			0		0	0				0-1
C. leucopomus (Lesson)	0				0	0	0	A	A		0-12
C. traceyi (Woods & Schultz)		0	0							A	2;3-40
Dascyllus aruanus (Linnaeus)			A	A	A	A	0				1-4
D. reticulatus (Richardson)			0		R	R		0	A	0	1>30
D. trimaculatus (Rüppell)			0		0		0	0	0		1-6
Plectroglyphidodon dickii (Lienard)					0	C	C	A	A		1-6
P. imparripennis (Vaillant & Sauvage)	0							A	C		1-6
P. johnstonianus Fowler & Ball					0	0		C	C		1-9 m
P. lacrymatus (Quoy & Gaimard)						0	0	R	0	0	1-40
P. leucozona (Bleeker)	A							A			1-3
P. phoenixensis (Schultz)								C			1-3

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Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Pomacentridae (continued)											
Plectroglyphidodon sp. cf. johnstonianus								0	0		1-6
Pomacentrus ambionensis Bleeker			0								3-4
P. pavo Bloch		0	C			0					1-4
P. vaiuli Jordan & Seale				0	C	C	C		C	C	1>30
Pomachromis guamensis Allen & Larson								A	A		3-12 m
Stegastes albifasciatus (Schlegal & Muller)			C	A	A	A	A				1-4
S. fasciolatus (Ogilby)							0	A	A		1-10
S. lividus (Bloch & Schneider)					A	A	0				1
S. nigricans (Lacepede)			0	0	C	A	A				1-4
Cirrhitidae											
Cirrhitichthys falco Randall									0	C	4-40
Cirrhitus pinnulatus (Bloch & Schneider)								0			1-3
Neocirrhites armatus Castlenau								C	C		1-6
Paracirrhites arcatus (Cuvier)								C	C		1>10
P. forsteri (Bloch & Schneider)								C	C		1>10
P. hemisticus (Günther)								0	0		1-6
Labridae											
Anampses caeruleopunctatus Rüppell								C	0		1.5-12 m
A. twisti Bleeker		R								0	1; 10
Bodianus axillaris (Bennett)										0	>10
Cheilinus celebecus Bleeker									0	C	4-40
C. chlorurus (Bloch)			0		0	0					1-4
C. trilobatus Lacepede		0	0	0	0	0	C	0	0		1≥10
C. undulatus (Rüppell)				0		0					
C. unifasciatus Streets[9]						0		0	0	0	1>30
Cheilio inermis (Forsskål)				0	0	0	0	0			1-6
Coris aygula Lacepede							0	0			1-4

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Labridae (continued)											
Coris gaimardi (Quoy & Gaimard)								0			1-4
Cirrhilabrus katherinae Shepard & Randall[10]			R						A	A	3;6-30 m
Epibulus insidiator (Pallas)		0		0	0	0	0	0			1>10
Gomphosus varius Lacepede				0	0	0	0	0	0		1>10
Halichoeres hortulanus (Lacepede)		0		0	0	0	0	0			1-4
H. margaritaceus (Valenciennes)	A			C			0	C	0		1-5
H. marginatus Ruppell		0			0	0	C	C			1-4
H. trimaculatus (Quoy & Gaimard)			C	A	A	A	A				1-4
H. biocellatus Schultz									0	C	7>20
Hemigymnus fasciatus (Bloch)				0	0	C	0				1
H. melapterus (Bloch)		0	0	0	0	0	0	0			1-4
Labrichthys unilineatus (Guichenot)						0					1
Labroides bicolor Fowler & Bean		0								0	1;>6
L. dimidiatus (Valenciennes)			0		0	0	0	0	0	0	0>30
Labropsis sp. 1[11]										0	>10
Macropharyngodon meleagris (Valenciennes)				0	0	0	C	0	0		1-6
Novaculichthys taeniourus (Lacepede)			0	0	0	0		0			1-4
Stethojulis bandanensis (Bleeker)	C	C	0	C	C	C	C	0	C		1>6
S. strigiventor (Bennett)		0		C		0					1
Thalassoma amblycephalus (Bleeker)								C	C		1>6
T. fuscum (Lacepede)								C			1-4
T. hardwickei (Bennett)				0	0	0	C				1
T. lutescens (Lay & Bennett)			0	0	0	0	C	0	C		1>6
T. purpureum (Forsskål)			0					0			1
T. quinquevittata (Lay & Bennett)	0							A	A		1>6
Scaridae											
Calotomus sandvicensis (Valencinnes)				R	0	0	0		0		1>6
Scarus brevifilis (Günther)						0j		0			3-4

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Scaridae (continued)											
Scarus globiceps Valenciennes								0			3-4
S. frontalis Valenciennes[12]						0	A				1
S. tricolor Bleeker[13]						0			0	0	1;4≥30
S. psittacus Forsskål					0		A	C	C		1≥6
S. rubroviolaceus (Bleeker)									0		4-6
S. sordidus Forsskål		C	0	C	C	A	A	A	A	0	1≥20
S. schlegeli (Bleeker)								C	C	C	1≥30
Scarus spp. - unid. juveniles[14]		A	C	A	A	A	C	0	0		1-6
Mugiloididae											
Parapercis cephalopunctata (Seale)			0			0	0	0	0		1≥30
P. clathrata Ogilby				C	C	0			0	0	1≥6
Blenniidae											
Alticus saliens (Forster)	A										0
Aspidontus taeniatus Quoy & Gaimard			0								1-2
Cirripectes sebae (Valenciennes)								0			1-4
C. variolosus (Valenciennes)							0	A	A		1-6
Ecsenius bicolor (Day)								0	0	0	4-6
E. opisfrontalis Chapman & Schultz									0	0	6≥20
Entomacrodus striatus (Quoy & Gaimard)	C	C									0-1
E. sp.	C										0-1
Exalias brevis (Kher)						R		0			1-3
Istiblennius coronatus (Günther)								A	C		1-6
I. edentulus (Bloch & Schneider)	C	C									0-1
Istiblennius sp.	C										0-1
Meiacanthus atrodorsalis (Günther)		C	C	C	C	C	0	0	0	0	1≥30
Plagiotremus tapienosoma (Bleeker)			0			0	0	C	C		1-5
Salarias fasciatus (Bloch)			C	0	C	C	C				1-3
Stanulus seychellensis Smith						0	0				1

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Blenniidae (continued)											
Unid sp. 1						R					1
Unid sp. 2	0										0-1
Petroscirtes xestus Jordan & Seale			0								1
Tripterygiidae											
Enneapterygius sp.	C										0-1
Unid sp.								C	C		3-7
Callionymidae											
Callionymus xanthosemeion Fowler			0			0					1-3
Diplogrammus goramensis (Bleeker)			0								1-3
Gobiidae											
Amblygobius albimaculatus (Rüppell)			C			0					1-4
Asteropteryx semipunctatus Rüppell			C	C		0					1-4
Cottogobius sp.						0					1
Ctenogobiops pomastictus Lubbock & Pulonin			C	C	0	A					1-3
Eviota zonura Jordan & Seale	C							0	0		1-6
Eviota sp.			0			0		0			3-4
Fusigobius neophytus (Günther)		C	C	0	0	A					1-4
Gnatholepis sp. cf. *cauerensis* (Bleeker)			C	0		0					1-3
Gnatholepis sp. 1					0	C					1
Gobiodon citrinus (Rüppell)								0			1-5
Gobiodon sp. 1								0			4
Istigobius ornatus (Rüppell)						0					1
Istigobius sp. 1						0					1
Nemateleotris magnificus Fowler									0	0	5>15
Oplopomus oplopomus (Valenciennes)			0			0					3-4

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Gobiidae (continued)											
<u>Paragobiodon</u> <u>echinocephalus</u> (Rüppell)			0								1-2
<u>Pogonoculias</u> <u>zebra</u> Fowler								A	A		3-12 m
<u>Ptereleotris</u> <u>evides</u> (Jordan & Hubbs)								0	0		2>6
<u>Valenciennea</u> <u>strigata</u> (Broussonet)			0		0	0		0	C		2>10
Unid sp.	0										0-1
Acanthuridae											
<u>Acanthurus</u> <u>achilles</u> Shaw								R			3-4
<u>A. achilles x glaucoparieus</u>			R								1
<u>A. glaucoparieus</u> Cuvier						R	0	0	0		1>10
<u>A. lineatus</u> (Linnaeus)				0		0	0	A	C		1>6
<u>A. mata</u> (Cuvier)					0				C		1>6
<u>A. nigricaudus</u> Duncker & Mohr								0	0		1>18
<u>A. nigrofuscus</u> (Forsskål)		0	0	0	0	0	C	A	A		1>10
<u>A. nigroris</u> Cuvier & Valenciennes					0		0	C	0		1-5
<u>A. olivaceus</u> Bloch & Schneider					0			R	0		4>10
<u>A. pyroferus</u> Kittlitz										C	>10
<u>A. triostegus</u> (Linnaeu)	A		0	C	0	0	A	A	0		1>10
<u>A. xanthopterus</u> Valenciennes			0	0							1
<u>Ctenochaetus striatus</u> Quoy & Gaimard		0		0	0	0	0	C	C	0	1>10
<u>Naso hexacanthus</u> (Bleeker)										C	>30 m
<u>N. lituratus</u> (Bloch & Schneider)					0	C	0	0	0	0	1>30
<u>N. unicornis</u> (Forsskål)		C		0		0	0	0			1-4
<u>N. vlamingi</u> (Valenciennes)						0j				0	>10
<u>Paracanthurus</u> <u>hepatus</u> (linnaeus)									0		6
<u>Zebrasoma</u> <u>flavescens</u> (Bennett)					0	0	0	0			1-4
<u>Z. scopas</u> (Cuvier)						0				0	1;>6
<u>Z. veliferum</u> (Bloch)			0j			0		0			1-2

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Zanclidae											
Zanclus cornutus Linnaeus		0	0	0	0	0	0	0	0	0	1-40
Siganidae											
Siganus argenteus (Quoy & Gaimard)									0		>6
S. spinus (Linnaeus)	C			0		0	0				1
Scombridae											
Gymnosarda unicolor (Rüppell)										o	>12
Bothidae											
Bothus mancus (Broussonet)			0					R	R		1-7
Balistidae											
Balistapus undulatus (Park)						0		0	0	0	1-40
Balistoides viridescens (Bloch & Schneider)			0					R	0	0	1>8
Melichthys niger (Bloch)								0	0		3-6
M. vidua (Solander)								0	0	0	1>10
Odonus niger (Rüppell)										C	>18
Rhinecanthus aculeatus (Linnaeus)			C	0	0	0					1-4
R. echarpe (Lacepede)					0		0	C	0		1-5
Sufflamen bursa (Bloch & Schneider)								0	0	0	1>20
S. chrysoptera (Bloch & Schneider)			0					0	0		1-6
Monacanthidae											
Cantherhines dummerilli (Hollard)								0	0		1-3
C. pardalis (Rüppell)						R	0	0	0		1-5
Oxymonacanthus longirostris Bloch & Schneider			0		C	A	C	0			1-4
Pervagor melanocephalus (Bleeker)					0	0		0	0		1-6
Paraluteres prionurus Bleeker			0		0			0	0		1-6

Table 1 Continued.

	1	2	3	4	5	6	7	8	9	10	11
Ostraciontidae											
Ostracion cubicus Linneaus		0	0	0	0	0					1-3
O. meleagris Shaw			R					0	0		1-6
Tetraodontidae											
Arothron hispidus (Linnaeus)											
Arothron meleagris (Lacepede)					R		0				1
A. nigropunctatus (Bloch & Schneider)			0		0	0	0	0			1≥7
Canthigaster amboinensis (Bleeker)	0j		Rj					C	0		0-3 m
C. bennetti (Bleeker)			0		0						1-3
C. janthinoptera (Bleeker)			0j		0	0		0			1-3
C. solandri (Richardson)	Cj	C	A	C	C	C	C	0	0	0	0-30
C. valentini (Bleeker)		0	0	0		0				0	1≥15
No. species per habitat	28	44	115	77	100	131	88	144	123*	73*	

Key to symbols: (Table 1)

A = Abundant; ≥21 individuals on any one transect or approximately 40 individuals sighted per diver hour, whichever is greater

C = Common; 6-20 per transect or 11-40 per diver hr.

O = Occasional; 2-5 per transect or 2-10 per diver hr.

R = Not more than one individual sighted on any one dive

S = Seasonal, not seen but caught by local fishermen

j = juveniles only

* = An underestimate due to incidental nature of sampling below 6 m

Footnotes

1. Occasionally observed by Marine Lab. personnel along the outer reef slope off the west end of Luminao reef.

2. One individual observed near the GORCO deballest discharge pipe, March 1978.

3. One individual observed along the sandy shoreline at the east end of Luminao moat.

4. & 5. Specimen collected in a surface plankton two off the east end of Cabras Island at night; not included in species counts.

6. Identification provided by J. E. Randall (personal communication).

7. Probably undescribed, but mistakenly referred to as _A. novaeguineae_ in most recent literature (J. E. Randall, personal communication).

8. The same as _Chromis_ sp. A of Allen (1974).

9. Mistakenly referred to as _C. rhodochrous_ in most recent literature (J. E. Randall, personal communication).

10. To be described by J. W. Shepard and J. E. Randall.

11. To be described by J. E. Randall.

12. A senior synonym of _S. jonesi_ (Streets) (J. E. Randall, personal communication).

13. A senior of _S. lepidus_ Jenyns (Streets). (J. E. Randall, personal comm.)

14. Refers to one or more of 6 unidentified juveniles; not included in species counts.

Table 2. Fishes censused in the moat of Luminao Reef. Explanation of numbers and symbols as in Table . Transects are arranged approximately zonally from most inshore to most offshore.

	TRANSECTS							
SPECIES	A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
Echidna nebulosa						+		
Lycodontis javanicus				1				
Saurida gracilis		3	4	1	2	+	+	+
Belone platyura					5		17	+
Hemiramphus archipelagicus				+		+		
Adioryx diadema		3		1	+			
Adioryx lacteoguttatus								1
A. microstomus	+	+			4	3	1	8
A. spinifer		1			2			
Flammeo sammara		5	1		5	2		1
Myriptristis amaenus		4			8		+	
M. berndti					+		+	
Aulostomus chinensis		1	+		+			
Fistularia commersonii				+			+	
Corythoichthys flavofasciatus								1
C. intestinalis			1					
Epinephelus merra		+						
Apogon fraenatus		1	+					
A. guamensis			+		+			
A. kallopterus					+		1	
A. nigrofasciatus			+	1			+	
A. novemfasciatus	1	2	+		1	4	2	1
Cheilodipterus quinquelineatus	+	2	+					
Carangoides sp.	+							
Scolopsis cancellatus	+	+	+	+	+		+	+
Lethrinus harak		+		+			+	
L. miniatus							+	

Table 2 Continued.

SPECIES	A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
	TRANSECTS							
Mulloidichthys flavolineatus	2	6	1	1	+	3	+	+
M. vanicolensis						+		
Parupeneus barberinus	+	+						
P. bifasciatus								+
P. chryserydros		+			2			
P. trifasciatus	+	+	+			1		3
Gerres argyreus				+				
Chaetodon auriga	+	+	+					
C. citrinellus	+	4	+	2	2	2	7	1
C. lunula	2	+			+			1
C. melannotus			+	1			+	
C. ornatissimus			+					
C. punctatofasciatus					+			
C. quadrimaculatus						+		+
C. reticulatus					+		+	
C. trifasciatus	+	2	1	5	2	1	1	7
C. uleitensis				+				
C. umimaculatus			+		+			
Heniochus chrysostomus		1			+			
Megaprotodon trifascialis			+	7		3	+	
Centropyge shepardi					1			
Amphiprion melanopus			2	+	+		1	
Abudefduf septemfasciatus							+	
A. vaigiensis							+	+
Amblyglyphidodon curacao			1					
Chromis atripectoralis								3
C. caerulea		78	70	+	39	34	+	+
Chrysiptera biocellatus	35	43	8	1	16	2	+	
C. glaucus	+		+				+	+

Table 2 Continued.

SPECIES	A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
				TRANSECTS				
Chrysiptera leucopomus				1		1		4
Dascyllus aruanus	3	32	111	61	3	44		
D. reticulatus					+			
D. trimaculatus					+			
Plectroglyiphidodon dickii						5		17
P. johnstonianus						1		
P. lacrymatus				1				2
Pomacentrus pavo			+					
P. vaiuli		1		7	3	11	11	14
Stegastes albifasciatus	19	49	8	72	34	53	48	10
S. lividus			18	13		21		
S. nigricans	1	1	8	36	11	13	42	80
Cheilinus chlorurus				+	+			
C. trilobatus	2	1	+	+	+	1	1	7
C. undulatus		+	+	+				
C. unifasciatus				+				
Cheilio inermis	+	1			+			
Coris aygula								+
C. gaimardi	+							
Epibulus insidiator		1		+	+		+	1
Gomphosus varius	+	1		+		1	1	3
Halichoeres hortulanus		1			2		3	
H. margaritaceus								1
H. marginatus			+		1			6
H. trimaculatus	31	57	25	59	45	39	34	23
Hemigymnus fasciatus		3		5	+	3		1
H. melapterus	+	+	1	1	1	1	+	+
Labrichthys unilineata			+	1				
Labroides dimidiatus				+	1	1	+	2

Table 2 Continued.

SPECIES	TRANSECTS A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
Macropharyngodon meleagris	+			2	1		+	4
Novaculichthys taeniourus	+	+						
Stethojulis bandanensis	15	11	1	14	7	4	12	14
S. strigiventor	7		1					
Thalassoma hardwickei	+		+	+	+	+	2	3
T. lutesceus	+			1	2		1	9
Calotomus sandvicensis		+			+			
Scarus brevifilis				1				
S. frontalis								1
S. tricolor			+					
S. psittacus					+		12	70
Scarus sp. 1 juv.	+	+	3	7	2	2		1
S. sordidus	3	40	29	86	15	11	6	27
Scarus sp. 2 juv.		3	1	8	2			
Scarus sp. 5 juv.				+				
Scarus sp. 6 juv.		2	1		+			
Parapercis cephalopunctata				+				1
P. clathrata					1			
Cirripectes variolosus								1
Meiacanthus atrodorsalis		6	6	2	5	2	+	
Salarias fasciatus		3	1	+	3	2	1	2
Stanulus seychelleusis				1				
Unid. blennid				+				
Callionymus xanthosemeion			1					
Amblygobius albimaculatus			+					
Asteropteryx semipunctatus			1					
Cottogobius sp.			1					
Ctenogobiops pomastictus		14	24			+		
Fusigobius neophytus		1	27	2	1		2	

Table 2 Continued.

SPECIES	A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
	TRANSECTS							
Gnatholepsis sp. cf. *cauerensis*		2	+					
Gnatholepsis sp. 1			3	2	1			
Istigobius sp. 1			+					
Oplopomus oplopomus			1					
Valenciennea strigata				2	+	+		
Acanthurus glaucoparieus								+
A. lineatus	+			+				
A. mata	+					1		
A. nigrofuscus	+	+	+	1		+	10	5
A. nigroris					+			
A. triostegus	6	3	+	1	1	1	6	13
Ctenochaetus striatus		1	+			1		2
Naso lituratus				+	1	+	1	+
N. unicornis		+		+			+	+
N. vlamingi				+				
Zebrasoma flavescens			2	1	2	1		
Z. scopas			+					
Z. veliferum			+					
Zanclus cornutus	+	1	1	1	+	2	+	2
Siganus spinus	+	+	+	+			+	+
Balistapus undulatus				+				
Rhinecanthus aculeatus				+	+			
R. echarpe					+		+	+
Oxymonacanthus longirostris			3	17	+	10	7	2
Pervagor melanocephalus					+			
Ostracion cubicus		+	+					
Arothron meleagris								+
A. nigropunctatus								+
Canthigaster janthinoptera					+			

Table 2 Continued.

SPECIES	A-1	C-1	B-1	B-2	A-2	C-2	A-3	A-4
				TRANSECTS				
Canthigaster solandri	7	1	1	5	8	2	3	6
C. valentini		2	+					
No. of species seen on transect	11	39	35	38	37	36	36	43
No. of species in vicinity	38	57	66	66	70	47	57	62
No. of individuals on transect	134	393	371	432	242	290	236	363
No. of individuals per m^2	0.89	2.62	2.47	2.88	1.61	1.93	1.57	2.42

Table 3. The ten most abundant fish species seen on Luminao Moat Transects. Each species is listed in order of abundance. Transects are arranged zonally from most inshore to most offshore. An asterisk indicates ties.

A-1	C-1	B-1
Chrysiptera biocellatus	Chromis caerulea	Dascyllus aruanus
Halichoeres trimaculatus	Halichoeres trimaculatus	Chromis caerulea
Stegastes albifasciatus	Stegastes albifasciatus	Scarus sordidus
Stethojulis bandanensis	Chrysiptera biocellatus	Fusigobius neophytus
S. strigiventor	Scarus sp. 2 juveniles	Halichoeres trimaculatus
Canthigaster solandri	Dascyllus aruanus	Ctenogobiops pomastictus
Acanthurus triostegus	Ctenogobiops pomastictus	Stegastes lividus
Dascyllus aruanus	Stethojulis bandanensis	*S. albifasciatus
Scarus sordidus	*Mulloidichthys flavolineatus	*S. nigricans
*Mulloidichthys flavolineatus	*Meiacanthus atrodorsalis	Chrysiptera biocellatus
*Chaetodon lunula		
*Cheilinus trilobatus		

A-2	C-2	A-3
Halichoeres trimaculatus	Stegastes albifasciatus	Stegastes albifasciatus
Chromis caerulea	Dascyllus aruanus	S. nigricans
Stegastes albifasciatus	Halichoeres trimaculatus	Halichoeres trimaculatus
Stegastes nigricans	Chromis caerulea	Belone platyura
Chrysiptera biocellatus	Stegastes lividus	Stethojulis bandanensis
Scarus sordidus	S. nigricans	Pomacentrus vaiuli
Myripristis amaenus	Pomacentrus aviuli	Acanthurus nigrofuscus
Canthigaster solandri	Scarus sordidus	Chaetodon citrinellus
Stethojulis bandanensis	Oxymonacanthus longirostris	Oxymonacanthus longirostris
*Flammes sammara	Plectroglyphidodon dickii	
*Belone playura		
*Meiacanthus atrodorsalis		

Table 3 Continued.

B-2	A-4
Scarus sordidus	Stegastes nigricans
Stegastes albifasciatus	Scarus psittacus
Dascyllus aruanus	S. sordidus
Halichoeres trimaculatus	Halichoeres trimaculatus
Stegastes nigricans	Plectroglyphidodon dickii
Oxymonacanthus longirostris	Pomacentrus vaiuli
Stethojulis bandanensis	Stethojulis bandanensis
Stegastes lividus	Acanthurus triostegus
Scarus sp. 3 juveniles	Stegastes albifasciatus
*Megaprotodon trifascialis	Thalassoma lutescens
*Pomacentrus vaiuli	
*Scarus sp. 1 juvenile	

All transects combined	No. of Transects with this species in top ten	Average density per m^2
Halichoeres trimaculatus	8	.261
Stegastes albifasciatus	8	.244
Dascyllus aruanus	4	.212
Chromis caerulea	4	.184
Scarus sordidus	6	.181
Stegastes nigricans	4	.160
Chrysiptera biocellatus	4	.088
Scarus psittacus	2	.068
Stethojulis bandanensis	5	.065
Pomacentrus vaiuli	4	.039

Table 4. Fishes censused in the moat of Piti Reef. Total number of each species seen is indicated; asterisks denote species seen in the immediate area within the same habitat type, but not on the transect at the time of the count. Transects are arranged from most inshore to most offshore. Refer to Table   for description of transect settings.

SPECIES	TRANSECTS J-1	J-2	J-3
Gymnothorax sp. cf. *thrysoideus*			+
G. undulatus	+		
Saurida gracilis			4
Hemiramphus archipelagicus		+	
Adioryx diadema		+	+
A. lacteoguttatus		+	+
A. microstomus		3	10
A. spinifer		1	1
Flammeo argenteus			2
F. sammara		2	24
Myripristis amaenus		1	3
M. berndti		2	9
Aulostomus chinensis			+
Fistularia commersonii		+	+
Corythoichthys flavofasciatus			+
C. intestinalis	1	+	2
Doryhamphus melanopleura	+		
Scorpaena tristis	4	+	+
Scorpaenodes guamensis	1		+
S. parvipinnis			+
Syananceia verrucosa			+
Epinephelus hexagonatus		1	
E. merra			+
Plesiops caeruleolineatus		+	
Apogon guamensis	+	+	4
A. kallopterus		1	
A. novemfasciatus	26	2	
Apogonichthys ocellatus	1		
Cheilodipterus quinquelineatus		+	4
Carangoides sp.	+		
Scolopsis cancellatus	1	+	3
Mulloidichthys flavolineatus	+	1	3
Parupeneus barberinus	7	1	1
P. trifasciatus	5	1	1
P. pleurotaenia			1
Chaetodon auriga		1	+
C. bennetti			1
C. citrinellus			+
C. lunula		4	
C. melannotus			3

Table 4 Continued.

SPECIES	TRANSECTS J-1	J-2	J-3
Chaetodon reticulatus			+
C. trifasciatus		1	11
C. unimaculatus			+
Heniochus chrysostomus		1	+
Megaprotodon trifascialis			19
Amphiprion melanopus			+
Chromis atripectoralis			+
C. caerulea		+	69
Chrysiptera biocellatus	68	13	9
C. glaucus	+		
C. leucopomus			1
Dascyllus aruanus	2	64	202
Plectroglyphidodon dickii			8
P. johnstonianus		2	+
P. lacrymatus			2
Pomacentrus vaiuli		14	4
Stegastes albifasciatus	1	23	19
S. lividus			136
S. nigricans	1	4	28
Cheilinus chlorurus		+	+
C. trilobatus	+	1	4
Cheilio inermis	1	1	+
Epibulus insidiator			2
Gomphosus varius		1	+
Halichoeres hortulanus		3	1
H. margaritaceus	5		
H. marginatus			1
H. trimaculatus	80	34	30
Hemigymnus fasciatus			1
H. melapterus		2	2
Labroides dimidiatus		1	1
Macropharyngodon meleagris		+	1
Novaculichthys taeniourus		+	+
Stethojulis bandanensis	16	7	3
Thalassoma hardwickei		2	+
Calotomus sandvicensis		1	1
Scarus frontalis			+
S. sordidus		1	10
Scarus sp. 1 juv.		2	
Scarus sp. 2 juv.	1	4	1
Scarus sp. 3 juv.		2	
Scarus sp. 4 juv.			2
Scarus sp. 5 juv.			+
Parapercis clathrata	5	4	3
Exalias brevis			1
Meiacanthus atrodorsalis		4	+

Table 4 Continued.

SPECIES	TRANSECTS J-1	J-2	J-3
Plagiotremus tapienosoma			+
Salarias fasciatus	2	8	2
Stanulus seychellensis			+
Callionymus xanthosemeion			+
Asteropteryx semipunctatus	1		+
Eviota sp.			+
Fusigobius neophytus			1
Gnatholepis sp. 1			+
Acanthurus galucoparieus			1
A. nigrofuscus		2	1
A. olivaceus		+	
A. triostegus		2	3
A. xanthopterus	+		
Ctenochaetus striatus		1	
Naso lituratus			12
N. unicornis			1
Zebrasoma flavescens			1
Zanclus cornutus			1
Siganus spinus	+		+
Rhinecanthus aculeatus	+		+
Cantherhines pardalis			+
Oxymonacanthus longirostris		3	19
Pervagor melanocephalus			+
Ostracion cubicus		1	1
Arothron hispidus		+	
A. nigropunctatus		+	+
Canthigaster bennetti		1	
C. janthinoptera			1
C. solandri	3	4	1
C. valentini			1
No. of species seen on transect	21	45	60
No. of species in vicinity of transect	34	62	89
No. of individuals on transect	232	235	695
No. of individuals per m^2	1.55	1.57	4.34

Table 5. The ten most abundant fish species seen in the moat transects of Piti Reef. Arrangement and symbols follow that of Table 2.

J-1	J-2	J-3
Halichoeres trimaculatus	Dascyllus aruanus	Dascyllus aruanus
Chrysiptera biocellatus	Halichoeres trimaculatus	Stegastes lividus
Apogon novemfasciatus	Stegastes albifasciatus	Chromis caerulea
Stethojulis bandanensis	Pomacentrus vaiuli	Halichoeres trimaculatus
Parupeneus barberinus	Chrysiptera biocellatus	Stegastes nigricans
P. trifasciatus	Salarias fasciatus	Flammeo sammara
Halichoeres margaritaceus	Stethojulis bandanesis	Megaprotodon trifascials
Parapercis clathrata	*Chaetodon lunula	Stegastes albifasciatus
Scorpaena tristis	*Stegastes nigricans	Oxymonacanthus longirostris
Canthigaster solandri	*Scarus sp. juvenile	Naso lituratus
	*Parapercis clathrata	
	*Meiacanthus atrodorsalis	
	*Canthigaster solandri	

All transects combined	No. of transects in top 10	Average density per m^2
Dascyllus aruanus	2	.596
Halichoeres trimaculatus	3	.320
Stegastes lividus	1	.302
Chrysiptera biocellatus	2	.200
Chromis caerulea	1	.153
Stegastes albifasciatus	2	.093
S. nigricans	2	.073
Apogon novemfasciatus	1	.062
Stethojulis bandanensis	2	.058
Flammeo sammara	1	.058

Table 6. Fishes censused on the reef front and upper submarine terrace. Explanation of numbers and symbols as in Table 2. Transects are arranged approximately zonally from the shallowest to the deepest.

	TRANSECTS				
SPECIES	J-4	I-1	H-1	A-5	J-5*
Adioryx lacteoguttatus	4				
A. spinifer	+				
Dorhamphus melanopleura	2				
Taenionatus triacanthus				+	
Caracanthus maculatus				1	
Cephalopholis urodelus			1	1	4
Epinephelus tauvina					1
Pseudochromis tapienosoma			4		+
Grammistes sexlineatus					1
Apogon angustatus					1
A. novemfasciatus	2				
Decapterus sp.					2
Aphareus furcatus		1	+	1	+
Lutjanus fulvus	+				
Lethrinus sp.			+		
Parupeneus bifaciatus	1				
P. trifasciatus	+		1	+	+
P. pleurostigma	+				
Chaetodon auriga					+
C. citrinellus	+	1	3	2	
C. ephippium	+				+
C. lunula	+				+
C. ornatissimus	+	+	2		
C. punctatofasciatus					3
C. quadrimaculatus		1			+
C. reticulatus	2	+	+		2
C. trifasciatus	2		+		+
C. uleitensis			+		
C. unimaculatus		+			+
Forcipiger flavissimus	+	+		+	+
Megaprotodon trifascialis	+		+		+
Apolemichthys trimaculatus				+	
Centropyge flavissimus				1	
Abudefduf waigiensis	10		+		+
Amphiprion chrysopterus	1			+	
A. clarckii		+			
A. perideraion				+	
Chromis acares					8
Chrysiptera leucopomus	148	174	203	21	3
Dascyllus reticulatus	3		+	115	26
D. trimaculatus					+
Plectroglyphidodon dickii	35		4	5	33

Table 6 Continued.

SPECIES	TRANSECTS J-4	I-1	H-1	A-5	J-5*
Plectroglyphidodon imparipennis	8	58	31	14	
P. johnstonianus			+	17	11
P. lacrymatus					+
P. leucozona	27				
P. phoenixensis	8				
P. sp. cf. johnstonianus	2				2
Pomachromis guamensis		5	54	121	1
Stegastes fasciolatus	45	2	18	17	96
Anampses caeruleopunctatus	2				
Cheilinus trilobatus	+		1		
C. unifasciatus	+	+		+	
Cheilio inermis		+			
Coris aygula			+		
Epibulus insidiator	1				
Gomphosus varius	1		+		+
Halichoeres hortulanus	+				
H. margaritaceus		7	7	3	
H. marginatus	5				
Hemigymnus melapterus		+			
Labroides dimidiatus	2		2		1
Novaculichthys taeniourus		+			
Stethojulis bandanensis	3		3	3	2
Thalassoma amblycephalus	1		3	18	+
T. fuscum	+		+		
T. lutescens			+	5	
T. quinquevittata	24	45	48	34	37
Scarus brevifilis	+				
S. psittacus		2	2	10	
S. rubroviolaceus					+
S. sordidus	+	16	11	4	3
S. schlegeli	+	5	+		
Cirrhitichthys falco				1	
Cirrhitus pinnulatus	1		+		
Neocirrhitus armatus				4	1
Paracirrhites arcatus	2			16	4
P. forsteri	2		2	4	2
P. hemistictus	1		1		
Cirripectes sebae	1		1		
C. variolosus	43	19	42	2	20
Ecsenius bicolor			2	+	1
Exalias brevis	2				
Istiblennius coronatus	4	44	17	4	
Plagiotremus tapienosoma				4	
Tripterygiid sp.	1		5		1
Eviota zonura	1				4
Eviota sp.		+			

Table 6 Continued.

SPECIES	J-4	I-1	H-1	A-5	J-5*
	TRANSECTS				
Gobiodon citrinus		4	1		
Gobiodon sp.			2		
Nemateleotris magnificus				3	
Pogonoculias zebra	21	+	44		
Ptereleotris evides		+	+		+
Valenciennea strigata		1		3	
Acanthurus achilles		+			
A. glaucoparieus	+		+		+
A. lineatus	2		9		+
A. nigrofuscus	+	9	11	10	9
A. nigroris		4	3	+	
A. olivaceus					+
A. triostegus	+	1			+
Ctenochaetus striatus		2	8		1
Naso lituratus		+	+		1
N. unicornis		1	+		
Zebrasoma falvescens	+				
Zanclus cornutus	+	+	+	+	+
Balistapus undulatus	+				+
Melichthys niger					1
M. vidua	+	1	+	+	
Rhinecanthus echarpe	4	5	2	+	
Sufflamen bursa		+	2		+
S. chrysoptera	+	1	+	3	+
Cantherhines pardalis	1	1	4	+	
Oxymonacanthus longirostris			2		
Pervagor melanocephalus					1
Paraluteres prionurus					+
Ostracion meleagris	1				+
Arothron nigropunctatus	1				
Canthigaster ambionensis	3		+		+
C. solandri		+	1	1	1
No. of species seen on transect	40	27	36	33	33
No. of species in vicinity of transect	65	44	58	45	62
No. of individuals on transect	409	431	512	495	291
No. of individuals per m^2	2.73	2.87	3.41	3.30	1.94

Table 7. The ten most abundant fish species seen on reef front and upper submarine terrace transects. Arrangement and symbols follow that of Table 2.

J-4	I-1	H-1
Chrysiptera leucopomus	Chrysiptera leucopomus	Chrysiptera leucopomus
Stegastes fasciolatus	Plectroglyphidodon imparipennis	Pomachromis guamensis
Cirripectes variolosus	Thalassoma quinquevittata	Thalassoma quinquevittata
Plectroglyphidodon dickii	Istiblennius coronatus	Cirripectes variolosus
P. leucozona	Pagonoculias zebra	Plectroglyphidodon imparipennis
Thalassoma quiquevittata	Cirripectes variolosus	Stegastes fasciolatus
Abudefduf waigiensis	Scarus sordidus	Istiblennius coronatus
Plectroglyphidodon imparipennis	Acanthurus nigrofuscus	Scarus sordidus
P. phoenixensis	Halichoeres margaritaceus	Acanthurus nigrofuscus
Halichoeres marginatus	*Pomachromis guamesis	Acanthurus lineatus
	*Scarus schlegeli	
	*Rhinecanthus echarpe	

A-5	J-5
Pomachromis guamensis	Stegastes fasciolatus
Dascyllus reticulatus	Thalassoma quinquevittata
Pogonoculias zebra	Plectroglyphidodon dickii
Thalassoma quinquevittata	Dascyllus reticulatus
Chrysiptera leucopomus	Cirripectes variolosus
Thalassoma amblycephalus	Plectroglyphidodon johnstonianus
Plectroglyphididion johnstonianus	Acanthurus nigrofuscus
Stegastes fasciolatus	Chromis acares
Paracirrhites arcatus	Pomacentrus vaiuli
Plectroglyphididon imparipennis	*Cephalopholis urodelus
	*Paracirrhites arcatus
	*Eviota zonura

Table 7 Continued.

All transects combined	No. of transects in top 10	Average density per m^2
Chrysiptera leucopomus	4	.732
Thalassoma quinquevittata	5	.251
Pomachromis guamensis	3	.241
Stegastes fasciolatus	4	.237
Dascyllus reticulatus	2	.192
Cirripectes variolosus	4	.168
Plectroglyphidodon imparipennis	4	.148
P. dickii	2	.103
Istiblennius coronatus	2	.092
Pogonoculias zebra	2	.087

WATER CURRENTS AND WATER QUALITY

by

Lucius G. Eldredge

Introduction

Knowledge of water currents in the vicinity of an OTEC facility are of vital importance because of plant dependence upon large uninterrupted supplies of both shallow warm and deep cold water for optimum operation. The design and location of shore-based OTEC intake and discharge pipes are especially critical because currents are generally more complex in the near-shore water mass. Complex eddies induced by the island land mass, submarine slope configuration, and bidirectional tide-generated currents increases the possibility of warm intake and cold discharge waters becoming intermixed. The currents revealed from this study are to be considered of a preliminary nature which indicates the presence of a complex near-shore water movement pattern. Such a current pattern is the resultant of a number of interacting variables, some of which include: 1) the magnitude of the North Equatorial Current that sweeps past the island; 2) wind direction, speed, and other climatic factors; 3) tides; 4) island shoreline and submarine slope configuration; and 5) seasonal variation of 1-3 above. Detailed annual cycle current patterns in the vicinity of Cabras Island were beyond the scope of this study, but such knowledge must be addressed and incorporated into the final design of a shore based OTEC plant.

Methods

Water current direction and speed were measured using drift drogues suspended in the water column at 1 and 5 meter depths at the eastern end of Cabras Island offshore from Piti Canal (Sta. I, Fig. 1). At the western end of Cabras Island (Sta. E., Fig. 2) and at the western end of Luminao Reef (Sta. A, Fig. 3) only 1-meter drift drogues were used. Fluorescein dye injection method was used on the shallow Luminao and Piti reef platforms (Fig. 4A and 4B). Dye patches were measures when they had drifted 10 meters.

Samples for water quality analysis were collected at 1-meter and 5-meter depths at four locations (Stations H, I, and J, Fig. 1; and Station A, Fig. 3)with the assistance of a vanDorn water sampler. Samples were appropriately fixed in the field. Analyses were carried out by the University of Guam Water and Energy Research Institute laboratory.

Results and Discussion

Currents

Currents were investigated at offshore locations and on the shallow Luminao Barrier Reef and Piti Reef platforms as shown in Figures 1-4.

Offshore currents were periodically measured between July 24, 1980 and April 14, 1981. Most of the information was gathered near the Piti Canal (Station I); however, some measurements were made at the west end of Cabras Island (Station E) and at the northwestern end of the Luminao Barrier Reef (Station A). A summary of the offshore drouge data is given in Table 1.

The currents at Station A (Fig. 3) were very irregular--a drogue (H-1) traveled 0.61 m/sec (1.99 ft/sec) in a northwesterly direction on August 7, 1980 and another (K-1) traveled 0.59 m/sec (1.94 ft/sec) in a northeasterly direction on September 16, 1981. Because of the irregular speeds and erratic directions of the currents, several drogues were lost here, and current investigations were discontinued in October 1980.

At Station E, currents were measured through December 1980 (Fig. 2). This station corresponds to that of Huddell et al. (1974) at the west end of Cabras Island. Currents predominantly flowed bidirectionally parallel to the shore of the island and fringing reef; however, on one occasion a drogue (X-1) had to be removed from the shallow reef-front zone.

Huddell et al. (1974) conducted surveys during the winter and spring of 1971. Current meters were placed at 10.7 m (35 ft) and 16.8 m (55 ft), respectively, for the two surveys. During the winter there was a westerly net movement. Tidal changes and changes in current speed and direction appeared to have little or no affect on the general current direction. In the spring current speeds were found to be less. Currents had a northerly net movement, shifting between northwest and northeast. Huddell et al. (1974) also carried out dye-injection studies near the shore. Dye injected at low- and high-tide intervals moved westward and spread out along the shore at the east end of the breakwater. In September, dye placed before low tide moved in an easterly direction toward Cabras Island.

On November 11, 1980, approximately 16,800 gallons of deballast oil from a spill which originated at the GORCO deballast facility outfall near Station F was noticed on the Luminao Reef near Station D. The oil had floated westward and shoreward as Huddell et al. (1974) has noted with their dye-injection studies. This deballast oil appears to have floated shoreward at the shallowest area of Station D. The oil continued to move parallel to the breakwater and exited at the western end of the barrier reef platform. It did seep through the breakater in at least two places. Huddell et al. (1974) reported that on one occasion (February 26, 1971) their dye was also found in Apra Harbor near the present site of the Marianas Yacht Club, having also seeped through the breakwater itself.

Currents were measured at depths of 1 and 5 meters at the Piti Canal (Station I) from a distance of 91 m (300 ft) to 914 m (3000 ft) from the shore, depending on the weather conditions. The majority of drogues moved in a westerly direction irrespective of tidal or wind conditions, although at times there were erratic drifts or northeasterly movement associated with tide changes. The drouge tracks at this station are shown in Figure 1.

The general westerly surface currents is further substantiated by studies carried out by the Pacific Island Engineers (1951). From Camel Rock, 288 wooden floats were released in May 1949. About 10 percent of them were collected at the shore along Cabras Island and on the east shore of the causeway. The remaining floats moved in a westward direction. One was reported from Japan in August 1950 (Pacific Island Engineers, 1951).

Currents were measured on the Luminao Barrier Reef at Stations Magundas, A, and B (Fig. 4A) at the breakwater and on the reef flat itself. Current direction and speed depends upon the amount of water transported onto the reef platform by ocean waves and swells and the direction of the approaching waves and swells. When waves and swells approach the reef margin with a northern or eastern component the current on the reef platform has a strong westerly movement, and when the waves and swell approach with a northwestern or western component the current on the reef platform has an easterly movement. When the reef platform current has a westerly movement the water returns to the ocean at Magundas (extreme western tip of Luminao Barrier Reef), and when the current has an easterly movement it exits near Station D (Fig. 2). Current speed is directly related to the volume transport of water onto the reef platform by waves and swells. In August 1980 during a very low tide when the reef margin was emergent along most of its length, there was virtually no water movement, a speed of 0.01 m/sec was calculated. In December 1980 following the deballast oil spill, a narrow band of oil moved westward along the breakwater and existed at the west end of the barier reef. A summary of the current data for the shallow reef-flat platforms of Luminao and Piti Reefs is given in Table 2.

At the east end of Cabras Island toward Piti Bay (Sta. J, Fig. 4B) currents were measured during an incoming tide and were found to have a speed of 1.0 m/sec. Marsh and Gordon (1971, 1974) conducted extensive current surveys in the Piti reef flat area. They described the current flow as dependent on tide and surf conditions. During periods of high surf water flows across the outer pavement and inner and outer moat zones of the reef platform and exits through the Tenpungan Channel. When there is little surf, there is little water transported onto reef platform itself.

Water Quality

Reactive nitrate-nitrogen (NO-N), reactive nitrite-nitrogen (NO-N), orthophosphate (PO-P), dissolved oxygen (O_2), and salinity were measured at depths of 1 meter and 5 meters at four stations (A, Fig. 3; and H, I, and J, Fig. 1) along Cabras Island-Luminao Barrier Reef.

Nitrite concentration was neglible or nonexistent at both depths. One very high measurement of 2.92 μg-at/l from a 1-meter depth on December 30, 1980 remains unexplained.

Nitrate and orthophosphate were always present and showed no mark difference between 1 and 5 meter depths. There were no apparent seasonal differences; therefore, the data are combined and are shown as mean values in Table 3. Both the nitrate and orthophosphate concentrations are lower than those of 0.2363 μg-at/l and 0.1399 μg-at/l for nitrate and orthophosphate, respectively, noted by Lassuy (1979).

Dissolved oxygen measurements showed little differences between location and depth. The mean values found are shown in Table 3. Surface oxygen concentration is relatively high but somewhat lower than that of 6.237 mg/l noted by Lassuy (1979) for the same area. Barkley (1968) showed open ocean oxygen concentration of 4.0-4.5 ml/l for the waters surrounding Guam.

Salinity remained constant throughout the period studied and at 1 meter and 5 meters as $34.4°/_{oo}$. Lassuy (1979) reported a salinity of $34.43°/_{oo}$ at the surface. Barkley (1968) reported an open ocean salinity of $35°/_{oo}$ for the waters near Guam.

The water quality data presented provides background information about the surface water layers along Cabras Island. This information is in basic agreement with that of Lassuy (1979).

Literature Cited

Barkley, R. A. 1968. Oceanographic atlas of the Pacific Ocean. University of Hawaii Press, Honolulu.

Huddell, H. D., J. C. Willett, and G. Marchand. 1974. Nearshore currents and coral reef ecology of the west coast of Guam, Mariana Islands. Naval Oceanographic Office SP-259. 185 p.

Lassuy, D. R. 1979. Oceanographic conditions in the vicinity of Cabras Island and Glass Breakwater for the potential development of ocean thermal energy conversion on Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 53. 30 p.

Marsh, J. A., Jr., and G. D. Gordon. 1971. A marine environmental survey of Piti Bay and Piti Channel, Guam. Univ. Guam Mar. Lab. Environ. Surv. Rept. No. 3. 28 p.

Marsh, J. A., Jr., and G. D. Gordon. 1974. Marine environmental effects of dredging and power-plant construction in Piti Bay and Piti Channel, Guam. Univ. Guam Mar. Lab. Tech. Rept. No. 8. 56 p.

Pacific Islands Engineers. 1951. Interim report on ocean current studies-island of Guam. Pacific Island Engineers.

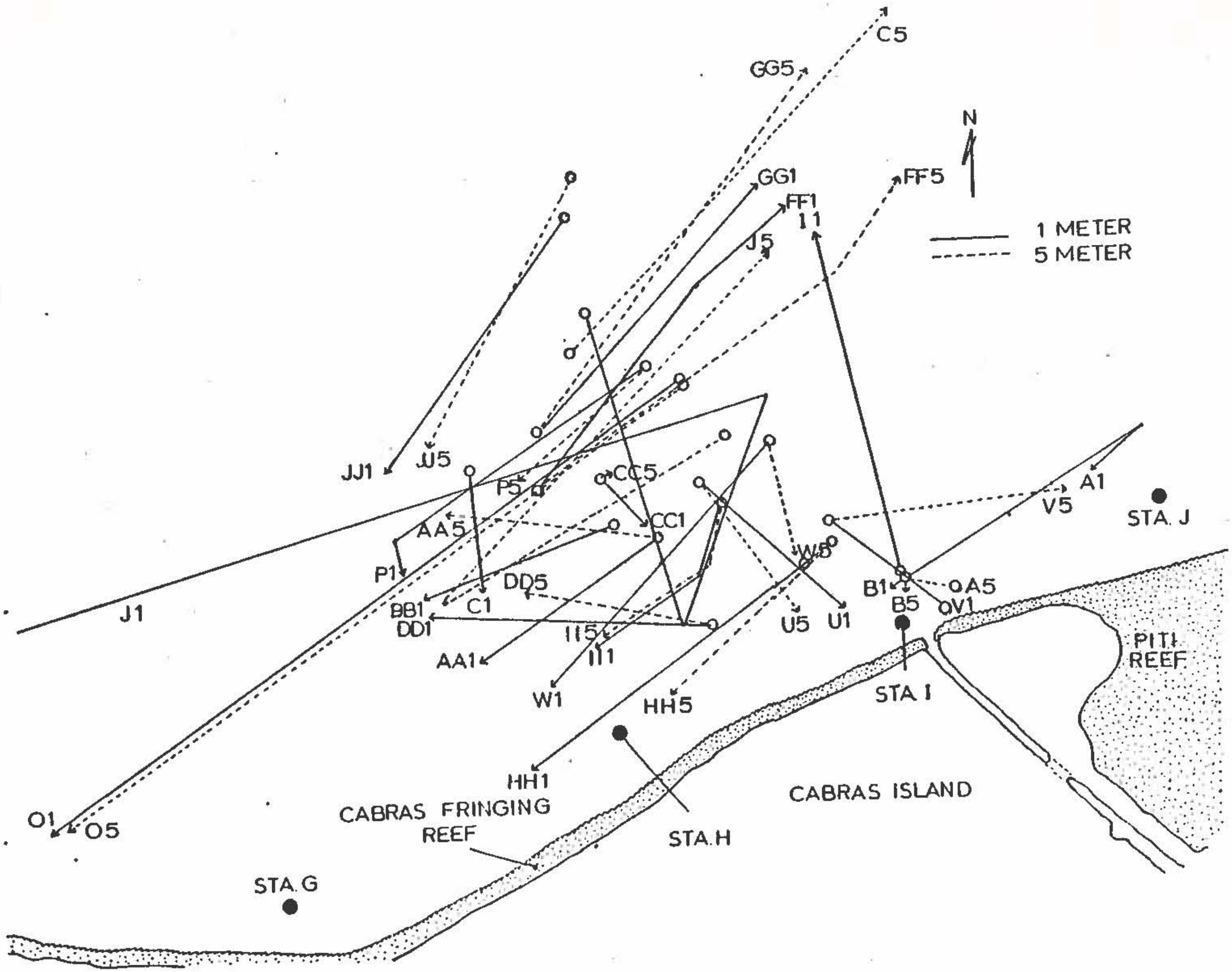

Figure 1. Offshore drift drouge tracks for 1 (solid line) and 5 (dashed line) meter depth casts at Station I. Open circles indicate starting points of drift drouge tracks and arrows indicate the end of tracks. For the end of drift track J-1 see Figure 2 (Sta. E). See Table 1 for other drift drouge data.

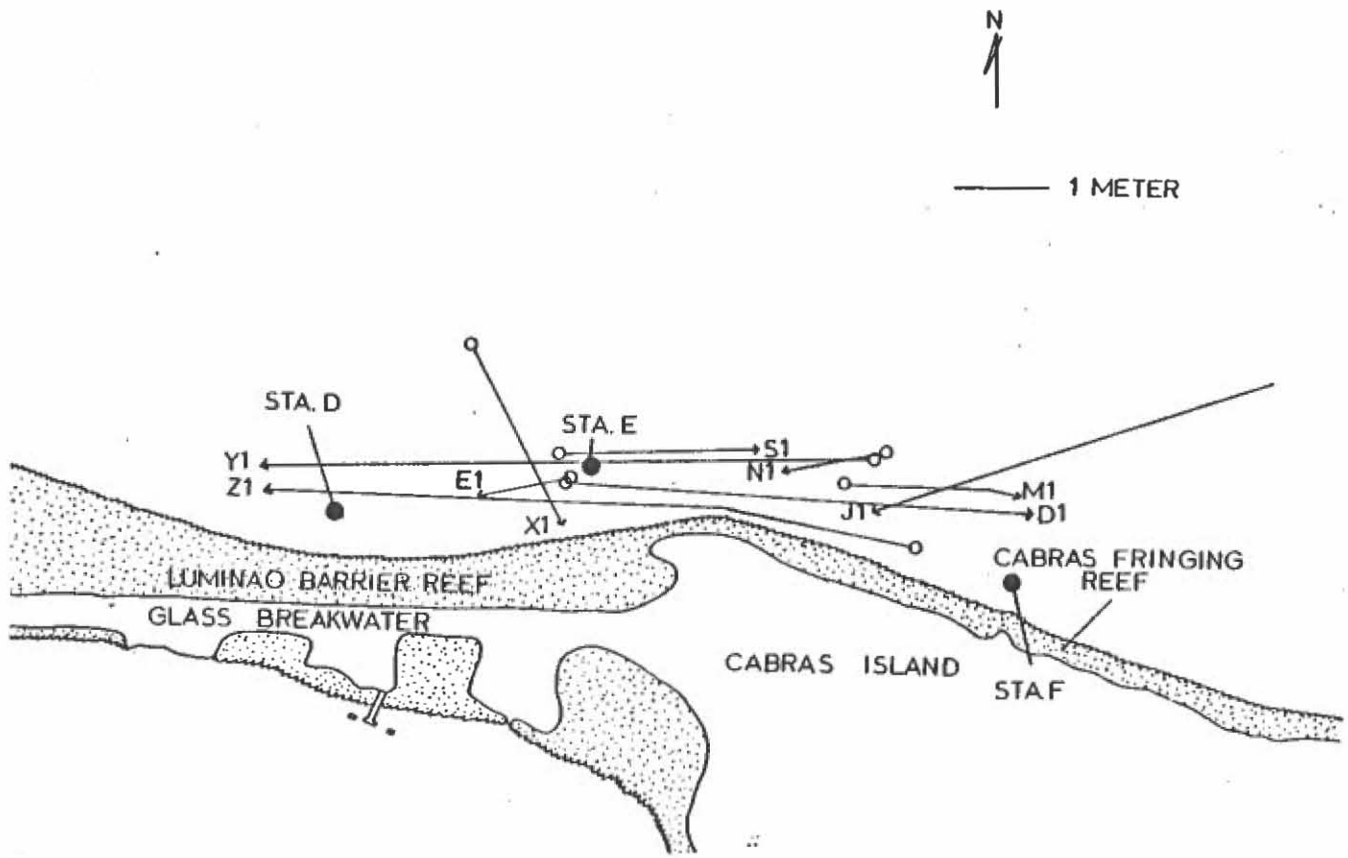

Figure 2. Offshore drift drouge tracks for 1 meter depth casts at Station E. Open circles indicate starting points of drift drouge tracks and arrows indicate the end of tracks. For the origin drift track J-1 see Figure 1 (Sta. I). See Table 1 for other drift drouge data.

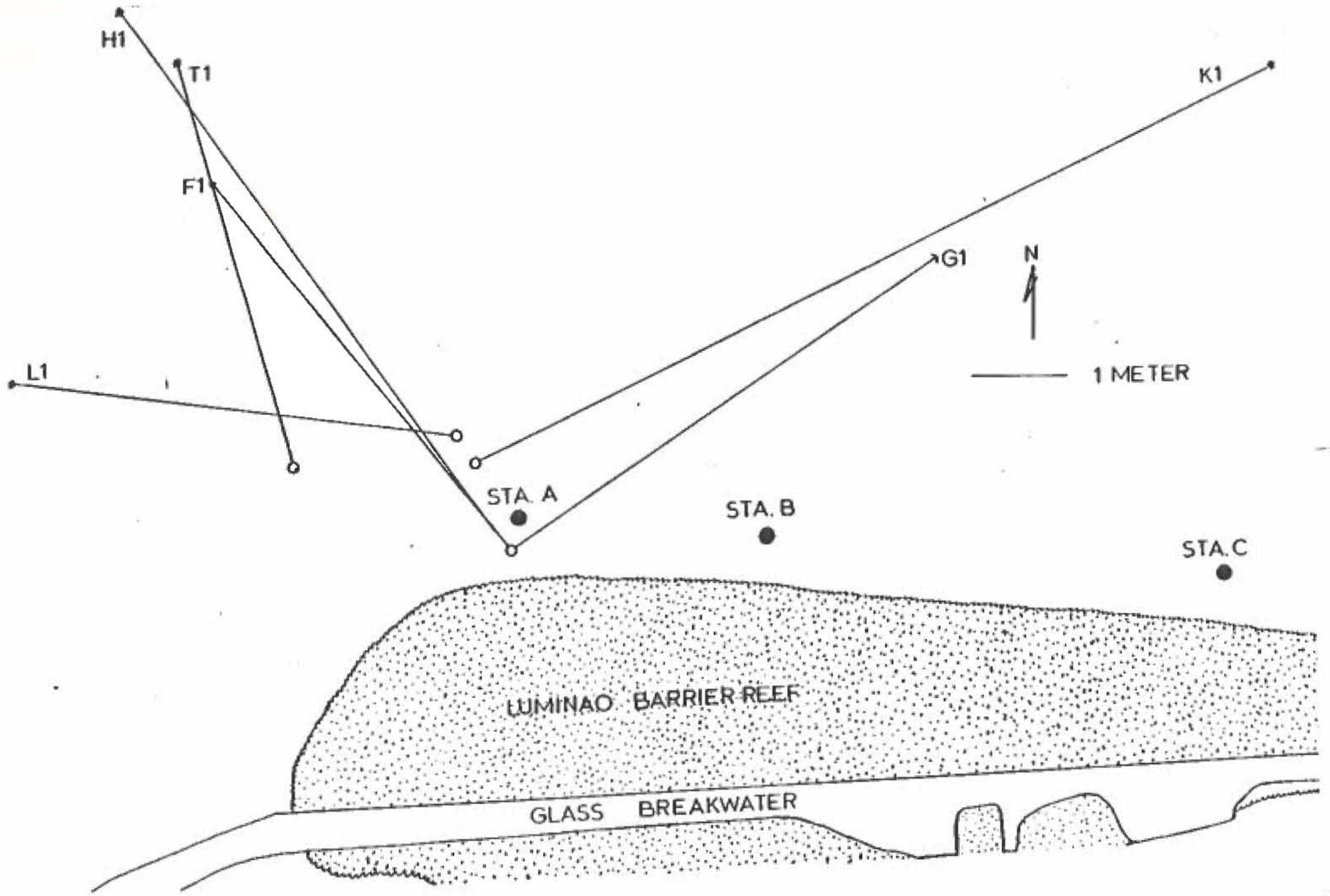

Figure 3. Offshore drift drouge tracks for 1 meter depth casts at Station A. Open circles indicate starting points of drift drouge tracks and arrows indicate the end of tracks. Drouge tracks terminating with an asterisk indicate a drift at the same bearing beyond that shown on map by 1356 meters for H-1, 1463 meters for K-1, 1234 meters for L-1, and 366 meters for T-1. See Table 1 for other drift drouge data.

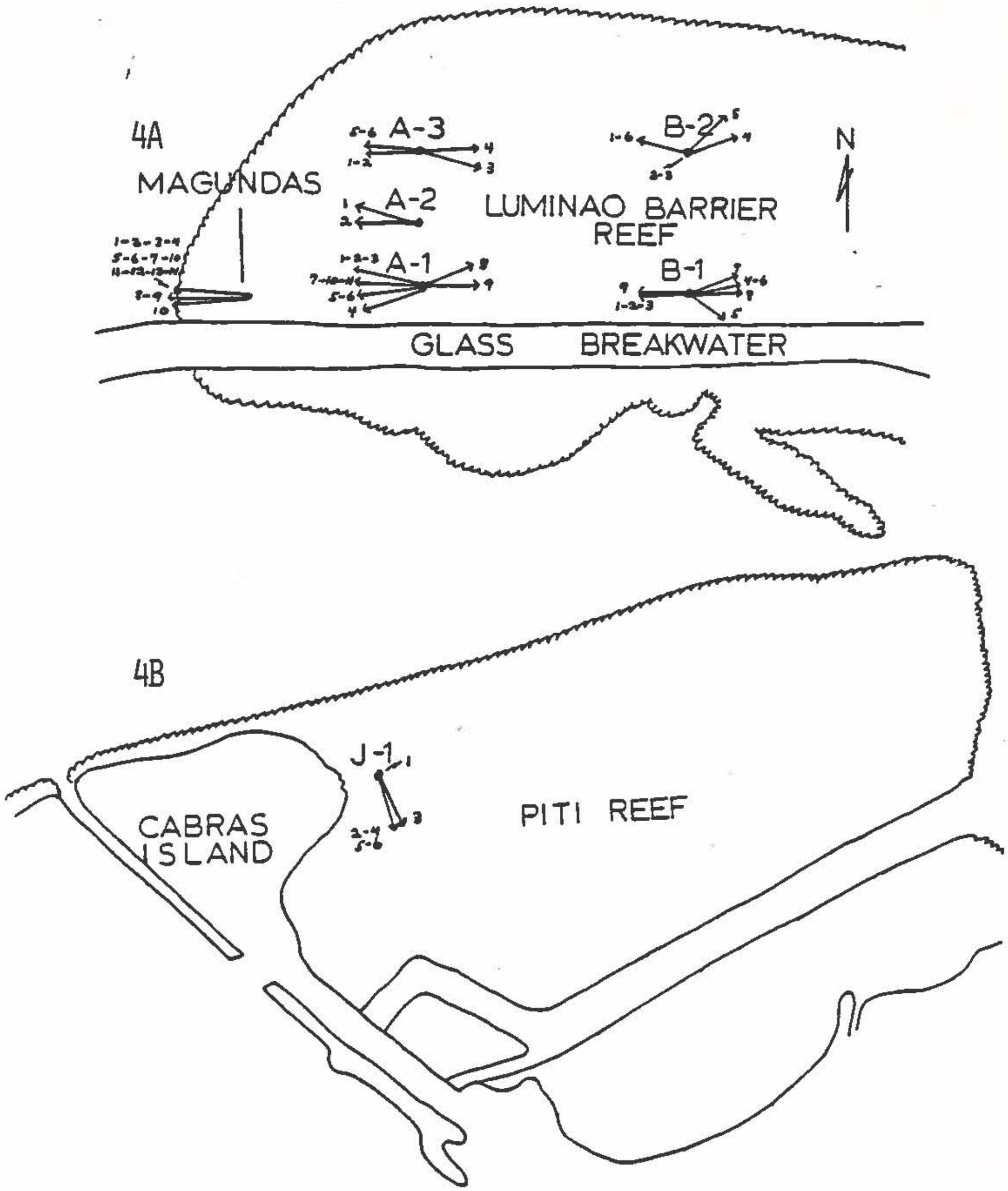

Figure 4. Drift tracks (not to scale) of dye patches on the shallow reef platforms of Luminao Barrier Reef (Magundas, A-1, A-2, A-3, B-1, and B-2 Stations) and Piti Reef (Station J-1). See Table 2 for other dye patch drift data.

Table 1. Summary of the offshore drouge data. Individual drouge tracks are plotted in Figures 1, 2, and 3 for Stations A, E, and I respectively.

Sta.	Drouge Cast	Date	Time In	Time Out	Distances (Meters)	Current Speed (M/Sec)	Tide Condition	Wind Dir.
I	A-1	7-24-80	0959	1154	556	.08	ebb	NE
I	A-5	7-24-80	1003	1050	88	.03	ebb	NE
I	B-1	7-24-80	1156	1254	27	<.01	flood	NE
I	B-5	7-24-80	1058	1254	15	<.01	ebb→flood	NE
I	C-1	8-07-80	1015	1120	198	.05	ebb	N
I	C-5	8-07-80	1013	1122	754	.18	ebb	N
E	D-1	8-07-80	1020	1131	655	.15	ebb→flood	N
E	E-1	8-07-80	1220	1348	130	.02	flood	N
A	F-1	8-07-80	0941	1025	732	.28	ebb	N
A	G-1	8-07-80	1032	1137	800	.21	ebb→flood	N
A	H-1	8-07-80	1141	1238	2086	.61	flood	N
I	I-1	8-07-80	1122	1227	556	.14	flood	N
I	I-5	8-07-80	1119	(drouge lost)			flood	N
I	J-1	9-16-80	1028	1440	2857	.19	flood→ebb	NW
I	J-5	9-16-80	1030	1231	1310	.18	flood	NW
A	K-1	9-16-80	1052	1211	2835	.59	flood	NW
A	L-1	9-16-80	1213	1314	1920	.52	flood→ebb	W
E	M-1	9-16-80	1040	1301	244	.03	flood→ebb	W
E	N-1	9-16-80	1310	1437	137	.03	ebb	W
I	O-1	10-29-80	1031	1235	1250	.17	flood	NE
I	O-5	10-29-80	1038	1235	1219	.17	flood	NE
I	P-1	10-29-80	1242	1446	556	.14	flood→ebb	NE
I	P-5	10-29-80	1243	1342	259	.07	flood→ebb	NE
E	Q-1	10-29-80	1057	(drouge lost)			flood	NE
E	R-1	10-29-80	1254	(drouge lost)			ebb	NE
E	S-1	10-29-80	1335	1453	549	.12	ebb	NE
A	T-1	10-29-80	1108	1151	1006	.39	flood	NE
I	U-1	11-25-80	0936	1035	320	.09	flood	NE
I	U-5	11-25-80	0937	1037	271	.08	flood	NE
I	V-1	11-25-80	1039	1135	251	.07	ebb	NE
I	V-2	11-25-80	1040	1140	396	.11	ebb	NE
I	W-1	11-25-80	1141	1247	526	.14	ebb	NE
I	W-5	11-25-80	1142	1249	183	.05	ebb	NE
E	X-1	11-25-80	0945	1025	274	.11	flood	NE
E	Y-1	11-25-80	1028	1123	822	.25	flood→ebb	NE
E	Z-1	11-25-80	1127	1237	884	.21	ebb	NE
I	AA-1	12-19-80	0935	1035	342	.10	ebb	E
I	AA-5	12-19-80	0935	1143	342	.04	ebb→flood	E
I	BB-1	12-19-80	1040	1140	328	.09	ebb→flood	E
I	CC-1	12-19-80	1145	1248	103	.03	flood	E
I	CC-5	12-19-80	1145	1246	27	<.01	flood	E
I	DD-1	12-19-80	1250	1335	450	.17	flood	E
I	DD-1	12-19-80	1250	1340	305	.10	flood	E
E	EE-1	12-19-80	1048	(drouge lost)			ebb	E

Table 1 Continued.

Sta.	Drouge Cast	Date	Time In	Time Out	Distances (Meters)	Current Speed (M/Sec)	Tide Condition	Wind Dir.
I	FF-1	1-15-81	1216	1402	610	.10	flood	E
I	FF-5	1-15-81	1216	1400	770	.12	flood	E
I	GG-1	1-15-81	1407	1517	533	.13	flood→ebb	SE
I	GG-5	1-15-81	1407	1515	732	.18	flood→ebb	SE
I	HH-1	4-14-81	1059	1257	602	.09	ebb→flood	NE
I	HH-5	4-14-81	1101	1300	358	.03	ebb→flood	NE
I	II-1	4-14-81	1311	1358	320	.11	flood	NE
I	II-5	4-14-81	1311	1356	297	.11	flood	NE
I	JJ-1	4-14-81	1105	1337	495	.05	ebb→flood	NE
I	JJ-5	4-14-81	1109	1341	488	.05	ebb→flood	NE

Table 2. Summary of the current data for the shallow reef flat platforms of Luminao and Piti Reefs. Station locations and dye patch drift bearings are shown in Figure 4. (*Reef margin exposed)

Drift No. and Station	Date	Time	Tide	Drift Time (sec)	Drift Bearing (deg)	Current speed (m/sec)	Other
(1) Magundas	8-26-80	1141	ebbing	27	276°	.37	
(2) Magundas	8-26-80	1143	ebbing	25	276°	.40	
(3) Magundas	8-26-80	1145	ebbing	22	276°	.45	
(4) Magundas	8-26-80	1414	flooding	36	276°	.28	
(5) Magundas	8-26-80	1415	flooding	45	276°	.22	
(6) Magundas	8-26-80	1416	flooding	42	276°	.24	
(7) Magundas	8-26-80	1541	flooding	75	276°	.13	
(8) Magundas	8-26-80	1543	flooding	105	256°	.10	
(9) Magundas	8-26-80	1545	flooding	85	270°	.12	
(10) Magundas	9-16-80	1110	flooding	90	276°	.11	
(11) Magundas	9-16-80	1330	ebbing	24	276°	.42	
(12) Magundas	9-16-80	1332	ebbing	22	276°	.45	
(13) Magundas	12-16-80	1355	flooding	40	276°	.25	
(14) Magundas	12-16-80	1600	ebbing	21	276°	.48	
(1) A-1	8-26-80	1200	ebbing	285	280°	.04	
(2) A-1	8-26-80	1208	ebbing	290	280°	.03	
(3) A-1	8-26-80	1213	ebbing	255	280°	.04	
(4) A-1	8-26-80	1236	ebbing	240	250°	.04	
(5) A-1	8-26-80	1241	ebbing	270	260°	.04	
(6) A-1	8-26-80	1246	ebbing	320	260°	.03	
(7) A-1	8-26-80	1444	flooding	440	270°	.02	(7 m drift)
(8) A-1	9-16-80	1128	flooding	91	069°	.11	
(9) A-1	9-16-80	1345	ebbing	109	089°	.09	
(10) A-1	12-16-80	1420	flooding	107	270°	.09	
(11) A-1	12-16-80	1610	ebbing	72	270°	.14	
(1) A-2	8-26-80	1301	ebbing	360	284°	.01	(5 m drift)
(2) A-2	8-26-80	1436	flooding	360	270°	.01	(5 m drift)
(1) A-3	8-26-80	1220	ebbing	590	268°	.02	
(2) A-3	8-26-80	1428	flooding	360	268°	.01	(2 m drift)
(3) A-3	9-16-80	1135	flooding	91	103°	.11	
(4) A-3	9-16-80	1359	ebbing	94	086°	.11	
(5) A-3	12-16-80	1430	flooding	81	270°	.12	
(6) A-3	12-16-80	1615	ebbing	97	270°	.10	
(1) B-1	8-26-80	1311	ebbing	180	268°	.06	
(2) B-1	8-26-80	1314	ebbing	330	268°	.03	
(3) B-1	8-26-80	1320	ebbing	390	268°	.03	
(4) B-1	8-26-80	1516	flooding	480	080°	.02	
(5) B-1	8-26-80	1525	flooding	315	130°	.03	
(6) B-1	8-26-80	1531	flooding	255	080°	.04	
(7) B-1	9-16-80	1159	flooding	64	070°	.16	
(8) B-1	9-16-80	1422	ebbing	75	086°	.13	
(9) B-1	12-16-80	1445	ebbing	99	270°	.10	
(1) B-2	8-26-80	1301	ebbing	360	284°	.01	(5 m drift)
(2) B-2	8-26-80	1507	flooding	360	(no dye movement) *		

Table 2 Continued.

Drift No. and Station	Date	Time	Tide	Drift Time (sec)	Drift Bearing (deg)	Current speed (m/sec)	Other
(3) B-2	8-26-80	1515	flooding	360	(no dye movement)		*
(4) B-2	9-16-80	1146	flooding	60	070°	.17	
(5) B-2	9-16-80	1411	ebbing	63	045°	.16	
(6) B-2	12-16-80	1450	ebbing	65	285°	.15	
(1) J-1	8-26-80	1342	ebbing	480	(no dye movement)		*
(2) J-1	9-16-80	1225	flooding	24	164°	.42	
(3) J-1	9-16-80	1455	ebbing	21	158°	.48	
(4) J-1	12-16-80	1535	ebbing	16	164°	.63	
(5) J-1	12-16-80	1537	ebbing	10	164°	1.00	
(6) J-1	12-16-80	1540	ebbing	16	164°	.63	

Table 3. Mean concentrations of nitrate, orthophosphate, and dissolved oxygen at the Cabras Island-Luminao Barrier Reef study site.

Station	Depth (m)	NO -N (μg-at/l)	PO -P (μg-at/l)	D.O. (mg/l)
A	1	0.12	0.10	5.19
	5	0.09	0.09	5.10
H	1	0.50	0.07	5.66
	5	0.46	0.10	5.69
I	1	0.37	0.10	5.47
	5	0.52*	0.12	5.17
J	1	0.40	0.08	5.48
	5	0.46	0.15	5.40

*One measurement of 10.02 μg-at/l reported on November 25, 1980, was not included in this mean value.

SEDIMENT GRAIN-SIZE DISTRIBUTION AT LUMINAO AND PITI REEFS

by

Russell N. Clayshulte

Sediment grain-size determinations provide quantitative information which is useful for interpreting depositional environments and modes of particle transport. Shallow-water marine sediments from Luminao barrier reef and Piti fringing reef, adjacent to the Cabras intake channel, were analyzed for grain-size distribution. Few quantitative analyses of reef and beach sediments have been conducted in Guam (Emery, 1962). However, there were no samples taken from either Luminao or Piti reefs which could be used for comparison with this study.

Deep water (to 300 m) sediments near Luminao and the entrance to Apra Harbor have been collected and examined for general content, presence of insoluble residue, and silts and clays. Emery (1962) provides a good review of known information dealing with off-shore deep-water sediments.

Reef-flat platforms and upper reef-fronts usually contain very little unconsolidated sediment. Reef-flat sediments are transported over the reef margin, deposited as intertidal beaches, or cemented into the reef framework. According to Bonem (1977), as much as 50 percent of a reef frame can consist of cement- and internal-sediment. Sediment deposits, which occur on reef flats, are commonly in local depressions or leeward of large framework features and massive coral heads. Upper reef-front sediment deposits are also restricted in distribution. They are usually confined to interstices fo the reef framework, grooves, or local depressions. These shallow-water unconsolidated sediments are mostly composed of sand- and gravel-size particles with only traces of silt and clay (Milliman, 1974). Off-shore sediments become finer with depth, since the finer sands and silts are more readily transported downslope.

Sediments at Luminao and Piti Reefs are almost exclusively bioclastic carbonates of recent origin. There is deposition of terrigenous Mariana Limestone at the Cabras intake channel. Sediment grain-sizes are dependent, in part, upon the crystalline structure, types and populations of the various component organisms. Calcareous algal components are rapidly reduced by mechanical erosion and biodegradation to produce very fine grains. Mollusk shells are slowly reduced to larger size classes which are controlled by organic or crystallographic constraints (Milliman, 1974). Additionally, carbonate components can originate as sand-size particles (e.g. foraminifera). Therefore, grain-szie distribution of reef platform sediments is dependent on a number of factors which include parent carbonate, biodegradation, mechanical erosion, wave energy and both the mode and distance of particle transport.

METHODS

Bulk sediment samples were collected on the reef-flat platforms and seaward of the reef margin to a depth of 5 m at Luminao barrier reef and Piti reef in June 1981. Samples were taken along transects, which were established perpendicular to the reef margin (Figure 1). A transect was divided into six zones (Table 1) and sediments, when present, were collected from each zone. A zone sediment consisted of four subsamples, about 100 g each, collected within a 5 m^2 area. The subsamples were surface scrapings and generally represented single sediment lamina. An attempt was made to collect sediments which appeared to be representative of the sampled zone. A total of 30 sediment samples was collected from the two reef areas with 15 samples taken from each reef.

RESULTS

Sediment samples were analyzed for grain-size distribution by a standard dry sieve analysis method (Royse, 1970). Table 2 presents the cumulative percentages of grain-sizes, by weight, retained on each sieve used in the grain-size classing sequence. The sieve sequence was selected to correspond to phi value classes. Cumulative percentages were plotted against phi values on probability paper and selected percentile values were obtained from these plots (Table 3). These were used with Folk and Ward descriptive measures (Royse, 1970) to describe characteristics of the grain-size distribution curves; mean particle size (Figure 2), grain-size dispersion (Figure 2), skewness of grain-size curve (Figure 3), and kurtosis of grain-size curve (Figure 3). The depression of sorting coefficient is a measure of particle size clustering about the mean, which is the moment per unit frequency (Friedman and Sanders, 1978). Skewness is a measure of the symmetry of the grain-size frequency distribution and is sensitive to the presence or absence of the fine fraction and coarse fraction in deposits of particles (Reineck and Singh, 1980). Skewness is used to interpret how sediments were deposited. Kurtosis is a measure of the peakedness of the grain-size frequency distribution curve. The kurtoses curves are defined by Friedman and Sanders (1978) as follows:

Leptokurtic -- sharpened or peaked distribution curve
Platykurtic -- flattened distribution curve
Mesokurtic -- normal distribution curve

The calculated numerical values of these descriptive measures for the sediment samples are presented in Table 4, along with general verbal terms as used by Royse (1970).

Grain-size descriptive measures were analyzed by the SPSS ANOVA program. The ANOVA significance levels ($P \leq 0.05$) are shown in Table 5. The sediments were examined by zones (Table 1 and Figure 1), areas (Luminao reef versus Piti reef), and pooled zones. The pooled location comparisons were made for zones which were generally similar, primarily in terms of wave energy. Zones 1, 3 m, and 5 m were high energy zones and, therefore, should have similar sediment deposits. However, zone 1 was a reef-flat zone and could have sediments which were more characteristics of Zone 2. The pooled location analysis showed zone 1 grain size distribution curves were more characteristic of zones 3 m and 5 m compared with zones 2, 3, and 4 (Table 5). Statistically, there were no differences in grain-size distribution between Luminao and Piti reefs (Table 5). Piti transect J extended from the reef margin to Tepungan Channel. Zones 1 and 2 of this transect were similar to Luminao's zones 1 and 2 (Figure 1). However, sampling sites 3 and 4 of transect J were dissimilar to corresponding zones at Luminao in relation to actual reef zonation, but received similar wave energies. Therefore, for statistical comparisons, sites 3 and 4 of transect J were treated as comparable with Luminao zones 3 and 4.

The mean particle diameter was plotted against the dispersion coefficient to assess zonal differences (Figure 4). The sediments deposited in zones 1, 3 m and 5 m were poorly sorted very fine gravels and very coarse sands. Beach sediments were moderately to well sorted coarse and medium sands. There was a tendency for the sediment grain-sizes to become smaller and better sorted toward shore which is the anticipated sediment breakdown sequence for this area.

DISCUSSION

The sediments are primarily bioclastic carbonate skeletal materials derived from recently living corals, calcareous algae, foraminifera, gastropods, bivalves and other invertebrates (e.g. urchins). Terrigenous limestone sediments were found in relatively large quantities at the Cabras intake channel; OTEC samples (zone 1), and transect I at 3 m (Figure 1). This limestone is derived from either adjacent cliffs which are Mariana Limestone or from the vicinity of the channel as a result of previous dredging activities. The larger limestone gravel is subrounded to rounded in texture which is caused by wave transport. This indicates the gravel is not recently eroded from the cliffs and introduced into the area as a run-off product.

The grain size of the sediments is a measure of the current, wave, or surf energy in the area of deposition. Coarser sediments are usually found in higher-energy environments and finer sediments in low-energy environments (Reineck and Singh, 1980). Grain size is known to decrease in the direction of transport (Figure 2). Therefore, sediment distribution across a reef-flat platform would range from rubble and gravel along the reef margin to finer sands in beach deposits. The degree of sediment breakdown and progressive sorting across the reef flat is dependent on width of the platform, wave energy and in the case of bioclastic sediments, the carbonate origin.

Calcareous algae, primarily *Amphiroa* and *Jania*, are easily broken down into medium and fine sands. Tests of the foraminiferan *Baculogypsina sphaerulata* are in the medium sand class. This foraminiferan grows in algal turf of the outer reef-flat zone near the reef margin, where its high production (up to 800 g $CaCo^3m^{-1}yr^{-1}$) produces large amounts of calcium carbonate sand. These tests are generally lighter in weight compared with other carbonate grains of similar size, and they tend to accumulate in the beach deposits. The calcareous algae which originated from the reef flats, tended to accumulate in zone 3. Coral fragments and reef-frame associated coralline algae dominate the sediments in zones 1, 2, 3 m, and 5 m, except in areas of *Baculogypsina* growth.

There are three major modes of sediment transport: rolling, saltation, and suspension (Reineck and Singh, 1980; Friedman and Sanders, 1978). Suspension transport at Luminao and Piti reefs occurs in the reef margin zone as a result of surf action and is not normally an important mode of sediment transport. In periods of excess surf generated by tropical storms, suspension transport can move large quantities of medium and fine sand throughout the reef-flat platform and upper reef slope. Saltation is the bouncing motion of sediments being moved by a water mass. This mode of sediemnt transport is also important in storm periods. Saltation transport is more prevalent in zones 3 m and 5 m compared with reef-flat platform zones. The primary mode of sediment transport for medium- to coarse-sand and gravel is rolling. Since most of the sediments in all the zones are in this grain-size range, rolling is presumed to be the main mode of sediment transport, at least in normal wave energy periods.

The mean particle size is statistically different (SPSS ANOVA) between the zones, regardless of area (Table 5). The 3 m zone sediments are composed of very fine gravels with almost no sand (Figure 3; Skewness) and zone 4 is coarse sand with almost no gravel (Figure 3; Skewness). The mean particle size with the inclusive graphic standard deviation (dispersion coefficient) compared by zones is still statistically significant ($P=0.050$). In order to access differences in grain-size distribution between the reef-flat platform and the upper reef slope, zone data were pooled and analyzed (Table 5). A comparison of the reef-flat platform with the upper reef slope shows no significant difference in the mean particle size. However, when zone 1 is pooled with zones 3 m and 5 m, there is a significant difference in grain-size distribution.

In terms of sediment deposition and transport characteristics the Luminao and Piti reefs can be divided into two general zones: reef-flat platform (outer reef-flat to higher intertidal) and reef-margin to upper reef slope (platform reef margin to 5 m). Sediment deposition and transport which occurs at these reefs are consistent with other shallow water environments subjected to moderate and occasional heavy wave energy (Emery, 1962; Friedman and Sanders, 1978; Reineck and Singh, 1980).

LITERATURE CITED

Bonem, R. M. 1977. Comparison of cavities and cryptic biota in modern reefs with those developed in lower Pennsylvanian Morrowan bioherms. Proc. Third Intern. Coral Reef Symp. 2:75-80.

Emery, K. O. 1962. Marine geology of Guam. U.S. Geol. Survey Prof. Paper 403-B:1-76.

Friedman, G. M., and J. E. Sanders. 1978. Principles of sedimentology. John Wiley and Sons, New York. 792 p.

Milliman, J. D. 1974. Marine carbonates: part 1. Springer-Verlag, New York. 375 p.

Reineck, H. E., and I. B. Singh. 1980. Depositional sedimentary environments. Springer-Verlag, New York. 549 p.

Royse, C. F. , Jr. 1970. An introduction of sediment analysis. Arizona State Univ. 180 p.

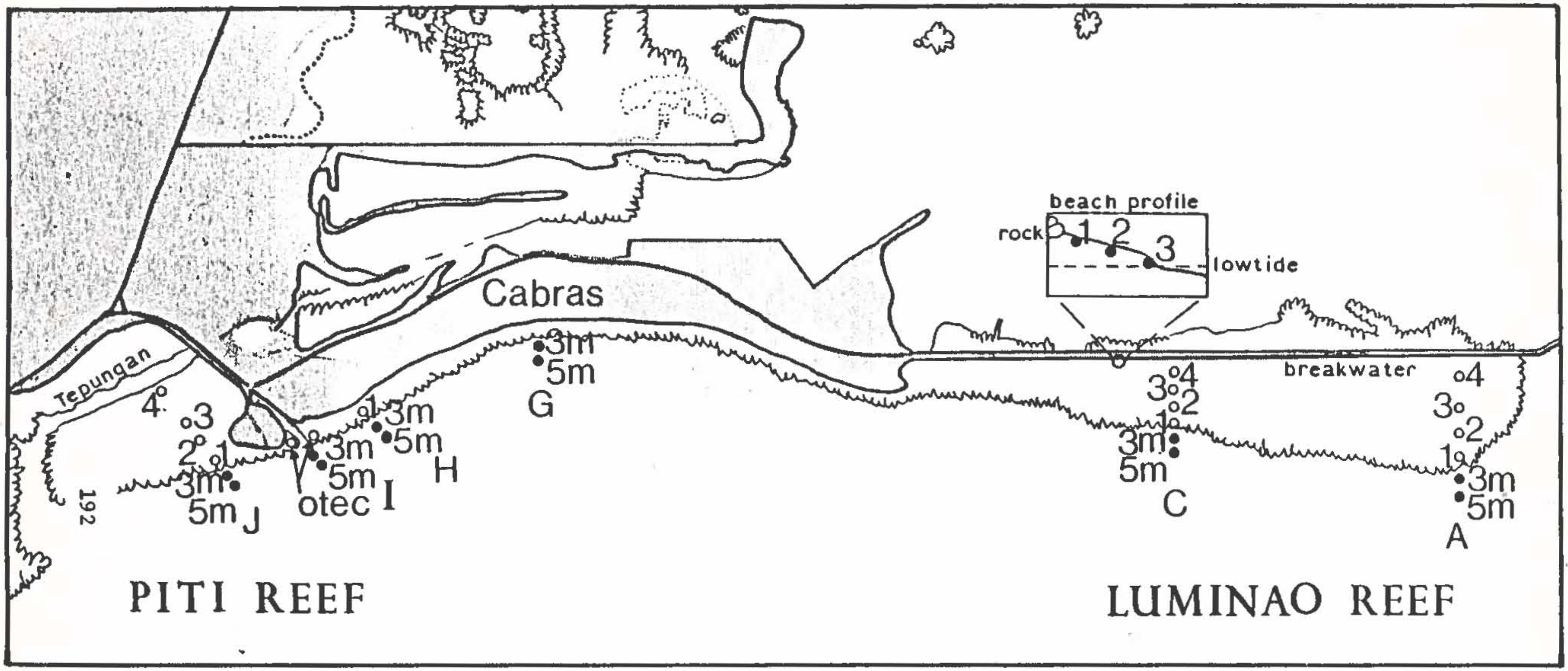

Figure 1. Sediment sampling locations at Piti and Luminao Reefs. The sediments were collected in June, 1981. Samples were surface scrapings of single sediment lamina.

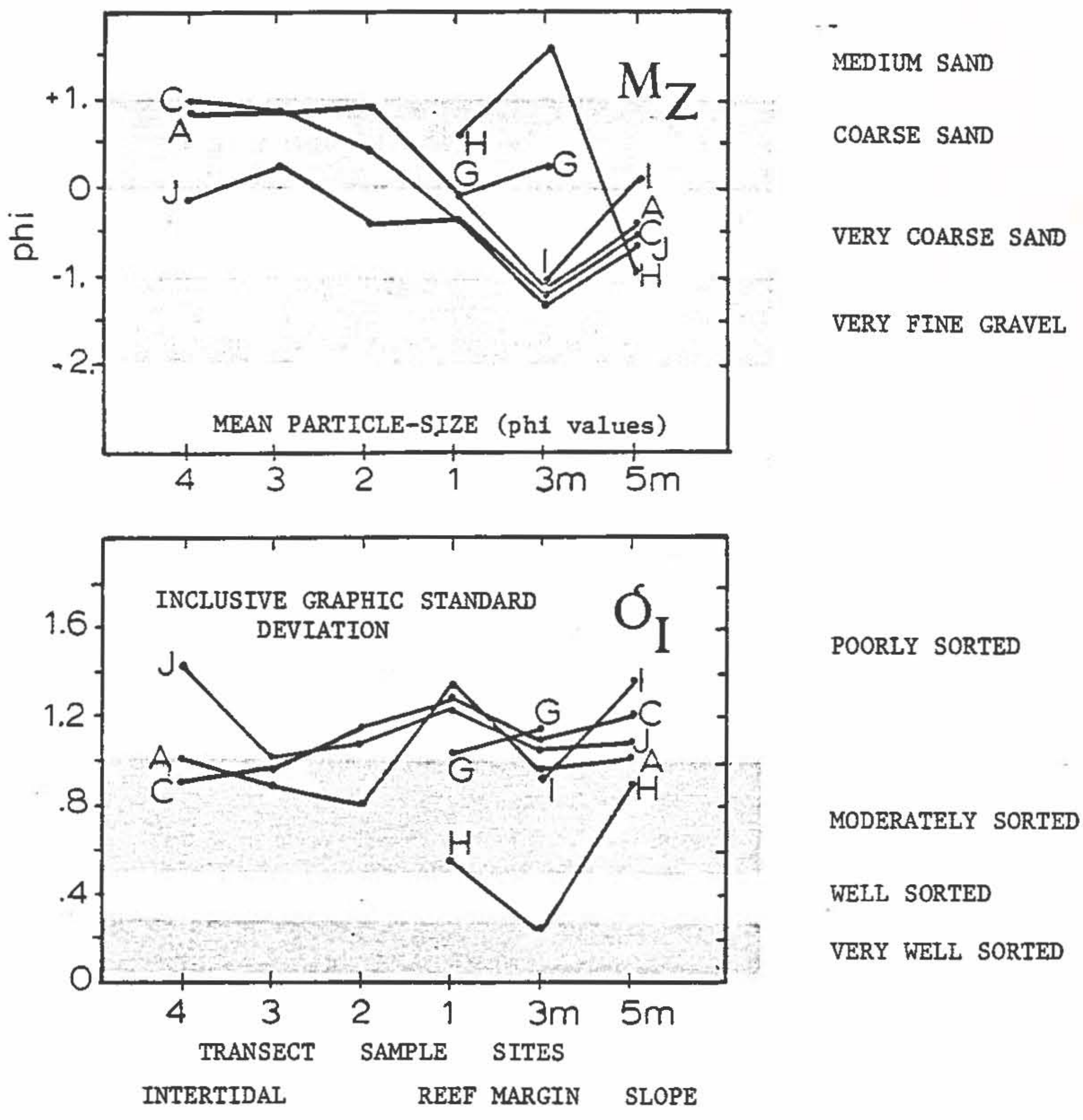

FIGURE 2. Mean particle sizes and sorting coefficients from grain-size distribution curves for luminao and Piti Reef sediments.

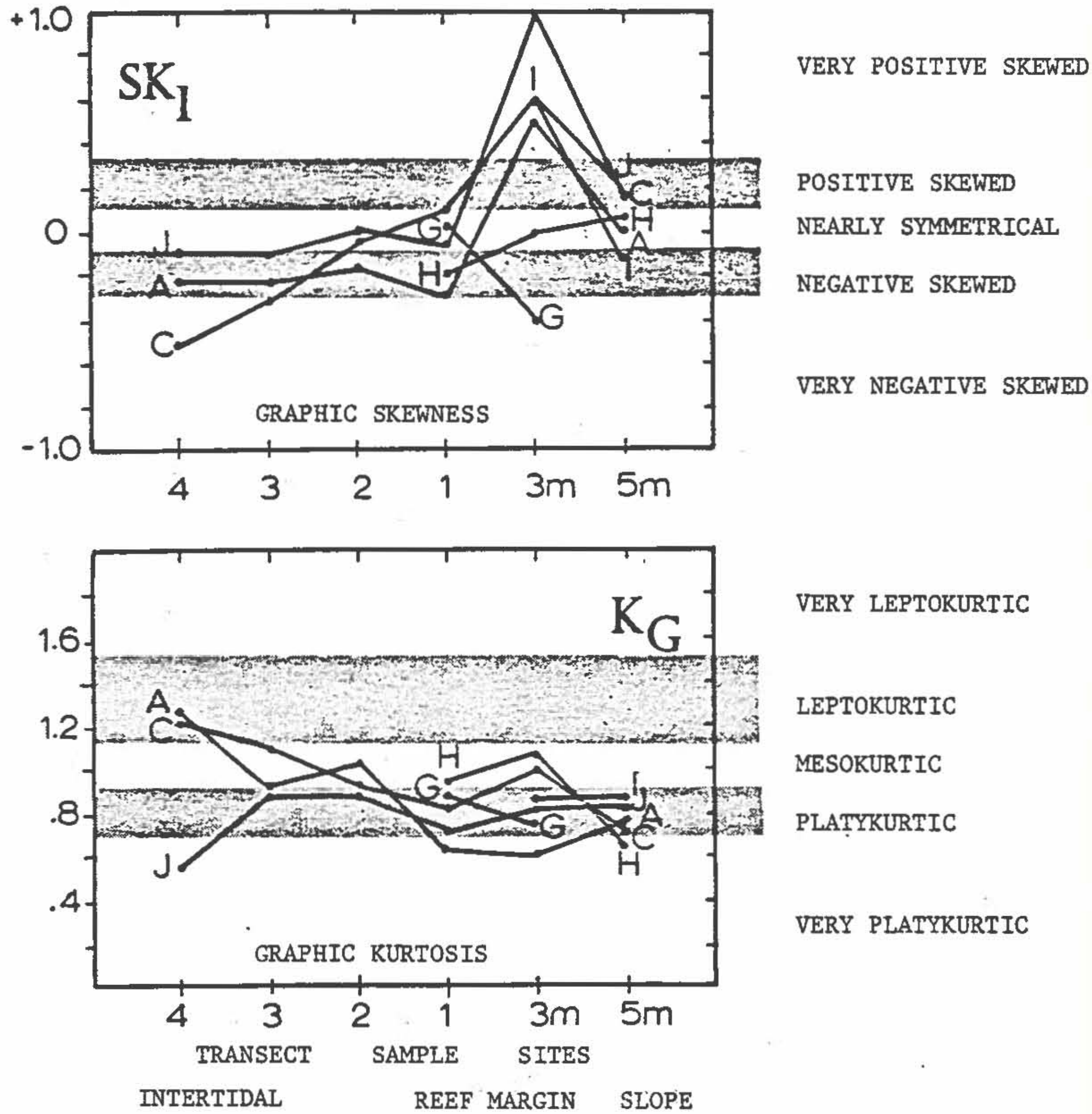

FIGURE 3. Graphic skewness and kurtosis of grain-size distribution curves for Luminao and Piti Reef sediments.

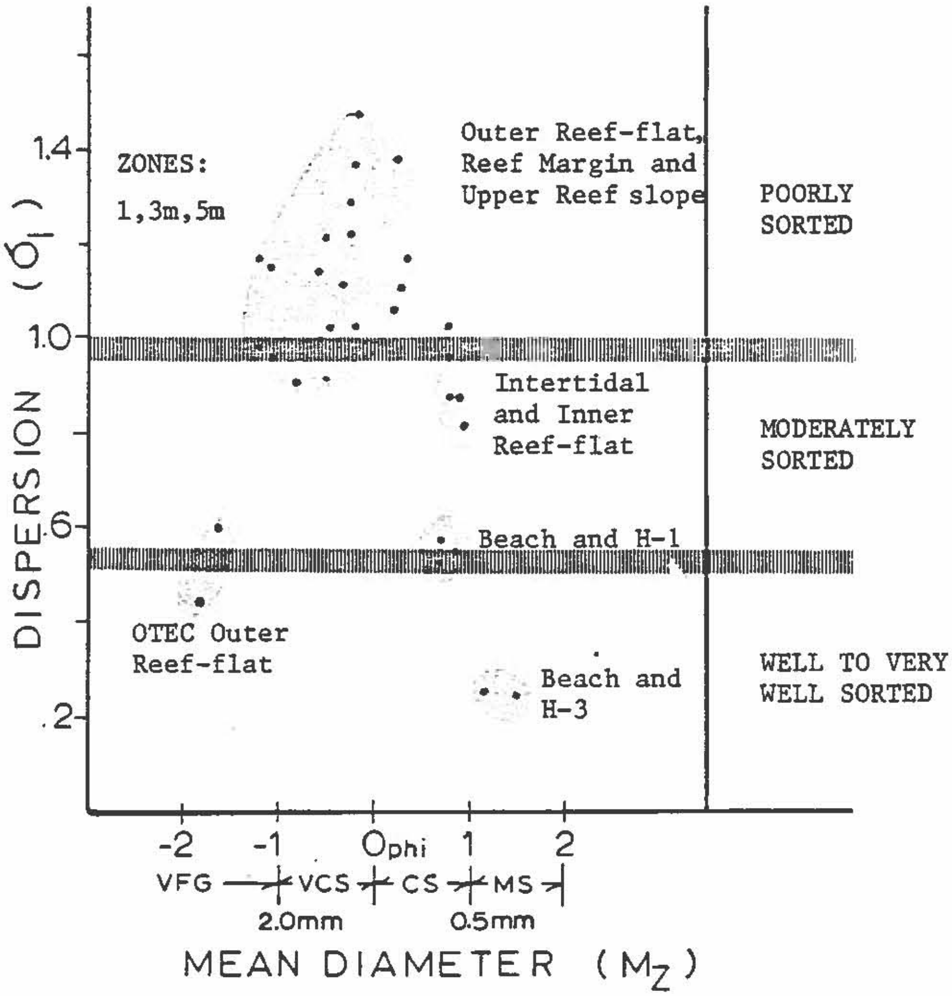

FIGURE 4. Mean particle diameter versus dispersion showing zonal sediment distribution at Luminao and Piti Reefs.

Table 1. Transect sampling zones at Luminao and Piti Reefs.

Sampling Zone	Transects in Zone	Description of Zones
4 [Beach, Intertidal to moat]	A, C, J, Beach 1-3	Back reef-flat platform; intertidal sand zone which extends from beach deposits to moat, low to moderate wave scour. Transect J is not intertidal but receives similar wave scour. Sediments are coarse to medium sands with traces of silt; depositional zone.
3 [Inner reef flat]	A, C, J	Inner reef-flat platform; outer moat zone which has living coral with pockets of sediment, rubble and pavement area with sediment venners. Sediments are moderately sorted coarse sands with large rubble. This is a moderate wave scour zone.
2 [Outer reef flat]	A, C, J	Outer reef-flat platform; pavement and scattered coral zone with sparse pockets of sediments, moderate to heavy scour. Sediments are fine gravels to coarse sands with finer sands transported shoreward. This is a zone of <u>Baculogypsina</u> production.
1 [Outer reef flat to reef margin]	A, C, J, G, H, OTEC N & S	Outer reef-flat platform; pavement zone near reef margin which receives heavy wave scour. Sediments are coarse to fine gravels with finer sands transported shoreward. This is an erosional zone.
3m [Lower reef margin @ 3m]	A, C, J, G, H, I	Outer reef margin; extensive coral zone with heavy surf scour. Sediments are sparse and restricted to pockets and interstices of reef frame. Sediments are fine gravels with finer sands transported downslope.
5m [Upper reef slope @ 5m]	A, C, J, H, I	Upper reef slope; extensive coral zone with moderate to heavy wave scour, normal wave base zone. Sediments are more common compared with 3m zone, but still restricted to pockets, grooves and reef frame interstices. Sediments are very coarse sands with few large rubble fragments with fine sands transported downslope.

Table 2. Cumulative percentages retained for particle size classes.

CUMULATIVE % RETAINED (BY WEIGHT)
[phi valves]

SAMPLE	-2 (4mm) Pebble	-1 (2mm) F. Gravel	0 (1mm) Coarse	+1 (0.5mm) Sand	+2 (0.25mm) M. Sand	+3 (0.12mm) Fine	+4 (0.6mm) Sand	<+4 Silt
Tran A 1	17.3	28.7	45.6	73.7	98.9	99.8	100.0	
2	0	2.7	13.6	48.8	94.6	98.5	99.4	100.0
3	0.1	3.0	17.5	51.1	93.4	98.7	99.4	100.0
4	1.8	5.8	17.2	42.9	93.0	98.9	99.5	100.0
3m	32.3	59.7	81.0	97.2	99.3	99.6	99.8	100.0
5m	7.9	31.5	60.1	90.0	99.5	99.7	99.8	100.0
Tran C 1	9.9	32.1	62.0	83.2	98.3	99.4	99.6	100.0
2	2.3	10.8	34.6	63.1	91.7	97.9	99.4	100.0
3	0.7	5.3	17.4	46.9	93.2	98.9	99.6	100.0
4	1.5	5.9	15.6	40.1	97.0	99.3	99.6	100.0
3m	35.3	63.1	83.7	95.0	99.3	99.6	99.7	100.0
5m	10.4	41.8	63.5	84.6	99.7	99.8	99.9	100.0
Tran G 1	1.9	25.3	59.9	85.2	98.8	99.5	99.7	100.0
3m	0	0	0.1	1.3	96.3	100.0		

Table 2. Continued.

CUMULATIVE % RETAINED (BY WEIGHT)
[phi valves]

SAMPLE	-2 (4mm) Pebble	-1 (2mm) F. Gravel	0 (1mm) Coarse	+1 (0.5mm) Sand	+2 (0.25mm) M. Sand	+3 (0.12mm) Fine	+4 (0.6mm) Sand	<+4 Silt
Tran H 1	0	1.4	13.4	63.6	99.8	100.0		
3m	1.6	15.8	32.2	59.5	98.4	99.5	99.8	100.0
5m	12.4	45.3	74.9	99.2	99.2	99.8	99.9	100.0
Tran I 3m	34.2	64.1	82.7	94.2	99.4	99.8	99.8	100.0
5m	4.3	22.4	42.3	64.5	93.0	98.5	99.5	100.0
Tran J 1	12.6	33.2	53.1	79.4	98.5	99.5	99.8	100.0
2	9.3	27.5	58.5	87.7	98.5	99.5	99.7	100.0
3	1.6	12.5	38.6	72.7	97.6	99.4	99.7	100.0
4	17.8	36.2	49.5	69.7	96.3	99.4	99.8	100.0
3m	56.1	66.9	77.5	88.2	98.0	99.2	99.7	100.0
5m	10.3	38.1	67.7	88.8	99.0	99.6	99.9	100.0
OTEC S. Side	52.0	80.8	94.7	98.6	96.3	99.6	99.8	100.0
OTEC N. Side	50.7	88.2	98.2	99.7	99.9	99.9	99.9	100.0

Table 2. Continued.

CUMULATIVE % RETAINED (BY WEIGHT)
[phi valves]

SAMPLE	-2 (4mm) Pebble	-1 (2mm) F. Gravel	0 (1mm) Coarse	+1 (0.5mm) Sand	+2 (0.25mm) M. Sand	+3 (0.12mm) Fine	+4 (0.6mm) Sand	<+4 Silt
Beach 1	0	0.1	0.5	12.8	99.9	100.0		
2	1.4	2.7	9.1	62.3	100.0			
3	0.9	3.8	13.6	79.6	100.0			

Table 3 . Percentile phi values of OTEC sediment analyses to be used with Folk and Ward descriptive measures (Royse, 1970).

Sample Site		Percentile phi values (Ø) 5	16	25	50	75	84	95
Tran A	1	-2.0	-2.0	-1.25	0.20	1.05	1.25	1.65
	2	-0.65	0.10	0.45	1.00	1.50	1.70	2.05
	3	-0.78	-0.10	0.25	0.90	1.45	1.70	2.15
	4	-1.50	-0.20	0.45	1.10	1.50	1.70	2.15
	3m	-2.0	-2.0	-2.0	-1.40	-0.25	0.15	0.70
	5m	-2.0	-1.60	-1.25	-0.40	0.45	0.80	1.25
Tran C	1	-2.0	-1.65	-1.25	-0.40	0.55	1.05	1.65
	2	-1.55	-0.75	-0.40	0.50	1.30	1.55	2.35
	3	-1.05	-0.15	0.30	1.05	1.50	1.70	2.20
	4	-1.20	0.0	0.45	1.20	1.50	1.65	1.90
	3m	-2.0	-2.0	-2.0	-1.45	-0.40	0.15	1.00
	5m	-2.0	-1.80	-1.50	-0.60	0.45	0.95	1.50
Tran G	1	-1.80	-1.35	-1.00	-0.25	0.55	0.90	1.35
	3m	-1.60	-1.05	-0.50	0.70	1.25	1.40	1.70
Tran H	1	-0.50	0.05	0.30	0.70	1.10	1.20	1.35
	3m	1.15	1.30	1.40	1.55	1.70	1.80	1.95
	5m	-2.0	-1.90	-1.55	-0.85	0.0	0.25	0.55
Tran I	3m	-2.0	-2.0	-2.0	-1.50	-0.50	0.05	1.05
	5m	-1.95	-1.30	-0.85	0.35	1.25	1.65	2.20
Tran J	1	-2.0	-1.80	-1.35	-0.15	0.80	1.15	1.60
	2	-2.0	-1.55	-1.15	-0.30	0.50	0.85	1.45
	3	-1.50	-0.85	-0.45	0.30	1.05	1.30	1.75
	4	-2.0	-2.0	-1.60	0.0	1.15	1.40	1.90
	3m	-2.0	-2.0	-2.0	-2.0	-0.25	0.50	1.55
	5m	-2.0	-1.75	-1.45	-0.65	0.30	0.75	1.40
OTEC	S. Side	-2.0	-2.0	-2.0	-2.00	-1.30	-0.85	0.05
	N. Side	-2.0	-2.0	-2.0	-2.00	-1.45	-1.15	-0.50
Beach	1	0.70	1.05	1.10	1.25	1.45	1.50	1.65
	2	-0.45	0.20	0.40	0.85	1.10	1.20	1.40
	3	-0.70	0.05	0.30	0.65	0.95	1.05	1.30

Table 4. Descriptive measures of sediment-size distribution. The measures are based on Folk and Ward equations (Royse, 1970). The transect sample sites are distributed from the high intertidal (4), across the reef flat to the outer-reef flat (1) and to a depth of 5m seaward of the reef margin.

Sample Site		Mean Particle Size M_Z	Verbal*1	Despersion (Sorting) σ_I	Verbal*2	Skewness SK_I	Verbal*3	Kurtosis K_G	Verbal*4
Tran A	4	0.80	CS	1.03	PS	-0.24	NSK	1.25	LEPTO
	3	0.87	CS	0.88	MS	-0.24	NSK	0.93	MESO
	2	0.93	CS	0.81	MS	-0.17	NSK	1.05	MESO
	1	-0.18	VCS	1.37	PS	-0.28	NSK	0.65	VPLATY
	3m	-1.08	VFG	0.95	MS	0.50	VPSK	0.63	VPLATY
	5m	-0.40	VCS	1.09	PS	0.01	NSYM	0.78	PLATY
Tran C	4	0.95	CS	0.88	MS	-0.50	VNSK	1.21	LEPTO
	3	0.87	CS	0.95	MS	-0.29	NSK	1.11	LEPTO
	2	0.43	CS	1.17	PS	-0.07	NSYM	0.94	MESO
	1	-0.33	VCS	1.23	PS	0.10	NSYM	0.83	PLATY
	3m	-1.10	VFG	1.13	PS	0.60	VPSK	1.00	MESO
	5m	-0.48	VCS	1.22	PS	0.16	PSK	0.74	PLATY
Tran G	1	-0.23	VCS	1.04	PS	0.02	NSYM	0.83	PLATY
	3m	0.35	CS	1.11	PS	-0.41	VNSK	0.77	PLATY
Tran H	1	0.65	CS	0.57	MS	-0.21	NSK	0.94	MESO
	3m	1.55	MS	0.25	VWS	0.00	NSYM	1.09	MESO
	5m	-0.83	VCS	0.92	MS	0.06	NSYM	0.67	PLATY
Tran I	3m	-1.15	VFG	0.97	MS	0.59	VPSK	0.83	PLATY
	5m	0.23	CS	1.37	PS	-0.11	NSK	0.81	PLATY
Tran J	4	-0.20	VCS	1.44	PS	-0.10	NSYM	0.58	PLATY
	3	0.25	CS	1.03	PS	-0.09	NSYM	0.89	PLATY
	2	-0.33	VCS	1.12	PS	-0.01	NSYM	0.86	PLATY
	1	-0.27	VCS	1.28	PS	-0.07	NSYM	0.69	VPLATY
	3m	-1.17	VFG	1.16	PS	1.00	VPSK	0.83	PLATY
	5m	-0.55	VCS	1.14	PS	0.16	PSK	0.80	PLATY
OTEC	S	-1.62	VFG	0.60	MS	1.00	VPSK	1.20	LEPTO
	N	-1.72	VFG	0.44	WS	1.00	VPSK	1.12	LEPTO
Beach	1	1.27	MS	0.26	VWS	-0.02	NSYM	1.11	LEPTO
	2	0.75	CS	0.53	MS	-0.35	VNSK	1.08	MESO
	3	0.58	CS	0.55	MS	-0.28	NSK	1.26	LEPTO

*1 VFG - Very fine gravel
VCS - Very coarse sand
CS - Coarse sand
MS - Medium sand

*2 PS - Poorly sorted
MS - Moderately sorted
WS - Well sorted
VWS - Very well sorted

*3 NSK - Negative skewed
VNSK - Very negative skewed
PSK - Positive skewed
VPSK - Very positive skewed
NSYM - Nearly symmetrical

*4 VPLATY - Very platy kurtic
PLATY - Platy kurtic
MESO - Meso kurtic
LEPTO - Lepto kurtic

Table 5. ANOVA significance levels for sediment sample textural and grain-size characteristics at Luminao and Piti reef flat areas. See Figure 1 for locations of sediment sampling zones.

	LOCATION	AREA	POOLED LOCATIONS	
	Sediment Sampling Zones*	Luminao Reef vs. Piti Reef	Zones 2, 3, 4* vs. Zones 1, 3m, 5m	Zones 1-4* vs. Zones 3m & 5m
Mean Particle Size (Mz)	0.033	NS	0.001	NS
Particle Dispersion (σ_I)	NS**	NS	NS	NS
Skewness of grain-size curve	NS	NS	0.004	NS
Kurtosis of grain-size curve	NS	0.034	0.012	0.026
Mz with σ_I	0.050	NS	0.001	NS

* Zones: (4) Intertidal and beach, (3) inner outer-reef flat, (2) outer-reef flat, (1) reef margin, (3m) 3m depth, (5m) 5m depth

** NS: Not significant at 0.05 level with SPSS ANOVA program

ANTICIPATED IMPACT OF OTEC DEVELOPMENT ON THE REEF PLATFORM AND UPPER FOREREEF SLOPE ZONES OF THE LUMINAO-CABRAS-PITI REEFS

by

Richard H. Randall

Introduction

Dames and Moore (1979) have addressed the anticipated environmental impacts of both shore-based (10 MW) and ocean-platform (100 MW) OTEC development on Guam. As no field work was undertaken, their study relied on engineering experience with shore-based power stations, existing work on Guam, and on the general OTEC literature. In this study, environmental impact of OTEC development will be addressed in relation to its effect on the marine communities located on the shallow reef platform and adjacent reef front slope zones (5 to 7 meter depth) of the Luminao-Cabras-Piti reef system. As with the Dames and Moore report, the impacts addressed here are of an anticipated and general nature as no specific plans or details of the OTEC generating facilities are available at this time. Also, at the present time a shore-based plant of 40-50 MW seems to be favored by the Guam Energy Office, and thus most of the our comments will be made accordingly.

Environmental impacts will primarily be of two types: those of a temporary nature incurred during construction of the OTEC plant and those of a continuous or periodic nature arising from plant operations. Because of periodic storm and typhoon waves the cold and warm water intake and discharge pipes would most likely have to be buried below the reef surface to a depth down the forereef slope that would be below wave base. Excavations necessary to bury the anticipated large diameter OTEC intake and discharge pipes (no actual diameter or number known at this time) would require considerable blasting and dredging and then back-filling with dredge material and possibly capped with concrete. Because of the magnitude of such excavation and back-filling operations the construction phase is anticipated to cause the most severe impact to the shallow areas of the Luminao-Cabras-Piti reef system.

Construction Impacts

Impacts arising from construction of a land-based OTEC plant would include increased sediment accumulation in the immediate area of excavation and the generation of a suspended sediment plume that could affect marine communities more distant from the construction site. Impacts of a more direct nature would be the destruction of benthic communities resulting from placement and burial of cold and warm water intake and discharge pipes across the reef platform and forereef slope zones. Evenso, such excavation impacts would not remove habitat from the marine environment, but it would alter the original reef surface and substitute it with a different type of substrate. The type of community that would eventually become established in the excavation and back-fill areas would, to a considerable degree, depend upon the stability of the back-fill material and whether or not the back-filled surface was capped with concrete. The original coral reef community that occupied the reef surface prior to disturbance may never become established if such back-fill material remains unconsolidated and is unstable duirng storm periods. If the back-filled area is stabilized with a concrete surface, then it is very likely that though a series of successional stages a reef community similar to the one destroyed will be restored.

During excavation and back-filling operations sediments will become suspended in the water column forming a plume. Depending upont he currents present the sediment plume will move away from the excavation site. According to their size, shape, and density the suspended sediments will begin to settle to the bottom in a gradient of large to small sized particles away from the excavation site. The sediment plume thus affects the marine communities primarily by reducing light transmission through the water column and by the accumulation of particles on both the surfaces of benthic organisms and on the reef substrate which may eventually cover or smother attached plants and animals. Stress from plume sediments varies will particular organisms, and depends upon the duration of the plume and rate of sediment fallout. Judging from the large grain size of the sediment presently found in the shallow reef platform and upper forereef slope zones, sediment accumulation from plume fallout will probably not be much of a problem as strong water movement from breaking surf and wave surge would keep smaller plume-sized particles swept off the reef surface. However, in deeper reef zones (lower forereef slopes) less water movement may allow plume-sized sediments to accumulate. Evenso, many reef organisms inhabiting these deeper reef zones are generally better adapted and more adjusted to greater sediment accumulation rates from the constant rain and transport of reef erosion products downslope. Reduction of light through the water column by the sediment plume may cause some stress to photosynthesizing organisms, but because of its temporary duration it does not seem to pose as much of an impact as the more permanent accumulation of sediments on the reef surface. The general inshore coastal current patterns indicate that the sediment plume will either move easterly or westerly along the reef margin axis, depending on tide, wind, and wave conditions, and then gradually attenuate as distance from excavation operations increases. Although wind-driven surface currents and offshore water transported across the reef margin by waves and swells, at times may carry plume-laden water onto the Luminao and Piti reef platforms, the impact is not expected to be great because strong currents generated on the platforms during such times will prevent plume-sized sediments from accumulating.

The effects of plume movement into adjacent reef areas may be considerably reduced by employing silt curtains around the immediate area of excavation (generally much larger than the actual excavation area). Such a method retains the sediment plume and allows much of the suspended sediment to settle out within the confines of the silt curtain. Actually the use of silt curtains may cause greater environmental damage to the benthic reef communities because its use restricts the sediment plume to a defined area in which increases of both turbidity (reduction in transmitted light) and sediment accumulation occurs. Such increased stress levels may be great enough to kill many reef organisms, whereas if the plume was allowed to disperse and spread over a greater area with reduced stress levels, fewer organisms would be so drastically affected. Also it may be difficult to effectively isolate forereef slope areas with very irregular bottom topography.

An alternate method of placing the pipes beneath the reef surface might be used by boring tunnels that would angle downward from the Cabras Island OTEC site and emerge on the forereef slope below wave base. Although this method would eliminate sediment-charged water from directly entering offshore waters, it would involve the construction of settling ponds on land to receive water pumped from the tunnels during construction. Tunneling beneath the reef surface would also eliminate the destruction of benthic reef communities that would occur if the surface excavation method was used to imbed the pipes.

Impacts arising from construction of the OTEC plant on Cabras Island (land site) should not have any significant impact on the marine community if erosion controls are employed and surface drainage waters are prevented from being discharged into the adjacent marine waters.

Operational Impacts

Anticipated plant operational impacts listed by Dames and Moore (1979) include: 1) nekton impingement and plankton entrainment at the warm and cold water intake pipes, 2) thermal, mechanical, and chemical stresses to entrained plankton in the evaporators and condensers, 3) entrained plankton displacement; heavy metal, working fluid, and biocide toxicity; and nutrient enrichment with possible increases in plankton and fish concentrations above the pycnocline from the warm and cold water discharge pipes, and 4) thermal stress from the cold water discharge pipes.

Impacts of nekton and plankton impingement and entrainment at the cold water intake pipe are not known because of the lack of data at such depths. At the shallow warm water intake pipe the nekton assemblage (mostly fish) present on the upper forereef slope (5-7 m depth) are known (see Myers this report), but the degree of impingement or entrainment at the pipe inlet is only speculative. Some organisms may be able to avoid being impinged upon the intake screens or entrained into the inlet by sensing the increased water currents or flow patterns around the pipe opening, but some may be unable to avoid such consequences. Also, some nektonic organisms may be attracted to the inlet area and thereby increase rates of impingement or entrainment. Passive organisms in the water column (mostly plankton) and suspended organic (drift algae and seagrass) and inorganic detrital materials would be unable to avoid impingement or entrainment within a certain distance of the inlet, depending upon flow patterns generated by currents and water movement in the vicinity of the pipe opening. During a study of the Piti Power Plant intake waters Grovhoug (1977) reported that faunal impingement at the intake structures is very low and that drift algae and seagrass constitute the major portion of the biomass retained at the intake screen structures.

Based upon this study, the number of planktonic organisms that could be expected to become entrained in the nearshore surface waters (upper 1.0 m layer) range from 300 organism/m^3 (.45g/m^3) to 1000 organisms/m^3(2.67g/m^3) (see Hillmann-Kitalong in this report). Plankton entrainment below the one-meter surface layer is only speculative as only the surface layer was sampled in this study. Once planktonic and nektonic organisms become entrained into the warm water intake pipe they will experience a drop in temperature and exposure to some chemical changes as the water passes through the evaporators. Although the exact temperature change that would occur as water passes through the evaporator of the proposed 40-50 MW OTEC plant is not known, most models of such size plants indicate temperature changes of only several degrees centigrade. Such small temperature changes may incur little thermal stress to entrained planktonic and nektonic organisms. Chemical stresses that entrained organisms would experience as they pass through the evaporator include biocides periodically injected into the water to control biofouling and the incorporation of erosion and corrosion products into the water that leach from OTEC plant components. Again, the amount, periodicity, and kinds of biocide used to prevent biofouling buildup and the kinds of metals and rates of erosion and corrosion products that leach into the sea water from a 40-50 MW OTEC plant are not known. If the OTEC plant uses a system of mechanical scrubbers to control biofouling buildups, then chemical stress to entrained organisms will be much less. Expected mechanical stresses that entrained organisms would experience as they pass through the evaporator would include turbulence, abrasion, and pressure changes. Such stresses will probably cause some mortality to entrained organisms, especially the larger nektonic organisms. Evenso, Grovhoug (1977) collected plankton samples directly from the discharge plumes of the Piti Power Plant and reported that many live zooplankters were observed and that considerably less than 100% entrainment mortality occurs.

Impacts from cold and warm water discharge of a shore based OTEC plant into marine waters would include: 1) displacement of entrained planktonic and nektonic organisms from their normal habitats in the water column; 2) toxicity resulting from the incorporation of erosion and corrosion products which leach into the water from OTEC plant components, biocides injected into the water to prevent biofouling buildup, and accidental spills or leaks of the plant working fluid (ammonia) and other plant discharges; 3) nutrient enrichment resulting from the pumping up of deep ocean water and discharging it into the relatively nutrient poor surface layer above the pycnocline; and 4) thermal stress from cold water discharge above the pycnocline. Dames and Moore (1979) have discussed most of the above anticipated impacts from warm and cold water discharge from a 10 MW land based OTEC plant. In their study impacts of a shore based plant are based upon discharging water into Piti Channel rather than on the seaward side of Cabras Island. If such a discharge method was used the increased volume of water from a 40-50 MW OTEC plant would drastically lower water temperatures and raise nutrient levels of Piti Channel, and most likely significantly alter much of Apra Harbor as well. Even bypassing some of the cold water discharge from a shore based OTEC facility for condenser cooling in the nearby Piti-Cabras power plants would cause considerable changes in the thermal and nutrient characteristics of Piti Channel. Such a trade off should be studied to determine whether or not the use of cold discharge water would be a tolerable environmental impact to Piti Channel.

Although little is known of the exact physio-chemical characteristics of the discharge water from the proposed 40-50 MW OTEC plant at Cabras Island, it is fairly certain that such water will be colder and denser than the warm layer above the pycnocline (even if the warm and cold waters are mixed before discharge). Such a plume of cold dense discharge water will sink into deeper water and become stabilized at a point where it and the surrounding water densities are equal. Because of the above anticipated behavior of the cold water discharge plume, it is not expected to have any significant impact upon the shallow water reef areas investigated in this study--provided of course that the release point is located below the zone of reef building corals. If for some reason the cold water discharge was released at the shoreline, or above the zone of reef building corals, and allowed to sink downslope in direct contact with the reef community there would be a significant impact.

Literature Cited

Dames and Moore. 1979. Environmental impact report projected OTEC development for the Territory of Guam. Guam Coastal Management, Bureau of Planning, Govt. Guam. 73 p.

Gorvhoug, J. G. 1977. Piti power plant intake survey, November 1977. Naval Ocean Systems Center, Tech. Rept. 288. 58 p.

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