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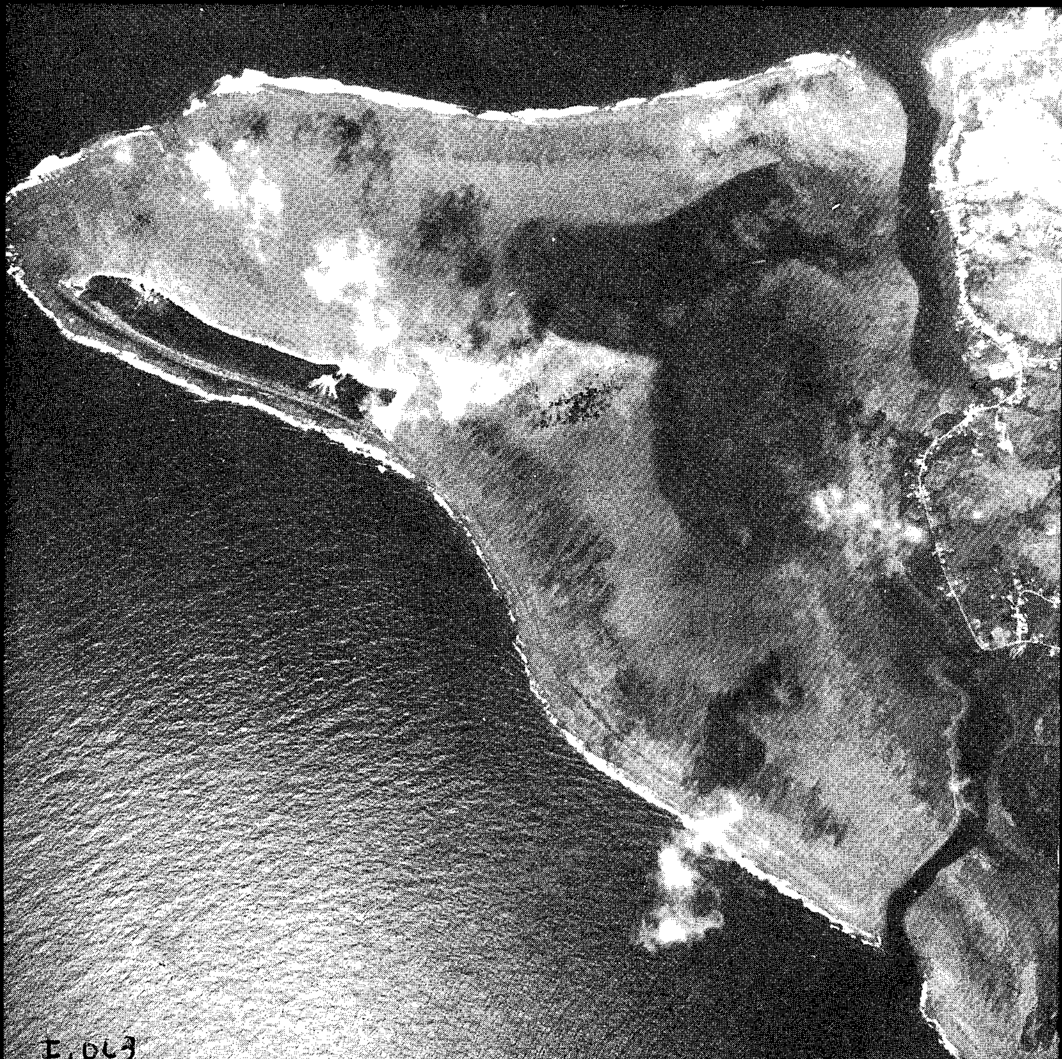

UNIVERSITY OF GUAM MARINE LABORATORY

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OF THE COCOS BARRIER REEFS AND ENCLOSED LAGOON

by

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ABSTRACT - Cocos Lagoon with its enclosed barrier reefs and three islands are presently the focal point for marine recreation on Guam where thousands of tourists as well as local people visit each year. The further development of support facilities in this area is inevitable to strengthen the tourist industry. This report presents the results of a marine survey conducted during July 1973 to December 1974 with major emphases on the physiography, marine biota, and to a limited extent the water circulation patterns within the lagoon.

Limited current studies thus far carried out in the Cocos area indicate a mass transport of water over the windward reef platform into the lagoon, and a predominantly seaward transport of water through Mamaon Channel.

The benthic biota (algae, corals and other macroinvertebrates) are characterized within 10 facies of two major biotopes - I. Lagoon, barrier reef flat platforms, and fringing reef flat platforms and II. Mamaon and Manell Channel. The fishes are in turn characterized and analyzed within seven biotopes - I. Outside reef, II. Channel wall, III. Lagoon patch reefs, IV. Barrier reef flat, V. Seagrass beds, VI. Sand bottom, and VII. Estuarine and freshwater.

The shallow channel margin shelves located at the upper margin of the channel slopes (Biotope II, Facies A), as well as the channel slope (Biotope II, Facies B), and the patch reefs in the lagoon (Biotope I, Facies D) possess the richest assemblage of both hard and soft corals. The marine flora is rather rich and diverse in those areas characterized by solid substratum. The results of the fish survey reveal that the lagoon as a whole does not support a rich ichthyofauna. The channel wall biotope possesses the richest fish assemblage.

Thus far, the white tern *Gygis alba candida*, the Micronesian starling *Aplonis opacus guami*, the blue-tailed skink *Enoia cyanura*, the recently discovered sea cow *Dugong dugong*, the hawksbill turtle *Eretmochelys imbricata*, and the coconut crab *Birgus latro* can be considered as endangered or threatened in the Cocos area.

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INTRODUCTION

Guam has two natural barrier reef lagoons -a deep and much modified one located at Apra Harbor, and a shallower and more natural one known as Cocos Lagoon, located at the southwest corner of Guam (Fig. 1). This survey is a marine ecological assessment of the Cocos barrier reefs and the enclosed lagoon. The region is a complex area consisting of both fringing and barrier reef flat platforms, a lagoon consisting of a deeper centrally located hollow surrounded by a broad shallow terrace, numerous lagoon patch reefs, two deep passes, a wooded mile-long barrier reef islet, mangrove swamps, river estuaries, and seagrass beds. The small village of Merizo fringes about two miles of shoreline along the north-east corner of the lagoon. Mangroves fringe much of the remaining lagoon shoreline southeast of Merizo.

The rapid rise of water related activities and increased use of the lagoon as a tourist attraction has generated a considerable amount of marine development in this important natural resource area. This survey then serves as a baseline study to evaluate the effect of rapid development in a rather small localized barrier reef and lagoon ecosystem.

Under Public Law 91-611 (Section 106 of the River and Harbor Act of 1970) the Chief of Engineers, under the direction of the Secretary of the Army, was given the responsibility to conduct a survey of "Rivers and harbors in the Territory of Guam in the interest of navigation, flood control, and related water resources purposes." As part of this study the University of Guam Marine Laboratory was contracted by the Army Corps of Engineers to conduct a marine environmental assessment of Cocos Lagoon. A contract (No. DACW84-72-C-0015) for this work was agreed upon, and the notice to proceed was received on June 21, 1973.

Scope of Work

Location of the study is Cocos Lagoon (Fig. 2). The study objectives include a general assessment within the study areas of:

a. The major structural elements of the ecosystems comprising the environment of the study area.

b. The dominant biological elements comprising the ecosystems in the study area.

c. The physical environmental factors in the study area.

Specific work items for the study area include the following:

a. Preparation of maps showing the major elements of the natural environment in the study areas.

b. Assessment of the major elements and specifying any instances where knowledge is weak or lacking.

c. Inventory the dominant environmental and ecosystem elements of the study areas to include the physical environment, biological elements, both flora and fauna, and any unique environmental elements. The dominant biological elements shall be those which in the cumulative total comprise in excess of 80 percent of the total population, and any species which individually comprise 10 percent or more of the biomass.

d. Give special attention to presence of rare or endangered species and fisheries.

e. Note any evidence of stability or stress on the ecosystem or population.

Utilization. The knowledge gained from this assessment will be used for defining Guam's water resource needs, for developing plans to meet these needs, and for analyzing the environmental impact of specific plans.

Literature Review

There has been no single field ecological assessment for the whole of Cocos Lagoon, although several studies report on certain physical and biological aspects of the region. Studies in which the overall investigations included parts or all of Cocos Lagoon, of marine and general geology, soils, vegetation, and hydrology were made as part of a program of geologic mapping of some islands of the western Pacific. These investigations were conducted jointly by the U. S. Army Corps of Engineers and the U. S. Geological Survey, and were published by Tracey et al. (1959). A later water resources supplement was published by Ward and Brookhart (1962).

A series of "Geological Survey Professional Papers" resulted from the field work and studies conducted during these investigations and from other related special investigations. Those which include studies of the Cocos Lagoon region follow:

Chapter A. Tracey _et al._ (1964), "General Geology of Guam" -- a general summary of the stratigraphy, structure, physical geography, and geologic history of the island.

Chapter B. Emery (1962), "Marine Geology of Guam" -- studies on the general aspects of submarine geology which include offshore island slopes, lagoon floors, channels through the fringing reefs, surfaces of barrier and fringing reefs, beaches, and rocky shores.

Chapter H. Ward, Hoffard, and Davis (1965), "Hydrology of Guam" -- studies of the ground-water areas, the Ghyben-Herzberg lens system, streamflow, and runoff characteristics of the island.

Chapter I. Todd (1966), "Smaller Foraminifera from Guam" -- study which records assemblages and illustrates some of the species of smaller Foraminifera characteristic of three different ages of sedimentary rocks on Guam. The Foraminifera found in beach sands, on the reefs, in the lagoons and channels, and on the outer slopes around Guam are also recorded.

Much of the descriptions of the physical environment of Cocos Lagoon and adjacent coastal regions is taken directly or summarized from the above "Geologic Professional Papers."

Randall and Holloman (1974) described the various physical features of the coastal regions of Guam by dividing it into 12, more or less similar, physiographic sectors. Sector XI of this report summarizes some of the previous biological and physical work known about Cocos Lagoon, Cocos barrier reefs, and the adjacent coastal region. The summary includes a brief description of physiography, geology, soils, engineering aspects of geology and soils, vegetation zones, hydrology, beaches and rocky shorelines, lagoon and barrier reefs, lagoon sediments, and development and use patterns.

A biological study of the Geus River Basin, which is the largest river basin draining into Cocos Lagoon, was made by Kami _et al._ (1974). The report includes a general description of the Geus River and valley and its associated terrestrial and aquatic flora and fauna.

The soils of Guam have been described by Stensland (1959), and the mineralogy of selected soils of Guam has been reported by Carroll and Hathaway (1963). Additional information on soils and geology can be found in May and Schlanger (1959).

Stone (1970) gives a comprehensive taxonomic analysis of the vascular plants of Guam. Fosberg (1959) describes the vegetation of Guam and includes a vegetation map of the island. Fosberg (1960) gives a detailed description of the forest types and plant communities of Guam. Fosberg's description includes the ravine forests and savanna vegetation of southern Guam, wet lands, swamps, and strand vegetation all of which are found bordering the coastal region of Cocos Lagoon or on Cocos Island.

Emery (1962) includes 24 species and varieties of marine algae in his treatise on the coastal geology of Guam. These algae identified by E. Y. Dawson, were mostly incidental collections made from the lagoon floor and adjacent reef flat in Cocos. Tsuda's (1972a) study on the brown algae of Guam include two species, Dictyota bartayresii and Rosenvingea intricata, from the lagoon area. The following year a more extensive study was reported (Tsuda and Kami, 1973) on algal succession on artificial reefs, constructed of tires, studied over a 26-month period in 9-10 m of water on the lagoon floor. Eighteen algal species inhabiting the artificial reefs were also reported.

Previous work on the fishes of Guam include checklists of species known from the island by Kami et al. (1968) and Kami (1971). Two transect stations for general fish surveys were conducted on artificial reefs in Cocos Lagoon and reported in the Guam Fish and Wildlife Annual Reports (1965 to 1974).

A summary of coral-reef damage by Acanthaster planci predation in the Cocos Lagoon area is given in a report by Cheney (1971). This report compares the earlier starfish surveys of Guam (Chesher, 1969; Tsuda, 1971), and gives the current status of Acanthaster distribution and reef damage around the island.

Jones and Randall (1973) made a marine survey at the mouth of the Geus River and head of Mamaon Channel. This survey describes the physical and biological aspects as well as the water circulation patterns of this region. A zonal distribution list of reef corals and fishes that occur in the area is also presented. Similar marine surveys were made near the mouth of Mamaon Channel by Randall and Jones (1972) and Randall and Eldredge (1974), and at the head of the Manell Channel in Achang Bay by Randall et al. (1973).

ACKNOWLEDGEMENTS

We acknowledge the U. S. Army Corps of Engineers for providing the funds under Contract No. DACW34-72-C-0015 which made this study possible; Mr. Nick Drahos of the Division of Fish and Wildlife for providing information on the avifauna of Cocos Island; Mr. Richard "E" Dickinson for identifying the mollusks; marine technicians Ted Tansy, Frank Cushing, and Pat Beeman for their help during field operations; the U. S. Navy for providing helicopter support for aerial photography and for providing photos of Cocos Lagoon; Mr. William FitzGerald for processing and printing many of the photos used in this report; Mr. Kida of Taisei Guam for permitting us to dock our boat overnight at the pier; Mr. Kim Gottwald for allowing us to use his pier and facilities; Mr. Hugh H. Fawcett for allowing us to use his facilities to launch our boat at the head of Mannell Channel; Mr. Augusto Terlaje for administrative handling of grant details; and Mrs. Terry Balajadia and Mary Mariano for typing the manuscript.

METHODS AND PROCEDURES

The work for this study was divided into four more or less sequential phases. The first phase involved a review of the literature pertinent to the objectives outlined in the scope of work. From this literature, it was determined in which objective areas information was weak or lacking.

The second phase consisted of an overall reconnaissance of the Cocos barrier reefs, channels, and lagoon to develop and map the general ecological divisions of the area. This operation was carried out by making SCUBA investigations of the deeper parts of the lagoon and in Mannell and Mamaon Channels. The barrier reef platforms and shallow lagoon terraces were investigated mainly by swimming with face mask and snorkel at high tide and walking on the exposed parts of the reef platform during lower tides. The deeper lagoon terraces were investigated by snorkelers who were towed behind a boat. Aerial photos were then used to correlate larger scale features with those of a smaller nature, made by direct observation, to map the area into a system of ecological units.

In this study the Cocos barrier reef-lagoon-channel system was divided into the primary ecological unit, the biotope (Hesse et al., 1951). The biotope concept normally "embraces the entire complex of habitat conditions in the area defined, including substrate, accretional and erosional processes, hydrologic factors, and life associations" (Cloud, 1959:374). The biotope descriptions are by no means complete, for it was impossible to acquire all or even a major part of the complex parameters which make up this ecological unit within the time frame and scope-of-work objectives of this study. The main concern here is to broadly characterize the macro-organisms and coral development.

When distinct but consistent differences occurred within the larger biotope unit, the biotope was subdivided into smaller ecological divisions called "facies" (Cloud, 1959).

The third phase consisted of specific biological inventories made by individual or team specialists. Specific biological inventories were conducted for the corals (scleractinians, alcyonaceans and zoanthids) by Randall and Gawel, fishes by Jones and Chase, algae by Tsuda and Rechebei. These biological inventories were more or less independent studies in which the distribution, density, frequency of occurrence, and dominance or biomass of the specific groups were determined both qualitatively and quantitatively within the descriptive framework of the various biotopes. The methodology used in the specific biological inventories is explained in each of the specific surveys.

The fourth phase consisted of reporting on the "specific work items" (d) and (e) as outlined in the scope of work.

DESCRIPTION OF COCOS LAGOON, ADJACENT COASTAL AREAS, BARRIER REEFS, AND COCOS ISLAND

This survey includes the Cocos barrier reefs and enclosed Cocos Lagoon, Cocos Island, and the coastal region lying between the mouth of Mamaon and Manell Channels (Fig. 2 and 3). The triangular lagoon is enclosed by barrier reefs nearly three miles long on the northwest side, three-and-a-half miles long on the south side, and by two-and-a-half miles of steep mountainous land and alluvial coastal low land on the northeast side. The Geus River forms a broad alluvial valley which trends northeasterly from the head of Mamaon Channel. Several rivers form alluvial valleys and a broad coastal plain at the head of Manell Channel. Two deep channels connect the lagoon waters with the open sea - Mamaon Channel opens to the Philippine Sea and Manell Channel opens to the Pacific Ocean.

Three islands are located on the south barrier reef. Cocos Island, slightly longer than a mile, lies along the west end of the south barrier reef. A second small, sandy island has developed on the lagoon side of the barrier reef, 1,000 feet east of Cocos Island. Babe Island, an elongated low strip of raised limestone, lies on the south barrier reef midway between the east end of Cocos Island and Manell Channel.

Cocos Lagoon, excluding the barrier reefs, has an area of 2.8 square miles. The area of the barrier reefs and lagoon together is 3.9 square miles. Aside from the deep Mamaon and Manell Channels, the deepest part of the lagoon is about 45 feet.

Adjacent Coastal Areas

Cocos Lagoon and its barrier reef probably developed on a basement of the Umatac formation (Tracey et al., 1964). The basic shape of the reef supports the idea that part of the Umatac formation dropped along the Cocos fault, which strikes northwest from the mouth of Manell Channel.

The landward margin of the lagoon (Fig. 4) is bordered by a low, narrow, coastal plain composed of alluvium along the Mamaon Channel. This shelf widens into a broad alluvial valley at the head of the channel and then narrows again at Jaotan Point. A low-lying section of argillaceous limestone of the Mariana formation (QTma) forms a small point on the north side of Achang Bay. A broad, swampy alluvial plain, composed mostly of volcanic clay and muck (Qal) borders Manell Channel and Achang Reef.

Steep mountain slopes consisting of Facpi volcanic (Tuf) and Bolanos pyroclastic (Tub) members of the Umatac formation border the inland side of the low coastal plain. Most outcrops of these members are deeply weathered to red, brown, and yellow clay.

Babe Island is composed entirely of a low strip of raised, solution-pitted Merizo limestone (Qrm) 1-3 feet higher than the general reef-flat level. Merizo limestone similar in elevation and lithologic characteristics to that at Babe Island also forms a low band on the seaward side of Cocos Island. The lagoonward side of Cocos Island is composed of unconsolidated beach deposits derived from the nearby barrier reefs.

The most extensive soil type along this shoreline is Inarajan clay, (Unit 10) which is developed on the low coastal plain bordering the lagoon (Fig. 5). A small section of Agat-Asan-Atate clay (Unit 7) is found along the shoreline near the mouth of Mamaon Channel.

Atate-Agat clay (Unit 6), Agat-Asan-Atate clay (Unit 7), and Agat-Asan clay (Unit 8) are found somewhat inland on the volcanic slopes bordering the coastal plain. Pago clay (Unit 9) is found on the upper alluvial valleys of the Geus and Manell Rivers.

Shioya soil (Unit 12) is developed on the unconsolidated sediments of Cocos Island. Rocky land types (Unit 13f) are found on the low strip of raised limestone at Babe Island. Although not mapped, the solution-pitted band of limestone located on the seaward side of Cocos Island should be grouped with Unit 13f.

The volcanic slopes bordering this sector are intricately dissected by streams. The Geus River basin drains the largest area along the sector, emptying into the lagoon at a small embayment at the head of Mamaon Channel (see Tables 1 and 2 for discharge data for this river) Tochog Creek and Manell River empty near the head of Manell Channel at Achang Bay. The volcanic mountain land bordering the east side of the lagoon lies within the ground water subarea 6a. The water-bearing materials of this subarea are largely volcanic rock and associated sediments. Height of the water table ranges from a few feet above sea level in coastal lowlands to several hundred feet in the interior highlands.

The vegetation zones along this sector are mapped in detail in Fig. 6. Mangrove communities border the shoreward side of Cocos Lagoon from Jaotan Point to Balang Point. Some scattered patches of mangrove are found near the mouth of the Geus River.

The shoreline along Cocos Lagoon is bordered mostly by alluvium. Near the mouth of the Geus River and at Achang Bay the shores are mud flats and mangrove swamps (Fig. 7).

Unconsolidated beach deposits border the lagoonward side of Cocos Island and a low, rocky, solution-pitted band of limestone bounds the seaward side. Babe Island consists entirely of low pinnacles of solution-pitted limestone. The small islet about 1,000 feet east of Cocos Island is composed entirely of unconsolidated beach deposits.

Physiographic Features of Cocos Lagoon, Barrier Reefs and Deep Channels

The following description of the Cocos Lagoon and barrier reefs has for the most part been summarized from Emery (1962).

The topography of the floor of Cocos Lagoon (Fig. 8) is known chiefly from some 3,000 sonic soundings made in 1945 by sound boats of USS BOWDITCH (AGS 4) (Emery, 1962). Figure 9 shows a histogram analysis of the percentage area of Cocos Lagoon, barrier reef platforms, and Cocos Island by depth and a cumulative depth curve for Cocos Lagoon. Based upon the submarine contours, Emery (1962) divided Cocos Lagoon and associated barrier reefs into five physiographic units: reef, lagoon hollow, reef bar, deep channel, and nearshore shelf. In this report we have included Manell Channel as a part of the Cocos Lagoon-barrier reef complex which increases the number of physiographic units to six.

Closest to land is the nearshore shelf, apparently merely a seaward continuation of the small coastal plain bordering the lagoon. Its slope is gentle from the shore to depths of about 5 feet at its outer margin which varies in width from less than 100 feet off Merizo to about a quarter-of-a-mile off Jaotan Point. At its eastern end and extending to the deep channel of Achang Bay, the shelf separates the reef from the shore, forming an area that is 1-2 feet deeper than a normal reef flat. Near the middle is a large indentation of the shore where the Geus River empties. A small mangrove swamp is present along the shore of this indentation.

The outermost physiographic unit of the lagoon is the barrier reef itself, which averages about 300 yards in width except at the northern end where it is blunt and some 600 yards wide, possibly because of better growth conditions along the side of Mamaon Channel. The outer edge of the reef is a low algal ridge. Near its southern tip is Cocos Island, a mass of sand and gravel 0.11 miles square, nowhere more than about 10 feet high. Since most of the material seen above high tide is unconsolidated, it is believed that the island owes its origin to waves and currents which have transported sediments along and across the reef. An example of the transporting ability of large waves was presented by Typhoon Allyn of November 17, 1949, which destroyed Navy installations at the west end of the island, carried away part of the eastern quarter-mile of the island, removed a small islet just north of the east end and built another small islet farther north.

Between the nearshore shelf and the north end of the reef is the deep Mamaon Channel. This is fairly straight, a mile long within the reef, 100-200 yards wide, and about 100 feet deep where it passes through the reef. Soundings show a continuation to depths of at least 400 feet about 1,100 yards out from the reef. The current in the channel flows outward strongly at ebb tide, and either inward or outward weakly at flood tide. The channel may have been the chief original exit from the lagoon of fresh water brought by streams.

The fourth physiographic unit is the shallow reef bar in the northern half of the lagoon which separates the nearshore shelf and channels from the main part of the lagoon. Most of the top of this reef bar is less than 10 feet deep, and it consists largely of branching and massive corals. Its position and distance from shore indicate that it may have been a fringing reef, now cut off from the open sea by the present barrier reef on which Cocos Island sits. Blasting operations for easier navigation in Mamaon Channel may have produced minor modifications of this area.

The fifth physiographic unit is the deep "lagoon hollow." Its southern part is a gently undulating surface generally less than 10 feet deep, but the northern part against the reef bar is deep and irregular. There are three main holes, with depths of 34, 40, and 43 feet.

The sixth physiographic unit is the deep Manell Channel which separates the southeast part of Cocos Lagoon from the wide Achang reef flat platform (Fig. 10). The head of this channel originates at the mouth of the Tochog Creek and the Manell River. The origin of this deep channel is probably very similar to that described above for the Mamaon Channel. At the mouth of the channel the depth is greater than 100 feet. Aerial photos and SCUBA investigations show that the channel continues in a seaward direction well beyond the reef margin edge.

Sediments

Emery (1962) collected 254 samples from the floor of Cocos Lagoon, including about a dozen from near the shore and a few from the lagoonward edge of the peripheral barrier reef platforms. Ninety more samples were collected from the shallow reef platforms on the east and west sides of Manell Channel. By making direct observations through the ports of a glass-bottomed boat, between sampling points to depths of 30 feet, an estimate was formed of the percentage of sand, dead coral, and living coral. The most significant of the three measured was sand, which is plotted and contoured in Figure 11. Most of the lagoon hollow is floored by a broad expanse of sand with few or no rocky masses. The shallow southern part of the area, except near the shore of Cocos Island, is 100 per cent sandy bottom. Similarly, sand covers the shallow eastern part of the reef bar and the nearshore shelf. Most of the nearshore shelf and those parts of the lagoon near the reef are between 50 and 100 per cent sand, whereas the seaward side of the reef and most of the reef bar are less than 50 per cent sand. The embayment of the nearshore shelf contains some mud mixed with sand. Practically all bottom material other than sand is either dead or living coral. The ratio of dead to living coral varies widely and unsystematically. The most striking expanse of living coral is found at the entrance of Mamaon Channel. Other large areas of living coral, mostly Porites, are present along both sides of the channel off Merizo and atop the reef bar. Different corals, less branching and more massive, form the reef surface and the areas just lagoonward of the reef.

At Achang Reef the results indicate that the inner half of the reef flat is dominantly sand, in part covered by Enhalus beds. Abundant mounds of sand one to three feet in diameter and several inches high are scattered over the inner reef flat surface. The mounds are thought to have been made by the burrowing activities of echiuroid worms. The outer half of the reef and the areas bordering Manell Channel consist chiefly of coral, reef rock boulders, and coral-algal reef rock pavement with sand occurring only in pockets or as a thin mat on the surface.

General Composition

The composition of each sediment sample was estimated on a volume percentage basis using a binocular microscope. Detrital grains from land runoff consist mostly of feldspar, augite, olivine, and magnetite, and some fine-grained sediments contain a high percentage of clay minerals. All other grains are of bioclastic origin from organisms that were identified according to shape, surface character, and susceptibility of the grains to staining by cobalt nitrate. Fine sand to coarse silt size grains too small to permit reliable identification were classed as fine sand and silt.

For detailed general features and horizontal and vertical distributional analysis of the sediments of Cocos Lagoon, refer to Emery (1962:22-25).

Sediments in Cocos Lagoon and Mamaon Channel

To simplify the picture of sediment distribution, the samples were classed as fine sand and silt, Foraminifera, Halimeda debris, and coral, according to the most abundant constituent. Calcareous red algae and shells were omitted because they were chief constituents in few or none of the samples. The results plotted in single map form are easier to visualize than separate maps of each constituent (Fig. 12).

In summary, it is evident that detrital sediments from the land--insoluble residue fractions--are not carried far into the lagoon. The chief Foraminifera are heavy ones which live on the reef, and after death of the organisms, the empty tests collect on the beaches inshore of the reefs. Halimeda evidently live best in the areas receiving new water from Mamaon Channel, for their debris is most abundant there. Madreporarian corals and calcareous red algae form the bulk of the sediment bordering the reef. The finest sediment from comminuted organic remains collects in the deeper areas of presumed quieter water, where organic growth is less rapid probably because less sunlight reaches the bottom. Thus, coarse debris is not available locally, and only the finer sediment is carried there by currents from distant areas of growth.

A rough value for the overall composition of the present lagoon floor and adjacent reef and beaches can be obtained by totaling the areas of the various constituents shown in Fig. 13. If the samples had been evenly distributed over the lagoon floor, the same result would be obtained by averaging together the composition of all 254 samples. In fact, approximately the same values were obtained when this method was used (Table 3). The results from both methods show that the contribution by animals is about twice that of plants.

Samples from Achang Reef and Manell Channel were treated in the same manner as those from Cocos Lagoon and Mamaon Channel. The distribution of the sample constituents on the reef surface were monotonously uniform and dominated by comminuted coral. Halimeda debris presents the greatest variation; the highest concentrations are on the deep reef flat west of Achang Bay, and the lesser ones are near the reef edge, along part of Manell Channel, and at some beaches. Fine sand and silt is abundant only in Manell Channel and along the shore at its head. Detrital grains average 25 per cent in the beach samples but are rare beyond 200 feet from shore.

Chemical Composition

Table 4 shows the chemical composition of sediment samples from Cocos Island, Achang Bay, Cocos Lagoon, and Mamaon Channel.

CURRENT PATTERNS

A complete analysis of the currents is beyond the scope of this work but some rather broad and generalized patterns of circulation can be drawn from four previous 24 hour studies--three in Mamaon Channel and one in Manell Channel.

During the field work of this project a 12 hour current study was conducted on July 29, 1974 at two stations in the main body of Cocos Lagoon and another 24 hour study was made at the mouth of Mamaon Channel on July 30-31, 1974. During the field reconnaissance and biological survey periods, additional observations were also noted.

Additional data from a current study conducted by the Naval Oceanographic Office (Huddell et al., 1974) is also included herein.

Previous Current Studies in Mamaon Channel

The first of these studies was made in April, 1972, by Randall and Jones (1972), in the Mamaon Channel and adjacent fringing reef flat about 2,500 feet lagoonward from the channel mouth (Station C-1, Fig. 19). Current patterns on the reef flat were determined by using drift cross and underwater dye release techniques. In Mamaon Channel the current patterns were determined by drift cross casts near the central part of the channel. A total of seven underwater dye releases and seven drift cross casts, each cast consisting of three drift crosses set at 10 cm depth were made from Station A (Fig.14).

Seven drift cross casts were made in the Mamaon Channel from Station B. Each of these drift cross casts consisted of three drift crosses: a 1 m depth cross to determine currents in the upper surface layer of water and 5 m and 10 m depth crosses to determine currents in deeper water layers. The axis of each dye plume and drift cross tract is plotted on Figure 14. Table 5 lists the magnetic bearing and velocity for each dye plume and drift cross tract. The current patterns on the lagoon reef flat and in the Mamaon Channel were found to be rather uniform with respect to current direction throughout the tidal cycle. During the entire study period there was a unidirectional seaward flowing current in the Mamaon Channel. This unidirectional flow is probably due to the high volume transport of water across the barrier reef enclosing Cocos Lagoon. During periods of calms and low wind velocity combined with lower low water spring tides, the transport of water across the barrier reef would be at a minimum. During these times the current direction in Mamaon Channel could conceivably be in a lagoonward direction. According to Emery (1962) there may be either a weak inward or outward flow in the channel at flood tide. It was found that the mass transport of water flowing seaward in the Mamaon Channel was rather uniform for the upper 10 m layer of water because, the 1 m, 5 m, and 10 m drift crosses all move at about the same velocity. It is strongly suspected that the mass transport of water in the entire water column of the Mamaon Channel is rather uniform. During a SCUBA dive in the channel floor at 100 feet, a current similar to that measured in the upper 10 m layer of water was encountered.

A second current study was made at the head of Mamaon Channel (Jones and Randall, 1973) and adjacent fringing reef flat on January 13, 1973 (Station C-2, Fig. 19). Current direction was determined by injecting fluorescein dye into the water mass and taking a bearing on the plume axis. Current speed was determined by measuring the time and length of the dye drift.

The data taken are shown on Figure 15 and in Table 6. The current sweeps through the study area more or less from east to west. This condition predominates at all stands of the tide. All of the water flowing through the study area eventually enters Mamaon Channel and moves westward to the Philippine Sea. These data are in agreement with a similar study conducted by Randall and Jones (1972), in an area along Mamaon Channel and farther to the west (Station C-1). On January 13 a weak west wind was encountered which is rare in the study area. The result of this wind was a reduction in current velocity (Table 6). During flood tides and strong west winds, there may be a current reversal in Mamaon Channel and water may then sweep from west to east across the study area.

One series of dye releases was made along the west causeway boundary. The two inshore stations showed a confused oscillating pattern that was related to translatory surge from the Cocos Lagoon reef margin. The inshore one third of the study area is sheltered from prevailing winds. Except during periods of southeast and southwest winds, there is little wave action here.

A third current study was made near the mouth of Mamaon Channel on December 1 and 2, 1973, by Randall and Eldredge (1974) (Station C-3, Fig. 19). Five stations were established on the reef-flat platform. An additional station (Station 6) was established in the middle of Mamaon Channel in line with the five reef flat platform stations. Current direction was determined by injecting fluorescein dye into the water mass at Stations 1 through 5. Direction was determined by taking a bearing on the plume axis. Current speed was determined by measuring the time and length of the dye drift. Current direction was determined at Station 6 by using one-meter and five-meter depth-drift drogues. Only relative direction was determined at this station in reference to seaward or lagoonward movements. A temporary tide staff gauge was established at Station 1 to determine whether or not the predicted tides at Apra Harbor followed those observed at the project site.

Table 7 summarizes the current data for reef flat platform Stations 1 through 5. Current vectors (direction only) for each of the stations are plotted on Figure 16. Table 8 summarizes the current data for Station 6, and Figure 16 shows the location and relative movement of the current at this station. The observed tide followed the predicted tide at Apra Harbor fairly well except for the magnitude of the lower low-water tide on December 2, 1973.

Wind direction ranged from 110°-120° during most of the twenty-four hour period. Velocity was quite variable because of the presence of rain squalls south of Cocos Island. Velocity ranged from virtually no detectable wind to gusts of approximately 15 knots. During this study period there was considerable wave transport of water over the south barrier reef into the lagoon. Surf was observed on the morning of December 1 to be 2-4 feet high on the south barrier reef. The sea was calm, and virtually no surf was present on the northwest barrier reef, which extends from the western tip of Cocos Island northeastward to Mamaon Channel.

It appears that when considerable wave transport is present over both the south and northwest barrier reefs, a seaward-flowing, unidirectional current in the Mamaon Channel may exist regardless of the stage of the tide. When wave transport is minimal, currents in the Mamaon Channel may flow seaward during ebb tides, may flow lagoonward during flood tides, or may be variable.

This study shows a lagoonward movement during an ebb tide from 1300 to 1530 on December 1, 1973. This lagoonward flow may have been caused by a carry-over of the high tide, which occurred at 1243. There was only a slight change in height between the high tide at 1243 (2.3 ft.) and the low tide at 1833 (1.5 ft.).

At 1005-1020 on December 2, 1973, a seaward-flowing current was observed in the Mamaon Channel during a flood tide. This seaward flow may have been caused by an increase in mass transport of water over the south barrier reef because of extensive squalls located immediately to the south. The increase in wave transport may have nullified the possible lagoonward movement during this flood-tide stage.

Current direction on the reef-flat platform generally had a westerly component. On a few occasions at Stations 3, 4, and 5 a southerly component was observed during flood tides. It should further be noted that at Station 5 there was a weak current toward the south during an ebb tide. There appears to be less dependency along the reef-flat platform on the stage of the tide with regard to current direction than there is in the Mamaon Channel proper, although the stations close to the channel margin (Stations 3, 4, and 5) do respond somewhat to the water movement present in the channel.

Previous Current Study at Manell Channel

This current study was made at the head of Manell Channel on June 8 and 9, 1973 by Randall et al. (1973) (Station C-4, Fig. 19). The current patterns presented at this location were conducted over a 24 hour tide cycle. Table 9 summarizes the data collected on the reef flat and adjacent Manell Channel. Figures 17 and 18 shows the various current vectors plotted at each station. Current patterns were determined by tracking dye injected into the water mass and with drift crosses. In the general region of the partially finished boat basin and access channel (Stations 3-7) there was virtually no current or, if present, it consisted of a slight movement to the west due to wind influence on the upper few cm of water. On the fringing lagoon reef flat (Stations 7-12) there was a general southwestern current except from 1515 to 1540 (June 8) when the currents showed a weak southern movement. Currents in Manell Channel (Stations 13-16) had a general westward movement toward the main body of Cocos Lagoon except during the latter part of the ebb tide and the first half of the flood tide from 0120 to 0300 (June 9). During this period of time the currents in the channel were moving seaward in a general southeastern direction.

The unidirectional, seaward-flowing current found during an earlier study at the head of Mamaon Channel by Randall and Jones (1972) was not observed during this study at the head of Manell Channel. Instead the predominant current was found to be toward the west, lagoonward, at the head of Manell Channel.

Current Studies Conducted by the Naval Oceanographic Office

The Naval Oceanographic Office initiated a study of nearshore currents and coral reef ecology on the island of Guam during 1971. Several of these studies were conducted in the vicinity of Cocos Lagoon. Following is a summary of the results of two current meter studies (Meters No. 407 and 418).

Current Meter No. 407 was installed at the 40-foot depth at tne entrance to Mamaon Channel. The meter was in operation from 1230 August 21, 1971 to 1250 September 9, 1971. Current speeds ranged up to 0.77 knot (.39 m/sec) with a relatively large number of observations over 0.5 knot (.25 m/sec). The direction of the currents were bidirectional, but the predominant flow was westerly. Current directions generally changed in concert with tidal cycles. During the period between August, 21 and 27, currents through Mamaon Channel, varied between inflow and outflow but were strongest during inflow. Although the dominant flow was westerly through Mamaon Channel, currents carried water from the Philippine Sea through the channel and into the lagoon on several occasions.

Current Meter No. 418 was installed on the bottom in 95 feet of water off the southwestern tip of Cocos Island. The meter was in operation from 1145 August 28, 1971 to 1325 September 9, 1971. Current speeds up to 0.65 knots (.325 m/sec) were recorded; low speeds were probably due to the presence of a precipitous slope rising just east of the meter location, blocking the flow of the dominantly northwesterly currents. The source of the dominant northwest drift is probably the North Equatorial Current. Very little periodicity is evident from the data recorded.

Current Studies Conducted During This Project

Two separate current studies were made -one on July 29, 1974, near the central part of Cocos Lagoon and another on July 30-31, 1974, at the mouth of Mamaon Channel (Fig. 19).

The study in Cocos Lagoon was conducted to determine the general movement of water in the main part of the lagoon, a region where no previous current data are available. When normal tradewinds are blowing the southern barrier reef is exposed to considerable more wave assault than the northwest barrier. This greater wave assault on the south barrier results in a greater volume transport of water into the lagoon from the south; a condition which would probably produce a general north to northwest current in the lagoon. The locations of Stations 1 and 2, shown in Figure 19, were selected to test this suspected current pattern. Only July 29, 1974, the weather was partly cloudy with rain squalls in the vicinity and the south barrier reef was receiving considerable more wave assault than the northwest barrier reef.

One meter deep drift crosses were released in pairs at each station. Their positions were determined by triangulation on known points along the shore at the end of each drift tract. Figure 19 shows that a general northwest current was flowing during the entire study period. Table 10 shows that the greatest current speed occurred during drift cross casts 2, 3, and 4, which coincides with the period of greatest wave assault on the south barrier. A flooding tide was present at this time which would also tend to produce a net inflow of water into the lagoon, especially from the south barrier reef because of greater mass transport there.

The 24 hour current study conducted at the mouth of Mamaon Channel shows a rather typical current pattern (Fig. 20), in most respects agreeing with the previous current studies done there (except for the unidirectional flow found by Randall and Jones, 1972). The deeper water in the channel allowed the use of both one meter and five meter depth drift crosses. For the most part both the one and five meter crosses moved together in the same direction, although the five meter drift cross usually moved somewhat slower. The only exception to this occurred during drift cross cast number six when the one meter cross moved in a seaward direction while the five meter cross moved lagoonward. This exception was due to the general seaward movement of both drift crosses during the first part of the drift period, at which time the one meter became grounded. The current then reversed during the mid-part of the flood tide which carried the five meter drift cross lagoonward while the grounded one meter cross remained in place. Current speed was not computed during this study because during the drift period of most casts the drift crosses became grounded on the margin of the channel (Table 11).

Summary of Current Data

If Cocos Lagoon were filling and emptying only through Mamaon Channel, a periodic current would exist in both directions. The current patterns at Mamaon Channel show a predominant seaward flow. Although no current studies were conducted at the mouth of Manell Channel, periodic lagoonward and seaward flows were noted at various times. The current patterns in Mamaon Channel indicate the presence of another current system other than that through the deep Mamaon Channel (Huddell et al., 1974). This other current system consists of a net mass transport of water over the windward exposed south barrier reef platform into Cocos Lagoon. This mass volume transport at times even overrides the flood tide periods, when a somewhat weaker lagoonward flowing current should be present in the channel (Randall and Jones, 1972). The presence of a lagoonward flowing current in these deep channels then depends upon the mass volume transport over the barrier reefs. When mass volume transport is high there may be a unidirectional seaward flow of water whereas during times of minimal transport there may be a lagoonward flow during flood tide conditions.

The current system in Manell Channel is somewhat more isolated from the main body of Cocos Lagoon by a wide shallow reef flat, especially during lower spring tides when it is then completely isolated by exposure of the reef flat. At several times during the current study at the head of Manell Channel there was a seaward flowing current at the mouth of the channel while a lagoonward flow was present at its head in Achang Bay. This seaward flow is in part caused by mass transport of water over the outer part of Achang Reef to the east, producing currents which curve back toward the channel where they then flow seaward through the channel mouth. A similar movement of water was noticed on the barrier reef flat platform adjacent to the mouth of the channel on the west side.

BIOTOPES

Following is an outline of the three biotopes and associated facies which were differentiated from the Cocos Lagoon region. Only a brief description and outline of the various units are given here as a more complete physiographic description is given in the coral section. Figure 21 shows the location and distribution of the biotopes and associated facies.

The benthic organisms were described and analyzed according to these biotopes. The fishes, however, were analyzed according to a different but more practical set of biotopes - outside reef, channel walls, lagoon patch reefs, barrier reef flat, seagrass beds, sand bottom, and estaurine and freshwater.

Biotope I - This biotope includes the lagoon, barrier reef flat platforms, and fringing reef flat platforms.

Facies A - Barrier reef flat platform. The barrier reef platform of this biotope corresponds to Emery's (1962) "reef" physiographic unit.

Facies B - Shallow lagoon terrace or floor which forms a shelf extending from the lagoonward edge of the barrier reef and fringing reef flat platforms to the 10 feet depth contour. This facies along with Facies C below are equivalent to Emery's (1962) "lagoon" and "reef bar" physiographic units.

Facies C - Lagoon floor deeper than 10 feet. This facies is included in Emery's (1962) "lagoon" physiographic unit.

Facies D - Patch reefs, mounds, and knolls which form distinct physiographic features on the lagoon floor. These features are part of Emery's (1962) "lagoon" physiographic unit.

Facies E - Nearshore shelf or fringing reef flat platform which borders the landward side of Cocos Lagoon. This facies is equivalent to Emery's (1962) "nearshore shelf" physiographic unit.

Biotope II - This biotope consists of the deep Mamaon and Manell Channels. This biotope is equivalent to Emery's (1962) "channel" physiographic unit.

Facies A - Shallow channel margin shelves located at the upper margin of the channel slopes or walls.

Facies B - Channel slope located between the upper channel margin or shelf and the channel floor. Substrate usually unconsolidated.

Facies C - Channel slopes which form steep rocky walls or submarine cliffs, located between the upper channel margin or shelf and channel floor.

Facies D - Cavernous parts of channel slopes and walls and the overhanging ceilings of submarine cliffs.

Facies E - Channel floor, usually composed of unconsolidated sediments.

Biotope III - This biotope consists of the terrestrial regions at Cocos Island and the small sand islet at its eastern end, Babe Island, and the landward border along Cocos Lagoon.

Facies A - Cocos Island and sand islet.

Facies B - Babe Island

Facies C - Landward border along Cocos Lagoon.

HARD CORAL SURVEY

The corals are discussed first because of their developmental role in producing much of the physiographic structure and sediments observed in the Cocos Barrier Reef ecosystem.

The coral community was quantitatively analyzed by using a modified point-centered quarter technique as described by Cottam et al. (1953). In this technique a series of 10 points, 10 m apart were selected along a straight 100 m long transect line laid on the substratum. The area around each transect point was divided into four equal quadrants. The coral nearest the transect point in each quadrant was located and its specific name, diameter, and distance from the center of the corallum to the transect point were recorded. If no coral was observed within a maximum distance of 5 m from the transect line, the quadrant was recorded as having no coral. The diameter was recorded as zero and the distance between transect point and coral was recorded as 5 m.

The basal area, density, percentage of substrate coverage, and frequency of occurrence of living corals were determined from the above data. An overall importance value for each transect species was calculated by summing the relative values of each of these parameters.

Furthermore, species seen adjacent to the transect line during a 20 min. search were included in the checklist (Table 12).

Biotope I

This biotope includes Cocos Lagoon and its peripheral reef flat platforms (Fig. 21). It is subdivided into five facies (A-E).

Facies A

This facies consists of the barrier reef flat platforms only. These platforms constitute a distinct facies from the fringing reef flat platforms (Facies B) because of their physical isolation, different sediment composition, and degree of exposure to waves and wind. The triangular-shaped barrier reef is isolated from the fringing reefs by two deep channels; the Mamaon Channel at the northern end of the lagoon and the Manell Channel at the southeastern end. Emery's (1962) studies reveal that Facies E reef flats sediments contain a considerable fraction of detrital sediments of terrestrial origin whereas the barrier reef flat sediments are primarily of bioclastic origin (Fig. 22). The barrier reefs also receive more wave assault, especially the southern reef which is exposed predominately to the tradewinds and wave refraction from around the southern end of the island.

The barrier reef platform can be subdivided into an outer seaward facing zone which is slightly elevated in respect to the inner lagoonward facing zone (Fig. 23). The seaward reef flat consists of a rather featureless flat reef-rock pavement (Fig. 24). In a lagoonward direction this flat barren outer pavement grades into a rocky platform which is slightly lower and covered with various amounts of boulder rubble. At places the boulder rubble is widely scattered while at other places it is tightly packed forming patches a foot or more in thickness (Fig. 25). During low spring tides much of the barrier reef flat surface is exposed. In general corals are mostly absent over much of the barrier reef surface because of this periodic exposure during times of mid-day insolation. Shallow pools contain a few small corals, generally Porites lutea and small branching colonies of Psammocora stellata, Psammocora contigua, Pocillopora damicornis, and Acropora teres (Table 12).

Eight transects (see Fig. 21 for locations) were run using the point quarter method on the barrier reef flat platform surface (Biotope IA) to determine coral density and percentage of substrate covered by living corals (Table 13, Transects 3, 5-10, and 22). Coral density ranged from $.37/m^2$ to $20.17/m^2$ and percentage of substrate covered from .15% to 4.55%. The wide range in density and substrate coverage values was due to the varying degree of exposure of the reef surface at the various transect locations. Transects 8 and 9 were run on the flat barren pavement zone of the outer seaward part of the barrier reef which has the greatest degree of exposure. Only one small Acropora teres colony was encountered along the 100 meter length of Transect 8 and 12 small Porites lutea colonies, ranging from 1 to 9 cm diameter, were observed along Transect 9. Transects 3, 5, 10, and 22 were run along the middle zone of the barrier reef flat platform which is slightly less exposed during low tides. In this middle zone, coral density ranged from $.37/m^2$ to $1.72/m^2$ and percentage of substrate coverage from .15% to 3.45%. Much of the increase in coral growth in this middle zone was due to the presence of numerous small shallow depressions and holes which retained water during the lower tides. Transects 6 and 7 were run on the inner lagoonward zone which is the least exposed part of the barrier reef flat. Coral density and substrate coverage were higher in this less exposed region than for any other zone of Biotope IA. The high density values ($14.42/m^2$ to $20.17/m^2$) for these two transects is due to the presence of numerous small colonies of Psammocora stellata and Porites lutea, many of which, were only 1-3 cm in diameter.

The locations of the above eight transects were selected to represent the range of various kinds of habitats present on barrier reef flat surface of Biotope IA. In general there is an increase in coral density, substrate coverage, and diversity from the seaward side of the reef flat to the lagoonward side. Greater areas of reef flat surface without coral growth were found on the northern leeward reef than on the southern windward reef. Although coral density and percentage of substrate covered were generally low on the barrier reef flat, coral diversity was fairly high. Table 12 lists a total of 39 coral species representing 18 genera that were observed in Biotope IA.

Facies B

This facies consists of a shallow peripheral lagoon terrace which forms a shelf extending from the lagoonward margin of the barrier reef flat (Facies A) and fringing reef flat (Facies E) platforms to the 10 foot submarine contour (Figs. 21 and 23). The lagoonward side of the barrier reef (Facies A) grades rather gradually into the lagoon terrace (Facies B). The outer boundary of Facies B is delimited at the point where the barrier reef surface is generally covered by water during low spring tides (Fig. 20). In a lagoonward direction the terrace gradually deepens to about 10 feet at which point the slope of the terrace floor generally increases rather abruptly, marking the boundary between this facies and the deeper part of the lagoon floor of Facies C (Fig. 23). Width of this facies varies greatly from a kilometer or more along the southern barrier reef and western end of Cocos Lagoon to an irregular narrow shelf 200 to 600 meters wide along the northwest part of the lagoon, nearshore shelf, and Mamaon Channel. The boundary along the nearshore shelf (Facies E) is more or less marked by the outer limit of Enhalus growth.

Composition of the terrace floor varies considerably from place to place but in general it becomes more sandy as the deep floor of Facies C is approached. Coral-algal-mollusk rubble, boulders, coarse sand and gravel, and living coral become more abundant toward the barrier reef and nearshore shelf boundaries. At most places the unconsolidated sediments are rather thick but at other places they form a thin veneer less than 30 cm in thickness and in some local areas bare reef rock predominates. Extensive regions of the terrace floor are covered by arborescent "staghorn" Acropora thickets that range in diameter from small patches a few meters wide to large expanses nearly a kilometer across as shown in Figure 27. In shallow water these Acropora thickets grow upward rather uniformly to the low tide water level which gives them a flattened "clipped" look whereas in deeper water the thickets form tall bushy clumps up to several meters in height (Fig. 28).

Eight transects (see Fig. 21 for locations) were run on the lagoon terrace (Biotope IB) at various kinds of habitats (Table 13, Transects 1, 2, 4, 16, 17, 21, 23 and 24). Coral density ranged from .28/m^2 to 17.88/m^2 and percentage of substrate covered by living corals from .10% to 51.66%. Coral growth was more predominant on the terrace which borders the southern barrier reef where it grades into Facies A. Transect 2 was run at this location which had a coral density of 17.88/m^2 and 51.66% of the substrate covered with living corals. Transects 1 and 4 were located in slightly deeper water near Transect 1, but farther lagoonward from the barrier reef border. Here the coral density was considerably less, ranging from 1.75/m^2 to 5.66/m^2 and the percentage of living coral coverage quite variable, ranging from a low of 4.50% to 30.52%. Coral density and percentage of coverage seemed to depend upon the type of substrate present with the highest values found in zones of fairly stable coral-algal-mollusk rubble and lowest values where unstable sand predominated. Transects 16 and 17 were run on the terrace behind Babe Island in water about 1-1.5 meters deep. Sand and various-sized pieces of scattered rubble made up the substrate floor. Many of the corals appeared to have developed from fragments which storm waves had transported lagoonward from the richer coral zone along the barrier reef margin. Coral density at these two transects ranged from .29/m^2 to .46/m^2 and the percentage of substrate covered by living corals from 3.52% to 5.51%. Arborescent Acropora species and small cespitose clumps of Pocillopora damicornis were the most frequently encountered corals. Most clumps of Acropora were less than a half a meter in diameter.

Toward the eastern end of the lagoon, the Acropora thickets become increasingly larger (Figs. 26 and 27) with zones of mixed corals between the patches (Fig. 29). Transect 21 is located on the eastern part of the lagoon in deeper water near the point where the terrace grades into the lagoon floor of Facies C. Coral density here was 1.95/m^2 and the percentage of living coral coverage was 12.22%. Coral diversity was higher here than for any other part of the lagoon terrace (Table 13, Transect 21).

Coral growth diminishes somewhat around the sand islet at the eastern end of Cocos Island. The extensive lagoon terrace at the western end of Cocos Lagoon has for the most part a depauperate coral community consisting of widely scattered clumps of Pocillopora damicornis and occasional small clumps of Acropora. Locally small colonies of Psammocora stellata, Psammocora contigua, Leptastrea purpurea, Porites lutea, and Porites cocosensis are found where rubbly, stable substrates are found.

Coral growth on the lagoon terrace along the northwest barrier reef increases steadily from Cocos Island toward Mamaon Channel. Width of the coral zone along this side of the lagoon is for the most part narrower than that found along the southern barrier reef except for the lagoon terrace bordering inner part of Mamaon Channel. Large but somewhat scattered patches of arborescent Acropora are common on the lagoon terrace along the northern barrier reef, particularly where it grades into Facies A.

At the extreme northern end of the lagoon, local areas lacked the rich development of arborescent Acropora thickets or, where present, they were widely scattered. Here ramose and massive species of Porites, small cespitose clumps of Pocillopora damicornis, and encrusting Montipora species are dominant. Transects 23 and 24 were run in the above type of coral community. Coral density and percentage of substrate coverage were 1.20/m^2 and 3.72% for Transect 23 and .28/m^2 and .10% for Transect 24. Transect 23 was run in a rich coral zone which had developed on a rubbly substrate close to the barrier reef boundary and Transect 24 was run farther lagoonward where less coral growth was present on a more sandy substrate.

Overall diversity for Biotope 1, Facies B was 79 species representing 27 genera. The only facies of this biotope with a higher diversity was the deep-water patch reefs of Facies D.

Facies C

This facies is located in the central part of Cocos Lagoon and consists of that portion deeper than 10 feet. It is roughly triangular in shape similar to the overall configuration of the lagoon. The peripheral boundary of the facies is at most places marked by a short steep slope which grades upward to the lagoon terrace of Facies B. The floor is undulating and is marked by numerous smaller cone-like topographic features which are the result of the burrowing activities of an unidentified worm

(Fig. 30). The sediments in this facies have a plastic consistency which is relatively stable except for the constant turnover caused by the burrowing worms. Coral mounds, knolls, and patch reefs are widely scattered over the floor of this facies and are the most conspicuous physiographic features found in this otherwise rather barren silty and sandy zone. These topographic relief features are zones of rich coral and algal growth which attract many other invertebrates and fishes and for this reason they are treated as a distinct habitat, Facies D, of Biotope I.

Corals in this facies are for the most part restricted to the mounds, knolls, and patch reefs of Facies D and were not abundant enough in any one location to measure quantitatively. Most coral growth consists of small isolated corals which have grown on scattered pieces of coral rubble (Fig. 31). Other corals which seem to thrive fairly well on the sandy substrates are the arborescent Acropora species, the bases which become anchored in the loose substrates giving the colony considerable stability, thus allowing them to develop upward and outward into small patches. These arborescent patches range from small clumps a few centimeters across to large bushy growths several meters across and high.

Although the corals in this region are widely scattered and small in size except for the arborescent Acropora and some ramose Porites species, the diversity was quite high. A thorough search of the floor of this facies revealed 51 species representing 25 genera (Table 12), which is higher than that found in Facies A or E.

Facies D

This facies consists of the patch reefs, mounds, and knolls located on the lagoon floor of Facies C. These topographic relief features differ from the small scattered patches of arborescent Acropora included in Facies C, in that the bases of these do not rest directly upon the sandy substrate. The bases of the patch reefs, mounds, or knolls of Facies D consist of coral and algal rubble which has been derived from the corals of the relief features themselves. This basal accumulation of coral rubble provides a suitable substrate for many other coral species to settle and develop upon in an environment that is otherwise unsuitable because of the presence of fine sand and silt. In this respect they are developmental features which consist of a community of corals capable of producing a structural framework. The lithification of this framework depends upon the dominant kinds of corals present and the degree of consolidation which has occurred by encrusting corals, algae, and other organisms.

Several kinds of relief features are found, the largest of which are the patch reefs which rise up from the lagoon floor to or near the low mean tide level. The largest of the patch reefs are mapped on Figure 21. Additional patch reefs and mounds can be seen as lighter areas in the darker colored lagoon region of Figure 3.

Mounds and knolls, the most common form of relief structure in Cocos Lagoon, rise up from the lagoon floor but their upper surfaces do not reach the mean low tide level. Some are rather low, less than 2 meters high, while others rise up close to the surface and with more upward development could be classed as patch reefs. In general the mounds and knolls are smaller in diameter than the patch reefs, the mounds being structural features where their diameters are greater than their height thus giving them a somewhat low-sloped dome shape. Knolls are structural features in which their diameter is equal to or less than their height. Since the maximum depth of the lagoon is only 45 feet, the size of knolls are considerably smaller than patch reefs and usually smaller than the mounds which may cover extensive areas. In many instances the main structural part of a knoll consists of a single coral colony, usually a massive, columnar, or ramose species of Porites, which upon the base, sides, and upper surface other corals are found growing. Some knolls are mushroom-shaped, while others are rounded or columnar. The under surface of overhanging mushroom-shaped knolls are the habitats of certain Leptoseris, Pavona, Plerogyra, and Porites species which are normally found in much deeper water habitats. Most of the large Porites mounds or knolls of solid massive growth form are dead in the lagoon or have scattered living remnant patches growing here and there on their surface. Mounds and knolls which have developed from ramose or columnar Porites species have a much greater incidence of still being alive or at least mostly alive. Perhaps these large Porites colonies were selectively killed during the time when Acanthaster planci were locally abundant in Cocos Lagoon (Tsuda, 1971). This is difficult to account for, as Acropora species are the preferred food for Acanthaster planci on Guam, and their dominance is much greater than the Porites species in the lagoon. Another possibility is the presence of a black encrusting sponge, of the genus Terpios, which has killed extensive areas of coral growth in Cocos Lagoon and other places around Guam (Bryan, 1974). Figure 32 shows this black sponge encrusting and killing an arborescent branch of Acropora.

Reef patches possess the greatest diversity of corals but the percentage of reef surface coverage is usually not as great because of a reduction in the predominance of large expanses of arborescent Acropora species due to exposure of parts of the upper surface during low spring tides. Six transects (see Fig. 21 for locations) were run in this facies (Table 13, Transects 11-15 and 20). Four Transects (12, 14, 15, and 20) were run on the upper surfaces of patch reefs. Coral density on these upper surfaces ranged from $1.44/m^2$ to $4.28/m^2$ and the percentage of substrate surface covered by living corals ranged from 5.95 to 9.11. Arborescent Acropora species were by far the dominant corals on Transects 12, 14, and 15 whereas on Transect 20 encrusting Montipora and massive Porites were the dominant corals along with numerous colonies of soft corals.

Transects 11 and 13 were run on the upper surface and sides of mounds. Coral density here ranged from $1.34/m^2$ to $25.63/m^2$ and percentage of living corals covering the substrate ranged from 33.43 to 45.18.

Transect 11 was run on a mound which was primarily dominated by large Acropora formosa and a few large Porites andrewsi colonies, which accounts for the low density and high coverage values there (Fig. 33). Transect 13 was run on the surface of a mound which was dominated by numerous small colonies of ramose Porites andrewsi and Porites matthaii which accounts for the high coral density.

In general, coral diversity, density, and percentage of substrate covered on the patch reefs, mounds, and knolls was irregular and unpredictable. In all parts of the lagoon floor topographic relief structures ranged from little to no coral coverage to those which were nearly 100 per cent covered by a single species (Fig. 34). Some mounds consisted of low mounds of mostly dead coral rubble, while a mound next to them might be thriving, with a mixture of branching, massive, columnar, and encrusting corals. Other mounds may have several dominant species or be composed primarily of Porites species with a massive (Fig. 35) or columnar (Fig. 36) growth form. In general, knolls which had developed from corals of massive growth form were the least populated by living corals than any other kind of topographic feature.

Coral diversity was higher in this facies of Biotope I than for any other. The total number of species was 102 representing 35 genera.

Facies E

This facies consists of the nearshore shelf or fringing reef flat platform which borders the landward side of Cocos Lagoon. The major physiographic differences between this facies and the barrier reef flat (Facies A) have been discussed earlier.

Along most of the length of Mamaon Channel the platform is quite narrow; widening somewhat at the mouth (Figs. 3 and 21). Southeastward from the head of Mamaon Channel the fringing reef flat platform becomes progressively wider and encloses both sides of the inner half of Manell Channel (Fig. 21).

The intertidal zone, from the mouth of Mamaon Channel to the point where mangroves dominate the shoreline at Aba Beach, consists of boulder rubble, sand and gravel, mud, and silt. At places the boulder rubble is encrusted with a pink coralline algae. Some small gastropods (Cerithium sp.), hermit crabs, and a few grapsid crabs are found here. The zone is rather barren biologically and shows signs of considerable past disturbance by man throughout the Merizo area. A few patches of mangroves are found at the mouth of the Geus River. Eastward from Jaotan Point the intertidal shoreline is dominated by mangrove swamps (Fig. 7).

At the mouth of the Mamaon Channel the fringing reef flat consists of a flat limestone platform with patches of bioclastic and detrital sediments scattered over the surface. Sediments along the outer part of platform are found mostly in small shallow holes and depressions and become more abundant toward the shores. Toward the head of Mamaon Channel the detrital fraction of the sediments becomes progressively more abundant. This increase of detrital sediments is reflected, in the aerial view of the reef flat platform in Figure 22, by a general darkening of the surface from the mouth of the channel to its head. The village of Merizo borders the platform along the Mamaon Channel and the reef flat has been changed and modified somewhat by dredging and construction of several piers and small boat marinas.

Between the head of Mamaon and Manell Channels the surface of the inner part of the reef flat platform consists primarily of unconsolidated sediments with scattered patches of bare reef rock. In a lagoonward direction the thickness and amount of unconsolidated bioclastic sediment increases. A zone of plastic mud and sand generally borders the mangrove shoreline.

A community of seagrass grows on nearly the entire reef-flat platform where unconsolidated sediments are present. During low spring tides the entire platform is generally exposed, which limits coral growth and development to shallow holes or depressed sections that retain water. Because of the general absence of corals, no coral transects were run on the part of the platform which borders the landward side of Mamaon or Manell Channels. The few corals that were found on the platform were generally restricted to the outer lagoon fringe where water is retained during low tides. Locally though, where large sandy pools or depressed zones occur, corals were quite abundant. Two transects were run in this facies -Transect 18 where coral density was low and Transect 19 where coral density and dominance was greater. At Transect 18 the dominant corals were ramose colonies of _Porites cocosensis_ and _Porites andrewsi_ and small colonies of _Porites lutea_ and _Porites lobata_ with massive growth forms. Coral density was .33/m^2 and the percentage of substrate coverage was only .34%. In contrast, the density and substrate coverage by living corals was 1.16/m^2 and 17.86 per cent, respectively, at Transect 19 which was run at a local depressed region where the water was deeper and coral more abundant.

In general, the coral communities on the muddy platforms of Facies E are rather depauperate, primarily because of exposure during low spring tides and to some degree because of the mud and silt which is brought to the platform by rivers and streams that drain the adjacent volcanic mountain slopes.

Biotope II

This biotope consists of the deep Mamaon and Manell Channels (Fig. 3). It is subdivided into five facies (A-E).

Facies A

This facies consists of the shallow channel margins or shelves located on the upper part of the channel slopes (Facies B) or channel walls (Facies C). The margins of both channels varies greatly from one location to another in regard to coral density, percentage of substrate coverage, species diversity, and physiographic characteristics. Physiographic features are quite variable from place to place. In general the lagoonward sides of the channels have margins with a greater percentage of surface covered by unconsolidated sediments, particularly at locations where strong currents carry water into the channels from the adjacent lagoon terraces and barrier reef platforms. The sediments are principally of bioclastic origin on the lagoon side of the channel and are a mixture of bioclastic and detrital materials on the shoreward side. The amount of the nonbioclastic fraction of the sediments on the channel margins increases toward the river mouths at the heads of the channels. Near the channel mouths the margin is exposed to considerable wave and swell action whereas the water movement and wave agitation is at a minimum at the heads of the channels.

Six transects (see Fig. 21 for locations) were run on the channel margins (Transects 25 and 28-32; Table 13). Coral density and diversity were observed to be the highest at the mouths of the channels but the percentage of substrate covered by living corals increased at the heads of the channels. Higher substrate coverage can be attributed to the presence of large colonies of Porites lutea, Porites (S.) iwayamaensis, Porites (S.) convexa, Porites cocosensis, and Porites andrewsi, some of which attain diameters of several meters or more. In general these species of Porites adjust well to habitats where high rates of sedimentation and turbid water occur. Coral growth was greater at the head of Mamaon Channel, where dominance ranged from 8 to 22 per cent coverage, than at the head of Manell Channel where it was less than one percent (Table 13 and Figure 21).

During floodwater conditions the Geus River plume is more or less restricted to the shoreward side of the Mamaon Channel. A somewhat similar, but not so pronounced effect takes place along the inner part of the Manell Channel in Achang Bay as well. Greater coral growth and development is found on the lagoonward sides of the channels as a result of the greater degree of siltation and presence of turbid water on the shoreward side of the channels.

Coral diversity for this facies was higher than for any other at Cocos Lagoon. A total of 104 species of corals representing 34 genera were observed along the channel margins. Even though these values are high, there was considerable unevenness in coral diversity observed from the channel mouths to their heads where rivers debouch into them. A rather constant feature of the channel margins, particularly as observations are made from the mouth toward the head, is the dominance of

Porites species. These corals form large, massive, hemispherical colonies in the deeper parts of the channel margin where they are not exposed at low tide and large, circular, flat-topped microatolls where their upward growth is limited by the low tide level. Acroporoid species are common at the channel mouths and except for Acropora palifera are nearly absent halfway to the heads of the channels and very rare at the heads themselves. Except for certain deeper water species, Acropora appears to be quite sensitive to turbid waters where high rates of sedimentation occur.

Facies B

This facies consists of the steep channel slopes located between the upper channel margin (Facies A) and the point where they grade into the rather flat channel floors (Facies D). This facies (Figs. 32 and 7), varies considerably in depth depending on the location along the course of the channel. Near the mouth of the channels the slopes extend downward to about 100 foot depth whereas near the heads of the channels the floor is encountered at 10 to 20 feet in depth. A rather constant feature of this facies is the presence of turbid water and high rates of sedimentation. There also appears to be a considerable movement of sediments across this part of the channel, from the lagoon shelves or terraces (Biotope IB) and the barrier reef flat platforms (Biotope IA), to the channel floor. Distinct sediment trails are evident from the channel margins, downward across the slopes to the channel floor. This constant movement of sediments tends to inhibit coral planula settlement except where hard rocky surfaces are exposed. Many of the coral colonies found growing on the slopes, particularly on the lower slopes, become established there by the slumping of coral colonies on the channel margin. These large broken off sections of corals slide downward and because of their large initial size can become established in the unstable sediments found on the lower part of the slopes.

The same generalizations about coral diversity, density, and percentage of substrate covered by living corals can be made for this facies as was stated for Facies A. Six transects (see Fig. 21 for locations) were run in this facies (Table 13, Transects 26 and 33-37). Percentage of substrate covered by living corals ranged from 1.84 to 39.00. Coral diversity (Table 12) was nearly as high in this facies as on the channel margin. This is partly due to the presence of the deep-water community of corals found at the channel mouths. The major differences in coral distribution on the channel slopes, compared to that found on the channel margins, was the dominance of ramose and columnar growth forms of Porites. These growth forms appear to be better adapted for growth in areas of high sedimentation. These species which fragment easily and slide down the channel slopes may account for their dominance there.

Facies C

This facies consists of the channel slopes which form steep rocky outcrops or submarine cliffs (Fig. 37) between the upper channel margin (Facies A) and the channel floor (Facies E). This facies is more commonly encountered along the slopes near the channel mouths but local regions also occur intermediate along the channel lengths. Only one transect was run in this facies (Transect 27) which was located at 40-80 foot depth near the mouth of Mamaon Channel. Coral density and percentage of substrate covered by living corals, are lower than the adjacent values for the channel slope on Transect 26 but the species composition was quite different. In general there is less sediment accumulation on these steep walls and cliffs which allow a greater variety of species which are less tolerant to sedimentation to settle and grow there. Particularly noticeable were the presence of various Pavona species, a few deep-water Acropora species, and small explanate colonies of Porites (S.) iwayamaensis.

Other conspicuous organisms observed here were numerous sponges of various colors and the presence of numerous clusters of Halimeda. Much of the sediment observed on the lagoon floor consists of segments from this algal genus.

Facies D

This facies consists of the cavernous parts of the channel slopes and walls and the overhanging ceilings of submarine cliffs (Fig. 37). No transects were run in these specialized local habitats but since they possess rather distinct communities of corals they were given a "facies" status.

Table 12 lists 24 species representing 17 genera which were observed in this facies. Overall diversity was lower for this facies than for any other, which is not surprising since the level of light intensity is quite low here. Deeper water corals such as Leptoseris sp., Stylocoeniella armata, Pavona minuta, Pachyseris speciosa, Porites (S.) hawaiiensis, Echinophyllia aspera, Mycedium, Plerogyra sinuosa, and Euphyllia glabrescens were the most common corals encountered. Hydrocorals such as Distichopora were also common where there was considerable water movement at the channel mouths.

Other common organisms found were sponges of various colors and growth forms, bryozoans, the sedentary scyphozoan Stephanoscyphus racemosus, and encrusting and larger foraminiferans.

Facies E

This facies consists of the channel floor, which is composed primarily of unconsolidated sediments composed of both bioclastic and nonbioclastic fractions. Depth of the floor ranges between 100 feet or more at the channel mouths to depths of 10 to 20 feet at their heads where rivers empty into them. The floor is relatively flat but locally is very hummocky due to the burrowing activity of an unidentified worm, similar to the mounds shown in Figure 30.

No coral transects were run on the channel floor because of the paucity of corals there. Occasional corals were observed on rare rocky outcrops near the mouths of the channels but most coral growth was found at the base of the channel slopes and walls where corals had accumulated by slumping and sliding down the slopes to the channel floor below. Occasionally a large knob or knoll was encountered where a large section of rock had broken loose from the channel wall. It was upon these larger relief features where the greatest density and diversity of corals were found.

Table 12 lists 32 species of corals representing 18 genera from this facies; many of which are the same as those found in the low-light habitats of Facies D. Porites (S.) iwayamaensis and Porites andrewsi were the most commonly encountered corals, mainly due to their presence by slumping downward from zones above. Porites (S.) horizontalata was the most abundant coral in this facies. This species is probably best adapted to habitats where high rates of sedimentation and turbid water occur.

Near the channel mouth, where currents were stronger, a few gorgonian corals and small hydroid colonies were observed attached to rocky outcrops, knobs, and knolls. Other common organisms observed were various kinds of holothurians (Fig. 38).

SOFT CORAL SURVEY

Soft corals are considered in this report to be the alcyonaceans and zoanthids which resemble corals but lack a solid calcareous skeleton. Their importance in certain major biotope facies of Cocos Lagoon has justified their being discussed in this separate section of the Cocos Lagoon report. The difficulty of identifying soft corals in the field is another reason for analyzing them separately from hard corals. The diversity and distribution of soft coral species in Cocos Lagoon and adjacent channels are shown in Table 14.

Unfortunately, most species found can presently only be identified to genus. Species identification has been delayed by difficulties in obtaining 1) taxonomic references, 2) translations of these references and 3) evaluation of many questionable species identifications in the references. After these problems are solved, some of the numbered species in this report may be combined, if they are seen to be only variations of a single species. If this occurs, the species checklist will be shortened, but most likely only a few variations of Sinularia will be combined.

Where the soft corals (Fig. 39) were sufficiently abundant the point-quarter system, as used with hard corals, was applied to measure total density and percentage of cover (Table 15).

An account of the soft coral populations, facies by facies, begins with the windward barrier reef. Only two species of soft corals were found - Sinularia conferta v. gracilis with long thin finger-like cylindrical branches of uniform diameter, approximately one centimeter (Fig. 40) and an undescribed species of Asterospicularia (Fig. 41). The Sinularia often occurred in large colonies over 15 cm in diameter, while Asterospicularia never exceeded 4 cm across. Asterospicularia was extremely abundant, with 159 point-quarter samples among the 500 meters of transects. Sinularia occurred only seven times in these measurements. The total densities and percentages of cover of the two species combined varied among the five independent transects. This is due to the absence of the large Sinularia in three of the transects and the absence of all soft corals in major parts of two transects. No soft corals occurred at the highest parts of the reef flat, which receive excessive exposure to air at low tides. Asterospicularia occurred on the seaward side of this highest zone, i.e., on the reef margin, and increased in abundance on the zones progressing from the highest zone lagoonward. The small size of Asterospicularia allows it to occur in reef flat areas which have a minimal cover of water at low tide while larger soft coral species inhabit slightly deeper situations. In a transect made closest to the lagoon shelf but still on the windward reef flat, the Asterospicularia colonies were so abundant that their density registered greater than 24/m^2, although they covered only slightly over one per cent of the substrate.

The leeward barrier reef flat had only ten specimens of soft corals within the 200 point quarters examined in 500 m of transects. These soft corals were only of two species, both of which occurred only in the deeper marginal zones of the reef flat which are usually not exposed at lowest tides. These two leeward species were different from those of the windward barrier reef flat and from those of all other facies of the lagoon biotope. They were identical with two of the species found in the Mamaon Channel margin facies. On the leeward reef flat, one large colony of Sarcophyton was found with a diameter of 54 cm (Fig. 42), while nine colonies of a Sinularia species were measured, showing diameters from 10 to 51 cm (Fig. 43). Soft coral densities and percentages of cover were too slight to bother calculating for the leeward barrier reef flat facies. The highest zone of the facies lacked both hard and soft corals while slightly deeper parallel transects on both sides of that zone provided some hard corals but no soft corals.

The facies of the lagoon shelf borders and surrounds the deeper part of the lagoon and occurs at depths less than three meters. Although five 100 meter transects were made here, they reflected little information about the soft corals other than their general absence from the facies. Three of the transects had no soft corals anywhere within five meters of their axial line while the other two showed soft corals and hard corals very infrequently, in only 15 of 40 and 6 of 40 point-quarters. Perhaps colonies of coral are absent from much of this area because of the lack of solid substrate. Most of the sampled locations of the lagoon shelf had bottoms of soft loose sand. Wherever rock surfaces rose above the sand, there seemed to be at least some hard corals or soft corals present. The soft corals were Asterospicularia sp., Sinularia polydactyla (Fig. 44) and Sinularia conferta v. gracilis. Any discussion of the density, percentage of cover and importance value of soft corals in this facies is unfeasible because of their scarcity.

Some Sinularia in station IB (see map, Fig. 39) appeared to have a few of their branch tips bitten off. If they were preyed upon by a fish it could well have been an Arothron species, the large puffer fish. These were seen to be the most abundant fish during tows over several thousand meters of lagoon shelf. They also are reported to feed on the tips of branched hard corals (Cloud, 1959).

The lagoon floor deeper than three meters is a facies which is characterized by a substrate of pure sand with various patches of algae and vascular plants. Soft corals are absent except for a few colonies of Sinularia and Sarcophyton on boulders and mounds close to the leeward lagoon shelf or adjacent to some of the patch reefs. As a rule, soft corals must have a solid piece of substrate for attachment. Many colonies can be found in Cocos Lagoon which seem to be growing on sand but which really are attached to a piece of coral rock buried in the sand. A single very small specimen of Sarcophyton with a deep base like a "taproot" penetrating the sand and lacking a basal attachment to any rock or piece of rubble was found on the lagoon bottom next to a patch reef. This is apparently a very exceptional specimen of a more normally attached species. Perhaps it survived following detachment from an original hard substrate on the patch reef above it.

The patch reefs in Cocos Lagoon have a higher diversity of soft corals than any other facies in the lagoon biotope, but their number of species is still only six. The very common species are Sinularia polydactyla and Asterospicularia sp., while one Alcyonium, two Sarcophyton species, a Zoanthus (Fig. 45) and a second species of Sinularia were each found at only a single ten meter long station among the 500 m of transects. The average density of soft corals on the five patch reefs sampled was 0.73 per m^2 or one soft coral for every 1.37 square meters.

The patch reefs typically had numerous dead skeletons of long-branched staghorn coral (Acropora formosa and A. teres). These branches were a common site of attachment for Asterospicularia colonies, which covered some skeletons or grew pennant-like on just the apical tips of others. Asterospicularia also occurred on smooth rock surfaces and boulders. The common Sinularia species did not often colonize dead Acropora skeletons but formed numerous large colonies on hard substrate and boulders and particularly on spicular rock formations. This spicular rock sometimes takes the form of large solid or fenestrated boulders often over one meter in height and diameter. It is constructed of fused calcareous spicules deposited by soft corals. These spicules are all less than 5 mm in length and 1 mm in diameter, cylindrical in shape and with pointed tips. They appear to be the largest spicules formed in the basal parts of Sinularia colonies. The Sinularia colonies on spicular boulders of the patch reefs seem to be relatively permanent. However, the Asterospicularia growths on dead staghorn coral will probably be broken off by future storm waves and may suffer high mortality because they are not large enough to stablize themselves if they are only attached to broken coral branches on the bottom. The larger colonies of Sinularia may be parted from the massive solid substrate and still maintain themselves without being rolled along the bottom by waves. The total percentage of cover of soft corals of those patch reefs measured was from 0.59 to 4.14, less than that of hard corals, but of some significance.

Soft corals were seen to be most important in the nearshore shelf facies of Cocos Lagoon. This area ranges from about zero to two meters depth at low tide. Much of the substrate is composed of coralline rock and spicular rock, both topped with large colonies of Sinularia polydactyla and Sinularia conferta v. gracilis. These colonies range in color from tan to pinkish to beige and change color when they expand or retract their polyps (Fig. 46). They typically have a low spreading base with upward projections which divide and subdivide to form numerous finger-like apices. Between the areas of rock which bear soft corals are irregular patches of sand. In some parts of the nearshore shelf these rocky substrates with soft corals are absent. Instead, large patches of seagrass (Enhalus) occur.

Transects of soft corals were not done in the seagrass areas. Four transects provided density measurements of one colony per 3 m^2 to one per 0.25 m^2. These averaged 2.72 colonies per square meter. The per cent of cover by soft corals was as high as 18.87 per cent on one transect. The soft coral populations seemed to be old and stable because of the large size of the colonies. The spicular rock formed by these species of Sinularia, as previously described, is very common in this nearshore shelf facies. However, the Asterospicularia which was common along with these Sinularia on patch reefs appeared to be absent in the nearshore shelf. Perhaps it is excluded because of the influence of run-off water from the land.

The northernmost end of the leeward barrier reef flat along Mamaon Channel is submerged deeper than the rest of the flat. Therefore this end of the leeward reef flat should be separated from the description of IA (Leeward) and called facies F of Biotope I (Fig. 39). The density and per cent of cover of soft corals here were not measured but seem to be approximately the same as those for the nearshore shelf. A few specimens of Xeniidae were found only here.

Biotope II includes facies from both Mamaon and Manell Channels. A search of the floor of Mamaon Channel at depths greater than 100 feet showed rubble on which grew ascidians, sponges and algae, especially coralline encrusting algae, but no soft corals.

Soft corals were very rare on the cliffs, caverns, and deeper slopes of Mamaon and Manell Channels, where only Palythoa and a large thin Sarcophyton shaped like a mushroom with a concave upper surface were found. Perhaps low light levels due to turbidity made these deeper facies unsuitable for soft corals.

The shallower parts of the slopes bordering these channels graded into the channel margin facies which was seen to contain a diverse collection of soft coral species. Up to twenty different species were collected here. Only four of these were found in other facies of Biotope I or Biotope II. Although the diversity of soft corals of all biotopes is highest in this facies, the density (one colony for every 2 to 10 m^2) and per cent of cover (0.27 to 0.83%) were much lower than those for soft corals of the nearshore shelf. Mamaon and Manell Channels each had different species of soft coral, e.g., only three species were common to both channel margins. Also soft corals varied between the land side and lagoon side of each channel. Margins of both channels had rich growths of live hard corals forming large heads and buttresses. The soft coral colonies were scattered among these growths.

The large soft corals of Cocos Lagoon have a few interesting associate animals. The large white egg "cowrie" Ovula ovum was seen to feed on the commonest species of Sinularia and Sarcophyton of Cocos Lagoon. Another large gastropod, Rapa rapa was found living completely enclosed in the living bases of Sinularia and Cladiella. Minute spider-like pycnogonids were found on most closely-inspected alcyonaceans.

The soft corals of Cocos Lagoon have been seen to lack the diversity and density of hard corals. But they are important in certain facies such as the patch reefs, windward barrier reef and channel margins. In some parts of the nearshore shelf and barrier reef shelf bordering the channels soft corals appear to be the dominant organisms.

FISH SURVEY AND FISHERY ASPECT*

Introduction

This section provides a list of the tropical marine shore fishes found in the lagoon, considers the distribution of species, and discusses the biotopes in which they are commonly found. It is also our intention to compare the relative diversity of the ichthyofauna inside the lagoon with other transects outside the barrier reefs.

Data included within this section are expected to serve not only as basic research but may also be useful in the future as a baseline study for evaluating the impact of the rapidly urbanizing Merizo municipality. It should be possible to duplicate the study at a later date for the purpose of measuring potential degredation of this valuable resource. For this reason, considerable space has been devoted to methodology.

Materials and Methods

Biotopes

Seven major biotopes (Fig. 47) were recognized as distinct for the ichthyofauna as follows:

I. Outside Reef - The combined lower reef margin and front, the submarine terrace, and the upper seaward slope to the west of the Cocos Lagoon barrier reef were used as one biotope in order to compare the diversity of the fish community (by biotope) inside the lagoon with that outside. Seven transects (described below) were made in this biotope parallel to depth contours (NE to SW). Four were run on the submarine terrace, two on the reef margin/front and one on the seaward slope.

II. Channel Walls - The walls of both Mamaon and Manell Channels vary from sand slopes to steep or overhanging coral developmental features. The latter form excellent cover for fish species. Transects were deliberately concentrated in the coral areas and were oriented parallel to channel margins at varying depths (vertical zig-zag). They included seven in all, five in Mamaon Channel and two in Manell. Transects were run at both the seaward (western) and lagoon (eastern) ends of Mamaon Channel.

III. Lagoon Patch Reefs - Numerous patch reefs of various sizes occur in the Cocos Lagoon at nearly all possible depths. Four separate patch reefs were investigated and seven transects run on them, normally along the longest axis of each reef. Transect lines were woven to include both sides and tops of patch reefs. Duplicate transects were run on three of these reefs. All the reefs rise to within one-half meter of the surface, at mean low tide, and all have live corals, usually dominated by dense thickets of branching species in the genus Acropora. Fishes seek cover

*A revised version of this section has been published by R. S. Jones and J. A. Chase (1975).

primarily among these coral branches.

IV. Barrier Reef Flat - This area is frequently exposed at low spring tides. During such times the fishes that occur here must migrate to deeper waters adjacent to the barrier to seek shelter in tide pools or in holes that connect with the water surface investing the reef framework. Primary cover for fishes includes holes and cracks in the coral framework and rubble tracts along the barrier. Four transects were run on the southeast barrier and three on the west. The transects were oriented perpendicular to the barrier axis and were normally parallel to water flow over the barrier.

V. Seagrass Beds - Two species of seagrasses occur in Cocos Lagoon. They are Halodule uninervis (Forsk) Ascherson and Enhalus acoroides (L.f.) Royle. The Halodule beds are located along a small sand spit northeast of Cocos Island. The Enhalus beds are concentrated more around the channels and fringing reef adjoining the mainland. Four transects were run in the Enhalus beds and three in the Halodule bed. All transects were allowed to meander at random through the grass beds. The seagrasses themselves form the basic cover for fishes living there.

VI. Sand Bottom - The sand bottom biotope includes channel floors, the floor of the lagoon proper, and the lagoon terrace. Three transects were run on the shallow (1 m) lagoon terrace floor, two on the lagoon bottom, and two on the channel bottom. Transect direction was random in each case. These virtually featureless habitats offered no cover for fishes except burrowing forms.

VII. Estuarine and Freshwater - The heavily silted fringing reef/mud flats, concentrated around river and creek mouths along the shore of mainland Guam, are essentially estuarine systems and often characterized by a mangrove community. No attempt was made to investigate this biotope because we chose to concentrate on the primary marine system. The freshwater and estuarine fauna is included in a report prepared by the Guam Division of Fish and Wildlife and appears in Kami et al. (1974).

Transects

Forty-two transects were run as noted above, seven in each biotope. Of these, 35 were run inside the lagoon and seven outside (Fig. 47). Each transect was arbitrarily set at 100 m in length. The transect line was unreeled in the biotope to be sampled. Some attempt was made to lay the transect lines in a random fashion. However, a deliberate bias was also introduced in order to compare the sand bottom, grass flat, and coral dominated biotopes. For example, transect lines in sand areas were set to avoid all grass flat and coral features, while coral transects were set to avoid sand bottoms and grass flats, and so forth.

All fishes seen by SCUBA-equipped observers within 1 m to either side of the transect line and 2 m above it were counted and their total lengths estimated in mm. It usually required about 20 minutes to complete one transect count. This was immediately followed by a 20-minute random count in the vicinity of, but not restricted to, the transect line. We considered this necessary because many of the ubiquitous species in a given transect area failed to appear on the transect. This is due not only to the natural non-random distribution of the fishes but also because many of them are wary of approaching SCUBA divers and move away from the transect line during the count.

It was obvious that many of the smaller species were territorial or adhered to restricted home ranges. These species (largely pomacentrids) tended to remain on the transect while larger species, even those with territories, had a tendency to leave the count zone (at least temporarily) when approached by the observers. This resulted in our transect data being biased in favor of smaller species. The random counts were somewhat helpful, if examined intuitively, in alleviating this bias. These counts frequently added as much as 30% more species to the transect station, thus considerably increasing species richness. However, the random counts only enumerated the species and not individuals, because it is virtually impossible to keep accurate counts of the swarms of fishes that surround a diver (360°) on a tropical reef. Duplicate counts are inevitable unless the observer confines himself to a control transect line or other devices.

Highly cryptic and nocturnal species were not sought out. Therefore, the transect data and random counts are relative instead of absolute indicators of fish community structure within the biotopes. No attempts were made to use chemical fish poisons to collect cryptic species because of the constant use of the lagoon as a recreational area.

Underwater tape recorders were used for recording observations because we found that a great many species were missed when we tried to use writing slates. Too much time is spent looking down at a slate, whereas with a recorder, the observer's eyes do not leave the transect.

The normal variability encountered in such visual counts, made it necessary to combine the seven transects in each of the six biotopes rather than consider the transects separately.

For each biotope, data on the species were treated and analyzed as follows:

Density

The total number of individuals of each species on the seven transects within a biotope were summed and the number per unit area computed in the normal manner:

$$\text{density (d)} = \frac{\text{number of individuals for a species}}{\text{area sampled}}$$

The area sampled in this case is 1400 m^2 (7 transects x 200 m^2)

From these values, relative densities were computed as:

$$\text{relative density (rd)} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100$$

Dominance and Linear Biomass

As is true of many organisms, small fish species often occur in much greater numbers than larger species. Therefore, density figures based on enumeration tend to be heavily biased toward the more numerous small species. It is obvious that it would be more appropriate if the large fishes (e.g., Scarus sordidus) could be weighted in some way to equal a number of individuals of a smaller species (e.g., Chromis caeruleus). We attempted to handle this bias by computing a dominance value similar to that used by plant ecologists. Such values usually consider, for example, the total area covered by a given plant, divided by the total area sampled. Fishes, however, being uncooperative and mobile organisms, are impossible to measure in this way. Instead, we estimated the combined lengths (in mm) of the individuals of each species in a given biotope. This number (total species length) was then related to the total length of the transects in each biotope (7 transects X 100 m X 1000 mm/m = 7 X 10^5 mm). In addition, Porter (1972) used a similar technique for studying reef corals and referred to it as a "linear biomass measurement." We calculated these values as:

$$\text{dominance (dm)} = \frac{\text{sum of individual lengths for a species}}{\text{total length of the transects}}$$

These values were then converted to relative dominance figures:

$$\text{relative dominance (rdm)} = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100$$

And:

$$\text{linear biomass (lbm)} = \frac{\text{sum of individual lengths for a species}}{\text{total length of all species combined}} \times 100$$

Since the data derived in each above case are linear only, and do not consider the actual physical bulk of each animal on a unit area basis, it is obviously not the best method of reducing the bias introduced by the large numbers of smaller species (e.g., a trumpetfish and a parrotfish of equal lengths differ considerably as to weight). It would be better to use some value based on actual fish weight (biomass) rather than length alone. Such estimations are possible from length measurements and predetermined length/weight constants (see below). However, since we did not have necessary conversion constants for all the species observed, we were forced to work with the lengths alone to determine dominance and linear biomass values. The lengths are also obviously subject to observer error.

Importance Value

The above two relative parameters (rd, rdm) were summed to give a single importance value (Cox 1972):

$$\text{importance value (I.V.)} = rd + rdm$$

Importance values are considered useful in comparing community structure between biotopes. The relative density (rd) value by itself is, as noted above, biased by inclusion of large numbers of small species. By adding relative dominance (rdm), some additional weight (numerical) is applied to the larger (longer) species.

Overall Importance Value

It became evident, early in the study, that the community structure of lagoon biotopes II - IV (all reef biotopes) were quite similar, as would be expected a priori, and differed considerably from lagoon biotopes V and VI (grass flats and sand bottoms). The raw data from lagoon biotopes II - IV were pooled and an overall importance value computed for the species occurring in these coral-dominated biotopes. The 21 transects were essentially treated as one large transect crossing all three of the major lagoon reef biotopes (4200 m^2). This analysis was done to ascertain the relative numerical importance of each species for combined coral biotopes.

Fish Biomass

Estimation of fish biomass was the third method of obtaining the relative contribution of each species within each biotope.

Brock (1954), in one of the pioneering works on visual fish transects conducted by SCUBA divers, used a standard fishery conversion of length to weight via constant computed for each species observed. The transformation equation is:

$W = A(L)^3$ Where: W = the weight of the fish

A = the constant for the species

L = the length of the fish

The estimates of weights for all individuals of one species thus obtained, were then summed to obtain the total weight of that species. The weights were converted to kilograms-per-hectare (kg/ha) for each species. The work was hindered somewhat in that length/weight constants were not available for all species. Fortunately, the Guam Division of Fish and Wildlife was able to furnish the constants for some of the more dominant species.

Shannon-Wiener Diversity Index

The sums of individuals for each species in each biotope as well as their linear biomass values were used to compute Shannon-Wiener diversity indices (Pielou, 1966) using the equation:

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where: p_i = the proportion of some measure of the i^{th} species in a population.

Since H' is the diversity for the entire population, which we were unable to measure, it must be approximated by:

$$H'' = -\sum \frac{N_i}{N} \log_e \frac{N_i}{N}$$

where: N = the total number of individuals, or total linear biomass for all species in a sample biotope and N_i = the number of individuals, or linear biomass for the i^{th} species.

Since diversity depends not only upon the number of species but also the equitable distribution of individuals (or lbm.) among the species, the population evenness (Pielou, 1966) was estimated as:

$$E \text{ (evenness)} = \frac{H''}{\log_e S}$$

where: S = the total number of species observed in the biotope. This includes both random and transect species (Table 17) and is a better measure of S than transect species alone. Herein lies another value of the random counts.

Community Comparisons

Importance values were used to compute coefficients of community or similarity (Oosting, 1956) for each biotope compared with every other biotope after the formula:

$$C = \frac{2w}{a + b}$$

Where: w = the sum of the lower of the two I.V.'s for each species shared by the two communities (biotopes)

a = the sum of all I.V.'s for the first community

b = the sum of all I.V.'s for the second community

These data were placed in a matrix of similarity coefficients. Dissimilarity coefficients were then computed as the difference between the calculated coefficients of similarity and the maximum possible value. These values are calculated because the ordination (below) depends on the difference between communities (biotopes) rather than similarities. The maximum value would theoretically be 1.0, however, as Cox (1972) points out, a maximum value of 0.85 more readily approximates a true community upon which replicate samples have been drawn. These dissimilarity coefficients (0.85 - C) are placed in the mirror image of the above matrix and used in a simple community ordination procedure such as that shown by Cox (1972). The result is a two dimensional ordination of fish communities (biotopes) on the basis of x ("the greatest component of community variation") and y ("the greatest component of the remaining community variation") coordinates (Fig. 48). The degree to which the spacing of the communities (biotopes) on the ordination accounts for variations in community composition is estimated by correlation of ordination interval with observed dissimilarity between community paris (Cox, 1972).

Results and Discussion

Table 16 is a list of fish species known from Cocos Lagoon and the outside reef biotope. The table shows distribution of species among biotopes and provides some insight as to the most common species in each. Kami et al. (1968) and Kami (1971) record a total of 598 fish species from Guam. The list of species in Table 16 includes a total of 276 species, 42 of which were observed only outside of the lagoon (biotope I) during this study. Thus, a total of 234 species are now recorded from the lagoon proper. This constitutes about 40 percent of the species known from Guam. Use of ichthyocides during surveys might well have added 50 or more species to the list. However, we chose to rely on visual counts to determine the most important of the ubiquitous fishes without regard to cryptic species. The latter, we suspect, comprises a small part of the total ichthyofauna. Of the 234 species recorded from the lagoon, 189 were actually observed on the transects and random counts, while another 45 were reported from other sources (Table 16).

Table 17 is a summary of observations made in this study. The combined area of the 42 transects was equal to 8400 m^2. Transect areas for each biotope amounted to 1400 m^2. A total of 10,032 individual fishes representing 181 species were counted on the transects.

On the basis of individuals and total species observed (Table 17), it is apparent that biotope I (outside) is "richer" than any of the lagoon biotopes. Lagoon biotope II follows in a close second and is itself approached by biotope IV only by virtue of the fact that IV has more individuals, although considerably fewer species. It is clear that while the first four (reef) biotopes are not widely separated in terms of individuals, biotopes I and II differ considerably from III and IV in number of species. Biotope V, although lower than the other biotopes in numbers of individuals, is still well represented. Biotope VI remains well below the range for other biotopes.

The picture changes somewhat when the biotopes are viewed in terms of biomass and the Shannon-Wiener diversity index. Biotope II supports the greatest biomass. Biotope III is in a distant second place with about half the value of II and biotope I falls to third place. Biotopes III and IV showed the same number of transect species and IV had more individuals than III, yet III had a biomass value of more than triple that of biotope IV. This suggests that larger species make a stronger contribution to biotopes II and III than to the other biotopes. The biomass value of biotope V represents a large number of the juveniles of larger species which apparently use the grass flats as nursery grounds. The reader should bear in mind the fact that conversion constants were not available for all species. Therefore the biomass figures in Table 17 are only for the more common species; in each case the number should be higher.

The Shannon-Wiener diversity index (based on individuals, N) shows the highest diversity value for biotope II, closely followed by I (Table 17). The fact that biotope I has a greater number of individuals (N = 2397) and total number of species (S = 150) than biotope II (N = 2044, S = 138) is offset by the fact that the calculations for the diversity index consider only the number of transect species and does not include random species (Ts = 94 for biotope I and 104 for biotope II). Moreover, the Shannon-Wiener function describes the degree of uncertainty in predicting the species of an individual picked at random from the community. The uncertainty, and therefore the value of the index, increases not only as the number of species increases but also as the individuals are distributed more evenly among the species present (Table 17). As expected from the lower numbers of species and lower equitability (evenness), biotopes III and IV show considerably lower indices than I and II. Biotope IV has a slightly higher diversity index than III, which indicates that although biotopes III and IV have the same number of species (Ts = 67), the individuals are more equitably distributed among the species in IV than those in III (Table 17).

The linear biomass values for each species in each biotope were also used to calculate the Shannon-Wiener function. These data are found in Table 17 and follow the same general pattern as the indices based on individuals and number of species, with the primary exceptions being the higher overall diversity values and the reversal of positions of biotopes III and IV. In the latter case there is an increase in the evenness in biotope III over biotope IV. Moreover, as noted above with biomass, there is a greater preponderance of large species in biotope III than IV. Since H" based on linear biomass takes into consideration the relative size of the species and the distribution of size among them, biotope III is the more diverse. The percent differences are not great in the latter case and may not be significant.

Figure 48 is a plot of community ordination based on the dissimilarity coefficients. The relationships of the communities of each biotope and the validity of these relationships are obvious from the figure and associated correlation coefficient. Communities of biotopes I-IV form a rather tight grouping when compared to V and VI, which are in turn widely separated from each other. It is apparent that the I-IV grouping is based on the one principal unifying factor that all four biotopes have in common, they are coral reef structures. Biotopes V and VI obviously are structurally different from the above. The separation between V and VI is no doubt based on the more adequate cover provided by the grass beds for the fishes themselves as well as the organisms the fishes feed upon. As pointed out above, the grass flats have a preponderance of juvenile fishes in temporary residence while awaiting maturity. The sand bottom fishes are either transients or burrowing forms. It comes as no surprise that the greater diversity of microhabitats available to reef dwelling species results in a much greater biological diversity and species richness.

Further inspection of Figure 48 reveals that the greatest similarity is between lagoon biotopes II and III. Moreover, biotopes I and II, and III and IV, have a fairly high degree of similarity or community concordance. This is of interest because it may indicate that the channel biotope (II) bridges, in part, the gap between the lagoon communities and those outside the barrier reef.

Table 18 compares for combined transects of biotopes II-IV, the rank order of the 20 species with the highest index values for each of the four indicated techniques used in estimating species value. For example, the rank order of the top 20 species is shown for number of individuals (N), for overall importance values (O.I.V.), for linear biomass (lbm.) and for actual biomass (kg/ha). The table not only compares the four methods but also shows the relative importance of each species in the three lagoon reef biotopes based on each method.

It is evident from Table 18 that only small differences exist between the rank orders of species listed by N, O.I.V. and lbm. Spearman's rank correlation coefficient indicated that the ranks of these three methods are highly correlated with each other (N vs O.I.V., $r_s = 0.91$; N vs lbm., $r_s = 0.81$; O.I.V. vs lbm., $r_s = 0.90$; in all cases $p < .0005$). Therefore, in this study and for these biotopes and fishes, any one of the three methods would have given similar results. There is some evidence to indicate that linear biomass provided more weighting to larger fishes (e.g. the advancement of Scarus sordidus from eighth and fifth places for N and O.I.V. to second for lbm.) to better equate them to the more numerous smaller species than did N and O.I.V. Biomass, on the other hand, provides an obvious across-the-board difference in rank order of the top 20 species. Chromis caeruleus which ranked number one in the first three techniques was last in kg/ha. Moreover, several species occur in the top 20, based on biomass, that did not rank high enough in the other techniques to make the lists. Likewise, several species dominant in the first three lists are absent from the biomass list. Spearman's rank order correlation indicates little or no correlation between the rank of the biomass technique and the other three (N vs kg/ha, $r_s = 0.03$; O.I.V. vs kg/ha, $r_s = 0.20$; lbm. vs kg/ha, $r_s = 0.35$; and the probability values are $p > .10$, $p > .10$, and $p > .01$, respectively). Of the above three, lbm. most closely approximates biomass.

We are left with the usual, perhaps rhetorical, question of whether a large number of individuals of small species are more "important" to a community than fewer individuals of larger species. They are no doubt both equally important to the community structure but the question plays havoc with sampling techniques.

The first four species in the biomass list account for more than 50% of the total weight of the top 20 species (Table 18).

Conclusions

Although the channel-wall biotope (II) of Cocos Lagoon proved to be more diverse than the biotope outside the barrier (biotopeI) in terms of transect species, diversity, and biomass, it seems that the lagoon as a whole is not supporting an exceptionally rich ichthyofauna. Even with the use of ichthyocides, we doubt that the total number of species in the lagoon would amount to much more than half of the nearly 600 species known from Guam to date. Moreover, if random species are also considered, then biotope I would exceed biotope II in species richness (150 to 138). We account for the higher diversity and biomass in biotope II by the fact that the steep lagoon slopes with their dense, and at times cavernous or overhanging, coral structures are a concentrating feature not duplicated in the outside reef biotope investigated.

Were it not for the reef development within the lagoon, as well as the rubble tracts and seagrass beds, the lagoon would be considerably more depauperate. Comparison of biotope VI (sand bottoms) with the other biotopes makes this point obvious. Unfortunately, the sand-dominated biotope makes up considerably more of the total lagoon than those areas (biotopes II-V) that provide more adequate cover and possibly a food supply for the fishes.

Qualitative observations as well as many of our transect counts indicated that large numbers of juvenile reef fish species occurred in the lagoon. This was true both in areas with reef cover and in the seagrass beds. These observations lead us to believe that the lagoon's enclosed nature, coupled with the natural cover available, makes Cocos Lagoon an invaluable nursery for many of the species. For example, large numbers of juvenile rabbitfishes, goatfishes, and snappers were observed in the *Halodule* beds and equally large numbers of juvenile parrotfishes were observed in the *Enhalus* beds. On one occasion, we saw enormous (too numerous to count) schools of juvenile surgeonfishes, *Ctenochaetus striatus*, swarming among the coral colonies of the channel walls (biotope II). All these species form important components of Guam's sport and commercial fishery.

The lagoon as a whole and the areas of natural cover within the lagoon do, therefore, make a significant contribution to the local fish fauna, both adults and juveniles. Physical disruption to the seagrass beds or the coral reefs and rubble tracts in the lagoon could seriously affect the fish populations of the lagoon as well as the rate of recruitment of subadults to nearby reef areas outside the lagoon.

ALGAE AND SEAGRASSES

Introduction

This section provides a preliminary outlook on the distribution of marine plants in the conspicuous biotopes and facies mentioned earlier in the report.

Methodology

Sampling was carried out on 24 transects (50-100 m long) in the biotopes and facies mentioned previously. For Biotope II, facies B, C, and D were grouped since the difference in flora was not significantly different. See Fig. 49 for location of transects.

Biotope IA. Barrier reef flat. (Transects 1, 2, 3, 17).
B. Shallow lagoon floor. (Transects 10 and 15).
C. Lagoon floor. (Transects 19, 21, 22, and 23).
D. Patch reefs. (Transects 11, 12, 13, 14 and 18).
E. Nearshore shelf. (Transects 5, 6, 8 and 9).
IIA. Channel margins and shelves. (Transects 4 and 7).
B-D. Channel slopes, walls, and caverns. (Transects 16 and 24).
E. Channel floor. (Transect 20).

Except for the lagoon floor, a modified point method (Tsuda, 1972b) was used throughout. This technique incorporates quadrats (25 x 25 cm) which are thrown at random within 5 m of either side of the transect line. The number of tosses varied from 2 to 30 within each 20 m^2 area. For those areas where few algae occurred, the number of tosses were fewer but sufficient to sample at least 80 percent of the algal species present.

The quadrat frame was divided into a grid of 25 squares, each 5 x 5 cm, providing 16 interior "points" where the grid line intersected. Each species was recorded at "points" at which it occurred. From these data, values for relative abundance and frequency were calculated. The relative abundance values provided a good index of the dominant algae while frequency was indicative of the distribution of the algae, i.e., widely distributed or patchy.

The lagoon floor which has less than one percent algal cover had to be sampled in a different manner because the majority of sites on which the quadrat landed, when tossed, were mainly sand. Thus, a modified version of the point quarter method was employed whereby the area around a point on the transect line was divided into equal quadrants. The algae closest to the point in each quadrant was identified and recorded.

Thus, four algae were recorded from each point (usually 10 m apart) on the transect line. Although the distance from the point to the alga was measured in each case, this data is not used in this report.

In addition, the percent of algal cover in relationship to the other substrata (live coral, dead coral, and sand) was calculated by considering all points on the gridded quadrat. A detailed search for other algae in the vicinity of each transect was made to provide a more meaningful checklist.

Results and Discussion

The marine plants found in each of the biotopes and facies are tabulated in Table 19. The highest species diversity was found in the barrier reef (Biotope IA) and patch reefs (Biotope ID) which had 61 and 64 species, respectively. The least number of species were found on the lagoon floor (Biotope IC) and the channel bottom (Biotope IIE) with 18 and 13 species, respectively. The species listing on the channel bottom may be increased with more transects.

The relative abundance and frequency of those marine plants comprising 80 percent (± 5 percent) in each area are tabulated in Table 20. This table provides a more meaningful method of assessing the dominant algae in each biotope and facies. Since past observations on Guam's reefs indicate a different algal composition on the windward and the leeward barrier reefs, the barrier reefs were analyzed separately.

Biotope IA - Polysiphonia sp. (R.A.=19%, F=18%) and Dictyota bartayresii (R.A.=18%, F=44%) were the two most abundant algae on the windward barrier reef. The higher frequency value of D. bartayresii indicates that this species is more widely distributed than P. sp. On the other hand, Caulerpa racemosa (R.A.=27%, F=48%) and Padina tenuis (R.A.=18%, F=48%) were the dominant algae on the leeward barrier reef. Both species had identical high frequencies which implies a scattered distribution on the reef.

Biotope IB - The most dominant algae on the lagoon slope were likewise Polysiphonia sp. (R.A.=10%, F=6%) and Dictyota bartayresii (R.A.=18%, F=12%), the same two species predominant on the windward barrier reef.

Biotope IC - The dominant algae on the lagoon bottom were those species which possessed specialized holdfasts making them capable of inhabiting the sandy substratum. Halimeda macroloba (R.A.=41%, F=32%) and Avrainvillea obscura (R.A.=24%, F=37%) both possess large holdfasts. Those species with creeping rhizome, i.e., Halophila minor and Caulerpa sertularioides were also present.

Biotope ID - Dictyota bartayresii (R.A.=34%, F=22%) and the filamentous brown algae Feldmannia indica (R.A.=17%, F=15%) were dominant on the patch reefs. Feldmannia indica is an important dietary item for juvenile siganids (Tsuda and Bryan, 1973) and for adult acanthurids (Jones, 1958).

Biotope IE - By far, the most dominant marine plant on the murky nearshore shelf was the seagrass Enhalus acoroides (R.A.=28%, F=41%) which was widely distributed in areas of heavy freshwater runoff. Two other species, Dictyota bartayresii (R.A.=15%, F=20%) and Padina tenuis (R.A.=20%, F=21%) were also abundant in this facies.

Biotope IIA - The murky channel margin and shelf also had an abundance of Enhalus acoroides (R.A.=24%, F=29%) and Padina tenuis (R.A.=20%, F=21%). This was not surprising since the channel margin is in essence an extension of the nearshore shelf where freshwater runoff is the dominant factor influencing flora composition.

Biotope IIB-D - These three facies (channel slope, channel wall, and caverns) are grouped together here since the algae seem quite similar in these areas. Halimeda incrassata (R.A.=14%, F=32%) and Tolypiocladia glomerulata (R.A.=12%, F=23%) were the dominant algae here. Both species are known to inhabit deeper waters.

Biotope IIE - The channel bottom consisted of coral rubble which made it different from the sandy lagoon bottom. Thus, none of the sand-dwelling algae was found here. Instead, the dominant algae were the coralline types, Peyssonelia sp. (R.A.=19%, F=71%) and Porolithon onkodes (R.A.=19%, F=57%), which encrusts coral rubble.

The marine flora of this atoll-like situation is rather rich and diverse (91 species) in those areas with solid substratum. They seem to provide ample food for herbivorous fishes and shelter for smaller fishes and invertebrates. However, a vast area of the lagoon itself consists of barren sandy areas which are depauperate of much marine plants. It may be that further artificial reefs should be located in the lagoon to entice a larger fish population.

OTHER MACROINVERTEBRATES

Table 21 lists the macroinvertebrates other than corals which were observed or collected in the various biotopes and facies of the Cocos area. Emphasis was placed on the mollusks and echinoderms.

ENDANGERED SPECIES

The most conspicuous marine organism in Cocos Lagoon which may be termed endangered is the one adult sea cow, Dugong dugong Mueller, which was discovered by M. Gawel, D. Hotaling and W. Tobias in the center of the lagoon on February 16, 1974. This seven to eight foot dugong has been seen surfacing for air several times since then by local boat operators and fishermen. It is a harmless herbivore probably feeding on the abundant seagrasses and algae of the lagoon. This may be the only dugong in Guam waters and may be derived from the populations in Palau or other islands where it occurs to the south and west of Guam. Over most of its range and especially in Guam, it is very rare and endangered. It must feed in shallow waters and surface for air. Therefore, it is very easy prey for man. Such a highly visible, large and unusual animal is an exciting sight for visitors such as the hundreds of tourists motoring to Cocos Island every day as well as for local boat passengers. It appears that this salt water animal will remain in Cocos Lagoon if it is not harrassed or injured by people. The species may have existed in Guam in the past and given rise to the legend of a girl that became half-fish and had to live in the sea.

The other rare marine organism is the hawksbill turtle Eretmochelys imbricata which was seen once during the study.

According to Mr. Nick Drahos of the Division of Fish and Wildlife, the white tern Gygis alba candida (Gmelin) can be considered as endangered. Cocos Island is a major breeding ground for this species during January through June. Of a total population of 80 birds estimated for Guam, about 20 to 40 birds nest on Cocos Island. Cocos, therefore, is a vital habitat for this species. In addition to the white tern, the Micronesian starling Aplonis opacus guami Momiyama is considered threatened since this species is rapidly disappearing from southern Guam. Cocos has a very small population remaining but this population may be threatened if more development occurs on the island.

It has come to our attention that numerous small coconut crabs (Birgus latro) are being harvested on Cocos Island. This harvesting should be prevented and Cocos designated a wildlife sanctuary for these crabs as well as the birds.

The blue-tailed skink Emoia cyanura has been collected only on Cocos Island. This species differs only slightly from the more common blue-tailed skink Emoia caruleocauda found on mainland Guam. Further collections may show that the Cocos species may occur on mainland Guam (M. V. Falanruw, personal communication).

Thus far, no rare or endangered species of vascular plants have been recorded from Cocos Island.

CULTURAL AREA

Cocos Lagoon is one of Guam's major centers of water-related recreational activities and small boat operations. At the present time it receives considerable traffic by tourists who are transported daily to Cocos Island and to various parts of the lagoon to view underwater corals, fishes, and other marine life from glass bottom boats. The lagoon is also popular region for both island residents and tourists for swimming, snorkeling, skin and SCUBA diving, sailing, and water skiing. Considerable boat traffic arises from the use of the deep Mamaon Channel as a means to gain access to the Philippine Sea for deep sea fishing or to the scenic bays situated along the southwest coast of Guam. The lagoon is also an important fisheries resource used by line, net, and spearfishermen. The Government of Guam also licenses a number of fish traps in the lagoon.

SENSITIVITY OF ENVIRONMENT TO ACTIVITIES OF MAN

The lagoon as a whole, and the areas of natural cover within the lagoon make a significant contribution to the local fish fauna, both adults and juveniles. Physical disruption to the seagrass beds or the coral reefs and rubble tracts in the lagoon could effect, seriously, the fish population of the lagoon as well as the rate of recruitment of subadults to nearby reef areas outside the lagoon. Of particular concern is the proliferation of construction activities for piers, marinas and channels along the Merizo municipality's waterfront. This includes the nearshore fringing reef flat and adjacent channel walls. Although there is room for some such projects and many are desirable for making the resource accessible, a master plan is needed. This would provide reasonable limits and possibly avoid the irreparable damage to the northern half of Mamaon Channel that may result if development is not controlled. Much of the habitat, which this study shows to be one of the richest in the entire lagoon, could well be destroyed.

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Table 1. Discharge records for the Geus River. Table from the Geologic Survey Water Supply Paper 1937 (1971).

Geus River near Merizo

Location.--Lat 13°16'15" N., long 144°40'40" E., on left bank 0.7 mile northeast of Merizo, 2.2 miles southeast of Umatac, and 4.7 miles west of Inarajan.

Drainage area.--0.95 sq. mi.

Records available.--April 1953 to September 1965.

Gage.--Water-stage recorder and broad crested weir. Altitude of gage is 60 ft (from topographic map).

Average discharge.--12 years, 3.36 cfs (2,430 acre-ft per year).

Extremes.--Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (350 cfs), water years 1960-65

Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height	Date	Time	Dis-charge	Gage height
Aug. 20, 1960	0100	427	2.81	Aug. 31, 1962	0130	372	2.72	Sept.28, 1963	0330	498	2.91
Sept.19, 1960	0700	*514	2.93	Sept.30, 1962	2300	*1,800	3.80	Oct. 4, 1963	0230	832	3.26
								Oct. 4, 1963	0230	832	3.26
Oct. 19, 1960	1930	*2,940	4.16	Nov. 11, 1962	a2400	1,310	b3.58	Oct. 11, 1963	1800	*1,040	3.41
Jan. 14, 1961	1000	469	2.87	Feb. 4, 1963	0900	772	3.21	Dec. 4, 1963	1030	992	3.38
Sept. 2, 1961	0730	642	3.06	Feb. 7, 1963	2400	506	3.92	May 12, 1964	0830	498	2.91
Sept.18, 1961	1700	2,460	4.00	Apr. 29, 1963	0400	1,140	3.48	May 19, 1964	2330	498	2.91
				May 29, 1963	0630	1,080	3.44	July 30, 1964	1200	514	2.93
Oct. 7, 1961	0700	390	2.75	June 1, 1963	0100	661	3.11	Sept. 5, 1964	2030	350	2.68
Dec. 14, 1961	0630	716	3.16	June 8, 1963	1730	530	2.95				
July 25, 1962	2400	570	3.00	Sept. 9, 1963	1330	*2,050	3.90	Jan. 21, 1965	2400	*408	2.78

a About. b From floodmarks.

Annual minimum discharge, water years 1960-65

Water year	Date	Discharge	Water year	Date	Discharge
1960	May 4, 5, 1960	a 0	1963	Apr. 20, 1963	0.28
1961	May 19, 1961	.20	1964	Mar. 25, 1964	.14
1962	Apr.14, May 14, 1962	.12	1965	May 26, 1965	.06

a Part of each day.

1953-65: Maximum discharge, 2.940 cfs Oct. 19, 1960 (gage height, 4.16 ft), from rating curve extended above 66 cfs on basis of slope-area measurements at gage heights 4.00 and 4.16 ft; no flow for part of each day July 17, 1953, May 4, 5, 1960.

Remarks.--Records good. Water is diverted half a mile upstream for domestic use and at station for irrigation.

Revisions (fiscal years).--Revised figures of peak discharge for the fiscal years 1954 and 1959, superseding those published in WSP 1751), are given as follows:

Revised peak discharge.--1953-54: Aug. 11 (1400) 265 cfs. 1958-59: July 16 (0730) 274 cfs.

Table 2. Discharge rates from low-flow partial-record stations at the Geus River. Data taken from Geological Water Supply Paper 1937 (1971).

Station Number	Station Name	Location	Drainage area (sq. mi.)	Period of record	Measurements Date	Measurements Discharge (cfs)
16-8200	Geus River above Siligin Spring tributary, near Merizo (formerly published as "above diversion").	Lat 13°16'45" N., long 144°40'55" E., upstream from pipeline diversion to village of Merizo, 2.0 miles northeast of Merizo School	.50	1960-65	3- 9-61	.22
					4-20-61	.19
					6-14-61	.20
					3-15-62	.16
					4-25-62	.13
					5-15-62	.10
					3-27-63	.22
					4-23-63	.18
					3-31-64	.13
					3-24-65	.12
					4-29-65	.08
					6- 8-65	.12
16-8207	Geus River below Siligin Spring tributary, near Merizo.	Lat 13°16'41" N., long 144°40'55" E., 1.6 miles northeast of Merizo School and 2.0 miles southeast of Umatac School.	.60	1962-65	3-15-62	.39
					5-15-62	.32
					4-23-63	.43
					3-31-64	.40
					3-24-65	.54
					4-29-65	.30
					6- 8-65	.28

Table 3. Composition of lagoon sediments, in percent. Table from Emery (1962).

	Foraminifera	Shells	Fine sand and silt	Halimeda debris	Madreporarian corals	Calcareous red algae
Guam (Cocos Lagoon):						
Simple average of all samples------	2	16	11	15	40	16
Samples weighted by areas of depth zones-------------	3	15	8	11	45	18
Corrected for areas of coral seen from boat--------------	2	11	5	8	60	14

Table 4. Chemical composition of sediments from Cocos Island beach, Achang Reef Flat, Cocos Lagoon, and Mamaon Channel. Table modified from Emery (1962).

	Beach Cocos Island	Reef Flats Achang Bay		Reef Flats Off Merizo		Lagoon Cocos				Channels Mamaon
Sample-------	201	635	602	607	611	503	407	464	556	141
Depth (feet)-	0	2	2	115	315	3	6	36	45	21
Dominant constituent---	F	C	S	C,A	F,fs	C	Sh	H	fs,S	S
SiO_2--------	0.14	0.47	18.66	0.81	5.31	0.29	0.24	8.80	1.15	13.13
$(Al,Fe)_2O_3$--	.13	.52	14.31	.75	4.58	.19	.13	2.89	.91	9.98
MgO --------	2.81	2.17	2.51	2.41	3.65	1.57	2.48	2.37	2.06	2.30
CaO --------	51.16	51.05	30.41	50.61	44.50	51.76	51.21	47.50	50.07	36.14
SO_3 --------	.46	.48	.32	.49	.34	.48	.49	.48	.55	.30
P_2O_5 -------	.10	.12	.15	.12	.11	.11	.14	.11	.12	.09
Ignition loss-	45.10	44.19	31.37	44.20	40.81	44.66	44.77	42.63	44.04	35.73
Nitrogen -----	.010	.015	.100	.015	.015	.010	.018	.068	.036	.074
$CaCO_2$ --------	91.3	91.2	-----	90.5	------	90.6	91.5	------	89.5	------
$MgCO_3$ --------	5.9	4.6	-----	5.1	------	3.3	5.2	------	4.3	------

C, coral; F, Foraminifera; Sh, shells; S, silt; H, Halimeda; fs, fine sand; A, red algae; L, limestone.

Table 5. Summary of the current, wind, water temperature, and Secchi disk data from Station C-1. See Figure 19 for the location of the station in relation to the whole of Cocos Lagoon.

	Time	Magnetic Bearing	Velocity in knots/hr.	Water Temp. in °C	Wind Direction	Wind Velocity in knots	Secchi Disk Reading in Ft.	Tide Condition
STATION A								
Drift Cross Cast #1	1007	283°	.211	--	102°	2-3,gusts 5-2	--	EBB
Dye Release #1	1007	283°	.164	--	102°	2-3,gusts 5-7	--	EBB
Drift Cross Cast #2	1216	288°	.185	--	90°	2-3,no gusts	--	EBB
Dye Release #2	1216	288°	.135	--	90°	2-3,gusts 5-6	--	EBB
Drift Cross Cast #3	1354	283°	.135	--	90°	2-3,gusts 5-6	--	Flood
Dye Release #3	1354	283°	.114	--	90°	2-3,gusts 5-6	--	Flood
Drift Cross Cast #4	1601	282°	.099	27.8	90°	2-3,gusts 5-6	--	Flood
Dye Release #4	1601	282°	.087	27.8	90°	2-3,gusts 5-6	--	Flood
Drift Cross Cast #5	1800	285°	.114	27.8	90°	2-3,gusts 5-6	--	Flood
Dye Release #5	1800	285°	.106	27.8	90°	2-3,gusts 5-6	--	Flood
Drift Cross Cast #6	2010	295°	.211	--	90°	1-2,gusts 3-4	--	EBB
Dye Release #6	(No dye release)		--	--	--	--	--	--
Drift Cross Cast #7	0625	296°	.135	26.3	--	--	--	Flood
Dye Release #7	0625	296°	.135	26.3	--	--	--	Flood
STATION B								
Drift Cross Cast #1								
1 meter	1004	295°	.411	--	102°	2-3,gusts 5-7	40	EBB
5 meter	1004	300°	.352	--	102°	2-3,gusts 5-7	40	EBB
10 meter	1004	300°	.380	--	102°	2-3,gusts 5-7	40	EBB
Drift Cross Cast #2								
1 meter	1216	300°	.617	--	90°	2-3,no gusts	2.5	EBB
5 meter	1216	300°	.548	--	90°	2-3,no gusts	2.5	EBB
10 meter	1216	300°	.352	--	90°	2-3,no gusts	2.5	EBB
Drift Cross Cast #3								
1 meter	1355	300°	.411	--	90°	2-3,gusts 5-6	20	Flood
5 meter	1355	300°	.411	--	90°	2-3,gusts 5-6	20	Flood
10 meter	1355	300°	.411	--	90°	2-3,gusts 5-6	20	Flood
Drift Cross Cast #4								
1 meter	1559	300°	.380	--	90°	2-3,gusts 5-6	30	Flood
5 meter	1559	300°	.449	--	90°	2-3,gusts 5-6	30	Flood
10 meter	1559	300°	.411	--	90°	2-3,gusts 5-6	30	Flood
Drift Cross Cast #5								
1 meter	1756	302°	.449	--	90°	2-3,gusts 5-6	--	Flood
5 meter	1756	302°	.380	--	90°	2-3,gusts 5-6	--	Flood
10 meter	1756	302°	.411	--	90°	2-3,gusts 5-6	--	Flood
Drift Cross Cast #6								
1 meter	1958	296°	.493	--	90°	1-2,gusts 3-4	--	EBB
5 meter	1958	296°	.617	--	90°	1-2,gusts 3-4	--	EBB
10 meter	1958	296°	.548	--	90°	1-2,gusts 3-4	--	EBB

Table 5, (continued)

	Time	Magnetic Bearing	Velocity in knots/hr.	Water Temp. in °C	Wind Direction	Wind Velocity in knots	Secchi Disk Reading in Ft.	Tide Condition
STATION B (Continued)								
Drift Cross Cast #7								
1 meter	0636	300°	.617	--	--	--	--	Flood
5 meter	0636	300°	.617	--	--	--	--	Flood
10 meter	0636	300°	.617	--	--	--	--	Flood

Table 6. Summary of current data from Station C-2. See Figure 19 for the location of the station in relation to the whole of Cocos Lagoon.

Date	Location	Time	Magnetic Bearing	Speed in Knots	Wind Direction	Wind Speed Kts.	Tide
Jan. 13, 1973	Fig. 10-a.	1440	270	0.18	290	4-5	near turn, flood/ebb
Jan. 14, 1973	"	1017	285	0.25	125	8-10	flood
"	"	1152	285	0.23	"	"	flood
"	"	1600	297	0.38	"	"	ebb
"	Fig. 10-b.	1200	281	0.36	115	10-12	flood
"	"	1210	332	0.23	"	"	"
"	"	1215	292	0.42	"	"	"
"	"	1218	340	0.25	"	"	"
"	"	1221	293	0.23	"	"	"
"	"	1225	108-288 oscillatory	--	"	"	"
"	"	1229	"	--	"	"	"
Jan. 19, 1973	Fig. 10-a.	2100	292	0.27	100	4-5	ebb
"	"	2200	289	0.26	"	"	"
"	"	2300	230	0.27	"	"	"
Jan. 20, 1973	"	0100	No current, area dry, low tide (-0.6 feet)				"
"	"	0200	"	"	"	"	"
"	River Channel	0230	260	0.30	100	4-5	"
"	Fig. 10-a.	0800	0	0	110	5-6	flood
"	"	1000	284	0.07	"	"	"

Table 7. Summary of current data from Station C-3. See Figure 19 for the location of the station.

Station	Time	Magnetic Bearing	Speed meters/sec	Wind Direction	Tide
December 1, 1973					
1	1140	316°	0.02	110°-120°	flood
2	1148	284°	0.06	"	"
3	1155	258°	0.10	"	"
4	1200	255°	0.44	"	"
5	1205	218°	0.06	"	"
1	1340	288°	0.05	"	ebb
2	1345	294°	0.08	"	"
3	1350	282°	0.09	"	"
4	1355	252°	0.07	"	"
5	1400	178°	0.04	"	"
1	1545	292°	0.05	"	"
2	1550	308°	0.08	"	"
3	1555	297°	0.10	"	"
4	1600	286°	0.11	"	"
5	1540	290°	0.07	"	"
1	1805	320°	0.04	"	flood
2	1800	010°	0.04	"	"
3	1755	342°	0.06	"	"
4	1750	358°	0.05	"	"
5	1740	310°	0.08	"	"

Table 7. (continued)

Station	Time	Magnetic Bearing	Speed meters/sec	Wind Direction	Tide
December 1, 1973, continued					
1	2110	300°	0.05	110°-120°	flood
2	2115	300°	0.04	"	"
3	2120	316°	0.08	"	"
4	2125	306°	0.08	"	"
5	2130	300°	0.08	"	"
1	2400	273°	0.02	"	ebb
2	2405	302°	0.08	"	"
3	2410	290°	0.06	"	"
4	2415	303°	0.05	"	"
5	2420	274°	0.12	"	"
December 2, 1973					
1	0245	340°	0.01	"	"
2	0250	255°	0.05	"	"
3	0255	315°	0.04	"	"
4	0258	280°	0.03	"	"
5	0300	270°	0.05	"	"
1	0710	oscil.	-	"	flood
2	0712	280°	0.03	"	"
3	0715	201° (oscil.)	0.04	"	"
4	0720	183°	0.02	"	"
5	0725	162°	0.02	"	"

Table 7. (continued)

Station	Time	Magnetic Bearing	Speed meters/sec	Wind Direction	Tide
December 2, 1973, continued					
1	0950	330°	0.05	110°-120°	flood
2	0955	276°	0.03	"	"
3	1000	302°	0.07	"	"
4	1002	290°	0.07	"	"
5	1005	280°	0.06	"	"

Table 8. Summary of current data from Station 6. See Figure 19 (Station C-3) for the location of the station.

Time	Current Direction	Tide	Drogue Depth
December 1, 1973			
1210-1255	lagoonward	flood	1m
"	"	"	5m
1300-1315	lagoonward	ebb	1m
"	"	"	5m
1575-1530	lagoonward	ebb	1m
"	"	"	5m
1605-1630	seaward	ebb	1m
"	"	"	5m
1730-1745	seaward	ebb	1m
2420-2430	seaward	ebb	1m
December 2, 1973			
0300-0315	seaward	ebb	1m
0725-0740	lagoonward	flood	1m
1005-1020	seaward	flood	1m

TABLE 9. Summary of current data. NM = no dye movement, diffusion only ; W = dye movement at surface only by wind; (.2m) = 20 cm drift cross, (1m) = 1 meter drift cross, and (5m) = 5 meter drift cross.

Date	Station Location	Time	Magnetic Bearing	Speed in Knots	Wind Direction	Wind Speed Knots.	Tide
June 8	7	1300	299	.058	094	10-15	ebb
"	8	1302	227	.065	"	"	"
"	9	1306	225	.043	"	"	"
"	10	1309	205	.031	"	"	"
"	11	1311	206	.024	"	"	"
"	12	1314	209	.040	"	"	"
"	13	1319	210	--	"	"	"
"	14	1324	300	--	"	"	"
"	15	1331	290	--	"	"	"
"	16	1340	301	--	"	"	"
"	3a	1312	NM	--	"	"	"
"	3b	1312	NM	--	"	"	"
"	3c	1312	NM	--	"	"	"
"	5a	1315	210W	--	"	"	"
"	5b	1315	208W	--	"	"	"
"	6a	1316	210W	--	"	"	"
"	6b	1316	210W	--	"	"	"
"	7	1530	NM	--	083	10-12	ebb/flood
"	8	1531	174	slight	083	"	"
"	9	1532	179	.013	"	"	"
"	10	1525	181	.019	"	"	"
"	11	1520	162	.019	"	"	"
"	12	1515	178	.039	"	"	"
"	13	1505	308	.026	"	"	"
"	14	1455	298	.029	"	"	"
"	15	1450	305	--	"	"	"
"	16	1445	298	--	"	"	"
"	13(1m)	1505	326	--	"	"	"
"	14(5m)	1455	280	--	"	"	"
"	13	1705	320	.058	074	8-10	flood
"	14	1700	317	.072	"	"	"

Date	Station Location	Time	Magnetic Bearing	Speed in Knots	Wind Direction	Wind Speed Knots.	Tide
June 8	3a	1720	NM	--	074	8-10	Flood
"	3b	1721	NM	--	"	"	"
"	3c	1722	NM	--	"	"	"
"	4a	1725	NM	--	"	"	"
"	4b	1727	NM	--	"	"	"
"	14(1m)	1900	260	Grounded	"	5-7	"
"	14(5m)	1900	270	"	"	"	"
"	12(.2m)	2150	260		"	"	Flood ebb
"	14(1m)	2145	263	Grounded	"	"	"
"	14(5m)	2145	275	"	"	"	"
June 9	14(5m)	0120	162	--	"	"	ebb
"	14(1m)	0230	155	--	"	"	"
"	9	0630	250W	--	065	0-5	Flood
"	10	0631	250W	--	"	"	"
"	11	0632	250W	--	"	"	"
"	12	0633	240	.026	"	"	"
"	13	0634	278	.032	"	"	"
"	14	0635	122	.032	"	"	"
"	14(1m)	0635	122	--	"	"	"
"	14(5m)	0635	122	Grounded	" "	"	"
"	3a	1000	NM	--	070	5-10	"
"	3b	1000	NM	--	"	"	"
"	3c	1001	NM	--	"	"	"
"	4a	1001	NM	--	"	"	"
"	4b	1002	NM	--	"	"	"
"	5a	1002	NM	--	"	"	"
"	5b	1003	NM	--	"	"	"
"	6a	1003	NM	--	"	"	"
"	6b	1004	NM	--	"	"	"
"	7	1004	225	Slight	"	"	"
"	8	1005	210	"	"	"	"
"	9	1007	222	"	"	"	"
"	10	1008	217	"	"	"	"
"	11	1009	221	"	"	"	"
"	14	1010	260	Grounded			

Table 10 . Summary of current data for Stations 1 and 2 in Cocos Lagoon on July 29, 1974. See Figure 19 . for station locations and drift tracts.

Station	Time	Drift Cast Number	Speed in Knots	Wind Direction	Wind in Knots	Stage of Tide
1	1145	1	.05	108°	21*	Early-Flood
1	1145	1	.05	108°	21*	Early-Flood
2	1230	2	.23	110°	15	Early-Flood
2	1230	2	.23	110°	15	Early-Flood
2	1430	3	.26	108°	15	Mid-Flood
2	1430	3	.26	108°	15	Mid-Flood
1	1515	4	.19	110°	15	Mid-Flood
1	1515	4	.19	110°	15	Mid-Flood
2	1645	5	.19	109°	17	Late-Flood
1	1700	6	.13	109°	17	Late-Flood

*Unusual high wind speed was due to a rain squall passing over the lagoon.

Table 11. Summary of current data for a station at the mouth of the Mamaon Channel. See Figure 20 for station location and drift tracts.

Drift Cross Cast Number	Depth of Drift Cross	Time of Drift	Bearing	Wind Direction	Wind Speed in Knots	Stage of Tide	Remarks
1	1m	0800-0915	277°	114°	.9	ebb	grounded
1	5m	0800-0915	277°	114°	.9	ebb	grounded
2	1m	0900-0930	305°	105°	7.4	ebb	grounded
2	5m	0900-0930	305°	105°	7.4	ebb	grounded
3	1m	0945-1045	292°	107°	5.8	ebb	
3	5m	0945-1045	292°	107°	5.8	ebb	
4	1m	1045-1145	304°	111°	12.6	ebb →flood	grounded
4	5m	1045-1145	304°	111°	12.6	ebb →flood	grounded
5	1m	1145-1245	258°	117°	13.6	flood	grounded
5	5m	1145-1245	273°	117°	13.6	flood	grounded
6	1m	1300-1400	280°	115°	12.8	flood	grounded
6	5m	1300-1400	158°	115°	12.8	flood	
7	1m	1400-1500	173°	-	-	flood	grounded
7	5m	1400-1600	192°	-	-	flood	grounded
8	1m	1600-1600	178°	110°	7.6	flood	grounded
8	5m	1500-1600	160°	110°	7.6	flood	grounded
9	1m	1600-1700	286°	125°	11.3	flood	
9	5m	1600-1700	286°	120°	11.3	flood	
10	1m	2030-2215	302°	no wind	-	ebb	grounded
10	5m	2030-2215	304°	no wind	-	ebb	
11	1m	2220-2340	304°	no wind	-	ebb	grounded
11	5m	2220-2340	298°	no wind	-	ebb	
12	1m	2340-0045	293°	no wind	-	flood	
12	5m	2340-0045	293°	no wind	-	flood	
13	1m	0045-0200	319°	no wind	-	flood	grounded
13	5m	0045-0200	303°	no wind	-	flood	
14	1m	0200-0330	290°	no wind	-	flood	
14	5m	0200-0330	286°	no wind	-	flood	
15	1m	0330-0600	286°	no wind	-	flood→ ebb	
15	5m	0330-0600	240°	no wind	-	flood→ ebb	

Table 12. Checklist of corals and their relative frequency of occurrence at Cocos Lagoon. Symbols for relative frequency are: D= dominant, A= abundant, C= common, O= occasional, U= uncommon, and R= rare.

BIOTOPES	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE
Stylocoeniella armata (Ehrenberg), 1834		O	O	C	R	O	C	C	C	
Stylocoeniella guentheri (Bassett-Smith), 1890			R				R	R		R
Psammocora contigua (Esper), 1797	C	O			R	O				
Psammocora nierstraszi van der Horst, 1921		O		O	R	O	C	U		
Psammocora profundacella Gardiner, 1898							R			
Psammocora stellata (Verrill), 1866	C	O			R	O				
Psammocora verrilli Vaughan, 1907							R			
Psammocora (S.) togianensis Umbgrove, 1940		U		U		O	O			
Psammocora (P.) haimeana Milne Edwards & Haime, 1851		O		O	R	O	C	O	R	
Stylophora mordax (Dana), 1846						O	O			
Seriatopora hystrix (Dana), 1846			R	O	O	O	C	O		
Pocillopora brevicornis Lamarck, 1816		O		O	O	O				
Pocillopora damicornis (Linnaeus), 1758	A	C	O	C	C	C	O	O	R	R
Pocillopora danae Verrill, 1864		O		R						
Pocillopora elegans Dana, 1846						R				
Pocillopora eydouxi Milne Edwards & Haime, 1960						U	U			
Pocillopora ligulata Dana, 1846		R				R				
Pocillopora meandrina Dana, 1846		R		R		O				
Pocillopora setchelli Hoffmeister, 1929						O				
Pocillopora verrucosa (Ellis & Solander), 1786		O	O	O	O	O	O			
Acropora abrotanoides (Lamarck), 1816						U				
Acropora acuminata Verrill, 1864	O	C	O	C	U	U				
Acropora arbuscula (Dana), 1846	O	C	U	C	U					
Acropora aspera (Dana), 1846	C	C	R	C	O					
Acropora brueggemanni (Brook), 1893						R	O			
Acropora convexa (Dana), 1846						O	O			
Acropora delicatula (Brook), 1891				R			R	R		
Acropora echinata (Dana), 1846				O						
Acropora formosa (Dana), 1846	C	D	D	D	C	U	U			
Acropora hebes (Dana), 1846	O	O								
Acropora humilis (Dana), 1846		R	R	O	R	O	O	O		
Acropora hystrix (Dana), 1846							U	R		
Acropora kenti (Brook), 1892			R				R	U		R

BIOTOPES	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE
Acropora murrayensis Vaughan, 1918						R	R			
Acropora nana (Studer), 1879						R				
Acropora nasuta (Dana), 1846		0	R	0		0	R			
Acropora nobilis (Dana), 1846		R								
Acropora palifera (Lamarck), 1816		C	0	C	R	0	C			
Acropora palmerae Wells, 1954						U				
Acropora rambleri (Bassett Smith), 1890							0	R		R
Acropora rayneri (Brook), 1892							0	R		R
Acropora smithi (Brook), 1893						R				
Acropora squarrosa (Ehrenberg), 1834							U	R		
Acropora surculosa (Dana), 1846		0		0	R	0	0	R		
Acropora syringodes (Brook), 1892										
Acropora studeri (Brook), 1893						0	R			
Acropora teres (Verrill), 1866	A	A	A	A	C	R	R			
Acropora tubicinaria (Dana), 1846		R		R						
Acropora virgata (Dana), 1846		0	0	0						
Acropora sp. 1				0						
Acropora wardii Verrill, 1901						R				
Astreopora gracilis Bernard, 1896				R		R				
Astreopora listeri Bernard, 1896				R		R				
Astreopora myriophthalma (Lamarck), 1816		R		R		R	0	0		
Montipora composita Crossland, 1952									R	R
Montipora conicula Wells, 1954							R			
Montipora ehrenbergii Verrill, 1875				0		0	0			
Montipora elschneri Vaughan, 1918				R	0	0				
Montipora floweri Wells, 1954							R			
Montipora foveolata (Dana), 1846		0	0	0	R	0	C	0	U	R
Montipora granulosa Bernard, 1897			U				U			
Montipora hoffmeisteri Wells, 1954		0		0		0	0			
Montipora lobulata Bernard, 1897	0	C	0	A	0	0	U			
Montipora monasteriata (Forskaal), 1775						R				
Montipora patula Verrill, 1869						R				
Montipora subtilis Bernard, 1897		0	R	0			0			
Montipora tuberculosa (Lamarck), 1816		0		0		0				
Montipora verrilli Vaughan, 1907	0	C	0	C	0	A	C	0		
Montipora verrucosa (Lamarck), 1816		R	0	0		0	C	0	U	R

BIOTOPES	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE
Pavona clavus (Dana), 1846						O	U			
Pavona decussata (Dana), 1846	R	O			A	R				
Pavona divaricata (Lamarck), 1816	O				C					
Pavona frondifera (Lamarck), 1816	R				O					
Pavona minuta Wells, 1954									R	R
Pavona varians Verrill, 1864	R	O	R	C	R	C	C	O	R	
Pavona gardineri van der Horst, 1922								R		R
Pavona (*P.*) *pollicata* Wells, 1954								R		
Pavona (*P.*) *planulata* (Dana), 1846				R		R	R	R		
Pavona (*P.*) *obtusata* (Quelch), 1884	R	O	O	C		O	C	R		
Pavona (*P.*) sp. 1				O	R	O	O			
Leptoseris hawaiiensis Vaughan, 1907			R	R					O	R
Leptoseris incrustans (Quelch), 1886			R	R					O	R
Leptoseris mycetoseroides Wells, 1954									R	
Pachyseris speciosa (Dana), 1846								R	R	R
Anomastraea sp. 1		R	R	O		O	O	U	U	
Coscinaraea columna (Dana), 1846						R				
Cycloseris sp. 1										R
Fungia fungites (Linnaeus), 1758		O		O			O			
Fungia scutaria Lamarck, 1801		U	U	O			O			
Goniopora columna Dana, 1846							R			
Goniopora arbuscula Umbgrove, 1939	R	O	O	O		U	U			
Stylaraea punctata Klunzinger, 1879	U	C	C	A	O	C	C	O		O
Porites andrewsi Vaughan, 1918	O	A	O							
Porites annae Crossland, 1952	O	O		O	O	U				
Porites australiensis Vaughan, 1918		R		O		O				
Porites cocosensis Wells, 1950	C	A	A	A	O	C	C	O		R
Porites compressa Vaughan, 1907	O	O	U	O		U				
Porites duerdeni Vaughan, 1907		U								
Porites lichen Dana, 1846		R		U		C	C			
Porites lobata Dana, 1846	U	O	O	C		C	C	C		O
Porites lutea Milne Edwards & Haime, 1851	A	A	O	A	C	D	C	O		R
Porites murrayensis Vaughan, 1918		U		O		O	O			
Porites matthaii Wells, 1954	O	A	O	A	O	A	C	O		O
Porites sp. 1						O				
Porites sp. 2				R		U	R			
Porites (*S.*) *convexa* Verrill, 1864		O	C	A	O	C	A	C		O

BIOTOPES:	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE
Porites (*S.*) *hawaiiensis* Vaughan, 1907		U	O	C		O	O	C	A	O
Porites (*S.*) *horizontalata* Hoffmeister, 1925			O	O			O	C	O	O
Porites (*S.*) *iwayamaensis* Eguchi, 1938	R	C	C	A	R	O	A	A	O	C
Porites (*S.*) sp. 1				U		R				
Alveopora japonica Eguchi, 1968		R								
Alveopora verrilliana Dana, 1872						R	U			
Favia favus (Forskaal), 1775		O								
Favia pallida (Dana), 1846		O	R	O		O	O	O		R
Favia speciosa (Dana), 1846		R		U		U	U	U		
Favia stelligera (Dana), 1846		R		R		O	O			
Favia rotumana (Gardiner), 1889				R			O			
Favites abdita (Ellis & Solander), 1786						U				
Favites complanata (Ehrenberg), 1834		R	O	O		U	U	U		
Favites favosa (Ellis & Solander), 1786				U			U			
Favites flexuosa (Dana), 1846				R			R			
Favites virens (Dana), 1846				R		R				
Oulophyllia crispa (Lamarck), 1816				R			R			
Plesiastrea versipora (Lamarck), 1816				R		O	U			
Plesiastrea sp. 1				R		U	U			
Goniastrea parvistella (Dana), 1846	U	O	U	C	R	C	C	O		
Goniastrea pectinata (Ehrenberg), 1834		R		O		U	O	C		
Goniastrea retiformis (Lamarck), 1816	U	O		O		C	O			
Platygyra rustica (Dana), 1846	U	U		O		O	O			
Platygyra lamellina (Ehrenberg), 1834				U			U			
Platygyra sinensis (Milne Edwards & Haime), 1849		O		O		O	O	U		
Leptoria phrygia (Ellis & Solander), 1786		R		R		O	O	O		
Hydnophora microconos (Lamarck), 1816				R		O	U	U		
Leptastrea bottae (Milne Edwards & Haime), 1849	U	O			U	R				
Leptastrea purpurea (Dana), 1846	C	A	O	A	O	A	A	O	O	O
Leptastrea transversa (Klunzinger), 1879				U			U			
Cyphastrea chalcidicum (Forskaal), 1775				U						
Cyphastrea serailia (Forskaal), 1775	O	O		C		C	C	U		R
Cyphastrea sp. 1				R						
Echinopora lamellosa (Esper), 1787				U		U		R		
Diploastrea heliopora (Lamarck), 1816							R	R		
Galaxea fascicularis (Linnaeus), 1758	U	C	O	C	U	O	O	U		
Galaxea hexagonalis Milne Edwards & Haime, 1857						U				
Acrhelia horrescens (Dana), 1846		O	O	C	O	O	O	U		

Table 12. (continued)

BIOTOPES	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE
Merulina ampliata (Ellis & Solander), 1786							U	U	U	
Lobophyllia corymbosa (Forskaal), 1775	U	U	R	R		O	O	U		
Lobophyllia costata (Dana), 1846				R		O				
Lobophyllia hemprichii (Ehrenberg), 1834				U			O			
Acanthastrea echinata (Dana), 1846				R		D	U			
Echinophyllia asper Ellis & Solander, 1786			U	O		U	O	O	R	R
Mycedium sp. 1				R						R
Paracyathus sp. 1				R					R	
Plerogyra sinuosa (Dana), 1846		R	O	O		O	O	C	O	O
Euphyllia glabrescens (Chamisso & Eysenhardt), 1821	U	O	O	O		O	C	C	C	O
Heliopora coerulea (Pallas), 1766	U	O	O	C	U	C	O	U		
Millepora dichotoma Forskaal, 1775	R	O		O		C	O			
Millepora exaesa Forskaal, 1775	O	O	O	C	O	A	C	O	O	O
Millepora platyphylla Hemprich & Ehrenberg, 1834	O	O		U		C	O	U		
Distichopora violacea (Pallas), 1776						C	C	C	C	O
Total Species per Biotope	39	79	51	102	40	104	98	57	24	32
Total Genera per Biotope	18	27	25	35	14	34	36	70	17	18

Total Species 159

Total Genera 44

Table 13. Living coral density, per cent of substratum coverage (Dominance), and frequency of occurrence. Importance Value is the sum of the above three parameters. Corals are arranged in order of their Importance Value.

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 1 (Biotope IB)							
Acropora formosa	2.02	35.71	9.03	29.59	.57	30.64	95.94
Porites andrewsi	1.62	28.57	11.44	37.48	.43	23.12	89.17
Porites cocosensis	1.01	17.86	9.27	30.37	.43	23.12	71.36
Acropora teres	1.01	17.86	.78	2.56	.43	23.12	43.55
Total Density	5.66/m^2						
Total Dominance	30.52%						
Total Species	4						
Total Genera	2						
TRANSECT 2 (Biotope IB)							
Porites andrewsi	8.49	47.50	9.17	17.75	.90	40.91	106.16
Acropora formosa	2.24	12.50	39.16	75.80	.20	9.09	97.39
Porites cocosensis	5.81	32.50	3.20	6.19	.80	36.36	75.05
Pocillopora damicornis	1.34	7.50	.13	.26	.30	13.64	21.40
Total Density	17.88/m^2						
Total Dominance	51.66%						
Total Species	4						
Total Genera	3						
TRANSECT 3 (Biotope IA)							
Porites cocosensis	.43	25.00	2.77	80.29	.40	18.18	123.47
Porites lutea	.43	25.00	.28	8.12	.40	18.18	51.30
Porites andrewsi	.26	15.00	.06	1.74	.40	18.18	34.92
Porites annae	.16	10.00	.04	1.16	.40	18.18	29.34
Pocillopora damicornis	.26	15.00	.09	2.61	.20	9.09	26.70
Pavona (P.) obtusata	.09	5.00	.18	5.22	.20	9.09	19.31
Heliopora coerulea	.09	5.00	.03	.86	.20	9.09	14.95
Total Density	1.72/m^2						
Total Dominance	3.45%						
Total Species	7						
Total Genera	4						

Species	Density (m2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 4 (Biotope IB)							
Acropora formosa	.55	31.25	2.13	47.33	.50	26.44	105.02
Acropora teres	.38	21.88	1.62	36.00	.25	13.23	71.11
Porites cocosensis	.22	12.50	.38	8.44	.25	13.23	34.17
Pocillopora damicornis	.22	12.50	.31	6.89	.25	13.23	32.62
Porites andrewsi	.12	6.24	.01	.22	.25	13.23	19.69
Porites (S.) convexa	.16	9.37	.01	.22	.13	6.88	16.47
Porites lutea	.05	3.13	.03	.68	.13	6.88	10.69
Pavona (P.) obtusata	.05	3.13	.01	.22	.13	6.88	10.23
Total Density	$1.75/m^2$						
Total Dominance	4.50%						
Total Species	8						
Total Genera	4						
TRANSECT 5 (Biotope IA)							
Acropora teres	.16	25.00	.21	25.30	.50	16.67	66.97
Porites (S.) convexa	.03	5.00	.36	43.37	.20	6.67	55.04
Porites lutea	.11	17.50	.11	13.25	.50	16.67	47.42
Pocillopora damicornis	.12	20.00	.01	1.20	.70	23.33	44.53
Porites cocosensis	.08	15.00	.07	8.43	.40	13.33	36.76
Pavona decussata	.05	7.50	.03	3.61	.30	10.00	21.11
Pavona varians	.03	5.00	.02	2.42	.20	6.67	14.09
Heliopora coerulea	.02	2.50	.01	1.21	.10	3.33	7.04
Total Density	$.62/m^2$						
Total Dominance	.83%						
Total Species	9						
Total Genera	6						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 6 (Biotope IA)							
Psammocora stellata	7.23	35.00	1.09	37.72	.80	29.64	102.36
Porites lutea	5.17	25.00	1.14	39.45	.50	18.52	82.97
Leptastrea purpurea	3.62	17.50	.23	7.96	.60	22.23	47.69
Pocillopora damicornis	1.03	5.00	.05	1.73	.20	7.41	14.14
Psammocora contigua	.52	2.50	.20	6.92	.10	3.70	13.12
Goniopora arbuscula	1.03	5.00	.01	.35	.10	3.70	9.05
Favia favus	.52	2.50	.07	2.42	.10	3.70	8.62
Cyphastrea serailia	.52	2.50	.04	1.38	.10	3.70	7.58
Porites (S.) iwayamaensis	.52	2.50	.04	1.38	.10	3.70	7.58
Porites cocosensis	.52	2.50	.02	.69	.10	3.70	6.89
Total Density	20.17/m^2						
Total Dominance	2.89%						
Total Species	10						
Total Genera	7						
TRANSECT 7 (Biotope IA)							
Psammocora stellata	5.05	35.00	.66	14.51	.70	23.34	72.85
Porites lutea	2.89	20.00	1.13	24.83	.60	20.00	64.83
Porites (S.) iwayamaensis	1.44	10.00	1.77	38.90	.40	13.34	62.24
Leptastrea purpurea	1.44	10.00	.10	2.20	.40	13.33	25.53
Pocillopora damicornis	.72	5.00	.12	2.64	.20	6.68	14.32
Montipora foveolata	.72	5.00	.17	3.73	.10	3.33	12.06
Porites cocosensis	.36	2.50	.23	5.05	.10	3.33	10.88
Millepora platyphylla	.36	2.50	.14	3.08	.10	3.33	8.91
Porites matthaii	.36	2.50	.10	2.20	.10	3.33	8.03
Porites andrewsi	.36	2.50	.05	1.10	.10	3.33	6.93
Psammocora contigua	.36	2.50	.05	1.10	.10	3.33	6.93
Stylocoeniella armata	.36	2.50	.03	.66	.10	3.33	6.49
Total Density	14.42/m^2						
Total Dominance	4.55%						
Total Species	12						
Total Genera	6						

Table 13. (continued)

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 8 (Biotope IA)							
No quantitative data--only one living coral (*Acropora teres*) found along a 100 m transect.							
TRANSECT 9 (Biotope IA)							
No quantitative data--only 12 living *Porites lutea* coral colonies ranging from 1-9 cm dia, were found along a 100 m transect.							
TRANSECT 10 (Biotope IA)							
Porites lutea	.32	77.50	.11	73.32	1.00	66.66	217.48
Pavona decussata	.03	7.50	< .01	6.67	.20	13.33	37.50
Leptastrea purpurea	.03	7.50	< .01	6.67	.10	6.67	20.84
Pocillopora damicornis	.02	5.00	< .01	6.67	.10	6.67	18.34
Psammocora stellata	.01	2.50	< .01	6.67	.10	6.67	15.84
Total Density	.41/m^2						
Total Dominance	.15%						
Total Species	5						
Total Genera	5						

Species	Density (m²)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 11 (Biotope ID)							
<u>Acropora formosa</u>	.90	68.09	11.54	23.10	.83	47.69	138.88
<u>Porites andrewsi</u>	.03	2.13	37.50	78.08	.08	4.60	81.81
<u>Montipora foveolata</u>	.11	8.50	.04	.08	.17	9.77	18.35
<u>Montipora verrilli</u>	.06	4.25	.21	.42	.17	9.77	14.44
<u>Pocillopora damicornis</u>	.06	4.25	.13	.26	.17	9.77	14.28
<u>Millepora exaesa</u>	.06	4.26	.50	1.00	.08	4.60	9.86
<u>Stylocoeniella armata</u>	.06	4.26	<.01	.02	.08	4.60	8.88
<u>Acrhelia horrescens</u>	.03	2.13	<.01	.02	.08	4.60	6.75
<u>Leptastrea purpurea</u>	.03	2.13	<.01	.02	.08	4.60	6.75
Total Density	$1.34/m^2$						
Total Dominance	48.18%						
Total Species	9						
Total Genera	8						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 12 (Biotope ID)							
Acropora formosa	1.74	40.74	7.64	90.95	.57	30.97	162.66
Stylocoeniella armata	.63	14.82	.02	.24	.29	15.76	30.82
Psammocora haimeana	.63	14.82	.21	2.50	.14	7.61	24.93
Galaxea fascicularis	.32	7.41	.18	2.14	.14	7.61	17.16
Montipora lobulata	.32	7.41	.12	1.43	.14	7.61	16.45
Montipora subtilis	.16	3.70	.18	2.14	.14	7.61	13.45
Pocillopora damicornis	.16	3.70	.03	.36	.14	7.61	11.67
Acrhelia horrescens	.16	3.70	.01	.12	.14	7.61	11.43
Pavona (P.) obtusata	.16	3.70	.01	.12	.14	7.61	11.43
Total Density	4.28/m^2						
Total Dominance	8.40%						
Total Species	9						
Total Genera	8						
TRANSECT 13 (Biotope ID)							
Porites andrewsi	12.81	50.00	17.93	53.63	.50	50.00	153.63
Porites matthaii	12.81	50.00	15.50	46.37	.50	50.00	146.37
Total Density	25.63/m^2						
Total Dominance	33.43%						
Total Species	2						
Total Genera	1						

Species	Density (m²)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 14 (Biotope ID)							
<u>Acropora teres</u>	.86	60.00	5.80	97.47	.80	40.00	197.48
<u>Montipora foveolata</u>	.25	17.50	.06	1.01	.40	20.00	38.51
<u>Goniopora arbuscula</u>	.07	5.00	.02	.34	.20	10.00	15.34
<u>Stylocoeniella armata</u>	.07	5.00	< .01	.17	.20	10.00	15.17
<u>Cyphastrea serailia</u>	.07	5.00	.01	.17	.10	5.00	10.17
<u>Montipora lobulata</u>	.04	2.50	.03	.50	.10	5.00	8.00
<u>Leptastrea purpurea</u>	.04	2.50	.01	.17	.10	5.00	7.67
<u>Millepora exaesa</u>	.04	2.50	.01	.17	.10	5.00	7.67
Total Density	1.44/m²						
Total Dominance	5.95%						
Total Species	13						
Total Genera	10						
TRANSECT 15 (Biotope ID)							
<u>Acropora formosa</u>	.57	50.00	3.61	41.41	.70	33.33	124.74
<u>Porites andrewsi</u>	.11	10.00	3.72	42.67	.10	4.76	57.43
<u>Leptastrea purpurea</u>	.15	12.50	.04	.46	.30	14.29	27.25
<u>Porites lutea</u>	.09	7.50	.33	3.78	.30	14.29	25.57
<u>Montipora foveolata</u>	.09	7.50	.01	.11	.30	14.29	21.90
<u>Acropora teres</u>	.06	5.00	.97	11.12	.10	4.76	20.88
<u>Pocillopora damicornis</u>	.06	5.00	.03	.34	.20	9.52	14.86
<u>Millepora exaesa</u>	.03	2.50	< .01	.11	.10	4.76	7.37
Total Density	1.16/m²						
Total Dominance	8.72%						
Total Species	8						
Total Genera	6						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 16 (Biotope IB)							
Acropora teres	.17	60.00	3.75	68.06	.90	47.37	175.43
Acropora formosa	.07	22.50	1.67	30.31	.60	31.58	84.39
Pocillopora damicornis	.01	5.00	.01	.18	.20	10.53	15.71
Montipora foveolata	.03	10.00	.01	.18	.10	5.26	15.44
Porites lutea	<.01	2.50	.07	1.27	.10	5.26	9.03
Total Density	.29/m^2						
Total Dominance	5.51%						
Total Species	5						
Total Genera	4						
TRANSECT 17 (Biotope IB)							
Pocillopora damicornis	.27	58.33	.32	9.09	.89	47.35	114.77
Acropora teres	.09	19.44	1.28	36.36	.33	17.55	73.35
Porites lutea	.03	5.56	1.30	36.93	.22	11.70	54.19
Acropora formosa	.06	13.89	.61	17.34	.33	17.55	48.78
Porites andrewsi	.01	2.78	<.01	.28	.11	5.85	8.91
Total Density	.46/m^2						
Total Dominance	3.52%						
Total Species	5						
Total Genera	3						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 18 (Biotope IB)							
<u>Porites cocosensis</u>	.14	42.50	.07	20.59	.80	32.00	95.09
<u>Porites andrewsi</u>	.06	17.50	.16	47.06	.50	20.00	84.56
<u>Porites lobata</u>	.05	15.00	.05	14.71	.40	16.00	45.71
<u>Porites lutea</u>	.04	12.50	.04	11.76	.40	16.00	40.26
<u>Montipora foveolata</u>	.02	7.50	<.01	1.96	.20	8.00	17.46
<u>Favia pallida</u>	.01	2.50	<.01	1.96	.10	4.00	8.46
<u>Pocillopora damicornis</u>	.01	2.50	<.01	1.96	.10	4.00	8.46
Total Density	$.33/m^2$						
Total Dominance	.34%						
Total Species	7						
Total Genera	4						
TRANSECT 19 (Biotope IB)							
<u>Porites lutea</u>	.20	17.50	16.98	95.07	.30	15.00	127.57
<u>Montipora foveolata</u>	.29	25.00	.45	2.52	.40	20.00	47.52
<u>Porites andrewsi</u>	.26	22.50	<.01	.03	.40	20.00	42.53
<u>Acropora teres</u>	.20	17.50	.24	1.34	.30	15.00	33.84
<u>Porites cocosensis</u>	.09	7.50	.14	.78	.30	15.00	23.28
<u>Porites (S.) iwayamaensis</u>	.06	5.00	<.01	.04	.20	10.00	15.04
<u>Porites lobata</u>	.06	4.00	.04	.22	.01	4.00	10.22
Total Density	$1.16/m^2$						
Total Dominance	17.86%						
Total Species	7						
Total Genera	3						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 20 (Biotope ID)							
<u>Montipora lobulata</u>	1.01	45.00	3.11	34.14	.70	30.42	109.56
<u>Pocillopora damicornis</u>	.45	20.00	.53	5.82	.50	21.74	47.56
<u>Porites australiensis</u>	.11	5.00	2.36	25.90	.10	4.35	35.25
<u>Acropora palifera</u>	.17	7.50	.82	9.00	.30	13.04	29.54
<u>Montipora verrilli</u>	.11	5.00	1.40	15.37	.20	8.70	29.07
<u>Montipora lobulata</u>	.17	7.50	.35	3.84	.20	8.70	20.04
<u>Stylocoeniella armata</u>	.17	7.50	.01	.11	.20	8.70	16.31
<u>Acropora delicatula</u>	.06	2.50	.53	5.82	.10	4.35	12.67
Total Density	2.25/m^2						
Total Dominance	9.11%						
Total Species	8						
Total Genera	5						
TRANSECT 21 (Biotope IB)							
<u>Porites cocosensis</u>	.24	12.50	6.07	49.67	.30	10.00	72.17
<u>Montipora sp. 1</u>	.39	20.00	.80	6.55	.50	16.67	43.22
<u>Montipora lobulata</u>	.28	15.00	1.99	16.29	.30	10.00	41.29
<u>Pocillopora damicornis</u>	.29	15.00	.25	2.05	.60	20.00	37.05
<u>Acropora formosa</u>	.15	7.50	1.02	8.35	.20	6.67	22.52
<u>Montipora verrilli</u>	.15	7.50	.17	1.39	.30	10.00	18.89
<u>Porites matthaii</u>	.05	2.50	1.40	11.46	.10	3.33	17.29
<u>Acropora palifera</u>	.10	5.00	.22	1.80	.20	6.67	13.47
<u>Stylocoeniella armata</u>	.10	5.00	.02	.16	.20	6.67	11.83
<u>Acropora tubicinaria</u>	.10	5.00	.19	1.55	.10	3.33	9.88
<u>Millepora platyphylla</u>	.05	2.50	.08	.65	.10	3.33	6.48
<u>Acropora nasuta</u>	.05	2.50	<.01	.08	.10	3.33	5.91
Total Density	1.95/m^2						
Total Dominance	12.22%						
Total Species	12						
Total Genera	6						

Table 13. (continued)

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 22 (Biotope IA)							
Porites lutea	.12	32.50	.69	83.14	.80	30.77	146.41
Porites cocosensis	.07	20.00	.01	1.20	.50	19.23	40.43
Pavona divaricata	.07	20.00	.05	6.03	.30	11.54	37.57
Porites annae	.04	10.00	.04	4.82	.40	15.38	30.20
Pocillopora damicornis	.03	7.50	<.01	1.20	.20	7.69	16.39
Goniastrea retiformis	.02	5.00	<.01	1.20	.20	7.69	13.89
Pavona decussata	.01	2.50	<.01	1.20	.10	3.85	7.55
Porites lobata	.01	2.50	<.01	1.20	.10	3.85	7.55
Total Density	.37/m^2						
Total Dominance	.83%						
Total Species	8						
Total Genera	4						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 23 (Biotope IB)							
Porites cocosensis	.42	35.00	1.10	29.49	.70	26.91	91.40
Porites lutea	.24	20.00	1.89	50.67	.40	15.38	86.05
Pocillopora damicornis	.18	15.00	.01	.27	.50	19.23	34.50
Montipora lobulata	.12	10.00	.09	2.41	.30	11.54	23.95
Porites matthaii	.09	7.50	.28	7.51	.20	7.69	22.70
Porites annae	.03	2.50	.31	8.31	.10	3.85	14.66
Heliopora coerulea	.03	2.50	.02	.53	.10	3.85	6.88
Goniastrea retiformis	.03	2.50	<.01	.27	.10	3.85	6.62
Montipora subtilis	.03	2.50	.01	.27	.10	3.85	6.62
Platygyra rustica	.03	2.50	.01	.27	.10	3.85	6.62
Total Density	1.20/m^2						
Total Dominance	3.72%						
Total Species	10						
Total Genera	6						
TRANSECT 24 (Biotope IB)							
Montipora lobulata	.07	25.00	.05	50.00	.70	28.00	103.00
Porites cocosensis	.11	37.50	.02	20.00	.90	36.00	93.50
Pocillopora damicornis	.06	22.50	.02	20.00	.60	24.00	66.50
Heliopora coerulea	.03	10.00	<.01	5.00	.20	8.00	23.00
Porites (S.) hawaiiensis	.01	5.00	<.01	5.00	.10	4.00	14.00
Total Density	.28/m^2						
Total Dominance	.10%						
Total Species	5						
Total Genera	4						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 25 (Biotope IIA)							
Montipora lobulata	.55	16.68	1.30	36.42	.66	16.67	69.77
Montipora verrilli	.27	8.33	1.66	46.50	.33	8.33	63.16
Psammocora nierstrazi	.55	16.68	.13	3.64	.66	16.67	37.00
Goniastrea parvistella	.27	8.33	.21	5.88	.33	8.33	22.54
Porites lobata	.27	8.33	.10	2.80	.33	8.33	19.46
Galaxea fascicularis	.27	8.33	.08	2.24	.33	8.33	18.90
Pavona varians	.27	8.33	.04	1.12	.33	8.33	17.88
Acropora humilis	.27	8.33	.02	.56	.33	8.33	17.22
Acropora studeri	.27	8.33	.02	.56	.33	8.33	17.22
Acropora convexa	.27	8.33	<.01	.28	.33	8.33	16.94
Total Density	3.26/m^2						
Total Dominance	3.57%						
Total Species	10						
Total Genera	8						
TRANSECT 26 (Biotope IIB)							
Porites lutea	.72	31.25	7.11	75.56	.775	27.27	134.08
Millepora exaesa	.43	18.75	.44	4.68	.25	9.09	32.52
Montipora verrilli	.29	12.50	.99	10.51	.25	9.09	32.10
Porites lobata	.29	12.50	.07	.74	.50	18.19	31.43
Montipora ehrenbergii	.14	6.25	.63	6.70	.25	9.09	22.04
Platygyra rustica	.14	6.25	.13	1.38	.25	9.09	16.72
Acropora palifera	.14	6.25	.03	.32	.25	9.09	15.66
Favia pallida	.14	6.25	.01	.11	.25	9.09	15.45
Total Density	2.29/m^2						
Total Dominance	9.41%						
Total Species	8						
Total Genera	6						

Species	Density (m^2)	Relative Density	Dominance (Per cent)	Relative Dominance	Frequency	Relative Frequency	Importance Value
TRANSECT 27 (Biotope IIC)							
<u>Porites lutea</u>	.04	18.75	.87	54.37	.50	20.00	93.12
<u>Porites lobata</u>	.06	25.00	.31	19.37	.50	20.00	64.37
<u>Porites (S.) horizontalata</u>	.07	31.25	.06	3.75	.50	20.00	55.00
<u>Lobophyllia costata</u>	<.01	6.25	.30	18.75	.25	10.00	35.00
<u>Lobophyllia hemprichii</u>	<.01	6.25	<.01	.63	.25	10.00	16.88
<u>Fungia paumotuensis</u>	<.01	6.25	<.01	.63	.25	10.00	16.88
<u>Fungia scutaria</u>	.01	6.25	.04	2.50	.25	10.00	18.75
Total Density	.22/m^2						
Total Dominance	1.60%						
Total Species	7						
Total Genera	3						

TRANSECT 28 (Biotope IIA) *

Total Dominance	22.00%
Total Species	1
Total Genera	1

TRANSECT 29 (Biotope IIA) *

Total Dominance	8.00%
Total Species	1
Total Genera	1

TRANSECT 30 (Biotope IIA) *

Total Dominance	<1.00%
Total Species	2
Total Genera	2

Table 13. (continued)

TRANSECT 31 (Biotope IIA) *

Total Dominance	<1.00%
Total Species	1
Total Genera	1

TRANSECT 32 (Biotope IIA) *

Total Dominance	<1.00%
Total Species	2
Total Genera	1

TRANSECT 33 (Biotope IIA) *

Total Dominance	39.00%
Total Species	3
Total Genera	1

TRANSECT 34 (Biotope IIB) *

Total Dominance	15-16%
Total Species	3
Total Genera	1

TRANSECT 35 (Biotope IIB)*

Total Dominance	1.84%
Total Species	2
Total Genera	2

Table 13. (continued)

TRANSECT 36 (Biotope IIB) *

Total Dominance	4.20%
Total Species	2
Total Genera	2

TRANSECT 37 (Biotope IIB) *

Total Dominance	8.11%
Total Species	3
Total Genera	2

* A single line transect method was used to calculate the percentage of substrate coverage in these transects. Data taken from Jones and Randall (1973) and Randall *et al.*(1973).

Table 14. Check list and distribution of Alcyonacea and Zoanthidea in the biotopes and facies of Cocos Lagoon.

SPECIES	BIOTOPE I Facies							BIOTOPE II Facies			
	A_W	A_L	B	C	D	E	F	A_1	A_2	B	C
ALCYONACEA											
Asterospiculariidae											
Asterospicularia sp.	X		X		X		X				
Alcyoniidae											
Alcyonium sp.		X			X				X		
Cladiella sp. 1 [c.f. *C. pachyclados* (Klunzinger)]								X			
Cladiella sp. 2 [c.f. *C. sphaerophora* (Ehrenberg)]								X	X		
Lobophytum sp. 1								X			
Lobophytum sp. 2									X		
Lobophytum sp. 3								X			
Sarcophyton sp. 1 [c.f. *S. trocheliophorum* (Marenzeller)]				X	X	X					
Sarcophyton sp. 2 [c.f. *S. glaucum* (Quoy & Gaimard)]		X						X	X	X	
Sinularia polydactyla		X	X	X	X	X	X	X			
Sinularia conferta var. *gracilis*	X		X			X	X		X		
Sinularia sp. 1					X						
Sinularia sp. 2								X			
Sinularia sp. 3								X			
Sinularia sp. 4								X			
Sinularia sp. 5									X		
Sinularia sp. 6									X		
Sinularia sp. 7									X		
Sinularia sp. 8									X		
Sinularia sp. 9			X								
Sympodium coeruleum									X		
Nephthyidae											
Species 1									X		
Species 2									X		
Xeniidae											
Xenia sp.							X				
Zoanthidae											
Palythoa sp. [c.f. *P. tuberculosa* Esper]								X	X	X	X
Zoanthus sp.					X						

Table 15 . Density and per cent cover of soft corals on each transect of Cocos Lagoon.

Facies	Transect	N	Total Density/m	Per cent Cover
Windward Barrier Reef Flat	IAWa	40	4.68	.71
Windward Barrier Reef Flat	IAWb	40	24.02	1.13
Windward Barrier Reef Flat	IAWc	36	2.54	.08
Windward Barrier Reef Flat	IAWd	30	.44	.26
Windward Barrier Reef Flat	IAWe	20	1.60	.07
Leeward Barrier Reef Flat	IALa	(8/40)	--	--
Leeward Barrier Reef Flat	IALb	(2/40)	--	--
Leeward Barrier Reef Flat	IALc	(0)	--	--
Leeward Barrier Reef Flat	IALd	(0)	--	--
Leeward Barrier Reef Flat	IALe	(0)	--	--
Lagoon Shelf	IBa	(0)	--	--
Lagoon Shelf	IBb	(0)	--	--
Lagoon Shelf	IBc	(0)	--	--
Lagoon Shelf	IBd	(6/40)	--	--
Lagoon Shelf	IBe	(15/40)	--	--
Lagoon Floor	ICa	(0)	--	--
Patch Reef	IDa	53	.43	1.14
Patch Reef	IDb	16	2.24	4.14
Patch Reef	IDc	(3/40)	--	--
Patch Reef	IDd	36	.20	.59
Patch Reef	IDe	40	.77	3.33
Nearshore Shelf	IEa	40	2.81	12.36
Nearshore Shelf	IEb	40	3.39	1.26
Nearshore Shelf	IEc	40	3.74	11.74
Nearshore Shelf	IEd	36	4.00	18.87
Manell Channel Margin	IIAa	40	0.52	0.83
Manell Channel Margin	IIAd	26	0.10	0.43
Mamaon Channel Margin	IIAb	31	0.16	0.27
Mamaon Channel Margin	IIAc	33	0.10	0.69
Manell Channel	IIBa	0	--	--
Mamaon Channel	IICa	0	--	--
Mamaon Channel	IIEa	0	--	--

Table 16. Checklist of the fishes. Fishes recorded from the lagoon by previous workers are shown in the first column and coded as 1 - Kami et al. (1968); 2 - Kami (1971); 3 - University of Guam Museum; 4 - Jones and Randall (1973); 5 - Randall et al. (1973); 6 - Collections or incidental observations in the lagoon during the study. Fishes observed by the present authors on random counts are shown as (+) under the pertinent biotope. Numbers refer to the actual number of a species seen on 7 combined transects. I - Outside of Lagoon, II - Channel Walls, III - Lagoon Patch Reefs, IV - Barrier Reef Flat, V - Seagrass Beds, and VI - Sand Bottoms. * - Fishes observed or recorded only outside of lagoon.

Family/Species		I	II	III	IV	V	VI
ACANTHURIDAE							
Acanthurus glaucopareius Cuvier		2	+	6	-	-	-
A. lineatus (Linnaeus)		1	+	-	-	-	-
A. mata Valenciennes	2						
A. nigrofuscus (Forskal)	1	19	15	1	6	-	-
A. olivaceous (Bloch & Schneider)	1						
A. pyroferus Kittlitz		+	+	-	-	-	-
A. thompsoni (Fowler)	*	+	-	-	-	-	-
A. triostegus (Linnaeus)		-	+	10	26	-	-
A. xanthopterus (Cuvier & Valenciennes)		+	5	2	-	6	-
Ctenochaetus binotatus Randall		4	5	-	-	-	-
C. striatus (Quoy & Gaimard)		56	89	57	23	-	-
Naso brevirostris (Cuvier & Valenciennes)	*	+	-	-	-	-	-
N. hexacanthus (Bleeker)	*	+	-	-	-	-	-
N. lituratus (Bloch & Schneider)	1	5	+	3	+	-	-
N. unicornis (Forskal)		+	1	1	2	-	-
Zebrasoma flavescens (Bennett)	1	+	9	9	-	-	-
Z. scopas (Cuvier)		-	1	+	-	-	-
Z. veliferum (Bloch)	1	+	4	2	-	-	-
APOGONIDAE							
Apogon exostigma (Jordan & Starks)		-	1	-	-	-	-
A. leptacanthus Bleeker	1						
A. mydrus (Jordan & Starks)	1						
A. novemfasciatus Cuvier & Valenciennes		-	-	-	14	-	-
A. robustus (Smith & Radcliffe)	1						
A. trimaculatus Cuvier & Valenciennes	5						
A. sp.		-	200	-	-	-	-
Cheilodipterus macrodon (Lacepede)		-	2	2	-	-	-
C. quinquelineata (Cuvier & Valenciennes)		-	34	33	-	3	-
ATHERINIDAE							
Pranesus insularum (Jordan & Evermann)	1						
AULOSTOMIDAE							
Aulostomus chinensis (Linnaeus)		+	6	2	-	1	-

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
BALISTIDAE							
Balistapus undulatus (Mungo Park)	1	+	1	-	-	-	-
Balistoides niger (Bloch)	*	+	-	-	-	-	-
Melichthys niger (Bloch)	*	+	-	-	-	-	-
M. vidua (Solander)	*	1	-	-	-	-	-
Pseudobalistes flavomarginatus (Ruppell)	1	-	-	+	-	-	-
Rhinecanthus aculeatus (Linnaeus)		-	-	-	+	-	-
R. rectangulus (Bloch & Schneider)		-	-	-	+	-	-
Sufflamen bursa (Bloch & Schneider)	1	1	-	-	-	-	-
S. chrysoptera (Bloch & Schneider)		3	+	-	-	-	-
BLENNIIDAE							
Aspidontus taeniatus Quoy & Gaimard		6	6	4	1	-	-
Cirripectes sebae Fowler	*	12	-	-	-	-	-
C. variolosus (Cuvier & Valenciennes)		47	+	-	3	-	-
Ecsenius bicolor (Day)	*	2	-	-	-	-	-
E. opsifrontalis Chapman & Schultz	*	4	-	-	-	-	-
Exallias brevis (Kner)	*	+	-	-	-	-	-
Istiblennius coronatus (Gunther)		1	-	-	1	-	-
Meiacanthus atrodorsalis (Gunther)	3	73	122	45	-	-	-
Petroscirtes mitratus (Ruppell)		-	-	-	-	+	+
Plagiotremus tapeinosoma (Bleeker)		6	2	-	1	-	-
P. sp.	*	+	-	-	-	-	-
Salarias fasciatus (Bloch)		+	-	-	4	-	-
BOTHIDAE							
Bothus mancus (Broussonet)		-	2	-	-	-	-
CANTHIGASTERIDAE							
Canthigaster amboinensis (Bleeker)	*	1	-	-	-	-	-
C. coronatus (Randall)	1	2	1	7	-	-	-
C. janthinopterus (Bleeker)		4	1	-	-	-	-
C. solandri (Richardson)		12	19	3	8	-	-
CARACANTHIDAE							
Caracanthus maculatus (Gray)	*	3	-	-	-	-	-
CARANGIDAE							
Carangoides malabaricus (Bloch & Schneider)	1						

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
Caranx melampygus Cuvier & Valenciennes		+	-	+	-	-	+
Gnathanodon speciosus (Forskal)	1						
CARAPIDAE							
Carapus homei (Richardson)	1						
CHAETODONTIDAE							
Centropyge bispinosus (Gunther)	*	9	-	-	-	-	-
C. flavissimus (Cuvier)	1	5	2	+	+	-	-
C. heraldi Woods & Schultz	*	+	-	-	-	-	-
Chaetodon auriga Forskal	1	1	2	11	5	-	-
C. bennetti Cuvier		+	1	+	-	-	-
C. citrinellus Cuvier	1	9	5	3	11	-	-
C. ephippium Cuvier		+	4	4	+	-	-
C. falcula Bloch		+	12	6	-	-	-
C. kleini Bloch		-	4	-	-	-	-
C. lunula (Lacepede)		+	4	1	3	-	-
C. melannotus Schneider	1	-	4	3	-	-	-
C. mertensii Cuvier	1	2	7	1	-	-	-
C. ornatissimus Solander	1	3	2	-	-	-	-
C. punctato-fasciatus Cuvier & Valenciennes	1	20	4	+	-	-	-
C. quadrimaculatus Gray	*	3	-	-	-	-	-
C. reticulatus Cuvier	1	11	1	+	-	-	-
C. strigangulus (Gmelin)		1	-	4	-	-	-
C. trifasciatus Mungo Park	1	+	23	14	+	-	-
C. unimaculatus Bloch	1	7	1	-	-	-	-
Forcipiger flavissimus Jordan & McGregor	2	4	-	-	-	-	-
Heniochus permutatus Cuvier	1	6	4	5			
H. varius (Cuvier)	1	-	-	-	-	-	-
H. monoceros Cuvier		+	4	+	+	-	-
Holacanthus trimaculatus Cuvier	*	+	-	-	-	-	-
Pomacanthus imperator (Bloch)	1	-	+	-	1	-	-
Pygoplites diacanthus (Boddaert)	1	-	1	-	-	-	-
CIRRHITIDAE							
Cirrhitus pinnulatus (Schneider)	*	+	-	-	-	-	-
Neocirrhites armatus Castelnau	*	8	-	-	-	-	-
Paracirrhites arcatus (Cuvier & Valenciennes)		8	-	1	-	-	-
P. forsteri (Bloch & Schneider)	1	16	+	-	-	-	-
P. hemistictus (Gunther)	*	+	-	-	-	-	-
DASYATIDAE							
Dasyatis kuhlii (Muller & Henle)	3						

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
Caranx melampygus Cuvier & Valenciennes		+	-	+	-	-	+
Gnathanodon speciosus (Forskal)	1						
CARAPIDAE							
Carapus homei (Richardson)	1						
CHAETODONTIDAE							
Centropyge bispinosus (Gunther)	*	9	-	-	-	-	-
C. flavissimus (Cuvier)	1	5	2	+	+	-	-
C. heraldi Woods & Schultz	*	+	-	-	-	-	-
Chaetodon auriga Forskal	1	1	2	11	5	-	-
C. bennetti Cuvier		+	1	+	-	-	-
C. citrinellus Cuvier	1	9	5	3	11	-	-
C. ephippium Cuvier		+	4	4	+	-	-
C. falcula Bloch		+	12	6	-	-	-
C. kleini Bloch		-	4	-	-	-	-
C. lunula (Lacepede)		+	4	1	3	-	-
C. melannotus Schneider	1	-	4	3	-	-	-
C. mertensii Cuvier	1	2	7	1	-	-	-
C. ornatissimus Solander	1	3	2	-	-	-	-
C. punctato-fasciatus Cuvier & Valenciennes	1	20	4	+	-	-	-
C. quadrimaculatus Gray	*	3	-	-	-	-	-
C. reticulatus Cuvier	1	11	1	+	-	-	-
C. strigangulus (Gmelin)		1	-	4	-	-	-
C. trifasciatus Mungo Park	1	+	23	14	+	-	-
C. unimaculatus Bloch	1	7	1	-	-	-	-
Forcipiger flavissimus Jordan & McGregor	2	4	-	-	-	-	-
Heniochus permutatus Cuvier	1	6	4	5			
H. varius (Cuvier)	1	-	-	-	-	-	-
H. monoceros Cuvier		+	4	+	+	-	-
Holacanthus trimaculatus Cuvier	*	+	-	-	-	-	-
Pomacanthus imperator (Bloch)	1	-	+	-	1	-	-
Pygoplites diacanthus (Boddaert)	1	-	1	-	-	-	-
CIRRHITIDAE							
Cirrhitus pinnulatus (Schneider)	*	+	-	-	-	-	-
Neocirrhites armatus Castelnau	*	8	-	-	-	-	-
Paracirrhites arcatus (Cuvier & Valenciennes)		8	-	1	-	-	-
P. forsteri (Bloch & Schneider)	1	16	+	-	-	-	-
P. hemistictus (Gunther)	*	+	-	-	-	-	-
DASYATIDAE							
Dasyatis kuhlii (Muller & Henle)	3						

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
DIODONTIDAE							
Diodon hystrix (Linnaeus)	1						
ENGRAULIDAE							
Thrissina baelama (Forskal)	1						
FISTULARIDAE							
Fistularia petimba Lacepede	1	-	-	-	1	-	-
GOBIIDAE							
Acentrogobius belissimus Smith	5	-	12	11	-	-	-
A. triangularis Weber	4						
Amblygobius albimaculatus (Ruppell)	1	-	+	4	+	+	+
A. decussatus (Bleeker)	4						
A. sp.		-	-	-	-	-	86
Asterropteryx semipunctatus Ruppell		-	-	-	2	10	63
Bathygobius fuscus (Ruppell)	6						
Eleotriodes strigata (Bleeker)	1	30	-	-	2	-	-
Eviota prasites Jordon & Seale	5						
Gnatholepis deltoides (Seale)		-	+	-	3	+	-
Gobius ornatus Ruppell		-	-	-	-	+	+
Nemateleotris magnificus Fowler	+	25	-	-	-	-	-
Obtortiophagus koumansi (Whitely)	5	-	-	-	-	7	-
Oxyurichthys guibei Smith	3	-	-	-	-	-	2
Periopthalmus koelreuteri Eggert	3						
Pogonoculius zebra Fowler	+	5	-		-	-	-
Ptereleotris tricolor Fowler	+	28	-	-	-	-	-
Rhinogobius decoratus Herre	3						
Trimma caesiura Jordon & Seale	4						
HEMIRAMPHIDAE							
Hyporhamphus laticeps (Gunther)	1						
HOLOCENTRIDAE							
Adioryx caudimacula (Ruppell)	+	10	-	-	-	-	-
A. microstomus (Gunther)		1	-	-	2	-	-
A. spinifer (Forskal)	1	+	3	-	2	-	-
A. tiere (Cuvier & Valenciennes)	1	3	-	-	-	-	-
A. lacteoguttatus (Cuvier)	6						
A. sp.		1	5	-	+	-	-
Flammeo sammara (Forskal)		-	92	11	5	-	-

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
Myripristis amaenus (Castelnau)		-	65	+	-	-	-
M. kuntee (Cuvier & Valenciennes)		-	1	-	-	-	-
M. microphthalmus Bleeker	1						
M. murdjan (Forskal)		6	46	+	1	-	-
KUHLIIDAE							
Kuhlia taeniura (Cuvier & Valenciennes)	1						
KYPHOSIDAE							
Kyphosus cinerascens (Forskal)	1						
LABRIDAE							
Anampses caeruleopunctatus Ruppell	*	+	-	-	-	-	-
Cheilinus celebicus Bleeker	1						
C. chlorourus (Bloch)		-	+	2	2	1	-
C. fasciatus (Bloch)	1	1	9	19	13	+	-
C. rhodochrus Gunther		2	5	2	-	-	-
C. trilobatus Lacepede		+	1	+	+	-	-
C. undulatus Ruppell		+	+	3	1	-	-
Cheilio inermis (Forskal)		-	-	+	2	41	-
Cirrhilabrus temmincki Bleeker	*	15	-	-	-	-	-
Coris aygula Lacepede	1						
C. gaimardi (Quoy & Gaimard)	1	2	-	-	1	-	-
Epibulus insidiator (Pallas)	1	2	9	1	1	-	-
Gomphosus varius Lacepede		5	3	8	+	-	-
Halichoeres biocellatus Schultz	*	4	-	-	-	-	-
H. hortulanus (Lacepede)		4	1	-	1	-	-
H. margaritaceus (Cuvier & Valenciennes)		1	+	-	82	3	-
H. marginatus Ruppell	1	3	2	-	3	-	-
H. trimaculatus (Quoy & Gaimard)	1	-	+	34	388	135	-
Hemigymnus fasciatus (Bloch)		+	+	-	-	-	-
H. melapterus (Bloch)	1	1	5	3	1	-	-
Hemipteronotus sp.		+	-	-	-	+	+
Labrichthys unilineata Bleeker		-	6	6	-	-	-
Labroides bicolor Fowler & Bean	1	+	+	-	-	-	-
L. dimidiatus (Cuvier & Valenciennes)		22	16	15	20	-	-
Macropharyngodon meleagris Seale		-	+	-	-	-	-
M. pardalis (Kner)		2	3	-	4	-	-
Pseudocheilinus hexataenia (Bleeker)	2	1	1	-	-	-	-
Pteragogus guttatus (Fowler & Bean)		-	3	-	-	-	-
Stethojulis (axillaris) bandanensis Bleeker	1	2	21	3	214	3	-
S. strigiventer (Bennett)		-	5	2	-	537	-
Thalassoma amblycephalus (Bleeker)		9	3	-	-	-	-
T. hardwickei (Bennett)		+	6	27	28	-	-
T. lutescens (Lay & Bennett)	1	12	4	2	9	-	-

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
T. purpureum (Forskal)	1	+	-	-	1	-	-
T. quinquevittata (Lay & Bennett)	1	93	-	-	12	-	-
Xyrichthys taeniourus (Lacepede)	1	1	-	-	12	-	-
LUTJANIDAE							
Aphareus furcatus (Lacepede)	1	+	+	1	-	-	-
Aprion virescens Valenciennes	*	+	-	-	-	-	-
Caesio caerulaureus Lacepede	1						
Gnathodentex aureolineatus (Lacepede)	1	-	1	-	-	-	-
Lethrinus reticulatus Cuvier & Valenciennes	1						
L. rhodopterus Bleeker		+	+	+	2	18	+
L. sp.		-	-	+	-	16	-
Lutjanus argentimaculatus (Forskal)		+	+	-	-	-	-
L. (vaigiensis) fulvus (Bloch & Schnieder)		11	4	2	+	-	-
L. kasmira (Forskal)	6						
L. monostigmus (Cuvier & Valenciennes)	*	+	-	-	-	-	-
Macolor niger (Forskal)	1						
Scolopsis cancellatus (Cuvier & Valenciennes)	1	-	-	+	+	-	-
MALACANTHIDAE							
Malacanthus latovittatus (Lacepede)	1						
MONACANTHIDAE							
Alutera scripta (Gmelin)	2						
Amanses carolae Jordan & McGregor	*	+	-	-	-	-	-
A. sandwichensis (Quoy & Gaimard)	1	1	+	+	-	-	-
Oxymonacanthus longirostris (Bloch & Schneider)	1	+	2	22	+	-	-
Paraluteres prionurus Bleeker	2	-	5	-	-	-	-
Pervagor melanocephalus (Bleeker)	1						
MONODACTYLIDAE							
Monodactylus argenteus (Linnaeus)		-	2	-	-	-	-
MUGILIDAE							
Chelon vaigiensis (Quoy & Gaimard)	1						
Crenimugil crenilabis (Forskal)	1						
Mugil cephalus Linnaeus	1						
MUGILOIDIDAE							
Parapercis cephalopunctatus (Seale)		+	1	-	-	-	-
P. clathrata Ogilby	1	1	1	-	+	-	-

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
MULLIDAE							
Mulloidichthys auriflamma (Forskal)		-	-	2	-	-	-
M. samoensis (Gunther)		-	3	+	4	2	+
Parupeneus barberinus (Lacepede)	1	+	+	+	2	76	-
P. bifasciatus (Lacepede)		1	-	-	3	-	-
P. cyclostomus (Lacepede)	1	3	1	+	+	-	-
P. multifasciatus (Quoy & Gaimard)	1	8	22	2	22	21	-
P. pleurostigma (Bennett)		-	3	-	+	+	-
P. porphyreus (Jenkins)	4	-	+	+	-	117	-
Upeneus vittatus (Forskal)		-	-	-	-	-	2
MURAENIDAE							
Echidna nebulosa (Ahl)		-	1	-	+	-	-
E. zebra (Shaw)	6						
Gymnothorax gracilicaudus Jenkins	2						
G. javanicus (Bleeker)	2	-	+	-	-	-	-
G. pictus (Ahl)	1						
G. undulatus (Lacepede)	*	+	-	-	-	-	-
Uropterygius concolor Ruppell	1						
MYLIOBATIDAE							
Aetobatus narinari (Euphrasen)	2	-	-	-	-	-	+
OPHICHTHIDAE							
Leiuranus semicinctus (Lay & Bennett)	1						
OSTRACIONTIDAE							
Lactoria cornutus Linnaeus	1						
Ostracion cubicus Linnaeus		-	3	3	-	-	-
O. meleagris camurum (Randall)	1	1	+	1	-	-	-
PEMPHERIDAE							
Pempheris oualensis Cuvier & Valenciennes		-	5	-	-	-	-
POMACENTRIDAE							
Abudefduf amabilis (deVis)	1	10	+	-	1	-	-
A. curacao (Bloch)		-	172	278	-	-	-
A. dicki (Lienard)		171	6	-	-	-	-
A. glaucus (Cuvier & Valenciennes)		-	-	-	266	-	-
A. imparipinnis (Sauvage)	*	+	-	-	-	-	-

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
A. johnstonianus (Fowler & Ball)	*	52	-	-	-	-	-
A. lacrymatus (Quoy & Gaimard)	1	60	68	8	2	-	-
A. leucopomus (Lesson)		55	+	-	5	-	-
A. leucozona (Bleeker)		-	-	-	39	-	-
A. saxatilis (Linnaeus)	*	+	-	-	-	-	-
A. septemfasciatus (Cuvier & Valenciennes)		+	-	-	+	-	-
A. sexfasciatus (Lacepede)		-	-	18	-	-	-
Amphiprion bicinctus Ruppell	1						
A. chrysopterus Cuvier	3	8	-	-	3	-	-
A. melanopus Bleeker	1	-	8	4	5	-	-
A. perideraion Bleeker	*	+	-	-	-	-	-
Chromis atripectoralis Welander & Schultz		-	1	+	3	-	-
C. caeruleus (Cuvier & Valenciennes)	1	-	222	544	158	-	-
C. (dimidiatus) hanui Randall & Swerdloff		78	1	-	-	-	-
C. leucurus Gilbert	*	3	-	-	-	-	-
C. vanderbilti (Fowler)	*	5	-	-	-	-	-
C. xanthochir (Bleeker)	*	+	-	-	-	-	-
C. sp.		5	+	-	-	-	-
Dascyllus aruanus (Linnaeus)	1	-	143	131	112	-	-
D. reticulatus (Richardson)	1	277	3	-	-	-	-
D. trimaculatus (Ruppell)	1	22	5	-	15	-	-
Pomacentrus albofasciatus Schlegel & Muller		-	-	-	380	-	-
P. amboinensis Bleeker		-	5	-	-	-	-
P. jenkinsi Jordan & Evermann		274	+	-	3	-	-
P. lividus (Bloch & Schneider)	1	-	10	36	+	-	-
P. nigricans (Lacepede)	1	-	8	211	24	-	-
P. pavo (Bloch)		-	1	2	-	-	-
P. traceyi Schultz		133	61	2	-	-	-
P. vaiuli Jordan & Seale		225	205	1	83	-	-
P. sp.	*	255	-	-	-	-	-
PSEUDOCHROMIDAE							
Plesiops corallicola Bleeker	1						
SCARIDAE							
Calatomus spinidens (Quoy & Gaimard)		-	+	-	+	-	-
Chlorurus bicolor (Ruppell)	1	-	1	+	-	-	-
C. gibbus (Ruppell)	2	-	-	+	-	-	-
Leptoscarus vaigiensis (Quoy & Gaimard)		-	-	-	-	2	-
Scarus dubius Bennett		+	+	4	-	3	-
S. lepidus Jenyns		9	+	+	+	-	-
S. sordidus Forskal		45	50	192	13	139	-
S. venosus Cuvier & Valenciennes		6	20	12	10	-	-
SCORPAENIDAE							
Pterois antennata (Bloch)	1						

Table 16. (continued)

Family/Species		I	II	III	IV	V	VI
P. volitans (Linnaeous)		+	+	-	-	-	-
Scorpaenopsis gibbosa (Bloch & Schneider)	1						
SERRANIDAE							
Cephalopholis argus Bloch & Schneider	1						
C. urodelus (Bloch & Schneider)	*	16	-	-	-	-	-
Epinephelus emoryi Schultz	*	+	-	-	-	-	-
E. merra Bloch	1	-	2	+	2	-	-
Grammistes sexlineatus (Thunberg)	*	+	-	-	-	-	-
SIGANIDAE							
Siganus argenteus (Quoy & Gaimard)		-	-	-	-	+	-
S. punctatus (Bloch & Schneider)	1	-	-	+	-	-	-
S. spinus (Linnaeus)	1	-	-	-	+	+	-
SPARIDAE							
Monotaxis grandoculis (Forskal)	1	+	3	+	+	-	-
SPHYRAENIDAE							
Sphyraena sp.		-	-	-	-	+	-
SYNGNATHIDAE							
Corythoichthys intestinalis waitei (Jordan & Seale)	1	-	8	2	-	2	-
C. sp.		-	-	-	3	-	-
SYNODONTIDAE							
Saurida gracilis (Quoy & Gaimard)	1	-	1	-	-	-	1
Synodus variegatus (Lacepede)	1	-	2	2	+	-	1
TETRAODONTIDAE							
Arothron alboreticulatus (Tanaka)	3	+	+	-	-	-	-
A. immaculatus (Bloch & Schneider)	1	-	-	-	-	+	-
ZANCLIDAE							
Zanclus cornutus (Linnaeus)		2	13	20	2	-	-

Table 17. Summary of data by biotope (based on seven combined transects for each biotope).
N = number of individuals observed on transects
Ts = number of species observed on transects
Rs = number of random species observed in 140 minutes (7 x 20 min.)
S = combined transect and random species or total species observed
H" = Shannon-Wiener diversity index (based on N and Ts; and linear biomass and Ts)
E = evenness values based on S (E = 1 would show perfect equitability)
Biomass = total kg/ha values, all species combined less those with values under 0.5 kg

	Area Sampled (Transects)	N	Ts	Rs	S	Biomass kg/ha	H" (N)	E (N)	H" (lbm)	E (lbm)
I Outside Reef	1400 m^2	2397	94	147	150	43.07	3.338	0.666	3.590	0.716
II Channel Walls	1400 m^2	2044	104	133	138	167.89	3.367	0.683	3.622	0.735
III Patch Reefs	1400 m^2	1859	67	92	94	85.80	2.562	0.564	2.936	0.646
IV Barrier Reef Flats	1400 m^2	2084	67	84	91	25.29	2.722	0.603	2.817	0.624
V Grass Flats	1400 m^2	1489	22	29	32	14.79	1.916	0.553	2.047	0.591
VI Sand Bottom	1400 m^2	159	7	11	14	3.38	0.966	0.366	1.059	0.401

Table 18. Comparison of rank order of top 20 species from reef biotopes II-IV using all four evaluation techniques (N,).I.V., lbm and kg/ha).

SPECIES	N	SPECIES	O.I.V.	SPECIES	lbm	SPECIES	kg/ha
C. caeruleus	924	C. caeruleus	22.6	C. caeruleus	7.9	S. sordidus	50.8
A. curacao	450	A. curacao	14.1	S. sordidus	7.6	M. amaenus	33.0
H. trimaculatus	422	H. trimaculatus	13.0	A. curacao	7.2	P. nigricans	25.3
D. aruanus	386	P. albofasciatus	11.7	H. trimaculatus	6.4	C. striatus	24.4
P. albofasciatus	380	S. sordidus	11.5	P. nigricans	6.0	M. murdjan	12.0
P. vaiuli	288	D. aruanus	10.7	P. albofasciatus	5.5	F. sammara	13.4
A. glaucus	266	P. nigricans	9.6	C. striatus	4.6	S. venosus	9.1
S. sordidus	255	P. vaiuli	7.8	D. aruanus	4.5	A. curacao	9.0
P. nigricans	243	C. striatus	7.0	F. sammara	3.5	P. albofasciatus	8.8
S. bandanensis	238	S. bandanensis	7.0	S. bandanensis	3.4	E. insidiator	7.4
Apogon sp.	200	A. glaucus	6.8	P. vaiuli	3.3	P. lividus	6.5
C. striatus	169	Apogon sp.	5.7	M. amaenus	2.9	H. trimaculatus	6.3
M. atrodorsalis	167	F. sammara	5.4	A. glaucus	2.6	D. aruanus	5.3
F. sammara	108	P. traceyi	5.2	Apogon sp.	2.4	Z. cornutus	4.9
H. margaritaceus	82	M. atrodorsalis	4.6	M. murdjan	1.9	C. trifasciatus	3.6
A. lacrymatus	78	M. amaenus	4.1	M. atrodorsalis	1.7	P. multifasciatus	3.4
C. quinquelineata	67	M. murdjan	2.6	C. quinquelineata	1.3	A. xanthopterus	3.3
M. amaenus	65	A. lacrymatus	2.5	P. lividus	1.3	S. bandanensis	3.0
P. traceyi	63	C. quinquelineata	2.3	S. venosus	1.3	A. chinensis	2.9
T. hardwickei	61	T. hardwickei	2.2	T. hardwickei	1.2	C. caeruleus	2.9

Table 19. Checklist of marine plants from Cocos Lagoon associated with each biotope and facies. Species are alphabetized under respective Divisions.

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B-D	E
CYANOPHYTA (blue-greens) - 6 spp								
<u>Calothrix</u> <u>crustacea</u> Thuret	X	X		X	X	X	X	
<u>Hormothamnion</u> <u>enteromorphoides</u> B. & F.	X	X	X	X	X	X		
<u>Microcoleus</u> <u>lyngbyaceus</u> (Kutz.) Crouan	X	X	X	X	X	X	X	X
<u>Schizothrix</u> <u>calcicola</u> (Ag.) Gomont	X	X		X	X	X	X	
<u>Schizothrix</u> <u>mexicana</u> Gomont	X	X		X	X	X		
<u>Rivularia</u> <u>atra</u> B. & F.					X			
CHLOROPHYTA (greens) - 31 spp								
<u>Acetabularia</u> <u>moebii</u> Solms-Laubach	X			X				
<u>Avrainvillea</u> <u>obscura</u> J. Ag.	X	X	X		X			
<u>Boergesenia</u> <u>forbesii</u> (Harv.) Feldmann	X	X		X		X		
<u>Boodlea</u> <u>composita</u> (Harv.) Brand	X	X		X	X	X	X	
<u>Caulerpa</u> <u>cupressoides</u> (West) C. Ag.	X	X	X	X	X	X	X	
<u>Caulerpa</u> <u>filicoides</u> Yamada								X
<u>Caulerpa</u> <u>lentillifera</u> J. Ag.		X		X	X			X
<u>Caulerpa</u> <u>racemosa</u> (Forssk.) J. Ag.	X	X	X	X	X	X	X	
<u>Caulerpa</u> <u>serrulata</u> (Forssk.) J. Ag.	X	X		X	X	X		
<u>Caulerpa</u> <u>sertularioides</u> (Gmel.) Howe	X	X	X	X	X			X
<u>Caulerpa</u> <u>taxifolia</u> (Vahl) C. Ag.	X	X		X	X	X		
<u>Caulerpa</u> <u>verticillata</u> J. Ag.		X		X		X		
<u>Chlorodesmis</u> <u>fastigiata</u> (C. Ag.) Ducker	X			X	X	X	X	
<u>Cladophoropsis</u> <u>membranacea</u> (Ag.) Boerg.	X				X			
<u>Codium</u> <u>edule</u> Silva				X				
<u>Dictyosphaeria</u> <u>cavernosa</u> (Forssk.) Boerg.	X	X		X	X	X		
<u>Dictyosphaeria</u> <u>versluysii</u> W-v. Bosse	X	X		X	X	X	X	
<u>Enteromorpha</u> <u>compressa</u> (L.) Grev.					X			
<u>Halimeda</u> <u>copiosa</u> Goreau & Graham				X		X		
<u>Halimeda</u> <u>discoidea</u> Decaisne	X	X		X	X	X	X	
<u>Halimeda</u> <u>gigas</u> Taylor						X	X	
<u>Halimeda</u> <u>incrassata</u> (Ellis) Lamx.				X	X	X	X	
<u>Halimeda</u> <u>macroloba</u> Decaisne	X	X	X	X	X			
<u>Halimeda</u> <u>opuntia</u> (L.) Lamx.	X	X	X	X	X	X	X	X
<u>Neomeris</u> <u>annulata</u> Dickie	X			X	X	X		
<u>Neomeris</u> <u>vanbosseae</u> Howe							X	
<u>Rhipilia</u> <u>orientalis</u> A. & E. S. Gepp						X		
<u>Tydemannia</u> <u>expeditionis</u> W-v. Bosse	X			X	X	X		
<u>Udotea</u> <u>argentea</u> Zanardini						X		X

Table 19. (continued)

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B-D	C
<u>Valonia fastigiata</u> Harv.	X	X		X	X	X	X	
<u>Valonia ventricosa</u> J. Ag.	X	X		X	X	X		
PHAEOPHYTA (browns) - 16 spp								
<u>Chnoospora implexa</u> (Hering) C. Ag.	X	X	X	X	X			
<u>Dictyota bartayresii</u> Lamx.	X	X	X	X	X	X		X
<u>Dictyota cervicornis</u> Kutz.	X	X	X	X	X			
<u>Dictyota divaricata</u> Lamx.	X	X	X	X		X	X	
<u>Dictyota friabilis</u> Setchell	X	X		X			X	
<u>Dictyota patens</u> J. Ag.				X	X	X		
<u>Ectocarpus breviarticulatus</u> J. Ag.	X				X			
<u>Feldmannia indica</u> (Sonder) Womersley & Bailey	X	X		X	X		X	
<u>Hydroclathrus clathratus</u> (C. Ag.) Howe	X	X	X	X	X			
<u>Lobophora variegata</u> (Lamx.) Womersley	X	X		X	X		X	
<u>Padina jonesii</u> Tsuda			X			X	X	
<u>Padina tenuis</u> Bory	X	X		X	X			
<u>Sargassum cristaefolium</u> C. Ag.	X							
<u>Sargassum polycystum</u> C. Ag.	X				X			
<u>Sphacelaria tribuloides</u> Meneghini	X			X	X		X	
<u>Turbinaria ornata</u> (Turner) J. Ag.	X	X		X	X	X	X	
RHODOPHYTA (reds) - 38 spp								
<u>Acanthophora spicifera</u> (Vahl) Boerg.	X	X	X	X		X	X	
<u>Actinotrichia fragilis</u> (Forssk.) Boerg.	X	X			X	X	X	
<u>Amphiroa foliacea</u> Lamx.	X				X	X	X	
<u>Amphiroa fragilissima</u> (L.) Lamx.	X	X		X	X	X	X	X
<u>Antithamnion</u> sp.								
<u>Asparagopsis taxiformis</u> (Delile) Collins & Harvey						X		
<u>Botryocladia skottsbergii</u> (Boerg.) Levring				X				
<u>Centroceras clavulatum</u> (C. Ag.) Montagne				X				
<u>Ceramium</u> sp.				X				
<u>Champia parvula</u> (C. Ag.) Harvey				X				
<u>Desmia hornemanni</u> Lyngbye						X	X	
<u>Galaxaura fasciculata</u> Kjellman	X	X		X	X	X		
<u>Galaxaura marginata</u> Lamx.				X				X
<u>Galaxaura oblongata</u> (E. & S.) Lamx.		X		X		X	X	X
<u>Gelidiella acerosa</u> (Forssk.) Feldmann & Hamel	X	X		X				
<u>Gelidiopsis intricata</u> (Ag.) Vickers	X	X		X	X			
<u>Gelidium divaricatum</u> Martens	X	X		X	X	X	X	
<u>Gelidium pusillum</u> (Stackh.) Le Jolis	X							

Table 19. (continued)

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B-C	E
Gracilaria arcuata Zanardini	X			X				
Gracilaria crassa Harvey	X			X	X			
Griffithsia sp.				X				
Halymenia durvillaei Bory				X				
Hypnea cervicornis J. Ag.							X	
Hypnea pannosa J. Ag.	X	X		X	X	X	X	
Hypnea valentiae (Turn.) Montagne	X			X				
Jania capillacea Harvey	X			X		X	X	
Laurencia sp.					X			
Lithophyllum sp.	X	X		X	X	X	X	X
Mastophora sp.	X					X		
Neogoniolithon sp.							X	
Peyssonelia sp.				X		X		X
Polysiphonia spp.	X	X		X	X		X	
Porolithon onkodes Foslie	X							
Porolithon sp.	X	X			X	X		
Rhodymenia sp.	X	X		X	X	X		X
Spyridia filamentosa (Wulf.) Harvey	X	X	X	X				
Tolypiocladia glomerulata (Ag.) Schmitz & Hauptfleisch	X			X		X	X	
Trichogloea sp.							X	
SPERMATOPHYTA (sea-grass) - 3 spp								
Enhalus acoroides (L.F.) Royle					X			
Halodule uninervis (Forssk.) Ascherson			X					
Halophila minor (Zoll.) Hartog			X					
TOTAL	61	46	18	64	53	47	35	13

Table 20. Relative abundance and frequency (in parenthesis) of marine plants representing 80 percent (± 5 percent) within each biotope and facies. W=windward reef, L=leeward reef.

Species	Biotope 1						Biotope 11		
	A		B	C	D	E	A	B-D	E
	W	L							
Percent Algal Cover	36	33	14	<1	32	22	26	56	97
Number of Tosses	214	90	197	38*	173	157	328	115	7
Number of Species	12	9	13	4	8	6	6	14	5
Cyanophyta									
Calothrix crustacea					3(6)				
Hormothamnion enteromorphoides				5(6)				2(10)	
Microcoleus lyngbyaceus					7(3)				
Schizothrix calcicola			3(2)		5(5)				
Chlorophyta									
Avrainvillea obscura				24(37)					
Boodlea composita	4(9)								
Caulerpa filicoides									11(43)
Caulerpa racemosa	3(7)	27(48)	7(6)			10(10)			
Caulerpa sertularioides				10(21)					
Dictyosphaeria versluysii		4(16)							
Halimeda discoidea					3(5)				
Halimeda incrassata								14(32)	
Halimeda macroloba				41(32)		6(12)			
Halimeda opuntia	4(10)		3(3)				13(16)	10(18)	15(43)
Udotea argentea								3(15)	
Phaeophyta									
Chnoospora implexa	3(4)		3(2)						
Dictyota bartayresii	18(44)		18(12)		34(22)	15(20)	10(15)		
Dictyota divaricata	3(2)							5(17)	
Dictyota friabilis								4(6)	
Dictyota patens					4(6)			3(18)	
Feldmannia indica	3(4)		8(6)		17(15)				
Hydroclathrus clathratus		6(18)	8(5)				6(5)		

Table 20. (continued)

Species	Biotope 1						Boitope 11		
	A		B	C	D	E	A	B-D	E
	W	L							
Lobophora variegata	14(24)	6(14)						2(6)	
Padina tenuis		18(48)	4(3)			15(20)	20(21)		
Sargassum polycystum		5(11)				9(10)	4(4)		
Sphacelaria tribuloides								5(7)	
Turbinaria ornata		7(18)							
Rhodophyta									
Actinotrichia fragilis		4(7)							
Amphiroa fragilissima								5(17)	14(43)
Galaxaura fascicularis	4(4)								
Gelidiella acerosa	3(6)								
Gelidium divaricatam								3(8)	
Peyssonelia sp.									19(71)
Polysiphonia spp.	19(18)		10(6)		10(5)				
Porolithon onkodes								7(10)	19(57)
Porolithon sp.	2(7)	6(16)							
Spyridia filamentosa			4(2)						
Tolypiocladia glomerulata								12(23)	
Trichogloea sp.								2(3)	
Spermatophyta									
Enhalus acoroides						28(41)	24(29)		
Halodule uninervis			2(1)						
Halophila minor			7(8)	10(36)					

* Number of quadrats (1 quadrat = 4 pts).

Table 21. Checklist of common macroinvertebrates, other than corals, collected or observed in Cocos Lagoon.

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B	C	D	E
Phylum Protozoa										
Class Sarcodina										
Marginopora vertebralis Blainville		X								
Phylum Cnidaria										
Class Scyphozoa										
Cassippea andromeda (Forskal)					X					
Stephanoscyphus racemosus Komai							X			
Class Hydrozoa										
Porpita sp.					X					
Phylum Annelida										
Class Polychaeta										
Spirorbis sp.				X						
Phylum Mollusca										
Class Gastropoda										
Acmaea sp.	X									
Arca ventricosa	X									
Astralium petrosum					X					
Barbatia sp.	X	X								
Bursa sp.	X									
Cantharus fumosus	X									
Cantharus undosus	X									
Cantharus sp.	X									
Cerithium columna	X									
Cerithium nesioticum	X									
Cerithium nodulosum	X	X								
Cerithium ravidum		X								
Cerithium sp.					X					
Chicoreus brunneus		X								
Chione sp.		X								
Chlarys sp.				X						
Codakia divergens					X					
Contumax nodulosus		X								

Table 21. (Continued)

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B	C	D	E
Conus arenatus	X									
Conus distans	X									
Conus flavidus		X								
Conus ebraeus	X									
Conus imperialis		X								
Conus litteratus		X								
Conus lividus	X				X					
Conus marmoreus		X								
Conus miliaris					X					
Conus pulicarius	X	X	X		X					
Conus rattus	X									
Conus sponsalis					X					
Conus sp.	X									
Coralliophilia violacea	X									
Ctelina sp.		X								
Ctelinidae sp.	X									
Ctena divergens					X					
Cymatium muricinum					X					
Cymatium pileare	X				X					
Cymatium sp.					X					
Cypraea carneola	X									
Cypraea moneta	X	X								
Cypraea tigris		X		X						
Drupa morum	X									
Drupa ricinus	X									
Drupa rubisidaeus	X									
Drupella cornus	X									
Fragum fragum	X	X	X							
Gafrarium pectinatum	X				X					
Imbricaria conularis			X							
Latirus barclayi					X					
Latirus polygonus					X					
Latirus sp.	X				X					
Maculotriton digitata					X					
Mitra mitra			X							
Mitridae sp. 1					X					
Mitridae sp. 2	X									
Modiolus auriculatus					X					
Morula uva	X									
Muricidae sp.	X									
Nassarius graniferus	X									
Natica marochiensis		X			X					
Nebularia cucumerina	X									
Oliva minacea			X							

Table 21. (Continued)

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B	C	D	E
Otopleura auriscatis					X					
Otopleura sp.	X									
Periglypta puerpera					X					
Pinctada sp.					X					
Pyramidella sp. 1	X				X					
Pyramidella sp. 2	X									
Quidnipagus palatam					X					
Rapa rapa	X				X					
Rhinoclavis asper	X	X	X		X					
Sagaminopteron psychedelicum						X				
Septifer bilocularis	X									
Spondylus sp.			X							
Strombus gibberulus	X	X	X							
Strombus luhuanus	X	X								
Strombus sp.	X									
Telina sp.	X									
Terebra affinis	X		X		X					
Terebra areolata			X							
Terebra babylonia			X							
Terebra dimidiata	X				X					
Terebra guttata			X							
Terebra maculata			X							
Terebra subulata			X							
Terebra sp. 1		X								
Thais armigera	X									
Thais tuberosa					X					
Tonna perdix					X					
Trochus niloticus						X				
Trochus ochroleucus	X									
Truidrupa bijubata					X					
Turridae sp.					X					
Turbo sp.						X				
Vasum turbinellus	X	X			X					
Phylum Echinodermata										
Class Asteroidea										
Acanthaster planci (Linnaeus)				X	X					
Asterina anomola H.L. Clark	X									
Asterina sp.	X									
Astropecten polyacanthus Muller & Troschel		X								
Choriaster granulatus Lutken					X					
Culcita novaeguineae Muller & Troschel	X			X	X					

Table 21. (Continued)

SPECIES	BIOTOPE I A	B	C	D	E	BIOTOPE II A	B	C	D	E
Echinaster luzonicus (Gray)	X									
Fromia hemiopla Fisher	X									
Gomophia egyptica Gray	X									
Linckia guildingi (Gray)	X									
Linckia laevigata (Linnaeus)	X									
Linckia multiflora (Lamarck)		X		X						
Mithrodia clavigera (Lamarck)					X					
Ophidiaster granifera Lutken	X									
Ophidiaster robillardi de Loriol	X									
Class Ophiuroidea										
Macrophiothrix longipeda (Lamarck)	X									
Ophiocoma erinaceus Muller & Troschel	X									
Class Echinoidea										
Diadema savignyi Mickelin				X						
Diadema setosum (Leske)						X				
Echinometra mathaei (de Blainville)	X	X		X	X	X				
Echinostrephus aciculatus Agassiz				X	X	X	X	X		
Echinothrix calamaris (Pallas)							X			
Echinothrix diadema (Linnaeus)	X				X					
Heterocentrotus mammillatus (Linnaeus)						X				
Toxopneustes pileolus (Lamarck)	X									
Tripneustes gratilla (Linnaeus)	X									
Class Holothuroidea										
Actinopyga echinites (Jaeger)	X									
Actinopyga mauritiana (Quoy & Gaimard)	X			X		X	X	X		
Bohadschia argus Jaeger	X	X	X	X	X	X				
Bohadschia bivitata Mitsukuri	X	X	X	X	X	X				
Holothuria (Cystipus) inhabilis Selenka		X								
Holothuria (Halodeima) atra Jaeger	X	X		X		X	X	X		
Holothuria (Halodeima) edulis Lesson	X	X	X	X	X	X				
Holothuria (Mertensiothuria) leucospilota Brandt	X	X	X	X	X	X	X			
Holothuria (Thymiosycia) hilla Lesson	X	X		X	X					
Holothuria (Microthele) nobilis Selenka	X	X	X	X		X				
Holothuria sp. 1					X					
Holothuria sp. 2	X									
Stichopus chloronotus Brandt	X	X	X	X	X	X	X	X		
Stichopus horrens Selenka	X			X						
Stichopus variegatus Semper	X			X						
Synapta maculata (Chamisso & Eysenhardt)	X	X		X	X	X				
Thelenota ananas (Jaeger)								X		

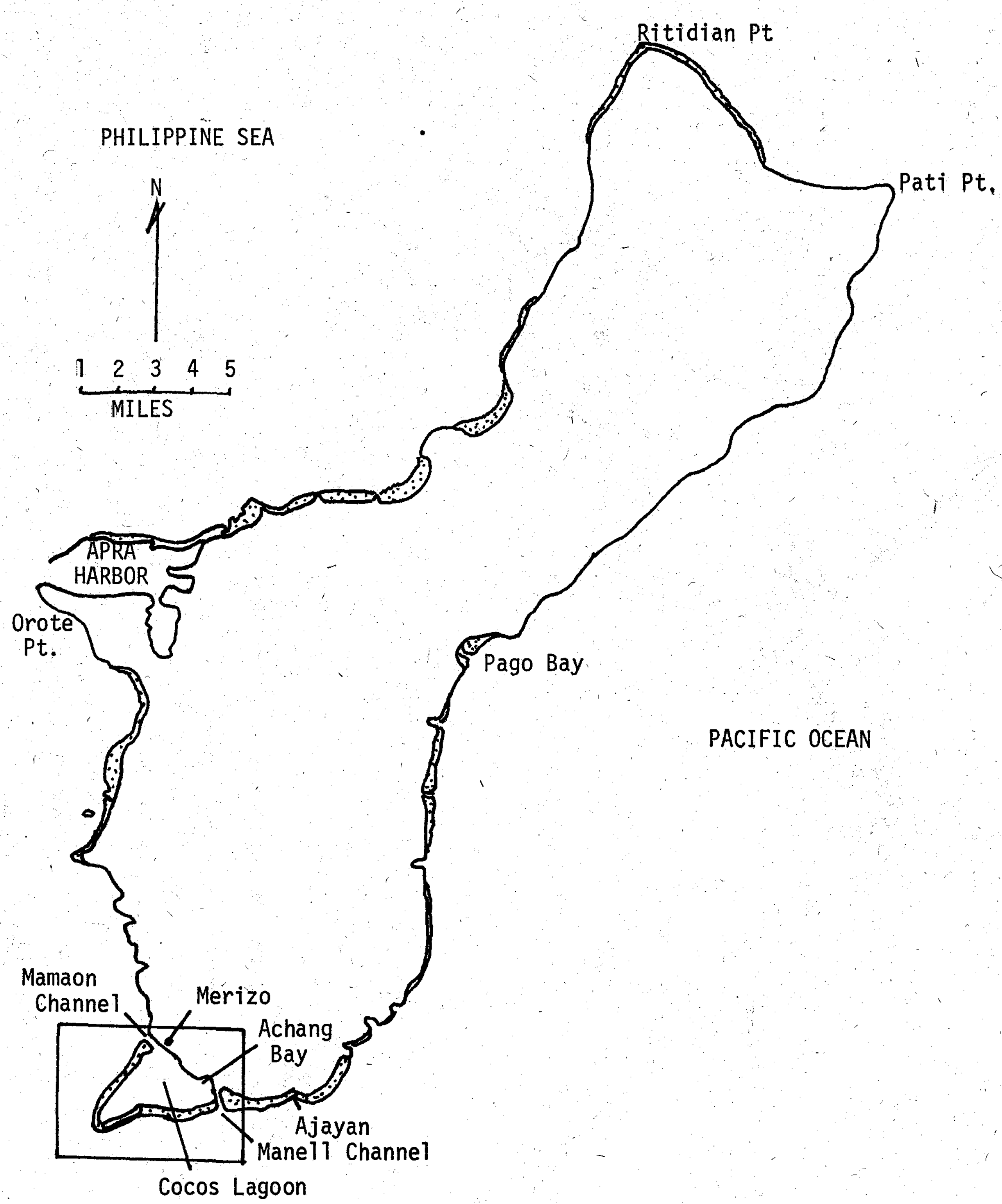

Figure 1. Map of Guam showing the location of the Cocos Lagoon Study area.

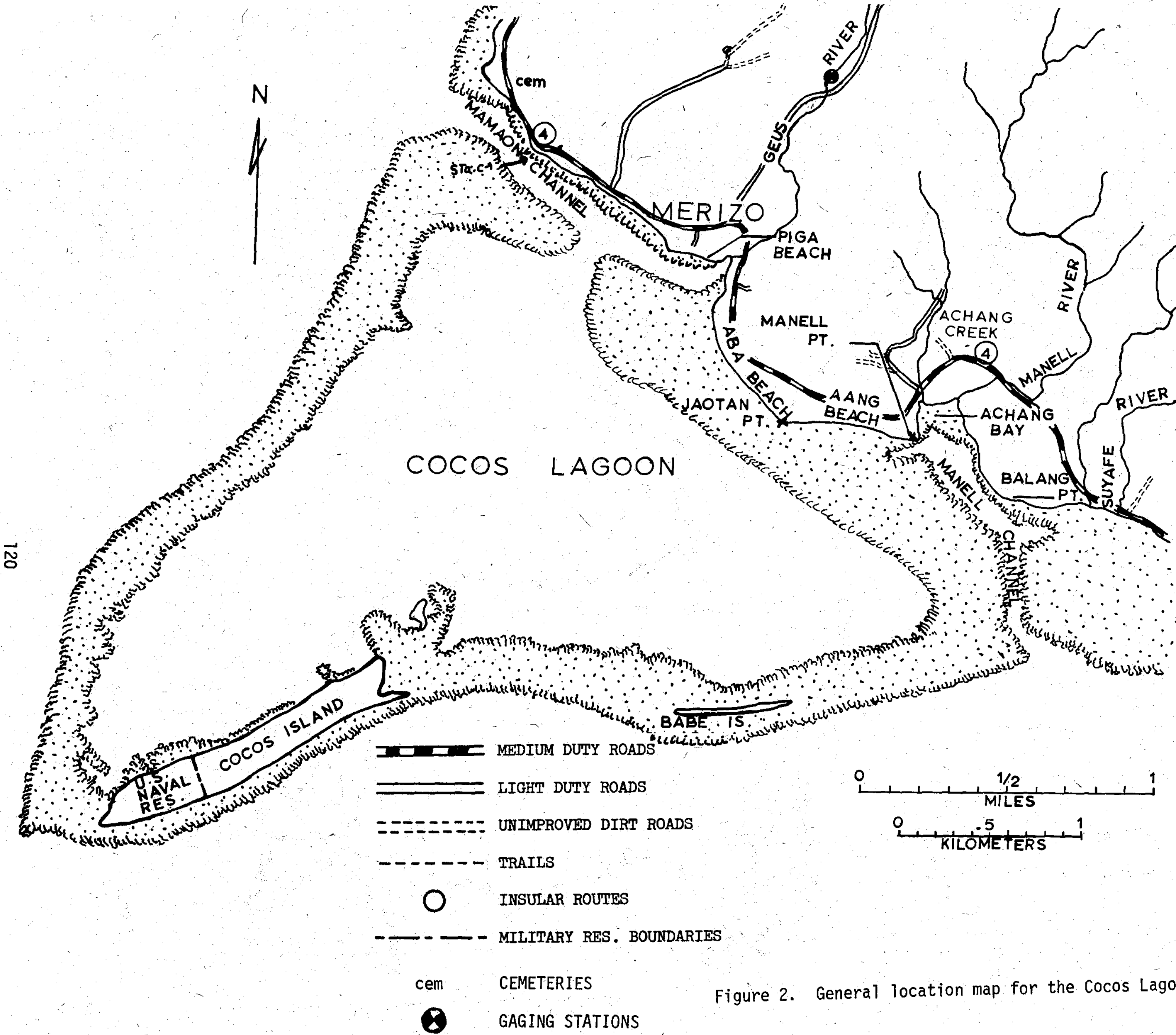

Figure 2. General location map for the Cocos Lagoon study area.

Figure 3. Aerial view of the Cocos Lagoon study area. The village of Merizo borders the landward side of the lagoon. Mamaon Channel cuts through the barrier reef at the upper right and Manell Channel cuts through it at the lower right.

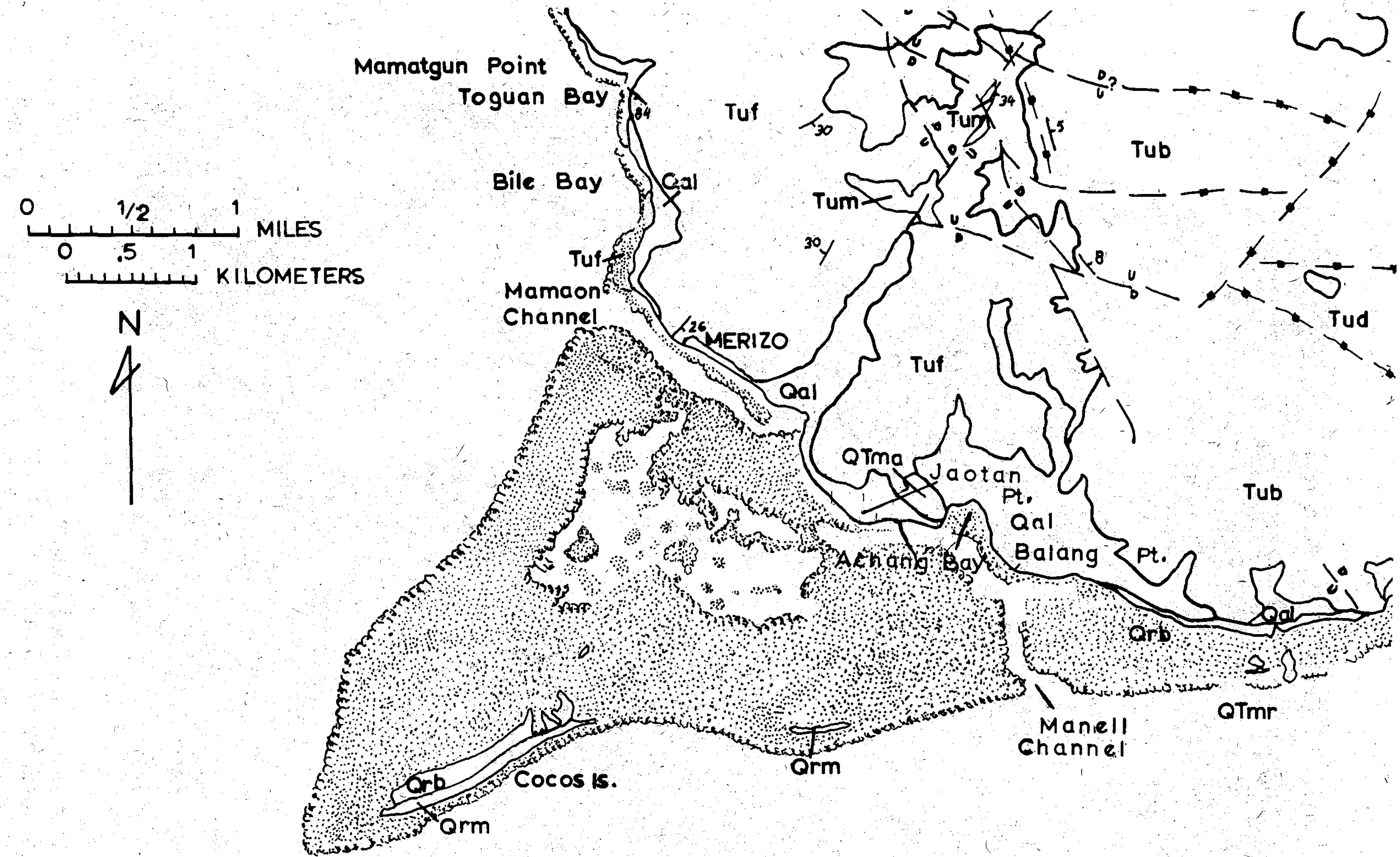

Figure 4. Geologic map for the Cocos Lagoon study area. Rock units designated are: Qal= alluvium, Orb= Beach Deposits, Qrm= Merizo Limestone, QTma= Agana Argillaceous Member of the Mariana Limestone, QTmr= Reef Facies of the Mariana Limestone, Tuf= Facpi Volcanic Member of the Umatac Formation, Tub= Bolanos Pyroclastic Member of the Umatac Formation, and Tum= Maemong Limestone Member of the Umatac Formation. Faults are shown as dashed lines where approximately known. The strike of vertical joints are shown with a (—•— —•—) symbol and the strike and dip of beds are shown with a (30) symbol.

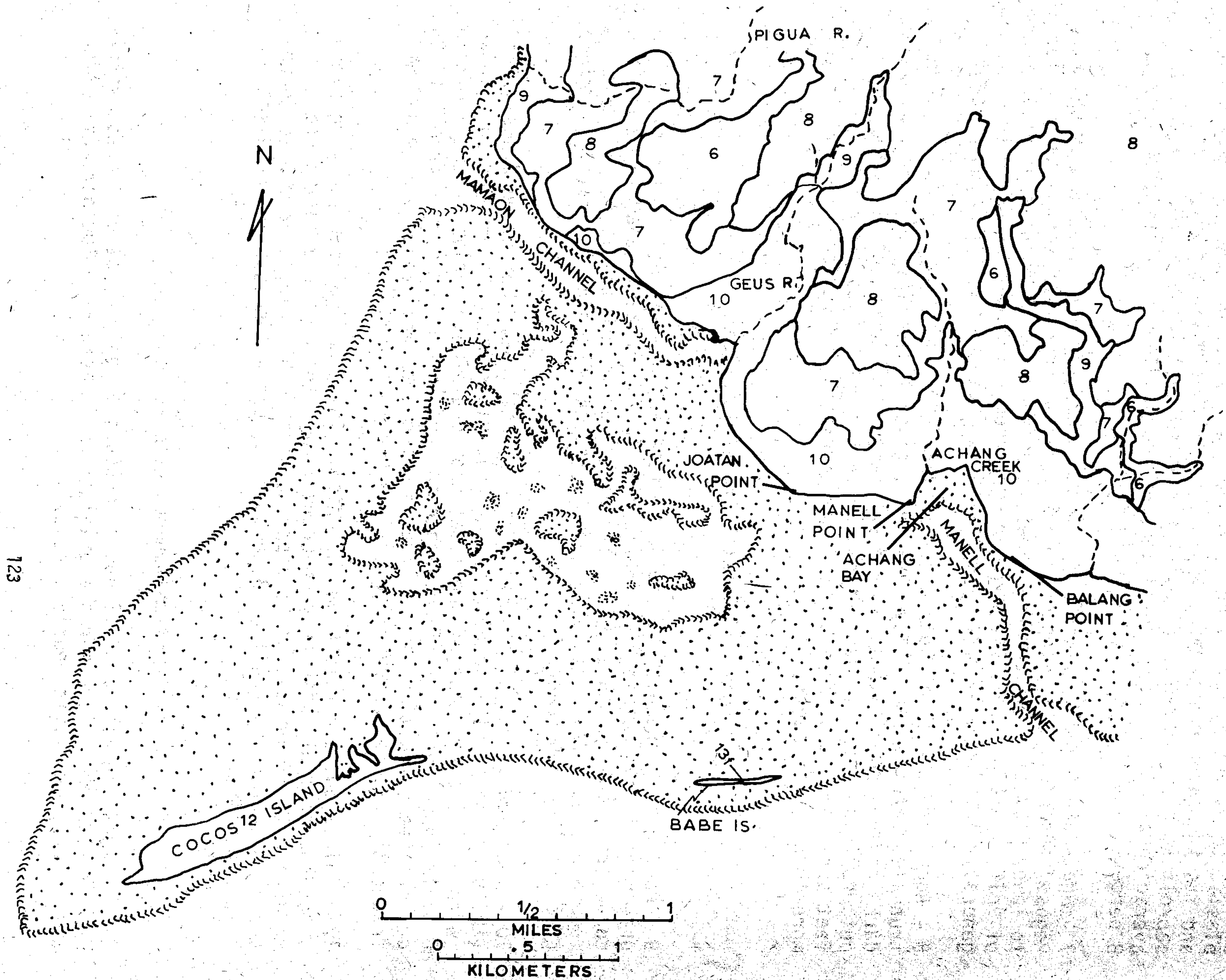

Figure 5. Soil map for the Cocos Lagoon study area. A soil unit explanation legend is given on the following page. Fringing reef-flat and shallow lagoon shelves are stippled.

SOILS EXPLANATION FOR COCOS

Upland Soils (On Volcanic Rocks)

6 - Atate-Agat Clay, Rolling. Remnant benches or small mesas of an old red, granular, porous, acid Latosol (Atate clay) with deep, reddish, mottled, plastic to hard clay C horizon, pale yellow, olive, or gray in lower part; and its truncated counterpart (Agat clay) with similar C horizon of saprolitic clay, ranging in depth from a few feet to about 100 feet, and averaging about 50 feet; prevailing surface gradient of Atate clay is 1 to 8 percent, and of Agat clay 8 to 15 percent.

7 - Agat-Asan-Atate Clays, Hilly. Atate-Agat clays and a dark grayish-brown Regosol (Asan clay) developed in more severely truncated saprolite (similar to lower part of C horizon described in Unit 6); soil depths similar to those of Unit 6, except Asan clay which ranges from a few feet in depth to generally less than 50 feet; prevailing surface gradient 15 to 50 percent.

8 - Agat-Asan Clays And Rock Outcrop, Very Hilly To Steep. Chiefly of the truncated Latosol (Agat clay) and the Regosol (Asan clay) with some un-named dark grayish-brown Lithosols and scattered small areas of volcanic rock outcrop (basalt and bedded tuffs); depth to rock ranges from 0 to 50 or more feet and averages perhaps 20 to 35 feet; prevailing surface gradient 35 to more than 100 percent.

Soils of Coastal and Valley Flats

9 - Pago Clay. Brownish, granular to firm and plastic Alluvial clay, with gray mottling to within 24 to 30 inches of the surface; generally alkaline to neutral; soil depth is generally more than 10 and less than 150 feet; moderately well drained; subject to occasional flooding; prevailing surface gradient 1 to 3 percent.

10 - Inarajan Clay. Similar to Pago Clay but lower, wetter, and shallower (thins out on coastal sands and bedrock); water table at or near the surface (within 30 inches) most of the time; poor drainage, mottlings (gray) within 6 to 12 inches of the surface; depth to sand or bedrock ranges from 3 to 25 or more feet; reaction is alkaline in water saturated zone; poorly drained; frequently flooded; prevailing surface gradient 0 to 1 percent.

12 - Shioya Soils. Pale brown to white, fine-, medium-, or coarse-grained limesand, commonly with grayish-brown loamy sand or sandy loam surface horizon 6 to 18 inches thick; depth to water table ranges from 5 to 25 feet, depth to bedrock ranges from 3 to 35 feet; prevailing surface gradient 1 to 5 percent.

Miscellaneous Land Types

13f - Limestone Rock Land, Steep. Consists largely of steep ridges, scarps, and cliffs; prevailing surface gradient 25 to more than 100 percent, with many scarps or cliffs nearly vertical.

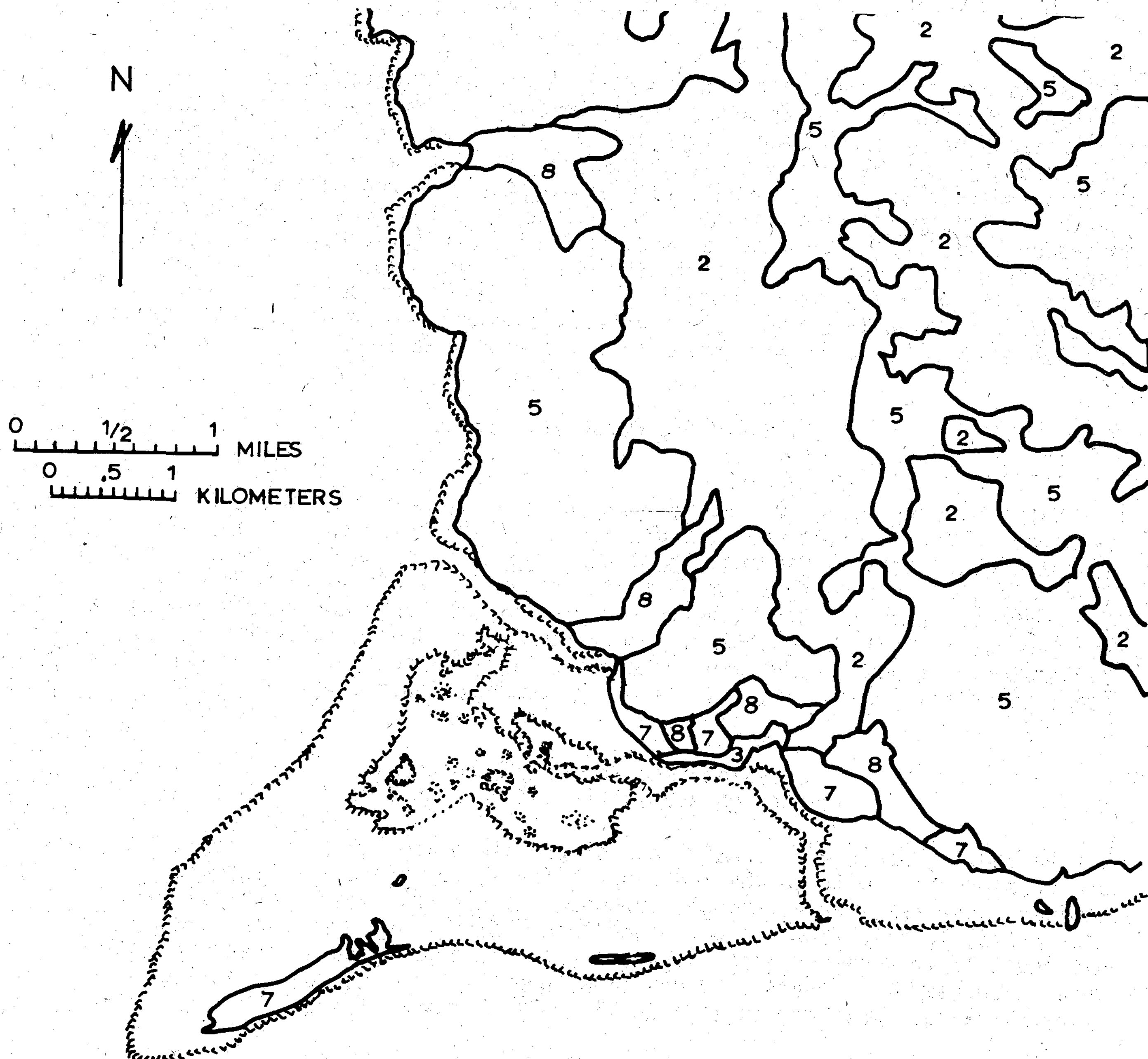

Figure 6. Vegetation map for the Cocos Lagoon study area. A legend explanation for the numbered vegetation units 2, 3, 5, 7, and 8 is given on the following page.

VEGETATION MAP

Explanation of Units

Forest Vegetation

2 - Mixed Forest on Volcanic Soil in Ravines and on Limestone Outcrops in Valleys. Basically a moist broad-leafed evergreen forest dominated locally by hibiscus or by screw-pine (Pandanus), rarely by wild breadfruit (Artocarpus or "dugdug"); usually very mixed, commonly containing betel palm (Areca) and with breadfruit scarce or absent; varies commonly to a dense scrub of limon-de-china (Triphasia) or to patches of reef marsh or hibiscus scrub. Coconut occasional to locally common. Stature generally low (seldom over 40 feet), canopy dense to irregular, large trees locally common and closely spaced; undergrowth generally dense, usually spiny. Concealment generally good; cover fair to usually poor. Some temporary construction timber of poor quality available locally. Unit may include small areas of savanna.

Swamp And Marsh Vegetation

3 - Swamp Forest. Mangrove and Nypa swamps locally near the sea, principally in river valley in river valley mouths, changing upstream to a mosaic of stands of Barringtonia racemosa, Hibiscus, Hibiscus and Pandanus, and reeds (Phragmites). Stature is about 50 feet and canopy is continuous where Barringtonia is dominant; elsewhere stature is much lower and canopy may be continuous, irregular, or absent. Undergrowth very dense, except in Barringtonia stands. Substratum usually mucky and unstable. Concealment good; cover fair to absent. Little or no construction timber.

Grassland And Woody Or Herbaceous Vegetation And Cultivated Or Open Ground

5 - Savanna. Mosaic of several kinds of grassland and herbaceous vegetation and erosion scars with shrubs and tangled ferns. Swordgrass (Miscanthus) dominant over large areas. Small ironwood (Casuarina) trees scattered in many parts, locally forming sparse woodland. Swordgrass very dense, extremely difficult to traverse on foot, leaves likely to lacerate skin; areas of other vegetation easy to traverse. Concealment poor or lacking; cover lacking. Timber lacking. Unit may include small areas of ravine forest.

7 - Coconut Plantation. Vegetation commonly dominated by coconut trees, often planted in rows; trees 10 to 30 feet apart. Canopy 50 to 75 feet high, usually incomplete. Undergrowth usually dense, often very dense, sometimes spiny. Concealment good; cover fair. Coconut logs available.

8 - Predominantly Open Ground And Pasture. Open cultivated ground, pasture-land, dwellings, and thickets. Concealment usually lacking; cover lacking. No timber.

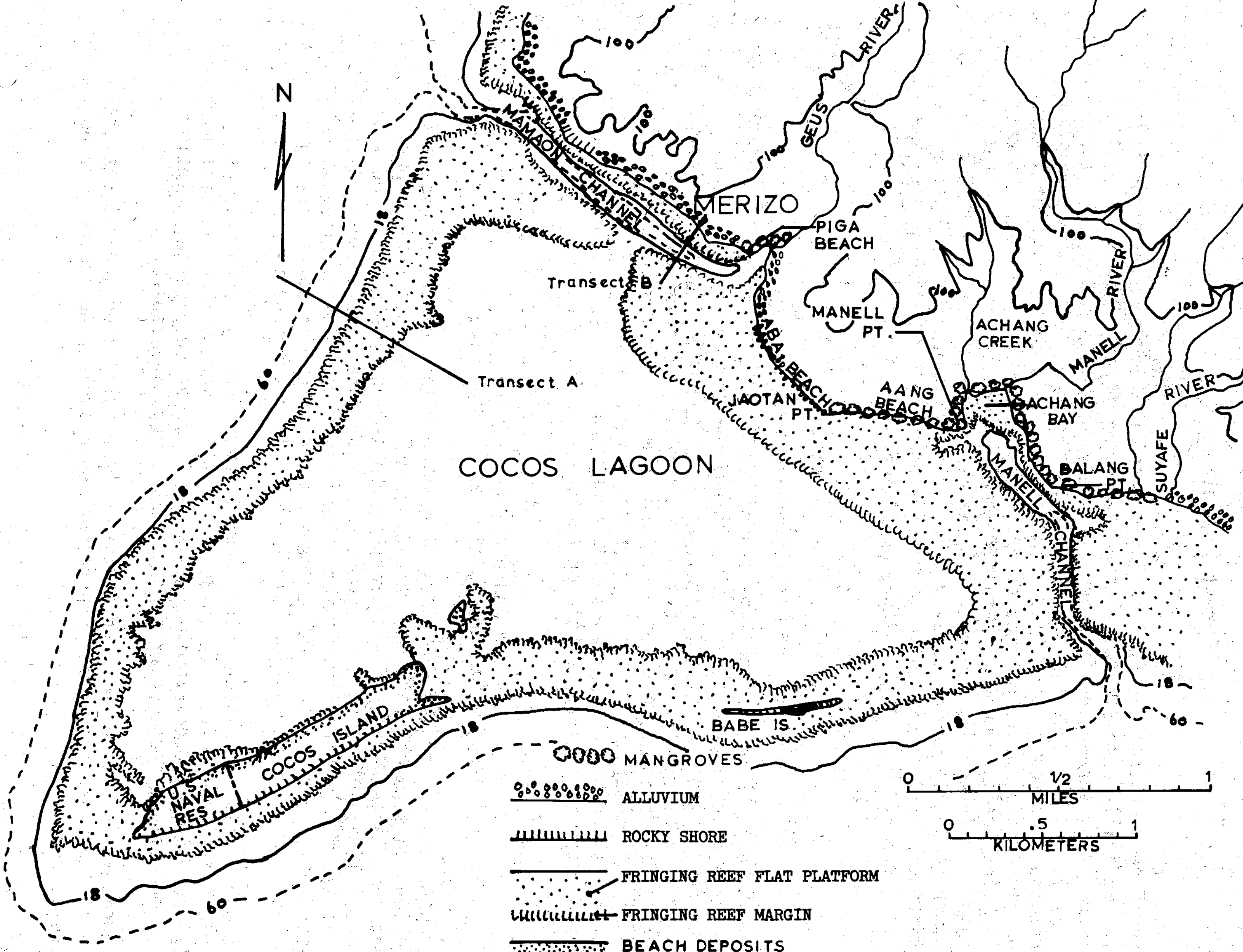

Figure 7. Map showing the 100 foot coastal contour (solid line), rocky shorelines, mangrove shorelines, beach deposits, alluvium, fringing and lagoon reef-flat platforms (stippled areas), reef margin, and the 18 foot (solid line) and 60 foot (dashed line) submarine contour lines for the Cocos Lagoon study area.

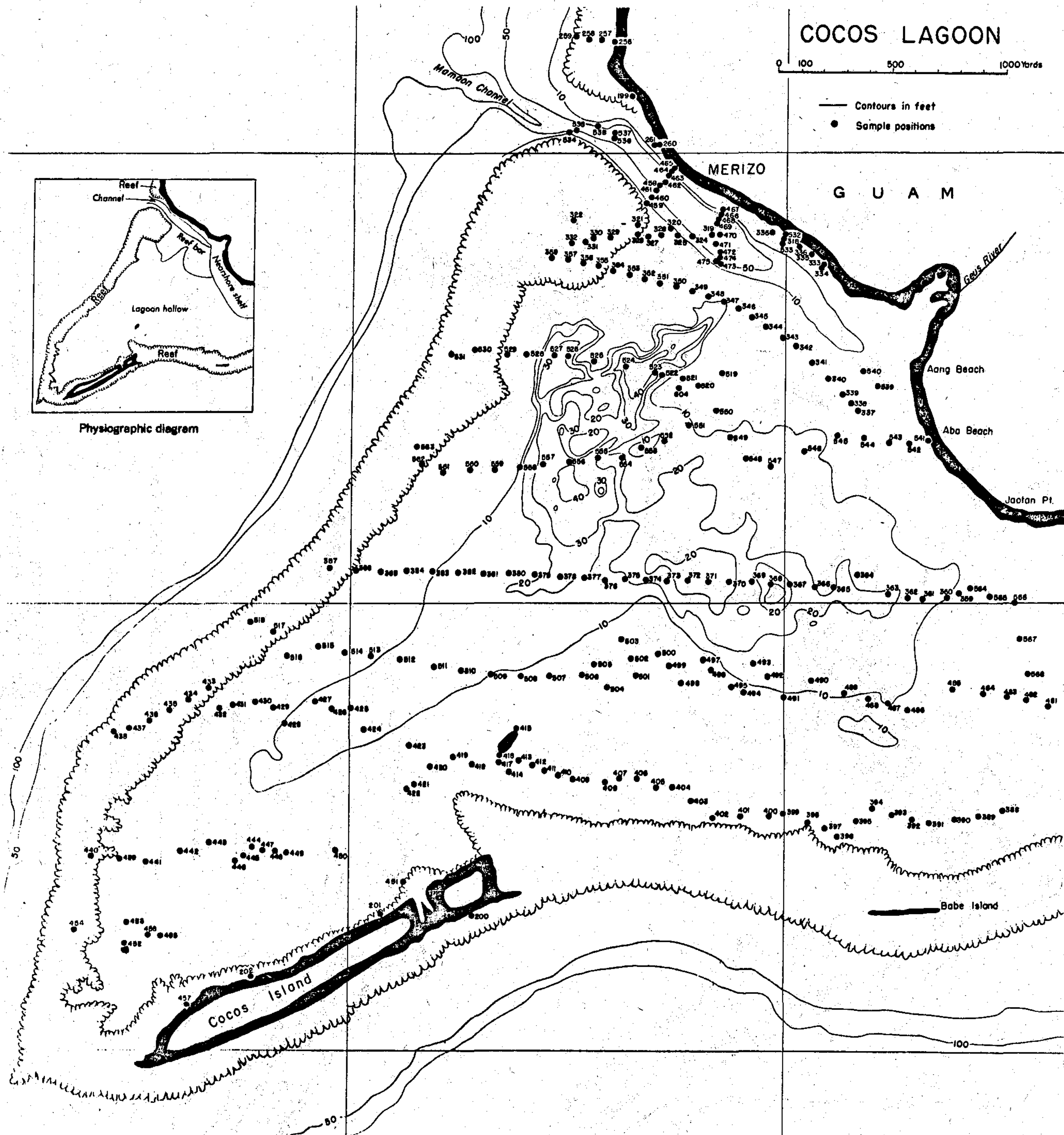

Figure 8. Topography map of Cocos Lagoon, Inset shows the location of the physiographic units, Map from Emery (1962),

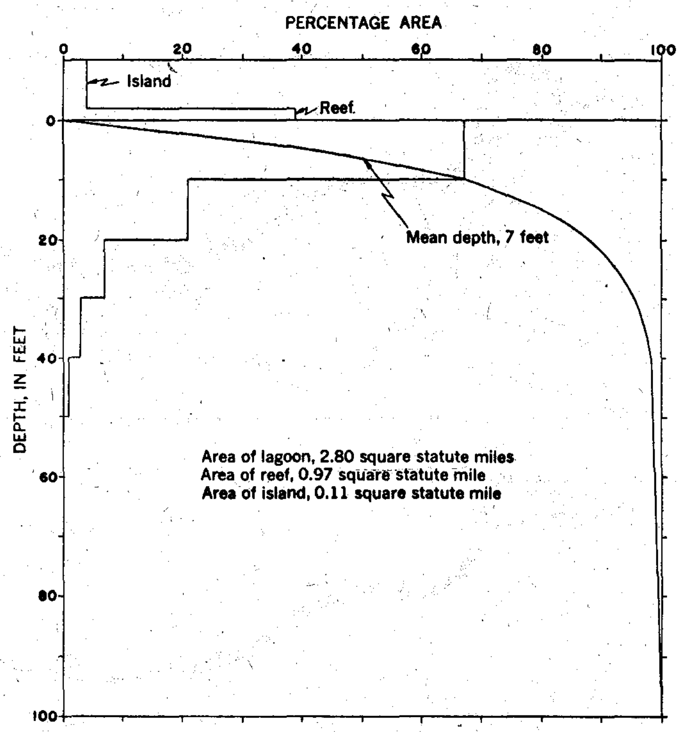

Figure 9. Histogram and cummulative depth curve of Cocos Lagoon. Figure from Emery (1962).

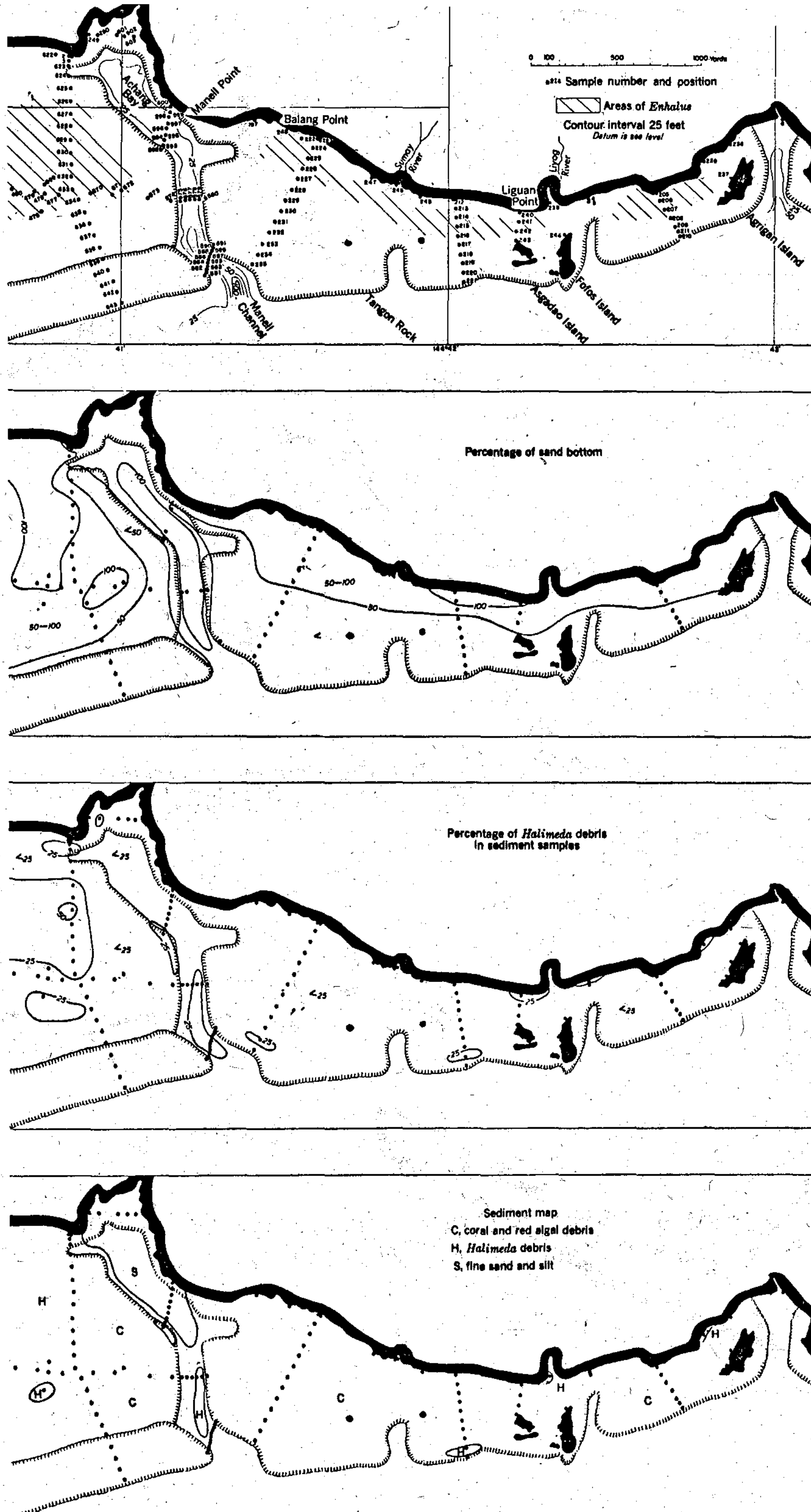

Figure 10. Eastern end of Cocos Lagoon, Manell Channel, and Achang reef flat platform showing topography and surface composition. Figure from Emery (1962).

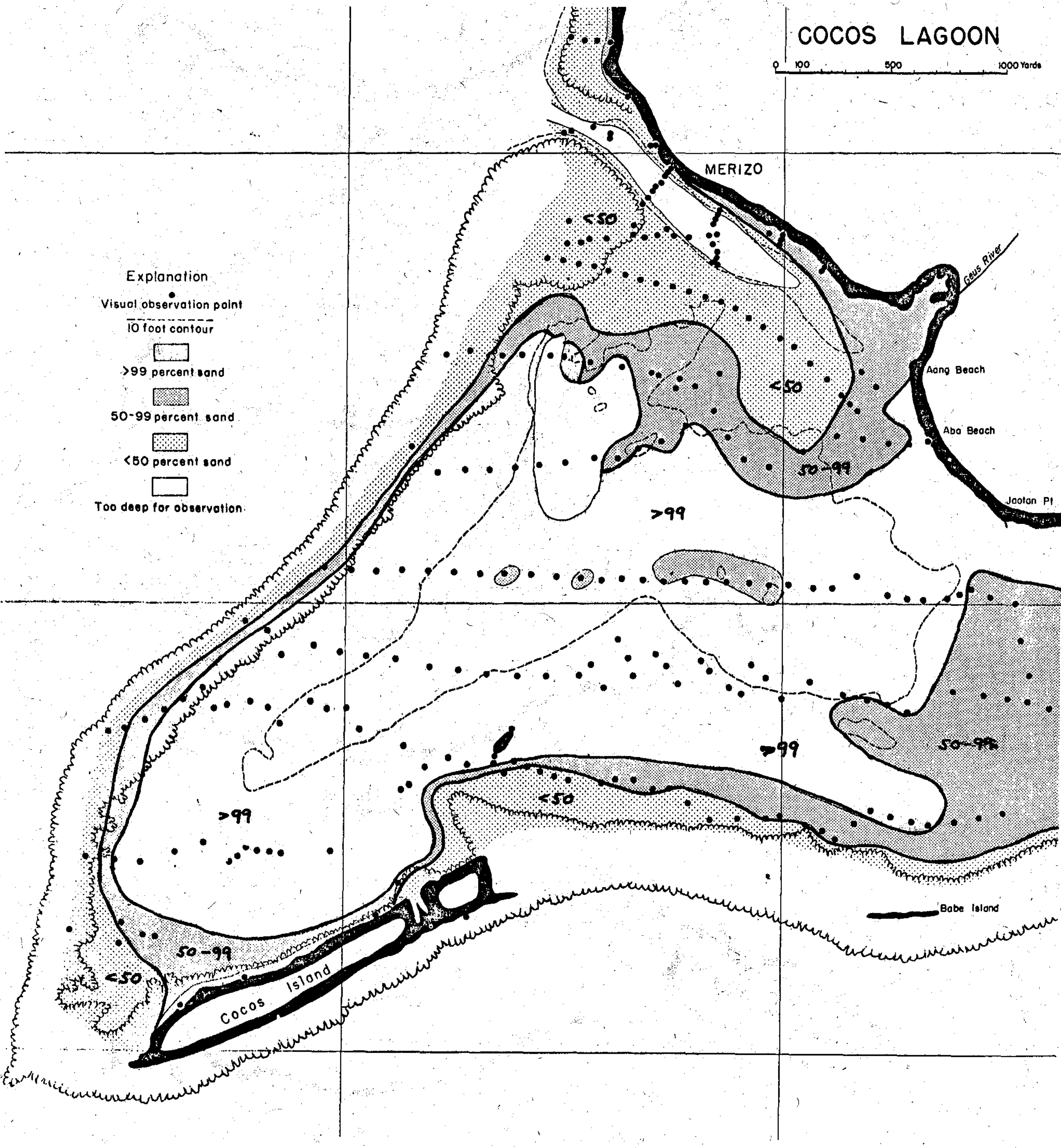

Figure 11. Percentage of sand and coral bottom on the floor of Cocos Lagoon as determined by visual observation. Figure from Emery (1962).

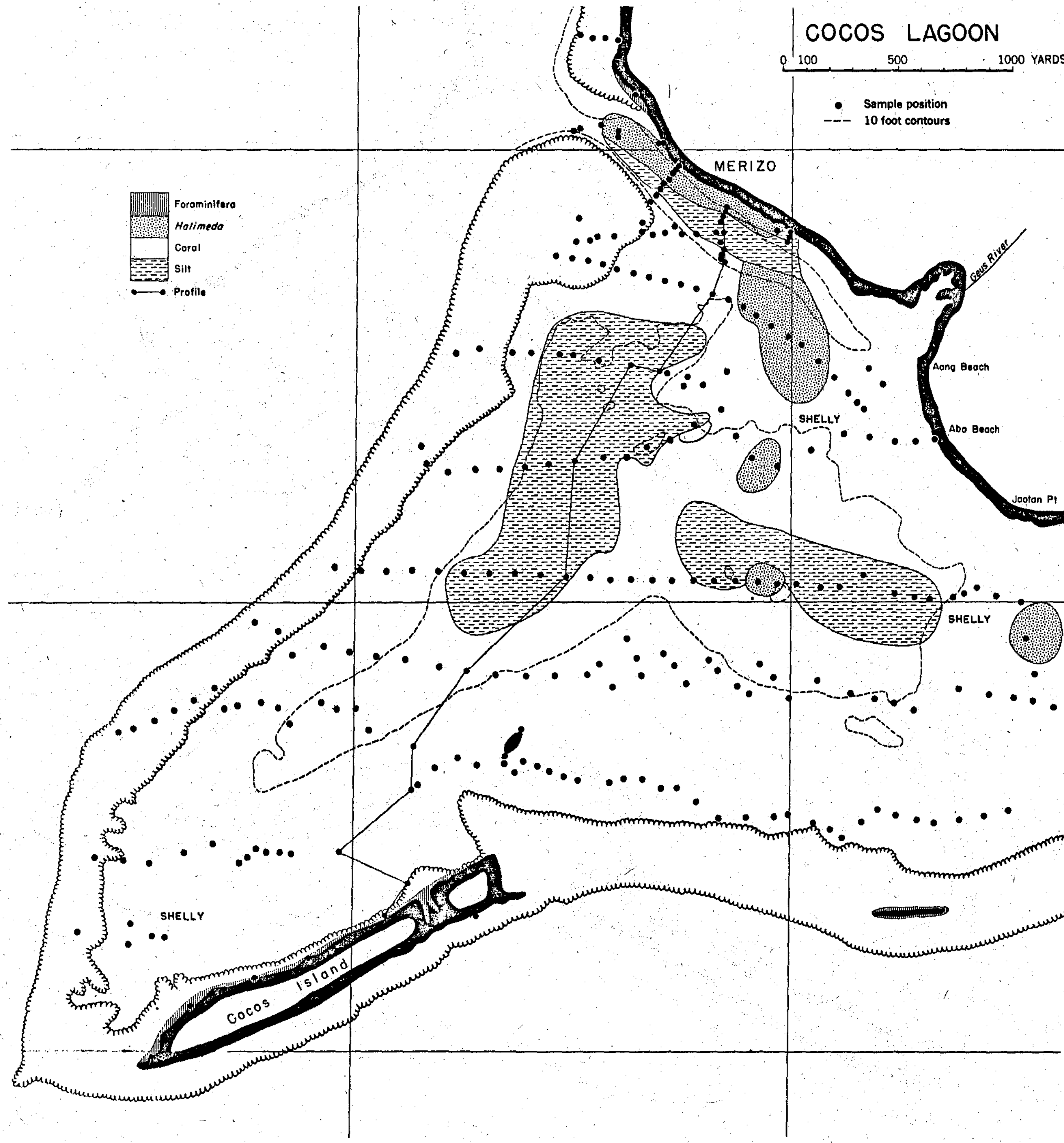

Figure 12. Generalized sediment map of Cocos Lagoon. Map from Emery (1962).

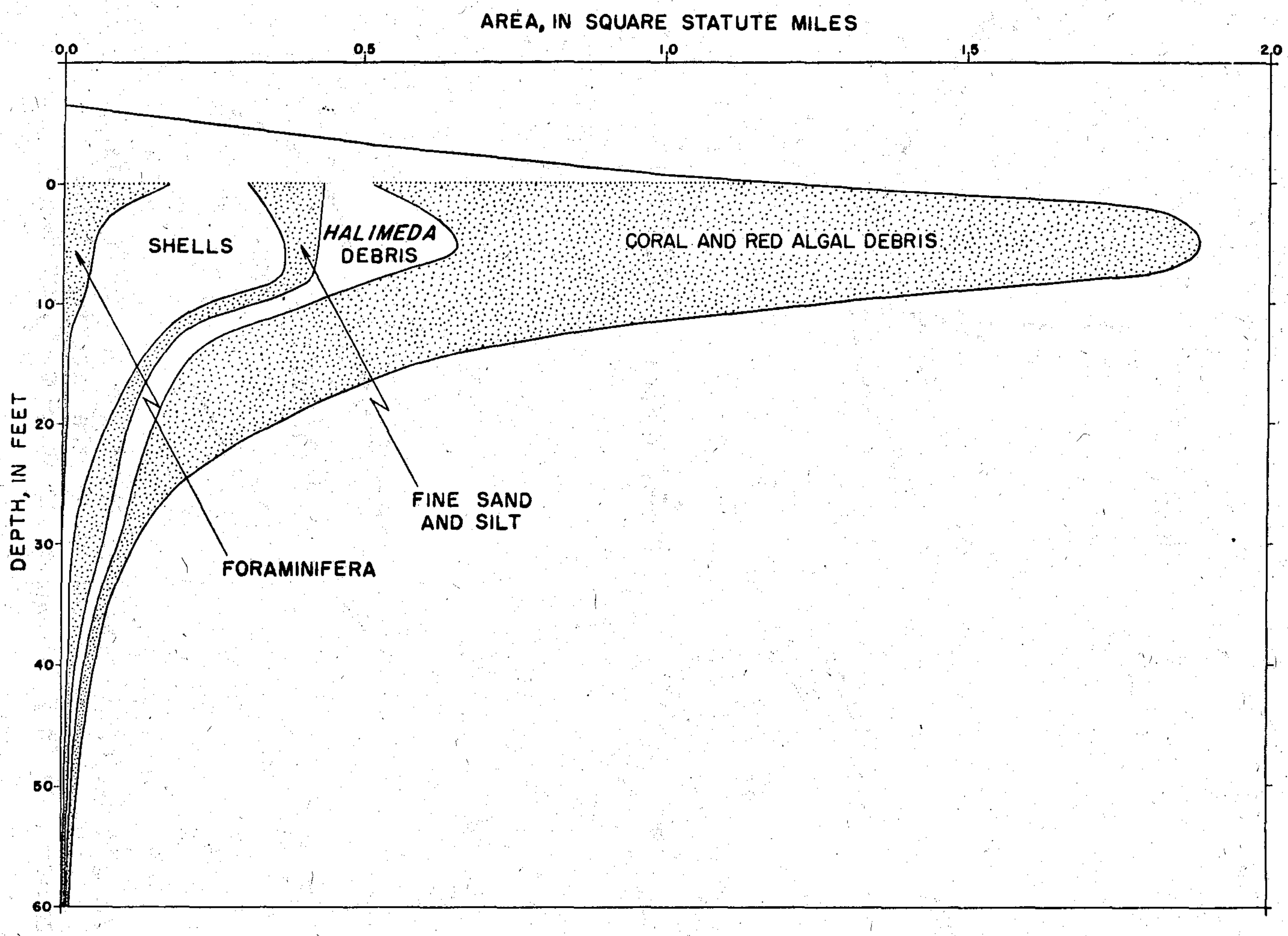

Figure 13. Vertical distribution of sediment composition corrected for actual area of the lagoon floor at various depths. From Emery (1962).

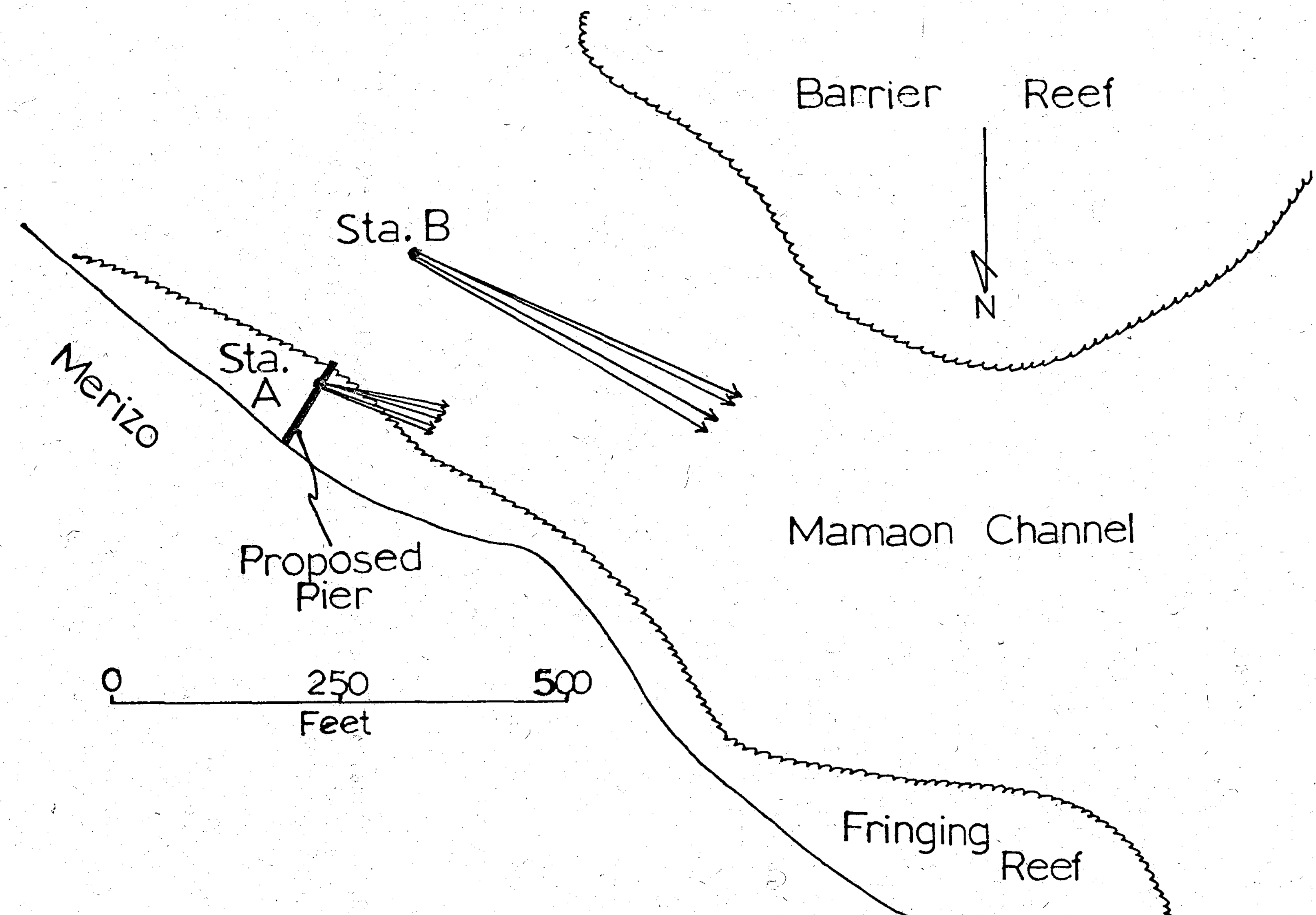

Figure 14. Drift cross and dye plume tracts at Station A and drift cross tracts at Station B. See Figure 19 for the location of the study (Station C-1) in relation to the whole of Cocos Lagoon.

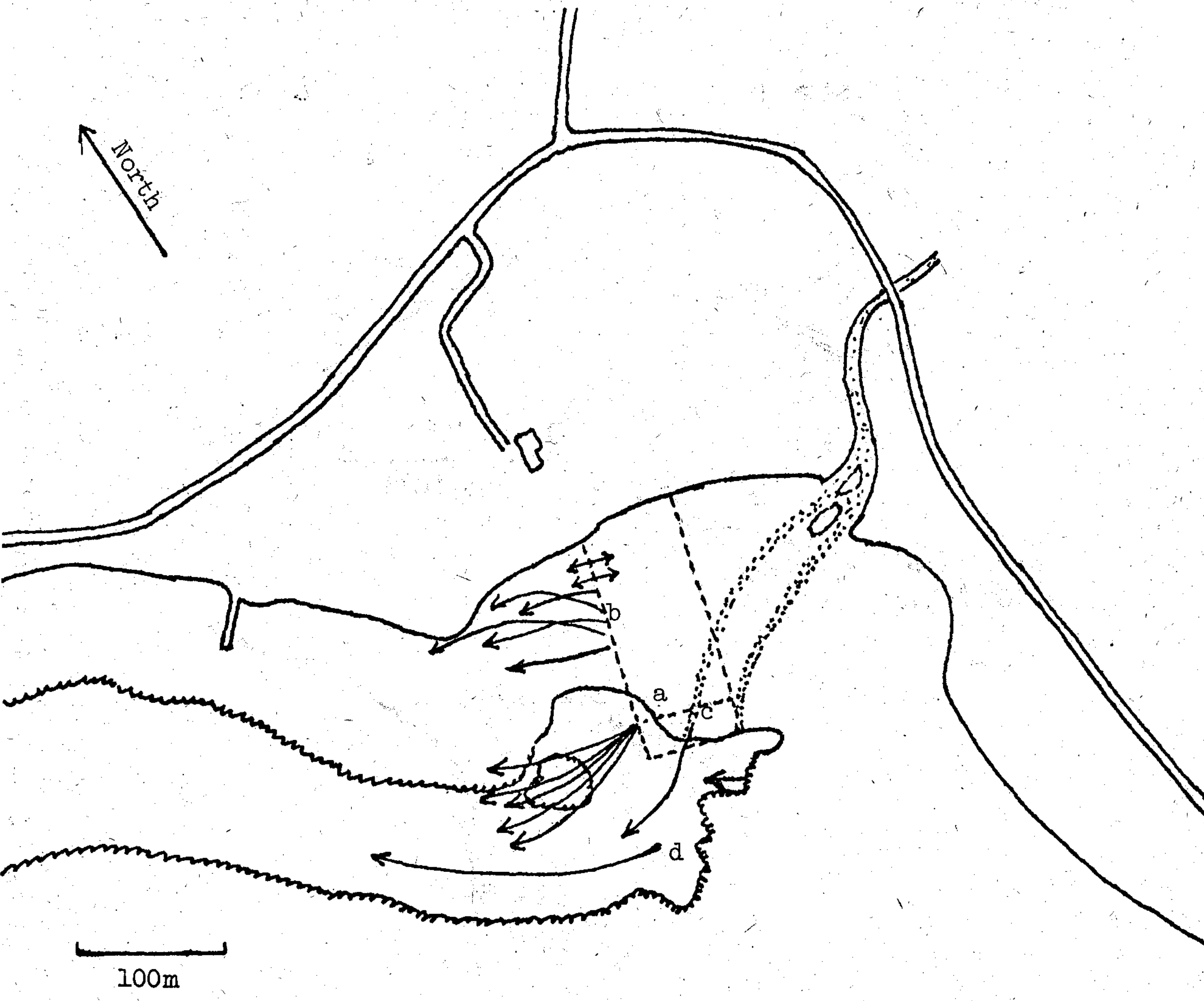

Figure 15. Dye plume tracts at the head of Mamaon Channel. The dashed lines enclose a proposed boat marina and the stippled area indicates the channels of the Geus River where they cross the reef-flat platform. Point (a) is the primary current sample station, Point (b) is the location of a series of stations along the reef flat at 10 m intervals, Point (c) is a river channel station taken at a minus tide, and Point (d) is the location of two dye releases made in Mamaon Channel.

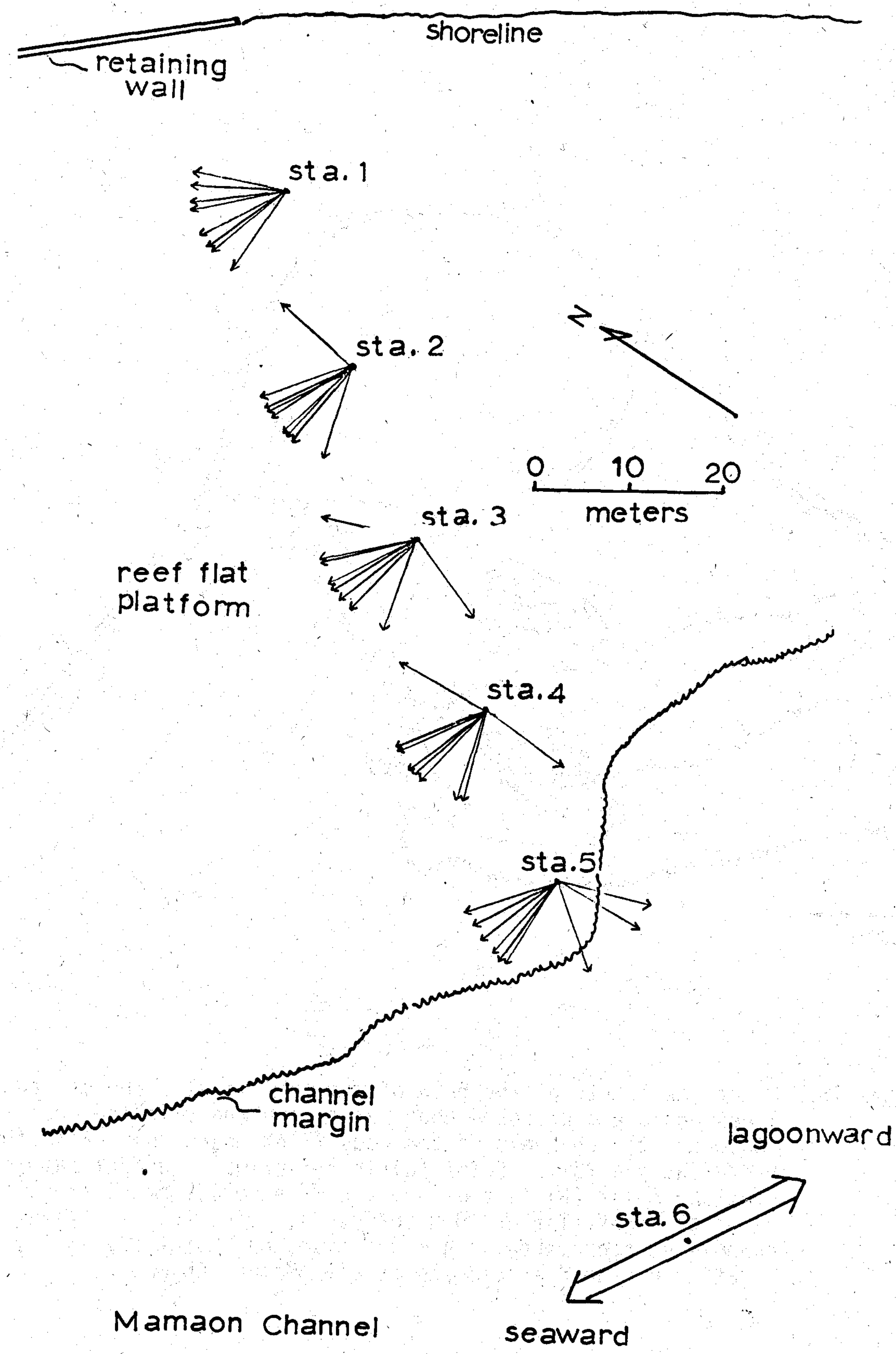

Figure 16. Current patterns on the reef-flat platform and in adjacent Mamaon Channel. Stations 1-5 are 20 meters apart. Station 6 is located in the middle of Mamaon Channel. See Figure 19 for the location of the study (Station C-3) in relation to the whole of Cocos Lagoon.

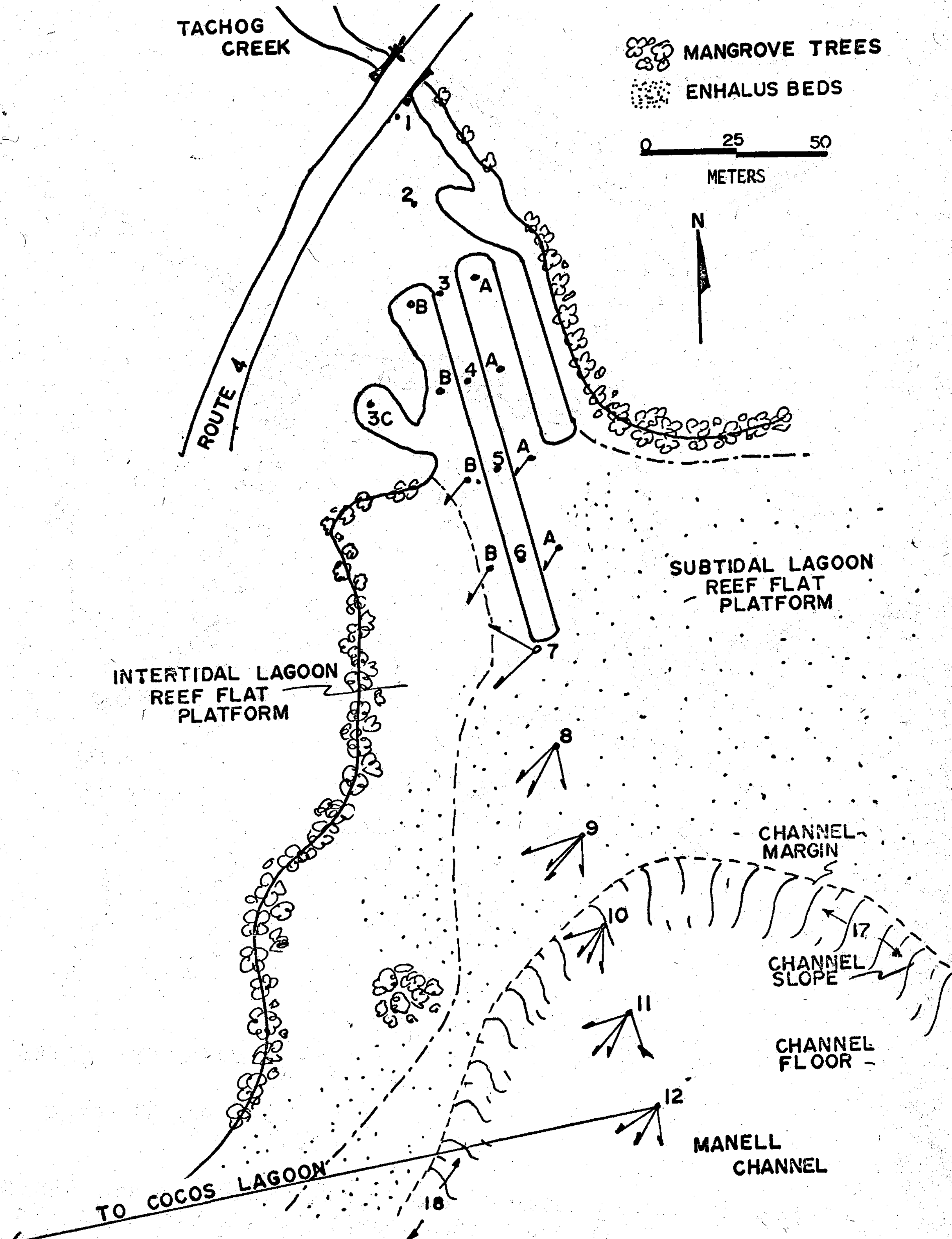

Figure 17. Current patterns on the fringing reef-flat platform (Biotope I, Facies E) for Stations 1-12. A summary of the current data is given in Table 9. Stations 17 and 18 are the locations of Coral Transects 30 and 31 respectively.

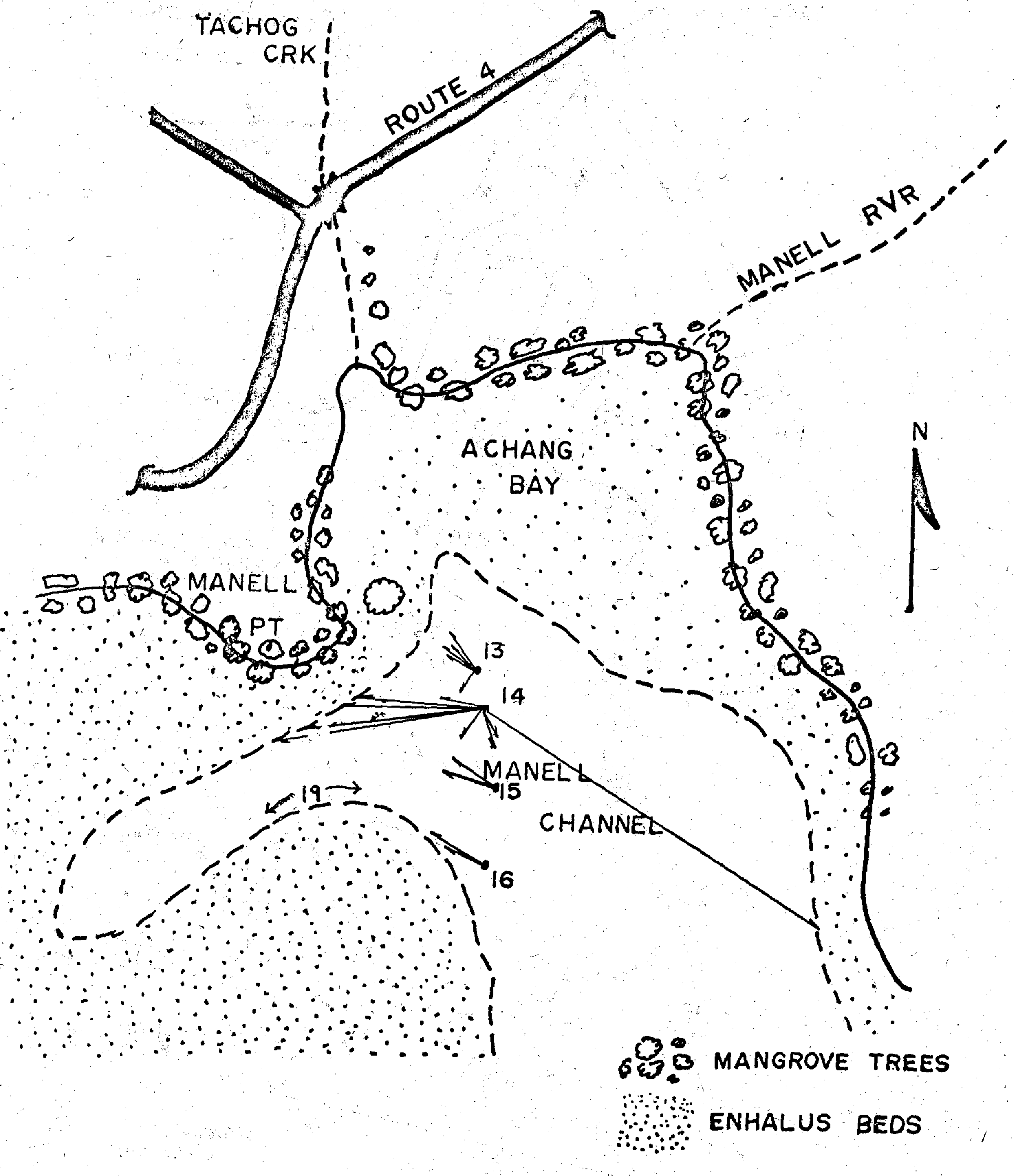

Figure 18. Current patterns at the head of Manell Channel (Biotope II) for Stations 13-16. A summary of the current data is given in Table 9. Station 19 is the location of Coral Transect No. 32.

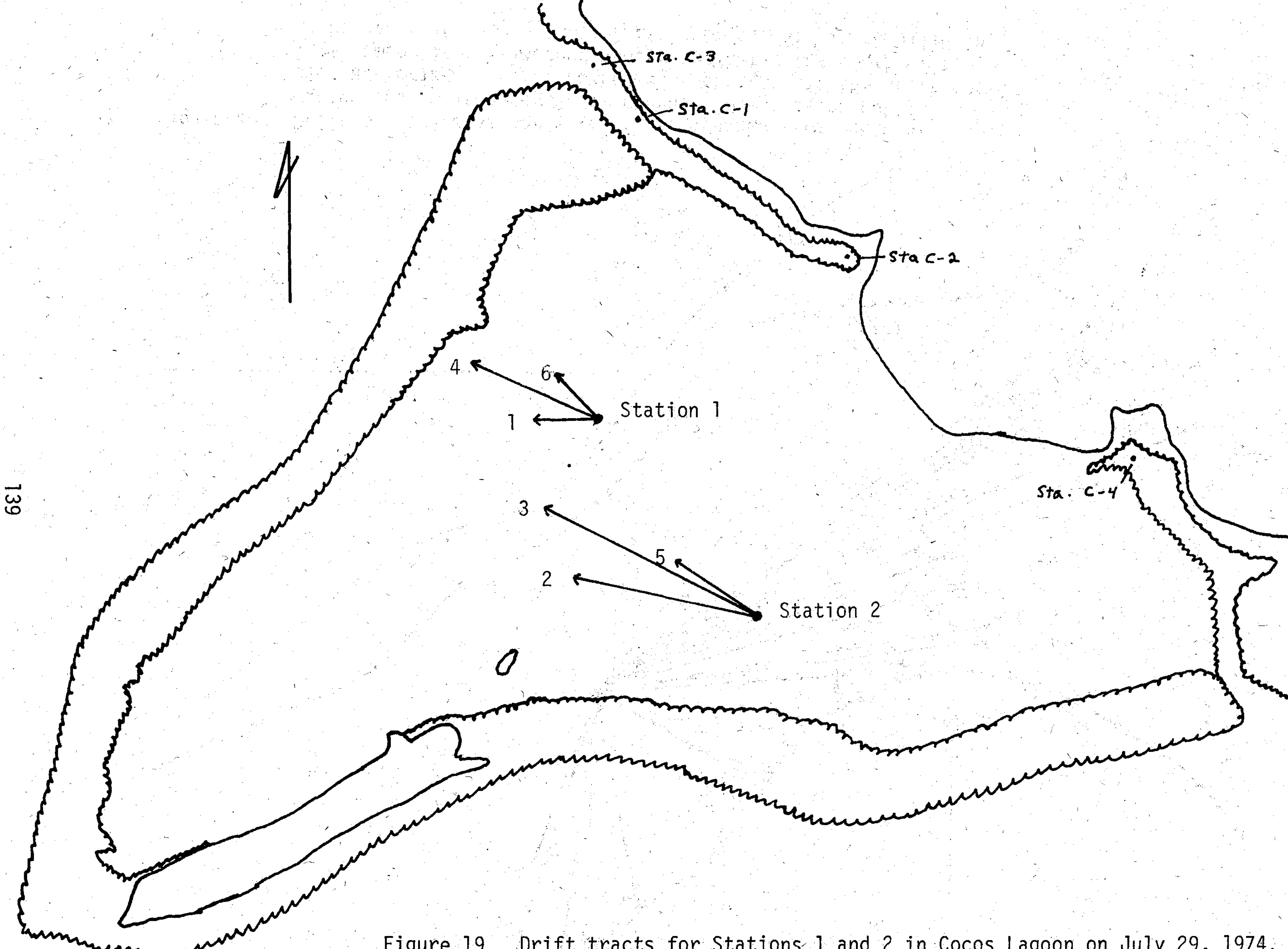

Figure 19. Drift tracts for Stations 1 and 2 in Cocos Lagoon on July 29, 1974. Other data for the drift cross tracts (1-6) are shown on Table 10. The locations of other current studies are also shown.

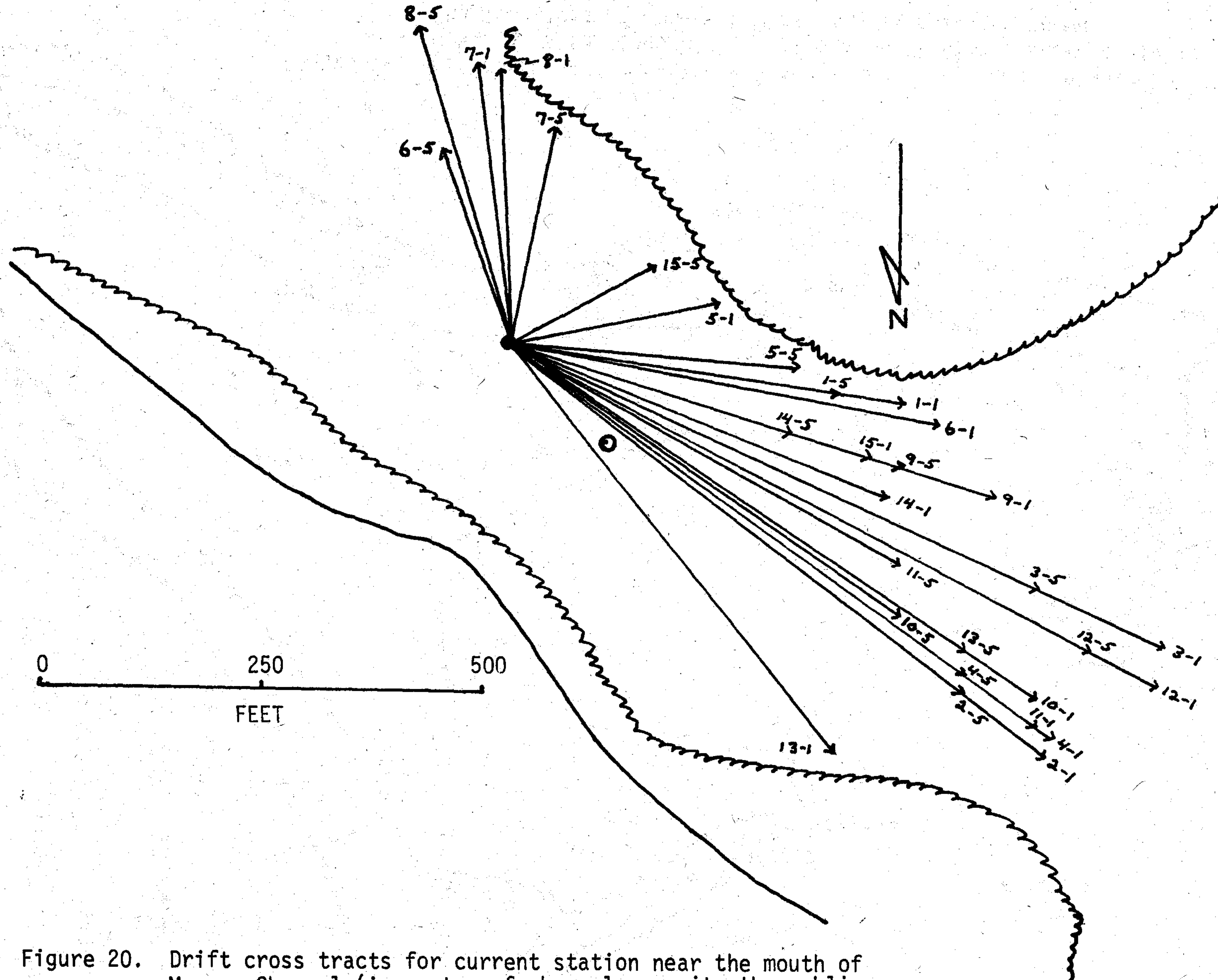

Figure 20. Drift cross tracts for current station near the mouth of Mamaon Channel (in center of channel opposite the public pier at Merizo). First number of each tract is the drift cross, last number and the second number indicates the depth of the drift cross in meters. Other drift cross data is compiled in Table 11.

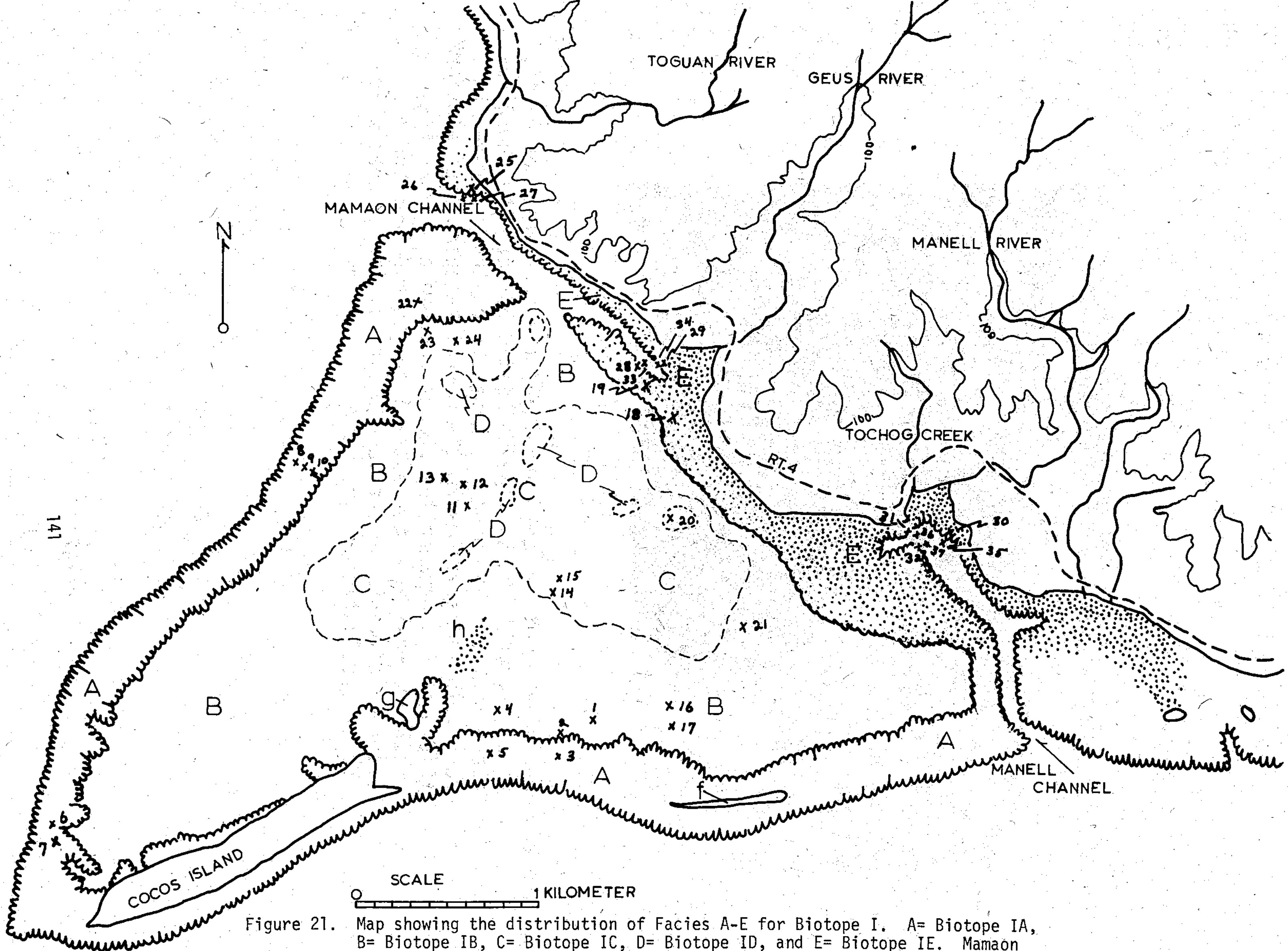

Figure 21. Map showing the distribution of Facies A-E for Biotope I. A= Biotope IA, B= Biotope IB, C= Biotope IC, D= Biotope ID, and E= Biotope IE. Mamaon and Manell Channels constitute Biotope II. See Figure 37 for the distribution of Facies A-E for Biotope II. Cocos Island= Biotope IIIA, Babe Island (f)= Biotope IIIB, and the landward border of Cocos Lagoon= Biotope IIIC. Sand islet= (g) and (h)= the location of a Halodule uninervis sea grass bed. The stippled area along the landward border of the lagoon shows the distribution of the Enhalus acoroides sea grass beds. Numbers 1-37 show the location of the coral transects (Table 13).

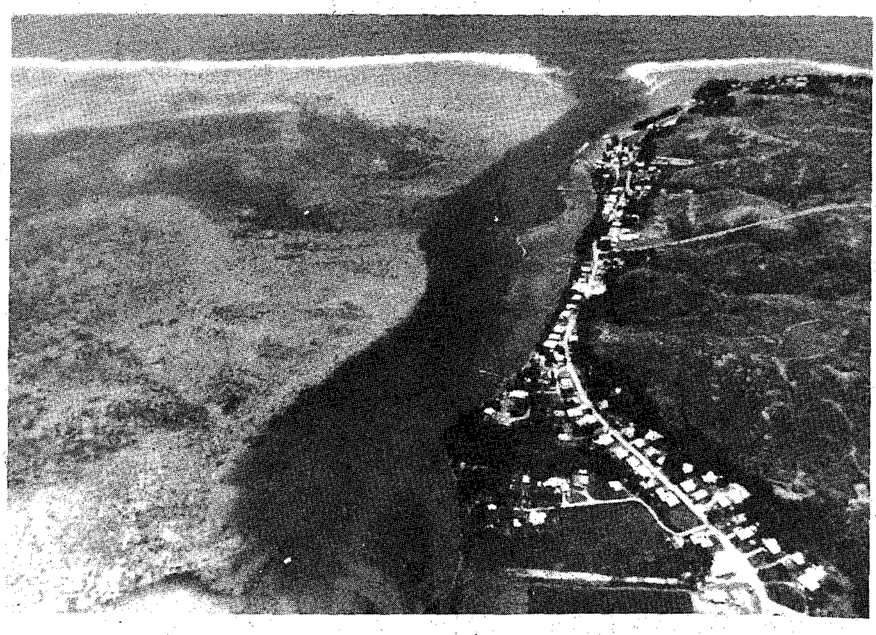

Figure 22. Aerial view of Mamaon Channel and the northeast corner of Cocos Lagoon. The village of Merizo borders the shoreline along much of the channel. Note the contrast between the dark colored sediments on the narrow fringing reef platform (Biotope IE), between the channel margin and shoreline, which are mostly of terrestrial origin and the lighter colored sediments on the lagoon side of the channel which are of bioclastic origin.

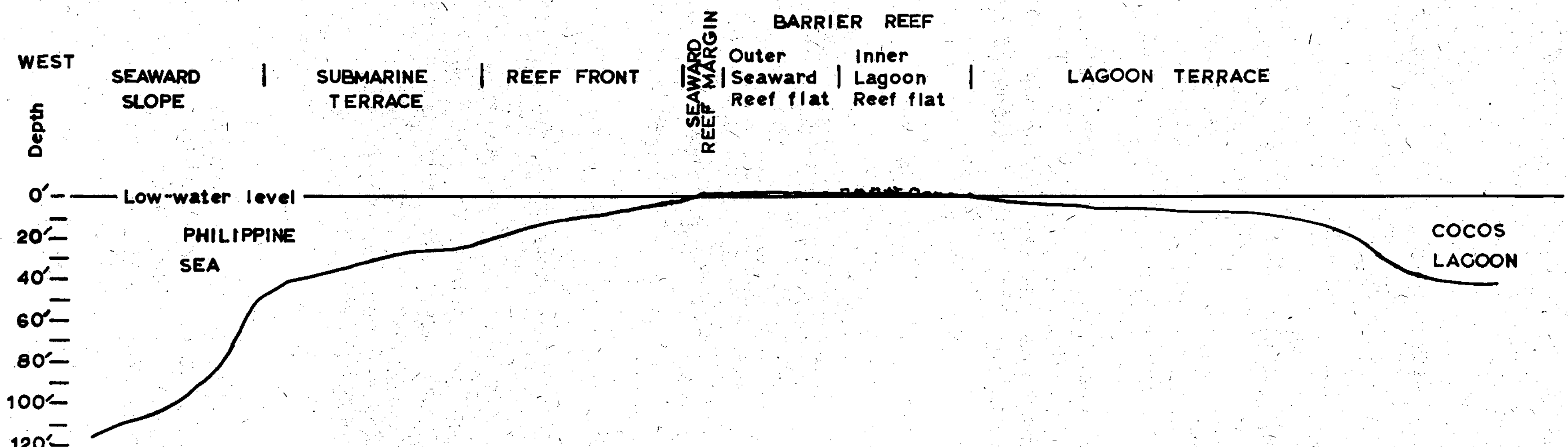

Figure 23. Vertical profile (A) of the northern barrier reef and lagoon. See Figure 7 for location of the transect.

Figure 24. A view toward the east on the southern barrier reef flat platform (Biotope I, Facies A). The outer seaward zone is flat and pavement-like and on the left scattered boulders can be seen on the inner lagoonward part of the reef flat.

Figure 25. Boulder rubble on the lagoonward side of the southern barrier reef flat platform. Most of the boulder debris is composed of corals and reef rock that have been broken loose and transported from the seaward side of the barrier reef by typhoon or storm waves.

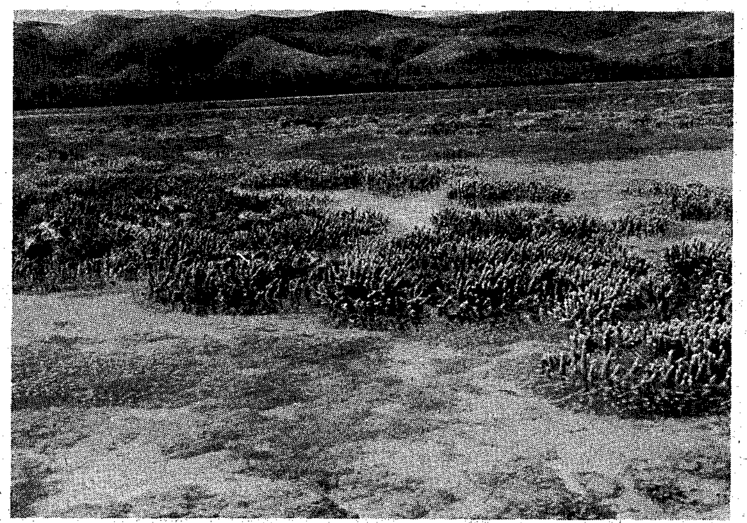

Figure 26. A lagoonward view of the lagoon terrace or shelf (Biotope I, Facies B) taken from the point where it grades into the barrier reef flat surface. Note the exposure of the tips of the Acropora hebes thickets.

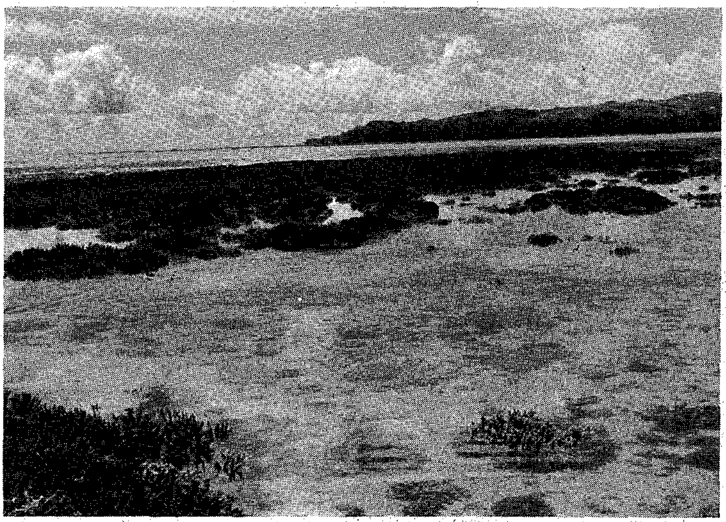

Figure 27. A large thicket of mixed arborescent Acropora species (dark area in background) over a kilometer across which has developed on the shallow lagoon terrace (Biotope I, Facies B) at the southeast corner of Cocos Lagoon. The upward growth of these thickets is controlled by the low tide level which gives the thicket an even flattened appearance. Much of the central part of the thicket has been killed by repeated exposure during low spring tides.

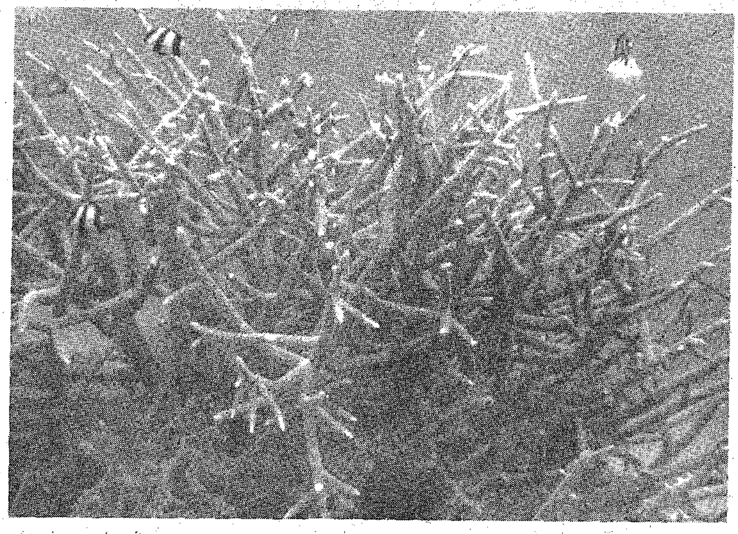

Figure 28. A bushy clump of Acropora formosa about 1.5 meters high growing in a deeper part of the lagoon terrace (Biotope I, Facies B).

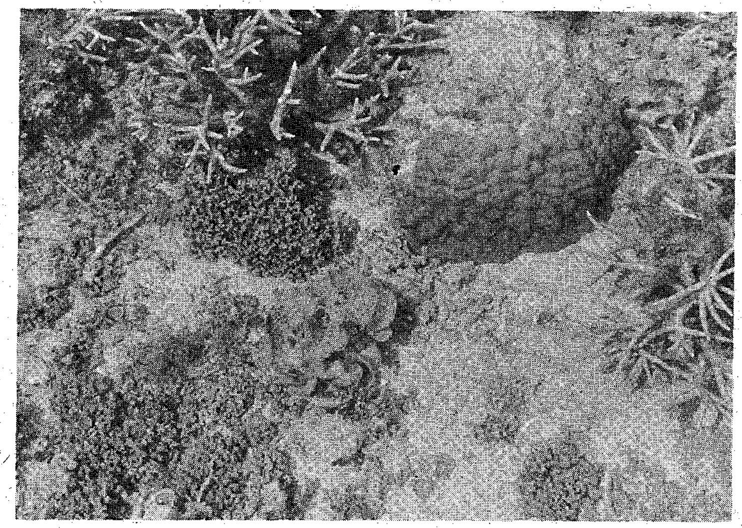

Figure 29. Small nodular colonies of Psammocora contigua and a massive head of Porites lutea growing between Acropora aspera thickets on the lagoon terrace (Biotope I, Facies B) along the eastern end of the southern barrier reef.

Figure 30. Cone-shaped mounds formed by the burrowing activity of marine worms on the Cocos Lagoon floor (Biotope I, Facies C). Height of the mounds is about 30 cm.

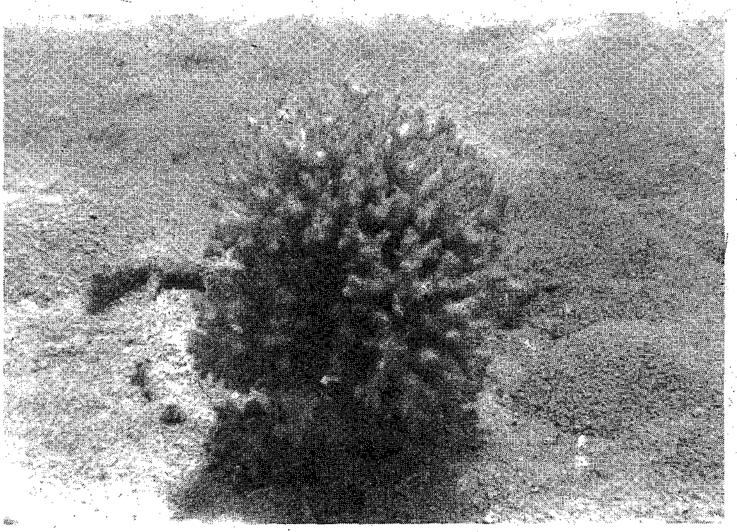

Figure 31. Small Pocillopora damicornis colony growing on isolated piece of coral rubble on the sandy floor of Biotope I, Facies C. Note the small mounds in the vicinity built by burrowing worms.

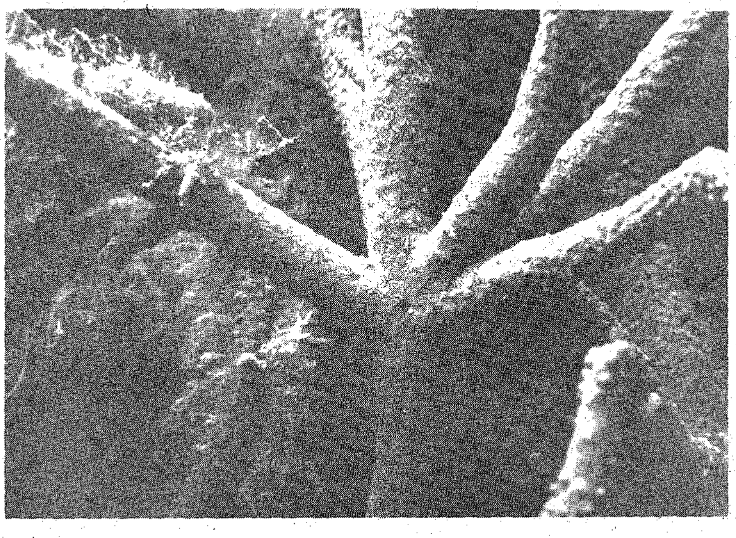

Figure 32. Black sponge, Terpios sp., encrusting and killing a branch of Acropora formosa growing at the base of a large mound in Biotope I, Facies D.

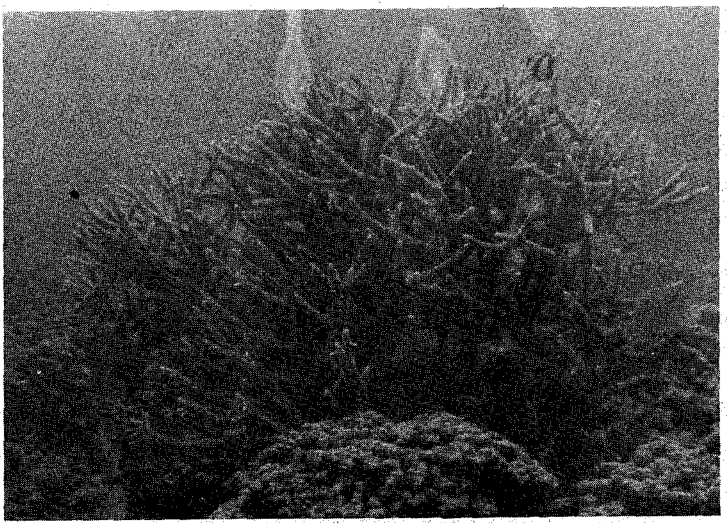

Figure 33. Upper surface of a coral mound (Biotope I, Facies D) which is dominated by large Acropora formosa and Porites (S.) iwayamaensis colonies. Height of this mound is about four meters.

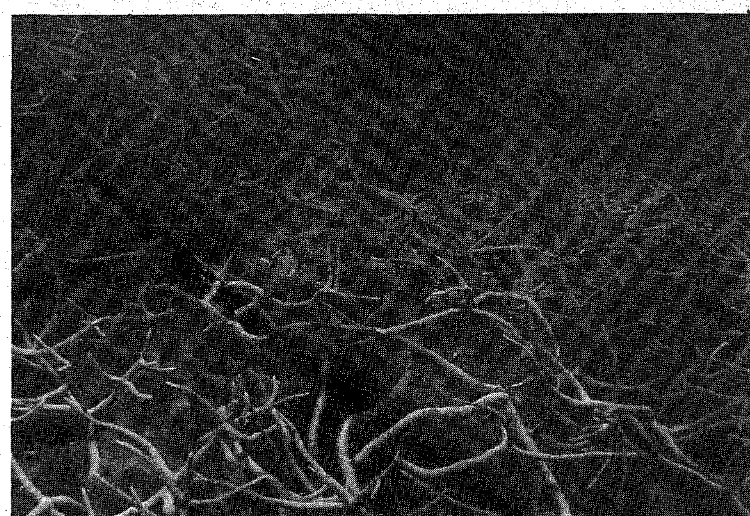

Figure 34. Mound (Biotope I, Facies D) dominated by a laxly branched arborescent coral _Acropora teres_.

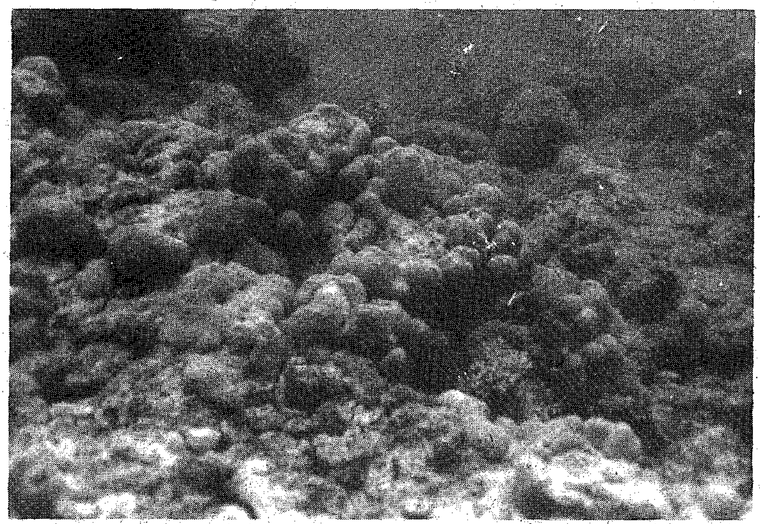

Figure 35. Side of a coral mound (Biotope I, Facies D) dominated by Porites lutea colonies with massive rounded to nodulated growth form.

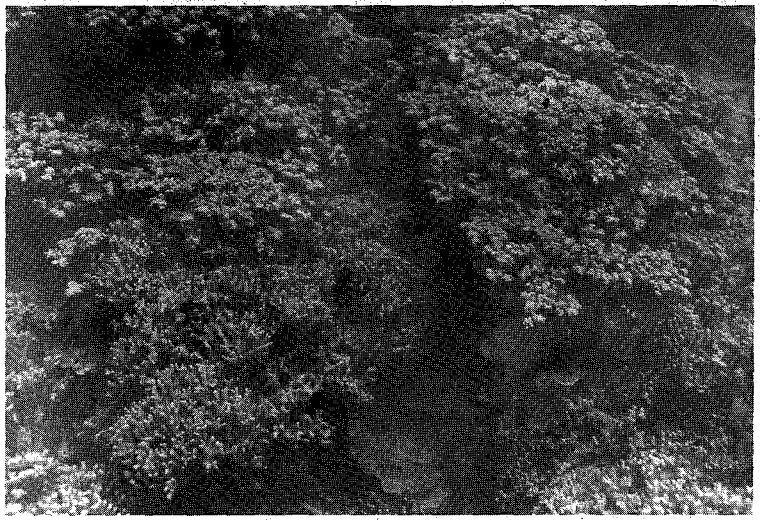

Figure 36. Coral mound (Biotope I, Facies D) dominated by columnar Porites (S.)iwayamaensis and ramose Porites andrewsi colonies

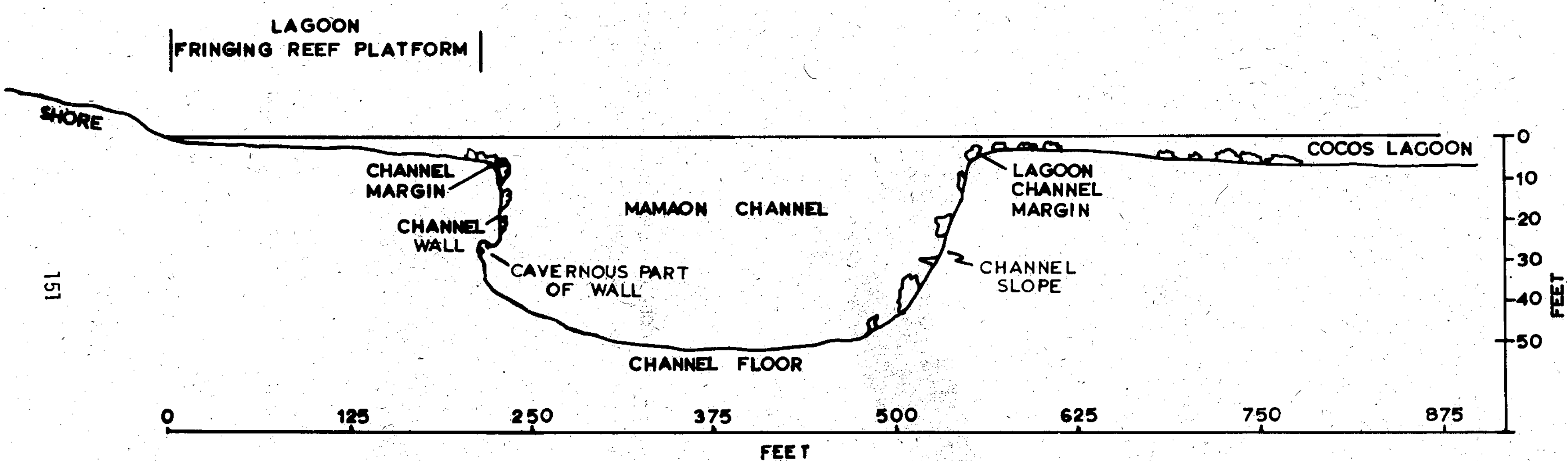

Figure 37. Vertical profile (Transect B) through Mamaon Channel showing the various facies of Biotope II. Facies A= channel margin, Facies B= channel slope, Facies C= channel wall, Facies D= cavernous parts of the channel slopes or walls, and Facies E= channel floor. See Figure 7 for the location of Transect B.

Figure 38. Holothuria edulis, a common sea cucumber found on the channel slope and floor and lagoon terrace and floor.

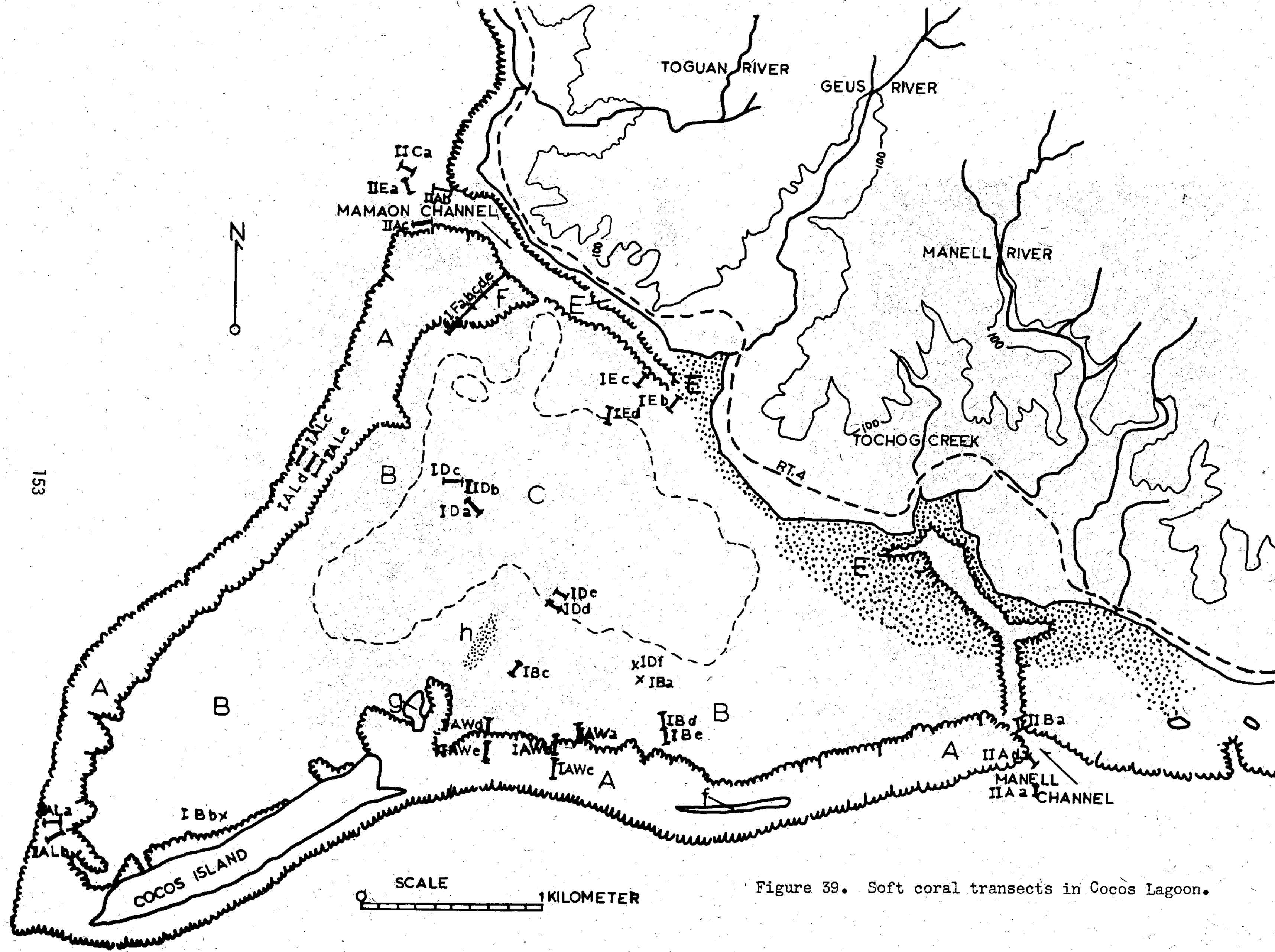

Figure 39. Soft coral transects in Cocos Lagoon.

Figure 40. Sinularia conferta v. gracilis.

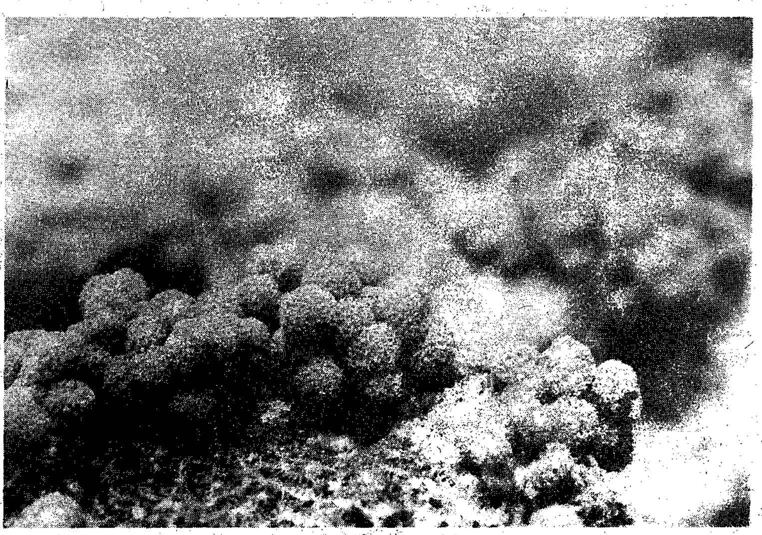

Figure 41. Asterospicularia sp.

Figure 42. Sarcophyton sp.

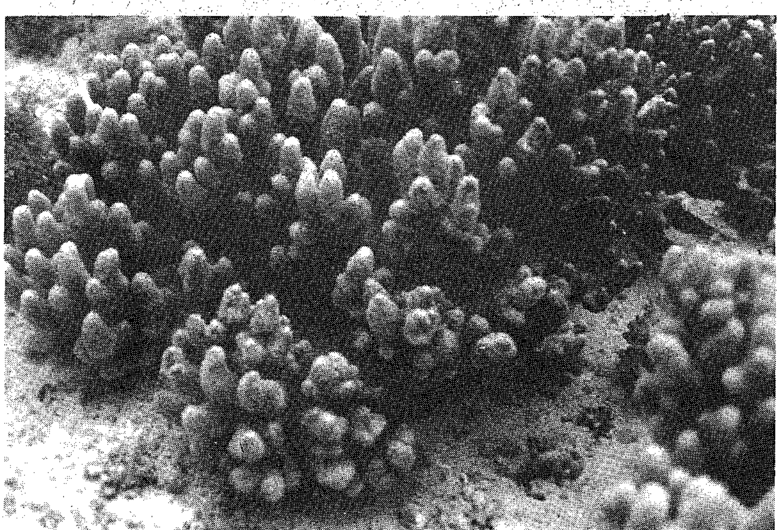

Figure 43. Sinularia sp.

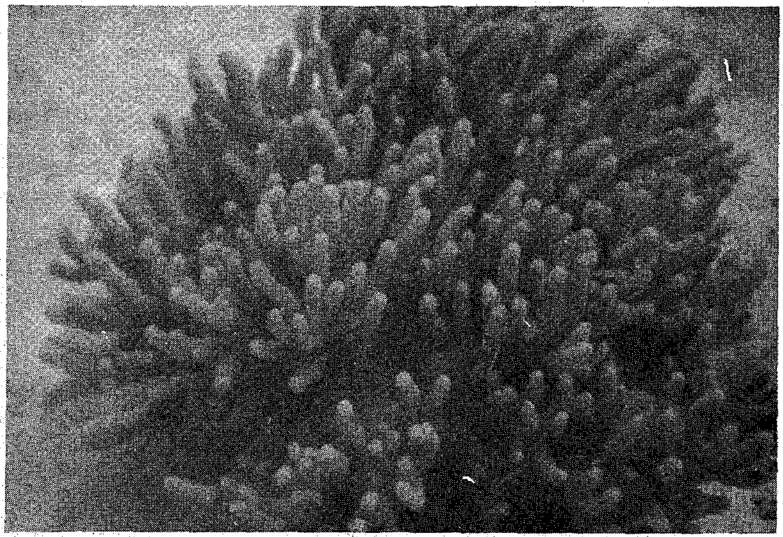

Figure 44. Sinularia polydactyla.

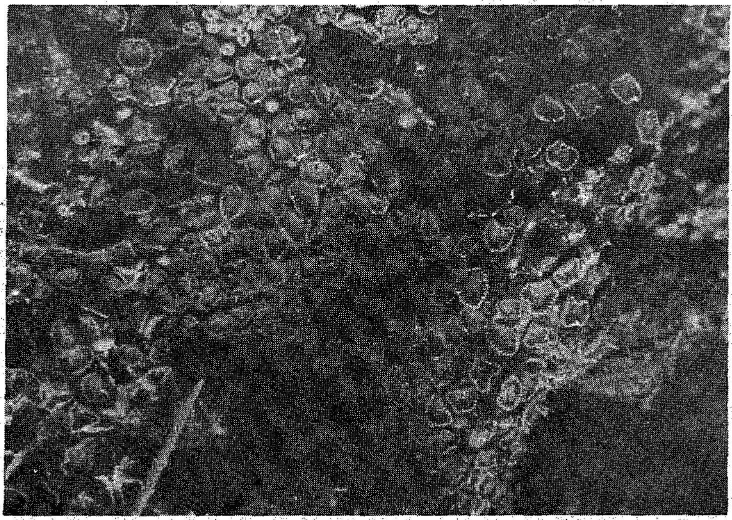

Figure 45. Zoanthus sp.

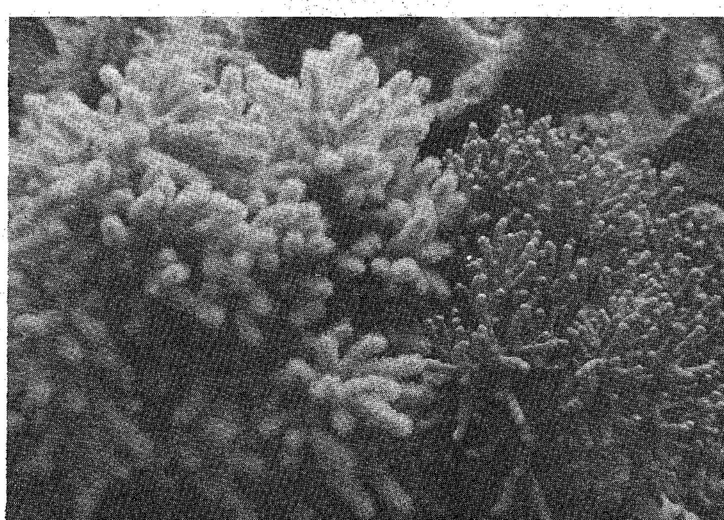

Figure 46. Sinularia sp. with expanded and contracted polyps.

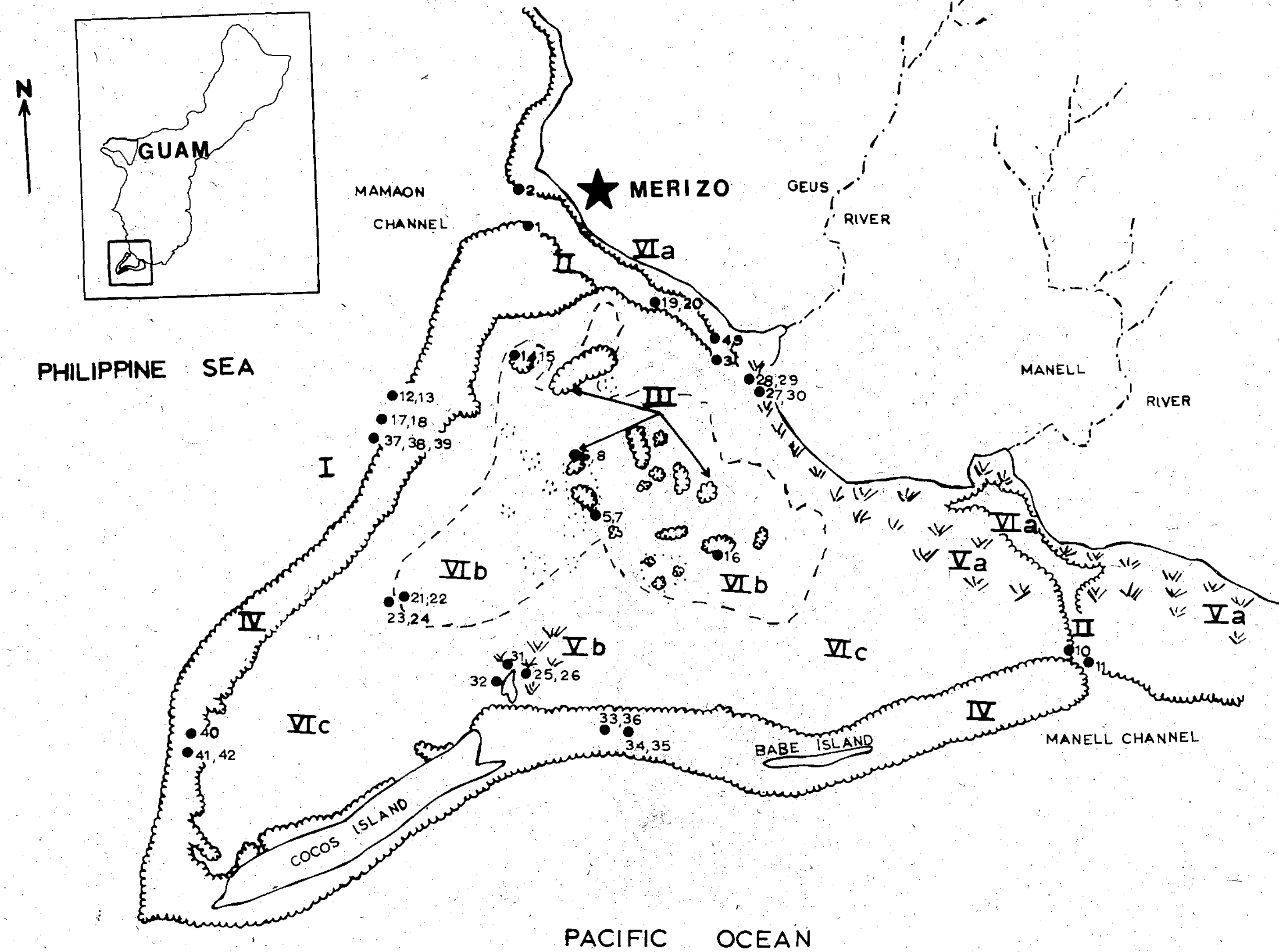

Figure 47. Map of Cocos Lagoon study area. The black spots show the approximate locations of the transect stations, the arabic numerals indicate the transect numbers, and the dashed line is the boundary between the lagoon terrace and the lagoon floor. The number of patch reefs and shoals shown is considerably less than the number that actually occurs in the lagoon. I-Biotope outside the barrier; II-Channel wall biotope; III-Lagoon patch reef biotope; IV-Barrier reef flat biotope; V-Seagrass biotope, a-Enhalus acoroides, b-Halodule uninervis; and VI-Sand bottom biotope, a-channel bottoms, b-lagoon floor, and c-lagoon terrace.

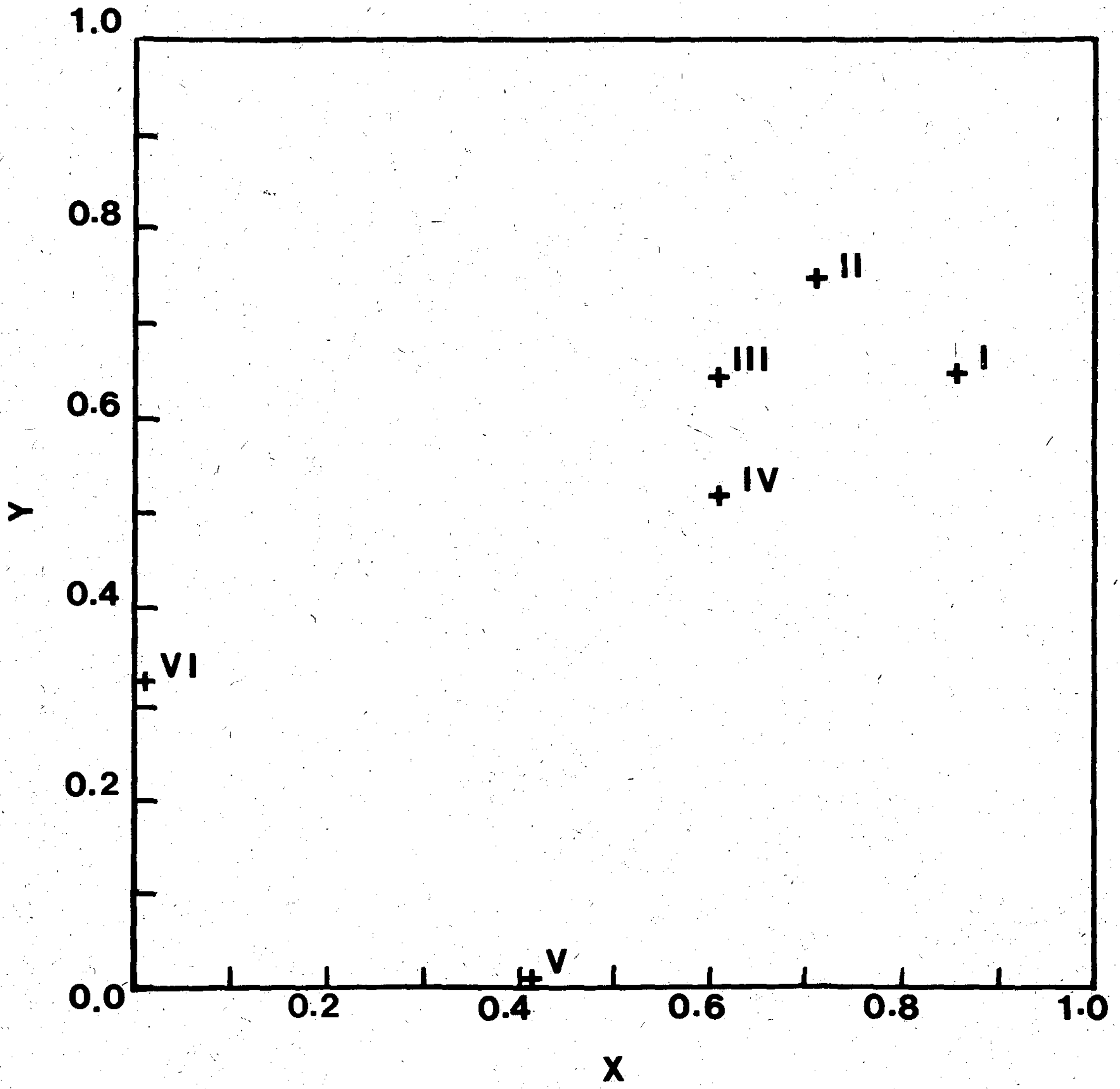

Figure 48. Plot of community ordination between biotopes using species importance values. (r=0.87).

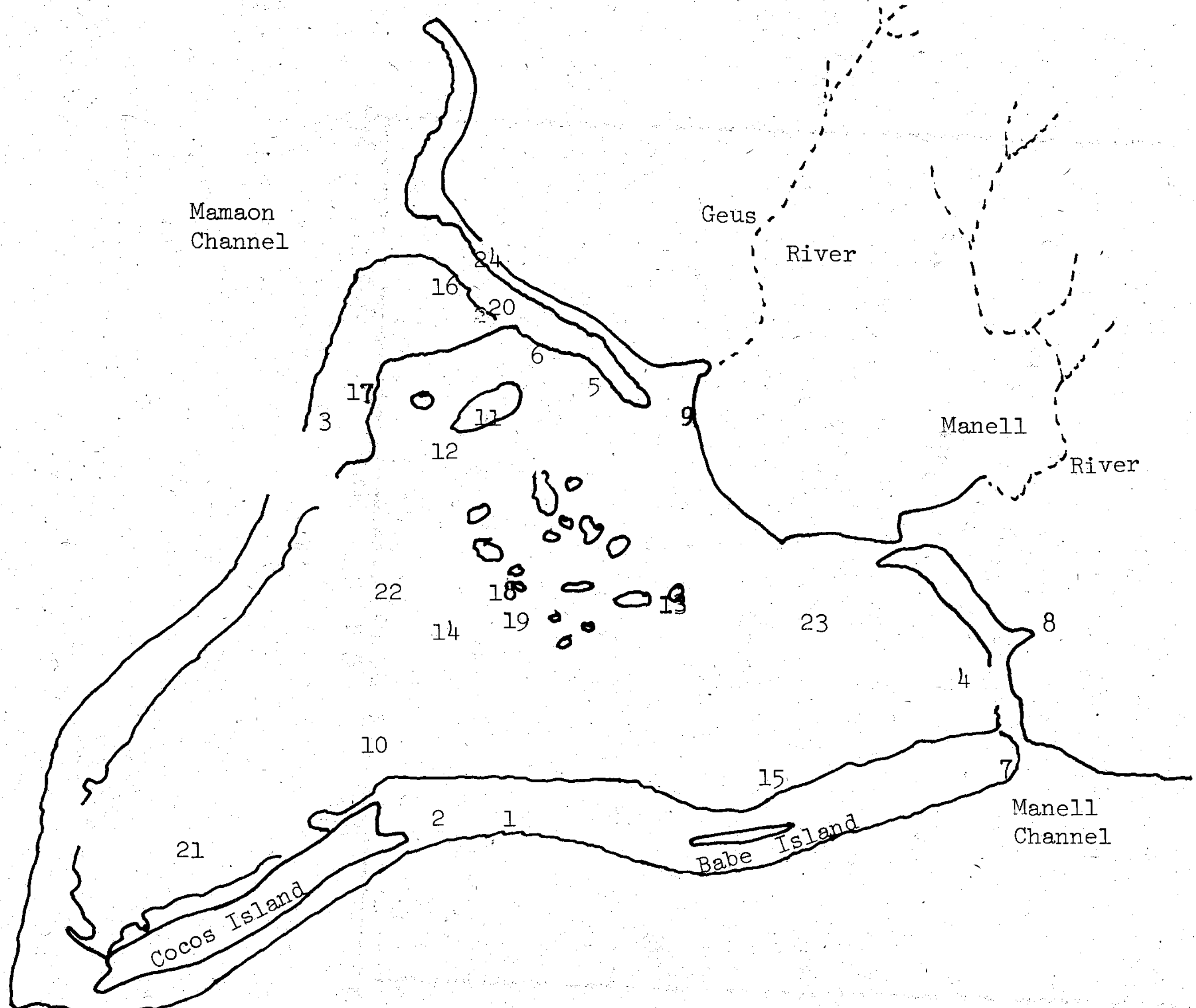

Figure 49. Location of the 24 algal stations.