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AQUATIC AND WILDLIFE RESOURCES DIVISION
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## ABSTRACT

The edible shellfish and sea urchin populations on the reefs of Guam were surveyed during the period 1 June through 23 August 1978. The sea urchins, *Diadema savignyi* and *Echinothrix diadema*, were surveyed and inspected periodically for gonad development. The highest population densities for *D. savignyi* were found at Piti and Agat. Large populations of *E. diadema* were found at Tumon, Piti, and Agat. Ripe gonads were not detected in either species during the study period. Both sea urchins were found to inhabit the reef margin and front where suitable overhangs and holes provide refuge. Piti reef flat was an exception. No size class zonations were observed for sea urchins.

Different size classes of *Trochus niloticus* were found to be distributed by reef zones. Juveniles (50 mm in shell diameter) inhabited the outer reef flat, and progressively larger size classes were found over the reef margin and down the reef slope to a depth of about 12 m. In isolated areas, the animals existed in depths down to 18 m.

Comparisons of population densities indicated similar numbers on the fringing reef of Tumon Bay and on the barrier reef of Cocos Lagoon. Areas inside lagoons contained few *Trochus*. In general, the population of *Trochus* on Guam is dense enough to support a limited commercial fishery.

There is a significant relationship between live wet weight and shell diameter of the animals. This relationship suggests that biomass estimations can be based on the equation: $W = 0.0003\ D^{3.03}$ where W is live wet weight (g), and D is shell base diameter (mm).

Of the three species of tridacnid clams found on Guam, only *Tridacna maxima* is common. This species occurs most frequently along the reef front. The population density of *T. maxima* on Guam is relatively low.

Populations of other edible bivalves are dense enough to support only a recreational fishery. Most species are presently harvested for home consumption. The greatest density of these bivalves occurs in seagrass beds in Cocos Lagoon.




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## INTRODUCTION

The economic potential of shellfish and sea urchin fisheries in Micronesia, and especially Guam, has not been significantly developed. Commercial interest in the gastropod Trochus niloticus and the giant tridacnid clams has centered on the value of their shells, which are sold for button manufacture and decorative purposes. Harvest of these shellfish as a food resource has been primarily for home consumption. Harvest of the smaller bivalve clams and oysters, as well as sea urchin gonads, has also been primarily limited to home use.

To date, no survey of the edible shellfish and sea urchins has ever been conducted for Guam's reefs. The possibilities of natural harvest and seeding of habitats, for commercial purposes, are of particular interest.

The purpose of this report is to provide baseline information. On 1 May 1978 a contract was received from the Coastal Zone Management Section, Bureau of Planning, Agana, Guam. Field work began on 1 June 1978 and continued through 23 August 1978. During that time data on distribution, habitat preference, size class, and standing crop were collected on the gastropod Trochus niloticus; several species of bivalve clams; an oyster; and two species of sea urchins.

It is hoped that this report will provide the impetus for more surveys and specialized studies in the near future, which may lead to proper fisheries development, conservation and management.

### Scope of Work

Four groups of shellfish and sea urchins were surveyed and are listed below, including their respective species:

1. Gastropods

    a. Trochus niloticus (Linnaeus)

2. Bivalves (Giant Clams)

    a. Tridacna maxima (Roeding)
    b. Tridacna squamosa Lamarck
    c. Hippopus hippopus (Linnaeus)

3. Other Bivalves

    a. Anodontia sternsiana (Oyama)
    b. Asaphis violascens (Forskal)
    c. Ctena delicatula (Pilsbry)
    d. Ctena divergens (Philippi)
    e. Fragum fragum (Linnaeus)
    f. Gafrarium pectinatum (Linnaeus)



    g. Gafrarium tumidum (Roeding)
    h. Modiolus (cf. auriculatus)
    i. Periglypta puerpera (Linnaeus)
    j. Quidnipagus palatum Iredale
    k. Saxostrea mordax (Gould)
    l. Scutarcopagia scobinata (Linnaeus)

Specific work items included:

1. A review of pertinent literature including ecology, life histories and commercial development to date.

2. Selection of study sites covering the possible range of environmental conditions around Guam.

3. Determination of specific habitats and zonations for each shellfish/sea urchin group.

4. Determination of standing crop, size, and weight relationships where applicable.

5. Determination of the periodicity of sea urchin gonad development.

The above items are presented in a systematic way, augmented by maps, tables, and photographs. Each shellfish or sea urchin group is discussed as a complete unit covering all the selected sites.

### Study Site Descriptions and Locations of Transects

Five major study sites were chosen around the island. Selection criteria included the recorded presence of shellfish and sea urchin populations, environmental range, habitat, and recommendations from various local people who regularly harvest these organisms.

### Tumon Bay (Fig. 1)

Tumon Bay, located on the west side of Guam, has been heavily developed for the tourist industry. The bay may be characterized as having a wide reef flat (greater than 1000 m) with a rather abrupt reef margin and slope. In several places, channels cut through the platform with concomitant overhangs and sand holes to 12 m in depth. The middle and inner reef flats are predominantly sandy with locally abundant corals (notably Acropora and Porites) and algal mats (notably Caulerpa and Padina).

The bay was divided into four sectors. Within each sector transects were run parallel to shore at depths to 24 m (80 ft).

Five transects were run in Sector I on the outer reef flat, rock and rubble zone (Transects A and B); reef margin (Transect C); reef front terrace, 6 m (Transect D); and terrace, 12 m (Transect E).

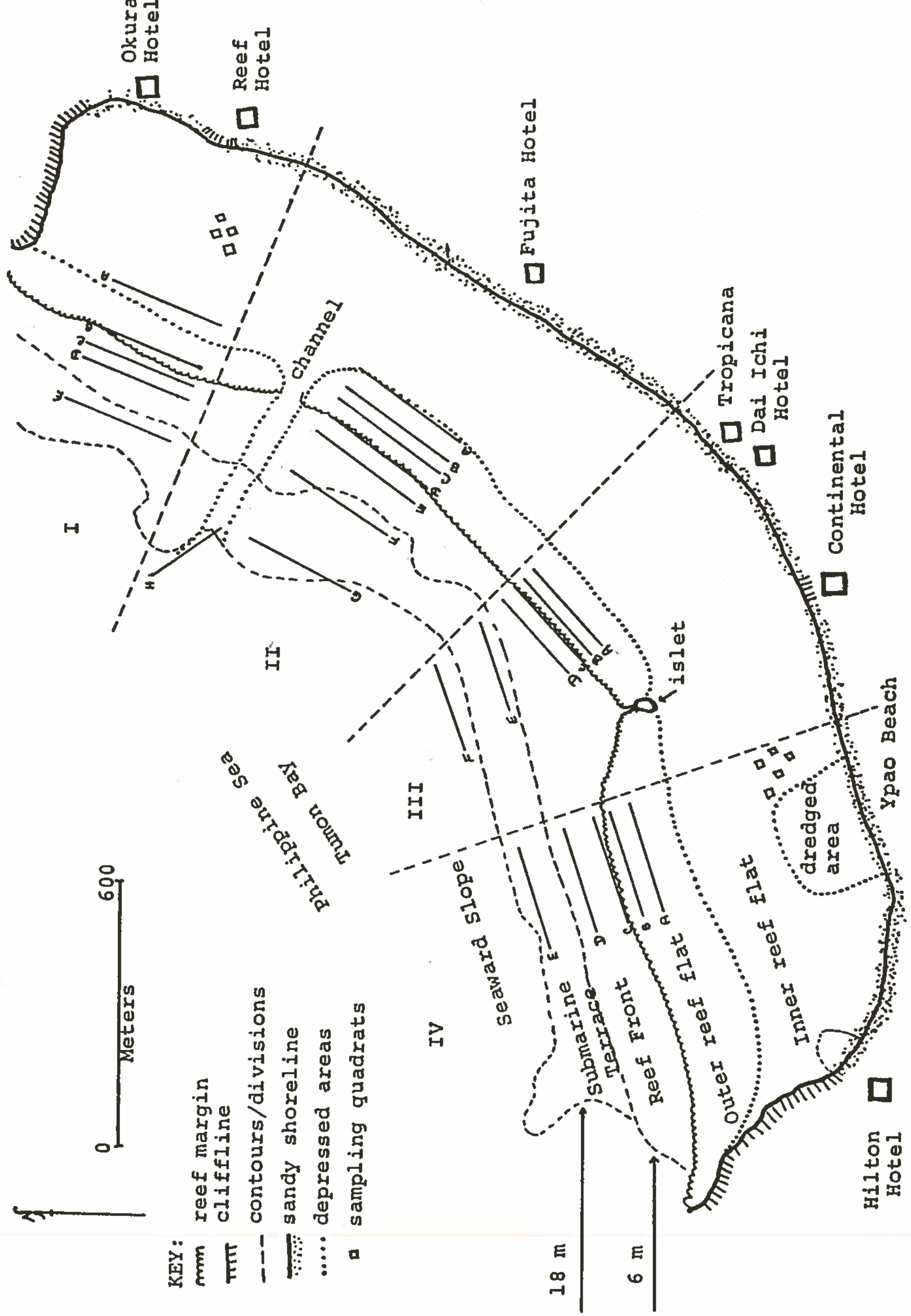


Figure 1. General location map of Tumon Bay showing the major reef zones, location of transects and sampling quadrats. (Adapted from Randall and Holloman, 1974)



Eight transects were run in Sector II. This sector was slightly different from the others owing to the presence of a small boat channel which cut through the reef and terrace platforms. Transects were established as follows: outer reef flat, turf and rubble zone (Transect A); outer reef flat, Caulerpa mat (Transect B); outer reef flat, rubble and red algal turf zone (Transect C); reef margin with many deep holes (Transect D); reef front terrace at 6 m (Transect E); terrace at 12 m (Transect F); fore-reef slope at 18 m (Transect G); and channel fringe at 12 m (Transect H).

The six and five transects run in Sectors III and IV, respectively, correspond to the physiographic descriptions given for Sector I.

A series of random quadrats was sampled for sand-dwelling bivalve clams in the sandy inner reef flat zone at the north and south ends of the bay.

Alupang Cove (Fig. 2)

Alupang Cove is located at the north end of Agana Bat and to the inside of Alupat Island. Physiographically, Agana Bay is very similar to Tumon Bay. The Alupang Cove area is characterized by a shallow sand moat, covered with scattered algal mats of Caulerpa and patches of the sea-grass Enhalus acoroides. At one point a dredged sand spit extends west towards Alupat Island. This area is considered one of the best for the sand clam Asaphis violascens. Over a 2-day period, reconnaissance digs and a small series of random .25-$m^2$ quadrats were excavated as shown. This area was not considered as one of the major study sites.

Piti Reef (Fig. 3)

Only that portion of Piti reef flat northeast of Cabras Island and delimited by Tepungan and Piti Channels was investigated. This reef flat is unique because of its physiography and its large echinoderm population.

Physiographically, the platform consists of a smooth pavement across the outer reef flat which is seasonally covered by red algal mats and the brown alga Sargassum polycystum. Towards Tepungan Channel the substratum is predominantly coral rubble with scattered low relief patches of Acropora, Porites, and the fire coral Millepora. The reef flat has few holes or rock ledges and, with the exception of the channel border, there is little sand. Beyond the reef margin the topography is relatively barren, with some low-relief corals. The terrace gently slopes to a depth of approximately 33 m where it abruptly ends in a cliff.

A series of seven transects was run parallel to Tepungan Channel and extending seaward to a depth of 12 m. Transects A, B, C, and G traversed a rubble zone. Sea urchins were limited exclusively to these transects. Transects D, E, and F corresponded to the reef margin, 6-m terrace, and 12-m terrace respectively.

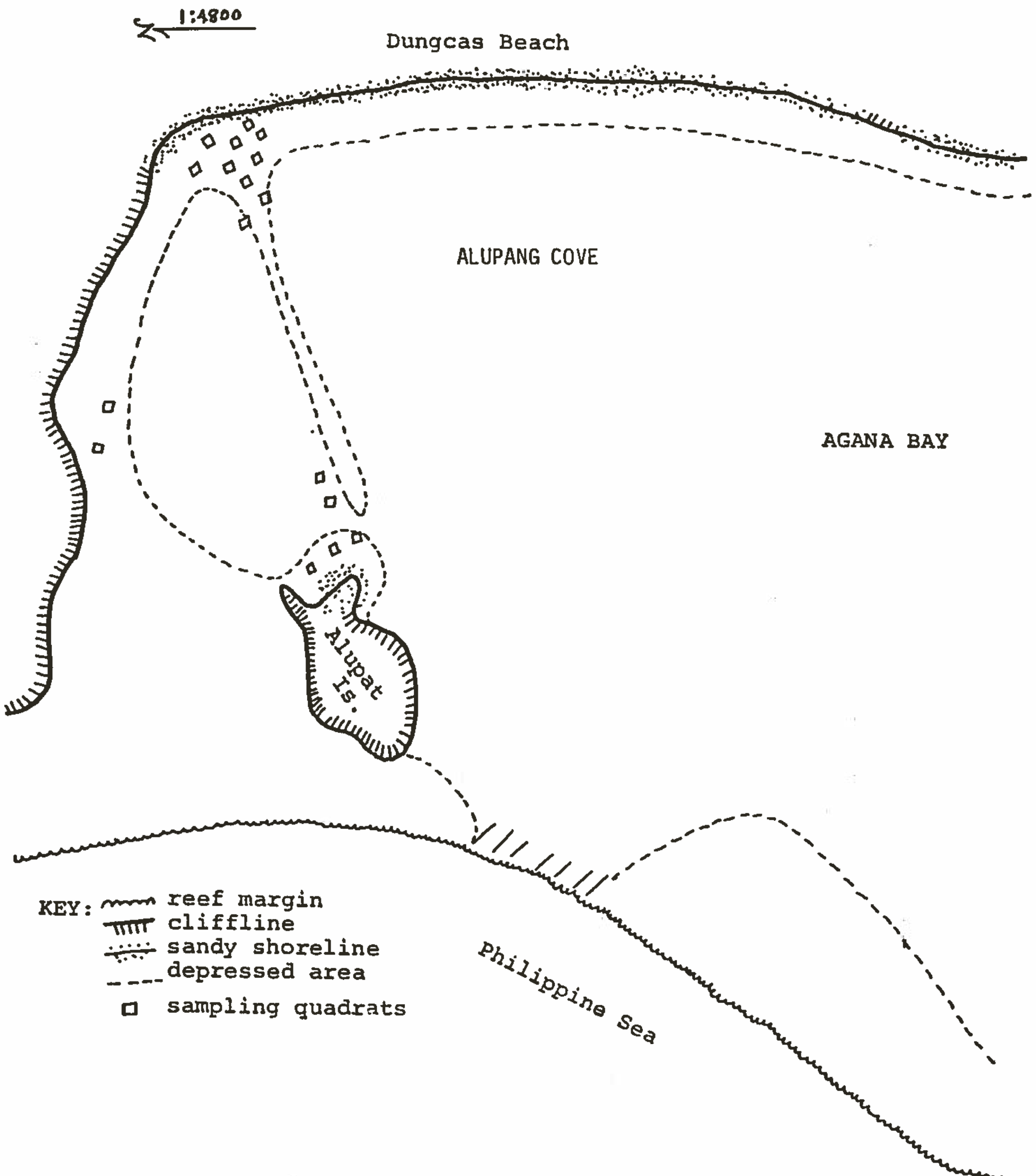


Figure 2. General location map showing the location of sampling quadrats at Alupang Cove. (Adapted from Randall and Eldredge, 1976).



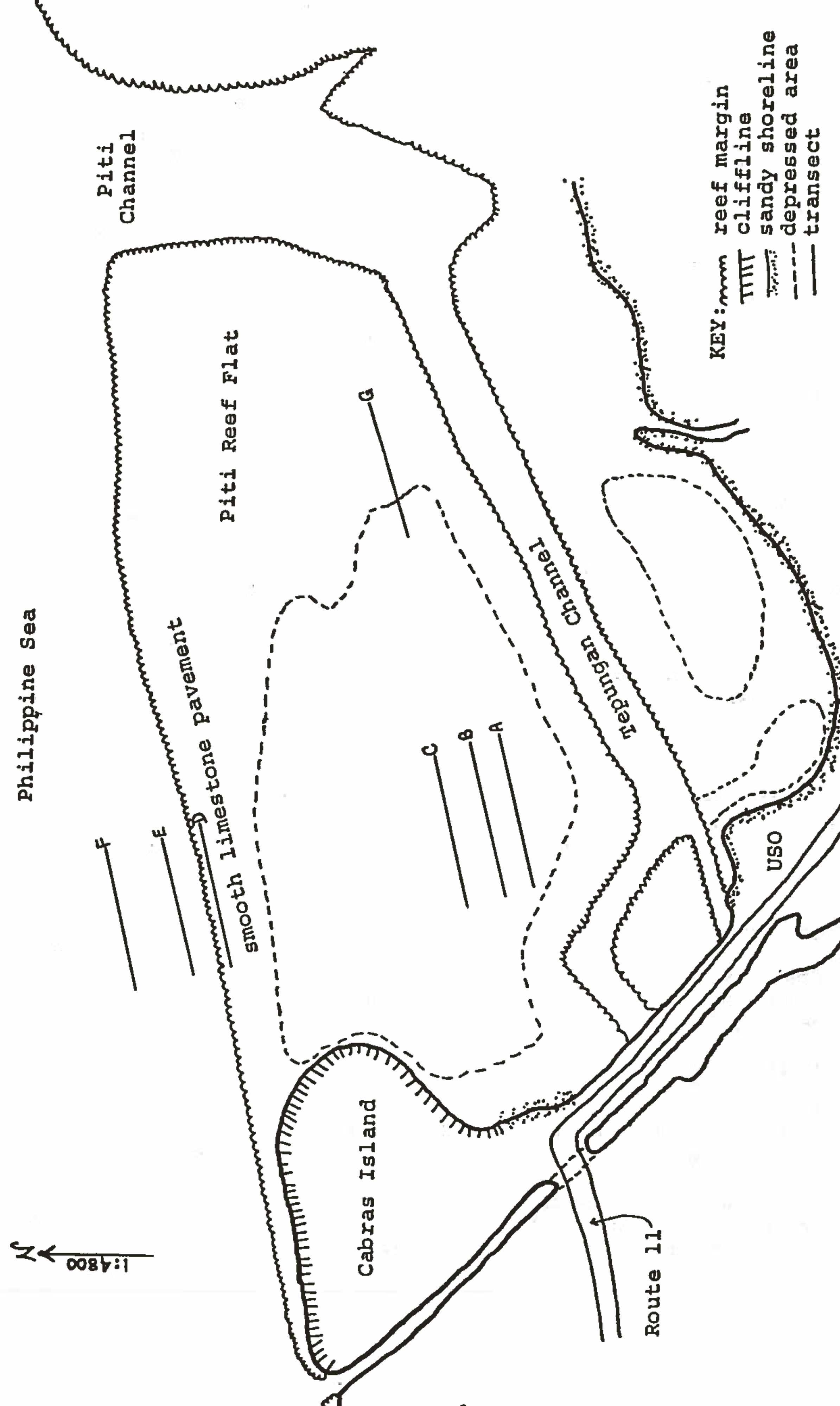


Figure 3. Piti Reef Flat showing location of transects. (Adapted from Randall and Eldredge, 1976)

Apra Harbor (Fig. 4)

Apra Harbor lies on the middle leeward coast of Guam and serves as a commercial, military, and recreational port facility. Because of its vast size, the port was not divided into sectors. Instead, the areas are referred to by their familiar names.

Transects for *Trochus* and sea urchins were run at Orote Beach, Gabgab Beach, Ironwood Patch Reef, and Western Shoals. All transects were run on or just over the reef margins, ranging in depth from 3 to 6 m.

Mud-and sand-dwelling bivalve clams and the oyster *Saxostrea mordax* were surveyed by dredging in Sasa Bay (inner harbor). In addition, a few random quadrats were raked or dredged in inner Piti Channel near the power plant.

Agat Bay (Fig. 5)

Agat Bay is located on the southwest coast of Guam and is characterized by a fringing reef platform ranging in width from 100 to 600 m (Eldredge *et al.*, 1977) and by highly variable physiography. Because of the size of this area only two sites were chosen, the Pelagi Islets and the Bangi-Alutom Islands complex. Together these represent the range in habitat one can expect along the entire bay.

The Pelagi area is characterized by a narrow reef flat platform and generally silty conditions, both on and over the reef flat. Three transects were run roughly along the reef margin (Transect A); reef front terrace, 6 m (Transect B); and terrace, 12 m (Transect C).

In contrast, the Bangi-Alutom area is characterized by a wide reef flat and generally clear water conditions. Four transects were run on the outer reef flat (Transect A); reef margin (Transect B); reef front terrace, 6 m (Transect C); and terrace, 12 m (Transect D).

Cocos Barrier Reef Complex (Fig. 6)

The Cocos barrier reef and associated lagoon lie off the extreme southwest coast of Guam. The area encompasses approximately 6.6 square kilometers and represents virtually the entire spectrum of possible physiographic features on Guam. These include barrier reefs, fringing reefs, patch reefs, channels, seagrass beds, and estuaries.

The area was divided into five sectors. Transects were run parallel to the barrier reef with the exception of those in Sector V, in which a transect was run across the seagrass flats. Selected dredging was carried out in several sandy areas both intertidally at Cocos Island and in the lagoon proper.

Five transects were run in Sector I. The transects roughly fall along the inner lagoon margin (Transect A); barrier reef margin (Transect B); reef front terrace, 6 m (Transect C); terrace, 12 m (Transect D); and slope, 18 m (Transect E).



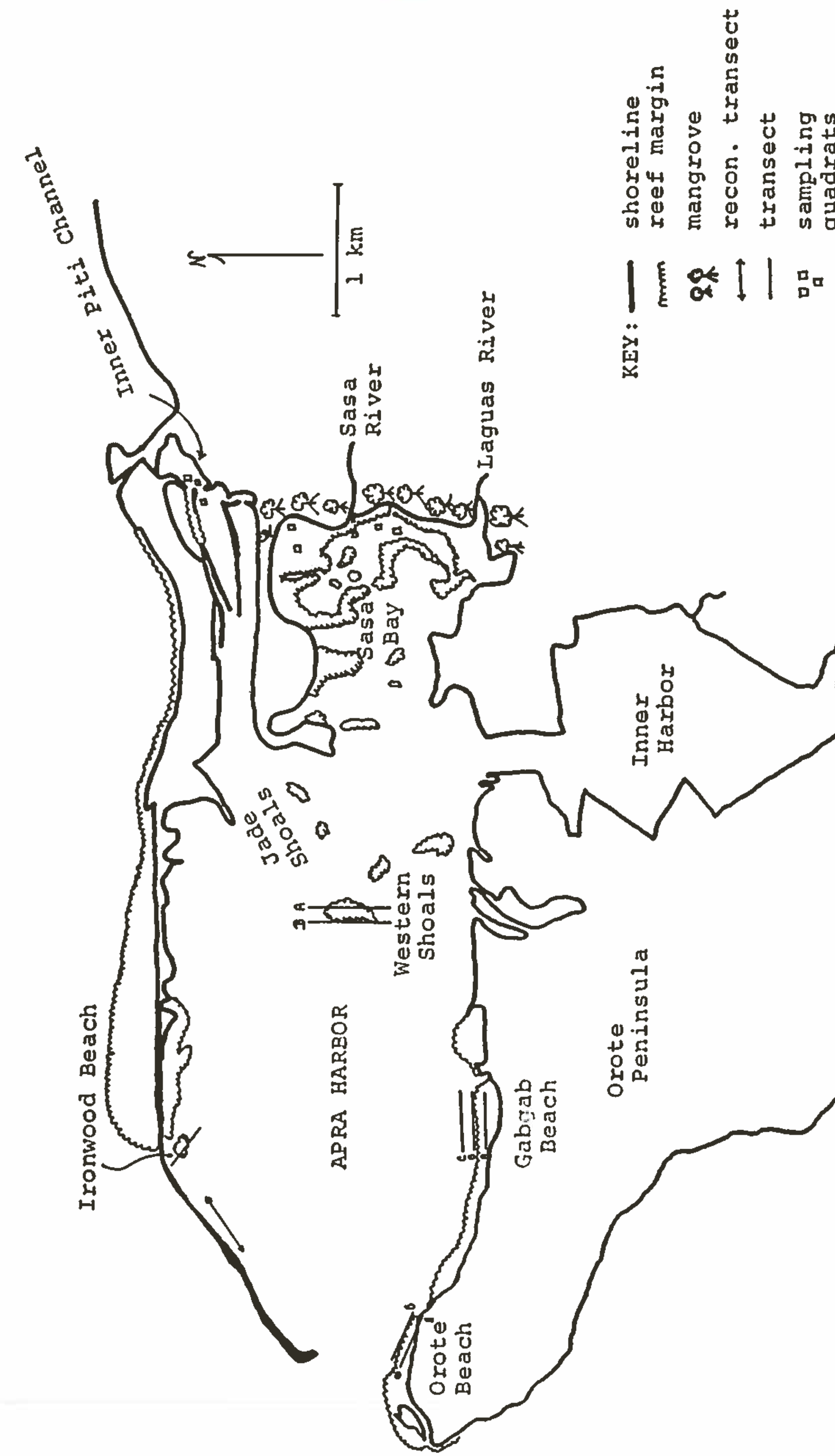


Figure 4. General location map of transects and sampling quadrats at Apra Harbor.

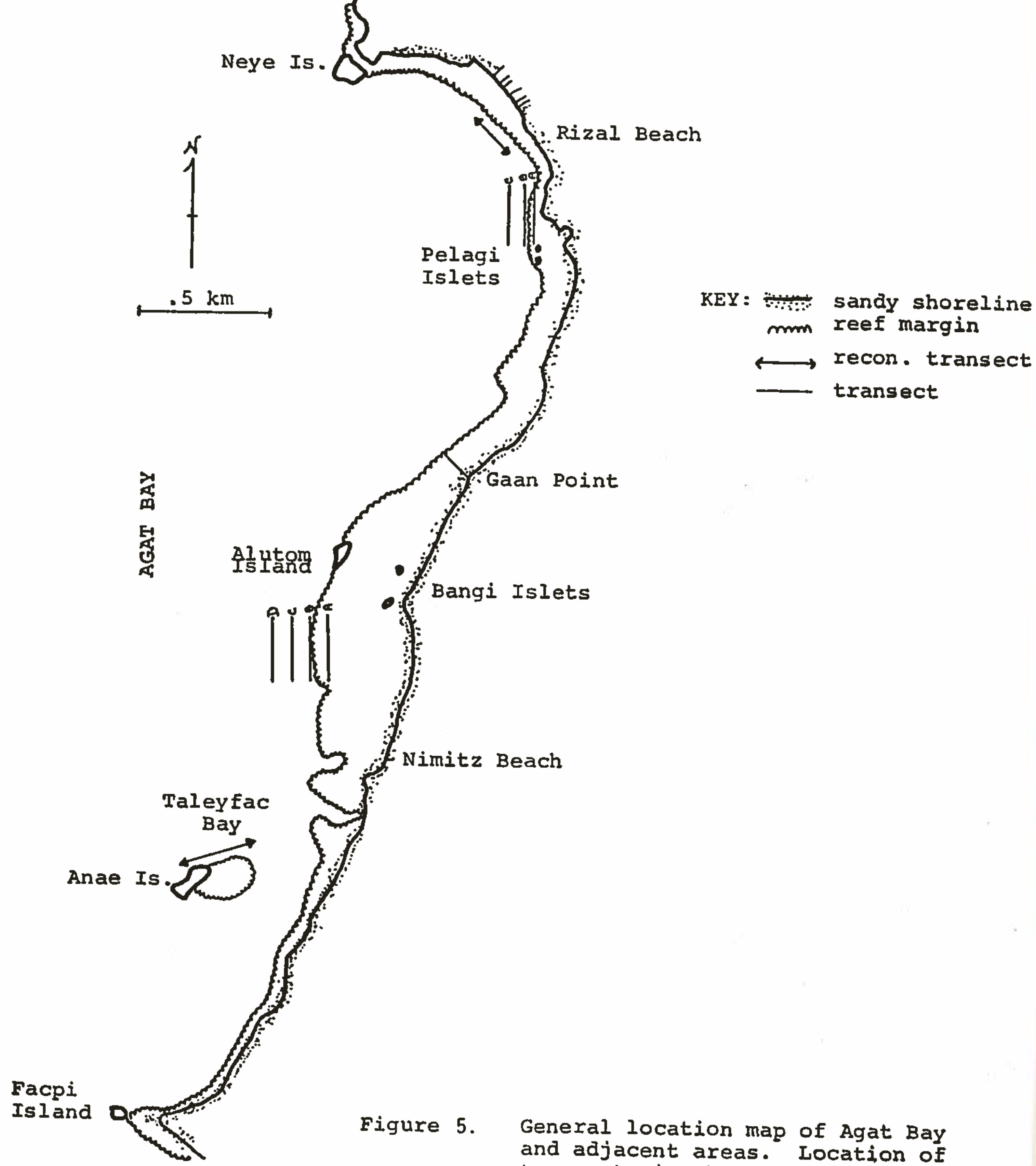


Figure 5. General location map of Agat Bay and adjacent areas. Location of transects is shown by the lettered solid lines. (Adapted from Randall and Holloman, 1974)

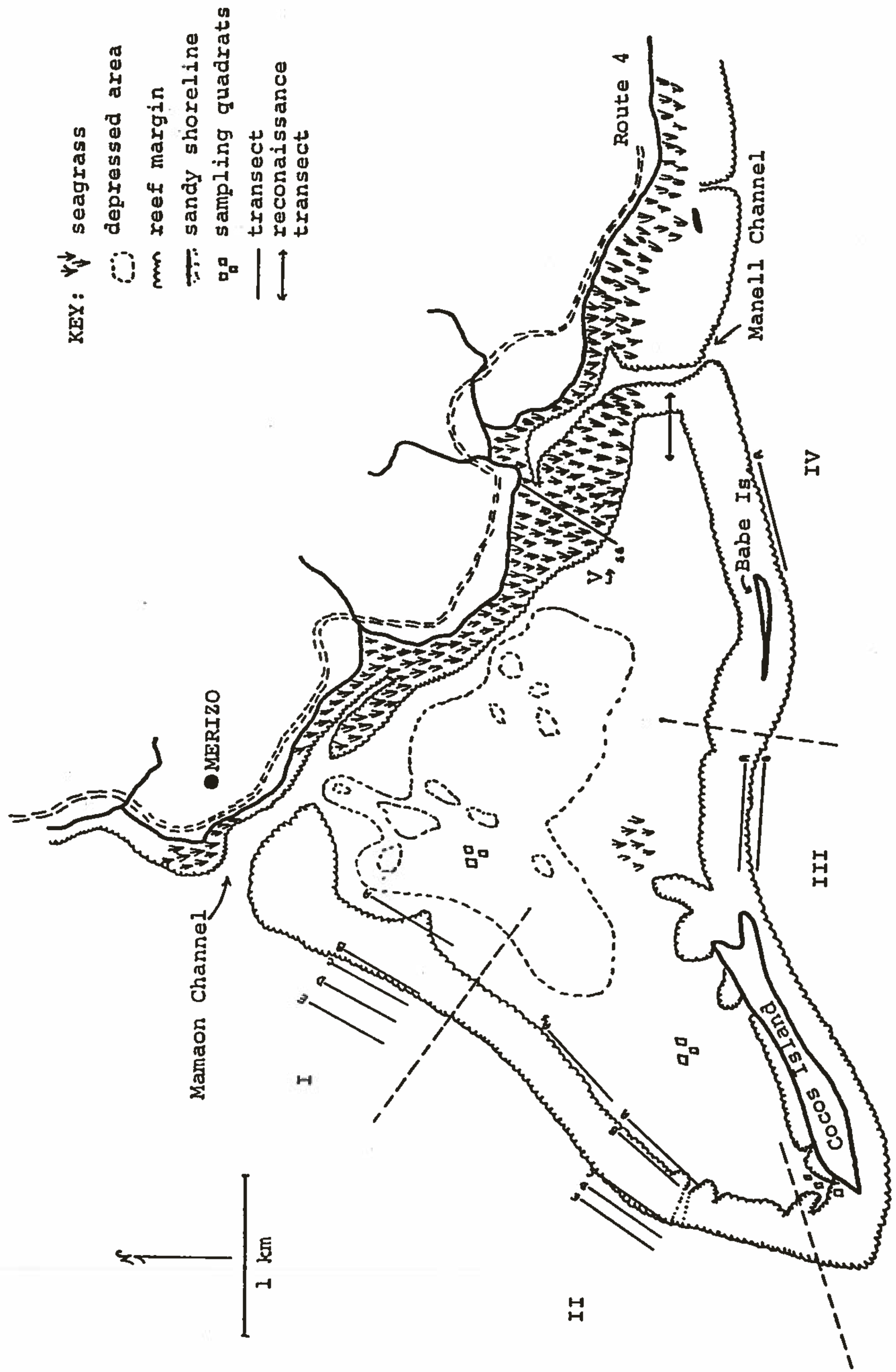


Figure 6. General location map of transects and sampling quadrats at Cocos Barrier Reef Complex. (Adapted from Randall et al., 1975)

Six transects were run in Sector II, traversing lagoonal sand and rubble (Transect $A_S$); sandy channel edge and rubble zone (Transect A); lagoon-side reef margin (Transect B); seaward reef margin (Transect C); reef front terrace, 6 m (Transect D); and deep terrace, 12 m (Transect E).

Two transects were run in Sector III. Rough conditions prevented additional transect studies on the windward side. Transect A was run on a barrier reef coral spit and terrace at approximately 4 m in depth. Transect B was run at a depth of 9 m.

Only one transect was run in Sector IV, slightly east of Babe Island at a depth of 12 m. A short reconnaissance swim was also conducted just inside Mannell Channel.

One 450-m transect was run perpendicular to the shoreline and across the seagrass flats in Sector V. Bivalve clams were excavated from the seagrass bed at 25-m intervals with 1-$m^2$ quadrats.

Digging, raking, and dredging for sand clams was also conducted at selected locations.

## Background and Review of Literature

### Sea Urchins (Plate I)

The commercial interest in sea urchins lies chiefly in their mature gonads, which are considered a delicacy in much of the Indo-West Pacific region. The large black sea urchins of the genera *Diadema* and *Echinothrix* are of particular interest in the tropics, and both occur on Guam.

As with most delicacies, procurement is difficult. The long brittle spines make handling difficult, and the quantity of "ripe" gonads per individual is relatively small. Additionally, ripeness is a cyclic phenomenon of some uncertainty which differs between genera and with seasonal variations.

While the natural harvest is probably of limited commercial potential, nothing is known of the potential for sea urchin mariculture. Information pertaining to recruitment, longevity, fertility factors, and maximum sustainable yield are lacking.

The two species investigated were *Diadema savignyi* and *Echinothrix diadema*. *Diadema setosum* and *E. calamaris* have equal commercial potential but are comparatively rare on Guam. Both *D. savignyi* and *E. diadema* are characterized by their large black tests (100-200 mm) and moderately to very long black spines (100-400 mm). Differentiation of the two is based on three simple characters. *Diadema savignyi* has a generally more delicate appearance, i.e., longer, narrower spines; a bright blue iridescent ring on the test; and a tendency to be found in very large aggregations or herds (up to 100) in relatively open areas. *Echinothrix diadema*, in contrast, has a more stout appearance with shorter (150-200 mm), thicker spines; no blue ring; and a tendency to



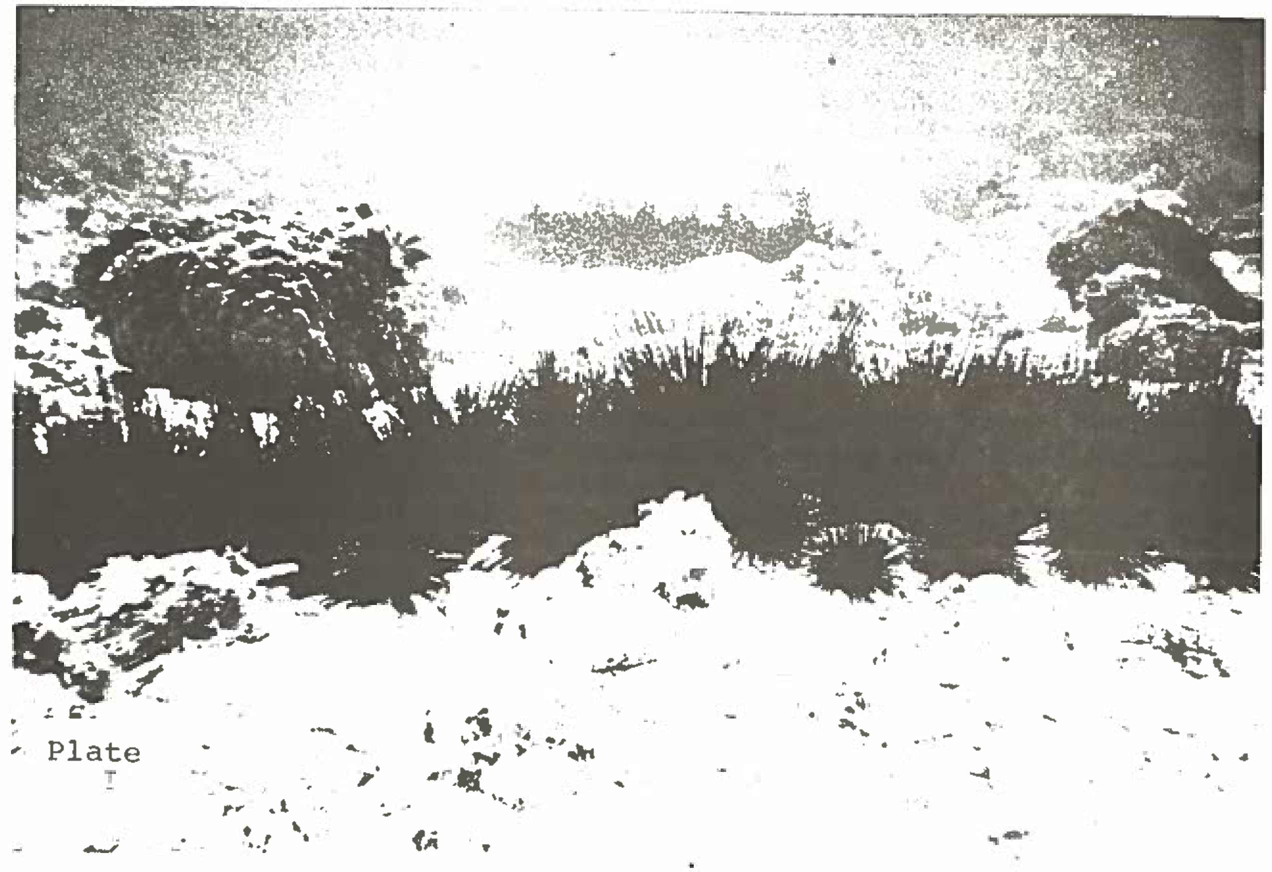

Plate I. Medium sized aggregation of the sea urchin *Diadema savignyi* at Piti reef flat. A second aggregation can be seen in the background.

seek more sheltered habitats. With some exceptions the herds are of smaller size (less than 20) and/or several individuals may be found in association with Diadema savignyi.

The distribution of these sea urchins is limited by suitable habitat and water flow. Those areas of the reef flat which provide small tunnels, nooks, crannies, and overhangs combined with good water motion are the most favorable. Generally, such requirements are met along the outer reef flat and margin. A marked exception is Piti reef flat, of which more will be said later. Rarely were urchins found in depths below 6 m or in potentially exposed portions of the reef flat.

There is no size class zonation across a range of habitats for D. savignyi or E. diadema. Juvenile sea urchins are found with adults, often relegated to the interior of the aggregations. It must be noted, however, that very few juveniles were encountered during the study.

Echinothrix and Diadema occur to some extent on most of the reefs of Guam, but significant populations seem to be limited to a few leeward reefs. Piti reef flat, immediately adjacent to Cabras Island, undoubtedly has the largest echinoid population on Guam. Tumon and Agana Bays also have sizable populations.

Although there is an abundance of literature on sea urchins, most deals with taxonomic and/or embryological studies of temperate species. Literature on tropical species is mostly concerned with new geographic records, with limited comments on ecology and life history. No papers were located dealing exclusively with mariculture and commercial marketing of tropical sea urchins, although Scattergood (1961) briefly describes the temperate sea urchin fisheries of New England.

Some personal communications with the Micronesian Mariculture Demonstration Center, Palau, Maura Gordon (Palauan); and B. D. Smith (former Peace Corps Volunteer in Fiji and Rotuma) have also yielded some insights into the discrepancies found in the literature and field observations made during this study.

Both D. savignyi and E. diadema are listed as toxic sea urchin species (Halstead, 1965). Fortunately, the toxicity is limited to their spines, which may cause extremely painful puncture wounds. Gonadal toxicity has not been reported in either species (Fish and Cobb, 1954).

Pearse (1968, 1974) and Ebert (1971) examined several Indo-West Pacific sea urchin species, with special attention given to their biogeographical distribution, community structure, and reproductive periodicities. Both Echinothrix and Diadema were included in their studies.

Past studies have attempted to correlate sea urchin reproductive cycles with such parameters as temperature, tide, lunar cycles, and latitude. The references and conflicting results of these early studies are extensively reviewed by Pearse (1968). His final conclusions, based on new findings, are summarized. Pearse (1968) found that for Diadema (and



possibly Echinothrix), at latitudes of less than 15 degrees and in temperatures greater than 25° C, the sea urchins reproduced monthly throughout the year. Furthermore, individuals of Diadema tend to be synchronous with respect to gametogenesis (ripeness). Synchronous gametogenesis within Echinothrix individuals is only surmised, and synchrony between genera is almost definitely not the case.

This is important from a commercial point of view since one would not wish to destroy sexually immature sea urchins in the quest for a few fertile ones.

Pearse further demonstrated that the widely held notion of lunar correlation to fertility cycles was coincidental and that subtleties in tidal fluctuations throughout the wet season (June to December) versus the dry season (January to May) were far more important. These findings fit nicely with local reports.

According to Pearse (1968), mature sea urchin gonads should be available monthly in the tropics. In Rotuma (lat. 13° S) and Palau (lat. 6° N) the larvest begins around Easter and continues through May. The present information indicates that they are almost exclusively found and harvested during the dry season.

Though generally considered sedentary creatures, sea urchins can move considerable distances, particularly at night. Individuals of D. savignyi have been observed to more over 50 m in less than 6 hours. Extensive movement and feeding studies have been conducted by Ogden et al. (1973) and Sammarco et al. (1974) in the West Indies. Such ecological studies are mentioned for two reasons. First, the general ecology of commercially valuable species is not well understood. It is apparently different from species to species as evidenced by the differential distribution of urchins on Guam reefs. Factors affecting recruitment need to be thoroughly examined. Ebert (1971) briefly discussed the role of open sand substrata, chemostimuli, and predation on sea urchin recruitment and survival in Hawaii. Obviously, these areas need further investigation. Second, reliable statistical measurement of populations is complicated by diurnal migrations and naturally clumped distributions.

In summary, the current state of knowledge with respect to tropical sea urchin species of potential commercial value is sparse. Life history and ecological studies with emphasis on mariculture and management of natural stocks are sorely needed.

Trochus niloticus (Plate II)

The topshell Trochus niloticus is one of the largest members of the family Trochidae. This species has a relatively wide distribution in the Indo-West Pacific, extending from Sri Lanka, Mergui, and the Andaman and Nicobar Islands in the west to Samoa in the east, and from Australia through New Caledonia and Fiji in the south to the Philippines and Lu Chu Islands of Japan in the north (Hedley, 1917, cited by Rao, 1937).


Plate II. Trochus niloticus.



In Micronesia, Trochus is indigenous to Palau, Yap, and Helen Reef (McGowan, 1956). Its current distribution throughout Micronesia is a result of transplanting operations carried out by the Japanese Government prior to World War II, by commercial fishing companies, and by private individuals. The first recorded presence of the species on Guam dates from a small shipment of Trochus introduced from Saipan by a local fisherman, Mr. I. Cruz (Van Pel, 1956). These animals were deposited "on a reef near Agana."

Specimens from Guam were introduced into Hawaii waters in 1952 (Kanayama, 1967). Their present status is unknown.

Trochus is one of six species of gastropods reported to be collected as a food resource on Guam (Hedlund, 1977). The number of topshells harvested for home consumption has not been determined.

There is no size limit imposed on the harvest of Trochus for home consumption, but there is a daily bag limit of about 22 kg (50 lbs) (Government of Guam, Department of Agriculture, Regulation No. 28). Up to 4.5 kg (10 lbs) of the daily harvest may consist of juvenile topshells having a base diameter of 51 mm (2 in) or less. Commercial harvest of Trochus on Guam is limited to shells with a base diameter of 101.6 mm (4 in) or more.

Although Trochus is harvested for human consumption, interest in it has historically been based on the commercial value of the shell. The thickness and hardness of the shell make Trochus one of the most sought after mother-of-pearl species. It has been used in the manufacture of buttons and jewelry, and small pieces of the shell have been used as seed in oyster culture of pearls (Gardner, 1948). The importance of Trochus shell declined as plastic substitutes were developed.

Overharvesting in many areas of the Indo-West Pacific led to a general decline in Trochus populations during the pre-World War II years and stimulated research into the life history of the species. A summary of the major studies was presented by Gail and Devambez (1958).

The preferred habitats of Trochus have been described for various ecosystems. Moorhouse (1932) stated that, in general, Trochus occurs in greatest numbers on the weather side of reefs, but where reefs are narrow they are more or less evenly distributed. Rao (1937) observed that the animals live on coral reefs and under rocky ledges covered with growths of green and brown algae, from between tide marks to depths of 22 m. McGowan (1956) indicated that topshells prefer the outer face and shelves of barrier reefs as opposed to fringing reefs. Muller (1973) found Trochus most frequently on the lagoon side of the windward algal reef and reported almost none of the animals on the leeward side of the atoll.

Zonation and distribution of Trochus on the reef are related to age, size, nutritional requirements, and availability of shelter (Moorhouse, 1932; Rao, 1936; McGowan, 1956). Moorhouse (1932) described a seaward gradient in sizes from 20 mm to 60 mm on the reef flat of the Great Barrier Reef, but stated that, as a result of intensive harvesting, none of the animals was found at depths greater than 1 m. In the Andaman Islands, young topshells up to 50 mm were found intertidally, and larger animals were at depths of 2 to 7 m (Rao, 1937). In New Caledonian waters, Trochus do not live below 15 m (Angot, 1958).

In Micronesia, McGowan (1956) noted the variation in the depth range of Trochus. In Ponape, the animals were most abundant at 6 m, but ranged downwards to 12 m. However, in Palau, many were found at depths of 24 m near Melekeiok.

Although the abundance of Trochus is discussed in the literature, few density figures are cited. Birkeland (1978) quantified juvenile Trochus on the outer reef flat in Tumon Bay.

Other references on the abundance of Trochus are related to output or to yield. McGowan (1956) discussed the weight of topshells collected by a man in a single day (lbs/man/day), and he referred to the yield of the reef as tons of Trochus per mile of reef (tons/mi). Muller (1973) reported abundance in terms of numbers of Trochus sighted during 20 min. intervals.

Tridacnid Clams

Giant clams of the family Tridacnidae are limited in distribution to the Indo-West Pacific region (Rosewater, 1965). Yamaguchi (1977) reported that, of the six species in this family, only Tridacna maxima is maintaining a population on Guam. However, the museum of the University of Guam Marine Laboratory contains two additional species collected on Guam. A single specimen of Hippopus hippopus (UGI #1892) was collected from shallow water in Apra Harbor, and a single specimen of Tridacna squamosa (UGI #3062) was collected from a depth of 24 m near Neye Island.

The life history of giant clams was reviewed by Rosewater (1965). A study of the early life history of Tridacna maxima on Guam, with additional data on tridacnids from Palau (Jameson, 1976), is of particular interest. Yamaguchi (1977) provided a review of the conservation and cultivation of giant clams, and the low recruitment and slow growth rates of tridacnids were discussed in terms of resource management paralleling that used in forestry management.

The habitats of tridacnid clams were described by Rosewater (1965). Tridacna maxima is reported to inhabit shallow water reefs, partially embedded in coral. Tridacna squamosa lives on the surface of coral reefs, usually in somewhat protected localities. Hippopus hippopus prefers a sandy substratum in coral reef waters to 6 m in depth. Adults of this species are unattached, but juveniles are found byssally attached to coral heads.

The larger species of the family, including Hippopus hippopus, are being exploited for their highly valued meat and shells. Tridacna maxima and



T. squamosa have smaller shells which are of lesser value, but they are in demand for their meat (Hester and Jones, 1974). The shells are valued as souvenirs, and the meat, especially the adductor muscles, is desired for human consumption.

Increased fishing pressures resulting from the value of the shells and meat have brought about decreases in the giant clam populations in some areas. As populations decline, more remote areas are subsequently exploited. Increased poaching of the tridacnids of Helen Reef has caused drastic reductions in the numbers of several species (Bryan and McConnell, 1976; McConnell and Hirschberger, 1976). Bryan (1975) presented recommendations for the conservation of giant clam stocks at Helen Reef.

Other Bivalves (Plates III-XIII)

Bivalve molluscs other than tridacnids have been largely neglected in the scientific literature of the Indo-West Pacific. Reasons for the paucity of work on these animals are unclear.

Waller (1972) reviewed the scallops of the family Pectinidae of the Marshall Islands. The taxonomy of Micronesian species was examined.

A survey of shellfish aquaculture potential among the Pacific islands was conducted by Glude (1972). During a brief stop over on Guam, Glude concluded that there were no local bivalve species with aquaculture potential. Experimental introduction of oysters from other localities was suggested.

Three species of marine bivalves other than tridacnids were reported to be harvested for local consumption on Guam (Hedlund, 1977). Codakia tigerina, Periglypta puerpera, and Quidnipagus palatum were said to be widely distributed in sandy intertidal areas.

Day (1977) reported on growth rates and predation on Quidnipagus palatum on Guam. This clam was reputed to be the most abundant infaunal bivalve on the reef flats of Guam. In regard to the fishery potential of the species, heavy predation upon juveniles was considered a major problem.

The common bivalves of the inner areas of Apra Harbor have been identified and quantified (Univ. Guam Marine Lab., 1977; Taylor, 1977). The oyster Saxostrea mordax was found in abundance along the mangrove fringe of Sasa Bay. The clam Gafrarium tumidum, an infaunal bivalve, was described as being unevenly distributed in the soft, muddy substratum.

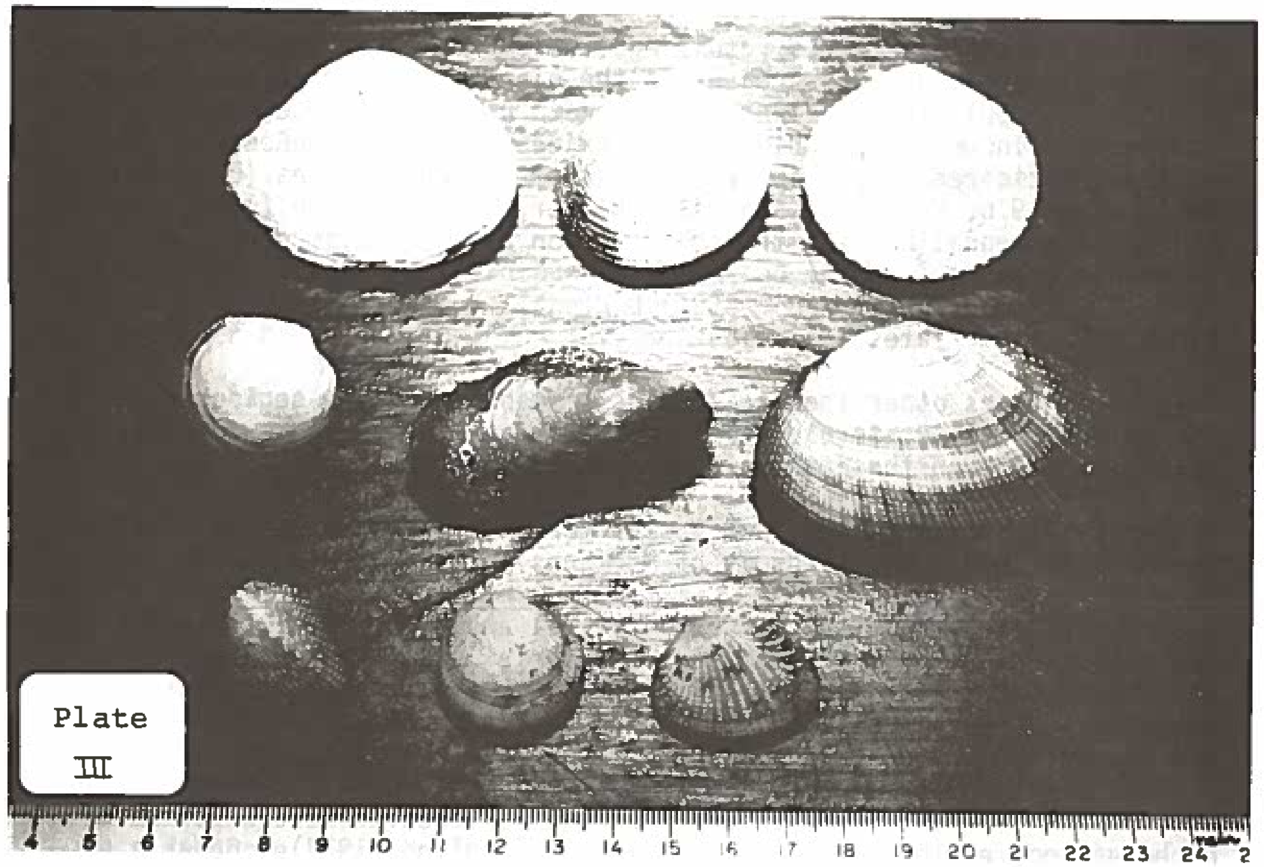


Plate III. Top: left to right. Quidnipagus palatum, Periglypta species, Scutarcopagia scobinata. Center: left to right. Anodontia sternsiana, Modiolus cf. auriculatus, Asaphis violascens. Bottom: left to right. Fragum fragum, Ctena divergens, Gafrarium pectinatum.




Plate IV. Enlarged view of Quidnipagus palatum.

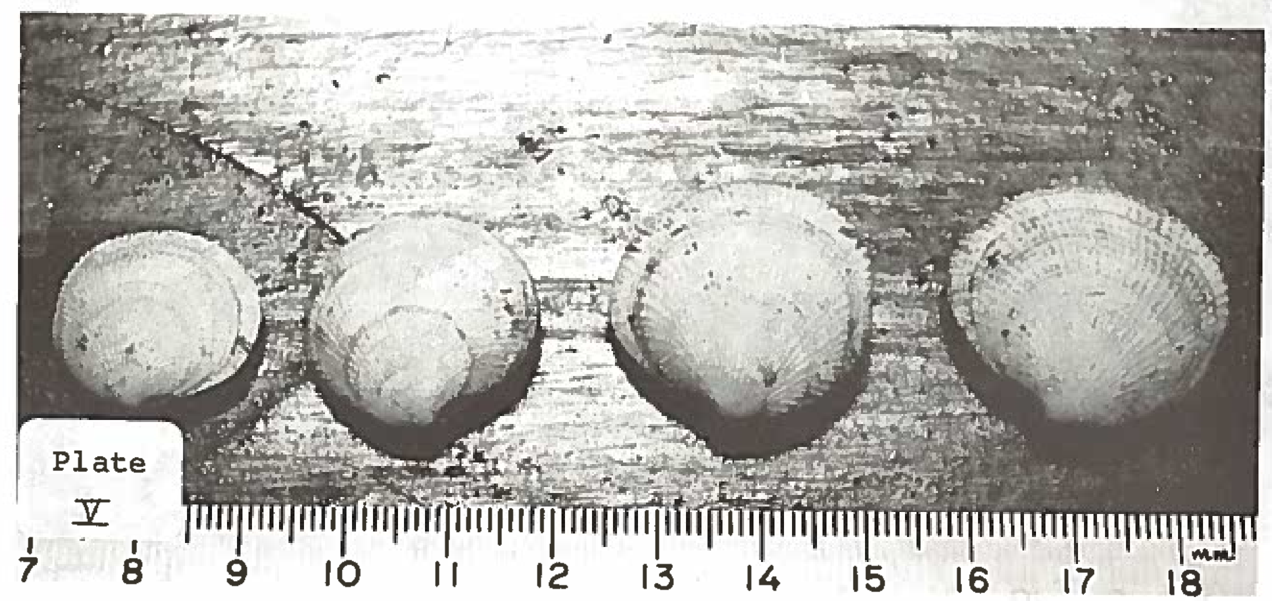


Plate V. Enlarged view of Ctena species showing four size classes.


Plate VI. Enlarged view of Modiolus cf. auriculatus.

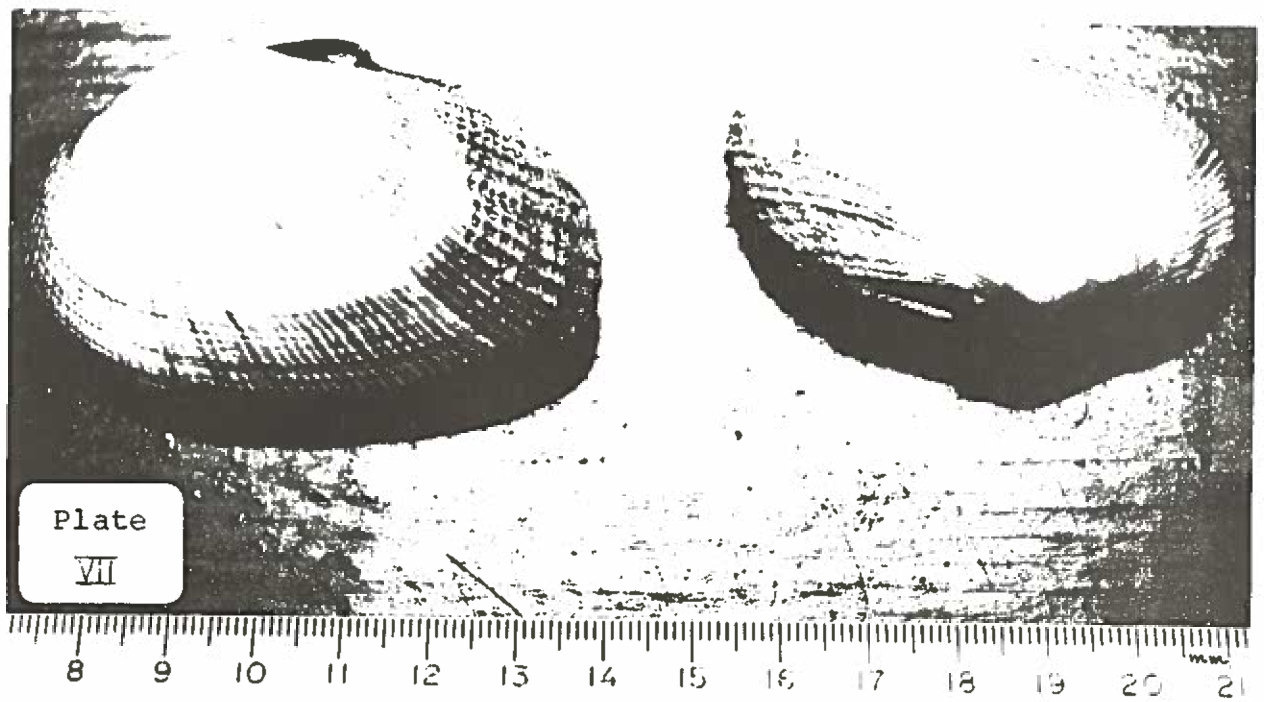


Plate VII. Enlarged view of Asaphis violascens.



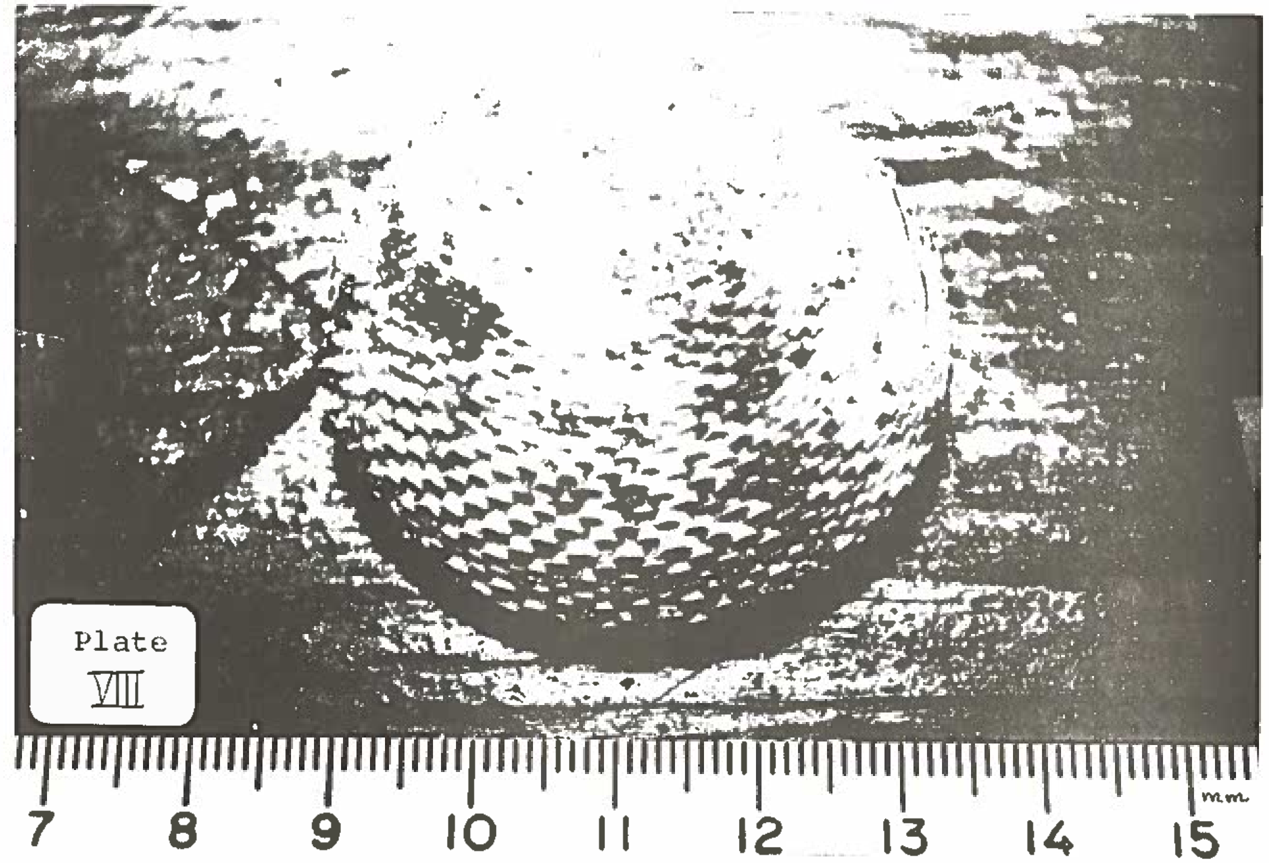


Plate VIII. Enlarged view of Scutarcopagia scobinata.

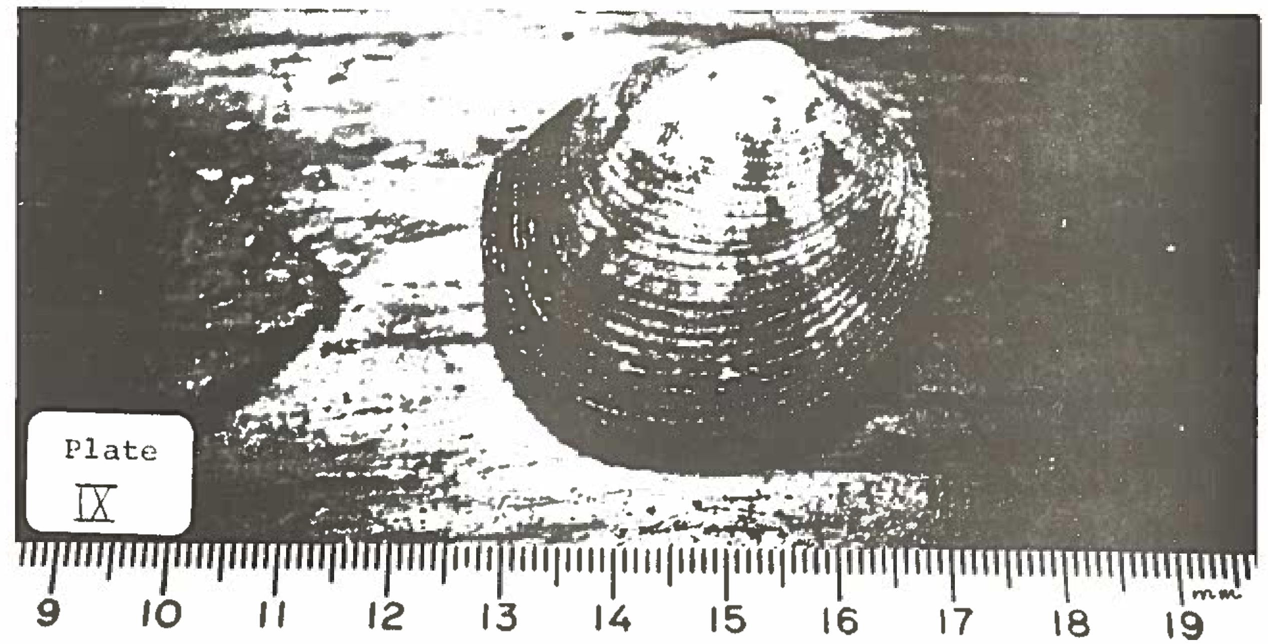


Plate IX. Enlarged view of Periglypta puerpera.

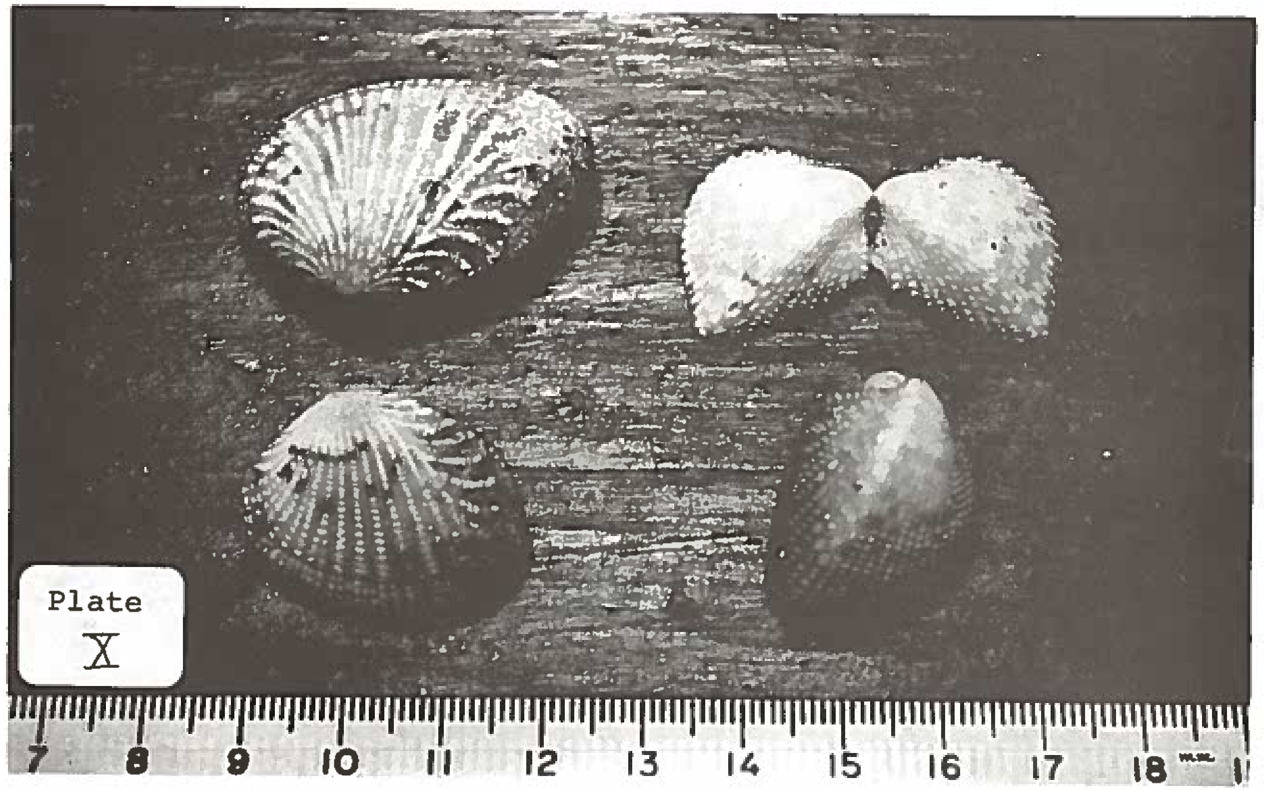


Plate X. Left. Enlarged view of Gafrarium pectinatum.
Right. Enlarged view of Fragum fragum.


Plate XI. Enlarged view of Anodontia sternsiana.

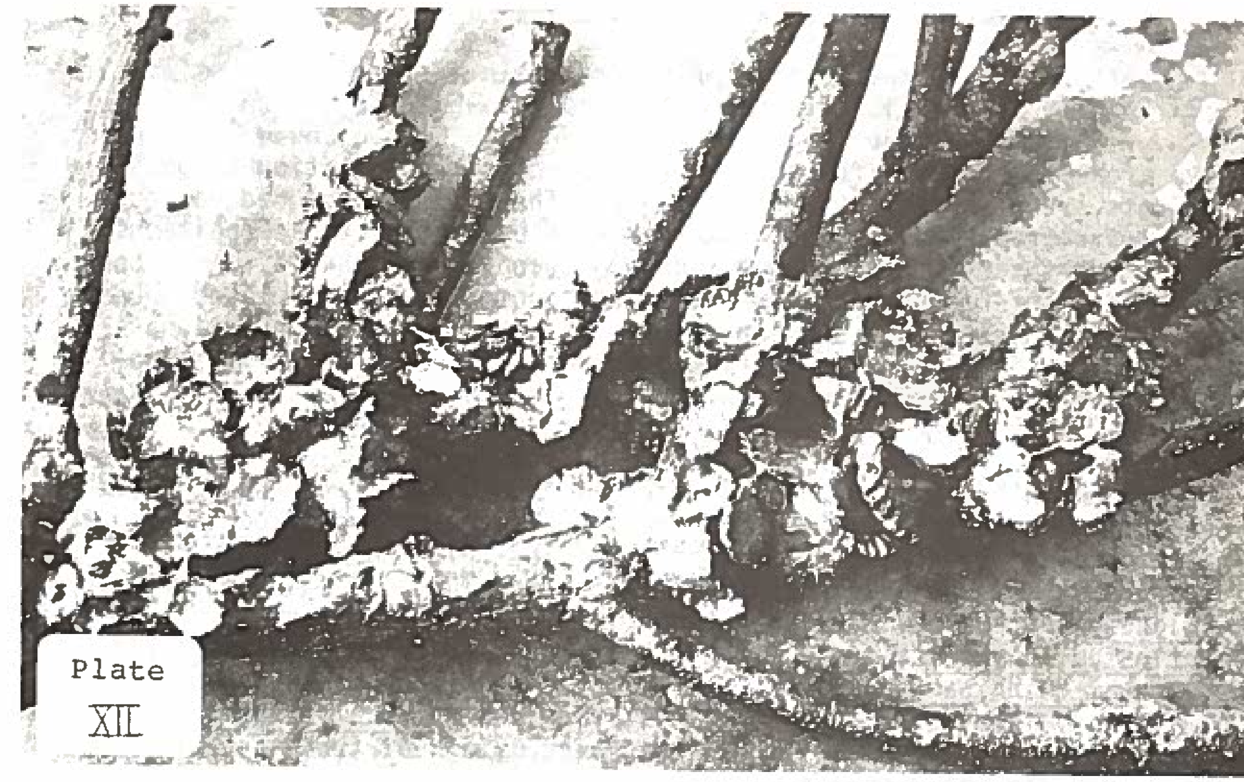


Plate XII. Mangrove roots covered by the oyster Saxostrea mordax.


Plate XIII. Close-up view of Saxostrea mordax.

# METHODS

Five areas were chosen for survey, reflecting a cross section of possible habitats, reef morphology, and exposure. These sites included various types of reef flats, terraces, lagoons, and barrier reefs. Conditions of calm versus rough water were taken into consideration. At least one or two days of reconnaissance work was performed with snorkel and/or scuba at each site to determine qualitative zonation and population densities of the various shellfish and sea urchins. Appropriate transect coordinates were then established and quantitative measurements begun.

The organisms of interest in this study were all food resources with a potential commercial market. They included the gastropod *Trochus niloticus* (topshell ); the large bivalve clam *Tridacna maxima*; eight genera of small mud-and sand-dwelling bivalve clams including *Asaphis violascens*, *Ctena delicatulus*, *Ctena divergens*, *Fragum fragum*, *Gafrarium pectinatum*, *Gafrarium tumidum*, *Modiolus* (c.f. *auriculatus*), *Periglypta puerpera*, *Quidnipagus palatum*, and *Scutarcopagia scobinata*; and one oyster *Saxostrea mordax*. Two echinoid species, *Diadema savignyi* and *Echinothrix diadema*, were also investigated. Both of these sea urchins are valued for their gonads.

Study sites were arbitrarily divided into sectors and then subdivided into appropriate zones for each group of interest. Quantitative censusing and measurement of all but the small bivalve clams were conducted by laying out a 100-m transect tape in a particular zone parallel to the landmass or reef margin. Each team member then swam the length of one side noting and/or collecting all the appropriate organisms occurring within 1 m of the transect tape. Each quadrat was 10 $m^2$ (or lumped to 20 $m^2$) in size. Each transect thus quantified 200 $m^2$.

The small bivalve clams were quantified by a modified method. Transect, random quadrat, and dredging methods were employed.

At the Cocos study site a transect was established seaward across the seagrass flats perpendicular to the mangrove fringe. At 25-m intervals a 1-$m^2$ rebar quadrat frame was placed on the reef flat and all substratum to approximately 20 cm was removed and sorted by hand to remove the clams. Because of the difficulties inherent in the method, including destructiveness and tediousness, replication quadrats were limited to two. However, preliminary analysis of the data showed that no further sampling was necessary.

At Sasa Bay, mud clams were randomly sampled with a small dredge of approximately .08 $m^2$ capacity. The dredge was pulled behind the boat until full and then pulled up for examination. This method was only marginally satisfactory and was often augmented by digging up substrate samples as well.

The oyster *Saxostrea mordax* adheres to mangrove roots and rocks. The sampling method employed here was less refined. Since it was very



difficult to reach the sample area and to distinguish dead from living clams, the number of mangrove roots with and without oysters within .25-$m^2$ quadrats were counted. At best this offers a rough estimate of population density.

At Tumon Bay and Alupang Cove a series of random .25-$m^2$ quadrats was raked (and in some cases excavated with a shovel) for clams. This method worked well in unconsolidated sand substrata.

All the clams from each quadrat, regardless of sampling method, were counted and measured to the nearest millimeter across the long axis.

*Trochus niloticus* were counted, collected, and measured to the nearest millimeter across the base diameter. Gross wet weights to the nearest 0.1 kg were taken in the field with a hand held spring scale. Individual wet weights were also measured in the laboratory on a triple-beam balance. It should be emphasized, however, that such measurements are crude, as these organisms are capable of retaining considerable quantities of water.

*Tridacna maxima* were counted, and aperature lengths were measured to the nearest millimeter. Since this organism was encountered only rarely, further measurements, such as weight and size class, were not considered.

The echinoids, *Echinothrix diadema* and *Diadema savignyi*, were counted and checked periodically for gonad development. Gonad development was monitored by breaking the sea urchin's test and directly examining the gonads. Five to ten individuals of each species were typically checked. Ripe sea urchins are distinguished by the presence of deep yellow and somewhat glossy, mucoid gonads; unripe gonads are a smoother pale yellow to beige with a non-mucoid, velvet-like texture.

The size of the sampling areas was determined both empirically and by the methods outlined by Dennison and Hay (1967). In the case of *Trochus*, for example, it was necessary to ascertain the minimum area required for 95 percent certainty that an accurate accounting of the true population density had been achieved. Analysis of preliminary field data indicated that there was at least one individual per 20 $m^2$. It was determined by the use of Dennison and Hay's standard curve that approximately 118 $m^2$ would be adequate to assure the desired 95 percent sampling confidence. This area was used as a minimum and was exceeded in every case.

The degree of statistical significance was determined by the standard methods outlined by Sokal and Rohlf (1969). Nonparametric or parametric tests were performed as necessary.

## RESULTS AND DISCUSSION

### Sea Urchins

#### Tumon Bay

Of several echinoid species present at Tumon Bay, Echinothrix diadema was the only one of commercial interest. This sea urchin was present on 9 of the 23 transects, and abundant on only 7. These included transects I-C, II-D, II-E, III-B, III-C, IV-B, and IV-C (Fig. 7). All these transects fall into what may be called an "Echinothrix zone" which physiographically corresponds to the reef margin and front. This is not surprising since the major habitat requirement seems to be the presence of holes and rock ledge overhangs, which provide refuge from rough surf and potential predators. Sea urchins were not found in the middle and inner reef flat areas where the substratum is entirely sand, nor on the deeper transects.

Among all sectors, the sea urchin densities ranged from 0 to 60 per quadrat pair (quadrat size is 10 m$^2$). Such a range is not indicative of inadequate sample size, but rather the natural tendencies of individuals to clump, and the effects of a heterogeneous habitat. A coefficient of dispersion was calculated for each transect and was greater than 1 (clumped distribution) in all cases (Table 1).

Nonparametric one-way anova (Kruskal-Wallis Test) was performed between comparable transects among sectors. A highly significant difference was found between the average numbers of sea urchins among transects (Table 1). Despite such differences among transects, the data presented in Figure 7 still offer a rough estimate of population density during the day. It is speculated that a night time census would yield higher values.

#### Piti Reef

The sea urchin population at Piti reef flat is undoubtedly the largest and most diverse on Guam, with most indigenous species present in appreciable numbers. Of the species present at Piti, Echinothrix diadema and Diadema savignyi, are two of the more dominant ones (surpassed only by Echinometra mathaei). Both species typically aggregate to form herds ranging in size from 10 to 100 individuals. Although this herding tendency is apparent everywhere, it is particularly obvious at Piti. Echinothrix diadema tends to form smaller aggregates and/or is often part of a larger D. savignyi aggregation. Both species are found continuously throughout the year, although aggregate size tends to be smaller during the summer months when water levels are lower.

Sea urchins were present on 4 of the 7 transects, but abundant only on transects A, B, and C. Because of herding, densities ranged from 1 to 59 per quadrat pair for D. savignyi and 1 to 29 per quadrat pair for E. diadema (Fig. 8). There appears to be an increase in clumping seaward across the reef, as shown both graphically and by increasing cofficients



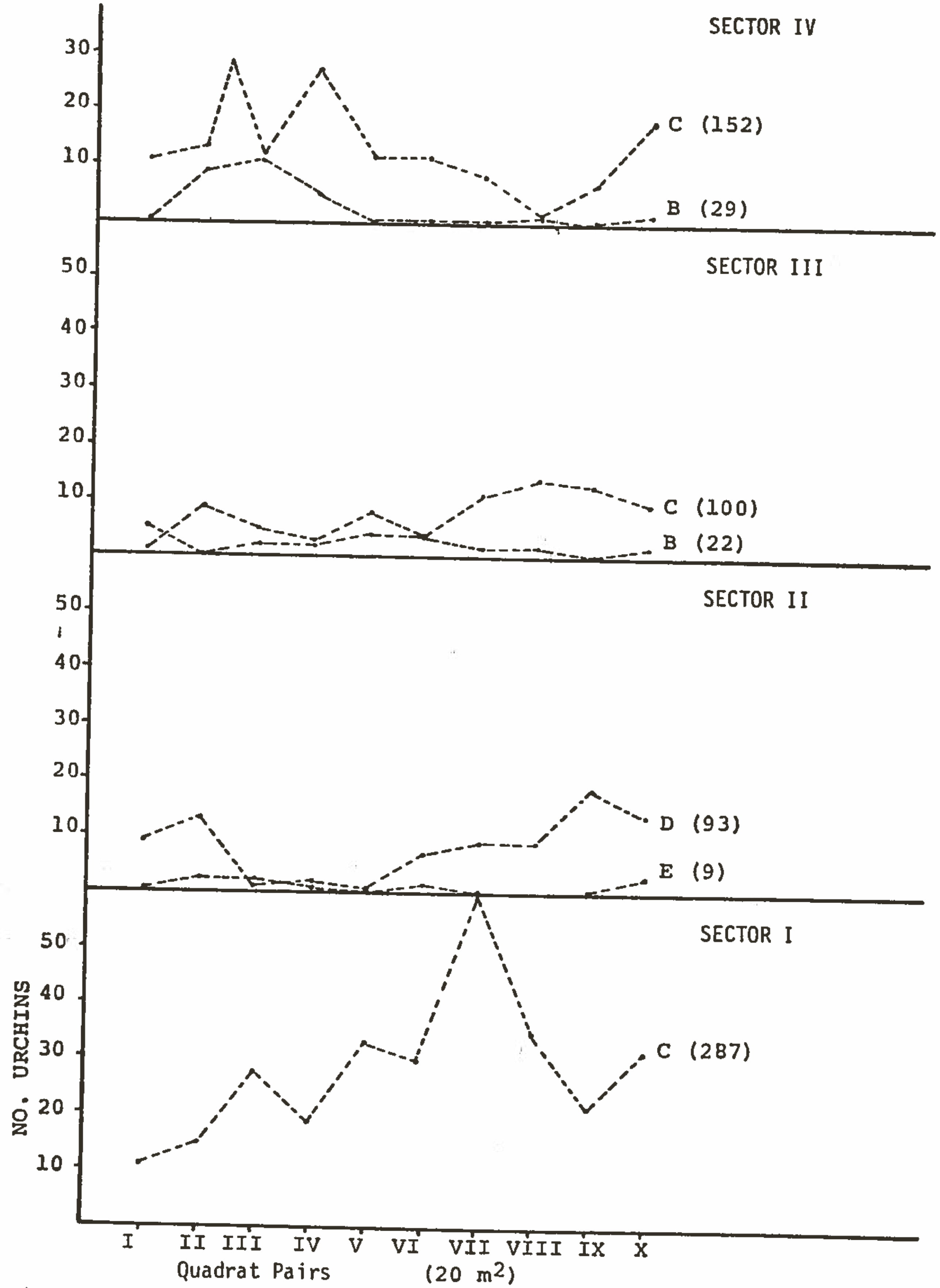


Figure 7. Graph showing the distribution of Echinotrix diadema at Tumon Bay. Transects on which fewer than five urchins were found are not shown. The number in parentheses denotes the total number of urchins encountered per transect.

Table 1. Summary of calculated statistics for Echinothrix diadema along four transects at Tumon Bay.

| | Transects | | | |
|---|---|---|---|---|
| Parameter | I-C | II-D | III-C | IV-C |
| No. Quadrats [1] | 20 | 20 | 20 | 20 |
| $\Sigma Y$ [2] | 287 | 84 | 78 | 123 |
| $\overline{Y}$ | 14.35 | 4.20 | 3.90 | 6.15 |
| Standard deviation: s | 7.74 | 3.42 | 2.76 | 3.85 |
| Standard error of the mean: $s_{\overline{Y}} = (s^2/\Sigma Y)^{1/2}$ | 0.456 | 0.373 | 0.312 | 0.347 |
| Coef. of dispersion: [3] $s^2/\overline{Y}$ | 4.17 | 2.78 | 1.95 | 2.41 |

Kruskal-Wallis$_s$ (between above transects) = 2762.42*** [4]

$X^2_{.05}\{3\} = 7.815$

[1] Quadrat size = 10 meter$^2$

[2] Total number of individuals encountered along the transect.

[3] When the coefficient of dispersion is:

>1, indicates clumped distribution;
=1, indicates random distribution;
<1, indicates even distribution.

[4] *** indicates significance at the .001 level.



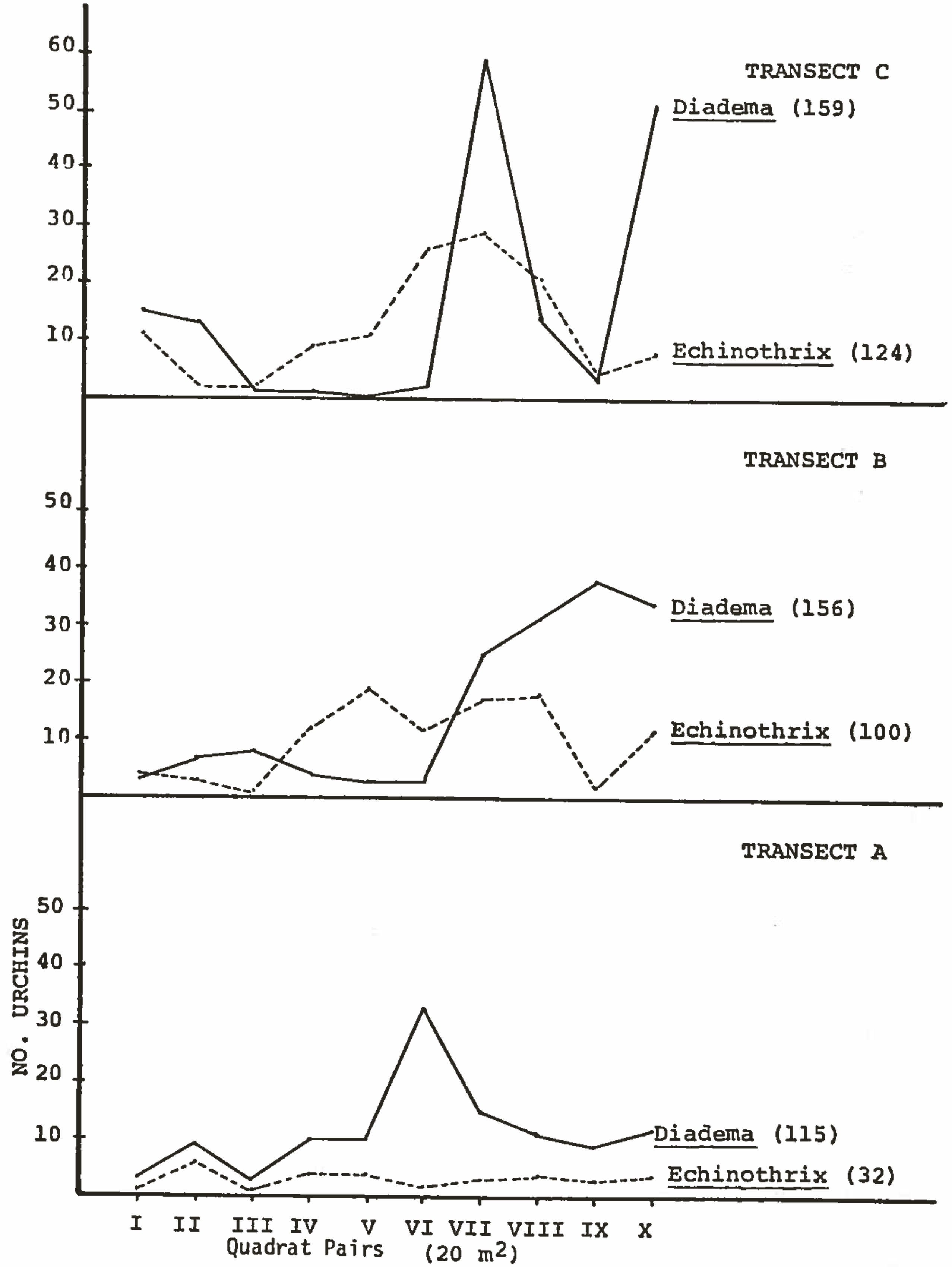


Figure 8. Graphs showing the distribution of Echinothrix diadema and Diadema savignyi along three transects at Piti reef flat. Numbers in parentheses denote the total number of urchins encountered per transect.

of dispersion (Table 2). This, however, may be an artifact of sampling. It is also apparent that the D. savignyi population is somewhat larger than that of E. diadema, but this may fluctuate seasonally.

Another interesting aspect of the Piti sea urchin community is its habitat. Sea urchins are found on the inner reef flat rather than on the reef margin. In part this is explainable by Piti's unusual physiography. Still this alone seems inadequate to account for the vast differences in overall population density compared to the other study sites.

A Kruskal-Wallis nonparametric one-way anova was performed among transects A, B, and C. In keeping with the above-noted trends, a highly significant difference between the average number of individuals per transect was found (Table 2). Since the three transects were run fairly close together, encompassing 600 $m^2$, the difference must be attributed to subtle habitat variability and to clumping rather than to inadequate sample size.

Both species were examined biweekly for gonad development. Observations were begun on 6-21 and extended through 8-31. Five to ten individuals of each species were broken open and checked. Ripe gonads were never detected.

Apra Harbor

The sea urchin population at Apra Harbor is quite sparse, with the exception of a few heavily populated areas in the inner Piti Channel. Interestingly enough, the seaplane ramp was entirely devoid of sea urchins, which was quite unexpected since there has been a sizable population there in the past.

Of the 8 transects, sea urchins were found on only 5. Densities ranged from from 0 to 7 per quadrat pair, with an overall average of less than 5. Because of the sparsity of the data, no statistical testing was performed. The raw data are presented in Table 3.

The paucity of sea urchins is not readily explainable, since the areas investigated all appeared to provide good refuge and food. Inner Piti Channel had several large aggregations of D. savignyi, but these were not quantified. It is interesting to note that these sea urchins do quite well in spite of water temperatures in excess of $35^{o}$ C.

Agat Bay

The sea urchin population density at Agat was about one-third the density found at Tumon (Agat = 0-20 per quadrat pair; Tumon = 0-60 per quadrat pair). However, the Agat population was unevenly distributed between the two sectors, i.e., Pelagi Islets and Gangi-Alutom (Fig. 9). This is probably related to the differences in width of the reef flats and in turbidity of the water.

Only E. diadema were abundant (Table 4), ranging in density from 0 to 21



Table 2. Summary of calculated statistics for Echinothrix diadema and Diadema savignyi along three transects at Piti reef flat (for an explanation of this Table, refer to Table 1).

| Parameter | Transect A | Transect B | Transect C |
|---|---|---|---|
| Echinothrix diadema | | | |
| No. Quadrats | 20 | 20 | 20 |
| $\Sigma Y$ | 32 | 100 | 124 |
| $\bar{Y}$ | 1.60 | 5.00 | 6.20 |
| s | 1.56 | 5.75 | 7.34 |
| $s_{\bar{Y}} = (s^2/\Sigma Y)^{\frac{1}{2}}$ | 0.275 | 0.575 | 0.659 |
| $s^2/\bar{Y}$ | 1.52 | 6.61 | 8.68 |

Kruskal-Wallis$_s$ (between above transects) = 1602.2***

$X^2_{.05}\{2\} = 5.991$

| Parameter | Transect A | Transect B | Transect C |
|---|---|---|---|
| Diadema savignyi | | | |
| No. Quadrats | 20 | 20 | 20 |
| $\Sigma Y$ | 115 | 156 | 159 |
| $\bar{Y}$ | 5.75 | 7.80 | 7.95 |
| s | 6.38 | 9.82 | 14.60 |
| $s_{\bar{Y}} = (s^2/\Sigma Y)^{\frac{1}{2}}$ | 0.594 | 0.786 | 1.15 |
| $s^2/\bar{Y}$ | 7.07 | 12.36 | 26.81 |

Kruskal-Wallis$_s$ (between above transects) = 1343.17***

$X^2_{.05}\{2\} = 5.991$

Table 3. Summary of sea urchin counts along eight transects at Apra Harbor study site. No statistical testing was performed on these data.

| Quadrat ($20\ m^2$) | TRANSECTS Orote Beach A | Orote Beach B | Gabgab Beach A | Gabgab Beach B | Gabgab Beach C | Ironwood Patch Reef A | Western Shoals A | Western Shoals B |
|---|---|---|---|---|---|---|---|---|
| *Echinothrix diadema* | | | | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 |
| 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 4 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 8 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 9 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 |
| *Diadema savignyi* | | | | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |



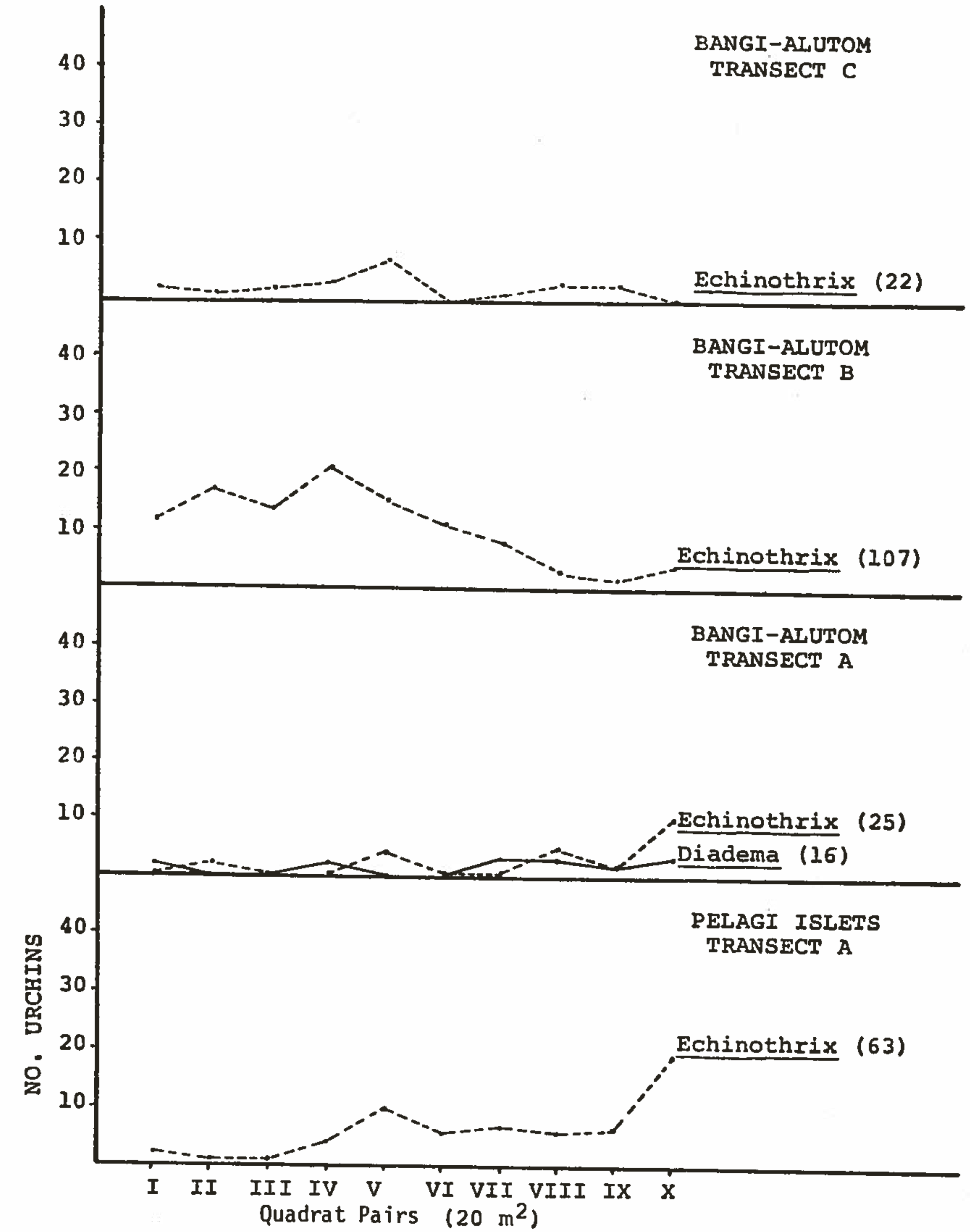


Figure 9. Graphs showing the distribution of *Echinothrix diadema* and *Diadema savignyi* at Agat Bay. Transects on which fewer than five urchins were found are not shown. The number in parentheses denotes the total number of urchins encountered per transect.

Table 4. Summary of calculated statistics for Echinothrix diadema and Diadema savignyi along seven transects at the Agat study site (for an explanation of this Table, refer to Table 1).

| | TRANSECTS | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pelagi Islets | | | Bangi/Alutom Is. | | | |
| Parameter | A | B | C | A | B | C | D |
| Echinothrix diadema | | | | | | | |
| No. Quadrats | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| $\Sigma Y$ | 63 | 3 | 2 | 25 | 107 | 22 | 0 |
| $\overline{Y}$ | 3.15 | - | - | 1.25 | 5.35 | 1.10 | - |
| s | 2.70 | - | - | 1.64 | 4.00 | 1.37 | - |
| $s_{\overline{Y}} = (s^2/\Sigma Y)^{\frac{1}{2}}$ | 0.34 | - | - | 0.328 | 0.386 | 0.292 | - |
| $s^2/\overline{Y}$ | 2.31 | - | - | 2.15 | 2.99 | 1.70 | - |
| Diadema savignyi | | | | | | | |
| No. Quadrats | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| $\Sigma Y$ | 4 | 0 | 0 | 16 | 0 | 0 | 0 |
| $\overline{Y}$ | - | - | - | 0.80 | - | - | - |
| s | - | - | - | 1.00 | - | - | - |
| $s_{\overline{Y}} = (s^2/\Sigma Y)^{\frac{1}{2}}$ | - | - | - | 0.25 | - | - | - |
| $s^2/\overline{Y}$ | - | - | - | 1.25 | - | - | - |



per quadrat pair with means ranging from 1.1 to 5.3. Diadema savignyi ranged in density from 0 to 16 per quadrat pair with means of less than 1. Coefficients of dispersion were calculated for the transects. All the values were greater than 1, indicating clumped distributions.

Cocos Barrier Reef Complex

Of the 14 transects run at Cocos, sea urchins were encountered on only 8. Transects A, B, and C in Sectors I and II, and Transect A in Sector III generally corresponded to the reef margin and/or rubble-strewn habitats. Transect $A_s$ in Sector II was a sand spit strewn with rubble.

Only E. diadema occurred in appreciable numbers (Fig. 10), and D. savignyi was rarely encountered. The total number of sea urchins ranged from 0 to 7 per quadrat pair with means of less than 2 per transect. This was a surprisingly small number.

Coefficients of dispersion were calculated for transects I-B and II-$A_s$ (Table 5). The sea urchins along Transect I-B (c.d. = 0.686) were evenly distributed, while those along Transect II-$A_s$ were clumped (c.d. = 1.05).

The sea urchin populations on Guam's reefs may be described as patchy (Fig. 11). Virtually all leeward reefs have small populations, but differences in overall population size are dramatic from one place to the next, even among areas that are apparently equivalent habitats. The reasons for this are not entirely clear, but could include predation by fishes and crabs, poor recruitment conditions for juveniles, seasonally rough water, and, possibly, harvesting by man. Unfortunately, investigation of these factors was beyond the scope of this report.

Among the five study sites, D. savignyi was dominant only at Piti. There the sea urchin population was very high. It is speculated that the physiography and unidirectional water flow are optimal factors in maintaining the community. Diadema savignyi were present at all of the areas investigated but were typically present in very low numbers, i.e., less than five individuals per 200-$m^2$ transect. The absence of ripe gonads is somewhat puzzling, and seems to indicate seasonality of some sort. Monitoring for at least one year is needed before firm conclusions can be made.

Echinothrix diadema were more evenly distributed among the study sites; Tumon, Piti, and Agat having the largest populations. Since this species prefers a habitat of holes and overhangs, enumeration is more difficult. Therefore, if one takes into account nocturnal migrations, standing crop estimates are all the more unreliable. Again, a year of weekly gonad inspection is in order for this species.

Trochus niloticus

Data gathered on transects in Tumon Bay indicate that the habitats of various growth stages of Trochus niloticus can be broadly based on reef topography. The transects shown in Fig. 1 can be designated as occurring

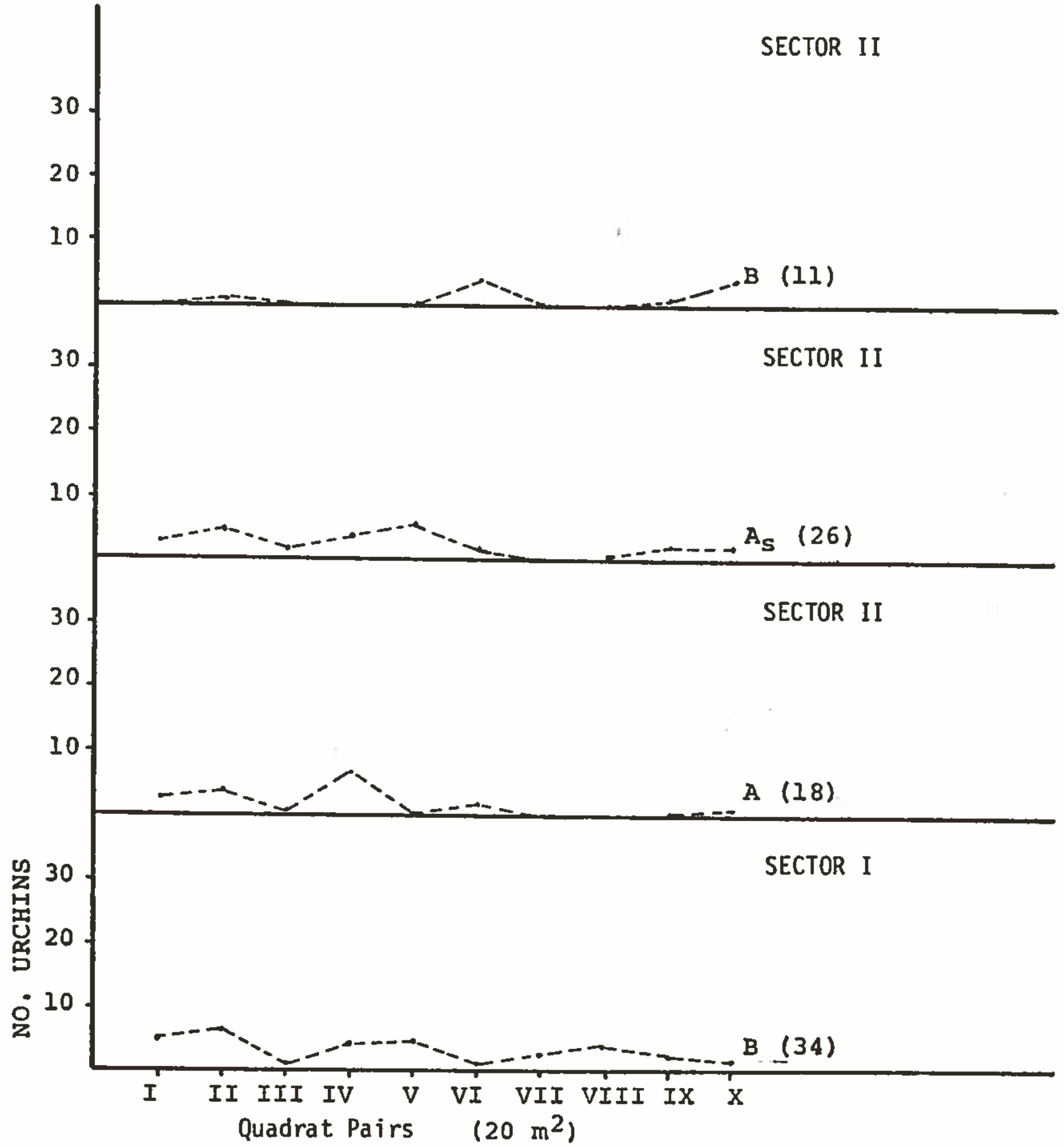


**Figure 10.** Graphs showing the distribution of Echinothrix diadema at Cocos Barrier Reef Complex. Transects on which fewer than five urchins were found are not shown. The number in parentheses denotes the total number of urchins encountered per transect.

Table 5. Summary of calculated statistics for Echinothrix diadema along eight transects at the Cocos Barrier Reef Complex (for an explanation of this Table, refer to Table 1).

| Parameter | TRANSECTS Sector I A | Sector I B | Sector I C | Sector II A | Sector II $A_s$ | Sector II B | Sector II C | Sector III A |
|---|---|---|---|---|---|---|---|---|
| No. Quadrats | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| $\Sigma Y$ | 3 | 34 | 1 | 18 | 26 | 11 | 6 | 5 |
| $\bar{Y}$ | - | 1.70 | - | 1 | 1.30 | 1 | 1 | 1 |
| s | - | 1.08 | - | - | 1.17 | - | - | - |
| $s_{\bar{Y}} = (s^2/\Sigma Y)^{1/2}$ | - | 0.185 | - | - | 0.229 | - | - | - |
| $s^2/\bar{Y}$ | - | 0.686 | - | - | 1.05 | - | - | - |

Kruskal-Wallis$_s$ (between II-A and II-$A_s$) = 621.16***

$X^2_{.05}$ {1} = 3.841

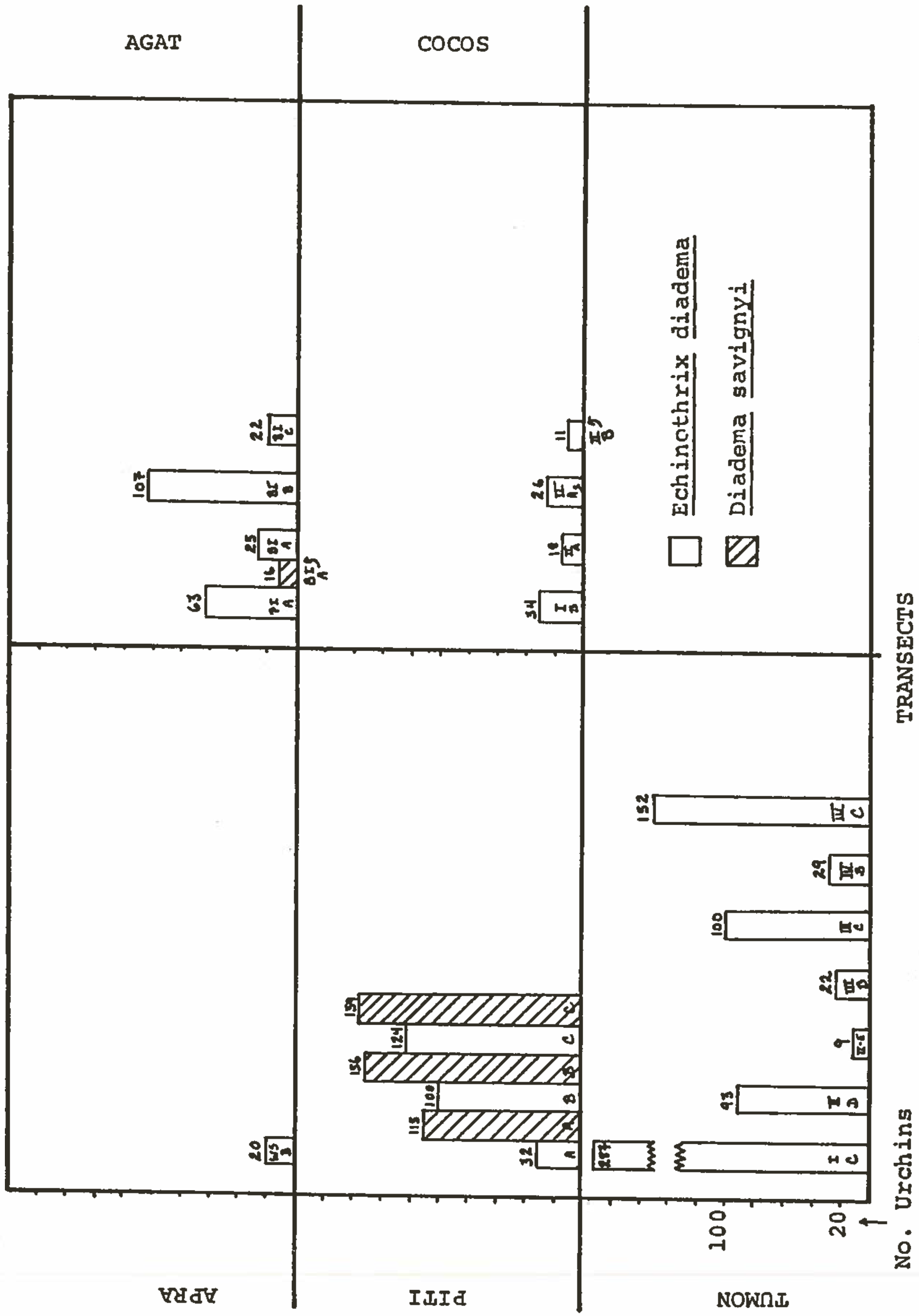


Figure 11. Summary comparisons of population size and distribution between the five study areas for *Echinothrix diadema* and *Diadema savignyi*. The number above each bar denotes the total number of urchins encountered per transect. Transects on which fewer than five sea urchins were found are not shown. Notations inside the bars denote transects.



in one of four zones. These zones are the outer reef flat, the reef margin, the reef front terrace (at a depth of 3 to 6 m), and the 12-m terrace.

Analysis of variance of the diameter of the shell base of *Trochus* from nine transects in the outer reef flat zone at Tumon indicates a significant difference among the transects ($F_s$ = 3.667, $.01<p<.025$). Perhaps this difference within the zone reflects the heterogeneity of the reef at Tumon, but it may be the result of harvesting pressures in the more accessible areas of this zone.

A comparison by analysis of variance of shell diameters among the four reef zones at Tumon reveals a very significant difference ($F_s$ = 728.4, $p<.001$). This suggests that the reef zones contain statistically different size classes of *Trochus*, in spite of the variation in sizes within zones. The mean shell base diameters of *Trochus* in the four reef zones at Tumon are presented in Table 6.

The Student-Newman-Keuls test can be used to elaborate on the variance among the reef zones. When applied to the data from Tumon, it indicates that there are significant differences ($p<.01$) between the size classes of shells in adjacent zones of the reef. These size classes are noticeable in the size-frequency distribution illustrated in Fig. 12.

As indicated in Table 6, *Trochus* in the other survey areas also show a general zonational trend, with individuals progressively increasing in size seaward from the outer reef flat. However, the statistically different distribution of size classes among four zones that is characteristic of Tumon Bay is not always evident in all areas.

The situation at Piti is notably different from that at Tumon. Four transects (A, B, C, and G) were established in the zone designated as the outer reef flat. The size of the single *Trochus* occurring on Transect C was not recorded, but analysis of variance among Transects A, B, and G indicates no significant difference in shell base diameter ($F_s$ = 3.046, $.05<p<.10$). In the seaward zones, only a single specimen was found. Reasons for the absence of *Trochus* in these zones at Piti are unknown.

There is a marked tendency towards zonation of size classes in Apra Harbor. The outer harbor is a lagoon ecosystem with a narrow reef flat, and its reef does not have the zone specified as the 12-m terrace.

Data from Apra Harbor were collected primarily at Orote Beach, Gabgab Beach, and Western Shoals. A single specimen was recorded on the transect at Ironwood Patch Reef. Extensive reconnaissance of the Ironwood Patch Reef sector revealed no *Trochus* near the transect site nor along Glass Breakwater.

Analysis of variance among reef zones in Apra Harbor shows a very significant difference in sizes of *Trochus* inhabiting the zones ($F_s$ = 652.78, $p<.001$). As was found for Tumon Bay, analysis of the data by means of Student-Newman-Keuls test reveals significant differences in

Table 6. Mean shell base diameters of Trochus niloticus in four reef zones at selected sites on Guam. Values are mean diameter ± standard error. The sample sizes are given in parentheses.

| Site | Outer Reef Flat | Reef Margin | Reef Front Terrace | 12-m Terrace |
|---|---|---|---|---|
| Tumon Bay | 40 ± 1.2(99) | 57 ± 3.0(30) | 97 ± 2.3(38) | 109 ± 0.8(135) |
| Piti | 36 ± 3.6(12) | 0 (0) | 83 (1) | 0 (0) |
| Apra Harbor | 23 ± 0.7(34) | 71 ± 6.4(13) | 102 ± 2.3(39) | - |
| Agat Bay | 34 ± 0.7(40) | 72 ± 7.9(7) | 105 ± 1.6(41) | 115 ± 1.5(3) |
| Cocos Barrier Reef | 40 ± 3.1(17) | 52 ± 5.1(4) | 108 ± 1.2(86) | 109 ± 0.8(119) |



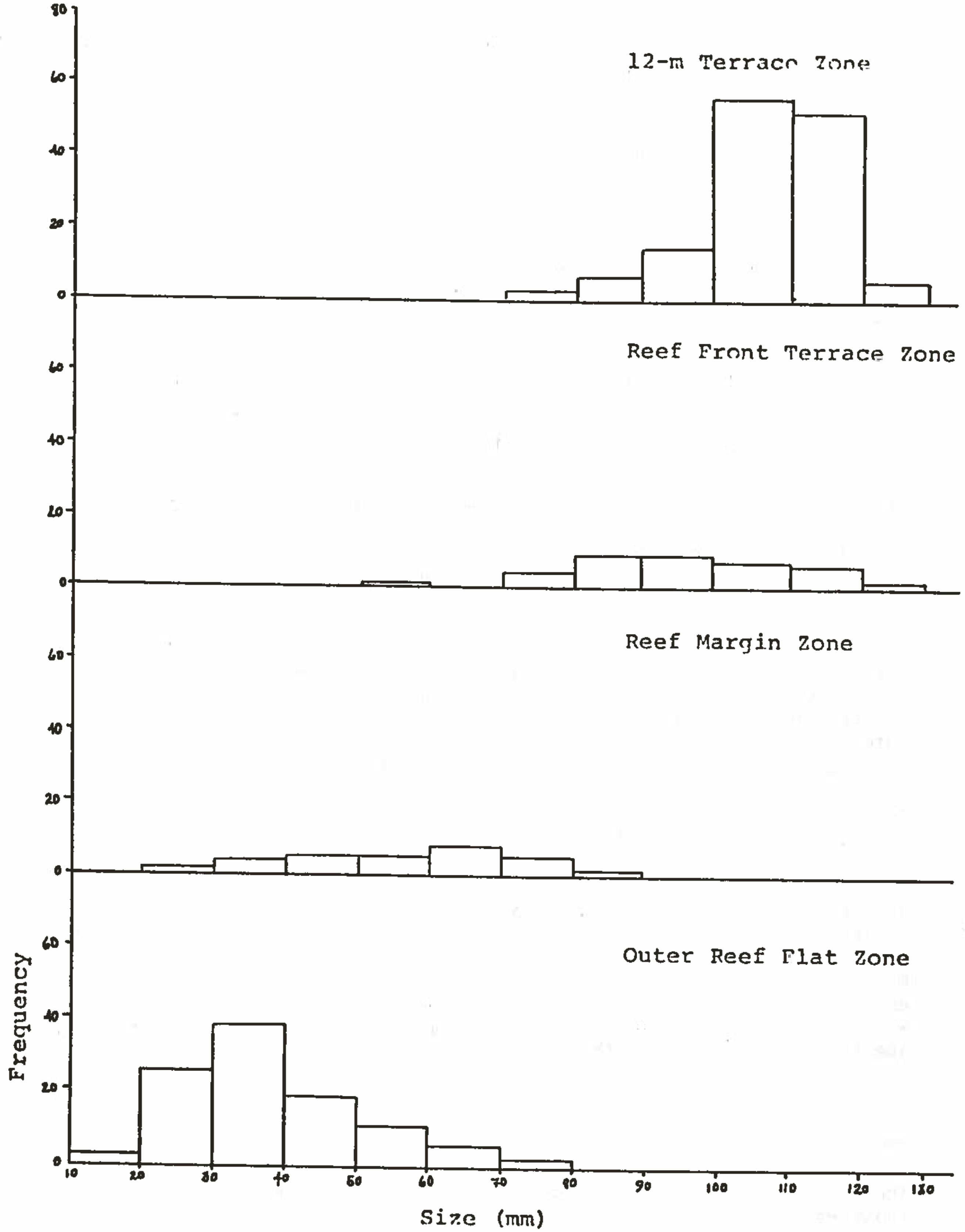


Figure 12. Size-frequency distribution of Trochus niloticus in four reef zones at Tumon Bay. Size refers to the diameter of the shell base.

size classes between adjacent zones ($p<.01$).

The distinctive zonation among the sizes of Trochus found in Tumon Bay and in Apra Harbor is not apparent in Agat Bay or on Cocos Barrier Reef. Only two sites were sampled in Agat Bay because of the limited time available for field work. However, brief reconnaissance swims revealed moderate numbers of Trochus near Rizal Beach, and a relatively abundant population near Anae Island.

Analysis of variance among reef azones in Agat Bay yields a very significant difference in shell diameters ($F_s = 409$, $p < .001$). When the Student-Newman-Keuls test is performed on the data, significant differences in size classes are indicated between the outer reef flat zone and the reef margin zone ($p<.01$) and between the reef margin zone and the reef front terrace zone ($p<.01$). However, the test discloses no significant difference between the reef front terrace zone and the 12-m terrace zone ($p>.05$). Thus, Trochus may be distributed among only three zones in Agat Bay.

The focus of transects on Cocos Barrier Reef was in Sectors I and II, because these sites are located on the leeward side of the lagoon, and are, therefore, more accessible. Three transects were established on the windward side of the lagoon, but rough seas prevented a more thorough survey.

A very significant difference in shell sizes among reef zones on Cocos Barrier Reef is indicated by analysis of variance ($F_s = 270.2$, $p<.001$). Comparison of size classes in adjacent reef zones by means of the Student-Newman-Keuls test reveals significant differences between the outer reef flat zone and the reef margin zone ($p<.05$) and between the reef margin zone and the reef front terrace zone ($p<.01$). No significant difference is shown between the reef front zone and the 12-m terrace zone ($p>.05$). Thus, the arbitrarily defined zones are not statistically valid for the barrier reef, or the parameters defining the zones have changed.

In addition to the four reef zones sampled, a search for Trochus to a depth of 18 m was carried out in each sector. The animals were found at this depth at only three sites. In Tumon Bay Trochus were sighted at 18 m in Sectors II (Transect G) and III (Transect F). Transects of 50 m and 100 m, respectively, were conducted in these sectors. No Trochus were located on the transect at this depth in Sector II, and a single specimen was observed on the transect in Sector III.

A substantial number of Trochus were found at a depth of 18 m in Sector II (Transect E) on Cocos Barrier Reef. A mean size of 101 ±0.9 mm was recorded for the 32 topshells occurring on this transect.

The depth range of Trochus on Guam appears to be intermediate between those reported by McGowan (1956) for Ponape and for Palau. The assertion by McGowan that animals of 50 mm or less in diameter are never found at depths greater than 3 m is supported by the body of data of this survey. No evidence was found to support the conjectures of Hedley



(1917, cited by Rao, 1937) and Rao (1973) that smaller Trochus from depths of more than 7 m periodically move upwards to replenish stocks decreased by harvesting.

The mean abundances of Trochus occurring in the four reef zones are shown in Table 7. Although the animals are by no means uniformly distributed on the reef, several areas do contain relatively large populations. McGowan (1956) stated that an average of 6 to 8 adults per 100 $m^2$ constitutes a dense population. The term harvestable population was used by Muller (1973) to designate counts of adults averaging more than 100 per 20-min observation period. Data from the present study suggest that some portions of Guam's reefs meet these criteria for commercial harvesting of topshells.

The inclusion in this survey of fringing reef, barrier reef, and lagoon ecosystems permits some interesting observations. A comparison involving densities of Trochus of commercially harvestable size on the leeward barrier reef ($\bar{Y}$ = 11.5/100 $m^2$) as opposed to the windward barrier reef ($\bar{Y}$ = 20.3/100 $m^2$) supports the statement by Moorhouse (1932) that the windward side is most heavily populated. However, this comparison of densities does not take into consideration the factor of human depredation. Rough sea conditions during most of the year probably prevent harvesting topshells on the windward reefs of Guam.

A comparison of densities of harvested Trochus on the fringing reef at Tumon ($\bar{Y}$ = 16.9/100 $m^2$) with the barrier reef at Cocos ($\bar{Y}$ = 14.8/100 $m^2$) contradicts McGowan's observation (1956) that barrier reefs constitute the primary habitat of the species. No such preference is apparent on Guam's reefs.

The lower density ($\bar{Y}$ = 5.0/100 $m^2$) of harvestable Trochus in the lagoon environment of Apra Harbor is comparable with the small numbers found by Bryan (1975). The distribution described by Muller (1973) is not applicable to Guam's reefs, nor has it been reported by other investigators.

The relationship of the increase in weight to the increase in shell base diameter of Trochus is illustrated in Fig. 13. Analysis of correlation between the weight and the size indicates a significant relation ($r = .98$, $p<.01$).

In order to provide some means of estimating standing crop of Trochus from data in this survey, a regression analysis on the logarithmic transformations of the weight and diameter of 82 shells, ranging from 28 to 120 mm in diameter, was performed. From this analysis, it was found that the curvilinear relationship shown in Fig. 13 can be expressed by the equation:

$$W = 0.0003\ D^{3.03},$$

where W is the live wet weight (g), and D is the diameter (mm) of the shell base. The estimation of weight can be broken down further by assuming that the weight of the empty shell is equal to about 2.25 times the weight of the animal (Rao, 1937).

Table 7. Abundance of Trochus niloticus in 20-$m^2$ quadrats at selected sites on Guam. Values are mean $\pm$ standard error, with the number of quadrats given in parentheses.

| Site | Outer Reef Flat | Reef Margin | Reef Front Terrace | 12-m Terrace |
|---|---|---|---|---|
| Tumon Bay | 1.1 $\pm$ 0.2(90) | 0.8 $\pm$ 0.2(40) | 1.0 $\pm$ 0.2(40) | 3.4 $\pm$ 0.3(40) |
| Piti | 0.3 $\pm$ 0.1(40) | 0 (10) | 0.1 $\pm$ 0.1(10) | 0 (10) |
| Apra Harbor | 1.7 $\pm$ 0.8(20) | 0.4 $\pm$ 0.1(30) | 1.3 $\pm$ 0.4(30) | - |
| Agat Bay | 4.0 $\pm$ 0.8(10) | 0.4 $\pm$ 0.2(20) | 2.1 $\pm$ 0.6(20) | 0.2 $\pm$ 0.1(20) |
| Cocos Barrier Reef | 0.6 $\pm$ 0.2(30) | 0.2 $\pm$ 0.1(20) | 2.9 $\pm$ 0.5(30) | 3.0 $\pm$ 0.4(40) |



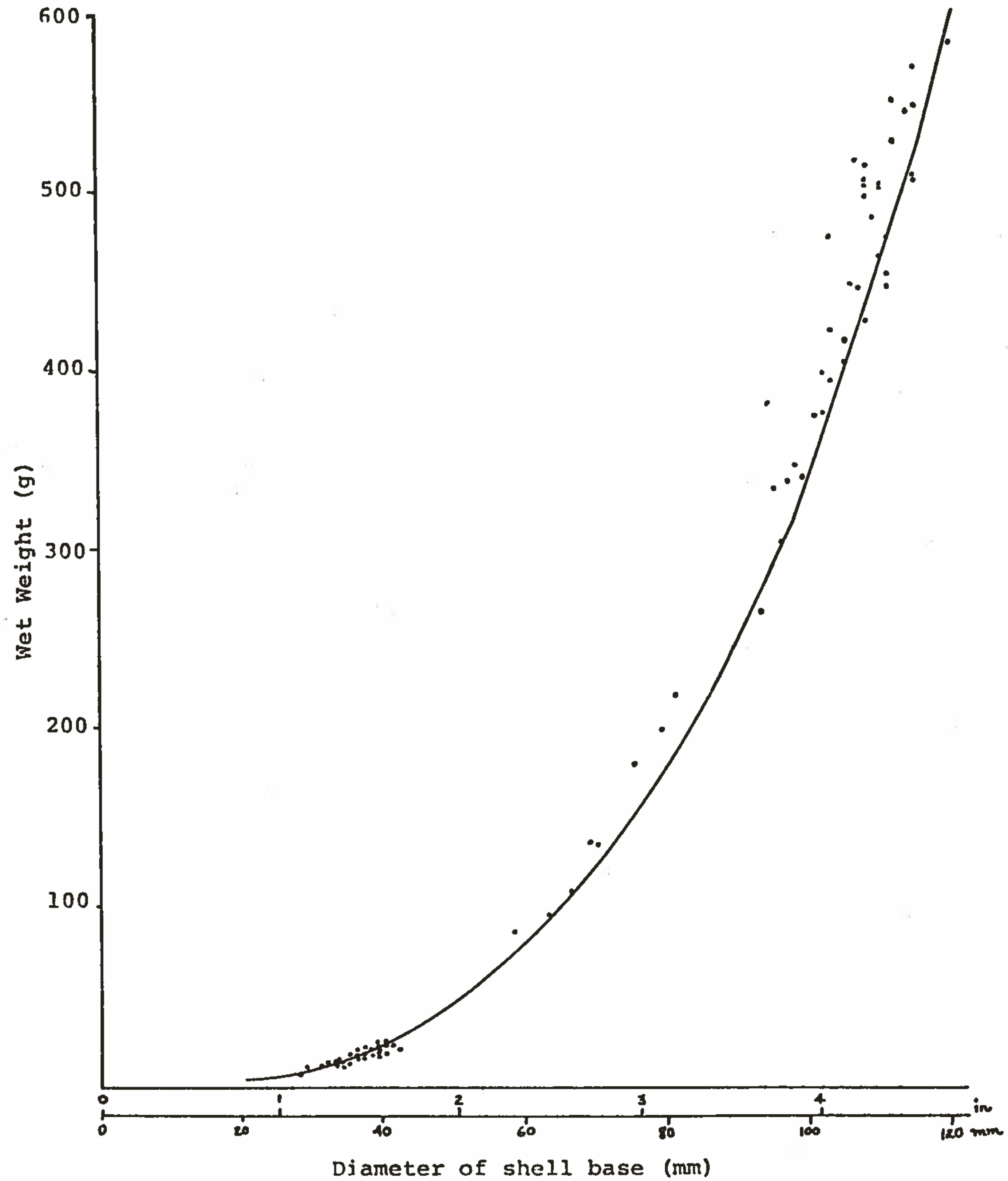


Figure 13. Scatter diagram showing the relationship of the increase in weight to the increase in diameter of the shell for Trochus niloticus.

Estimates of the biomass of commercially harvestable *Trochus* on several Guam reefs are presented in Table 8. These figures suggest that commercial harvesting would require the use of scuba equipment, as the 12-m terrace zone generally contains the greatest biomass of topshells. However, the commercial harvesting of *Trochus* on Guam's reefs could result in shifts of size class, population density, and biomass of topshells in any given reef zone. Careful monitoring of the harvest of shells and of any subsequent changes in population structure would provide useful information in regard to possible management strategies for future harvests.

Although *Trochus* on Guam reefs are maintaining dense populations, there are large numbers of sexually mature individuals present, many of which would be removed by a commercial fishery. Male and female *Trochus* become sexually productive at different sizes, and presumably, at different ages (Moorhouse, 1932; Rao, 1937; McGowan, 1956). Males may possess viable spermatozoa when they reach a shell diameter of 57 mm (2.25 in), and females may begin producing eggs when they become 64 mm (2.5 in) in diameter (McGowan, 1956). While individuals as small as these are sexually mature, the size of their gonads is small, and consequently they spawn fewer gametes. As the animals grow larger, their gonads increase in size, and they become more prolific.

Since small *Trochus* are sexually immature, the allowance of collection for home consumption of juveniles of 50.8 mm (2 in) or less in diameter is counter productive to perpetuation of a breeding stock. Individuals should be allowed to reach sexual maturity and to reproduce before they are harvested for any purpose, be it commercial or recreational. Harvest of both mature and immature individuals will inevitably lead to the extinction of Guam's *Trochus* populations.

Tridacnid Clams

Fifty-two specimens of *Tridacna maxima* were recorded from 58 transects covering an area of 11,500 $m^2$. This species was found in depths ranging from just below the low-tide level on the outer reef flat to 20 m on the reef slope.

Although *Tridacna maxima* occurred in all the reef zones specified in this study, it was most abundant in the reef front terrace zone, extending from the reef margin seaward to a depth of 3 to 6 m. This zone contained over 65% of all the giant clams sighted. The mean density for the reef front terrace zones of all the study areas combined is 1.3 *Tridacna maxima*/100 $m^2$. Table 9 lists a summary of the data from the transects on the reef front terrace in selected areas around Guam.

In general, the density of *Tridacna maxima* on Guam is low. As noted by Bryan and McConnell (1976), the population of *T. maxima* at Helen Reef has been poached upon but to a lesser extent than the larger species have. However, the population of *T. maxima* at Helen Reef still is greater than the density of the species on Guam.

*Tridacna squamosa* and *Hippopus hippopus* were not observed on any transect.



Table 8. Biomass estimates of commercially harvestable *Trochus* in selected areas of Guam. Biomass estimates are based on the equation:

$$W = 0.0003\ D^{3.03}$$

Biomass estimations (W) are based on the mean shell size (D) in given zones of the reef.

| Site | Reef Zone | Mean Shell Size (mm) | Mean Density (No./100$m^2$) | Biomass Estimation (kg/100$m^2$) |
|---|---|---|---|---|
| Tumon Bay | 12-m terrace | 109 | 17.0 | 7.6 |
| Apra Harbor | Reef front terrace | 102 | 6.5 | 2.4 |
| Agat Bay | Reef front terrace | 105 | 10.5 | 4.2 |
| Agat Bay | 12-m terrace | 115 | 1.0 | 0.5 |
| Cocos Barrier Reef | Reef front terrace | 108 | 14.5 | 6.3 |
| Cocos Barrier Reef | 12-m terrace | 109 | 15.0 | 6.7 |

Table 9. Abundances, size ranges, and mean valve lengths of *Tridacna maxima* observed in the reef front zone in selected areas around Guam.

| Site | No. *T. maxima* | Area Surveyed ($m^2$) | Size Range of Valves (mm) | Mean Valve Length (mm) | Abundance/100 $m^2$ |
|---|---|---|---|---|---|
| Tumon Bay | 13 | 800 | 49-265 | 148 $\pm$ 18 | 1.6 |
| Piti | 2 | 200 | 73-124 | 99 $\pm$ 26 | 1.0 |
| Apra Harbor | 7 | 600 | 98-160 | 125 $\pm$ 9 | 1.2 |
| Agat Bay | 5 | 400 | 53-175 | 104 $\pm$ 26 | 1.3 |
| Cocos Barrier Reef | 7 | 600 | 50-145 | 81 $\pm$ 13 | 1.2 |



While juvenile *T. squamosa* may have been confused with juvenile *T. maxima*, adults of both *T. squamosa* and *H. hippopus* are easily distinguishable from adults of *T. maxima*. This indicates that *T. squamosa* and *H. hippopus* are rare, if breeding populations of these species exist at all.

Other Bivalves

No large populations of bivalves were found in Tumon Bay. The majority of those present were small infaunal forms, and harvesting would require destruction of the reef.

At the northern end of Tumon Bay, the bivalves live burrowed in sand beneath colonies of the coral *Porites* and beneath algal mats of *Caulerpa*. The small clams *Ctena divergens* and *C. delicatula* formed the predomiant populations (21.2 clams/$m^2$) in 10 randomly placed quadrats. Because of difficulties in differentiating between these two species in the field, they are combined into one unit in all following discussions of the genus.

Other bivalves exhibited patchy distributions in this area. Juveniles of *Scutarcopagia scobinata* and *Gafrarium pectinatum* were the other edible species present in the quadrats. Valves of dead adults of these were commonly found and indicate that predation pressures are relatively high. A summary of bivalves observed or collected in the area is presented in Table 10.

Sandy areas near the southern end of Tumon Bay contained the cockle *Fragum fragum*. Randomly sampled quadrats at this site revealed a mean density of 4.4/$m^2$. No other species of bivalve occurred in the quadrats.

The clam *Quidnipagus palatum* occurred in all 10 quadrats sampled in Alupang Cove. However, numbers of individuals varied widely, and a mean density of 43.6/$m^2$ was calculated. This estimation of population density lies in the middle portion of the 4 to 73/$m^2$ range found by Day (1977) in an adjacent area of the bay.

The edible venerid clam *Asaphis violascens* was also common (7.6/$m^2$) in muddy sand beneath rubble. This species attains a size that makes it attractive for consumption (mean valve length = 48 $\pm$3.9 mm). However, the clams were found only in a narrow sand-rubble bar extending outwards from shore. Conversations with local fishermen indicated that this species can also be found in a similar habitat on the eastern end of Alupat Island.

Few bivalve molluscs were observed at Piti. The reef flat at this site is more exposed and seemingly less suitable for these organisms. Valves of dead *Scutarcopagia scobinata* and *Periglypta puerpera* indicate the presence of these species in sandy patches on the reef flat.

The major populations of bivalves in Apra Harbor are associated with the mangrove ecosystem in Sasa Bay. *Gafrarium tumidum* and *G. pectinatum* were found in the soft, muddy substratum along the mangrove fringe. A

Table 10. A checklist of bivalve molluscs observed or collected on Guam's reefs during the study. X denotes the observation of a living specimen, and * denotes observation of a dead specimen.

| Species | Tumon Bay | Alupang Cove | Piti | Apra Harbor | Agat Bay | Cocos |
|---|---|---|---|---|---|---|
| Family Arcidae: | | | | | | |
| arcid sp. 1 | X | | | | | X |
| arcid sp. 2 | X | | * | | | X |
| Family Mytilidae: | | | | | | |
| Septifer bilocularis (Linnaeus) | | | | X | | |
| Modiolus (cf. auriculatus) | | | | | X | X |
| Family Pinnidae: | | | | | | |
| Pinna muricata Linnaeus | | X | | X | | |
| Family Pteriidae: | | | | | | |
| Pinctada margaritifer (Linnaeus) | | | | | | X |
| Family Limidae: | | | | | | |
| Limea fragilis (Gmelin) | X | | | | | |
| Family Ostreidae: | | | | | | |
| Saxostrea mordax (Gould) | | | | X | | |
| Family Chamidae: | | | | | | |
| Chama sp. | X | | X | | | X |
| Family Lucinidae: | | | | | | |
| Anodontia sternsiana (Oyama) | | | | | X | X |
| Ctena divergens (Philippi) | X | X | | | X | X |
| C. delicatula (Pilsbry) | X | | | | X | X |
| Codakia punctata (Linnaeus) | * | * | * | | * | |
| Family Cardiidae: | | | | | | |
| Fulvia tenuicostata (Lamarck) | | | | | | X |
| Fragum fragum (Linnaeus) | X | | | | X | X |



Table 10. Continued.

| Species | Tumon Bay | Alupang Cove | Piti | Apra Harbor | Agat Bay | Cocos |
|---|---|---|---|---|---|---|
| Family Tridacnidae: | | | | | | |
| Tridacna maxima (Roeding) | X | | X | X | X | X |
| Family Tellinidae: | | | | | | |
| Tellina crassacostata | X | | | | | |
| tellinid sp. | X | | | | X | X |
| Scutarcopagia scobinata (Linnaeus) | X | | * | | X | X |
| Quidnipagus palatum Iredale | X | X | | | X | X |
| Family Psammobiidae: | | | | | | |
| Asaphis violascens (Forskal) | | X | | | | X |
| Family Veneridae: | | | | | | |
| Pitar (cf. obliquatum) (Hanley) | X | * | * | | * | |
| Periglypta puerpera (Linnaeus) | * | | | | * | X |
| Gafrarium pectinatum (Linnaeus) | X | X | | X | X | X |
| G. tumidum (Roeding) | | | | X | | |
| Glycydonta marica (Linnaeus) | | | | | | X |

total of five dredge hauls in the area indicated a mean density of $5.2/m^2$ for each of these species. This estimate for G. tumidum is lower than those of previous studies. The University of Guam Marine Laboratory (1977) found $14/m^2$, and Taylor (1977) reported densities ranging from 3.6 to $26.9/m^2$. These values emphasize the patchy distribution of the species. Gafrarium pectinatum was not recorded by the previous investigators.

The oyster Saxostrea mordax forms dense aggregations on the prop roots of mangroves and on buoys and markers near the mouth of the Sasa River. In this area, approximately 50% of all mangrove roots support oysters. Because of the density of the roots and the three-dimensional aspects of the distribution of the oysters on the roots, estimates of the abundance of oysters in the mangrove fringe were not considered feasible. Sampling with quadrats on flat surfaces resulted in an estimated mean density of 2,500 ±665 oysters per $m^2$ (Univ. Guam Mar. Lab., 1977).

Dredging and quadrat sampling in the inner Piti Channel area of Apra Harbor did not produce any live bivalves. Valves of dead Quidnipagus palatum and Fragum fragum were noted at all sampling stations. Taylor (1977) found populations of Gafrarium tumidum inhabiting areas farther east in the channel.

The seagrass beds in Agat Bay contain small populations of edible bivalves. Although Ctena spp. are relatively abundant (Table 11), their small size is a disadvantage in regard to market potential.

The larger bivalves are not common in the seagrass beds at Agat (Table 11). It should be noted that although the clam Quidnipagus palatum was not often found in the quadrats, the beach near the study area was littered with thousands of valves of this species. This implies that Q. palatum is heavily harvested in this area.

The seagrass beds of the Cocos Barrier Reef Complex contain the richest bivalve fauna of all the areas surveyed. The predominant species are Quidnipagus palatum and Ctena spp.

Figure 14 gives comparisons of the mean valve length and mean density to distance from the shoreline for Quidnipagus palatum and for Ctena spp. From the graph, it appears that two zones occur in the seagrass bed. Quidnipagus palatum are small but very abundant near shore, and Ctena spp. are relatively large but scarce. At a distance of about 100 m from the shoreline, these relationships undergo a reversal. Quidnipagus palatum becomes less abundant, but its mean size increases. Ctena spp. become more abundant, but their mean valve length decreases beyond the 100-m distance from the shore.

Replicate quadrats were placed 50 m and 200 m from the shoreline in an area adjacent to the bivalve transect. Student's t-tests of the difference in mean valve length of Quidnipagus palatum between the two quadrats at 50 m ($t_s$ = 1.743, $.05<p<.10$) and the two quadrats sampled at 200 m ($t_s$ = 0.791, $.40<p<.50$) indicated no significant differences. For Ctena spp., one of the quadrats 50 m from shore contained two



Table 11. Mean sizes and mean densities of edible bivalves inhabiting seagrass beds near Bangi Island, Agat Bay. Estimates are based on data from ten .25-$m^2$ quadrats. Values are means ± standard errors. The sample sizes for valve length estimations are given in parentheses.

| Species | Mean Valve Length (mm) | Mean Density (No./$m^2$) |
|---|---|---|
| Ctena spp. | 16 ± 0.3(175) | 70.0 ± 20.4 |
| Gafrarium pectinatum | 27 ± 1.7 (3) | 1.2 ± 0.8 |
| Fragum fragum | 18 ± 3.3 (3) | 1.2 + 0.8 |
| Modiolus (cf. auriculatus) | 35 ± 3.0 (2) | 0.8 ± 0.4 |
| Quidnipagus palatum | 26 ± 1.5 (2) | 0.8 ± 0.8 |
| Scutarcopagia scobinata | 42 (1) | 0.4 ± 0.4 |

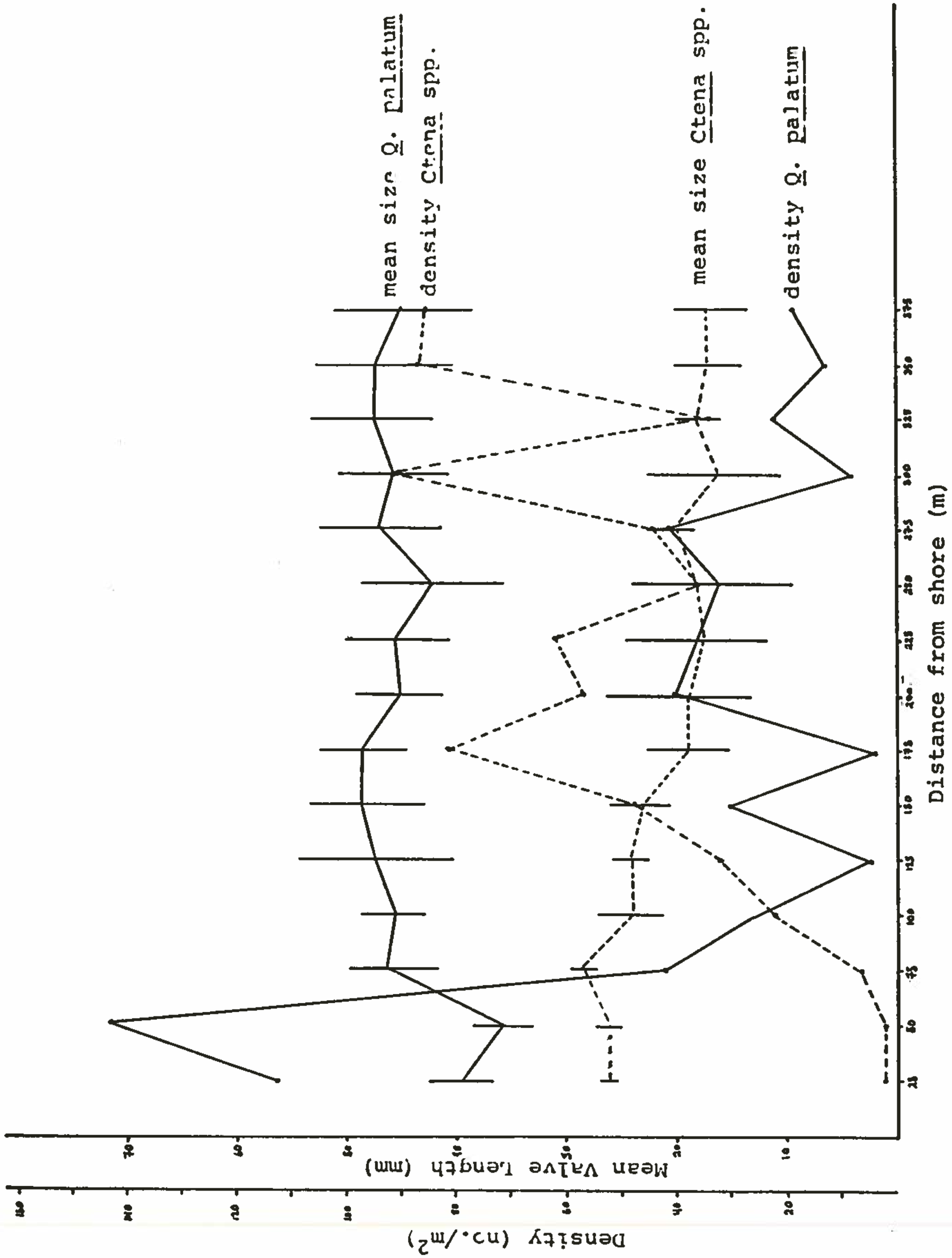


Figure 14. Comparisons of mean valve length and density to distance from the shoreline for Quidnipagus palatum Iredale and for Ctena spp. at Cocos; Sector V.



specimens, and the other contained none. Student's t-test of the mean valve lengths of Ctena spp. in quadrats 200 m from shore revealed no significant difference ($t_s = 1.90$, $.05<p<.10$). Thus, the relationship suggested by the graph appears to exist in other areas of the seagrass beds.

Of the edible bivalves listed in Table 12, all but Quidnipagus palatum are harvested for consumption by the people of Merizo. The clams are located by running one's fingers through the sandy substratum in the seagrass bed. Because Q. palatum usually lives beneath the matted root system of the seagrass, it is not often found by the method described above.

Quadrat sampling and dredging in other areas of the lagoon yielded small numbers of several bivalve species. Four randomly placed quadrats were sampled near the western end of Cocos Island. Clam populations were sparse in the area. Quidnipagus palatum was the most abundant species, with an estimated density of $10/m^2$. Other species occurring in the quadrats were Asaphis violascens, Ctena divergens, and Scutarcopagia scobinata. The low densities of the clams and the large boulders and rubble covering the area make harvesting of the bivalves at this site difficult at best.

Small populations of cockles were found by means of dredging in sandy areas of the lagoon floor. Fragum fragum and Fulvia tenuicostata were widely distributed but in low densities.

Table 12. Mean sizes and mean densities of edible bivalve molluscs in the seagrass beds near Merizo, Guam. Estimates are based on fifteen 1-$m^2$ quadrats. Values are mean $\pm$ standard errors. The sample sizes for valve length estimations are given in parentheses.

| Species | Mean Valve Length (mm) | Mean Density (No./$m^2$) |
|---|---|---|
| Ctena spp. | 19 ± 0.2(737) | 49.1 ± 9.8 |
| Quidnipagus palatum | 43 ± 0.8(582) | 38.8 ± 10.0 |
| Gafrarium pectinatum | 30 ± 0.5 (64) | 4.9 ± 1.1 |
| Modiolus (cf. auriculatus) | 52 ± 1.3 (21) | 1.5 ± 0.6 |
| Scutarcopagia scobinata | 47 ± 2.0 (4) | 0.3 ± 0.1 |
| Anodontia sternsiana | 32 ± 1.8 (3) | 0.2 ± 0.1 |
| Periglypta puerpera | 41 (1) | 0.1 ± 0.1 |



## CONCLUSIONS AND RECOMMENDATIONS

### Sea Urchins

The potential for commercially harvesting sea urchins on Guam depends upon at least three factors. First, population size could easily be depleted, especially at Piti where sea urchin aggregations are very accessible. The time required to reach adult size is unknown, but may possibly be on the order of several years. Second, E. diadema is more difficult to harvest because of its preferred habitat. Extraction from reef margin holes and overhangs is tedious and not feasible during rough surf. Third, the periodicity of gonad maturity (ripeness) is still not clear. If, in fact, the ripe period lasts only a few months of the year, then harvesting is probably not economically feasible on a commercial scale.

On the positive side, however, sea urchins are easy to maintain in large tanks. If they can be induced to spawn throughout the year then the commercial opportunities are more promising. Ideally, one could raise juveniles to a reasonable size and then transplant them to suitable reef flats (obviously those out of the mainstream of recreational and fishing areas). Adults could, in turn, be brought to maricultural tanks and fertility induced. In this manner the sea urchin population for any given area could be controlled.

Desirable studies for the immediate future include in situ growth, recruitment, and gametogenic observations for at least a 1-year period. Transplantation studies and laboratory manipulations are also desirable.

### Trochus niloticus

Different size classes of Trochus niloticus are found in different zones of the reefs. Progressively larger sizes of topshells are found seaward from the outer reef flat. There does not seem to be a greater density of topshells on barrier reefs than on fringing reefs.

The population of Trochus is probably dense enough to support a limited fishery. Provided that commercial harvest is initiated, regulations governing the size of harvestable shells should be strictly enforced. Provisions for taking smaller shells from the reef flat for home consumption either should be abolished, or the size limit should be raised to 76 mm (3 in), as concurrent harvesting of both immature and mature individuals will inevitably lead to drastic decreases in the stock.

The Trochus population should be monitored yearly to determine season length and bag limits. Areas in which no harvest is allowed should be established to ensure perpetuation of a breeding population.

### Tridacnid Clams

While the larger, more valuable species of tridacnid clams are rarely found, Tridacna maxima is relatively common along the reef front.

However, the small size and low density of the clams probably render economic costs of harvesting this species prohibitive. Since the life histories of giant clams are documented, experimental seeding of the reefs and introduction of the larger species could be considered.

Other Bivalves

Species of bivalves other than tridacnids are present in quantities large enough to support only a recreational fishery. The larger species, such as *Asaphis violascens*, *Quidnipagus palatum*, *Modiolus* (cf. *auriculatus*), and *Scutarcopagia scobinata*, are not abundant enough to be commercially harvested. Since little is known of the biology of these indigenous species, studies should be undertaken to gain more knowledge of their relationships on the reef and to determine if they have any aquaculture potential.



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## ADDENDUM

Several additional reports on *Trochus* were brought to our attention after the manuscript was completed. Devambez (1959) surveyed the reefs of the New Hebrides to determine whether or not the *Trochus* population had recovered after the fishery was closed in 1958. He found that the density of *Trochus* was noticeably low and that the population consisted of mature and immature *Trochus* in a ratio of approximately 10:1.

Three causes for the decline of the *Trochus* population in the New Hebrides were suggested by Devambez. Because there was no legislation to protect *Trochus*, shells of all sizes were indiscriminately harvested. *Trochus* fishermen removed all shells bored by worms because they believed that this practice would improve future harvests. The rising prices of *Trochus* shell between 1952 and 1958 also contributed to the population decline by encouraging more intensive fishing activity.

Davambez also pointed out that the process by which *Trochus* reproduce adds complexity to harvesting strategies. Although these animals are believed to reproduce throughout the year, even large males and females release only a few gametes at a time. This implies that there is a critical density of *Trochus* required for the perpetuation of the population. Devambez believed that the New Hebridean fishery had lowered the *Trochus* population to a point near the critical density and that recovery would be very slow.

In contrast to the New Hebridean fishery, the *Trochus* fishery on Ponape is relatively profitable and appears to be rather stable. The annual yield has averaged about 80 tons in recent years, and the 1977 harvest earned about $55,000 in foreign exchange (Johannes, 1978).

One explanation for the stability of the *Trochus* population on Ponape is the existence of significant numbers of large *Trochus* in deep-water areas on the outer reef slope beyond the reach of free-diving fishermen (Johannes, 1978). However, *Trochus* fishermen on Ponape have recently shown an increased interest in scuba-diving, and this may endanger these deep-water sanctuaries. Legislation to prohibit the use of scuba for *Trochus* harvesting may have to be enacted in order to sustain the fishery.

These reports emphasize the need for regulation in a fishery. Yields can be very high in the initial stages of an unregulated fishery, but they cannot usually be sustained at these levels. The introduction of more efficient harvesting equipment also has profound effects upon population levels, even in a regulated fishery. Therefore, effective management requires comprehensive legislation and strong enforcement.

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