THE DISTRIBUTION AND ABUNDANCE OF HOLOTHURIANS IN SAIPAN LAGOON, MARIANA ISLANDS

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ABSTRACT: The distribution of holothurian species in Saipan lagoon was studied and the factors affecting their presence were analyzed. A total of eleven species of holothurians were found in the three types of habitats studied including nearshore sea grass beds, midlagoon sand flats, and outer rocky reef margins. Holothurian species show distinct habitat preferences, with species diversity and abundance of individuals being inversely proportional to distance from shore. Diversity and abundance were greatest in the nearshore sea grass beds, and lowest in the midlagoon sand flats. *Holothuria atra* occurred in near shore grass beds, midlagoon sand flats and outer rocky reefmargin zones. *Bohadschia marmorata* was found predominantly in high energy rocky reef margin areas where wave action was strong. Temperature and sediment grain size seem to play a role in the habitat selection of *Holothuria leucospilota*. *Holothuria atra*, an edible species, occurred in harvestable quantities. Large numbers of juveniles of *H. atra* were found, for the first time, in nearshore *Halodule uninervis* sea grass beds. *Stichopus chloronotus* was found in the nearshore grass beds and the rocky outer reef margin zones, and showed partial separation of habitats when present along with *Holothuria atra*. No predators of holothurians were found.

TO THE OFFICE OF GRADUATE SCHOOL AND RESEARCH

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INTRODUCTION

Sea cucumbers (Echinodermata: Holothuroidea) are ecologically and economically important marine organisms. They constantly rework the sediments on which they feed and thus help in the redistribution of nutrients in the ocean (Bakus, 1973). Holothurians are widely distributed ranging from arctic waters to tropical waters and from the intertidal to the deep ocean (Dalyell, 1951; Deichmann, 1921; Hammond, 1983; Conand, 1983). Sea cucumbers are a culinary delicacy in many oriental nations. According to Sachithananthan (1971), at least thirty-two countries either produce, consume, export or import "Beche-de-Mer" (Trepang) as the holothurians are commercially known. Due to their ecological and economic importance, sea cucumbers have been the focus of recent research, especially in the Pacific region.

Holothurians are elongated, bilaterally symmetrical organisms with varying numbers of tentacles that are used in feeding. The exact food preference of the holothurians is not well understood. They ingest sediments ranging from fine sand to large particles but have also been reported to feed on suspended particles (Lawrence, 1979). Holothurians select food on the basis of organic coating on the sand grains (Massin and Jangoux, 1976; Khirpounoff and Sibuet, 1980). Hammond (1982) suggested that the adhesive mucus on the buccal podia might play a role in sediment selection. Sloan (1980) found that species distribution is related to differences in substrate characteristics and that specializations have occurred in the morphology of the feeding apparatus.

Apart from substratum characteristics, other ecological factors such as water depth, wave action, temperature and other ecological factors also influence the distribution of holothurians. Holothurians can be found in deeper waters as well as shallow water habitats, and they comprise between 50 and 90 percent of the biomass at depths between 4000 and 8500 m (Zankevitch, 1963; Hansen, 1956). Holothurians have adapted to a wide range of temperatures and can be found in both arctic and tropical waters. Bonham and Held (1963) reported that *Holothuria atra* can tolerate temperatures up to 39.4° C. While some species are common in the intertidal areas, others are frequently found on the reef edges where wave action is considerably higher. Factors such as distance from shore also affect holothurian distribution. Certain species such as *Holothuria atra* occur in decreasing abundance from shore towards the reef margin. Bakus (1973) and Conand (1981) have indicated that holothurians also generally occur in "one size-class per locality." Information on the distribution of juveniles is sparse.

Although holothurians are widely distributed, they seem to have few predators. Birkeland, Dayton and Engstrom (1982) reported that there are some asteroid and gastropod predators. Kropp (1982) reported that five holothuroid species were attacked and engulfed by a gastropod, *Tonna perdix* , both under laboratory conditions and in the field. Holothurians evade predators by using toxins, eviscerating, releasing cuverian tubules, and living cryptically (Bakus, 1981; Yamanouti, 1952). Holothurians produce a toxin which has been used as fish poison (Frey, 1951; Rowe and Doty, 1977).

Available information on holothurian ecology is sparse compared to the information on the economic aspects of these organisms. In many Asian countries such as China, Hong Kong, Singapore, Sri Lanka and some Pacific island nations, holothurians are favorite food items. At least thirty-two countries either export, import, or consume holothurians. Among these nations, Singapore, Sri Lanka and Hong Kong are major market centers. Between 1962 and 1970, Singapore imported about 800,000 pounds of Beche-de-Mer annually from nearly twenty-five countries and re-exported nearly 500,000 pounds to at least ten countries in Asia (Sachithananthan, 1971). According to market surveys conducted by Gentle (unpublished report), Sri Lanka was the largest producer of dried Beche-de-Mer in the world until recent war broke out. Because of the large increase in the Sri Lankan Beche-de-Mer production, world market price for this product declined in the past. Hong Kong, which imports approximately 1,000,000 pounds of sea cucumbers every year, is still the largest importer in the world. In the past, the Beche-de-Mer industry was prevalent in the South Pacific island nations as well as on Guam.

There are more than ten edible species of which the most desirable species are *Actinopyga nobilis*, *Holothuria fuscogilva*, *Actinopyga echinites*, *Holothuria scabra*, *Theloneta ananas*, *Bohadschia marmorata*, *Actinopyga mauritiana*, *Holothuria atra*, *Holothuria edulis*, and *Stichopus chloronotus* (Sachithananthan, 1971; Shelley, 1985; Conand, 1981; and Rowe and Doty, 1977). Eight of these species occur on the reefs of Guam. At least four of these species, namely *Holothuria atra, Stichopus chloronotus, Bohadschia marmorata,* and *Actinopyga echinites,* are commonly found in the lagoon of Saipan, Northern Mariana Islands.

A preliminary survey of Saipan's waters found nearly thirty species of holothurians. Of these, only twelve species occurred within the lagoon. Other species were found in deeper waters. Within the lagoon, in almost all areas, *Holothuria atra* was the predominant species. Goreau et al. (1972) found that *Holothuria atra* was present in the lagoon in such numbers that it was impossible to avoid stepping on them while wading through the waters. In general, higher numbers of *H. atra* were present along the shore than along the reef margin. However, this was not true for all species. Other species, such as *Bohadschia marmorata,* were found only near the reef margin. Abundance was also noticeably higher in the sea grass beds than in the other zones. Juveniles were found only in the sea grass beds.

Preliminary observations indicate that holothurians are the most abundant macro invertebrates in the lagoon of Saipan. The holothurians of Saipan exhibit several interesting ecological patterns in distribution such as gradual decrease in abundance from shore, absence of juveniles in many habitats where medium or large specimens are abundant, separation of habitats, and isolation of species. Since most of these phenomena have not been documented for the species on Saipan, a study of holothurian distribution and abundance was deemed useful in establishing a data base of ecological and economic value.

The data from this study will enable comparisons with existing studies from neighboring Pacific islands, to determine if generalized patterns exist. A check list of the holothurian species in the lagoon, with descriptions of the preferred habitat types and population structures, will support development of holothurian fishery projects. Additionally, since some of the species found on Saipan are of commercial value, a detailed study of the distribution of these species will provide data on habitat preferences and other environmental factors necessary for the development of the fishery.

OBJECTIVES OF THE PRESENT STUDY:

1. To determine the abundance and distribution of sea cucumber populations in select habitats within Saipan lagoon.

2. To describe the abiotic (substratum, sediment grain size, water temperature, salinity) and biotic (predators) factors that account for the distribution of sea cucumbers in Saipan.

DESCRIPTION OF SAIPAN LAGOON:

Saipan is located at 15° 10'N latitude, and 145° 45'E longitude, about 260 km northeast of Guam. A complete description of the reef system of Saipan is given by Goreau et al (1972). Cloud (1959) has described submarine topography, shoal water ecology and sediment distribution in Saipan. The lagoon on the west coast, on the lee side of the island, extends almost continuously from Puntan Makpi in the north to Puntan Agingan in the south. The reef has two passes: one at Tanapag harbor and the other at Chalan Kanoa. There is also a narrow boat channel near the Garapan area. At its broadest point, the lagoon is up to 5 km wide. The narrowest points, located at Puntan Magpi and Puntan Agingan, are less than 100 m wide. Depth in the lagoon varies from less than one meter to 15 m. However, the lagoon is shallow in most areas. The northern areas of the lagoon are characterized by consolidated reef material with deep cuts and crevices. These hard substrata are replaced by fine grained sand patches as one proceeds south. These sand patches are bordered by dense stands of the coral *Acropora* sp. in some parts. Further south, starting from Garapan, two thirds of the lagoon reefwards from shore is covered by either *Enhalus acoroides* or *Halodule uninervis* sea grass beds. Within these sea grass beds, other algae, mostly different species of *Halimeda, Padina*, and *Dictyota*, are present in high densities. The sea grass beds extend almost to Puntan Agingan in the south. In most parts of the lagoon, the sea grass beds are bordered by fine grained sand along the midlagoon region from Puntan Agingan to the Garapan area. On the reef side of the sand zone, there is usually an extensive zone of *Acropora* colonies which are exposed during low tides in certain places.

The reef margin is typically composed of rocks and boulders with very little coral growth. Visibility is generally clear in most parts of the lagoon with the exception of Garapan and Magpi areas, where currents constantly stir up the sediments. The only major fresh water outfall into the lagoon is near Tanapag Harbour where a river joins the lagoon.

MATERIALS AND METHODS

A preliminary survey of the lagoon was undertaken by swimming, snorkelling, and diving in different areas. A walk along most parts of the reef margin was done to select the sites and to observe the holothurians along the reef margin. The lagoon was divided into three habitat zones: nearshore sea grass beds, midlagoon sand flats, and rocky outer reef flats. At least two sites for each habitat type were chosen. In each site, four or more 10 m X 1 m transects were laid, both parallel and perpendicular to the shore. All holothurians occurring within the transects were recorded by species and number of specimens. The length of all recorded specimens was measured to the nearest 0.5 cm using a flexible meter tape, without disturbing the animal. All specimens were then classified according to length. Specimens measuring 1-6 cm were called small; 7-15 cm were called medium; all others were called large specimens. This size classification is not indicative of the reproductive stage of the organisms measured. If specimens had scars of fission (which are identifiable as constrictions and twists) after complete division into two pieces, they were called fission products.

Physical parameters including salinity, temperature, sediment grain size, and water depth were measured at each site. Salinity was estimated by volumetric titration with 0.1 N $Hg(NO_3)_2$ solution in accordance with the procedure followed by the Department of Environmental Quality, Saipan (Strickland and Parsons, 1972). Mean values from three replicates for each sample were recorded. Water temperature was measured using a centigrade thermometer. The average temperature for each site was recorded from readings taken in early morning, midday, evening, and at night over a period of ten days. The body temperature of the sea cucumbers was also measured at all times by placing the mercury bulb of the thermometer on the clear upper surface of the body of the holothurian. Four random samples of the substratum, each 500 grams dry weight, were collected from each site. Sediments were collected from the top two or three centimeters of the substratum, on which Hammond (1982) reported that the holothurians fed. Care was taken to collect samples from areas where holothurians were feeding. Sediment grain size was determined by sieving the dry samples using standard USGS sieves. Sediment samples were analysed for percent carbonate (also included organic material such as sea grass blades) by treating 10 g of the dry sample with concentrated HCl and weighing the residue. Depth at all sites was measured with a depth gauge.

RESULTS

SITE DESCRIPTIONS:

SITE 1A. SAN ANTONIO SAND FLAT AND SITE 1B. SAN ANTONIO REEF SITE:

San Antonio sand flat is approximately 250 m north of Puntan Agingan on the southern extremity of the lagoon. This site was characterized by a fine grain sand zone that extended almost halfway through the lagoon, bordered reefwards by boulders and rocks with many deep cuts and crevices. The total area of sand cover was approximately 500 m^2. Unlike the rest of the sand flats studied, the sand flat at this site was near the shore. The sand zone was devoid of algal growth although various species of algae were found attached to the rocks bordering this zone. Wave action was considerably less than at the Wing Beach site because of prevailing southward wind patterns. Depth varied from 0.5 m to 1.5 m in different localities within the site. Visibility was over 2 m. The reef margin area (Site 1B) is primarily composed of rocks and boulders with many deep cuts and crevices. Near the outer reef margin, limestone rocks with sparse coral growth were encountered. Colonies of *Acropora* are found along the northern side of the site, near the Surf Hotel. See Fig.1 for the general location of all the study sites.

SITE 2. CIVIC CENTER SHORE GRASS BED:

Site 2 is immediately north of the Diamond Hotel in Susupe village. The fine sand beach at this site was broadened by Typhoon Kim, in December of 1986, which uprooted many of the *Casuarina equisetifolia* trees that bordered the beach. This site was within the extensive *Halodule uninervis* sea grass bed that extended from the Chalan Kanoa boat ramp on the south to San Jose village on the north. The *H. uninervis* bed started from the low tide mark along the beach and extended about 600 m into the lagoon. In this extensive sea grass zone, occasional patches of the algae *Halimeda, Padina*, and *Avrainvillea* were noticed. *Dictyota bartereysii* was found scattered throughout the site. Immediately after Typhoon Kim, this site was littered with logs, foliage and seeds of *Casuarina equisetifolia*. A large quantity of sand was also shifted along the shore, which killed the sea grass *Halodule uninervis* . Observations during the period between May and July 1987 indicated extensive regrowth of *H. uninervis*. The substratum consisted of sand particles of various sizes held in place by the sea grass. Depth ranged between 0.5 m and 1.5 m. There were no apparent currents. Since this site was close to the Diamond Hotel, tourist-related water sports activities were carried out in this area; however, these did not appear to have disturbed the holothurian population as yet.

SITE 3. CIVIC CENTER MIXED ZONE:

The third site is due west of Site 2, about 650 m from the shore, lying between the *Halodule uninervis* grass bed and the extensive midlagoon sand flat. The floor of this site was covered with scanty growth of *Halophila minor* and *Halodule uninervis*. The total bottom cover of sea grasses was less than 5% of the total bottom area. Sand particle sizes were comparable to samples from Site 2. Depth varied from 0.5 m to 1.5 m and visibility was extremely clear.

SITE 4. CIVIC CENTER SAND FLAT:

Site 4 is a part of the major midlagoon sand flat that extends almost the entire length of the lagoon from Puntan Afetna in the south to Garapan in the north. This site is at least 125 m west of Site 3. Except for the rare occurrence of dead *Acropora* sp. coral pieces, this zone was completely devoid of other macroscopic organisms. The bottom was covered throughout by fine grain sand. Extensive *Acropora* sp. coral formations were present along the western border. There was some surface turbulence of water, however, visibility was extremely clear. Depth varied between 1.0 and 1.5 m.

SITE 5. SUSUPE SAND FLAT:

The Susupe sand flat is about 400 m north of Site 4. This site was very similar to Site 4 in its structure, location and life forms. It was deeper by 1 m. For other details, refer to the description of Site 4.

SITE 6. GARAPAN GRASS BED:

Transects in this site were laid within the large *Enhalus acoroides* sea grass bed that started at San Jose village and extended beyond the Garapan dock area. This bed extended from the shore and covered almost two-thirds of the lagoon's width in many localities. The sea grass was 60 cm to 1 m tall and was exposed during low tides. Although the predominant vegetation was *E. acoroides*, small patches of *Halimeda* *macroloba* were scattered throughout the site. The northwesterly current, going out into the channel near the beacon in Garapan, caused much turbulence. As a result, visibility was extremely poor. This site was relatively deeper than other sites, varying from 1 to 2.5 m at different localities. Small rocks with extensive algal growth were noticed in some areas. For a list of common algal species in this area, see Goreau et al. (1972). About 500 m from the shore, a dredged channel, about 10-15 m wide, opened into the ocean near the beacon in Garapan.

SITE 7. WING BEACH ROCKY REEF FRONT:

Site 7, lying on the northern most tip of the lagoon near Puntan Magpi, is also known as Papau Beach. This site was characterized by high wave action and undertow currents that flowed through limestone rock slabs with concave cuts and crevices. The rocks were submerged even during low tides, and enclosed small pools of water about 1 m deep at all times. On these rocks were found various coralline algae. Coral growth was very sparse with occasional colonies of *Porites, Millipora tuberosa, Pocillopora* and *Pavona*. Depth varied from 1 to 2 m. Typhoon Kim extended the beach along the shore by at least 15 m. Sand particles were coarse. Visibility in certain localities was poor due to siltation.

DISTRIBUTION:

SAND FLAT SITES:

SITE 1 A. SAN ANTONIO SAND FLAT:

Holothuria atra was the only species recorded here (Fig. 2) with 96 specimens, all of which were medium or large specimens ranging from 8 cm to 23 cm in length. No smaller individuals were found. The predominant size-class was 12-15 cm with 52 individuals (Fig. 3).

SITE 3. CIVIC CENTER MIXED ZONE:

Holothuria atra, Synapta maculata, and *Actinopyga echinites* were the three species found in this site (Fig. 4). *H. atra* was predominant with 249 specimens. The other two species had one large specimen each. The size of *H. atra* varied from 9-26 cm. The size class of 13-16 cm was 50% more common than other size classes (see Fig. 5). Only one juvenile of *H. atra* was recorded at this site. The large specimen of *A. echinites* was 15 cm long and the large specimen of *S. maculata* was 60 cm long. The presence of two fission products of *H. atra* was worthy of note. Although only one *A. echinites* was recorded from this site, a few more were seen in the adjacent sea grass bed.

SITE 4. CIVIC CENTER SAND FLAT:

Holothuria atra was the only species found here (Fig. 6). The most common size class in this site was 9-16 cm (Fig. 7). All individuals were either medium or large size individuals and no fission products were seen. A total of 38 individuals was recorded.

SITE 5. SUSUPE SAND FLAT:

This site was also poor in species diversity. *Holothuria atra* was again the only species recorded (Fig. 8). A total of 126 individuals ranging from 8-23 cm in length was found. The predominant size class was 12-15 cm with a total of 50 individuals. For details of size-class distribution refer to Figure 9.

SEA GRASS BED SITES:

SITE 2. CIVIC CENTER SHORE GRASS BED:

Six species, including *Holothuria atra, Holothuria hilla, Synapta maculata, Euapta goddefreyi, Bohadschia similis*, and *Stichopus horrens* were encountered (Fig. 10). Among these, *H. atra* was predominant with 680 individuals. *Holothuria hilla* was represented by 106 individuals. Three individuals each of *S. maculata* and *S. horrens* were present. Prior to Typhoon Kim, *H. hilla* was present at very low densities. Seventy-one smaller specimens of *H. atra* found in this site were all less than 6 cm long, and the length of the medium or large specimens varied from 13 to 20 cm. Individuals between 13 and 18 cm were more common than other size-classes. *H. hilla* medium or large specimens measured up to 27 cm. However, for this species, there were twice as many medium size specimens between 13 and 16 cm as other size-classes. The only individual of *B. similis* may have been transported to shallow waters by Typhoon Kim. For details of size-class distribution of *H. atra* refer to Figure 11.

SITE 6. GARAPAN GRASS BED:

Two sets of transects were laid to cover the extensive *Enhalus acoroides* grass beds. In the first set of transects, which were located closer to San Jose village, four species, *Holothuria atra*, *Holothuria hilla*, *Holothuria impatiens*, and *Stichopus horrens* were recorded (Fig. 12). *Holothuria atra* was the predominant species with 573 individuals ranging in length from 8-27 cm. The predominant size-class was 16-19 cm (Fig. 13). *Holothuria hilla* was represented by 11 individuals (Fig. 14) whereas there were nine *H. impatiens*. Six individuals of *S. horrens* were present. All individuals of all species were medium or large specimens and no smaller specimens or fission products of any species were found.

In the second set of transects, five species, *H. atra*, *H. hilla*, *H. impatiens*, *S. chloronotus* and *S. horrens* were recorded. Of these, *H. atra* was predominant with 489 individuals. No smaller specimens of this species were found. The size range 18-20 cm was common. *Holothuria hilla* and *S. horrens* were equally abundant with 23 individuals each. Four *S. chloronotus* and two *H. impatiens* individuals were found. A few fission products of *H. atra* were found outside the transects although none were recorded within.

ROCKY REEF MARGIN SITES:

SITE 1 B. SAN ANTONIO REEF SITE :

From the transects that were laid along the rocky reef margin, three species, *Holothuria atra*, *Bohadschia marmorata*, and *Stichopus chloronotus* , were recorded. Thirteen *H. atra*, 46 *B. marmorata*, and 13 *S. chloronotus* were recorded. No smaller specimens were found. The predominant sizes were 8-11 cm, 10-13 cm, and 8-11 cm for *H. atra*, *B. marmorata*, and *S. chloronotus* respectively. *Bohadschia marmorata* was the predominant species in the reef front zone of this site.

SITE 7: WING BEACH ROCKY REEF FRONT

Four species, *Holothuria leucospilota*, *Holothuria atra*, *Actinopyga echinites*, and *Stichopus chloronotus*, were recorded from this site (Fig.15). *Holothuria leucospilota* with 237 individuals was the predominant species (Fig.17). Thirty-three *H. atra*, 12 *S. chloronotus*, and 6 *A. echinites* were recorded. *Holothuria leucospilota* individuals were 25-55 cm long. The predominant size range was 26-30 cm. All of the *H. atra* were specimens, mostly between 10 to12 cm long (Fig. 16). No smaller specimens or fission products were seen. *Holothuria leucospilota* was almost always found attached under rocks or in crevices.

DISCUSSION

Holothurians in Saipan lagoon appear to occupy distinctively different habitats, with the exception of *Holothuria atra* which was present in all types of habitats studied. Certain important questions are yet to be addressed: Why are certain species, such as *H. atra*, found in all types of habitats while others are isolated in select habitats? Why are the juveniles so hard to find in all of these habitats? What are the predators? How do environmental factors such as sediment grain size, temperature and wave action influence species composition of a particular habitat?

Bonham and Held (1963) reported that *H. atra* was frequently found in the intertidal area of the seaward side of the islets of Rongelap Atoll, Marshall Islands, at the edge of the reef nearest shore. Relatively higher densities of *H. atra* were also reported to occupy *Enteromorpha* algal beds in Thilimad Island, Yap (Grosenbaugh, 1981). Although Bonham and Held (1963) reported a considerable number of *H. atra* from the surf zone in the reef margin area, Grosenbaugh (1981) found this species to be only occasionally present along the reef margin. *Holothuria atra* was seldom found on the exposed reef flats of Enewetak, Marshall Islands (Bakus, 1968). Bakus suggested that *H. atra* preferred areas with sand bottoms. However, Lawrence (1979) reported that H. atra did not survive in sandy areas when transplanted from algal zones. In Palau, *H. atra* is almost always associated with sea grass beds where organic matter was rich (Yamanouti, 1938). In Saipan, *H. atra* exhibits a clear preference for the sea grass beds of either *Halodule uninervis* or *Enhalus acoroides* (Fig.18). The hypothesis that *H. atra* prefers sea grass is true for Saipan. As Yamanouti (1938) suggested, the organic content of the sea grass areas is high. Matson (In press) reported that the sea grass beds of Saipan contained more organic matter than the sandy areas. It may be that the higher organic content of the sea grass beds is one of the reasons for the higher species abundance and diversity in this type of habitat.

With the exception of the San Antonio area (Site 1) where the shore area was sandy, all other shore sites were sea grass beds. Comparing the abundance of *H. atra* from Site 1 and Sites 2 and 6, it becomes clear that *H. atra* is six to seven times more abundant in shore sea grass beds than in the reef front sites. Furthermore, *H. atra* also shows a gradual decrease in number proceeding from shore to reef margin. Table 1 shows that 669 specimens were present in the shore area compared to 413 in the midlagoon area and 46 in the reef front area. Results from the present study confirm similar trends reported by other authors mentioned earlier. A gradual decrease in number from shore towards the reef margin is a general pattern noticed for this species by many authors (Birkeland, personal communication). Sea grass beds may provide the cover for this species. This explanation is further supported by the observation that when specimens collected from sea grass beds were placed in sandy areas, they showed quickened movements. This quickened movement was not merely a reaction to being disturbed because other specimens, within the sea grass beds, did not exhibit this rapid movement when they were disturbed for tagging purposes. The former specimens also covered their bodies with a thin film of sand that concealed their distinct black color. This sand cover may protect them from predators, and to some extent may also lower the body temperature.

Holothuria leucospilota was found exclusively in the crevices and cuts of the rocky reef front of the Wing Beach area. Preference of a similar zone in the beach rocks of the intertidal reef flats was reported for this species from Enewetak Atoll (Lawrence, 1979). Since this species ingests mainly the organic coating on the sand grains, they are always found in rocky areas that enclose small pockets of sand. Lawrence reported that there is direct correlation between size of individuals and their density in a particular locality; large individuals are found in low densities. However, my observation was that *H. leucospilota* occurred in clumps consisting of 10 or more individuals that were about the same size. Hence, there is no correlation between size of individuals and their density for this species in Saipan. It is also noteworthy that Wing Beach was the only area in which this species was found. This species always inserted its posterior end into the crevices and extended its anterior end to feed. It exhibited quick reaction to touch by immediately withdrawing its anterior end, thus reducing the length by one third. In Saipan, this species was found closer to the shore than along the outer reef flat, however, Lawrence (1979) found this species along the reef front area in the Enewetak Atoll. A similar finding was reported from Rongelap Atoll by Bonham and Held (1963). These authors also stated that *H. leucospilota* preferred a cooler environment than *H. atra*. This is found to be true in Saipan also, as the Wing Beach site was at least 3° C cooler than the other sites.

In Saipan, *A. echinites* was widely distributed in the nearshore sea grass beds of *Halodule uninervis* that are located in calm waters. However, only a few specimens were found. Only 7 individuals were recorded in the present study, 6 of which were found in the Wing Beach area. The thin mantle of sand reported by Rowe and Doty was not found on these specimens.

Rowe and Doty (1977) reported that *Actinopyga echinites* is always found exposed on sandy areas and always with a thin mantle of sand. However, Yamanouti (1938) suggested that species of *Actinopyga* are relatively indifferent to the substratum for these were noticed to wander around among coral heads and in the algal beds of *Halimeda* in Palau. He further observed that this species preferred a sea bottom with much plant growth and with calm water. Shelley (1981) also reported juveniles of this species from sea grass beds on a sand bar exposed at low tide. Complete details of different habitats of this species have been given by Shelley (1985). This species also exhibits a clumped, or "piled" distribution, with five or more individuals in each clump or pile (Amesbury et al., 1976).

Four specimens of *Synapta maculata* and one *Euapta goddefreyi* were recorded in this study. These are always observed in sea grass beds as they primarily feed not only on the substratum, but also on the coating on the sea grass blades. In Saipan, these two species are always seen in *Halodule uninervis* and *Enhalus acoroides* beds. They show greater activity during night time although they feed throughout the day and night.

Little is known about the habitats of *Bohadschia* species. In Saipan, *B. marmorata* was mainly found strongly attached to the substratum on the rocky areas of the reef margin zone where wave action was considerable. This species showed very little movement during day or night. It should also be noted that all of these specimens of *B. marmorata* from shallow areas were small, but larger ones were seen in deeper waters in many places near Puntan Magpi, Laulau Bay and

Agingan Beach. This species had many different pigment patterns on the body surface. Some were completely light brown while others had varying patterns of transverse white dots and stripes along the body.

The only specimen of *Bohadschia similis* recorded in this study was found near the shore at the Civic Center grass bed immediately after Typhoon Kim. This species has not been seen in sea grass beds since. It may be that this single specimen was brought into the shallow waters by the typhoon. This species was present in deep waters at 10-13 m near Laulau Bay.

Lawrence (1979) reported that *Stichopus chloronotus* did not persist in an area where *Holothuria atra* was dense. In my study, these two species exhibited at least partial separation of habitats. Where *H. atra* was abundant, only a few specimens of *S. chloronotus* were recorded (see Table 1). In the midlagoon and outer reef margin coral zones of San Antonio, Garapan and Wing Beach sites of Saipan, these two species were found adjacent to each other although *S. chloronotus* was found in fewer numbers than other species. Although *Stichopus chloronotus* was also found adjacent to *H. atra* in the sand zone of San Antonio village, the ratio of *S. chloronotus* to *H. atra* was 96:13. Lawrence (1979) also reported this species to be common on sand in protected water on the lagoon side of an interisland channel. Moriarty (1982) showed that *S. chloronotus* preferred food with more carbon than nitrogen. This may explain the presence of this species in sandy areas devoid of algae or sea grass.

Stichopus horrens was always found in grass beds and was seen feeding on the grass blades. The body of this species was pale green with many bumps. Thus the species is more cryptic when it is living among the sea grass beds. Bakus (1981) reported that this species may be less toxic than other holothurian species. The lack of protective toxins may be compensated for, to some extent, by the cryptic coloration.

Holothuria impatiens and *Holothuria hilla* were both found in sea grass beds. While *H. hilla* was found in both *Enhalus acoroides* and *Halodule uninervis* sea grass beds, *H. impatiens* was recorded only in *E. acoroides* beds (see Table 1). These two species were found to occur with *H. atra*. *Holothuria hilla* had been reported to feed during night time (Kropp, 1982). Both of these species were very cryptic.

Holothuria hilla was always seen attached to the bottom of the sea grass blades. Although *H. impatiens* were seen feeding during the day time, they were more active at night.

Some information is available on the density distribution of *Holothuria atra* in a few Pacific islands. According to Yamanouti (1952), Palau had 0.44 *H. atra* per m^2. Rongelap Atoll, Marshall Islands had 4.7 *H. atra* per meter (Bonham & Held, 1963). On Saipan, the density of *H. atra* is approximately 6.381 specimens per m^2. The estimated population numbers of other species in this study can be found in Table 4.

Densities of other species from other islands are not available except for *Holothuria leucospilota* from Rongelap Atoll, Marshall Islands (0. 068 / m^2, Bonham & Held, 1963).

ABIOTIC FACTORS AFFECTING DISTRIBUTION:

SALINITY:

The effect of salinity on the distribution of holothurians in Saipan was negligible, for all sites in this study had a similar range of salinity varying from 18494 mg/l to 23992 mg/l of chlorine (see Fig. 20). This range is quite typical for ocean water in the lagoon area. In general, echinoderms cannot tolerate low salinity. Pawson (1966) observed that holothurians are particularly intolerant to low salinity.

TEMPERATURE:

Temperature has been cited as one of the causal factors for holothurian distribution. In Saipan, lagoon temperatures varied from 25° C to 31° C for most places, with the lowest observed reading from Wing Beach at night time (see Fig. 19). During the day, the water is normally warm with an average temperature of 29° C. Bonham and Held (1963) observed that there was 0.25°C difference in temperature between sand covered *H. atra* and uncovered ones. This was found to be true in Saipan. *Holothuria atra* from the midlagoon sand flats with a covering of sand measured 0.50 C less than the environment at all times. The ones without sand cover had the same temperature as the surrounding water. Therefore, it could be concluded that sand covering affords some protective insulation for *H. atra.*

In another experiment, two groups of *H. atra*, one with 32 individuals and the other with 21 individuals, collected from the midlagoon sand flats, were left in an enclosed area for a period of 24 hours after removing all sand particles from the body surface. At the end of this period, all individuals in both groups were found to have a thick sand cover. Physical movement after sand removal appeared to be rapid. In both groups, the individuals had moved at least 2 m within 24 hrs. Earlier observations indicated that *H. atra* moved only 75-80 cm in 48 hrs. This experiment further indicates that *H. atra* may use sand covering on its body to maintain a lower body temperature than the environment and probably to become more cryptic. Other species did not show any difference in body temperature.

Holothuria leucospilota was found in the coolest site of the lagoon, Wing Beach. Bonham and Held (1963) reported that *H. leucospilota* was negatively phototropic and preferred shady rocky areas. The shade in the Wing Beach site may account for the lower temperature measured there. The temperature readings from Wing Beach support their hypothesis. Although Wing Beach site is a reef front site, the average temperature in this site is lower than the other sites.

The species found on the exposed reef fronts had higher temperature tolerances than the other species. The highest temperature along the reef front was 34.7° C during midday. Thus *Bohadschia marmorata* and *Stichopus chloronotus* which occurred in this area showed higher temperature tolerance than other species. It may be that temperature difference is one of the reasons for the absence of *B. marmorata* in the inshore areas and sea grass beds. Body temperature of both species was similar to the surroundings.

DISTANCE FROM SHORE:

There are more species found along the shore than along the reef margin. Fewest species were found in the midlagoon sand flats (Fig. 29-33). Along the shore, more individuals of all species were found (see Table 2). It could be concluded that the absence of wave action, and cryptic environment afforded by the sea grass beds are causes for the presence of higher numbers of individuals along the shore. Birkeland (personal communication) also pointed out that this is a general trend in distribution of holothurians in many places.

SUBSTRATUM:

Most parts of the lagoon, with the exception of Wing Beach, contain fine grain sand. Analysis of the dried samples from different sites showed no appreciable difference in size of the sediment grains (results of the four samples of sediment from each site are provided in Fig. 21-28). In most of the areas, the most frequent size of the grains fell between 0.0515 and 0.0210 cm. This could be considered coarse sand. Wing Beach sand had larger particles. The most frequent grain diameter in this area were 0.0937 and 0.0515 cm. However, Fig. 28 shows that the actual composition of substratum in this site was a mixture of larger and medium-sized sand particles. Hammond (1982) reported that the sand particles did not undergo much physical change after they passed through the digestive tract of the holothurians. Other studies have also indicated that holothurians do not digest the sand particles to any appreciable degree. For this reason, the current study did not analyze the particles in the fecal matter of the holothurians. In addition, since holothurians are such slow-moving organisms they have to feed on the nutrients available in their immediate vicinity. Care was taken to collect sediment samples from areas where sea cucumbers were feeding.

Apart from sediment size characteristics, other factors, such as organic coating on sand grains, may have some influence on the selection of food. When the sediments were tested for carbonate content, it was found that all sites, except the sea grass bed sites, had negligible quantities of terrigenous material (99.9% carbonate content, Table 3). However, the sea grass bed sites contained from 1.87% (in Site 3) to 10.77% (in Site 2) of insoluble organic materials, mainly sea grass blades. The increased abundance and diversity in the nearshore grass beds could be explained to some extent on the basis of the sediment composition. Since grass beds have more organic materials, the holothurians may have chosen this site for that reason. This hypothesis would not hold true for all the species, for species like *Holothuria atra* occur in all sites. More detailed studies have to be done on the role of the substratum in influencing population distribution.

BIOTIC FACTORS AFFECTING DISTRIBUTION:

PREDATION AND DEFENSE MECHANISMS:

Although fishes rarely eat holothurians, there are several other predators. Parrish (1972) suggested that a cymatiid gastropod, *Charonia variegata* , may be a significant predator on holothurians in Jamaica. Kropp (1982) observed a hermit crab, *Dardanus megistos,* and a xanthid crab, *Atergatis floridus,* eating holothurians. He also conducted laboratory experiments with a gastropod, *Tonna perdix*, which attacked and engulfed five different species of holothurians. Still, data from field observations of predation are sparse. In Saipan, I did not see any organism attack the holothurians. However, Goodwill (personal communication) said that he saw an unidentified tun shell attack *H. atra* in the lagoon area.

Holothurians have several defensive mechanisms to avoid predation. *Holothuria atra* produces a saponin, holothurin, which is highly toxic to fish. When disturbed, this species releases a burgundy colored fluid from its body surface which is toxic to fishes. Holothurin also affected crabs (*Pagurus*), polychaetes and flatworms (Bakus, 1968). Frey (1951) discusses holothurin's use as a fish poison. Bakus (1968, 1981) reported that *S. chloronotus* and *H. hilla* are both highly toxic to fish. Evisceration of cuverian tubules, preference for cryptic environments, and feeding rhythms are some of the potential defense mechanisms common in holothurians. In general, holothurians appear to have very few predators. Endean (cited in Bakus, 1968) has never witnessed an attack on any of the holothurians in Moreton Bay and Heron Island, Australia.

JUVENILES:

Juveniles of holothurians are generally hard to find. They may have a different habitat preference, or they may be very cryptic. Very little is known about juveniles. In Saipan, for the first time, juveniles of *Holothuria atra* were found in high densities in nearshore *Halodule uninervis* beds behind Saipan Community School in the Chalan Kanoa district. These juveniles were 1-2 cm long and were seen attached to the bottoms of the sea grass blades. Most of them were inactive during the daytime and some of them were seen feeding on the sediment attached to the grass blades at night. Closer analyses of other *Halodule uninervis* beds did not show the presence of juveniles. Temperature in the Community School area was comparable to that at the Civic Center shore grass bed site. The only marked difference between the Community School area and other sites was depth (2-2.5 m). Other factors are comparable to those at Site 2. *Holothuria atra* has a biannual sexual cycle with spawning in November and May in Heron Reef, Great Barrier Reef (Harriott, 1982). However, this may not be true for the same species found in Saipan because of differences in latitude. Despite frequent diving in the area during day and night, no predation on sea cucumbers was observed. Another factor worth noting was the presence of relatively few large specimens. While Site 2, which is about 700 m away, had numerous *H. atra* medium or large specimens, this area had very few such specimens.

FISSION:

Transverse fission is one of the common means of asexual reproduction reported in many holothurians, especially in the genus *Holothuria*. In Saipan, the only species that exhibited fissioning was *Holothuria atra*. Fissioning in this species on Saipan was not so frequent as earlier reports suggested. A few fission products of this species were seen in the grass beds. Two fission products were recorded from the midlagoon sand flat areas. The actual cycle of fissioning in the species found in Saipan is unknown. In general, fissioning does not appear to be a common method of reproduction for the species found on Saipan.

CONCLUSIONS

Holothurians in Saipan show clear habitat separation. *Holothuria atra* occurs in all three types of habitats (nearshore sea grass beds, midlagoon sand flats, and rocky outer reef margins) although there is a marked decrease in abundance in reef front areas. *Holothuria leucospilota* is found only in the cooler and more turbulent waters of the Wing Beach area. The larger size particles of sand in this area may be one of the factors for their occurrence here. *Bohadschia marmorata* is present only in the reef front sites. Strong wave action is probably the main reason for the presence of this species in the reef fronts. *Stichopus chloronotus* is present in low densities where it shares the habitat with *H. atra*. In general, more species with high population densities were found near shore in sea grass beds. Among the three types of habitats, the midlagoon sand flats had the fewest species. Lack of nutrients in the sand flats is perhaps a cause for the low species diversity in this habitat. Additionally, the distinct colors of the holothurians might work against them if they chose to live in the clear sand areas. It should also be noted that no predators were seen to feed on holothurians. Species diversity is inversely proportional to the distance from shore.

Substrate characteristics, calm waters and absence of predators seem to be influential factors responsible for the high abundance of holothurians in Saipan. The edible species *H. atra* was present in harvestable quantities in almost all types of habitats. Other edible species were present in smaller numbers. More studies on the reproductive cycle and fissioning of *H. atra* are required to develop a fisheries program for this resource.

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Table 1. Species Abundance and Distribution.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
H. atra	109	680	249	38	126	573	33
H. hilla	0	106	0	0	0	34	0
H. leucospilota	0	0	0	0	0	0	237
H. impatiens	0	0	0	0	0	11	0
S. maculata	0	3	1	0	0	0	0
E. goddefreyii	0	1	0	0	0	0	0
B. marmorata	46	0	0	0	0	0	0
B. similis	0	1	0	0	0	0	0
S. chloronotus	13	0	0	0	0	4	12
S. horrens	0	3	0	0	0	29	0
A. echinites	0	0	1	0	0	0	6

Data under Site 1 in this table includes the organisms observed in both Site 1A and Site 1B.

Table 2. Abundance and diversity of holothurians in the three zones of the lagoon.

Species	nearshore	midlagoon	reef front
H. atra	1349	413	46
H. hilla	140	0	0
H. leucospilota	0	0	237
H. impatiens	11	0	0
S. maculata	3	1	0
E. goddefreyii	1	0	0
B. marmorata	0	0	46
B. similis	1	0	0
S. chloronotus	17	0	12
S. horrens	32	0	0
A. echinites	0	1	6

TABLE 3. Percent carbonate of the lagoon sediments.

SITE	% CARBONATE	% RESIDUE
1 A	100. 00	0.00
1 B	100.00	0.00
2	90.5	9.50
3	98.13	1.87
4	100.00	0.00
5	100.00	0.00
6	89.23	10.77
7	100.00	0.00

Table 4. Estimation of the population abundance for the species found within the study sites. The total area of the lagoon is 51.8 km^2. The estimated population is derived from the recorded number of specimens within the transect areas used in the sites.

SPECIES	ESTIMATED POPULATION	DENSITY/M^2
Holothuria atra	330,512,770	6.381
Holothuria hilla	60,433,333	1.167
Holothuria leucospilota	306,915,000	5.925
Holothuria impatiens	7,122,500	0.138
Synapta maculata	1,295,000	0.025
Euapta goddeffreyii	1,295,000	0.025
Bohadschia marmorata	59,570,000	1.150
Bohadschia similis	1,295,000	0.025
Stichopus chloronotus	12,518,333	0.242
Stichopus horrens	13,813,333	0.267
Actinopyga echinites	4,532,500	0.088

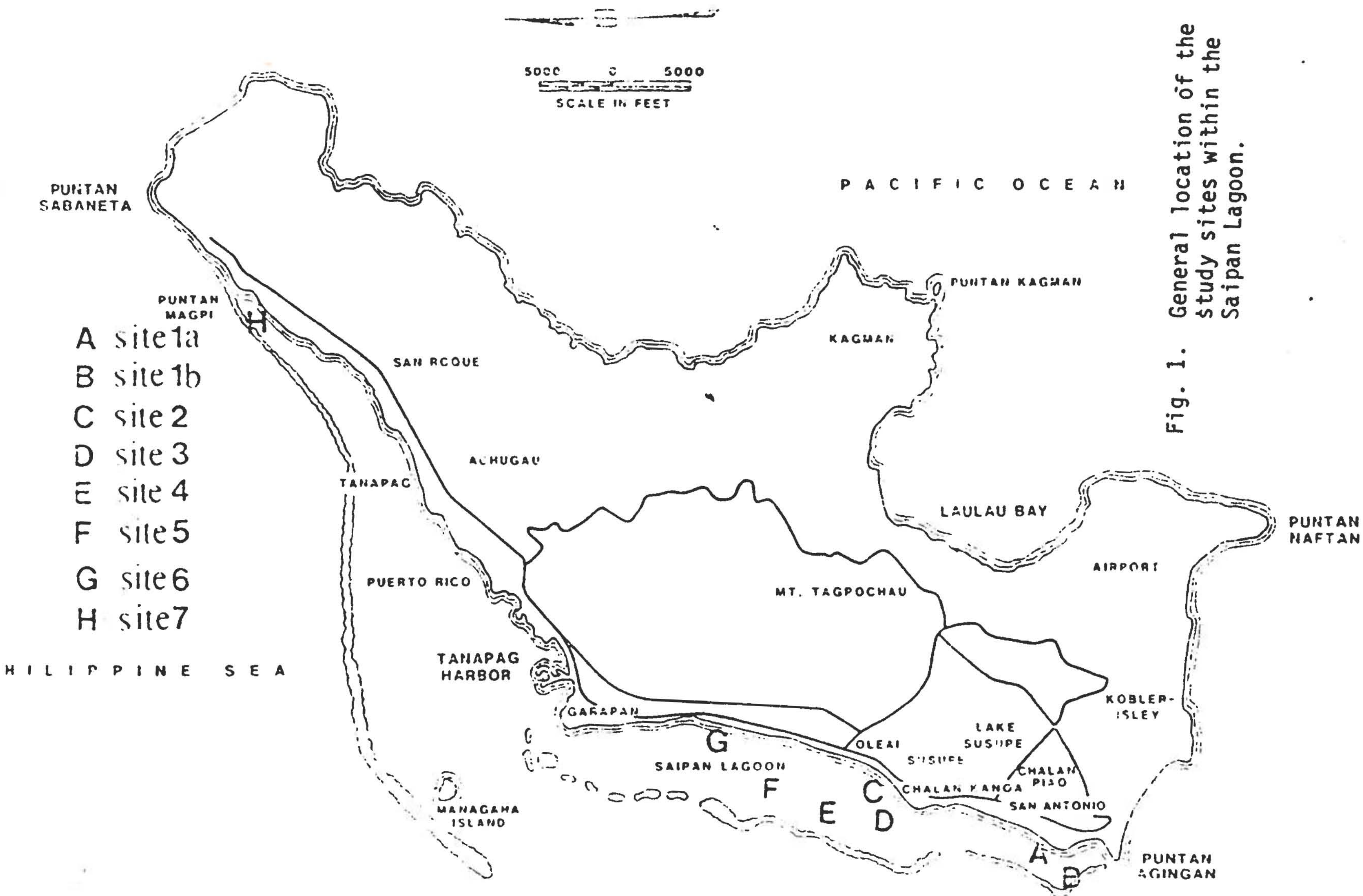

Fig. 1. General location of the study sites within the Saipan Lagoon.

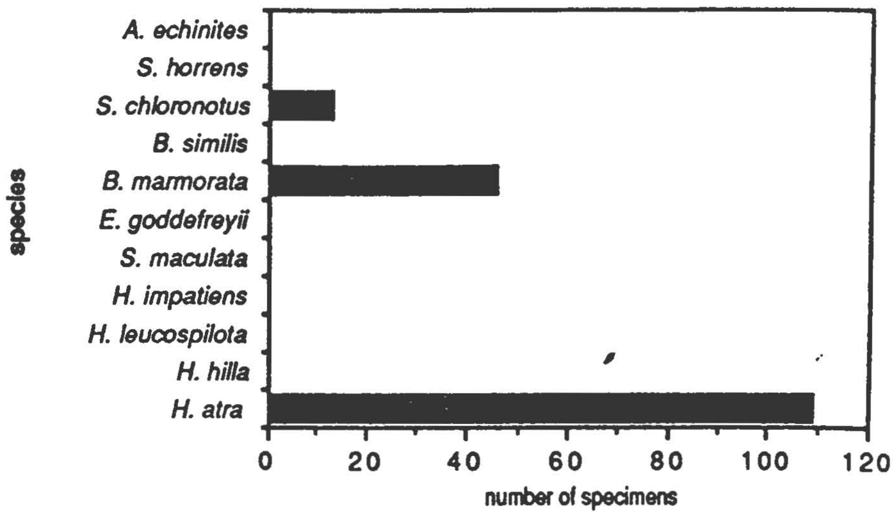

Fig. 2. Holothurian abundance and diversity in Site 1A, San Antonio sand flat and Site 1B, San Antonio reef site

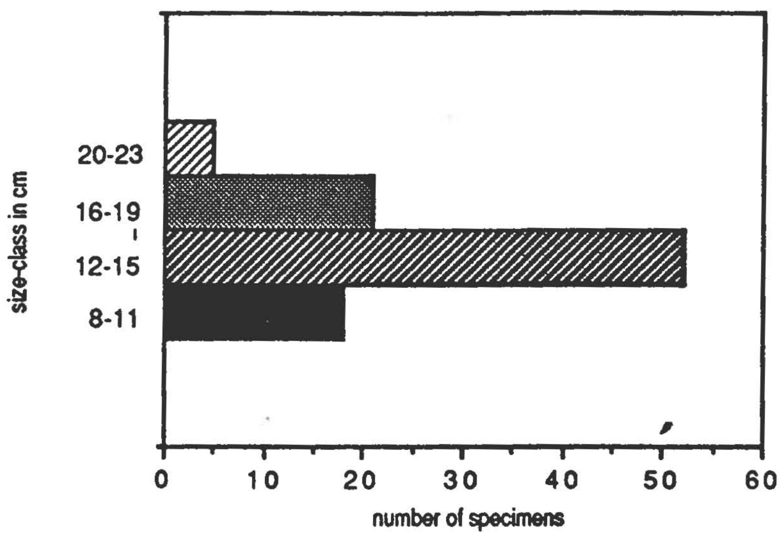

Fig. 3. Size-class distribution of *H. atra* in Site 1, San Antonio sand flat

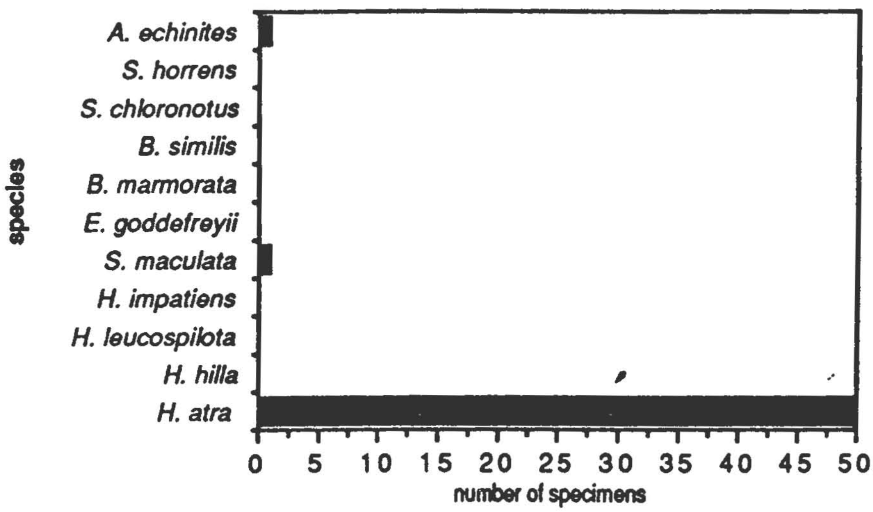

Fig. 4. Holothurian abundance and diversity in Site 3, Civic Center mixed zone. For the recorded number of the most abundant species, see text.

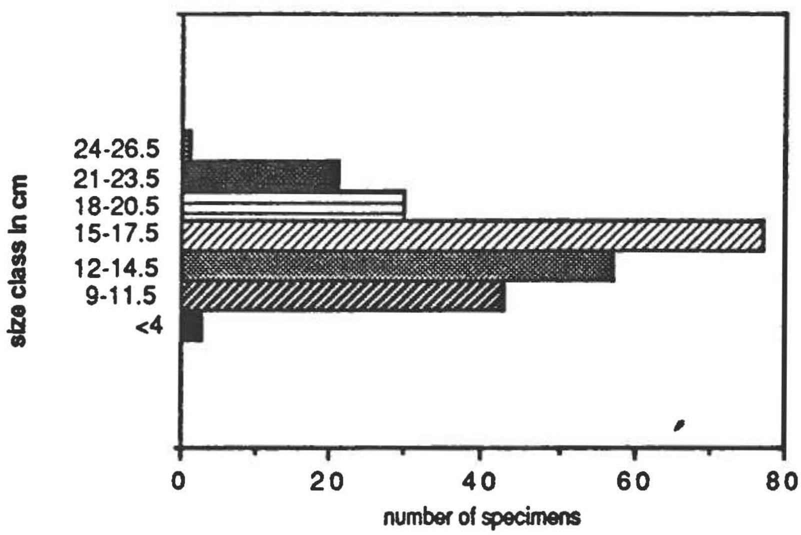

Fig. 5. Size-class distribution of H. atra in site 3, Civic Center mixed zone

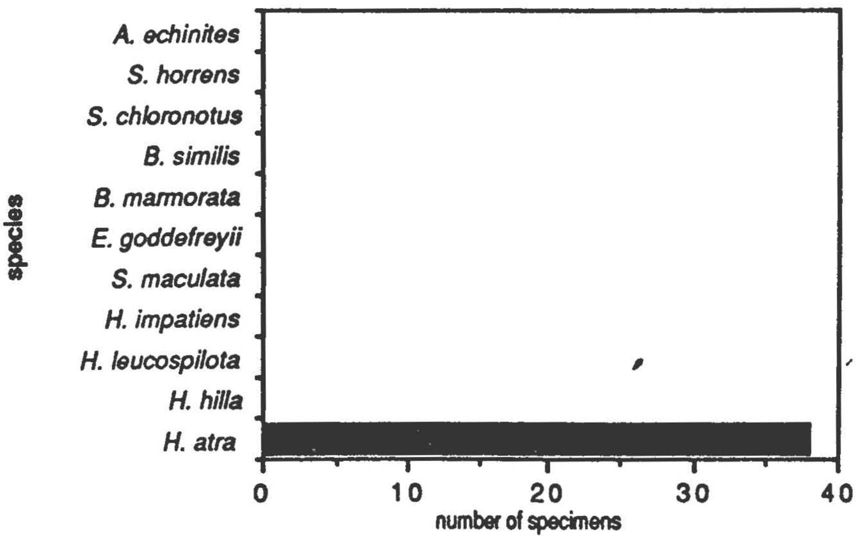

Fig. 6. Holothurian abundance and diversity in Site 4, Civic Center sand flat

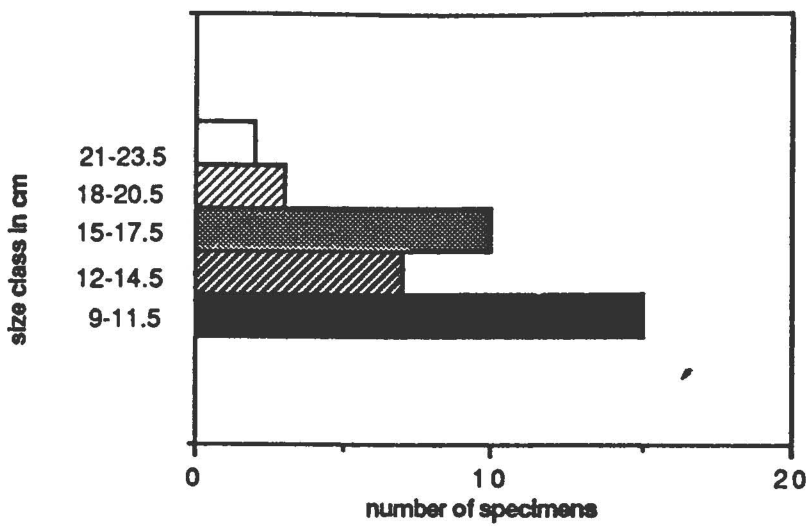

Fig. 7. Size-class distribution of H. atra in Site 4, Civic Center sand flat

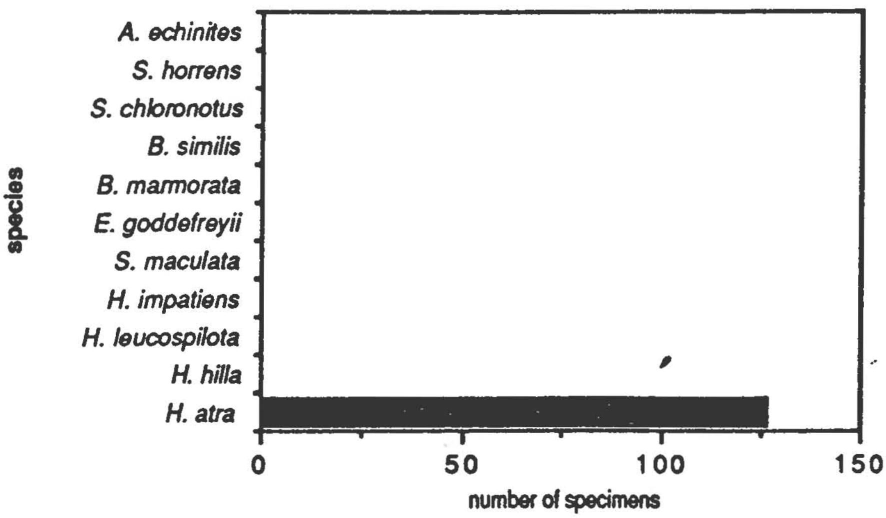

Fig. 8. Holothurian abundance and density in Site 5, Susupe sand flat

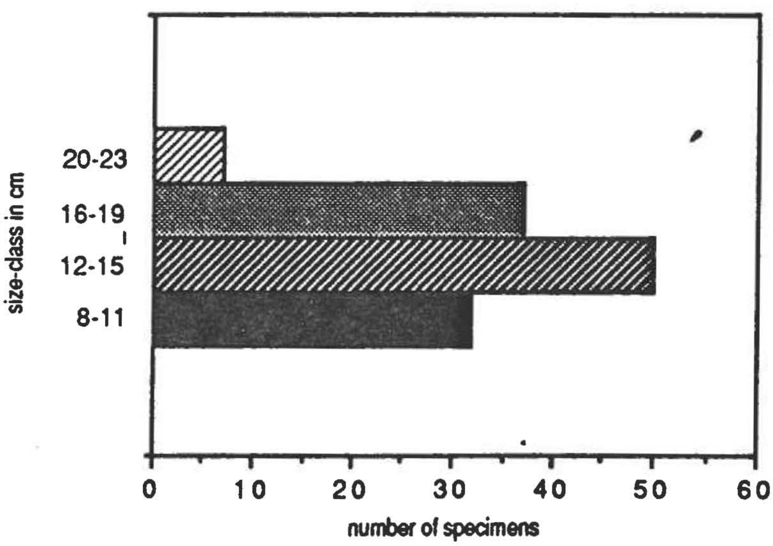

Fig. 9. Size-class distribution of H. atra in Site 5, Susupe sand flat

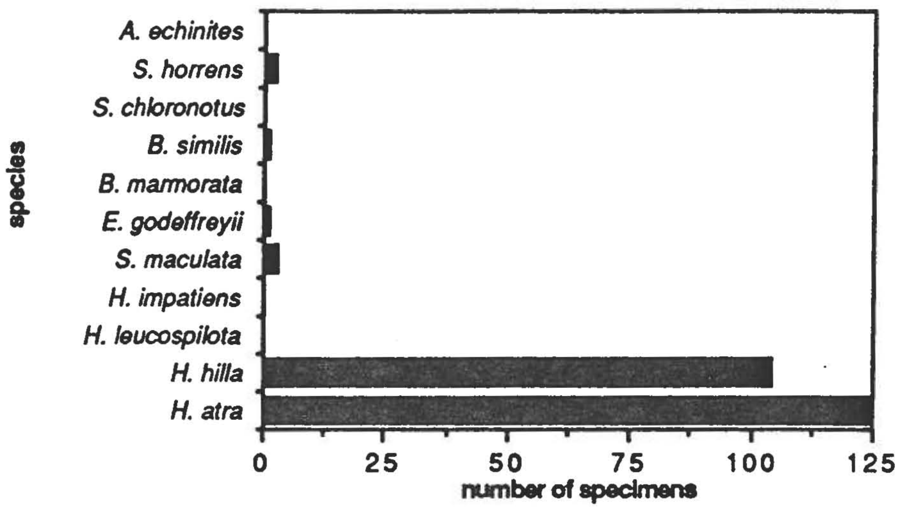

Fig. 10. Species and their abundance in Civic Center Shore grass bed. For the recorded number of the most abundant species, see text

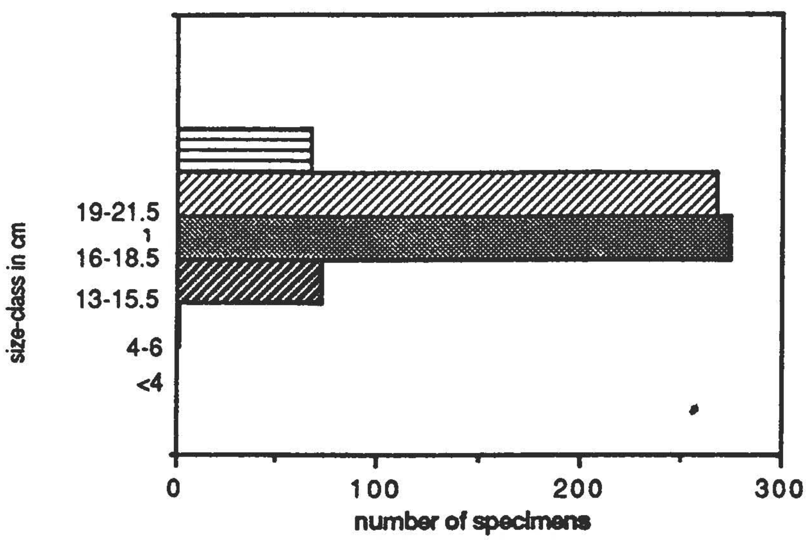

Fig. 11. Size-class distribution of H. atra in Site 2, Civic Center shore grass bed

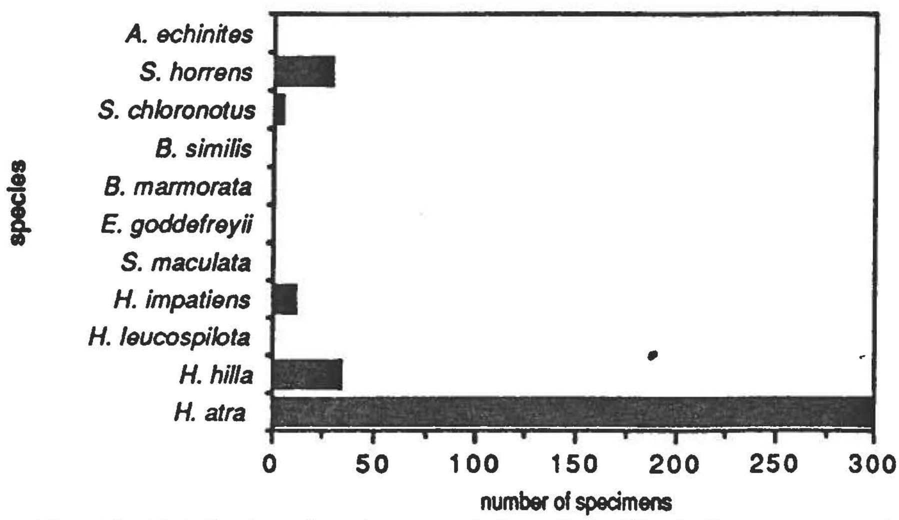

Fig. 12. Holothurian abundance and diversity in Site 6, Garapan grass bed. For the recorded numbers of the most abundant species, see text.

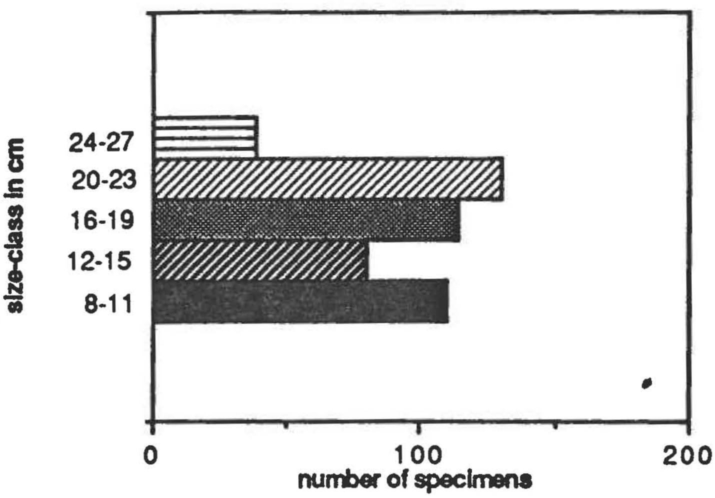

Fig. 13. Size-class distribution of H. atra in E. acoroides bed in Site 6, Garapan grass bed

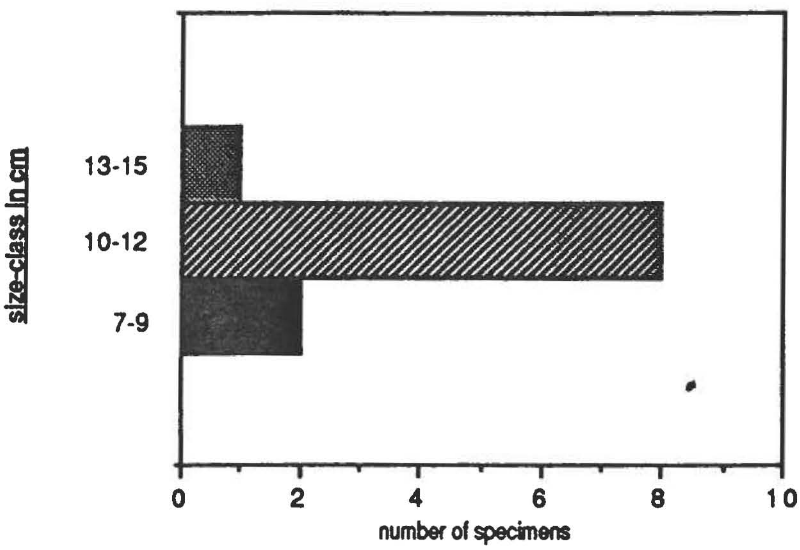

Fig. 14. Size-class distribution of H. hilla in H. uninervis bed in Site 2, Civic Center shore grass bed

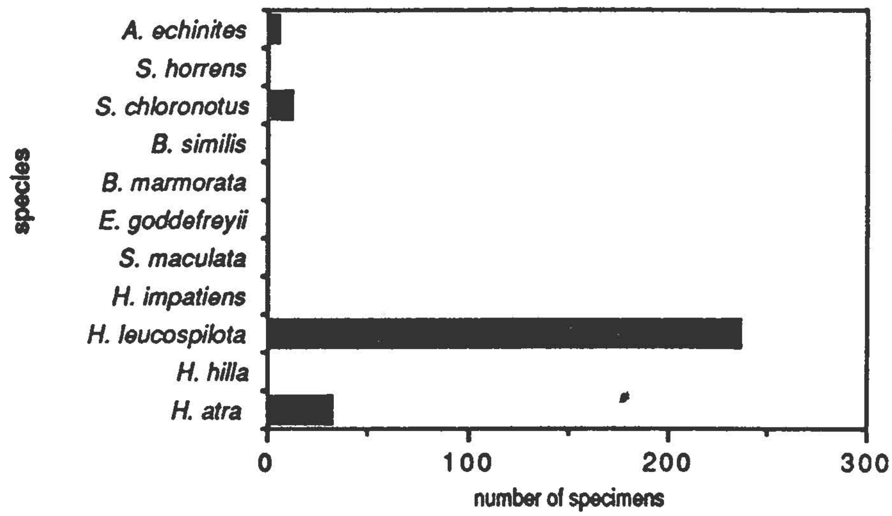

Fig. 15. Holothurian abundance and diversity in Site 7, Wing Beach

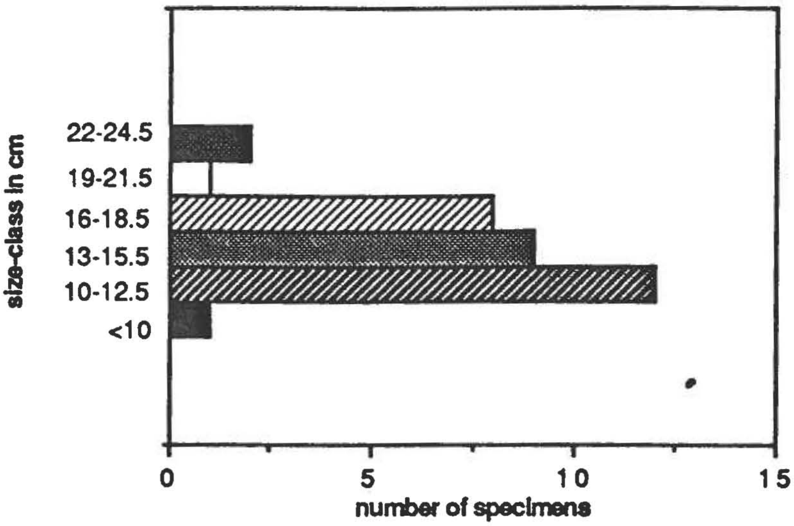

Fig. 16. Size-class distribution of H. atra in Site 7, Wing Beach

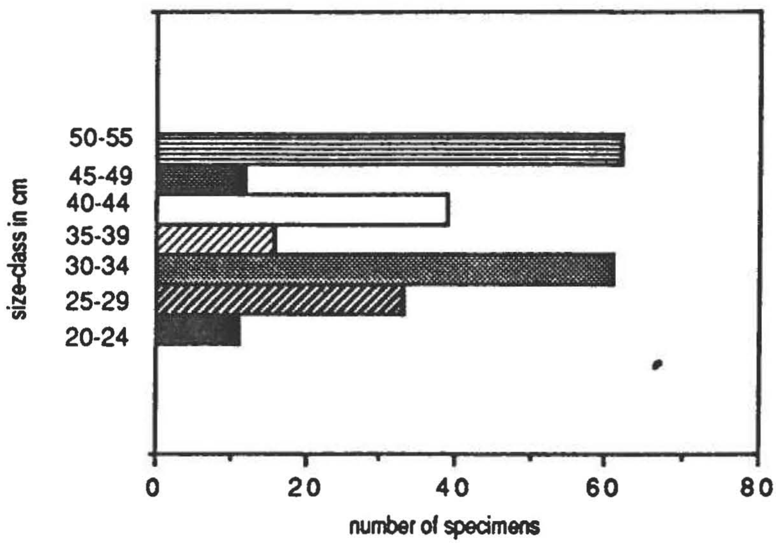

Fig. 17. Size-class distribution of H. leucospilota in Site 7, Wing Beach

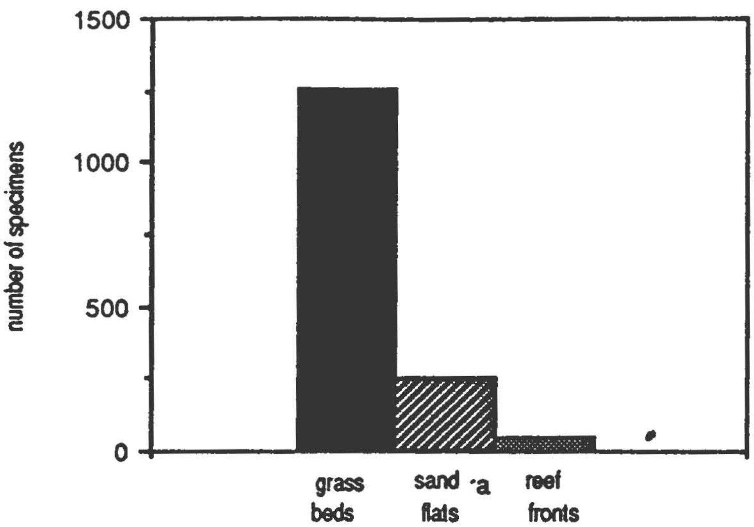

Fig. 18. Comparison of the number of specimens of H. atra in grass beds, sand flats and reef fronts. (Species abundance/eight transects)

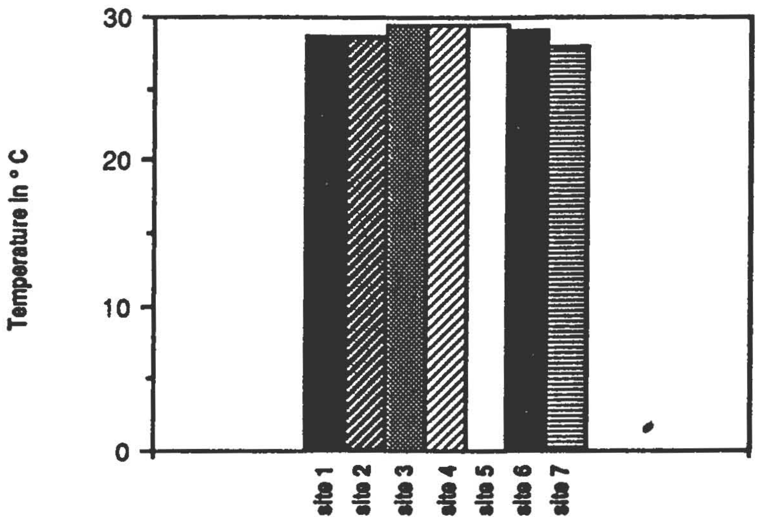

Fig. 19. Average temperature of sites from measurements taken morning, midday, evening, and night

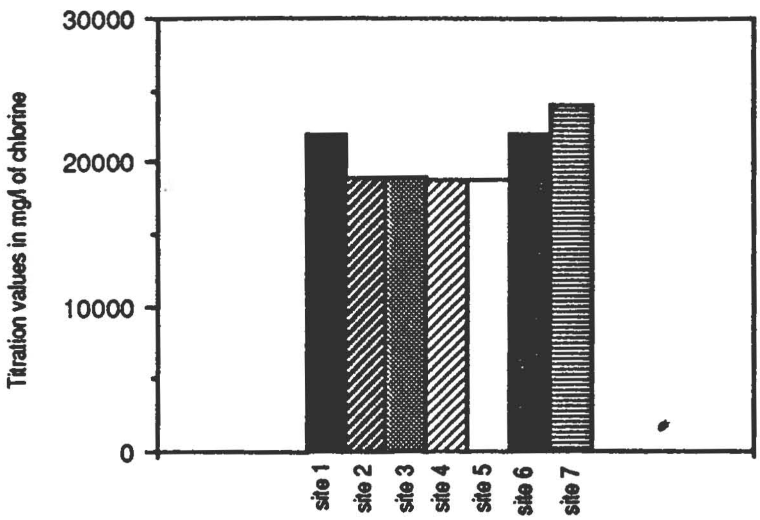

Fig. 20. Salinity estimation for all sites

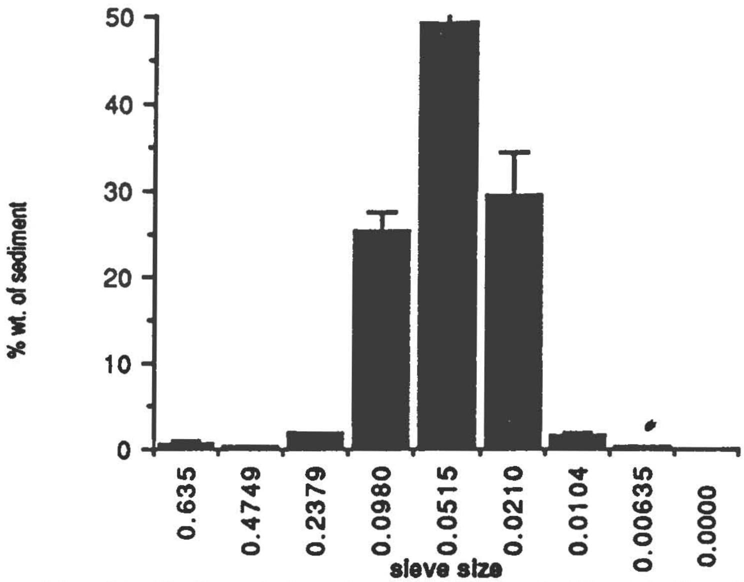

Fig. 21. Sediment size-class distribution in Site 1A, San Antonio Sand Flat. (n=4) Lines on bars show std. error of data

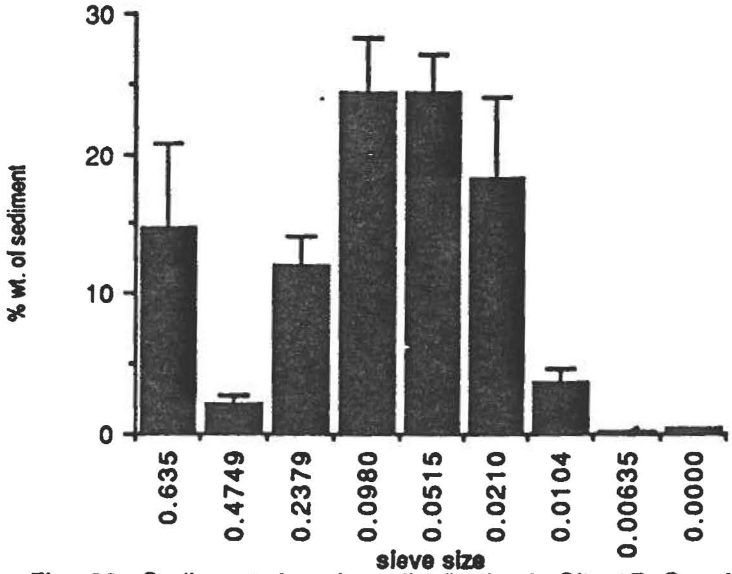

Fig. 22. Sediment size-class distribution in Site 1B, San Antonio Reef site. (n=4) Lines on bars show std. error of data

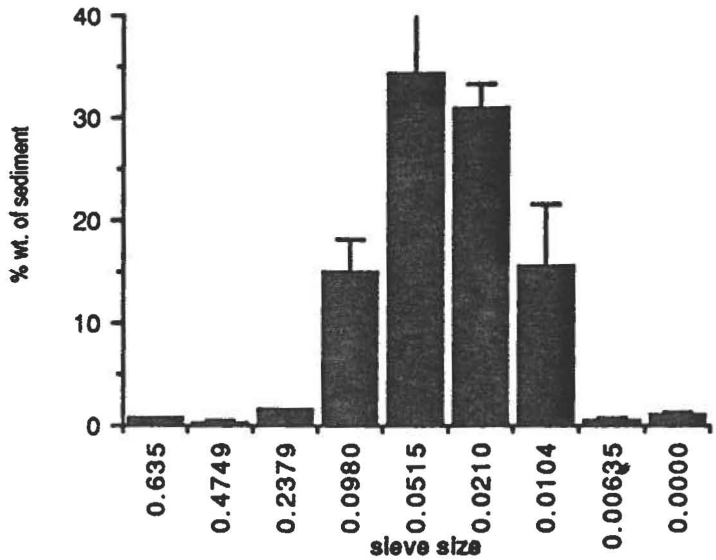

Fig. 23. Sediment size-class distribution in Site 2, Civic Center Shore grass bed. (n=4) Lines on bars show std. error of data

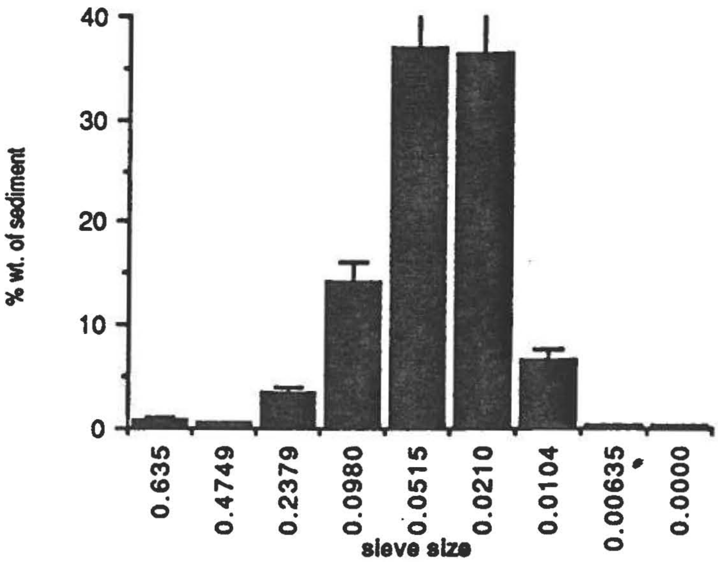

Fig. 24. Sediment size-class distribution in Site 3, Civic Center Mixed Zone. (n=4) Lines on bars show std. error of data

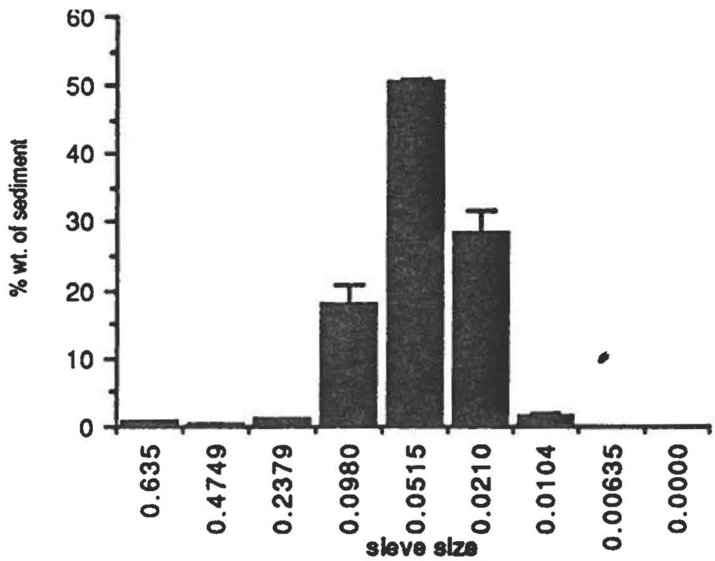

Fig. 25. Sediment size-class distribution in Site 4, Civic Center Sand Flat. (n=4) Lines on bars show std. error of data

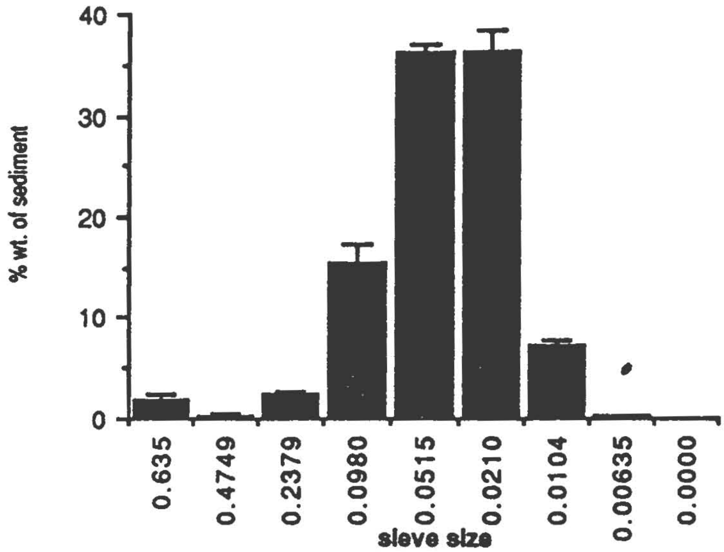

Fig. 26. Sediment size-class distribution in Site 5, Susupe Sand Flat. (n=4) Lines on bars show std. error of data

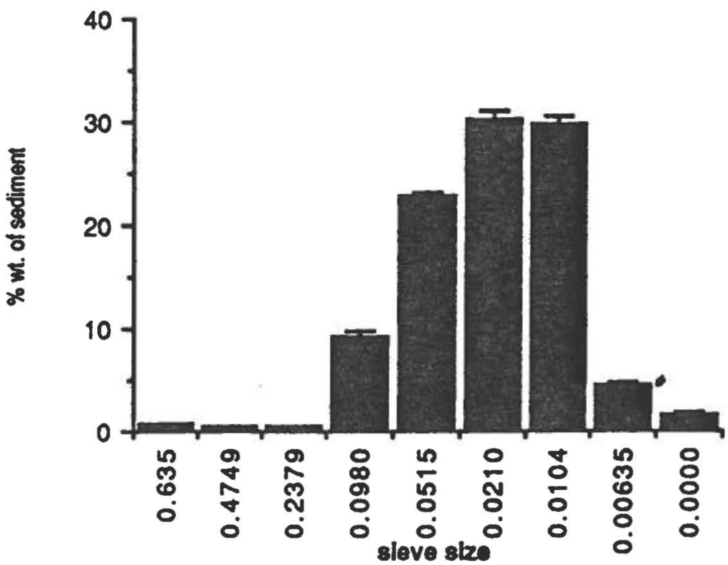

Fig. 27. Sediment size-class distribution in Site 6, Garapan Grass Bed. (n=4) Lines on bars show std. error of data

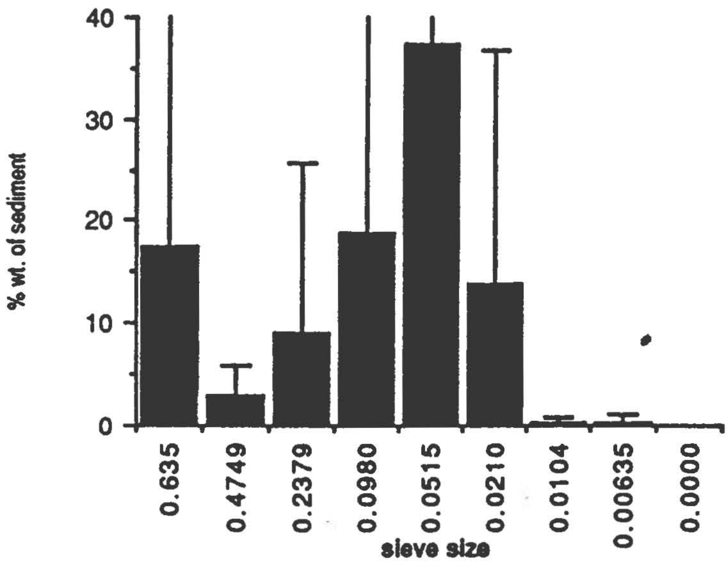

Fig. 28. Sediment size-class distribution in Site 7, Wing Beach Rocky Reef site. (n=4) Lines on bars show std. error of data

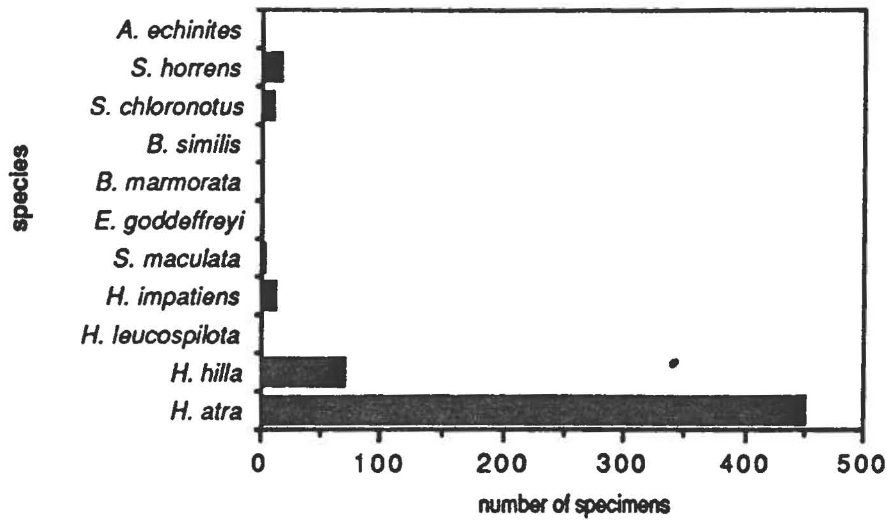

Fig. 29. Holothurian abundance and diversity in all of the nearshore sites combined. (Species abundance/four transects)

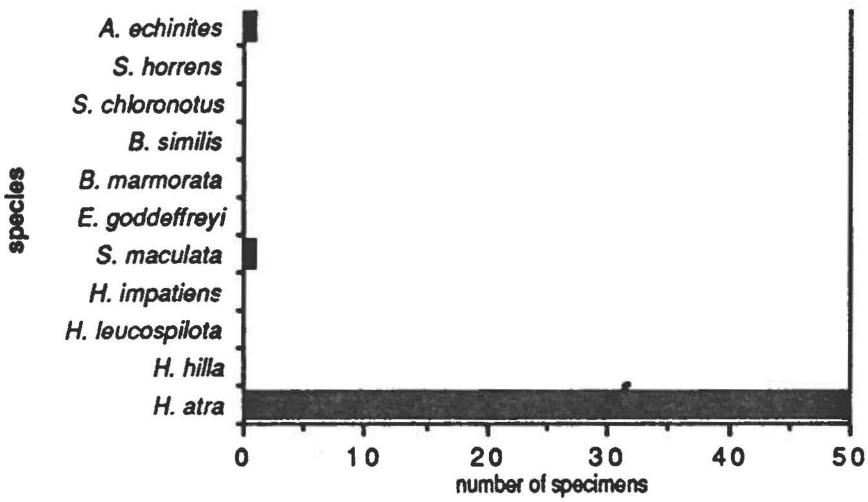

Fig. 30. Holothurian abundance and diversity in all of the midlagoon sites combined. (Species abundance/four transects)

For the recorded number of the most abundant species, see text.

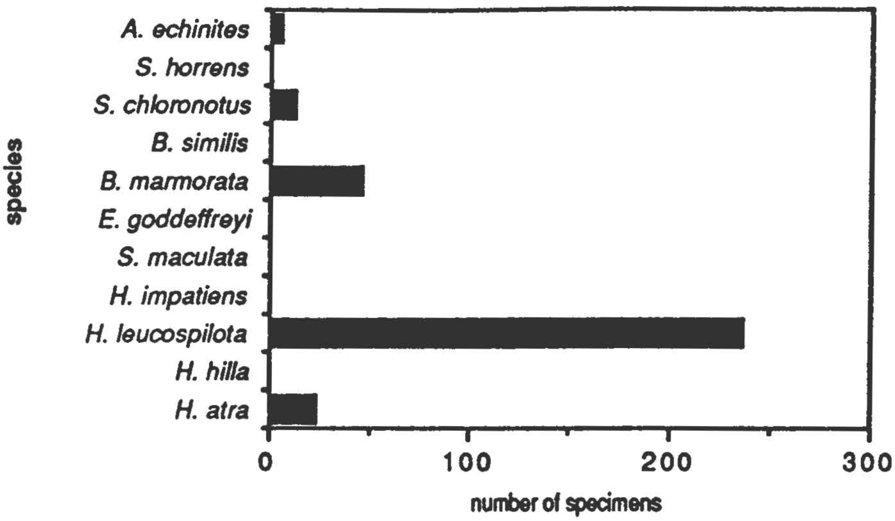

Fig. 31. Holothurian abundance and diversity in all of the reef front sites combined. (Species abundance/four transects)

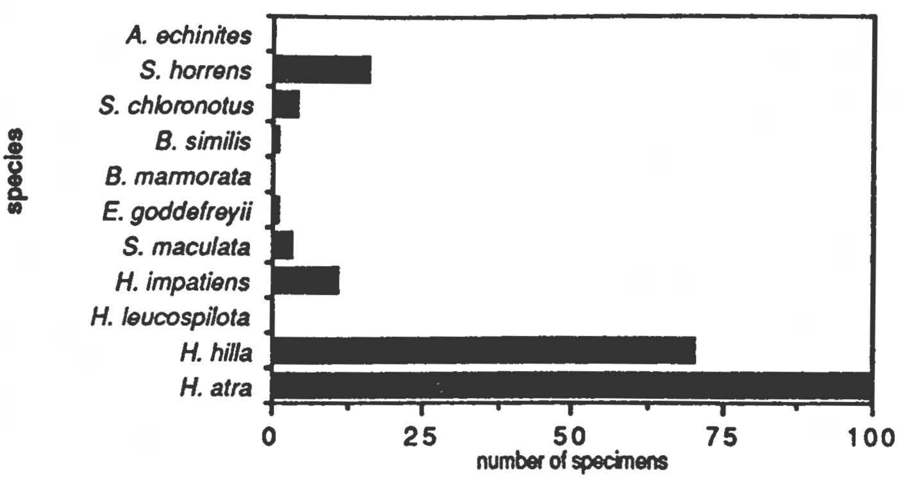

Fig. 32. Holothurian abundance and diversity in all of the grass bed sites combined. (Species abundance/four transects)
For the recorded number of the most abundant species, see text

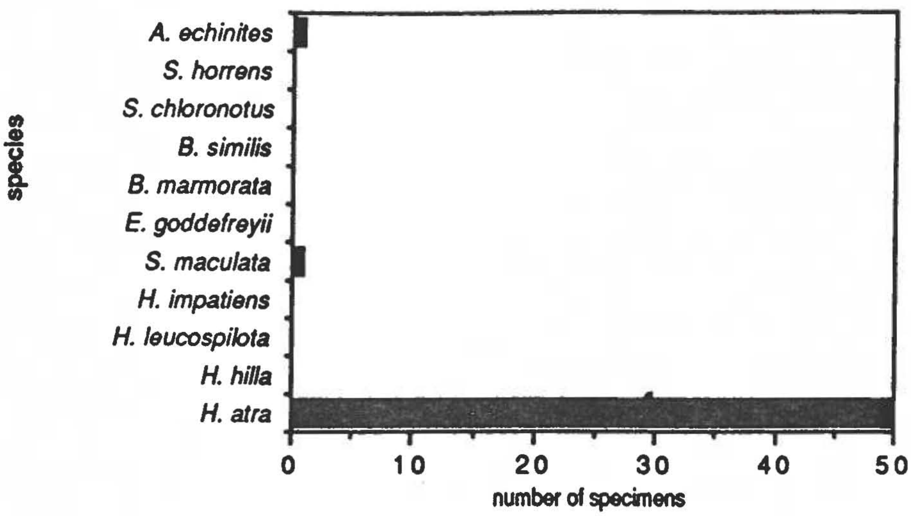

Fig. 33. Holothurian abundance and diversity in all of the sand flat sites combined. (Species abundance/four transects)