AN ABSTRACT OF THE THESIS OF Russell N. Clayshulte for the Master of Science Degree in Biology presented February 20, 1981.

Title: Distribution and Recruitment of Foraminifera in the Families Acervulinidae and Homotrematidae in Shallow Coral Reef Environments on Guam.

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Occurrence and recruitment of adherent foraminiferans were quantified for natural substratum habitats and artificial biofouling surfaces. Species occurrence and recruitment were assessed in lagoon, fringing reef, barrier reef and coral community environments.

Species from the Families Acervulinidae and Homotrematidae are a conspicuous component of epibenthic communities in the upper littoral zone of Guam's leeward coast. Foraminiferal species occurrence, surface coverages and frequencies of occurrence on natural substratum vary between reef zones and habitat types. Species readily recruit to biofouling plates, with species recruitment variable between reef environments. Foraminiferal densities on artifical and natural habitat types are generally less than 1 specimen/cm^2 (10,000 individuals/m^2). Although adherent species are visually obvious on habitat surfaces, the average total surface coverage is about 1%.

Planogypsina squamiformis, Acervulina inhaerens and *Gypsina vesicularis* readily recruit to biofouling surfaces after short exposure periods (37-180 days), and they can successfully compete with other benthic taxa, excluding fleshy algae, for space on exposed surfaces. These early successional species, which have encrusting growth forms,

are generally not as successful on exposed surfaces after longer exposure periods (>1 yr). The late successional species *Homotrema rubrum, Miniacina miniacea, Carpenteria utricularis, C. monticularis, Sporadotrema cylindricum* and possibly *S. rubrum* have a preference for shaded or cryptic habitat surfaces. *Homotrema rubrum* is the dominant species on reef flat substrata and shows a distinct decrease in density and surface coverage seaward of the reef margin. *Miniacina miniacea* is the principal species on reef slope habitats where it can successfully compete for space with calcareous algae and other benthic encrusters. *Carpenteria utricularis* occurs on most substratum types in all reef environments. Specimens of *S. cylindricum* are usually found on cryptic surfaces, particularly in the reef margin zone, as massive "pseudo-colonies."

TO THE GRADUATE SCHOOL AND RESEARCH

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DISTRIBUTION AND RECRUITMENT OF FORAMINIFERA IN THE FAMILIES ACERVULINIDAE AND HOMOTREMATIDAE IN SHALLOW CORAL REEF ENVIRONMENTS ON GUAM

by

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INTRODUCTION

Adherent Foraminifera

From a geological perspective, the coral reef is a complex association of calcareous frame-building organisms, associated flora and fauna, and biogenic sediments. Scleractinian corals and calcareous algae provide the hard substratum essential to the existence of other reef-dwelling organisms. An extensive portion of the hard-substratum surface area of coral reefs lies within crevices and cavities of the framework (Jackson and Buss, 1976). These cavities and interstices provide additional living space that allows for an increase in total reef biomass. Garrett et al. (1971), on the basis of blasted sections of a Bermuda patch reef, estimated that 30 to 50 percent of the total reef volume was occupied by sediment fill and open cavity. Additionally, small cavities such as body cavities, skeletal interspaces and borings can significantly increase the available surface area of the framework (Bonem, 1977; Garrett et al., 1971).

Cryptic epibenthic communities which occupy the cavities and interstices are an important element of modern reefs and play a major role in the reef community structure (Bonem, 1977; Garrett et al., 1971; Steinker et al., 1977; Vasseur, 1977). According to Bonem (1977), as much as 50 percent of the reef frame consists of cement- and internal-sediment-producing communities. Cryptic communities occupy shaded cavities where reduced illumination restricts growth of the faster growing fleshy algae. Although illumination is only one of the physical-chemical factors influencing the community structure, it is the most conspicuous and easily measured. Dark cavities may permit deeper-water, light-sensitive organisms to inhabit shallower depths in protection (Bonem, 1977).

A characteristic component of the cryptofaunal assemblage residing in cavities and interstices of the reef framework is the Order Foraminiferida. These framework-associated species can be significant contributors to bioclastic sediments and important cementing agents (Hanzawa, 1957; Loeblich and Tappan, 1964). Adaptation for a sessile existence produces encrusting forms and branching shapes (Hottinger, 1978). Recent foraminiferans from the Families Acervulinidae and Homotrematidae characteristically attach themselves permanently to reef-associated substrata by means of a cement which persists after death of the animal. As a result of this attachment, species from these families are conspicuous components of the cryptofaunal assemblage of Cenozoic reef systems.

Foraminiferans are potentially useful in better understanding paleoecological conditions of tropical and subtropical reef systems. An understanding of the factors controlling the distribution of living species of foraminifera can be used to estimate ecological conditions under which foraminiferans lived in the geologic past (Douglas, 1979; Loeblich and Tappan, 1964). A foraminiferal assemblage can be used as a Paleoecological indicator if quantitative information on the distribution and species composition within specified limits or zones is acquired for the living species of the assemblage. An estimate of environmental response of foraminiferal species is obtained by determining the standing crop, or the number of living specimens per unit area. Areas that have high standing crops are generally areas of high productivity, not only for foraminifera but also for associated organisms (Boltovskoy and Wright, 1976). The distribution, standing crop and species composition of coral-reef-associated benthic species have not been well documented; nor have the ecological factors influencing the distribution and standing crop. Physical and biological factors which can influence specific recruitment to reef zones are temperature, light intensity, pressure, salinity, oxygen and carbonate solubilities, turbulence, pH, substrata, food availability, symbiotic organisms, parasites, and predators (Boltovskoy and Wright, 1976; Loeblich and Tappan, 1964; Phleger and Parker, 1951). The variability of physical and biological factors within specified coral-reef zones makes it difficult to assess differences between zones. As a result, it is impractical to determine the isolated effects of these factors for the shallower portions of the reef framework, either reef flat or reef slope (to ca. 100m). The major physical factors which could influence the distribution of adherent species are illumination, substratum availability and water circulation patterns. The substratum configurations which control the amount of cryptic space may affect the density, coverage and species composition in different reef zones. Adherent foraminiferans are usually associated with the cryptic reef interstices, but they can successfully compete for space in shaded and occasionally in exposed habitats. The cryptic interstices are generally areas with reduced water circulation. Circulation patterns, turbulence and tidal movement (to a lesser extent) can influence food availability and recruitment patterns.

Literature Review

Eight genera with living species from the Families Acervulinidae and Homotrematidae are found throughout the tropical and subtropical oceans (Loeblich and Tappan, 1964). The geographical, geological and depth distributions of these species are presented in Table 1. The information was drawn from Boltovskoy (1976), Chapman (1901), Cushman

Table 1. Geographical distribution and first geological occurrence of Holocene foraminifera in the Families Acervulinidae and Homotrematidae. The biogeographical regions are adapted from Ekman (1953). The Caribbean region includes the West Indies, Gulf of Mexico and Bermuda. The numbers in parenthesis are depths (m): R designates reef systems, and S refers to shallow collections.

Family ACERVULINIDAE	
Acervulina inhaerens Schultze	Lower Eocene. + INDO-WEST PACIFIC; C. Pac. (33), Guam (R-38), Indian, S/T* Aust. (R-72), Hawaii (73). TEMPERATE NORTH PACIFIC (S). MEDITERRANEAN (664). ATLANTO-EAST PACIFIC; Carib. (347-2200), W. Africa, Brazil. TEMPERATE NORTH ATLANTIC. TEMPERATE SOUTH ATLANTIC.
Gypsina Carter	Eocene. + INDO-WEST PACIFIC; C. Pac. (732), Guam (R-200), Indo-Malayan, Indian, S/T Aust., Hawaii, Japan. MEDITERRANEAN. ATLANTO-EAST PACIFIC; Carib., Brazil, S/T E. Pac., S/T W. Brazil.
G. plana (Carter)	Eocene. + INDO-WEST PACIFIC; C. Pac., Guam (S), Indian. ATLANTO-EAST PACIFIC: Carib.
G. vesicularis (Parker & Jones)	Upper Oligocene INDO-WEST PACIFIC; C. Pac. (33), Guam (S), Indo-M. (32), S/T Aust. (33), Japan (97). ATLANTO-EAST PACIFIC; Carib. (7-713), S/T E. Pac. (4-188).
G. fimbriata (Chapman) [possibly *P. squamiformis*]	Eocene INDO-WEST PACIFIC; S/T Aust. (35).
Planogypsina squamiformis (Chapman)	Upper Tertiary INDO-WEST PACIFIC; C. Pac. (48), Guam (S), S/T Aust. (35).
Sphaerogypsina globulus (Reuss) *[G. globula]* *[G. globulus]*	Eocene INDO-WEST PACIFIC; C. Pac. (R-732), Guam (S-30), S/T Aust. (35), Indo-M. (44-582), Japan (1-97), Hawaii (73). MEDITERRANEAN. ATLANTO-EAST PACIFIC; Carib., S/T E. Pac. (91), Brazil.

Table 1. Continued.

Family HOMOTREMATIDAE	
Subfamily Homotrematinae Cushman	
Homotrema rubrum (Lamarck)	Upper Oligocene** INDO-WEST PACIFIC; C. Pac. (S), Guam (R-250), Indo-M. (R-894), Indian (R), S/T Japan, S/T Aust. (S), Hawaii, ATLANTO-EAST PACIFIC; Carib., Brazil. S/T E. Pac., (W. Africa?).
Miniacina miniacea (Pallas)	Upper Eocene. INDO-WEST PACIFIC; C. Pac. (R-64), Guam (250), Indo-M. (9-2124), Indian (229), S/T Aust. (S), Hawaii. TEMP. NORTH PACIFIC; (<1800). MEDITERRANEAN. ATLANTO-EAST PACIFIC; Carib. (796), S/T E. Pac.
M. miniacea alba (Carter) (probably a variety)	Eocene INDO-WEST PACIFIC; C. Pac., Indo-M. (113).
Sporadotrema Hickson	Eocene INDO-WEST PACIFIC; C. Pac. (S), Guam (S), Indo-M., Indian, Hawaii, ATLANTO-EAST PACIFIC; S/T E. Pac.
S. cylindricum (Carter)	Eocene INDO-WEST PACIFIC; C. Pac., Guam (S), Indo-M. (16-125), Indian (37-143).
S. mesentericum (Carter)	Eocene INDO-WEST PACIFIC; Indo-M. (15-96), Indian.
S. rubrum (d'Orbigny)	Eocene INDO-WEST PACIFIC; Indo-M. (18-27), Guam (R).
Subfamily Victoriellinae Chapman & Crespin	
Carpenteria Gray	Upper Cretaceous INDO-WEST PACIFIC; C. Pac., Guam, Indo-M., Indian, S/T Japan, S/T Aust., New Zealand, Hawaii. TEMP. NORTH PACIFIC. ATLANTO-EAST PACIFIC; Carib., Brazil, S/T E. Pac., S/T W. Africa. TEMP. SOUTH ATLANTIC; Falkland.
C. utricularis (Carter)	Upper Cretaceous INDO-WEST PACIFIC; C. Pac. (16-64), Guam (R-250), Indo-M. (20-503), Indian (R). ATLANTO-EAST PACIFIC; Carib., Brazil (640).

Table 1. Continued.

C. *monticularis* (Carter)	Upper Cretaceous INDO-WEST PACIFIC; C. Pac. (29-539), Guam (R-250), Indo-M. (59-403), Indian (R), S/T Japan (1593), S/T Aust. (S), Hawaii (78-236). TEMP. NORTH PACIFIC (186). ATLANTO-EAST PACIFIC; Carib. (796), S/T W. Africa (768). TEMP. SOUTH ATLANTIC; Falkland (1803).
C. *proteiformis* Göes	Upper Cretaceous INDO-WEST PACIFIC; C. Pac. (30), Guam (S), Indo-M. (330-628), S/T Japan (110), New Zealand (348). ATLANTO-EAST PACIFIC; Carib. (713-796), S/T E. Pac. (357).
C. *raphidodendron* Möbius	Upper Cretaceous INDO-WEST PACIFIC; Indo-M. (22-694).
C. *balaniformis* Gray	Upper Cretaceous INDO-WEST PACIFIC; C. Pac. (183), (S/T Aust.?). ATLANTO-EAST PACIFIC; S/T E. Pac., S/T W. Africa (768), (Carib.?).

\+ First geological occurrence as recorded in some papers was Cretaceous

* S/T - Subtropical/tropical

** Probably occurred in Eocene

(1970c), Emiliani (1951), Flint (1975), Galloway (1933), Hickson (1911), Lindsey (1913), Millett (1970), Nyholm (1962), Phillips (1977), Uchio (1968) and other references in the Literature Cited. The distribution of East-Pacific species designated by McCulloch (1977) was considered only to the generic level; therefore no attempt was made to subdivide the East-Pacific faunas. Species recorded in the literature as *Gypsina globulus* and *G. globula* were tabulated under *Sphaerogypsina globulus*. According to Todd (Cushman and Todd, 1972), *G. vesicularis* is probably a synonym of *G. globula*, and *S. globulus* may also be a form variation. Nyholm (1961) considered *Gypsina* to be a resting stage of *Cibicides*, but this has not been proven with life-cycle studies. *Miniacina album* (Carter), as recorded by Hofker (1963), appears to be a color morph of *M. miniacea*. Cushman et al. (1954) referred to this species as the variety *M. miniacea alba* (Carter). Living specimens of both *M. miniacea* and *H. rubrum* ranging in color from dark red to white have been examined during this study. Since the only observable difference was color, no distinction was made between red or pink and white specimens.

In particular, adherent foraminiferans are an important component of the cryptofaunal communities on hard substrata in different reef zones around Guam. They are found in fringing reef, barrier reef, lagoon and coral community environments. Previous records (Brady, 1884; Cole, 1963; Cushman and Todd, 1972; Todd, 1966) and personal investigations indicate that the adherent foraminifera associated with Guam's reefs are *Homotrema rubrum* (Lamarck), *Gypsina globula* (Reuss), *G. vesicularis* (Parker and Jones), *G. plana* (Carter), *Miniacina miniacea* (Pallas), *Sporadotrema cylindricum* (Carter), *S. rubrum* (d'Orbigny), *Carpenteria proteiformis* Goes, *C. utricularis* (Carter), *C. monticularis* Carter, *Acervulina* *inhaerens* Schultze, *Planogypsina squamiformis* (Chapman), *Sphaerogypsina globulus* (Reuss) (Table 1). *Homotrema rubrum* and *Miniacina miniacea* are the most conspicuous species and have been observed on a wide variety of substrata from different reef zones.

Todd (1966) recorded four species of adherent foraminiferans in various reef and lagoon samples in a study of the smaller foraminifera from Guam. *Gypsina globula* and *H. rubrum* were the most widely encountered species, with *G. vesicularis* and *C. proteiformis* found only in outer reef slope samples. Cole (1963) recorded only *G. vesicularis* in a study of the larger foraminifera from Guam. *Acervulina inhaerens* and *G. globula* were recorded in a 21-fathom (60m) sample collected during a Guam anchorage of the "Albatross" expedition (Cushman and Todd, 1972). Cole (1957b), Hanzawa (1957) and Todd (1957) found five species of adherent foraminiferans in samples from Saipan. The same species found in Guam were recorded for Saipan. Adherent foraminiferal species have been recorded throughout the Pacific provinces during both major oceanic studies (Brady, 1884; Cushman, 1970a; Cushman and Todd, 1972; Hofker, 1963; McCulloch, 1977) and regional foraminiferal studies (Collins, 1958; Cushman, 1970b; Hanzawa, 1957). Localized foraminiferal studies of Pacific Islands have been conducted for Guam (Cole, 1963; Todd, 1966), Bikini (Cole, 1954; Todd and Post, 1954), Fiji (Cole, 1960), Palau (Cole, 1950), Gilbert Islands (Todd, 1961), Eniwetok (Cole, 1957a; Todd and Low, 1960), Marshall Islands (Cushman et al., 1954), Midway (Cole, 1969; Todd and Low, 1970), Okinawa (LeRoy, 1964), Saipan (Cole, 1957b; Todd, 1957), and Tonga (Todd, 1970). According to Hanzawa (1957), *Homotrema* is the most common encrusting foraminiferal genus in shallow waters of the tropical Pacific Ocean, followed by *Sporadotrema* and then *Miniacina*.

It is evident that although numerous qualitative studies have described and listed the foraminiferal species from different locales throughout the tropical and subtropical provinces, few have considered the contribution of living foraminiferans to the coral reef community structure. There is a need for quantitative descriptions of abundance, composition and distribution of benthic coral reef communities (Loya, 1978).

Objective

The purpose of this investigation was to provide a quantitative assessment of the adherent foraminiferal component of the cryptofaunal assemblage. The adherent foraminifera recruited to artificial biofouling surfaces and found on the dominant natural habitat types were quantified from reef systems on the leeward coast of Guam. Selected substrata from leeward coral reef systems were examined for standing crop and surface coverage of adherent species. An understanding of the distribution, species composition, abundance and surface coverage can be useful in assessing the importance of these species in the benthic reef community structure.

MATERIALS AND METHODS

The distribution, standing crop and surface coverage of adherent foraminiferal species were assessed on both artificial biofouling surfaces and hard natural substrata. Recruitment of benthic biofouling communities to artificial substrata, at depths from 10 to 40m, was previously investigated near Tanguission Point, Guam (Neudecker, 1977). My species recruitment collectors were designed after I observed Neudecker's plexiglass settling plates. The adherent foraminiferans *Homotrema rubrum, Miniacina miniacea* and *Gypsina vesicularis* were found to recruit readily to the shaded lower surfaces. *Acervulina inhaerens* and *G. vesicularis* recruited to exposed upper surfaces. The highest densities were observed from the greater depths and longer time periods on the lower surfaces of Formica shade-plates. Neudecker's plexiglass plates were 5x15cm with 75 cm^2 surface area. This plate size has been used in additional biofouling studies of coral reef development (Birkeland, 1977; Rowley, 1980). Formica plates measuring 5x15cm were used in this study.

In order to assess the effects of shading on the recruitment of adherent foraminiferans, plates were mounted horizontally on both the exterior upper surface and in the cavities of concrete blocks. The plates were attached to seawater-cured blocks with brass hardware. The exposed and shaded plates were bolted 2cm above the blocks' surfaces. A block had four mounted plate sets, with two of the sets on the upper surface and two in the block's cavities. A plate set consisted of an upper and lower Formica plate mounted together with the rough sides exposed. The primary environmental factor tested with this design was illumination of exposed versus shaded surfaces and upper versus lower surfaces. Although illumination was being tested, other environmental factors potentially had as much effect on species recruitment. The plate sets in the block cavities were subjected to modified water circulation patterns as compared to the exposed plate sets. The orientation of the blocks was suspected of influencing the species recruitment patterns on the plates. Additionally, the biological factor of associated fauna could affect the biofouling community. Farmer fish, *Stegastes* spp., occupied the cavities in blocks placed at depths shallower than 20m.

The concrete block was also considered as a biofouling surface. The block had three recruitment surface types distinguished on the basis of the degree of illumination. The exterior surfaces were exposed to ambient light intensities for a given placement depth. The cavities provided reduced-illumination (shaded) surfaces. The base of the block adjacent to the reef substratum provided a cryptic environment with low illumination. Each exposed and cryptic surface area was 770cm^2, while the shaded surface area was variable, ranging from 600 to 750cm^2.

A total of twenty blocks was placed in the field at four coral reef environments (Table 2). Paired blocks were placed at preselected depths at the sites and cabled either to large structural reef components or in open areas with cavities. Although water circulation patterns were different between paired blocks, orientations in relation to illumination were similar.

The recruitment study sites were Tanguisson Point, Facpi Point, Agat Bay and Western Shoals (Apra Harbor). The Tanguisson site had 6 blocks placed at three depths: 10, 20 and 30m. Blocks were exposed for a period of 20 months. The Facpi Point and Agat Bay sites had 2 blocks each placed at a single depth, 24m. The blocks were exposed for 12 months at the Facpi site and 24 months at the Agat site. The 10 blocks at the Western

Table 2. Substratum collection and biofouling recruitment sites in relation to coral reef zonation.

Reef Zones	Sampling sites	Biofouling Blocks depth (m)	Biofouling Blocks blocks (no.)	Biofouling Blocks exposure (days)	Biofouling plates (total)	Transects depth (m)	Transects samples (no.)	Bulk Substrata depth (m)	Bulk Substrata sites (no.)
FRINGING/BARRIER REEF									
Reef-flate platform	Tanguisson					1	32		
	Luminao					1	31		
Reef margin	Tanguisson							1-3	5
	Rizal							1-3	9
Reef front	Tanguisson	6	2	365	61	6	33		
	Luminao					6	37	7	5
	Rizal							5-7	3
Seaward reef slope submarine terrace	Tanguisson	10	2	541	40	12	40	10	3
	Luminao	12	4	365	72	12	39	10-12	15
	Rizal							10	1
seaward slope (15-55m)	Tanguisson	23	2	541	61			20	1
		30	2	541	32				
	Luminao	24	4	365	72			26	2
		36	3	365	72			55	1
LAGOON									
Patch reef	Western Shoals	6	2	105-182	16			2-6	8
		12	2	105-182	16			12	1
		18	2	105-182	16			18	1
		24	2	105-182	16			24	1
		30	2	105-182	16			30	2
CORAL COMMUNITY									
Mounds	Facpi Point	20	2	364	16			20	2
	Agat Bay	20	2	560	16				

Shoals site were placed at 5 depths: 6, 12, 20, 26 and 33m. One block from each of the 5 depths was collected after 3 months' exposure and the remaining blocks after 5 months.

The four recruitment sites are generally representative of three coral reef types: Tanguisson is a leeward fringing reef, Facpi Point and Agat Bay are coral communities, and Western Shoals is a lagoon patch reef. Additionally, recruitment of biofouling communities in a fourth coral reef type, the barrier reef, was studied near Luminao barrier reef. Biofouling studies for an ocean thermal energy conversion (OTEC) project were conducted on the submerged Calalan Bank near Luminao Reef (Rowley, 1980). Plexiglass and PVC plates ($75cm^2$) were mounted to the horizontal and vertical exterior surfaces of concrete blocks. Four horizontal and vertical plate sets, upper and lower plates, were mounted to each block which were placed at four depths: 6, 12, 24 and 36m. Plates from two blocks at each depth were collected at time intervals of 37, 77, 100 and 180 days. The 100-day blocks also had a shaded plate set. The blocks used in the study were left in the field for approximately 12 months. Four blocks from 12 and 24m, three from 36m and two from 6m were collected and analyzed for adherent foraminiferans.

Hard natural substratum samples were collected from various reef zones on the leeward coast of Guam (Table 2). A variety of substratum samples with shaded or cryptic surfaces were collected seaward of the reef margin by using scuba. An attempt was made to obtain bulk substratum samples which were reasonably representative of the sampled reef area. The samples were collected without regard to adherent foraminiferans. Irregular pieces were broken from the reef framework with hammer, prybar, and chisel, then labeled and placed in plastic bags. Samples were returned to the laboratory, air dried and placed in storage for later examination.

Hard substratum was quantitatively sampled at two sites on the leeward coast of Guam (Table 2). Transect substrata were subdivided into five basic habitat categories: living coral, dead coral, rubble, cavity and exposed knob. The coral habitats had natural distinguishable subunits: branching, tabulate and massive forms of living coral; and branching and tabulate forms of dead coral. The cavity habitat was subdivided into exposed and cryptic (<10cm opening) cavities. The exposed knob was generally a low-relief solid topographic feature (i.e., eroded massive or branching coral). Branching calcareous algae, important habitat types in some reef zones, were not encountered on the transects. The habitats generally represented the major types of topographic relief features found in the reef zones. Substratum characterization was achieved along transects at Tanguisson Point and Luminao reef in three zones at each site with the point-centered or point-quarter technique (Cox, 1967). A 50m transect was established parallel to the reef margin in each zone: the reef flat, upper reef slope (ca. 6m), and reef slope (ca. 12m). Ten substratum collection points were randomly selected along each transect line. A line bisecting the point at right angles to the line established four quadrants around a point. Substratum types from each quadrant were quantified.

The adherent foraminiferal species composition, density and surface coverage were analyzed on bulk substrata, samples collected from each transected habitat type, biofouling blocks and recruitment plates. The substratum samples were transected by using a modified point-quarter technique (mPQT). The mPQT is a reproducible method for quantifying foraminiferal community structure on substrata with intricate relief. The mPQT requires that species be randomly distributed and have an upper size range smaller than the maximum point-to-specimen distance. Tests conducted on both artificial and foraminiferal populations with the mPQT showed that total density estimates varied in relation to expected normal distribution. However, there was a tendency for the mPQT to underestimate higher-density populations. Quadrat analyses usually resulted in over-estimates of population densities. The mPQT was tested on substrata with 10, 20 and 30 random points per analysis set. Twenty random points per sample were shown to adequately quantify the foraminiferal component of a substratum. Appendix A presents the modified point-quarter technique, a comparison of transecting methods and the foraminiferal characterization calculations.

Comparisons of foraminiferal species, density, surface coverage and frequency were made between habitats in the transected zones and for the bulk substratum samples. The distribution of species was compared between the transected zones for the Tanguisson and Luminao sites to assess the foraminiferal component variation between a fringing and barrier coral reef system.

Comparisons of foraminiferal species, density and surface coverage were made for the biofouling plates and bricks. The effects of illumination (exposed, shaded or cryptic), plate orientation and surface exposure direction (horizontal, vertical, upper and lower) and exposure depth (6 to 40m) were assessed for the five biofouling sites.

Comparative studies were made with analysis of variance (Hull and Nie, 1979; Nie et al., 1975; Pimentel, 1979; Sokal and Rohlf, 1969). The block analysis factors were orientation to light, depth and location.

Biofouling factors were plate surface direction (upper surface versus lower surface) and illumination (exposed versus shaded). Comparisons of species distribution on transected natural substrata were made within each zone, between zones and between sites.

RESULTS

Foraminiferal Species

Distribution and recruitment of epibenthic foraminiferans were quantified on natural and man-made substrata from the upper littoral zone on the leeward coast. Distribution and densities of naturally occurring cryptic foraminiferal populations were assessed for substrata collected from zonal transects and for random bulk collections. Recruitment densities were determined from artifical biofouling surfaces (concrete blocks and plates and evaluated in relation to light exposures (exposed, shaded, and cryptic).

Total species densities on natural substrata and fouling collectors in the different reef zones were generally less than 1 specimen/cm^2 with values up to 2.14/cm^2 on block surfaces, 16.32/cm^2 on plates, 1.08/cm^2 on transected substrata, and 3.75/cm^2 on bulk substrata (Table 3). Most substrata examined had foraminiferans with lower overall densities on lagoon substrata and higher densities on the barrier reef substrata.

All plates recovered from fringing and barrier reef zones were fouled by foraminiferans. Exposed upper and lower barrier reef plate surfaces had the highest total densities with the higher values generally from 36m (Table 3). Shaded upper and lower barrier reef plate surfaces showed similar total densities which were lower than those of exposed plates. The fringing reef exposed and shaded plates had similar total density ranges. Plates recovered from lagoon patch reef and coral community mound environments had the greatest recruitment to the exposed upper plate surfaces with densities of 0.27 to 5.40/cm^2. Exposed lower and shaded lagoon plate surfaces had lower densities (0 to 0.77/cm^2), while densities on the coral community plates ranged from 0 to 2.31/cm^2.

Table 3. Ranges of foraminiferal total species densities (no./cm^2) on natural substrata and artifical biofouling collectors in relation to coral reef zonation.

Reef Zones	Sampling sites	Depth (m)	Biofouling Block Surfaces exposed	shaded	cryptic
FRINGING/BARRIER REEF					
Reef-flat platform	Tanguisson	< 1			
	Luminao	< 1			
Reef margin	Tanguisson				
	Rizal				
Reef front	Tanguisson	6			
	Luminao	6	0	0.067-0.467	0.154-1.540
	Rizal	6			
Seaward reef slope					
submarine terrace	Tanguisson	12	0.118-0.155	0.476-1.109	0.588-1.000
	Luminao	12	0	0.049-0.277	0.016-0.673
	Rizal	10			
seaward slope	Tanguisson	20	0.315-0.556	1.396-1.807	1.825-2.139
		30	0.140-0.211	1.030-1.251	0.972-1.328
	Luminao	24	0-0.033	0.276-0.398	0.261-1.106
		36	0.016-0.101	0.179-0.379	0.431-0.544
LAGOON					
Patch reef	Western	6	0-0.033	0	0
	Shoals	12	0.049-0.533	0	0
		18	0.157-0.178	0	0
		24	0.033-0.102	0	0
		30	0	0	0
CORAL COMMUNITY					
Mounds	Facpi Point	20	0.175-0.407	0.351-0.370	0.283-0.499
	Agat Bay	20	0.294-0.585	0.032-0.113	

Table 3. Continued.

Sampling sites	Biofouling Plate Surfaces exposed upper	Biofouling Plate Surfaces exposed lower	Biofouling Plate Surfaces shaded upper	Biofouling Plate Surfaces shaded lower	Transect substrata	Bulk substrata
Tanguisson					0 -0.317	
Luminao					0 -0.797	
Tanguisson						0.180-0.825
Rizal						0.067-2.029
Tanguisson					0 -0.947	
Luminao	0.12- 6.80	0.05- 2.29	0.63-4.33	0.35-6.60	0 -0.810	0.050-0.176
Rizal						0.353-0.762
Tanguisson	0.27- 0.81	0.11- 2.03	0.11-1.33	0.79-2.15	0.032-0.590	0.179-0.481
Luminao	0.07- 1.51	0.12- 6.91	1.64-5.04	0.07-1.28	0.033-1.085	0.138-3.746
Rizal						0.102-0.323
Tanguisson	0.32- 1.97	0.03- 0.39	0.11-0.25	1.28-1.75		0.513
	0.79- 3.05	0.07- 0.21	0.05-0.20	0.69-1.72		
Luminao	0.15- 6.76	0.08- 6.73	1.80-3.83	0.11-1.17		0.138-0.681
	0.33-10.75	0.04-16.32	1.43-2.51	0.04-0.43		@55m: 0.280
Western Shoals	0.27- 0.37	0 - 0.32	0.07-0.55	0 -0.11		0.016-0.180*
	1.11- 5.40	0 - 0.05	0.03-0.09	0		0.050
	0.35- 2.04	0 - 0.05	0 -0.05	0		0.016
	0.32- 1.74	0 - 0.27	0.07-0.11	0 -0.77		0
	0.32- 0.93	0 - 0.05	0.03-0.07	0		0
Facpi Point	3.11- 3.60	0.04- 0.08	0 -0.08	0.17-0.73		0.103-0.122
Agat Bay	0.56- 2.23	0.03- 0.08	1.57-2.31	0.01-0.08		

* 1 to 6m

All shaded and cryptic block surfaces recovered from fringing reef, barrier reef and coral community environments had adherent foraminiferans with a low density of 0.016/cm^2 (Luminao, 12m) and a high density of 2.139/cm^2 (Tanguisson, 20m). Exposed block surface densities ranged from 0 (Luminao, 6 and 12m) to 0.556/cm^2 (Tanguisson, 20m). There were no adherent foraminiferans recruited onto the shaded and cryptic surfaces of blocks recovered from the lagoon environment. There was species recruitment to the exposed surfaces, except at 30m, with a density range of 0 to 0.533/cm^2 (Western Shoals, 12m). Lagoon bulk-collected natural substrata from 24 and 30m at Western Shoals had no adherent foraminifera on either the exposed or cryptic surfaces.

The most conspicuous adherent foraminiferal species in the cryptic interstices of the reef flat complex around Guam was *Homotrema rubrum*. Specimens of living *H. rubrum* occurred on upper littoral reef zone substrata and on material dredged from 400m along the northwest coast of Guam. Specimens had considerable color and form variation depending on locale and depth zonation. Reef flat specimens were generally mound-like encrustations with light red to dark red hues. Reef slope (reef margin to 50m) specimens were small, robust branching forms with white to light red hues. Although most specimens had branching tests, there were specimens with quite variable test shapes (eg. globose, pseudo-ramose, encrusting). Emiliani (1951) suggested that dead *H. rubrum* would eventually bleach from red to a light pink and finally to a white color. I found living specimens of *H. rubrum* which ranged in color from light pink to pure white; and they frequently had mixed colors, white branches with red bases and red branches with white bases. Dredged specimens (300-400m) were thin, finely branched forms with pale pink to red hues.

Additional foraminiferal species which were equally conspicuous components of the reef cryptofaunal assemblage were *M. miniacea*, *C. utricularis* and *S. cylindricum*. There species were particularily common on reef slope substrata as compared with cryptic surfaces of reef flat substrata. Specimens were observed on most substratum types with relative high densities on shaded and cryptic cavity surfaces and occassionally on exposed surfaces of reef margin substrata. Living specimens of *C. utricularis* and *C. monticularis* were found on outer reef slope dredged substrata (150-400m). There were wide color variations within species which could not be attributed to either locale or depth zonation: *M. miniacea* ranged from white to light red and rarely orange hues; *S. cylindricum* ranged from off-white to orange-brown and rarely dark red. The form variations of *M. miniacea* were similar to those associated with *H. rubrum*. Although specimens of *Carpenteria* were size-variable, the variations in chamber orientation and structure were minimal. Specimens of *S. cylindricum* were usually plurivalent and produced massive "pseudo-colonies" on reef substrata, particularily in the reef margin zone.

Gypsina spp. were common on exposed and shaded surfaces of natural substrata and recovered biofouling surfaces from lagoon, reef flat and reef slope environments with a few small encrustations on dredged substrata (150-400m). Continuous encrustations of *Gypsina* ranged in size from 50µ to 0.5m. Lindsey (1913), in a review of *Gypsina plana* and its relation to the rest of the genus, recognized 4 species: *G. plana*, *G. inhaerens*, *G. vesicularis*, and *G. globulus*. Subsequently, *G. inhaerens* has been changed to *Acervulina inhaerens* and *G. globulus* has become *Sphaerogypsina globulus* (Loeblich and Tappan, 1964). The primary taxonomic features used to distinguish species were the size range of areolae (chambers): *G. plana,* 49 to 230μ; and *G. vesicularis,* 30 to 48μ. According to Lindsey (1913), "the distinction lies mainly in the form and habit and not in any real difference of structure." *Gypsina* commonly attaches to various substrata in the upper littoral reef complexes of Guam in two distinguishable forms: a large, thick, glossy, dark grey encrustation; and a small, thin, dull white to pale grey encrustation. The larger encrustation usually has an areolar range of 50 to 180μ with the small encrustation areolae ranging from 32 to 96μ; however, there were some continuous encrustations which had both form characteristics and an areolar range of 32 to 180μ. As a result of those ambiguous specimens, *Gypsina* could not be satisfactorily distinguished at the species level. The form types were both referred to as *G. vesicularis,* which has taxonomic preference over *G. plana* (Loeblich and Tappan, 1964). Quantification of *Gypsina vesicularis* with the mPQT was not possible because of the extreme size variability of specimens. Therefore, the density and coverage of *Gypsina* on natural and artifical substrata could not be calculated or adequently compared with the other adherent foraminiferans. *Gypsina* occurrence was not accounted for in the total density and mPQT calculations. As a result, *Gypsina* distribution and recruitment characteristics are only briefly reviewed.

The less frequent species were *Planogypsina squamiformis, Acervulina inhaerens, Sporadotrema rubrum* and *Sphaerogypsina globulus.* The species *S. rubrum,* as described by Hofker (1963), and *A. inhaerens* occurred on exposed and shaded surfaces of both natural and artifical substrata from reef flats to depths of 50m. Small specimens of *S. globulus* (75 to 500μ diameter) were occassionally found on natural substrata but no attached specimens were found. *Gypsina* produced megalospheric, multi-chambered offspring (75 to 200μ diameter) which were indistinguishable from literature descriptions of *S. globulus*.

Carpenteria proteiformis has been recorded from Guam (Todd, 1966); however, no specimens which completely fit the literature descriptions of this species were quantified. A few specimens of a *Carpenteria* species similar to *proteiformis* were recorded from lagoon biofouling plates (Western Shoals; exposed upper plate at 12m) and on the cryptic surfaces between fringing reef biofouling plates (Tanguisson; shaded plates at 23m). The specimens were a uniseral set of 3 to 6 subglobular chambers which typify *C. proteiformis*, but the aperture was not situated in a stout tubular neck as described by Hofker (1963). The three Holocene species *C. rhaphidodendron, C. balaniformis* and *S. mesentericum* recorded from the Indo-West Pacific (Table 1) were not quantified on either the natural substrata or biofouling collectors.

Species Recruitment and Natural Fouling

Specimens of *P. squamiformis*, as described by Loeblich and Tappan (1964) and Chapman (1901), recruited to plates exposed in the barrier reef and coral community environments. A similar species described by Hanzawa (1957) as a new species from Holocene limestone on Saipan, *Acervulina (Ladoronia) vermicularis* (p. 69, pl. 25), has all the characteristics of *P. squamiformis*. This species recruited to all plate surfaces exposed at Luminao barrier reef for 37 to 180 days and at depths from 6 to 36m, with mean densities of replicate plates ranging from 0.11/ cm^2 to 11.12/cm^2 (Table 4).

Additional species which recruited to the Luminao plate surfaces were *H. rubrum, M. miniacea, G. vesicularis* and *A. inhaerens* (Table 5).

Table 4. *Planogypsina squamiformis* recruitment at Luminao barrier reef. Values are mean densities (no./cm^2) and standard deviation from biofouling plate surfaces *(n=4).

		Days 37	77	100	180
Surfaces		Depth 6m	6m	6m	6m
PLEXI.	UH	**0.13±0.01	0.45±0.27	1.32±0.90	**0.14±0.02
	LH	**1.30±0.30	0.17±0.11	1.23±0.52	**0.37±0.08
	VO	**0.12	0.52±0.16	0.67±0.07	**0.55±0.21
	VI	**2.75	0.61±0.26	0.82±0.30	**0.40±0.16
PVC	UH	**5.43±1.49	1.07±1.00	0.53±0.17	0.18±0.06
	LH	**0.98±0.28	1.16±0.81	0.71±0.58	0.24±0.19
	VO	**2.11±0.57	2.23±0.57	1.39±0.51	0.34±0.10
	VI	**3.56±2.04	2.70±0.48	1.39±1.24	0.32±0.15
PLEXI.	SUH	2.77±1.28		0.87±0.32	
	SLH	3.97±3.07		1.21±0.63	
		12m	12m	12m	12m
PLEXI.	UH	0.42±0.19	0.11±0.03	0.79±0.75	1.07±0.32
	LH	1.38±0.51	0.49±0.20	3.88±1.18	3.39±2.40
	VO	0.33±0.09	0.50±0.82	0.61±0.33	1.48±1.11
	VI	1.79±0.80	0.32±0.19	2.37±1.02	1.91±1.28
PVC	UH	1.09±0.48	0.62±0.35	0.96±0.36	0.51±0.11
	LH	3.81±2.85	0.86±0.80	1.45±0.03	0.18±0.06
	VO	2.95±0.58	1.54±1.53	3.62±2.15	2.11±0.82
	VI	2.86±0.56	2.45±1.94	1.45±0.04	1.55±0.88
PLEXI.	SUH	3.28±1.59		3.34±0.03	
	SLH	0.31±0.21		0.69±0.46	

Table 4. Continued.

Surfaces		Days 37 Depth 24m	77 24m	100 24m	180 24m
PLEXI.	UH	2.59±1.61	0.97±0.27	1.23±0.59	2.32±0.53
	LH	5.14±0.69	1.13±0.52	4.62±0.90	4.91±1.31
	VO	0.81±0.96	1.49±1.75	3.21±1.15	2.81±0.56
	VI	2.42±1.43	1.78±0.48	4.48±1.50	3.36±0.42
PVC	UH	3.34±3.61	1.36±0.25	1.86±0.63	1.39±0.38
	LH	1.38±0.51	0.12±0.04	0.63±0.59	0.32±0.22
	VO	2.00±1.92	1.70±0.81	4.13±1.02	1.97±0.45
	VI	1.53±0.45	2.78±2.38	4.89±1.52	1.58±0.44
PLEXI.	SUH	3.44±0.35		2.30±0.48	
	SLH	0.72±0.36		0.25±0.15	
		36m	36m	36m	36m
PLEXI.	UH	0.41±0.12	2.21±0.12	4.69±1.14	2.43±0.50
	LH	3.58±1.26	2.34±1.00	12.19±4.41	2.33±0.76
	VO	0.22±0.11	1.21±0.14	5.08±2.15	2.34±0.91
	VI	1.71±1.02	2.15±0.56	11.12±3.92	1.59±0.70
PVC	UH	1.28±0.29	3.54±1.24	8.79±1.74	2.90±1.75
	LH	1.12±0.78	0.08±0.05	0.53±0.21	0.18±0.12
	VO	0.82±0.50	2.57±1.07	8.02±1.79	2.80±0.85
	VI	1.24±0.35	1.34±0.69	7.18±1.45	1.05±0.50
PLEXI.	SUH	2.18±0.42		2.12±0.48	
	SLH	0.26±0.19		0.23±0.11	

*Surfaces: UH, upper horizontal; LH, lower horizontal;
VO, vertical away from block; VI, vertical toward block.
** N less than 4 plates

Table 5. Mean total densities of foraminiferal recruitment on combined plexiglass and PVC biofouling plates recovered from Luminao barrier reef. The species abbreviations are as follows: Ps, *P. squamiformis;* Hr, *H. rubrum;* Ai, *A. inhaerens;* Mm, *M. miniacea;* Gyp, *G. vesicularis.*

Days		37		77		100		180	
Depth	Species	Plate*	Density (no./cm^2)	Plate	Density (no./cm^2)	Plate	Density (no./cm^2)	Plate	Density (no./cm^2)
6m	Ps	HU	2.78	HU	0.76	HU	0.40	HU	0.03
		HL	1.14	HL	0.67	HL	0.97	HL	0.31
		VI	3.16	VI	1.66	VI	1.11	VI	0.36
		VO	1.12	VO	1.38	VO	1.03	VO	0.45
	Hr		0		0	HU	0.003		0
	Ai		0		0		0		0
	Mm		0		0		0		0
	Gyp		0		0		0		0
12m	Ps	HU	0.76	HU	0.37	HU	1.06	HU	0.79
		HL	2.60	HL	0.68	HL	2.67	HL	1.79
		VI	2.33	VI	1.39	VI	1.91	VI	1.73
		VO	1.64	VO	1.02	VO	2.12	VO	1.80
	Hr		0	HU	0.010	HL	0.003	HL	0.007
	Ai		0		0		0	HU	0.010
								HL	0.010
								VI	0.017
								VO	0.003
	Mm		0		0		0	HL	0.003
	Gyp		0		0		0	HL	0.003
								VI	0.003
24m	Ps	HU	2.97	HU	1.17	HU	1.55	HU	1.86
		HL	3.26	HL	0.63	HL	2.63	HL	2.62
		VI	1.98	VI	2.28	VI	4.69	VI	2.47
		VO	1.41	VO	1.60	VO	4.47	VO	2.39
	Hr		0	HL	0.003	HL	0.002	HL	0.003
								VO	0.003
	Ai		0		0	HL	0.018	HL	0.012
						VI	0.020	VI	0.010
						VO	0.073		
	Mm		0		0		0	HL	0.003
	Gyp		0		0		0	VI	0.002
								VO	0.002

Table 5. Continued.

36m	Ps	HU	0.85	HU	2.88	HU	6.74	HU	2.67
		HL	2.35	HL	1.21	HL	6.36	HL	1.26
		VI	1.48	VI	1.75	VI	9.15	VI	1.32
		VO	0.52	VO	1.89	VO	6.55	VO	2.57
	Hr	HL	0.002			HU	0.008	HL	0.010
						HL	0.023	VO	0.002
				VO	0.003	VO	0.002		
	Ai		0		0	HU	0.008	HU	0.133
						HL	0.030	HL	0.007
						VI	0.048	VI	0.018
						VO	0.005	VO	0.033
	Mm		0		0		0		0
	Gyp		0		0		0	HL	0.035
								VI	0.052
								VO	0.017

*Surface: HU, horizontal upper; HL, horizontal lower;
VO, vertical away from block; VI, vertical toward block.

These species had low recruitment densities at the shallower depths (6 and 12m) and shorter exposure periods (37 and 77 days).

Plates exposed at Tanguisson fringing reef at 10, 23 and 30m were fouled by 7 species: *M. miniacea, H. rubrum, C. monticularis, S. cylindricum, A. inhaerens* and *G. vesicularis* (Table 6). The most frequently encountered species was *M. miniacea,* which had mean densities ranging from $0.107/cm^2$ (exposed upper plate surface) to $1.460/cm^2$ (shaded lower plate surface). The exposed upper plate surfaces from 23 and 30m were fouled only by *A. inhaerens* with mean densities of 0.903 and $1.733/cm^2$, respectively. *Homotrema rubrum* and *C. utricularis* recruited at low densities (0.003 to $0.067/cm^2$) to most of the plate surfaces. *Sporadotrema cylindricum* occurred at low densities (0.003 to $0.010/cm^2$) on primarily lower plate surfaces. Low densities of *C. monticularis* (0.003 to $0.010/cm^2$) were found on upper and lower plate surfaces at 10 and 23m with correspondingly low surface coverage. The total surface coverage for both exposed and shaded plate sets was about 1%.

The concrete blocks recovered from Tanguisson fringing reef (Table 7) were extensively fouled on the exposed surfaces by *G. vesicularis* and *A. inhaerens*, with lower densities of *P. squamiformis, M. miniacea, C. utricularis* and *H. rubrum*. In addition to the 6 species found on the exposed surfaces, the shaded and cryptic surfaces had *C. monticularis* and *S. cylindricum*. *Homotrema rubrum* was the dominant species on the shaded and cryptic surfaces with a density range of 0.507 to $1.522/cm^2$, while *M. miniacea* had a range of 0.075 to $0.263cm^2$. This recruitment pattern of *H. rubrum* and *M. miniacea* on the block surfaces is opposite to the plate recruitment pattern (Table 6), which had higher *M. miniacea* densities (0.107 to $1.460/cm^2$). There was a tendency toward greater

Table 6. Average species recruitment on biofouling plates exposed at Tanguisson fringing reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Ai, *A. inhaerens;* Sc, *S. cylindricum.*

Plate surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Relative importance	Total number of specimens
Exposed upper	10	Mm	0.207	0.305	75.82	62
		Hr	0.027	0.039	9.05	8
		Cm	0.007	0.031	4.75	2
		Ai	0.370	0.415	110.37	111
	Total		0.610	0.835	200.00	183
Exposed lower		Mm	0.693	0.653	138.83	208
		Hr	0.133	0.137	27.73	40
		Cu	0.030	0.301	30.56	9
		Cm	0.010	0.019	2.88	3
	Total		0.867	1.110	200.00	260
Shaded upper		Mm	0.427	0.271	118.20	128
		Hr	0.003	0.000	0.73	1
		Cu	0.043	0.561	73.31	13
		Ai	0.017	0.038	7.76	5
	Total		0.490	0.870	200.00	147
Shaded lower		Mm	1.173	1.777	146.69	352
		Hr	0.133	0.182	14.52	34
		Cu	0.063	0.851	33.94	19
		Cm	0.007	0.036	1.74	2
		Ai	0.010	0.020	1.43	3
		Sc	0.007	0.035	1.68	2
	Total		1.373	2.902	200.00	412
Exposed upper	23	Ai	0.903	1.034	200.00	271
Exposed lower		Mm	0.107	0.056	74.43	32
		Hr	0.023	0.016	16.80	7
		Cu	0.010	0.626	93.48	3
		Ai	0.013	0.006	9.22	4
		Sc	0.007	0.014	6.07	2
	Total		0.160	0.717	200.00	48

Table 6. Continued.

Shaded upper		Mm	0.147	0.124	70.83	44
		Hr	0.017	0.014	8.04	5
		Cu	0.043	1.082	95.87	13
		Cm	0.007	0.124	11.70	2
		Ai	0.023	0.052	13.56	7
	Total		0.237	1.395	200.00	71
Shaded lower		Mm	1.460	1.074	162.74	438
		Hr	0.067	0.076	9.18	20
		Cu	0.030	0.300	21.49	9
		Cm	0.003	0.015	1.21	1
		Ai	0.003	0.007	0.66	1
		Sc	0.013	0.059	4.73	4
	Total		1.577	1.531	200.00	473
Exposed upper	30	Ai	1.733	1.297	200.00	520
Exposed lower		Mm	0.123	0.133	170.34	37
		Hr	0.017	0.018	23.02	5
		Sc	0.003	0.007	6.64	1
	Total		0.143	0.158	200.00	43
Shaded upper		Mm	0.107	0.049	137.52	32
		Hr	0.020	0.016	34.07	6
		Cu	0.003	0.007	10.66	1
		Sc	0.007	0.011	17.74	2
	Total		0.137	0.083	200.00	41
Shaded lower		Mm	1.110	1.252	188.02	333
		Hr	0.040	0.029	5.60	12
		Cu	0.010	0.056	5.02	3
		Sc	0.007	0.011	1.36	2
	Total		1.167	1.348	200.00	350

Table 7. Average species recruitment on concrete blocks exposed at Tanguisson fringing reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Ai, *A. inhaerens;* Sc, *S. cylindricum;* Ps, *P. squamiformis*. Two blocks were recovered from each depth.

Block surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Frequency of species occurrence	Relative importance	Total number of specimens
Exposed	10	Hr	0.037	0.006	0.125	72.0	5
		Cu	0.007	0.036	0.025	24.5	1
		Ai	0.084	0.158	0.200	183.1	11
		Ps	0.007	0.007	0.025	20.4	1
	Total		0.135	0.207	0.375	300.0	18
Shaded	10	Mm	0.207	0.049	0.350	76.4	21
		Hr	0.507	0.508	0.500	153.1	43
		Cu	0.049	0.194	0.175	44.0	5
		Cm	0.019	0.121	0.050	23.0	2
		Ai	0.012	0.002	0.025	3.5	1
	Total		0.794	0.874	1.100	300.0	72
Cryptic	10	Mm	0.075	0.199	0.175	47.3	7
		Hr	0.657	0.858	0.700	218.6	58
		Cu	0.012	0.109	0.025	10.4	1
		Ai	0.051	0.057	0.100	24.7	5
	Total		0.795	1.223	1.000	300.0	74
Exposed	23	Mm	0.020	0.066	0.050	12.7	2
		Hr	0.018	0.018	0.050	13.1	2
		Cu	0.018	0.947	0.025	49.2	2
		Ai	0.351	0.739	0.375	195.6	37
		Ps	0.030	0.280	0.075	29.5	3
	Total		0.437	2.050	0.575	300.0	46
Shaded	23	Mm	0.182	0.208	0.275	38.9	13
		Hr	1.266	1.527	0.975	203.4	89
		Cu	0.056	0.623	0.050	32.7	4
		Cm	0.014	0.078	0.025	6.0	1
		Sc	0.073	0.077	0.125	16.7	5
		Ps	0.014	0.001	0.025	2.3	1
	Total		1.602	2.512	1.475	300.0	113
Cryptic	23	Mm	0.263	0.152	0.325	37.0	16
		Hr	1.522	1.948	1.000	182.7	92
		Cu	0.182	2.209	0.275	78.1	11
		Cm	0.016	0.016	0.025	2.3	1
	Total		1.983	4.325	1.625	300.0	120

Table 7. Continued.

Exposed	30	Mm	0.008	0.007	0.025	15.0	1
		Hr	0.016	0.004	0.050	20.0	2
		Ai	0.152	0.340	0.150	265.0	19
		Total	0.176	0.351	0.225	300.0	22
Shaded	30	Mm	0.163	0.285	0.325	64.5	14
		Hr	0.955	0.901	0.950	225.2	82
		Ps	0.024	0.074	0.050	10.3	2
		Total	1.141	1.260	1.325	300.0	98
Cryptic	30	Mm	0.174	0.090	0.325	46.4	14
		Hr	0.939	1.075	0.925	238.5	76
		Cu	0.013	0.063	0.025	7.4	1
		Cm	0.013	0.025	0.025	4.0	1
		Ps	0.012	0.006	0.025	3.7	1
		Total	1.151	1.259	1.325	300.0	93

total surface coverage on the cryptic surfaces, which had a range of 1.259 to 4.325%.

The concrete blocks recovered from Luminao barrier reef (Table 8) had lower foraminiferal fouling than the fringing reef blocks. The exposed surfaces at 6 and 12m had no foraminiferal recruitment, and there were only low average densities of *A. inhaerens* at 24m (0.012/cm^2) and 36m (0.044/cm^2). The shaded and cryptic surfaces were fouled by *M. miniacea, H. rubrum, C. utricularis, C. monticularis, S. cylindricum* and *G. vesicularis*. The dominant species was *M. miniacea*, with a density range of 0.151 to 0.522/cm^2. *Homotrema rubrum* had an average density range of 0.005 to 0.191/cm^2 with the higher densities on the cryptic surfaces. The recruitment of these species to the plates (Table 5) was too sporadic to establish a pattern; however, there was greater recruitment of *H. rubrum*. The total surface coverage on the 6m shaded and cryptic block surfaces (1.689 and 4.229%) was higher than similar surfaces of the 12 to 36m blocks (0.277 to 1.290%).

Coral community plates (Table 9) and blocks (Table 10) exposed at 24m were fouled by 7 species: *M. miniacea, H. rubrum, C. utricularis, A. inhaerens, P. squamiformis, S. rubrum* and *G. vesicularis*. Species densities were low except for *A. inhaerens*. Its recruitment densities on upper plate surfaces were 1.443 to 3.410/cm^2, with high surface coverages (2.521 to 6.692%). *Miniacina miniacea* occurred on lower plate surfaces with a mean density range of 0.030 to 0.287/cm^2. *Sporadotrema rubrum* recruited to the Agat Bay plate sets but not to the Facpi Point plate sets. *Homotrema rubrum* recruited to the shaded and cryptic Facpi Point block surfaces but not to the Agat Bay block surfaces. *M. miniacea* was found on all surfaces with the highest density on a cryptic surface.

Table 8. Average species recruitment on concrete blocks exposed at Luminao barrier reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Sc, *S. cylindricum;* Ai, *A. inhaerens.* Two blocks were recovered from 6m, 4 blocks from 12 and 24m, and 3 blocks from 36m.

Block surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Frequency of species occurrence	Relative importance	Total number of specimens
Exposed	6	none					
Shaded	6	Mm	0.151	0.371	0.325	142.0	17
		Hr	0.007	0.030	0.025	44.5	1
		Cu	0.109	1.288	0.150	113.5	12
	Total		0.267	1.689	0.500	300.0	30
Cryptic	6	Mm	0.522	1.526	0.525	152.3	40
		Hr	0.191	0.458	0.275	78.0	15
		Cu	0.106	1.510	0.175	55.7	8
		Cm	0.028	0.736	0.050	14.0	2
	Total		0.847	4.229	1.025	300.0	65
Exposed	12	none					
Shaded	12	Mm	0.362	0.333	0.425	251.8	62
		Hr	0.029	0.028	0.050	8.5	4
		Cu	0.033	0.097	0.075	39.7	6
	Total		0.424	0.458	0.550	300.0	72
Cryptic	12	Mm	0.311	0.360	0.400	274.7	63
		Hr	0.005	0.001	0.015	2.7	1
		Cu	0.011	0.033	0.025	22.6	2
	Total		0.327	0.394	0.440	300.0	66
Exposed	24	Ai	0.012	0.016	0.050	300.0	4
Shaded	24	Mm	0.289	0.528	0.490	227.3	65
		Hr	0.009	0.017	0.025	11.1	2
		Cu	0.023	0.095	0.065	26.1	4
		Sc	0.035	0.074	0.050	35.5	5
	Total		0.356	0.714	0.630	300.0	76
Cryptic	24	Mm	0.446	0.743	0.675	242.9	88
		Hr	0.056	0.112	0.100	25.1	9
		Cu	0.031	0.129	0.075	27.6	6
		Sc	0.014	0.044	0.015	4.4	2
	Total		0.547	1.028	0.865	300.0	105
Exposed	36	Ai	0.044	0.125	0.120	300.0	9
Shaded	36	Mm	0.284	0.257	0.285	278.7	49
		Hr	0.018	0.009	0.025	13.0	3
		Sc	0.006	0.011	0.015	8.3	1
	Total		0.308	0.277	0.325	300.0	53
Cryptic	36	Mm	0.422	0.994	0.600	212.9	63
		Hr	0.059	0.061	0.150	32.8	9
		Cu	0.014	0.044	0.035	7.7	2
		Sc	0.077	0.191	0.135	46.6	8
	Total		0.572	1.290	0.920	300.0	82

Table 9. Species recruitment on biofouling plates exposed at Agat Bay and Facpi Point coral community environments. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Ai, *A. inhaerens;* Ps, *P. squamiformis;* Sr, *S. rubrum.*

Plate surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Relative importance	Total number of specimens
Exposed upper	24	Cu	0.010	0.338	9.06	3
		Ai	1.443	2.521	148.33	433
		Ps	0.067	0.056	5.33	20
		Ar	0.177	1.070	37.27	53
	Total		1.697	3.985	200.00	509
Exposed lower		Mm	0.040	0.040	172.68	12
		Hr	0.007	0.006	27.32	2
	Total		0.047	0.046	200.00	14
Shaded upper		Cu	0.007	0.046	2.02	2
		Ai	1.657	2.296	170.38	497
		Ps	0.063	0.061	5.56	19
		Sr	0.160	0.377	22.04	48
	Total		1.887	2.780	200.00	566
Shaded lower		Mm	0.030	0.073	175.21	9
		Cu	0.003	0.001	10.84	1
		Sr	0.003	0.004	13.95	1
	Total		0.037	0.078	200.00	11
Exposed upper	24	Ai	3.410	6.692	200.00	1023
	Total		3.410	6.692	200.00	1023
Exposed lower		Mm	0.043	0.094	162.33	13
		Hr	0.010	0.022	37.67	3
	Total		0.053	0.115	200.00	16
Shaded upper		Mm	0.023	0.047	186.24	7
		Hr	0.003	0.001	13.76	1
	Total		0.027	0.048	200.00	8
Shaded lower		Mm	0.287	0.154	154.72	86
		Hr	0.047	0.046	34.85	14
		Cu	0.003	0.021	10.43	1
	Total		0.337	0.221	200.00	101

Table 10. Average species recruitment on concrete blocks exposed at Facpi Point and Agat Bay coral community environments. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Ai, *A. inhaerens;* Ps, *P. squamiformis;* Cu, *C. utricularis;* Sr, *S. rubrum.* Two blocks were recovered from each site.

Block surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Frequency of species occurrence	Relative importance	Total number of specimens
Exposed	24	Mm	0.018	0.004	0.050	11.6	2
		Ai	0.254	0.550	0.425	266.4	29
		Ps	0.018	0.085	0.050	22.0	2
		Total	0.290	0.639	0.525	300.0	33
Shaded	24	Mm	0.044	0.042	0.125	47.4	5
		Hr	0.308	0.291	0.575	241.3	35
		Ai	0.009	0.018	0.025	11.3	1
		Total	0.361	0.351	0.725	300.0	41
Cryptic	24	Mm	0.077	0.072	0.225	81.1	9
		Hr	0.241	0.250	0.500	218.9	28
		Total	0.318	0.322	0.725	300.0	37
Exposed (Agat)	24	Cu	0.074	1.623	0.200	82.1	8
		Sr	0.312	0.847	0.500	170.9	34
		Ai	0.054	0.085	0.150	47.0	6
		Total	0.440	2.555	0.850	300.0	48
Shaded	24	Mm	0.073	0.065	0.200	300.0	10
Cryptic	24	- Surfaces were abraded, no analyses					

Planogypsina squamiformis (Facpi Point) and *H. rubrum* (Agat Bay) were found only on exposed surfaces with average densities on 0.018/cm^2 and 0.312/cm^2, respectively. The cryptic surfaces of the Agat Bay blocks were severely damaged by abrasion and were not quantitatively analyzed.

The lagoon environment plates exposed at 6, 12, 18, 24, and 30m on Western Shoals patch reef showed greatly reduced fouling by 4 species: *A. inhaerens, P. squamiformis, G. vesicularis* and *C.* cf. *proteiformis* (Table 11). The highest species densities occurred on exposed upper plate surfaces for all depths with a mean total density range of 0.320 to 3.040/cm^2. *Acervulina inhaerens* had higher densities and surface coverage on upper plate surfaces, while *P. squamiformis* was more prevalent on the lower surfaces. No specimens of *H. rubrum* or *M. miniacea* occurred on the plates or blocks (Table 12); however, they were quantified on the bulk substratum samples, as was *C. utricularis* (Table 13). The blocks recovered from the lagoon environment had low species recruitment on exposed surfaces from 6 to 24m (Table 12). Densities of the dominant foraminiferan *A. inhaerens* ranged from 0.033/cm^2(6m) to 0.291/cm^2(12m). *Planogypsina squamiformis* occurred at 12 and 18m with average densities of 0.024/cm^2 and 0.022/cm^2, respectively. The 30m blocks, which had no foraminiferal recruitment, were covered on exposed surfaces by a veneer of silty clay, while the shaded surfaces were covered with small bivalves.

All natural substrata collected from a coral community at Facpi Point and a protected fringing reef at Rizal (Table 13), as well as from Tanguisson fringing and Luminao barrier reefs (Table 14), had adherent foraminiferal species. The principal species in the cryptic and shaded habitats of these environments were *M. miniacea, H. rubrum* and *C. utricularis*. Substrata collected from the lagoon environment deeper

Table 11. Average species recruitment on biofouling plates exposed at Western Shoals patch reef. The species abbreviations are as follows: Ai, *A. inhaerens;* Ps, *P. squamiformis;* Cp, *C.* cf. *proteiformis.*

Plate surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Relative ranking	Total number of specimens
Exposed upper	6	Ai	0.310	0.175	194.66	93
		Ps	0.010	0.004	5.34	3
		Total	0.320	0.179	200.00	96
Exposed lower		Ai	0.013	0.012	30.10	4
		Ps	0.103	0.051	169.90	31
		Total	0.117	0.063	200.00	35
Shaded upper		Ai	0.253	0.364	184.72	76
		Ps	0.023	0.027	15.28	7
		Total	0.277	0.390	200.00	83
Shaded lower		Ai	0.010	0.005	48.46	3
		Ps	0.033	0.015	151.54	10
		Total	0.043	0.020	200.00	13
Exposed upper	12	Ai	2.890	4.223	190.72	867
		Ps	0.143	0.188	8.98	43
		Cp	0.007	0.004	0.30	2
		Total	3.040	4.414	200.00	912
Exposed lower		Ai	0.017	0.008	131.82	5
		Ps	0.007	0.005	68.18	2
		Total	0.023	0.014	200.00	7
Shaded upper		Ai	0.057	0.035	200.00	17
Shaded lower		none				
Exposed upper	18	Ai	0.593	0.497	120.42	178
		Ps	0.480	0.266	79.58	144
		Total	1.073	0.763	200.00	322
Exposed lower		Ps	0.023	0.001	200.00	7
Shaded upper		Ai	0.023	0.017	169.32	7
		Ps	0.003	0.004	30.68	1
		Total	0.027	0.021	200.00	8
Shaded lower		none				

Table 11. Continued.

Exposed upper	24	Ai	0.743	0.348	164.69	223
		Ps	0.170	0.070	35.31	51
		Total	0.913	0.418	200.00	274
Exposed lower		Ai	0.003	0.002	19.17	1
		Ps	0.070	0.010	180.83	21
		Total	0.073	0.011	200.00	22
Shaded upper		Ai	0.033	0.002	112.09	10
		Ps	0.057	0.004	87.91	17
		Total	0.090	0.017	200.00	27
Shaded lower		Ps	0.330	0.015	200.00	99
Exposed upper	30	Ai	0.403	0.172	141.09	121
		Ps	0.160	0.075	58.91	48
		Total	0.563	0.247	200.00	169
Exposed lower		Ps	0.027	0.001	200.00	8
		Total	0.027	0.001	200.00	8
Shaded upper		Ai	0.040	0.032	200.00	12
Shaded lower		none				

Table 12. Average species recruitment on concrete blocks exposed at Western Shoals patch reef. The species abbreviations are as follows: Ai, *A. inhaerens;* Ps, *P. squamiformis*. There were 2 blocks recovered from each depth.

Block surface	Depth (m)	Species	Species density (no./cm^2)	Species coverage (%)	Frequency of occurrence	Relative importance	Total number of specimens
Exposed	6	Ai	0.033	0.076	0.150	300.0	3
Shaded	6	none					
Cryptic	6	none					
Exposed	12	Ai	0.291	0.331	0.275	300.0	30
Shaded	12	none					
Cryptic	12	none					
Exposed	18	Ai	0.144	0.249	0.325	260.0	18
		Ps	0.024	0.036	0.050	40.0	3
	Total		0.168	0.285	0.375	300.0	21
Shaded	18	none					
Cryptic	18	none					
Exposed	24	Ai	0.046	0.171	0.175	224.0	7
		Ps	0.022	0.147	0.075	76.0	3
	Total		0.068	0.318	0.250	300.0	10
Shaded	24	none					
Cryptic	24	none					
Exposed	30	none					
Shaded	30	none					
Cryptic	30	none					

Table 13. Average species recruitment on bulk natural substrata from Facpi Point, Rizal and Western Shoals. The Species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Sc, *S. cylindricum;* Sr, *S. rubrum.*

Location	Depth (m)	Species	Density (no./cm^2)	Coverage (%)	Frequency of occurrence	Relative importance	Average no. of specimens
Facpi Point	24	Mm	0.090	0.047	0.200	243.5	6
(coral		Hr	0.023	0.010	0.050	56.0	2
community)		Total	0.113	0.057	0.250	300.0	8
Rizal	1	Hr	0.230	0.414	0.340	247.5	13
(fringing		Cu	0.072	0.174	0.125	52.5	8
reef)		Total	0.302	0.588	0.465	300.0	21
	2	Mm	0.078	0.118	0.150	20.0	3
		Hr	0.544	0.880	0.750	121.0	21
		Cu	0.673	1.470	0.750	159.0	26
		Total	1.295	2.468	1.650	300.0	49
	3	Mm	0.091	0.044	0.165	30.0	3
		Hr	0.422	0.517	0.480	159.8	16
		Cu	0.453	1.227	0.400	101.4	15
		Cm	0.008	0.005	0.015	3.6	1
		Sc	0.011	0.094	0.015	5.2	1
		Total	0.985	1.887	1.075	300.0	36
	5	Mm	0.265	0.229	0.350	210.0	15
		Hr	0.071	0.076	0.150	71.0	4
		Cu	0.018	0.018	0.050	19.0	1
		Total	0.353	0.322	0.550	300.0	20
	7	Mm	0.162	0.075	0.300	56.0	7
		Hr	0.139	0.118	0.200	48.0	6
		Cu	0.462	0.902	0.550	196.0	20
		Total	0.762	1.094	1.050	300.0	33
	8	Mm	0.164	0.043	0.300	66.0	8
		Hr	0.123	0.156	0.250	68.0	6
		Cu	0.308	0.593	0.350	166.0	15
		Total	0.596	0.793	0.900	300.0	29
	9	Mm	0.215	0.076	0.400	176.2	12
		Hr	0.072	0.031	0.150	64.4	4
		Cu	0.036	0.053	0.100	59.4	2
		Total	0.323	0.160	0.650	300.0	18
	12	Mm	0.087	0.055	0.300	260.0	6
		Hr	0.015	0.007	0.050	40.0	1
		Total	0.102	0.062	0.350	300.0	7

Table 13. Continued.

Western Shoals (lagoon, patch reef)	1-2	Mm	0.021	0.009	0.075	136.2	2
		Hr	0.025	0.068	0.075	163.8	2
	Total		0.046	0.077	0.150	300.0	4
	2-3	Mm	0.061	0.093	0.100	132.7	4
		Hr	0.041	0.038	0.100	113.1	3
		Cu	0.005	0.045	0.015	23.6	1
		Sr	0.004	0.007	0.015	30.6	1
	Total		0.111	0.183	0.230	300.0	9
	6	Hr	0.016	0.003	0.050	300.0	1
	Total		0.016	0.003	0.050	300.0	1
	12	Mm	0.025	0.057	0.100	182.6	2
		Hr	0.012	0.004	0.050	57.6	1
		Cu	0.012	0.006	0.050	59.8	1
	Total		0.050	0.068	0.200	300.0	4
	18	Hr	0.016	0.004	0.050	300.0	1
	Total		0.016	0.004	0.050	300.0	1
	24	none					
	30	none					

Table 14. Average species recruitment on bulk substrata from Luminao barrier reef and Tanguisson fringing reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Sc, *S. cylindricum.*

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

Table 14. Continued.

Tanguisson (fringing reef)	2	Mm	0.367	1.195	0.450	104.7	16
		Hr	0.367	0.416	0.450	91.9	16
		Cu	0.046	0.097	0.100	17.0	2
		Cm	0.023	0.297	0.050	12.1	1
		Sc	0.023	4.094	0.050	74.3	1
	Total		0.825	6.100	1.100	300.0	37
	3	Mm	0.059	0.045	0.150	56.3	3
		Hr	0.103	0.286	0.330	184.7	13
		Cu	0.035	0.077	0.085	51.4	2
		Sc	0.006	0.011	0.015	7.6	1
	Total		0.203	0.419	0.580	300.0	19
	10	Mm	0.277	0.173	0.435	206.5	15
		Hr	0.067	0.065	0.150	73.8	4
		Cu	0.012	0.018	0.035	12.8	1
		Cm	0.007	0.013	0.015	6.9	1
	Total		0.363	0.269	0.635	300.0	21
	20	Mm	0.285	0.130	0.400	109.4	15
		Hr	0.095	0.062	0.100	32.7	5
		Cu	0.076	0.454	0.200	51.2	4
		Cm	0.019	0.246	0.050	16.2	1
		Sc	0.038	3.502	0.050	90.5	2
	Total		0.513	4.394	0.800	300.0	28

than 20m had no adherent foraminiferal species; and there were only low densities of *M. miniacea, C. utricularis, H. rubrum* and *S. rubrum* on the shallower substrata (Table 13). The densities of *H. rubrum* and *M. miniacea* were similar on lagoon substrata from 1 to 3m, with a mean range of 0.012 to 0.061/cm^2. The dominant species on the Rizal substrata from 1 to 3m were *H. rubrum* and *C. utricularis,* which had density ranges of 0.067 to 0.832/cm^2 and 0.033 to 0.998/cm^2, respectively. *Miniacina miniacea* became prominent on substrata from 5 to 12m with subsequent decreases in the density of *H. rubrum. Carpenteria utricularis* decreased in density at 9m (0.036/cm^2) and did not occur on the 12m substrata. *Carpenteria monticularis* and *S. cylindricum* occurred rarely on 3m substrata. Deep shaded cavities of the reef margin zone (1-3m) were visually inspected; *C. utricularis* and *S. cylindricum* covered a major portion of the substratum surfaces.

Tanguisson fringing reef natural substrata from 2 to 20m had *M. miniacea, H. rubrum* and *C. utricularis* as the primary species with low densities of *C. monticularis* and *S. cylindricum* (Table 14). *Homotrema rubrum* was denser at 2 to 3m (0.115 to 0.367/cm^2) than at 10 and 20m (0.049 to 0.095/cm^2). *Miniacina miniacea* was equally dense on substrata from 2, 10 and 20m (0.277 to 0.367/cm^2), but was less dense at 3m (0.059/cm^2). *Carpenteria utricularis* had similar lower densities and surface coverage on all substrata from 2 to 20m (0.020 to 0.076/cm^2). Cavities in the reef margin, particularly in the vicinity of the Tanguisson power plant outfall, were visually inspected; the vertical substrata were heavily encrusted with large clusters of *S. cylindricum* (1 to 15cm in diameter and 0.5 to 4cm in height). Additionally, large specimens of *M. miniacea* and *H. rubrum* (0.5 to 2cm diameter) grew on living

S. cylindricum, with *C. utricularis* and *C. monticularis* common on the upper "ceiling" substratum of the cavities. Species surface coverage of *S. cylindricum* was relatively high on 2 and 20m substrata (4.094 and 2.502%).

Foraminiferans colonizing the Luminao barrier reef natural substrata were similar in species composition and density to those of the fringing reef substrata (Table 14). The average densities of *M. miniacea* and *H. rubrum* were similar at a given depth from 7 to 20m, with increased densities and decreased surface coverage at the deeper depths. At 27 and 55m there were higher densities of *M. miniacea* (0.123 and 0.210/cm^2) than *H. rubrum* (0.015 and 0.035/cm^2). External test variations and coloration of *M. miniacea* and *H. rubrum* varied consistently within 2 general depth zones: specimens from the reef margin to 9m had robust or globose tests and darker red hues, while specimens from 12m to 55m generally had branching tests with light red to white hues. *Sporadotrema cylindricum* was uncommon on all natural substrata, even those of the barrier reef margin. *Carpenteria monticularis* occurred in low densities on substrata from 12 to 55m.

Reef zones at Tanguisson fringing reef and Luminao barrier reef were transected to determine the major habitat types and subsequent standing crops of adherent foraminiferans. Up to 8 habitat types which could provide surface area for foraminiferans were quantitatively sampled within three zones at each site: reef flat, upper reef slope at 6m, and the seaward edge of the first submarine terrace at 12m (Table 15). Total habitat density ranged from 2.79/m^2 (Tanguisson; reef flat) to 6.71/m^2 (Luminao; 12m).

Table 15. Density, coverage, frequency of occurrence and relative ranking of transected habitat substratum types. The symbol RF is the abbreviation for reef flat.

Habitat Types	Habitat Density (no./cm^2)						Habitat Coverage (%)					
	TANGUISSON			LUMINAO			TANGUISSON			LUMINAO		
	RF	6m	12m	RF	6m	12m	RF	6m	12m	RF	6m	12m
Living coral branching (LCB)	----	1.03	0.47	1.03	0.76	1.38	----	6.59	2.84	15.81	3.76	6.26
Living coral massive (LCM)	0.09	0.09	0.47	0.57	0.25	1.03	0.35	0.34	3.02	4.21	0.90	4.72
Dead coral branching (DCB)	----	0.09	0.39	0.11	0.08	----	----	0.52	2.32	1.82	0.53	----
Dead coral tabulate (DCT)	----	0.17	----	0.23	----	0.17	----	4.30	----	4.10	----	1.74
Exposed knob (EXK)	0.17	0.77	1.18	0.11	0.25	0.52	1.36	4.90	4.75	0.29	2.34	2.51
Rubble (R)	1.83	----	----	0.46	1.09	0.69	9.59	----	----	5.28	5.15	4.61
Cavity exposed (CAEX)	----	0.17	0.16	----	0.08	1.72	----	0.48	0.99	-----	0.34	7.24
Cavity cryptic (CAL)	0.70	0.52	0.47	1.03	0.59	1.20	4.77	2.33	1.74	10.13	3.56	4.27
Total Habitat Density	2.79	2.84	3.14	3.54	3.10	6.71						
Habitat Coverage, %							16	19	16	42	17	31

	Habitat Frequency of Occurrence						Habitat Relative Ranking					
	TANGUISSON			LUMINAO			TANGUISSON			LUMINAO		
	RF	6m	12m	RF	6m	12m	RF	6m	12m	RF	6m	12m
LCB	---	0.9	0.4	0.6	0.5	0.6	---	109	48	91	68	67
LCM	0.1	0.1	0.3	0.5	0.3	0.3	11	9	46	46	26	44
DCB	---	0.1	0.5	0.1	0.1	---	---	10	47	12	10	--
DCT	---	0.2	---	0.2	---	0.1	---	37	--	24	--	13
EXK	0.2	0.5	0.8	0.1	0.3	0.2	27	74	99	8	35	25
R	0.9	---	---	0.4	0.6	0.3	178	---	--	42	91	39
CAEX	---	0.1	0.2	---	0.1	0.3	---	13	19	--	9	62
CAL	0.5	0.4	0.4	0.6	0.5	0.4	84	48	41	77	61	50

Statistically, there were no differences in habitat types within or between the fringing and barrier reef zones; however, the habitat density, coverage and relative ranking were statistically different between zones and reefs at the 0.05 level as tested by SPSS ANOVA (Statistical Package for the Social Sciences, analysis of variance). The frequency of habitat occurrence was statistically different within zones but not between the fringing and barrier reefs. The barrier reef 12m transect had a significantly higher total habitat density [$F=4.995$; $F_{.05(7,2)}=4.74$] (Sokal and Rohlf, 1969). All the transects had massive living corals, exposed knobs and cryptic cavities. The barrier reef flat had 7 habitat types, compared with 4 on the fringing reef flat. The total habitat surface coverage ranged from 16% (Tanguisson; reef flat and 12m) to 42% (Luminao; reef flat). Living coral and cryptic cavities were the most frequently occurring of the habitat types [$F=8.49$; $F_{.05(7,2)}=4.74$].

Transect substrata from Tanguisson fringing reef (Table 16) and Luminao barrier reef (Table 17) were analyzed for species occurrence in relation to density, surface coverage, frequently of occurrence and relative ranking by SPSS ANOVA for habitats, zones and sites. *Homotrema rubrum* was the dominant species on habitats from both the fringing and barrier reef flats. The density of *H. rubrum* on reef flat substrata ranged from 0.008/cm^2 (Tanguisson, Living coral massive) to 0.410/cm^2 (Luminao, rubble). Its surface coverage and frequency of occurrence were high on the reef flat habitats, with ranges of 0.301 to 2.118% and 0.050 to 0.410%, respectively. The relative importance of *H. rubrum,* calculated on the basis of density, surface coverage and frequency, was greatly reduced on habitat types from the fringing reef 6 and 12m transects.

Table 16. Average species density, coverage, frequency of occurrence and relative ranking for transected habitat substrata from the Tanguisson fringing reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Sc, *S. cylindricum;* Sr, *S. rubrum.* The symbol RF is the abbreviation for reef flat. See Table 15 for explanation of habitat type symbols.

Habitat Type	Species	Species Density (no./cm^2)			Species Coverage (%)			Frequency Of Species Occurrence			Relative Species Ranking		
		RF	6m	12m	RF	6m	12m	RF	6m	12m	RF	6m	12m
LCB	Mm		.078	.051		.098	.115		.170	.130		147.2	168.7
	Hr		.029	.032		.126	.303		.075	.075		62.7	65.7
	Cu		.020	.013		.180	.097		.050	.040		67.3	34.5
	Cm		.002			.003			.005			3.7	
	Sc		.003	.013		.012	.036		.010	.040		19.1	31.1
LCM	Mm		.118	.103		.172	.085		.300	.180		126.0	110.6
	Hr	.008	.017	.034	.338	.002	.108	.050	.050	.080	180.5	15.5	67.1
	Cu		.017	.034		.106	.104		.050	.030		32.0	24.0
	Cm		.017	.003		.008	.001		.050	.010		16.5	2.7
	Sc		.068	.054		.363	.202		.150	.140		110.0	95.6
	Sr	.008			.082			.050			119.5		
DCB	Mm		.297	.134		.375	.546		.450	.250		203.2	125.3
	Hr		.112	.100		.193	.538		.250	.210		96.8	97.5
	Cu			.020			.134			.040			35.2
	Cm			.007			.040			.020			6.0
	Sc			.015			.231			.090			36.0
DCT	Mm		.347			.447			.525			88.5	
	Hr		.243			.277			.350			64.8	
	Cu		.220			1.808			.350			116.0	
	Cm		.058			.252			.100			18.8	
	Sc		.023			.240			.050			11.9	

Table 16. Continued.

Habitat Type	Species	Species Density (no./cm^2)			Species Coverage (%)			Frequency Of Species Occurrence			Relative Species Ranking		
		RF	6m	12m	RF	6m	12m	RF	6m	12m	RF	6m	12m
EXK	Mm	.007	.088	.086	.007	.117	.162	.025	.190	.170	21.8	151.6	120.7
	Hr	.188	.027	.035	1.922	.023	.090	.250	.070	.100	175.9	55.3	73.4
	Cu	.079	.030	.027	.675	.144	.215	.075	.080	.070	42.9	88.7	58.2
	Cm		.002	.005		.004	.039		.010	.010		4.4	4.6
	Sc			.024			.297			.060			43.2
	Sr	.014			.045			.050			58.8		
R	Mm	.008			.115			.020			20.8		
	Hr	.057			.632			.120			122.0		
	Cu	.013			.232			.030			31.0		
	Cm	.002			.010			.005			2.7		
	Sc	.002			.059			.005			8.2		
	Sr	.065			.340			.115			115.3		
CAEX	Mm		.110	.251		.391	.189		.275	.425		164.3	131.6
	Hr		.124	.054		.235	.050		.150	.150		73.8	43.1
	Cu		.049	.076		.179	.421		.075	.200		35.1	90.5
	Cm		.017	.028		.065	.218		.050	.075		26.8	34.8
CAL	Mm	.002	.227	.273	.004	.368	.259	.010	.370	.320	4.0	174.8	179.6
	Hr	.231	.077	.060	2.118	.069	.133	.230	.160	.150	254.0	44.2	69.9
	Cu	.002	.036	.023	.259	.262	.114	.070	.100	.070	37.0	44.5	32.7
	Cm		.007	.008		.021	.048		.020	.025		5.1	8.8
	Sc	.004	.024	.009	.004	.119	.017	.010	.070	.025	2.9	31.4	9.0
	Sr	.002			.004			.010			2.1		

Table 17. Average species density, coverage, frequency of occurrence and relative ranking for transected habitat substrata from Luminao barrier reef. The species abbreviations are as follows: Mm, *M. miniacea;* Hr, *H. rubrum;* Cu, *C. utricularis;* Cm, *C. monticularis;* Sc, *S. cylindricum;* Sr, *S. rubrum.* The symbol RF is the abbreviation for reef flat. See Table 15 for explanation of habitat type symbols.

Habitat	Species	Species Density ($no./cm^2$)			Species Coverage (%)		
		RF	6m	12m	RF	6m	12m
LCB	Mm	.006	.073	.073	.005	.098	.094
	Hr	.090	.096	.072	.438	.121	.114
	Cu	.025	.011	.006	.041	.170	.128
LCM	Mm		.121	.083		.115	.059
	Hr	.103	.008	.090	.429	.008	.188
	Cu	.047	.057	.028	.301	.177	.064
	Cm	.003			.013		
DCB	Mm	.087	.197		.356	.269	
	Hr	.173	.016		1.370	.016	
DCT	Mm	.008		.462	.004		.252
	Hr	.145		.292	.471		.193
	Cu	.017		.194	.121		.382
EXK	Mm		.122	.074		.258	.040
	Hr		.177	.102		.280	.154
	Cu		.049	.034		.337	.062
	Sr		.022			.061	
R	Mm	.028	.058	.211	.051	.101	.195
	Hr	.277	.022	.221	1.398	.032	.264
	Cu	.148	.005	.141	1.591	.056	.492
	Cm	.004		.024	.245		.075
	Sc		.003			.007	
	Sr		.022			.044	
CAEX	Mm		.202	.100		.396	.068
	Hr		.037	.220		.476	.540
	Cu		.037	.047		.118	.224
	Cm		.018	.012		.238	.122
	Sr		.055			.090	
CAL	Mm	.019	.273	.111	.017	.399	.159
	Hr	.328	.090	.180	1.217	.292	.575
	Cu	.118	.072	.123	1.246	.248	.418
	Cm	.003	.003	.026	.016	.005	.332
	Sc	.004		.003	.279		.282
	Sr		.006			.018	

Table 17. Continued.

Habitat	Species	Frequency of Species Occurrence			Relative Species Ranking		
		RF	6m	12m	RF	6m	12m
LCB	Mm	.110	.105	.170	13.4	177.0	178.9
	Hr	.155	.070	.160	201.0	93.5	96.2
	Cu	.020	.030	.020	85.6	29.5	24.9
LCM	Mm		.225	.190		159.7	101.8
	Hr	.190	.025	.200	203.6	12.2	150.8
	Cu	.110	.150	.070	83.8	128.1	47.4
	Cm	.010			12.6		
DCB	Mm	.100	.400		104.0	276.3	
	Hr	.100	.050		196.0	23.7	
DCT	Mm	.025		.600	12.6		122.2
	Hr	.175		.550	258.6		93.7
	Cu	.025		.250	28.8		84.1
EXK	Mm		.220	.150		172.9	83.8
	Hr		.250	.180		73.1	151.4
	Cu		.100	.100		46.0	64.8
	Sr		.030			8.0	
R	Mm	.090	.100	.340	23.9	121.2	98.9
	Hr	.410	.045	.360	161.6	35.9	108.8
	Cu	.275	.010	.240	104.3	20.8	78.8
	Cm	.010		.050	8.2		13.5
	Sc		.010			5.0	
	Sr		.060			117.1	
CAEX	Mm		.350	.200		142.0	74.0
	Hr		.100	.285		62.0	163.4
	Cu		.050	.110		27.1	43.2
	Cm		.050	.025		30.9	19.4
	Sr		.100			38.0	
CAL	Mm	.050	.365	.220	10.4	161.9	66.3
	Hr	.350	.200	.315	176.4	74.6	122.0
	Cu	.240	.120	.230	99.5	57.8	85.7
	Cm	.005	.005	.050	1.3	1.6	18.3
	Sc	.010		.005	12.5		7.7
	Sr		.005			4.1	

Sporadotrema rubrum was relatively important on the more exposed fringing reef flat habitats (Tanguisson: Living coral massive, rubble, exposed knob) and on similar habitats from the barrier reef 6m transect. *Miniacina miniacea* occurred in low densities with small surface coverages on reef flat substrata. It was dominant at both sites on 6m transect habitats and on the Tanguisson 12m transect habitats. Similar relative importance values were obtained for *H. rubrum* and *M. miniacea* on habitat types from the barrier reef 12m transect (Table 17). *Carpenteria utricularis* and *C. monticularis* occurred at lower densities on most habitat types at both sites. The surface coverages of *C. utricularis* was comparatively high, with the greatest percent coverage on cryptic reef flat surfaces. *Sporadotrema cylindricum* occurred in low densities with comparatively high surface coverage on fringing reef 6 and 12m habitats. This species was relatively unimportant on barrier reef habitat types.

A summary of significance levels of ANOVA F factors is shown in Table 18. Species occurrence was statistically different between habitat types, zones and reef environments. The sporadic occurrence of *S. rubrum*, *C. monticularis* and *S. cylindricum* caused this statistical variation. There was no difference in the occurrence of *H. rubrum* and *M. miniacea* between habitats, zones and reef environments. The species coverage and frequency of occurrence were statistically different between habitat types and zones. The relative importance of species was statistically different only between habitat types. The species densities between the fringing and barrier reefs were different with higher densities on the barrier reef substrata. There was a difference in surface coverage of *H. rubrum* and *M. miniacea* between reef environments which is not apparent in the average habitat coverages (Table 16 and 17).

Table 18. Summary of significance levels of ANOVA F factors from transects, blocks and fringing reef and coral mound plates. The ANOVA tables were generated with SPSS by the regression Approach.

Type Of Substrata	Species by Factor	Species Analyzed	Species Occurrence	Significance Level of Covariates F			
				Density	Coverage	Frequency	Rank
Natural	Habitat	All	0.003	NS*	0.001	0.001	0.001
	Habitat	Hr/Mm**	NS	NS	0.001	0.001	0.001
	Zone	All	0.001	NS	0.001	0.006	NS
	Zone	Hr/Mm	NS	NS	0.001	0.008	NS
	Reef	All	0.001	0.008	NS	NS	NS
	Reef	Hr/Mm	NS	0.004	0.002	NS	NS
Block	Reef	All	0.045	0.032	NS	NS	0.001
	Reef	Hr/Mm	NS	NS	NS	NS	0.001
	Depth	All	NS	NS	NS	NS	NS
	Depth	Hr/Mm	NS	0.036	NS	0.031	0.021
	Surface	All	0.001	NS	NS	NS	NS
	Surface	Hr/Mm	NS	NS	NS	NS	NS
Plate (fringing and coral mound)	Reef	All	0.007	NS	NS	—	NS
	Reef	Hr/Mm	0.013	NS	NS	—	0.001
	Depth	All	NS	NS	NS	—	NS
	Depth	Hr/Mm	NS	NS	NS	—	0.033
	Plate	All	NS	NS	NS	—	NS
	Plate	Hr/Mm	NS	NS	NS	—	NS
	Surface	All	NS	NS	NS	—	NS
	Surface	Hr/Mm	0.038	NS	NS	—	0.041

* NS: not significant at the 0.05 level with a one-tail test.
** Hr/Mm: *H. rubrum/M. miniacea*

Species recruitment, density, surface coverage, frequency of occurrence and relative ranking were assessed by SPSS ANOVA for block surfaces from fringing reef and coral mound environments (Table 18). Species recruitment was statistically different between reef environments and block illumination surfaces while species density varied only between reef environments. Recruitment of *H. rubrum* and *M. miniacea* was primarily onto shaded and cryptic block surfaces and did not differ between reef environments, depths or illumination surfaces; however, these species did differ in recruitment density, frequency of occurrence and relative importance between depths. The relative rankings of *H. rubrum* and *M. miniacea* were different between reef environments, with *H. rubrum* dominant on fringing reef blocks (Table 7) and *M. miniacea* on barrier reef (Table 8) and coral mound blocks (Table 9). Recruitment onto lagoon blocks was restricted to the exposed ambient light surface and therefore was not statistically analyzed (Table 12). *Planogypsina squamiformis, A. inhaerens,* and *S. rubrum* generally recruited to exposed or shaded block surfaces, while *C. monticularis* preferred shaded and cryptic surfaces. *Carpenteria utricularis* recruited to all surfaces with the highest surface coverages on cryptic surfaces. This trend was also apparent with *H. rubrum* and to a lesser extent *M. miniacea*.

Species recruitment, density, surface coverage and relative ranking were assessed by SPSS ANOVA for fringing and coral mound plate sets (Table 18). Species recruitment was different between reef environments but not for depth or plate exposure (shaded and exposed). *Homotrema rubrum* and *M. miniacea* recruitment onto plate surfaces (upper and lower) was significantly greater on lower surfaces. The relative importance of *H. rubrum* and *M. miniacea* varied between reef environments, depths and surfaces. *Homotrema rubrum* was relatively more important on coral mound plates while *M. miniacea* dominated fringing reef plates.

The recruitment patterns of *P. squamiformis* onto biofouling plates at Luminao barrier reef were assessed by SPSS ANOVA factor comparisons (Table 19). The surface orientation (lower, upper, toward and away) and plate type (plexiglass or PVC) did not affect species recruitment densities onto the horizontal and vertical plate sets in relation to exposure time, placement depth and plate type. Vertical PVC plates had apparently higher densities as compared with the plexiglass vertical plates. Higher species densities occurred at the greater depths and 100-day exposure period. Density recruitment of *P. squamiformis* was primarily affected by placement depth since the factors of time, plate and surface orientation and plate type in relation to recruitment density varied statistically. *Planogypsina squamiformis* densities were reduced on plates exposed for 180 days. The biofouling blocks after 1 yr of exposure had no quantified *P. squamiformis* recruitment (Table 8).

Adherent foraminiferans readily recruited to artifical biofouling surfaces and occurred on most natural substrata in fringing reef, barrier reef and coral community environments. Although adherent species were visually obvious and appeared to have extensive surface coverages, the species surface coverages were usually below 1% and rarely as great as 5%.

Table 19. Summary of significance levels of ANOVA F factors from *P. squamiformis* plate density recruitments. The ANOVA tables were generated with SPSS by the regression approach. Factor comparisons were made with density as the covariate. The significance levels are for one-tail tests.

Factors by Factors	Time (37, 77, 100, 180)	Depth (6, 12, 24, 36m)	Plates (horz, vert)	Surface (upper, lower, toward, away)	Type (plexi, PVC)
Time (days)	——	0.046	NS	NS	NS
Depth (m)	0.001	——	0.001	0.001	0.001
Plate (horz,vert)	0.030	0.036	——	0.001	0.036
Surface (direct)	NS	NS	NS	——	NS
Type (plexi,PVC)	NS	NS	NS	NS	——

* NS: not significant at the 0.05 level with one-tail test

DISCUSSION

There have been 16 species of recent foraminiferans from the Families Acervulinidae and Homotrematidae recorded in the literature for the Indo-West Pacific, of which 10 species were recorded in this study for Guam (Table 1). The three species of *Gypsina* were believed, on the basis of field observations and from morphological growth forms of cultured specimens, to be environmental form variations and were treated as a single species, *G. vesicularis*. *Sphaerogypsina globulus* does not characteristically attach to substrata and was therefore not quantified. *Sporadotrema mesentericum* and *C. raphidodendron* have been recorded only from the Indo-Malayan and Indian Ocean regions (Hofker, 1963) and were not observed on substrata on Guam. Additionally, *C. balaniformis,* which has been recorded from deeper depths (183-768m) in the Indo-West Pacific and Atlanto-East Pacific, was not observed on Guam (Table 1). *Sporadotrema rubrum* as described by Hofker (1963) and previously recorded from only the Indo-Malayan region was quantified on shallower reef environment substrata.

Planogypsina squamiformis readily recruited to artifical biofouling surfaces which were exposed for periods up to 180 days and became uncommon after longer exposure periods. This species, a species recorded from the lagoon at Funafuti (Chapman, 1901) and a new species identified by Hanzawa (1957) in Holocene limestone from Saipan, seemed to be identical. Specimens of *P. squamiformis* on concrete blocks which had been exposed for 1 yr were extensively eroded and overgrown. The largest specimens of *P. squamiformis* (1cm diameter) were measured on biofouling plates exposed at Luminao barrier reef for 100 days. Specimens were generally much smaller with diameters of about 1mm. *Acervulina inhaerens* and *G. vesicularis* were generally associated with *P. squamiformis* but they were also recorded for longer recruitment periods and on natural substrata. These species were found primarily on exposed surfaces, particularily those surfaces with reduced algal growth. Cultured specimens of *A. inhaerens, G. vesicularis* and *P. squamiformis* were readily destroyed when they became overgrown with algae. *Gypsina vesicularis* was widely distributed on substrata from most coral reef environments seaward of the reef margin. It readily recruited to artifical biofouling surfaces in fringing reef and coral community environments. Tanguisson fringing reef plates exposed for 1 yr at 30m were fouled by *G. vesicularis* with 25 to 50% encrustation of the exposed and shaded plate surfaces; however, much of this encrustation was non-living material. There was reduced recruitment of *G. vesicularis* in lagoon and barrier reef environments, partly as a result of the reduced exposure periods in these environments.

Miniacina miniacea, H. rubrum and *C. utricularis* were the characteristic foraminiferans adherent on substrata from the various coral reef environments. *Carpenteria utricularis* occurred on most substratum types from all the examined reef environments (fringing barrier, lagoon and coral community). There was a tendency for *C. utricularis* to recruit to shaded and cryptic surfaces with generally higher surface coverage on these surfaces. The largest specimens of *C. utricularis* occurred on substrata in deep overhanging crevices in fringing reef margins. Although *H. rubrum* was quantified from all the reef environments, the density and surface coverage of specimens were distributed by depth zonation on natural substrata. *Homotrema rubrum* was the dominant species on reef flat substrata and showed no habitat preference, nor was there a difference in occurrence between fringing and barrier reef flats. On reef flat substrata, it had an encrusting or pseudo-ramose growth form and subsequently greater surface coverage (Table 16 and 17). The density and surface coverage of *H. rubrum* decreased seaward of the reef margin. The recruitment of *H. rubrum* was particularily low on the 6m transect habitat types as compared with reef flat and 12m recruitment densities (Tables 16 and 17) and the bulk natural substrata from similar depths (Table 14). Dredged substrata (150-400m) were fouled extensively by *H. rubrum*, which were small specimens with a maximum base diameter of 1mm. *Miniacina miniacea* showed the reverse trend of recruitment densities compared with *H. rubrum*. It was not prevalent on reef flat substrata, and when it did occur the surface coverage was low (0.004 to 0.356%). Seaward of the reef margin, *M. miniacea* was the dominant species on natural substrata. Fringing reef bulk-collected substrata showed *H. rubrum* as the important species from 1 to 3m (reef margin zone) and *M. miniacea* from 5 to 12m (upper reef slope zone) (Table 13). The recruitment density and surface coverage of *C. utricularis* onto these substrata were more variable; however, there were some decreases at the deeper depths. There was an opposite pattern of recruitment of *H. rubrum* and *M. miniacea* between blocks and plates. At the fringing reef site, the blocks were fouled primarily by *H. rubrum* (Table 7) while the plates had *M. miniacea* (Table 6). The barrier reef blocks were fouled by *M. miniacea* (Table 8) while *H. rubrum* was more prevalent on plates (Table 5); however, the plates were exposed for shorter periods (37 to 180 days) than were the blocks (1 yr). This recruitment anomaly can be explained partly as a result of space competition. *Homotrema rubrum* recruits to surfaces which are not extensively fouled by encrusting biofoulers, particularily calcareous algae. The fringing reef and coral community blocks with high *H. rubrum* recruitment were not heavily fouled by encrusting organisms, whereas the barrier reef blocks were heavily encrusted and subsequently had low *H. rubrum* recruitment. *Miniacina miniacea* frequently grew on encrusting calcareous algae and *G. vesicularis*. As a result, *M. miniacea* could compete for space on encrusted surfaces and was prevalent on the biofouling plates and barrier reef blocks.

Homotrema rubrum recruited to the barrier reef biofouling surfaces before *M. miniacea* (Table 5). Although these species recruited to surfaces exposed for short time intervals (37 to 180 days), the densities and surface coverages were low. After 1 yr exposure periods, these species were more dense, covered greater surface area and occurred more frequently, which means that they are later successional biofoulers. The species *C. utricularis, C. monticularis, S. cylindricum* and possibly *S. rubrum* are also in this category.

Planogypsina squamiformis, A. inhaerens and *G. vesicularis* readily recruited to biofouling surfaces after short exposure periods (37-100 days). *Planogypsina squamiformis* was the dominant species on barrier reef plates with the peak recruitment period after 100 exposure days. Living specimens of this species did not occur on biofouling blocks recovered from the same locations after 1 yr. Hence, *P. squamiformis* in the barrier reef environment is an early successional biofouler which cannot compete with late successional species. Although *A. inhaerens* and *G. vesicularis* appeared to be early successional species, they could continue to compete for space after longer periods. *Carpenteria* cf. *proteiformis* was quantified too infrequently to ascertain recruitment patterns.

The early successional species recruited mostly to surfaces exposed to ambient light conditions, occasionally onto shaded surfaces, and rarely onto cryptic surfaces. The late successional species recruited mostly to cryptic and shaded surfaces, and rarely to exposed surfaces. Heavy algal growth on exposed and shaded surfaces prevented species recruitment and eliminated established species. The heavy calcareous growth in the 10-12m zone at the barrier reef site also reduced foraminiferal recruitment and establishment. The recruitment of late successional foraminiferans to illumination surfaces is more a function of the exclusion of light-related biofoulers of other taxa from these surfaces than an actual light response by foraminiferans.

Adherent foraminiferal species are a conspicuous component of the cryptofaunal community on substrata from the reef environments of Guam. Species recruited to most habitat types, with densities generally less than 1 specimen/cm^2 (10,000/m^2). The total surface coverage by foraminiferans was usually about 1%. The species occurrence, surface coverages and frequencies of occurrence on natural substrata varied between reef flat and seaward slope zones and between habitat types. The more massive habitat types and living coral had lower species recruitment and density with smaller specimens. This resulted from the reduced surface areas available on these substrata for species attachment. Exposed and cryptic cavities and dead branching corals provided more surface area for attachment and subsequently had higher species recruitment and densities. Species readily recruited to biofouling plates with species recruitment variable between reef environments. The principal species, *H. rubrum*, *M. miniacea* and *C. utricularis*, were found in all the reef environments with variation in recruitment patterns by minor species, *A. inhaerens, P. squamiformis, C. monticularis, S. rubrum* and *S. cylindricum*. *Gypsina vesicularis* was prevalent on substrata from the reef environments with particularly luxuriant growth on lagoon and coral community exposed natural substrata.

Although adherent foraminiferans occupy only about 1% of substratum surface area, they are important biofoulers. On reef flat and reef margin substrata they can be the major cryptofaunal component and occupy up to 50% of cryptic surface areas. Since foraminiferal tests remain attached to the reef substrata after the animals die, adherent foraminiferans do indeed make a small contribution to the overall coral reef biomass.

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APPENDIX A

Microtransect Methods

The point-quarter techniques (PQT) is a plotless distance sampling method adapted for assessing communities in which individuals are numerous but generally widely spaced (Cox 1967; Greig-Smith, 1964; Loya, 1978). Plotless sampling is a more efficient method than standard plot techniques when the topography surveyed has intricate relief. Additionally, plotless methods provide a considerable amount of information per man-hour expended (Loya, 1978); and they are designed to measure randomly distributed populations. As a result, population density estimates must be carefully scrutinized. Density estimates of aggregated, associated or evenly distributed benthic populations are generally biased to the low side; and it is unlikely that a single correction factor could be found which would allow for this bias (Loya, 1978).

The PQT as designated by Cox (1967) was modified (mPQT) for coral reef studies by Randall (1978). A limitation was placed on the distance from the sampling point to specimen being measured. The only specimens recorded occurred within the limitation or had their center at the limit boundary. This distance limitation can result in quadrants that have zero specimen encounters. If the number of zero encounters was small in relation to the total number of quadrants then the density calculation presented in Cox (1967) was still applicable. However, when the number of zeros was large the density equation became invalid.

The transected substratum habitats were quantified for density, coverage and frequency with the mPQT. The first of the designated habitats encountered in each quadrant was collected. The distance from the point to the center of the habitat and the maximum and minimum dimensions were recorded. If a zero encounter occurred within a maximum distance of 1m from the sampling point, the quadrant was recorded as having a point-to-habitat distance of 1m and size of zero. Since the number of zero encounters was small, the following calculation, based on Cox (1967), was used to estimate the habitat total density:

$$\text{Total Density (no./cm}^2) = \frac{\text{Unit Area } (10{,}000\ \text{cm}^2/\text{m}^2)}{\left[\dfrac{\Sigma\ \text{distances}}{\text{total no. of quadrants}}\right]^2}$$

A large number of zero encounters in the foraminiferal transecting required adapting an equation based on standard plot techniques for calculating the foraminiferal total density. The area surveyed in each quadrant was a calculable portion of a quarter-circle. This area was treated as a variable size quadrat with only one specimen present. The point-to-specimen distances (radii) and total specimens encountered were used to determine the total density. The following calculation, adapted from Poole (1974), was used to estimate the foraminiferal total density:

$$\text{Total Density (no./cm}^2) = \frac{4\ (\text{no. of individuals} - 1)}{\pi\ \ \Sigma\ \ \text{radii}^2}$$

According to Poole (1974) N-1 should be used to eliminate bias in the calculation.

The adherent foraminiferal species composition, density, surface coverage and frequency were determined for transected substratum habitats, bulk substratum samples and biofouling block surfaces with the mPQT. Samples were situated in the corner of a measurement table which had nails spaced at 1cm intervals along each side. The surface area of a substratum sample could be divided into 1cm^2 squares. A random number table was used to generate a set of numbers for both the X and Y axes with the range of random numbers dependent on the size of the specimen. The intercept of the X and Y lines on the substratum surface designated a sampling point. The use of a pair of random numbers as coordinates from right angle axes to position a sampling point constituted restricted randomization (Greig-Smith, 1964). The mPQT was then applied for the sampling point. The distance was measured to the first adherent foraminiferan in each quadrant up to a maximum distance of 1cm; the field of view through the stereomicroscope. The diameter was recorded for each encountered species.

From the total density [PQT or quadrat density calculation] and surface coverage data the following calculations were used to characterize the reef substratum habitats and foraminiferal components on the substratum types:

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

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

$$\text{Percent coverage} = \frac{\text{density of a species}}{\text{average coverage value for species}} \times 100$$

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

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

$$\text{Relative frequency} = \frac{\text{frequency of a species}}{\text{total frequency of species}} \times 100$$

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

A study was conducted to test the mPQT and quadrat total density calculation with an artificial population sampler. Sets of randomly distributed colored dots on a $1m^2$ plexiglass sheet constituted one of the artificial populations. Twenty points were selected per test run by restricted randomization. A maximum distance of 10cm was used as the point-to-specimen distance. A comparison of the mPQT and a quadrat sampling method with a standard 10cm circle is presented in Table A-1. The data were analyzed with a sign test at the t_s (.05) level (Sokal and

Table A-1. Population board study of random specimens with mPQT and quadrat methods. The deviation of specimen densities obtained from the mPQT and quadrat methods compared to the actual population density was analyzed with a sign test.

Population	Population Density (no./cm^2)	N	mPQT Density (no./cm^2)	change	Quadrat Density (no./cm^2)	change
1 2-sp	.0412	74	.0383	-.0029	.0366	-.0046
2 2-sp	.0299	71	.0295	-.0004	.0240	-.0059
3 2-sp	.0270	70	.0277	+.0007	.0282	+.0012
4 2-sp	.0400	73	.0365	-.0035	.0349	-.0051
5 2-sp	.0428	79	.0491	+.0063	.0406	-.0022
6 3-sp	.0462	77	.0447	-.0015	.0471	+.0009
7 3-sp	.0477	80	.0509	+.0031	.0466	-.0011
8 3-sp	.0602	80	.0804	+.0202	.0646	+.0044
9 3-sp	.0507	80	.0438	-.0069	.0441	-.0003
10 3-sp	.0570	79	.0588	-.0018	.0541	-.0029
11 3-sp	.0427	78	.0450	+.0023	.0409	-.0018
12 3-sp	.0554	80	.0582	+.0028	.0505	-.0049
13 3-sp	.0556	80	.0593	+.0037	.0490	-.0066
14 3-sp	.0557	80	.0643	+.0086	.0509	-.0048
15 3-sp	.0491	79	.0565	+.0074	.0395	-.0096
16 4-sp	.0699	80	.0705	+.0006	.0700	+.0001
17 4-sp	.0777	80	.0739	-.0038	.0761	-.0016
18 5-sp	.0919	80	.0928	+.0009	.0872	-.0047
19 1-sp	.0220	69	.0255	+.0035	.0269	+.0049
20 1-sp	.0157	60	.0187	+.0030	.0175	+.0018
19*	.0220	30	.0250	+.0030	.0236	+.0016
20*	.0157	29	.0221	+.0064	.0216	+.0059
sign test $t_s(\infty)[.05]= 1.960$				14+/6- 1.79		14+/6- 1.79

*These tests were run with the same set of random points as populations 19 and 20, but the maximum point-to-specimen distance was 5cm.

Rohlf, 1969). The mPQT with the quadrat density calculation and the circle quadrat density estimates compared to the actual population density (μt) showed that deviation from μt could have occurred by chance. Total density was underestimated for an artificial population sampler with mixed random, aggregated, associated and even distributions (Table A-2).

A comparison of foraminiferal density was made with the mPQT and a quadrat method on twenty natural populations (Table A-3). The actual population density was determined by counting all foraminiferans and measuring the surface area of the natural substratum with a surface-fit aluminum foil method (Marsh, 1970). The mPQT point-to-specimen distance was 2.5cm. A quadrat size of $1cm^2$ was used with 20 and 33% of the areal surface area surveyed.

The mPQT and quadrat method are both one-dimensional areal or planar surveys. Therefore, the surveyed quadrat area was actually greater, due to the topographic relief of the surface, than the planar measurement indicated. As a result, the quadrat method tended to overestimate the total density (Table A-3). A sign test showed that the mPQT estimate of density variation from the actual population at t_s (.05) could have occurred by chance. The quadrat data were statistically an overestimate of the total density.

A point-to-specimen distance limitation can be applied only to randomly distributed populations. A major criterion in establishing the maximum distance was the species' upper size ranges. The distance should allow equal sampling of all species, which requires it to be greater than the largest specimens. The foraminiferal specimens were usually much smaller than 1cm. Specimens of *Sporadotrema cylindricum*

Table A-2. Population board study with aggregated, random, even and associated specimens.

Population Pattern	Population Density (no./cm^2)	N	mPQT density (no./cm^2)	mPQT change	Quadrat density (no./cm^2)	Quadrat change
Aggregated-Random-Even	.0814	77	.0445	-.359	.0597	-.0217
Aggregated-Random-Even	.0814	77	.0528	-.0272	.0832	+.0018
Associated-Aggregated-Even	.0444	69	.0250	-.0194	.0334	-.0110
Aggregated-Aggregated-Even	.0409	66	.0250	-.0159	.0349	-.0060

Table A-3. Total density study of 20 foraminiferal populations with mPQT and a quadrat method.

Population density (no./cm^2)	mPQT density (no./cm^2)	mPQT change	mPQT No. of zeros	Quadrat Method 20% coverage	Quadrat Method change	Quadrat Method 33% coverage	Quadrat Method change
0.66	0.38	-	12	1.08	+	0.98	+
0.59	0.31	-	7	0.82	+	0.72	+
0.45	0.31	-	13	0.54	+	0.58	+
0.53	0.35	-	8	0.86	+	0.96	+
2.12	0.64	-	3	3.60	+	2.68	+
0.80	0.96	+	0	0.67	-	0.88	+
1.84	0.94	-	2	1.65	-	1.53	-
1.20	0.44	-	2	1.27	+	0.96	-
1.34	0.53	-	5	1.20	-	1.84	+
1.08	0.67	-	4	2.17	+	1.88	+
0.19	0.20	+	11	0.20	-	0.16	-
0.51	0.38	-	5	0.93	+	1.00	+
0.65	0.49	-	6	0.96	+	1.20	+
0.50	0.56	+	4	0.53	+	0.60	+
0.42	0.34	-	6	0.44	+	0.39	-
0.28	0.34	+	6	0.71	+	0.76	+
0.47	0.50	+	9	0.89	+	1.25	+
1.05	1.16	+	0	2.38	+	1.83	+
0.85	1.11	+	1	1.13	+	1.08	+
1.35	0.93	-	0	2.33	+	2.12	+
sign test		7+/13-			16+/4-		16+/4-
$t_s(\infty)[.05] = 1.960$		1.34			2.68		2.68

were occassionally larger than 1cm, while *Gypsina* spp. commonly exceeded 1cm. Although *Gypsina* was recorded if it occurred at a sampling point and size of the encrustation measured, it was not included in the mPQT calculations.

Comparisons of total density, species density, coverage and frequency on a single foraminiferal population (ca. 750 cm^2 of substratum) with mPQT and quadrat method are presented in Table A-4. The mPQT was tested with 15, 20 and 25 random points. The maximum point-to-specimen distance was 1 cm. A rectangular quadrat with 75 one cm^2 squares was randomly placed on the substratum with 5, 10 and 15 tosses. Total areas of 50, 75 and 100cm^2 were surveyed with the quadrat method. The number of specimens encountered with the quadrat method was tested with a Poisson distribution analysis (Sokal and Rohlf, 1969). The distribution of foraminifera was tested at the t_s (.05) level with a Chi-square goodness of fit and found to be random on a natural substratum. The total densities for the 3 mPQT tests were similar ranging from 0.51 (20 pts.) to 0.57 (25 pts.) specimens/cm^2 (Table A-4). The quadrat total densities were higher and more variable with densities ranging from 0.63 (100cm^2) to 1.00 (50cm^2) specimens/cm^2.

Homotrema rubrum, M. miniacea, S. cylindricum, C. utricularis were present in about the same ratios for the mPQT tests (Table A-4). The quadrat tests showed greater occurrences of *C. utricularis* with the remaining species present in similar ratios to the mPQT tests. Generally, the species density, total coverage dominance and frequency of occurrence were comparable for the three mPQT tests and the 75cm^2 quadrat test. The 50 and 100cm^2 quadrat tests had less total coverage of *S. cylindricum* and greater coverage of *M. miniacea* and *C. utricularis*.

Table A-4. Comparison of mPQT and quadrat methods on a large flat substratum. The species abbreviations are as follows: Hr, *H. rubrum;* Mm, *M. miniacea;* Sc, *S. cylindricum;* Cu, *C. utricularis*.

Method and No. of Points	Species	Total Density (no./cm^2)	Species Number	Species Density (no./cm^2)	Total Coverage (cm^2)	Relative Percent Coverage	Frequency of Occurrence	Number of Zeros
mPQT	Hr	0.558	17	0.431	4.40	0.112	0.67	38
(15 pts)	Mm		3	0.076	0.01	<0.001	0.13	57.9%
	Sc		1	0.025	14.4	0.360	0.07	
	Cu		1	0.025	0.25	0.006	0.07	
mPQT	Hr	0.511	24	0.438	3.15	0.057	0.60	52
(20 pts)	Mm		2	0.036	0.04	0.001	0.10	53.8%
	Sc		1	0.018	15.05	0.271	0.05	
	Cu		1	0.018	0.13	0.002	0.05	
mPQT	Hr	0.566	26	0.420	2.99	0.048	0.52	65
(25 pts)	Mm		2	0.032	0.06	0.001	0.04	53.8%
	Sc		5	0.081	13.9	0.225	0.08	
	Cu		2	0.032	1.61	0.026	0.16	
Quadrats	Hr	1.00	37	0.74	4.40	0.090	0.90	
(5/10)	Mm		2	0.04	0.21	0.004	0.20	
50cm^2	Sc		3	0.06	3.00	0.060	0.20	
	Cu		8	0.16	0.71	0.014	0.50	
Quadrats	Hr	0.71	28	0.37	3.28	0.040	1.00	
(15/5)	Mm		3	0.04	0.11	0.001	0.60	
75cm^2	Sc		11	0.15	11.0	0.150	0.40	
	Cu		11	0.15	1.25	0.017	0.60	
Quadrats	Hr	0.63	48	0.48	4.52	0.040	0.90	
(10/10)	Mm		3	0.03	0.24	0.002	0.30	
100cm^2	Sc		3	0.03	3.00	0.030	0.30	
	Cu		9	0.09	1.52	0.015	0.60	

The bases of 2 concrete blocks with planar surfaces which had higher foraminiferal densities (1.5 and 1.60/cm^2) were analyzed by the mPQT (Table A-5). The mPQT was tested with 10, 20 and 30 random points. The 10 and 20 random point tests were run in triplicate. Density estimates were made with both the point quarter method (PQM, Cox, 1967) and modified quadrat (mPQT) equations. The densities with the PQM calculation were higher in 13 of the test runs. The densities with the mPQT calculation were higher (+12%) on one block surface and lower on the other (-29%). The variation within a random point series (10 or 20 points) was greater than the variation between series. The 20 random points per sample were selected since the range of variation was smaller than for the 10 random points per sample series.

The reproducibility of the mPQT was tested on a .25cm^2 flat substratum (Table A-6) with *H. rubrum* and *C. utricularis* the only foraminiferal species. Four sets of 20 random points with a maximum distance of 1cm were analyzed. Total density estimates were similar for the test runs with a range of 0.383 to 0.417/cm^2. The density, coverage and frequency of occurrence for *H. rubrum* was similar for the test runs. *C. utricularis* had similar density and coverage values between the test runs. The frequency of occurrence of *C. utricularis* varied from 15 to 40 percent between the tests.

The mPQT is a reproducible method that adequately characterizes foraminiferal density and coverage on artifical and natural substrata. Frequency of occurrence is dependent on the number of specimens present. Frequency estimates are more reliable for species with a relatively large number of specimens present on a substratum.

Table A-5. Test of PQM and mPQT on concrete block surfaces with high total densities.

	Total Population Density (no./cm^2)	Number of Random Points	PQM, Cox (1967) total density (no./cm^2)	PQM, Cox (1967) change (%)	mPQT total density (no./cm^2)	mPQT change (%)	
Block base [3 species]	1.51	10	1.49	-1	0.91	-40	
		10	1.85	+18	1.18	-22	-29±9%
		10	2.04	+26	1.12	-26	
		20	1.62	+7	1.04	-31	
		20	1.73	+13	1.01	-33	-29±5%
		20	1.94	+22	1.15	-24	
		30	1.75	+14	1.07	-29	
				+14±9%		-29±6%	
Block base [4 species]	1.60	10	2.34	+32	1.69	+6	
		10	2.23	+28	1.74	+7	+12±9%
		10	2.69	+41	2.04	+22	
		20	2.29	+30	1.71	+7	
		20	2.51	+36	1.88	+15	+12±4%
		20	2.29	+30	1.86	+14	
		30	2.41	+34	1.82	+12	
				+33±4%		+12±6%	

Table A-6. mPQT repetitive analysis on single substratum. The species abbreviations are as follows: Hr, *H. rubrum;* Cu, *C. utricularis*.

Total Density (no./cm^2)	Species, total number	Species Density (no./cm^2)	Coverage (%)	Frequency (%)	Frequency of Zero Points	Number of Zeros
0.417	Hr,13	0.246	0.1	40	50	58
	Cu,9	0.171	0.1	40		
0.416	Hr,17	0.321	0.5	45	50	58
	Cu,5	0.095	0.7	15		
0.383	Hr,14	0.255	0.8	45	50	59
	Cu,7	0.128	0.6	30		
0.431	Hr,16	0.300	0.8	45	50	57
	Cu,7	0.131	0.7	25		
$\bar{X}$±s.d.						
0.412	Hr,15	0.281±.036	6.6±2.1	44±2		
±.020	Cu,7	0.131±.031	3.3±0.7	28±10		