COMPARATIVE ANALYSIS OF COMMUNITY STRUCTURE
OF TWO FRINGING REEFS
OF MAGNETIC ISLAND
(NORTH QUEENSLAND)

Dissertation submitted by
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ABSTRACT

The scleratinian coral distributions on two fringing reefs (Geoffrey Bay and Cockle Bay) of Magnetic Island were surveyed using a line transect method.

The community structures are discussed in relation to prevailing environmental conditions. Of the two reefs surveyed, the Cockle Bay reef is less exposed and more heavily sedimented than the Geoffrey Bay reef.

The communities are divided into "zones" on the evidence of percentage coral cover, number of species per transect, colony size, Shannon and Weaver diversity indices and numerical classification of transects. The species composition and dominant species of each zone reflect the environmental conditions.

The relative severity of the environment in Cockle Bay is reflected in a smaller number of species and lower values of the Shannon and Weaver diversity indices, than are found in the Geoffrey Bay community.

The community structures and zonation patterns of these Magnetic Island reefs are discussed and compared with those of other high island fringing reefs. It appears that Magnetic Island reefs exhibit features typical of fringing reefs in very sheltered and sedimented areas.

STATEMENT OF SOURCES

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

G.D. BULL
April 1977

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1 INTRODUCTION

1.1 AIMS OF PRESENT STUDY

A line transect survey of the scleratinian coral distributions of two fringing reefs of Magnetic Island was undertaken. From this survey the community structures could be described and discussed in relation to environmental conditions. Two particular reefs were chosen (Geoffrey Bay and Cockle Bay) to enable comparisons of two communities with different prevailing environmental conditions.

1.2 THE STUDY AREA

1.2.1 Physiography

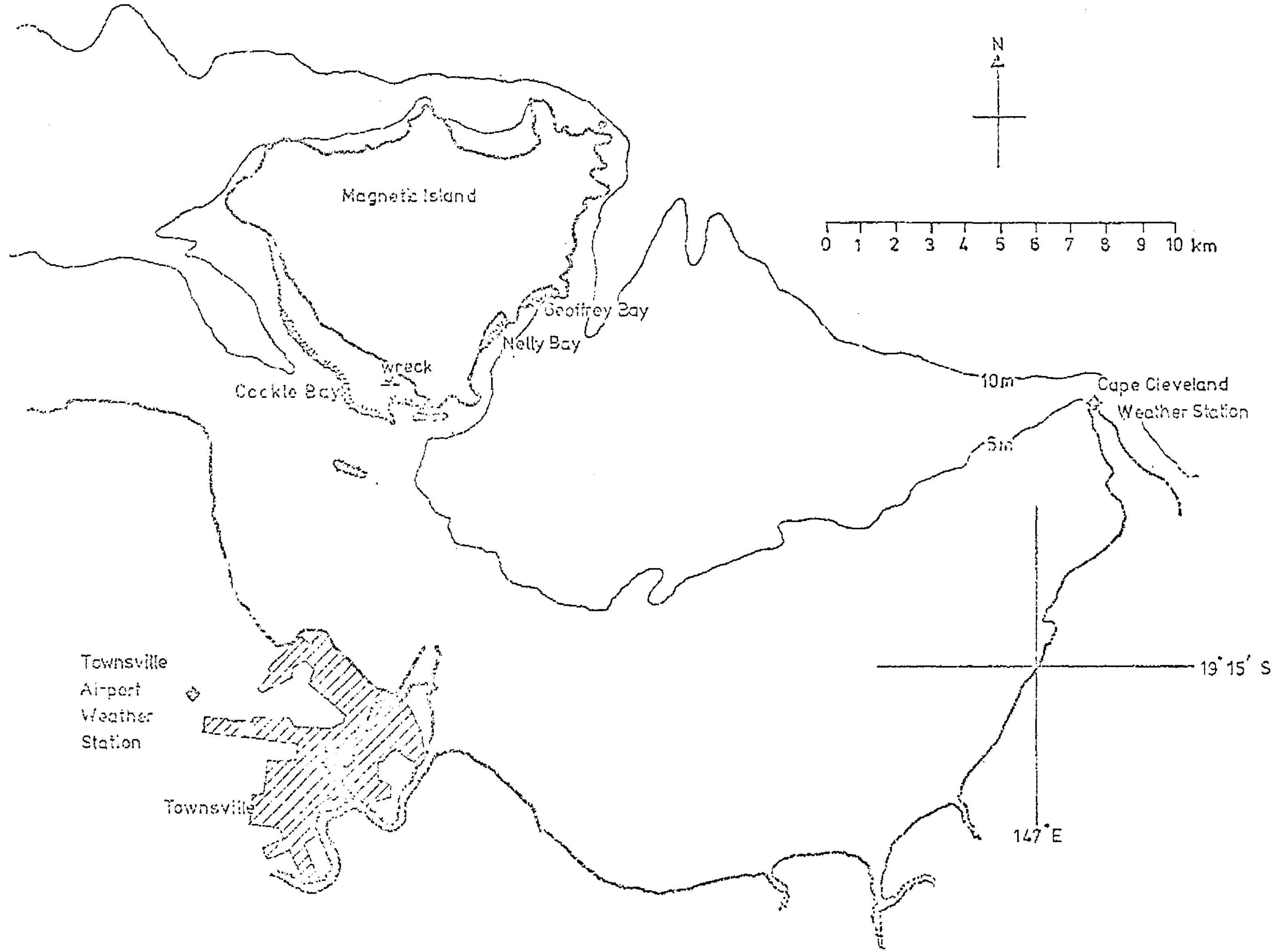
Magnetic Island is situated in Cleveland Bay approximately 8km off Townsville (Fig. 1). Cleveland Bay is shallow with a maximum depth of 12.5m off the south-east side of Magnetic Island, and 4.25m between Cockle Bay reef and the mainland.

Magnetic Island is of the "High Mainland Island" type (Hopley, 1970), being composed of granitic rocks similar to those of the local mainland coast. Most of the Island's numerous bays have fringing coral reefs. The most conspicuous of these are Cockle Bay reef on the mainland side of the island (south-west side) and Geoffrey and Nelly Bay reefs on the south-east side. The reefs of Geoffrey Bay and Cockle Bay were chosen for this study as two reefs which might be expected to show different community structures in response to their different environmental conditions.

Both bays have typical fringing coral built platforms

FIGURE 1

Map of Cleveland Bay showing positions of Geoffrey Bay and Cockle Bay


N
0 1 2 3 4 5 6 7 8 9 10 km
Magnetic Island
Geoffrey Bay
Nelly Bay
wreck
Cockle Bay
10m
5m
Cape Cleveland
Weather Station
19°15' S
147°E
Townsville
Airport
Weather
Station
Townsville

backfilled with sand and coral debris. The "front reef ensemble" (using the spatial classification of Pichon, 1972, 1973) of the seaward slope and crest, extends from 0 to 9m in Geoffrey Bay and 0 to 4m in Cockle Bay (taken from the Om tidal datum). The "epireef ensemble" of the reef flat extends 150m landward of the crest in Geoffrey Bay and 200m in Cockle Bay. The landward fringe of the sand flat areas are a sandy bluff in Geoffrey Bay and a mangrove fringe in Cockle Bay. There is no development of a boat channel or lagoon (back reef ensemble) in either bay.

1.2.2 Environmental Factors

Temperature

Data for surface sea water temperatures for Cleveland Bay are given by Kenny (1974). Off the Townsville Harbour breakwater there is an annual variation from 20° to 33°. Collins (Ph.D. thesis, unpublished) found an annual surface temperature variation from 18° to 31° in Nelly Bay, Magnetic Island (adjacent to Geoffrey Bay).

Reef flat areas are likely to show a greater variation of sea water temperature than the rest of Cleveland Bay, but no data is available for this.

Salinity

Grigg (1972) gives data for annual surface salinity variation at one station in open water in Cleveland Bay (range from 27.1°/oo to 38°/oo). Collins (Ph.D. thesis, unpublished) measured exceptional extreme values of 11°/oo to 36°/oo in Nelly Bay. There are small creeks emptying into both Nelly Bay and Geoffrey Bay, which contribute to reduction of salinity on the reef flats during heavy cyclonic or post-cyclonic rains.

Winds and Swell

Wind strength and direction data are recorded at the Cape Cleveland and Townsville Airport weather stations (Bureau of Meteorology, Commonwealth Government, Department of SCience). Unfortunately no data are available for Magnetic Island itself which is affected by both a land breeze effect and the prevailing sea trade winds. Directional wind-roses for data from Cape Cleveland and Townsville Airport are given in Figure 2.

At most times there is a steady swell entering Cleveland Bay from the east-north-east, built up by the north-east to south-east winds shown in the Cape Cleveland wind-roses. This prevailing swell appears to be refracted along the depth contours on the south-east side of Magnetic Island, and enters Geoffrey Bay and Nelly Bay from the south-east, so that the swell front is often parallel to the reef edges.

The south-west side of Magnetic Island is probably more affected by the north and north-west land breezes shown in the Townsville Airport wind-roses. However, the fetch for build up of a north-westerly swell between the mainland and Cockle Bay reef (south-west side of Magnetic Island) is only about 5km. This compares with a fetch of about 100km between the Great Barrier Reef and Cleveland Bay from an easterly direction.

The Geoffrey Bay reef can therefore be considered as more exposed to the effects of swell than the relatively sheltered Cockle Bay reef.

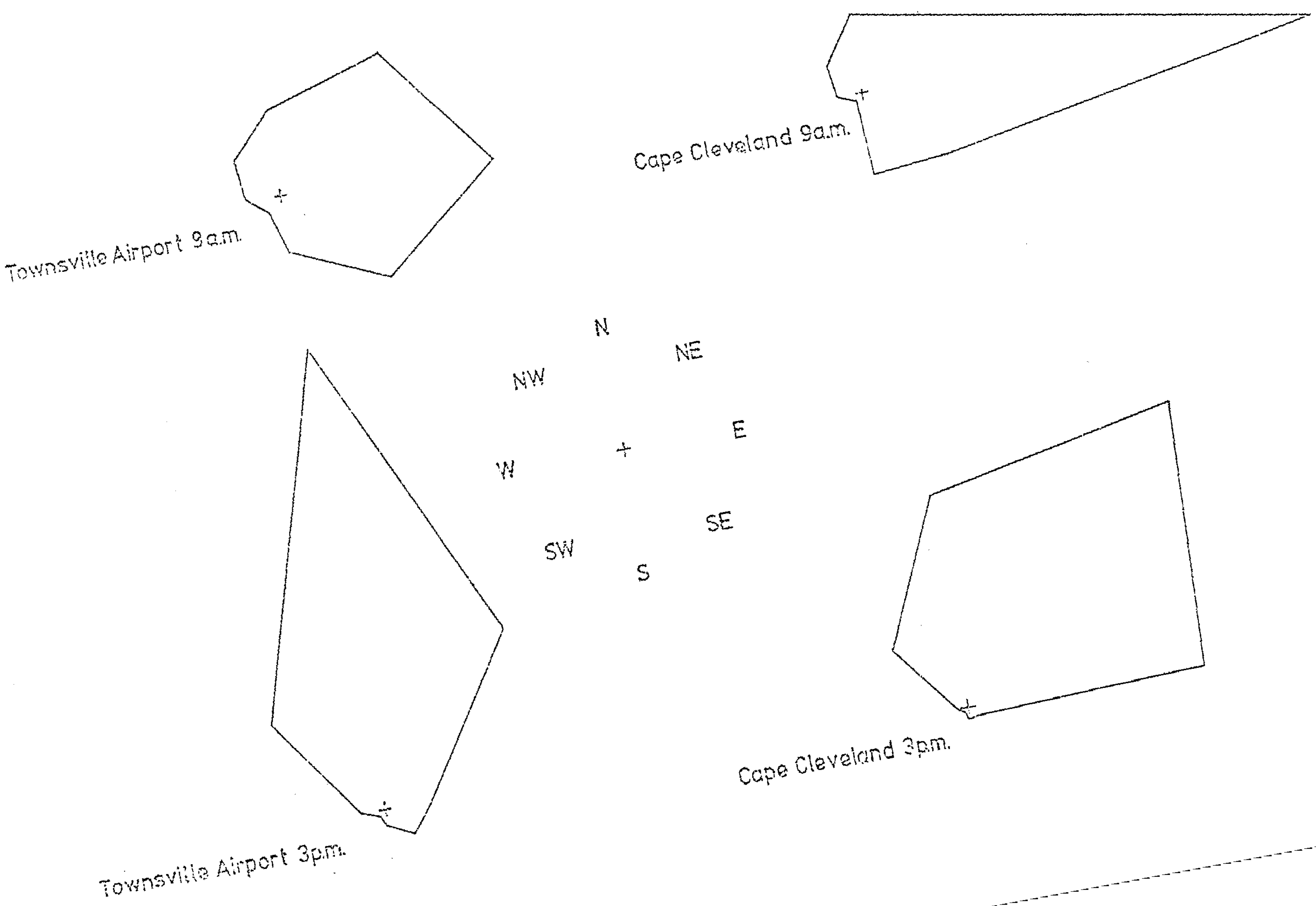
Tides

The tidal regime in Cleveland Bay is semidiurnal with diurnal inequality (Easton, 1970), with two high tides and low tides in each 24h 50m period. Spring tides and neap tides alternate regularly. During spring tide

FIGURE 2

Directional wind-roses for Townsville Airport and Cape Cleveland weather stations, representing percentage frequencies of wind recordings from eight compass points (at 9.00 a.m. and 3.00 p.m.)

Drawn from data supplied by the Bureau of Meteorology, Melbourne to the Department of Geography, James Cook University.


Townsville Airport 9a.m.
Cape Cleveland 9a.m.
N
NE
NW
E
W
SW
SE
S
Townsville Airport 3p.m.
Cape Cleveland 3p.m.

periods the mean tidal range is 2.5m (Department of Harbours and Marine, Queensland, 1976). During neap tide periods the mean range is 0.8m. As a consequence of the tidal range the reef flat areas of both Geoffrey and Cockle Bays are exposed for a few hours daily during spring tide periods, but not during neap tide periods.

Sediments

Cleveland Bay has a sandy mud bottom composed of sand material eroded around headlands (especially Cape Cleveland), silt and clay brought down by major rivers including the Burdekin River, and locally some large particle size, carbonate deposits from reef areas (A. Belperio, Geology Department, James Cook University, personal communication.)

Smith (1974) provides data for Geoffrey and Nelly Bay reef sediments. However, no data for Cockle Bay is given. To enable comparisons of the sediment conditions in Geoffrey Bay with those in Cockle Bay, sediment samples from those areas were collected for analysis (Section 2.6).

1.2.3 Other studies on Magnetic Island reef areas

During the last fifteen years there have been fears that the fringing reefs of Magnetic Island were becoming adversely affected by silt. Brown (1972) suggested that dredging spoil dumped in Cleveland Bay by the Townsville Harbour Board's vessel "Townsville" was settling on mainland beaches and in the bays around Magnetic Island. Brown states that blanketing by dredge spoil was causing mass mortality of coral colonies to the extent that between 1961 and 1972 "more than 60% coral death" had occurred. This was disputed by various authorities including the Townsville Harbour Board (Townsville Harbour Board report, 1973).

The reefs of Magnetic Island have been and are being used as a study by various reef workers including: Smith (1974), sediment distribution; Collins (unpublished), biology of corals; Isdale (unpublished), growth of *Porites*; and Yamaguchi (unpublished), population dynamics of corals.

1.3 REVIEW OF ECOLOGICAL REEF STUDY METHODOLOGY

1.3.1 Early studies

Stoddart (1969) has reviewed ecological reef studies published up to that date. It is clear that both the survey methods used and the ways in which communities have been described vary greatly from author to author.

Many studies have been entirely qualitative, involving no quantitative survey. When such surveys have been done at all, a huge variety of sampling strategies have been used. Until fairly recently quadrat sampling has been the most common method used to determine the abundance and distribution of corals. Quadrat sizes have varied from $1.5m^2$ (Abe, 1937, at Koror, Palao) to $930m^2$ (Hiatt, 1957, at Arno Atoll, Marshall Islands) and some workers have even changed their quadrat sizes from reef to reef or from biotope to biotope (see Scheer, in press, and Pichon, in press). Furthermore the data recorded in quadrats, and the ways in which estimates of cover or abundance are made, vary from study to study. Data recorded has included: percentage areas covered by corals, number of species or genera of corals per quadrat, number of colonies of each species per quadrat, qualitative estimates of abundance according to predetermined scales, and growth forms (Stoddart, 1969). One method that has been used to estimate cover and abundance of corals has been to draw a sketch of their distribution within a quadrat as seen in plan. From such a sketch, cover can be calculated and the number of colonies counted. This method was used by Manton (1935) and Abe (1937).

The manner in which zonation patterns from qualitative and quantitative studies have been described also varies greatly. Some authors have used geomorphological terms (including Lewis, 1968) and others describe "zones" on the basis of their most dominant genus or species (including Wells, 1957). "Zones" are often described as reef areas, but the ecological value or significance of these is rarely given. Furthermore they are too often identified and named after their most abundant species, and that particular species may be present or abundant only locally.

The total lack of standardization of survey method and inconsistencies in terminology have meant that many zonation patterns described are extremely individual and are specific to one area only. This has made comparison of different studies and generalizations about reef zonation extremely difficult.

1.3.2 The modern approach to quantitative sampling

The line transect method is becoming commonly used for coral community surveys (Loya & Slobodkin, 1971; Loya, 1972; Porter, 1974; Done, 1977; and others, including the present study). The method enables standardization of technique in different studies and has practical advantages over quadrat methods.

Such a method is based on principles first used in phytosociology (Scheer, in press). It is explained in detail by Loya (1972, and, in press) and the procedures he describes are now accepted for most line transect studies.

The projected length of each colony on a line or tape laid along a depth contour parallel to the shore, is measured. From this a percentage cover and number of colonies of each species can be taken. As Loya (1972) points out, ambiguities arise when measuring corals with different growth forms in this way. The projected length of a branching species will have a different meaning to that of a massive colony. Therefore this method does not give any indication of biomass or amount of calcium carbonate; it merely indicates the proportion of space occupied by a colony.

As with any survey method used on corals, problems arise when defining an individual or colony unit. Loya (1972) took an individual as a colony which grows independently of its neighbour (i.e. when empty space is recorded between two adjacent colonies). In cases where an individual colony is separated into two or more portions by the death of intervening parts, Loya considered the separated portions as one individual.

By plotting the cumulative number of species against the metre number along the transect, it is possible to determine the shortest length of line that is representative of the transect area. Loya (1972) found no significant increase in the number of species after the eighth or ninth metre, so he used 10m transects.

In most line transect surveys the lines are spaced at regular intervals on the reef. Loya (1972) surveyed 84 transect lines spaced at intervals of 1m on the reef flat, and 5m on the reef slopes. By visually placing each transect line within a single zone, it is possible to cover all the zones of a reef without fixing intervals between the lines. In this manner it is possible to cover a reef with fewer transect lines than would otherwise be necessary. This strategy was adopted for the purposes of the present study. Although this practice introduces a subjective element (defining the zones), it maximises the return of information per unit of field time.

The amount of information derived from line transects is, for many purposes, as useful as that derived from quadrat sampling (Loya, 1972). The method is also less time consuming for the amount of information gathered, and is more easily applied to areas with uneven bottom topography. These factors make it particularly useful for underwater work using S.C.U.B.A.

1.4 SYNTHETIC ATTEMPTS

The universal nature of zonation on intertidal rocky shores has been pointed out by Stephenson & Stephenson (1949) and Lewis (1964). Only recently have attempts been made to form a similar comparative synthesis of coral reef ecology which is more universally applicable than previous individual or local studies.

Rosen (1971) pointed out a relationship between hydrological conditions (especially with respect to strength of water movement) and growth forms of corals in particular conditions. Rosen (1971, 1975) resolves increasing strength of water movement into three mutually perpendicular components from "O", a theoretical point of zero water movement (Fig. 3):

<u>Depth</u> - vertical component
<u>Direction of wave approach</u> - horizontal component
<u>Longshore effect (Aspect)</u> - horizontal component

On this basis Rosen (1971) defined three major assemblages for the Mahé (Seychelles) reefs, arranged from shallow to deep water and from the reef front to the shore:

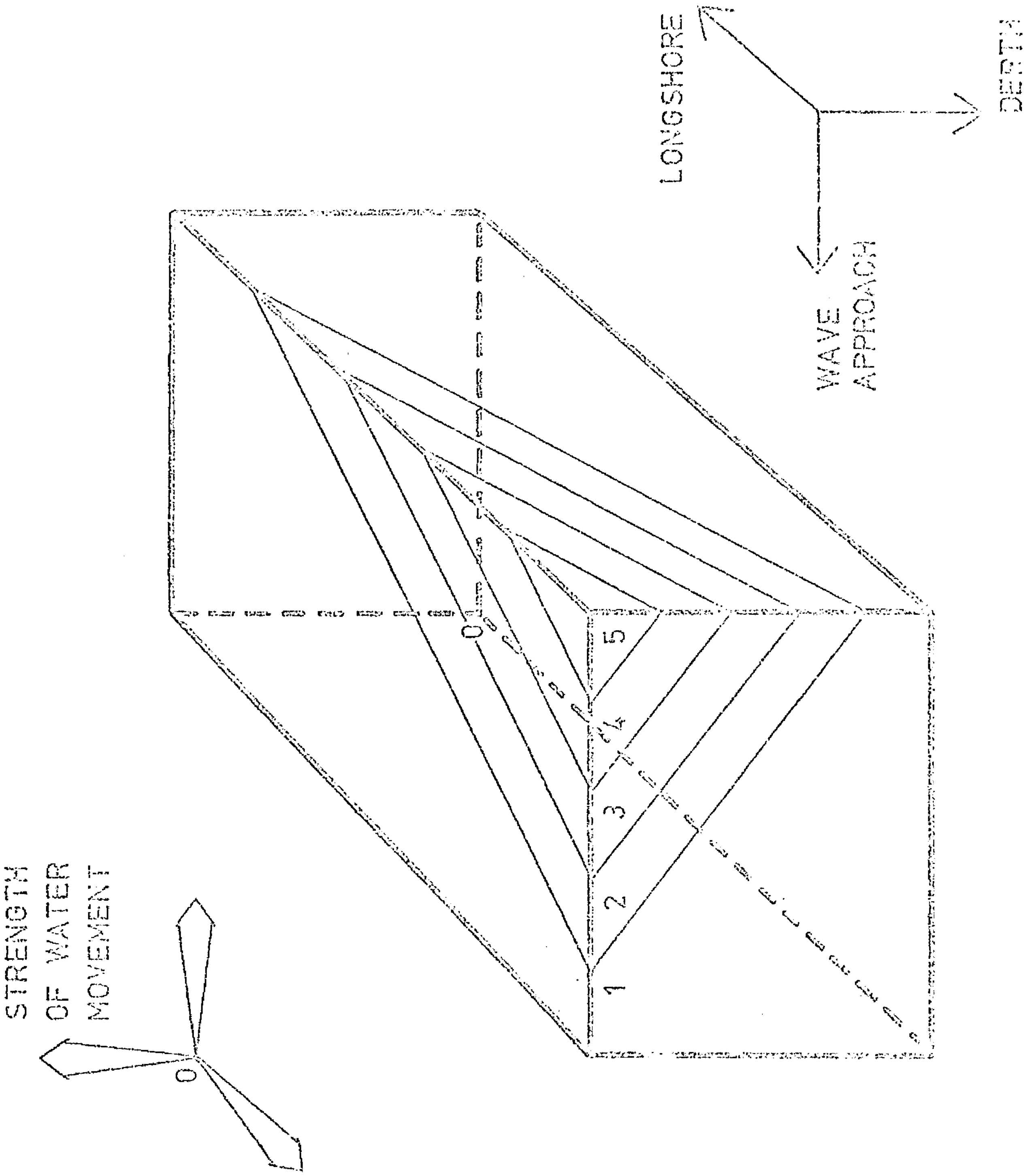
Pocillopora Assemblage - typically dominated by species with thick and short digitations - found in EXPOSED CONDITIONS.

FIGURE 3

Schematic reef model, after Rosen (1975) relating spatial arrangement of coral associations to strength of water movement. Associations are:

1. *Porites*; 2. Faviids; 3. *Acropora*; 4. *Pocillopora*; 5. Calcareous algae.

Water movement is considered in three mutually perpendicular components from 0, a theoretical point of zero water movement.



LONGSHORE
DEPTH
WAVE APPROACH
STRENGTH OF WATER MOVEMENT
0
0
1
2
3
4
5

Acropora Assemblage - tall branching species - SEMI-PROTECTED CONDITIONS.

Porites Assemblage - dominated by massive species - PROTECTED CONDITIONS.

Rosen (1975) points out that this is only a reference system and that each genus may be found in a coral association bearing another name, though less prominently. Numerous other genera are usually present. Rosen (1975) also extends the "Mahé Scheme" to include a fourth coral association, between that of *Acropora* and *Porites*, the Faviid association (dominated by the Faviidae and Mussidae). A further association is added to include the Algal Ridge (dominated by calcareous algae, especially species of *Porolithon*) found on some Indo-Pacific reefs. Rosen's (1975) expanded scheme is as follows:

Sequence of Associations

1)	*Porites*	least exposed
2)	Faviids	
3)	*Acropora*	
4)	*Pocillopora*	
5)	Calcareous algae	most exposed

The succession of assemblages 1) to 5) can be placed within three dimensional space (Fig. 3).

Pichon (1972, 1973), uses the term "ensemble" as defined by Picard (1967): "an ensemble is a unit of the benthic space, in which conditions are homogeneous (or vary regularly within the limits of each unit) from the following standpoints: hydrodynamics, morphology, sedimentology, bionomy".

Applying this concept to reefs leads to definition of the following three ensembles (Pichon, 1973):

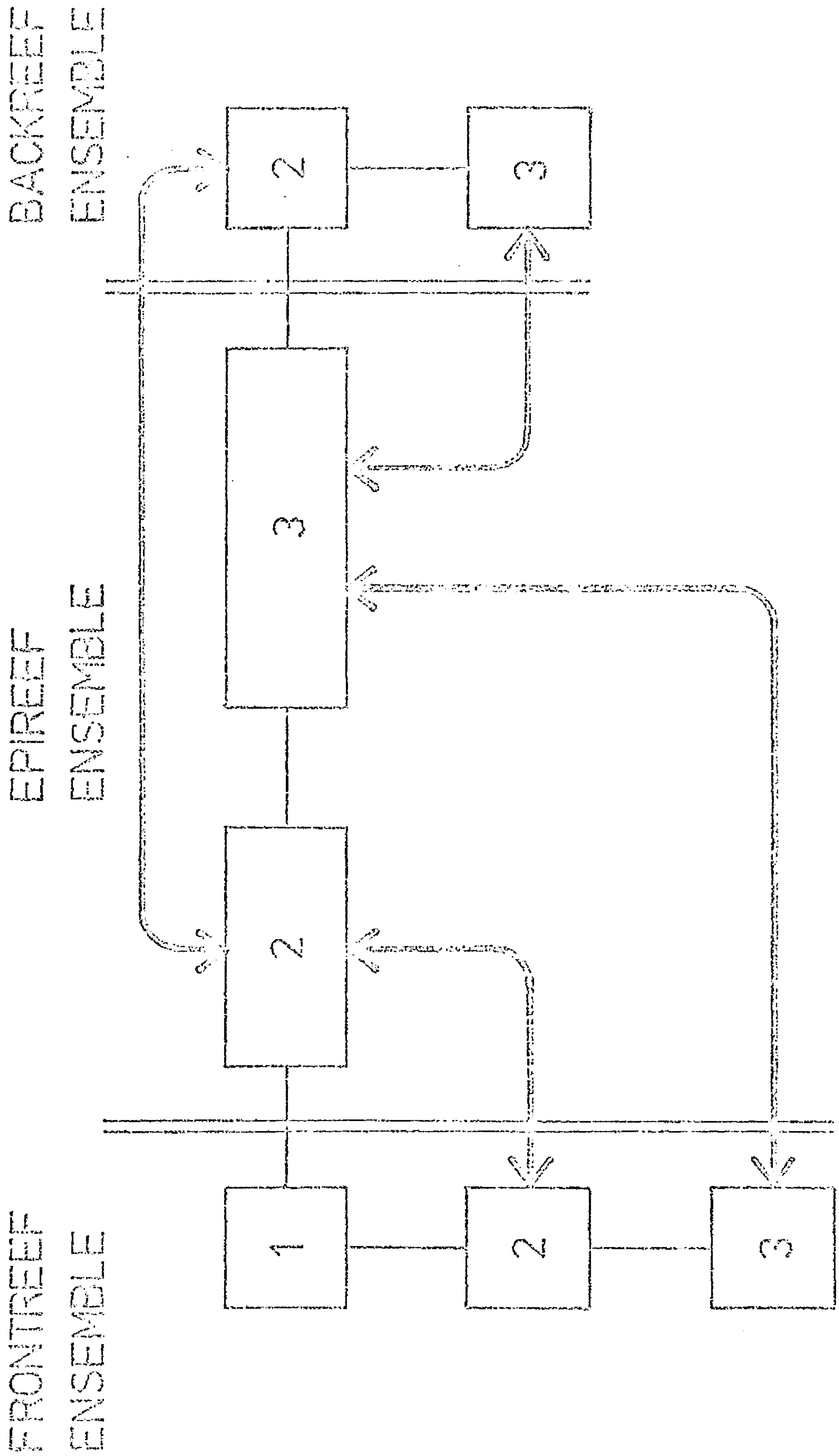
FRONT-REEF ENSEMBLE

The biotopes of the seaward slope and part of the

FIGURE 4

Schematic reef model, after Pichon (1973), showing spatial arrangements of zone types:

1. dominated by encrusting forms or forms with thick and short digitations;
2. dominated by branching forms;
3. dominated by massive forms.


BACKREEF ENSEMBLE
EPIREEF ENSEMBLE
FRONTREEF ENSEMBLE
1
2
3
2
3
2
3

outer reef flat.

EPI-REEF ENSEMBLE

The major part of the reef flat.

BACK-REEF ENSEMBLE

The lagoon slope, the lagoon bottom and part of the shore slope.

Within a framework of these ensembles Pichon (1973), defines three major zone types:

1) Zones where the dominant growth forms are encrusted with short and thick digitations (corresponds to Rosen's *Pocillopora* assemblage).

2) Zones where branching forms are dominant (corresponds to Rosen's *Acropora* assemblage).

3) Zones where massive forms are dominant (corresponds to Rosen's *Porites* assemblage).

The spatial positions of these zone types within the reef ensembles are shown in Figure 4.

In defining the parts of his "Integrated Ecological Model of Coral Reefs" Pichon avoids the use of generic or specific names for zones, making the scheme perhaps more universally applicable than Rosen's model.

It is clear that the schemes of Pichon and Rosen vary only in minor detail and application. At present these are the only two attempts to form a general comparative synthesis of coral reef ecology which is applicable on a world-wide basis.

1.5 QUANTITATIVE ANALYSIS

Multivariate analysis techniques such as Cluster Analysis (classification) and Principal Components Analysis (ordination) are becoming commonly used as an aid to the interpretation of ecological data. Such techniques involve the comparison of each "individual" of a "population" with every other individual on the basis of a number of "attributes". In ecological studies, stations, transects, quadrats, etc. comprise the population, and environmental or biological observations made at each station are used as attributes.

Classification is used more often than ordination in benthic ecology. However Hughes & Thomas (1971) compared the results of both classification and ordination, finding that they gave similar results for their data. Loya (1972), Jokiel & Maragos (1976), and Maragos (1973) used classification for reef coral community studies to show details of zonation patterns. Their populations were a series of transects and the presence, abundance or cover of each coral species were used as attributes.

Done (1977) compared the performances of measured, graded and binary (presence/absence) data in classification of coral survey transects. He found that graded and measured data gave similar classifications for his data from fringing reefs in the Palm Islands. This implies that if a coral survey is done only for the purpose of classification, it may not be necessary to collect complete measured data of abundance and cover by line transect, and that graded data may be sufficient. It has in fact been suggested that binary (presence/absence) data could be quite sufficient for this type of classification (Pichon, personal communication).

In cluster analysis a matrix of similarity (or dissimilarity) coefficients is calculated using one of many possible similarity measures. The available measures are not equally suitable for all kinds of data (Williams, 1976). In particular, they vary greatly in their response to pairs of zero values and to outlying values (isolated values out of scale with the bulk of the data matrix). Matrices of presence or abundance from marine ecological surveys usually contain many zero values and often have outlying values.

The dissimilarity measure used in the present study was the "Bray-Curtis measure" (Bray & Curtis, 1957). This does not include pairs of zero values in the calculation and has the property of isolating groups within the population which have outlying values. In ecological work this property tends to accentuate the division of the population into clusters of individuals which are dominated by the same species.

The similarity or distance matrix is usually transformed to a hierarchy of most to least similar individuals. Williams (1976) describes various agglomerative and divisive fusion strategies. The "Lance-Williams Flexible-Beta" strategy (Lance & Williams, 1967) was used in this study. This strategy was chosen because it produces dendrograms with tight clusters of individuals, rather than dendrograms with a chain linked configuration.

At this stage in the development of the use of classification for coral surveys, the only way of checking the validity of a particular classification is to compare it with a zonation pattern drawn subjectively from the raw data, or from viewing the reef itself. This suggests that classification is most useful not for determining the zonation pattern of one community, but for comparing different communities.

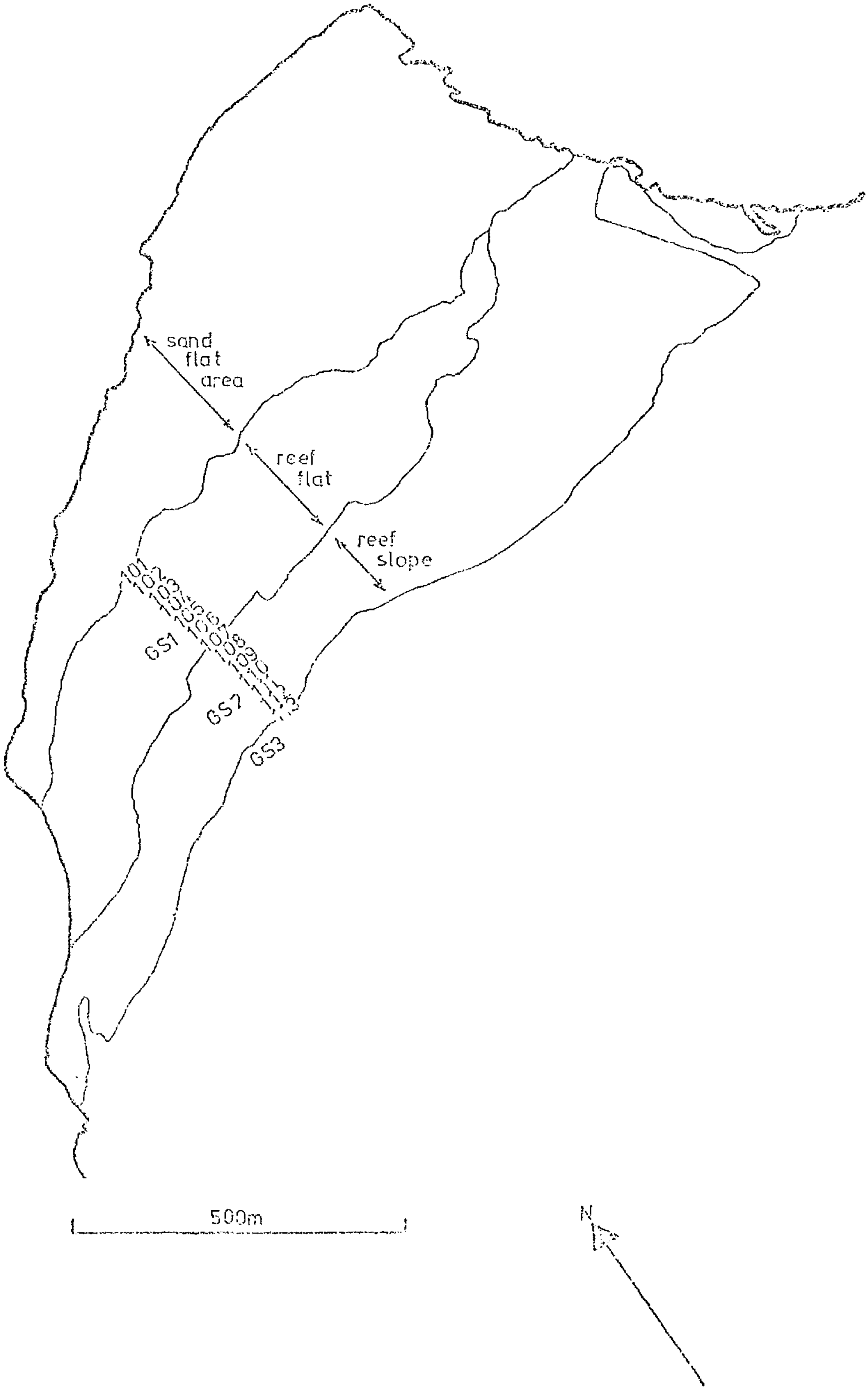
Various species diversity indices have been used in coral community analysis. Loya (1972) compared the merits of the species count, Shannon and Weaver's Index and Simpson's Index as ecological indicators for this kind of study. The species count and Shannon and Weaver's Index were used in the present study. The species count takes no account of the relative importance of each species. The Shannon and Weaver Index, however, is a more complex measure which takes the relative abundance or cover of each species into account. Thus the value of the Shannon and Weaver Index is affected by both the number of species on a transect line, and the "equitability" or evenness of the values for cover or abundance of each species.

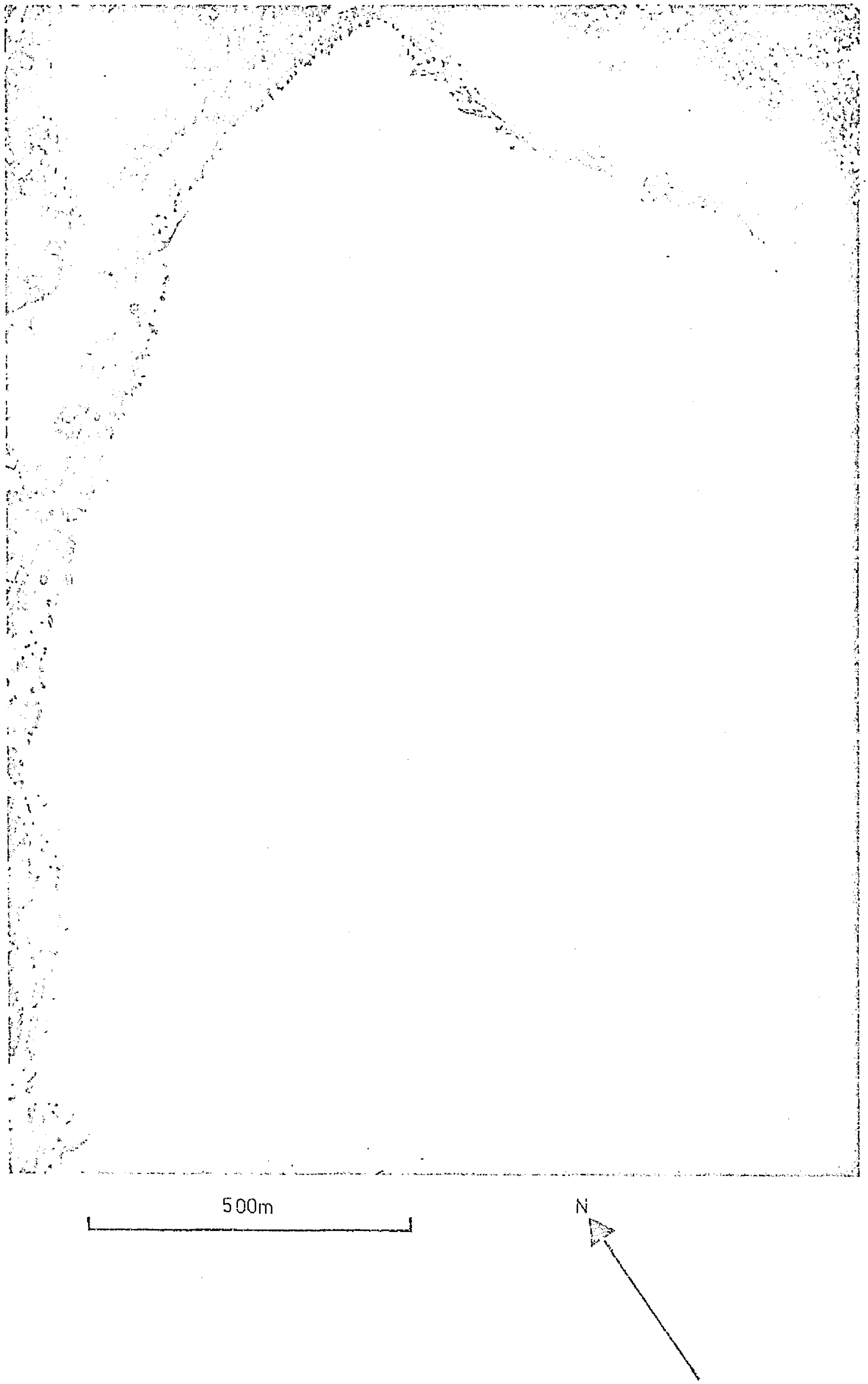
FIGURE 5

Map of Geoffrey Bay showing positions of line transects (numbers 101 to 113) and sediment sampling sites (numbers GS1, GS2 and GS3).

PLATE 1 (following page)

Aerial photograph of Geoffrey Bay. (Photograph supplied by the Surveyor-General, Queensland and reproduced by arrangement with the Queensland Government).


sand
flat
area
reef
flat
reef
slope
GS1
GS2
GS3
500m
N


500m
N

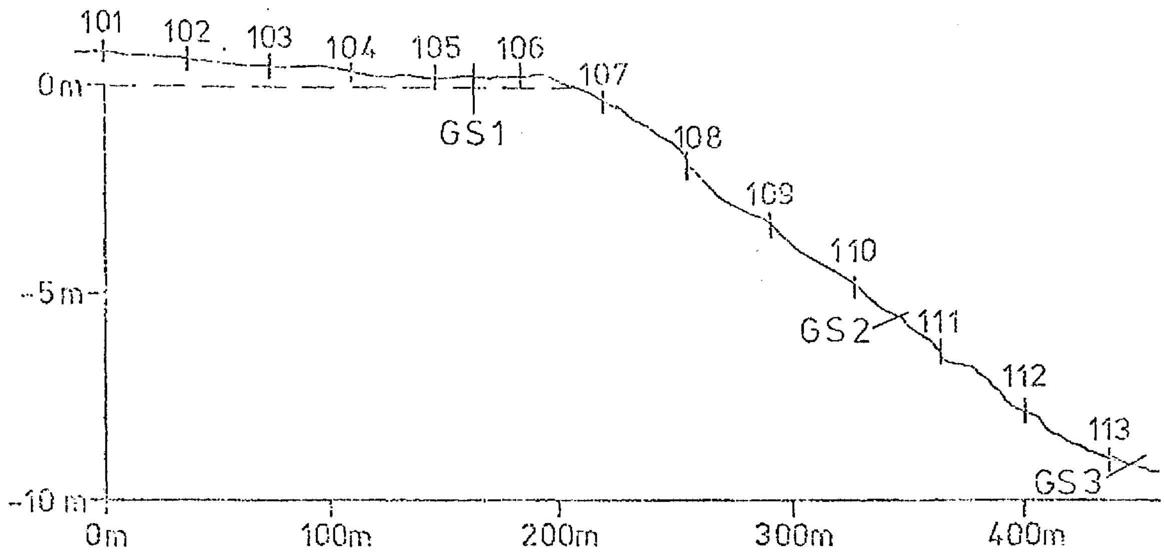


FIGURE 6

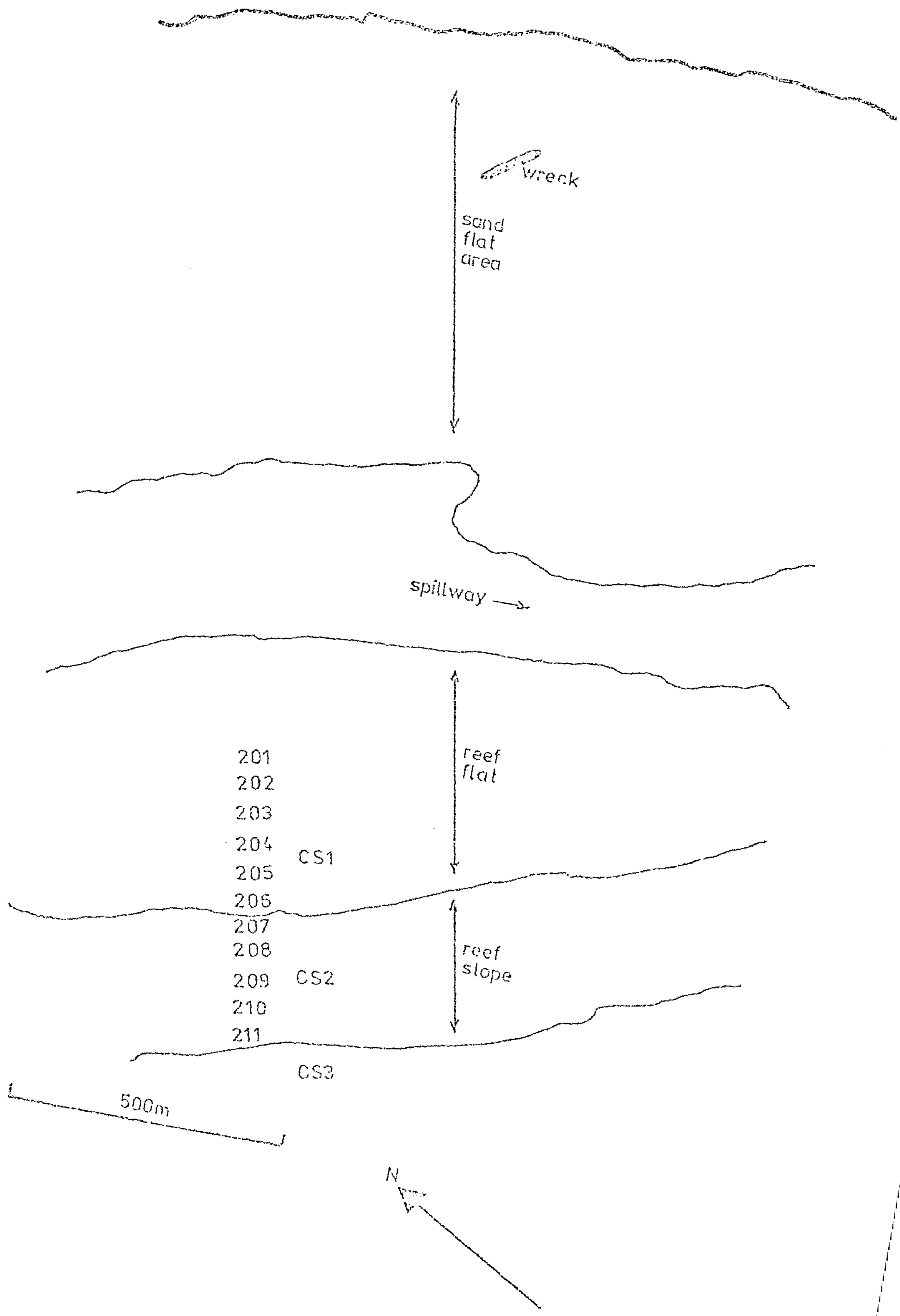
Diagrammatic profile of the Geoffrey Bay reef showing positions of line transects (numbers 101 to 113) and sediment sampling sites (numbers GS1, GS2 and GS3).

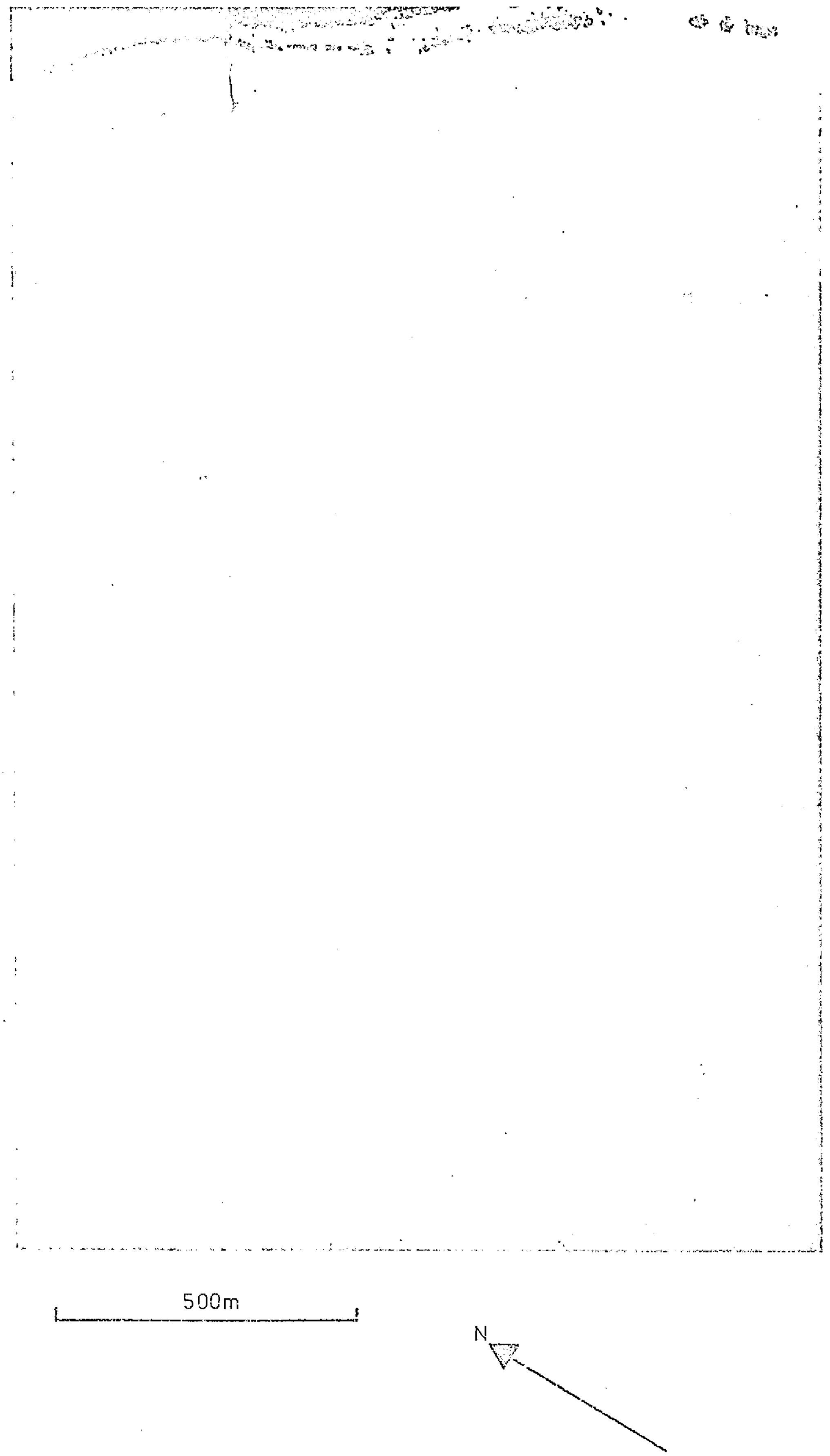
FIGURE 7

Map of section of Cockle Bay showing positions of line transects (numbers 201 to 211) and sediment sampling sites (numbers CS1, CS2 and CS3).

PLATE 2 (following page)

Aerial photograph of Cockle Bay. (Photograph supplied by the Surveyor-General, Queensland and reproduced by arrangement with the Queensland Government).


wreck
sand flat area
spillway
reef flat
201
202
203
204
205
206
207
208
209
210
211
CS1
CS2
CS3
reef slope
500m
N


500m
N

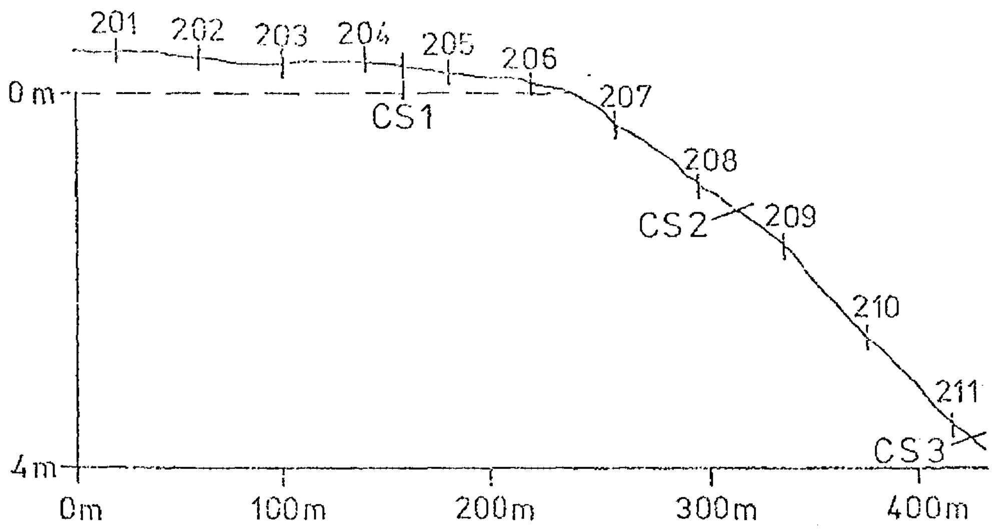


FIGURE 8

Diagrammatic profile of the Cockle Bay reef showing positions of line transects (numbers 201 to 211) and sediment sampling sites (numbers CS1, CS2 and CS3).

2 MATERIALS AND METHODS

2.1 POSITIONS OF TRANSECTS

The transects in each bay were positioned at right angles to a chosen line running perpendicular from the beach edge to the reef front (see Figures 5, 6, 7 and 8). Hand sighting compass bearings were taken in order to return to the site on each collection day.

Each transect line was positioned so as to fall within a single, visually homogeneous area, so that each of the major areas, reef flat, crest and seaward slope, were represented by three to five transects.

2.2 SAMPLING PROCEDURES

Sampling of reef flat transects was done on foot during periods of low spring tides of 0.2m or less. The remainder were surveyed using S.C.U.B.A.

At each transect position a 30m fibreglass tape was laid parallel to the shore line and along an even depth contour. The projected distance of every live coral colony on the line was recorded along with the species name.

Portions of colonies not immediately identified to species were chiselled off and placed in individually labelled plastic bags. These specimens were later tagged with embossing tape labels and bleached in a calcium hypocholorite bath for identification.

2.3 CORAL IDENTIFICATION

Assistance with identification was given by Professor

M. Pichon (Department of Marine Biology, James Cook University) and Dr J. Veron (Australian Institute of Marine Science). Because many species collected in the Magnetic Island area show unusual growth forms, it was not always possible to assign a definite species name. In such cases an individual code letter was assigned to specimens falling into a single species group, for the purposes of numerical analysis.

2.4 DATA PROCESSING

The initial results from the line transects were in the form of genus and species names, and size readings in cm, for each 30m transect line. For the purposes of data processing a three digit number was used to identify each transect; the first is an area code ("1" for Geoffrey Bay and "2" for Cockle Bay) followed by the numbers "01" to "13" corresponding to the position on the reef.

Each species was identified by a further three digit code number. The species numbers were the same as used by Dr Terry Done (Department of Marine Biology, James Cook University) for processing similar data (Done, 1977).

The raw data were then coded for input to the James Cook University's Dec. System 10 computer. Various computer programs were used to convert the raw data to various matrices and summary tables. A full list of programs and their uses is given in Appendix 1. Many of these programs were kindly provided by Dr Terry Done.

The Shannon and Weaver diversity indices (Shannon & Weaver, 1949), H'c and H'n were calculated according to the following formulae:

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

where s = the total number of species on the transect line

p_i = the porportion of the recorded live coverage on the transect line contributed by species i.

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

where s = the total number of species on the transect line

p_i = the proportion of the total number of individuals on the transect line belonging to species i.

2.5 HIERARCHICAL CLUSTER ANALYSIS

Numerical classifications of the transect lines were made using the program package CLUSTAN 1C (documentation Wishart, 1975). The transects were used as the "population" and the cover in cm or the number of individuals of each species on each line, were used as continuously varying numerical attributes.

Various combinations of dissimilarity measures and fusion strategies were tested:

The "Squared Euclinian Distance" dissimilarity measure was tested with the "Nearest Neighbour", "Furthest Neighbour" and "Group Average" fusion strategies. The "Bray-Curtis" dissimilarity measure was tested with "Group Average" and "Lance-Williams Flexible beta" fusion strategies.

The most satisfactory results were obtained using the combination of the Bray-Curtis metric measure (incorrectly named the "Canberra Metric" in CLUSTAN 1C Wishart, 1975) and the Lance-Williams Flexible beta fusion strategy.

The matrix of values for dissimilarity or "distance" between individuals is calculated using the Bray-Curtis measure (Bray & Curtis, 1959) as follows:

$$d_{ij} = \frac{\Sigma_k \mid x_{ik} - x_{jk} \mid}{\Sigma_k (x_{ik} + x_{jk})}$$

where d_{ij} = the distance between individual i and individual j.

x = the values of each of k attributes for the individuals i and j.

Individuals are fused into groups or clusters using the Lance-Williams Flexible beta strategy (Lance & Williams, 1967) in the following manner:

if individuals i and j are to be fused into a group k, the distance between another group h and the group k is calculated as follows:

$$d_{hk} = (\frac{1-\beta}{2}) d_{hi} + (\frac{1-\beta}{2}) d_{hj} + \beta d_{ij}$$

where d_{hk} = the distance between groups h and k.

d_{hi} = the distance between group h and individual i etc.

$\beta<1$, the value of β used for this study was $\beta = -0.25$.

2.6 SEDIMENT SAMPLING AND ANALYSIS

Three samples of bottom sediment were collected from each locality (Geoffrey Bay and Cockle Bay) using S.C.U.B.A. 300ml samples (equivalent to approximately 300g of dry sediment) were taken from the reef flat, halfway up the seaward slope, and the base of the slope (Figs. 5, 6, 7 and 8). Large pieces of shell and coral rubble (1cm diameter and above) were not included, as the distribution of such particles was uneven, and a much larger sample size would have been required to obtain a representative sample.

By its very nature the sampling technique was not random, nor comprehensive, but it was felt that three such samples would give some indication of sediment conditions in each bay.

The percentage weight of each sample falling into various grain size groups was determined using a procedure developed by A. Belperio (Geology Department, James Cook University) for the "Three Bays Multidisciplinary Project", according to principles reviewed by Carver (1971, Section II, Size Analysis). Particles were separated into the following grain size classes:

mm ($=10^{-3}$m)		ø (phi scale)
> 2.057	≡	> -1.04
2.057 to 0.455	≡	1.04 to 1.14
0.455 to 0.251	≡	1.14 to 1.99
0.251 to 0.0635	≡	1.99 to 3.98
0.0635 to 0.004	≡	3.98 to 7.95
< 0.004	≡	< 7.95

Large grain sizes were separated using sieves of different mesh sizes. The suspended sediment washed through the finest of the sieves was separated into the two finest grain size classes in a settling column using sinking velocities calculated according to Stoke's Law (Appendix 1 for details of procedures).

The mean, skewness and sorting coefficients of each sample were calculated using a graphical computation technique described by Carver (1971) (Appendix 2 for details of coefficients used).

3 RESULTS AND DISCUSSION

3.1 SEDIMENT ANALYSIS

Table 1 gives the mean, sorting and skewness figures, and the percentage weight of clay for each of the six sediment samples.

Sorting values are all similar, except for the Cockle Bay reef slope (CS2) and for the base of the reef slope (CS3) samples, which show a greater sorting range. These two samples also have high positive skewness. Skewness from the mean particles size implies an excess of fine particles (positive skewness) or an excess of coarse particles (negative skewness). Thus these two sub-tidal samples from Cockle Bay (CS2 and CS3) have an excess of fine particles. This is reflected in their high percentage clay values.

The mean grain size, sorting and skewness of the Geoffrey Bay samples are similar to those given by Smith (1974) for stations in Geoffrey Bay.

The two reef flat samples are similar except that the Cockle Bay reef flat sample (CS1) has a slightly smaller mean grain size than the Geoffrey Bay reef flat sample (GS1), which has a greater excess of coarse particles. The general similarity between the reef flat samples reflects a similarity of hydrodynamic and sediment conditions on the reef flats of the two Bays.

The sub-tidal samples from each Bay, however, differ greatly. The Cockle Bay sub-tidal samples (CS2 and CS3) have a much smaller grain size, greater excess of fine particles and higher percentage clay content than the

TABLE 1

Values of mean, sorting, skewness and percentage weight of clay for each of the six sediment samples.

	Sample Number	Sampling Position	Mean ø Value	Sorting (in ø units)	Skewness of Distribution about Mean ø Value	Percentage Weight of Clay
GEOFFREY	GS1	reef flat	1.23	1.56	-0.200	1.5
BAY	GS2	reef slope	0.75	1.86	-0.050	2.3
	GS3	base of slope	0.33	1.34	+0.025	1.2
COCKLE	CS1	reef flat	1.54	1.82	-0.050	1.2
BAY	CS2	reef slope	3.34	2.44	+0.225	7.8
	CS3	base of slope	1.58	2.46	+0.275	4.1

sub-tidal samples from Geoffrey Bay (GS2 and GS3). This reflects the reduced wave action and turbulence in Cockle Bay as compared to Geoffrey Bay. There may also be more suspended sediment in the Cockle Bay area due to the particularities of the local hydrodynamic conditions.

3.2 SPECIES COMPOSITION AND COMPARATIVE ABUNDANCE OF SPECIES ON THE GEOFFREY AND COCKLE BAY REEFS

A list of coral species recorded from the surveyed areas is given in Table 2. Full tables of the total cover and number of colonies of each species on each reef are given in Table 3 (Geoffrey Bay) and Table 4 (Cockle Bay).

78 species belonging to 33 genera and 14 families were recorded during the line transect survey. 69 species were recorded in Geoffrey, and 42 species were recorded in Cockle Bay. 33 species (42% of the total number recorded in the study) were common to both reefs. 36 species (46% of the total) were recorded only in Geoffrey Bay and 9 species (12% of the total) were recorded only in Cockle Bay.

These figures do not represent the total numbers of species present on the particular reefs. The line transect survey method is not intended to supply a full species list for an area. It is likely that other species will be present outside the transect areas at other places along the reefs. Furthermore, uncommon species which are present in the vicinity of a transect will only be recorded if the transect line happens to fall on colonies of those species. The number of species that are present but not recorded, however, is likely to be small, especially if the transect lines are of sufficient length and are well spaced over the reef.

TABLE 2

Full list of species recorded on the Geoffrey Bay and Cockle Bay transects (in taxonomic order), showing presence in each bay.

Species number		Presence recorded in Geoffrey Bay	Presence recorded in Cockle Bay
312	*Stylocoeniella guentheri* (Bassett-Smith, 1890)	x	
805	*Psammocora contigua* (Esper, 1797)	x	
809	*Stylophora pistillata* (Esper, 1797)	x	x
933	*Seriatopora caliendrum* (Ehrenberg, 1834)	x	x
800	*Pocillopora damicornis* (Linnaeus, 1758)	x	
885	*Acropora acuminata* (Verril, 1864)	x	x
890	*Acropora arcuata* (Brook, 1892)	x	
882	*Acropora echinata* (Dana, 1846)	x	
886	*Acropora hebes* (Dana, 1846)	x	
705	*Acropora humilis* (Dana, 1846)	x	
883	*Acropora rambleri* (Bassett-Smith, 1890)	x	
884	*Acropora rayneri* (Brook, 1892)	x	
891	*Acropora* sp. A	x	
892	*Acropora* sp. B	x	
893	*Acropora* sp. C	x	
876	*Montipora ramosa* Bernard, 1887	x	x
897	*Montipora* sp. A (foliose)	x	
898	*Montipora* sp. B (foliose)	x	x
899	*Montipora* sp. C (foliose)	x	
930	*Montipora* sp. D (foliose)	x	x
931	*Montipora* sp. E (foliose)	x	
756	*Pavona cactus* (Forskål, 1775)		x
783	*Pachyseris speciosa* (Dana, 1846)	x	x
463	*Coscinaraea columna* (Dana, 1846)	x	

739	*Fungia actiniformis* (Quoy & Gaimard, 1833)	x	
741	*Fungia fungites* (Linnaeus, 1758)		x
544	*Herpolitha limax* (Esper, 1797)	x	
804	*Polyphyllia talpina* (Lamarck, 1816)	x	
784	*Parahalomitra robusta* (Quelch, 1886)	x	
877	*Goniopora columna* Dana, 1846	x	
197	*Goniopora somaliensis* Vaughan, 1907	x	
878	*Goniopora tenella* (Quelch, 1886)	x	
879	*Goniopora tenuidens* (Quelch, 1886)	x	x
008	*Porites australiensis* Vaughan, 1918	x	x
932	*Porites horizontalata* Hoffmeister, 1925	x	
194	*Porites lobata* Dana, 1846	x	x
556	*Porites mayeri* Vaughan, 1918	x	x
889	*Porites murrayensis* Vaughan, 1918	x	x
875	*Porites solida* (Forskål, 1775)	x	x
881	*Porites* sp. (massive)	x	
888	*Porites viridis* Gardiner, 1898	x	
713	*Calaustrea furcata* Dana, 1846		x
724	*Favia favus* (Forskål, 1775)	x	x
727	*Favia speciosa* Dana, 1846	x	x
730	*Favites abdita* (Ellis & Solander, 1786)	x	
731	*Favites acuticollis* (Ortmann, 1889)	x	
936	*Favites bennettae* (Veron, Pichon & Wijsman-Best, 1977)	x	
732	*Favites chinensis* (Verrill, 1866)	x	x
935	*Favites flexuosa* (Dana, 1846)	x	x
736	*Favites pentagona* (Esper, 1794)	x	
737	*Favites virens* Dana, 1846	x	
186	*Goniastrea aspera* Verrill, 1865	x	x
745	*Goniastrea favulus* (Dana, 1846)	x	x
746	*Goniastrea palauensis* (Yabe, Sugiyama & Eguchi, 1936)	x	x
748	*Goniastrea pectinata* (Ehrenberg, 1834)	x	
795	*Platygyra daedalea* (Ellis & Solander, 1786)	x	x
797	*Platygyra pini* (Chevalier, 1975)	x	x
796	*Platygyra sinensis* (Edwards & Haime, 1849)	x	x
751	*Hydnophora exesa* (Pallas, 1766)	x	
774	*Montastrea valencienesi* (Edwards & Haime, 1848)	x	x
757	*Leptastrea transversa* Klunginger, 1879	x	x
513	*Cyphastrea microphthalma* (Lamarck, 1816)	x	

516 *Cyphastrea serailia* (Forskål, 1775)	x	x
777 *Moselya latistellata* Quelch, 1884	x	x
880 *Galaxea astreata* (Lamarck, 1816)	x	
766 *Merulina ampliata* (Ellis & Solander, 1786)		x
762 *Lobophyllia corymbosa* (Forskål, 1775)		x
763 *Lobophyllia hemprichi* (Ehrenberg, 1834)	x	x
274 *Symphyllia recta* Dana, 1846	x	x
719 *Echinophyllia aspera* (Ellis & Solander, 1786)		x
937 *Echinophyllia echinata* (Saville-Kent, 1871)		x
781 *Oxypora lacera* (Verrill, 1864)	x	x
778 *Mycedium Elaphantotum* (Pallas, 1766)	x	x
023 *Pectinia lactuca* (Pallas, 1766)	x	x
009 *Turbinaria auricularis* Bernard, 1896	x	x
820 *Turbinaria peltata* (Esper, 1797)	x	
887 *Turbinaria* sp. A		x
527 *Turbinaria stephonsoni* Crossland, 1952		x

TABLE 3

List of species recorded in Geoffrey Bay (in alphabetical order), showing total values recorded for each species on the 13, 30m transect lines.

Species number		Number of transect lines on which species was recorded	Total number of colonies recorded	Total cover (in cm) recorded
885	*Acropora acuminata*	3	9	394
890	*Acropora arcuata*	1	2	132
882	*Acropora echinata*	1	4	42
886	*Acropora hebes*	3	7	98
705	*Acropora humilis*	1	1	17
883	*Acropora rambleri*	3	4	72
884	*Acropora rayneri*	2	9	257
891	*Acropora* sp. A	2	5	222
892	*Acropora* sp. B	2	3	94
893	*Acropora* sp. C	1	1	15
463	*Coscinaraea columna*	2	4	91
513	*Cyphastrea microphthalma*	2	3	49
516	*Cyphastrea serailia*	7	14	107
724	*Favia favus*	4	12	126
727	*Favia speciosa*	7	8	80
730	*Favites abdita*	2	2	66
731	*Favites acuticollis*	1	1	10
936	*Favites bennettae*	1	1	11
732	*Favites chinensis*	1	1	14
935	*Favites flexuosa*	1	1	25
736	*Favites pentagona*	1	1	22
737	*Favites virens*	1	1	16
739	*Fungia actiniformis*	1	1	8

880	*Galaxea astreata*	2	2	18
186	*Goniastrea aspera*	7	33	249
745	*Goniastrea favulus*	3	3	16
746	*Goniastrea palauensis*	2	3	32
748	*Goniastrea pectinata*	2	2	41
877	*Goniopora columna*	2	2	33
197	*Goniopora somaliensis*	1	1	4
878	*Goniopora tenella*	1	5	89
879	*Goniopora tenuidens*	2	3	47
544	*Herpolitha limax*	1	1	11
751	*Hydnophora exesa*	2	3	74
757	*Leptastrea transversa*	2	2	21
763	*Lobophyllia hemprichi*	2	3	52
774	*Montastrea valencienesi*	3	4	29
876	*Montipora ramosa*	8	52	487
897	*Montipora* sp. A (foliose)	1	1	83
898	*Montipora* sp. B (foliose)	2	3	41
899	*Montipora* sp. C (foliose)	3	4	99
930	*Montipora* sp. D (foliose)	2	5	151
931	*Montipora* sp. E (foliose)	4	12	269
777	*Moselya latistellata*	2	3	15
778	*Mycedium elephantotum*	1	1	22
781	*Oxypora lacera*	2	3	149
783	*Pachyseris speciosa*	3	6	130
784	*Parahalomitra robusta*	1	1	6
023	*Pectinia lactuca*	1	1	26
795	*Platygyra daedalea*	3	6	92
797	*Platygyra pini*	4	6	37
796	*Platygyra sinensis*	7	28	231
800	*Pocillopora damicornis*	2	4	51
804	*Polyphyllia talpina*	3	4	49
008	*Porites australiensis*	7	9	89
932	*Porites horizontalata*	1	1	9
194	*Porites lobata*	6	8	87
556	*Porites mayeri*	1	1	2
889	*Porites murrayensis*	1	1	13
875	*Porites solida*	2	4	24

881 *Porites* sp. (massive)	1	1	2
888 *Porites viridis*	1	1	35
805 *Psammocora contigua*	1	1	1
933 *Seriatopora caliendrum*	1	1	15
312 *Stylocoeniella guentheri*	1	1	10
809 *Stylophora pistillata*	4	7	110
274 *Symphyllia recta*	2	4	32
009 *Turbinaria auricularis*	6	10	132
820 *Turbinaria peltata*	1	1	10

TABLE 4

List of species recorded in Cockle Bay (in alphabetical order), showing total values recorded for each species on the 11, 30m transect lines.

Species number		Number of transect lines on which species was recorded	Total number of colonies recorded	Total cover (in cm) recorded
885	*Acropora acuminata*	1	1	4
713	*Calaustrea furcata*	1	1	3
516	*Cyphastrea serailia*	6	8	69
719	*Echinophyllia aspera*	1	2	23
937	*Echinophyllia echinata*	1	1	12
724	*Favia favus*	6	18	121
727	*Favia speciosa*	2	6	74
732	*Favites chinensis*	1	2	16
935	*Favites flexuosa*	1	1	9
741	*Fungia fungites*	1	4	70
186	*Goniastrea aspera*	6	17	136
745	*Goniastrea favulus*	2	20	155
746	*Goniastrea palauensis*	1	4	15
879	*Goniopora tenuidens*	5	34	705
757	*Leptastrea transversa*	2	2	24
762	*Lobophyllia corymbosa*	1	3	40
763	*Lobophyllia hemprichi*	6	7	79
766	*Merulina ampliata*	3	8	106
774	*Montastrea valencionesi*	2	4	44
876	*Montipora ramosa*	3	127	2886
898	*Montipora* sp. B (foliose)	1	5	72

930 *Montipora* sp. D (foliose)	1	1	19
777 *Moselya latistellata*	2	3	23
778 *Mycedium elaphantotum*	1	1	25
781 *Oxypora lacera*	1	1	15
783 *Pachyseris speciosa*	1	1	4
756 *Pavona cactus*	1	1	7
023 *Pectinia lactuca*	1	1	36
795 *Platygyra daedalea*	1	1	6
797 *Platygyra pini*	1	1	47
796 *Platygyra sinensis*	2	3	76
008 *Porites australiensis*	2	3	25
194 *Porites lobata*	5	6	46
556 *Porites mayeri*	5	15	96
889 *Porites murrayensis*	2	2	4
875 *Porites solida*	4	5	115
933 *Seriatopora caliendrum*	1	1	8
809 *Stylophora pistillata*	1	1	5
274 *Symphyllia recta*	4	14	287
009 *Turbinaria auricularis*	8	24	290
887 *Turbinaria* sp. A	3	6	54
527 *Turbinaria stephonsoni*	1	1	18

The number of species recorded on each reef indicates a generally greater diversity of coral species on the Geoffrey Bay reef than on the Cockle Bay reef. This reflects the relative extremeness of the environment in Cockle Bay. Both reef flat areas can be regarded as environmentally extreme and will therefore have few species. The sub-tidal area of Cockle Bay, however, can also be regarded as environmentally extreme with regard to sediment conditions. Hence the smaller number of species in Cockle Bay than in Geoffrey Bay.

The number of species that are common to both Bays indicates an overall degree of similarity with regard to species composition on the two reefs. Abundant species common to both reefs include *Montipora ramosa*, *Favia favus*, *Goniastrea aspera* and *Turbinaria auricularis*.

Acropora species which are fairly abundant in Geoffrey Bay are almost totally absent in Cockle Bay; one colony of *A. acuminata* was the only *Acropora* recorded in Cockle Bay. Other ramose species, *Stylophora pistillata* and *Pocillopora damicornis* , in particular, are similarly sparse in Cockle Bay. Many of the delicate foliose species with small corallites such as foliose *Montipora* species, *Pachyseris speciosa* and *Oxypora lacera* are more abundant in Geoffrey Bay than in Cockle Bay. There is, however, a greater abundance of some large polyped species including *Goniopora tenuidens*, *Symphyllia recta* and *Fungia fungites*, in Cockle Bay than in Geoffrey Bay.

It is generally considered that coral species with large fleshy polyps and those with active ciliary or tentacular actions are more favoured in silty conditions than most species with small polyps (Maragos, 1972; Pichon, 1973, and Loya, 1976a). Hubbard & Pocock (1972) describe the following four mechanisms for sediment rejection by recent scleratinian corals:

- Distension of polyp by stomodeal uptake of water
- Tentacular cleaning action
- Ciliary cleaning action
- Mucous entanglement.

It is noticeable that many of the species that are particularly abundant in the Cockle Bay transects have such adaptations to resist siltation. Similarly many of the species conspicuously rare or absent in Cockle Bay, but common to Geoffrey Bay, are not resistant to siltation.

3.3 DISTRIBUTION OF VARIOUS SPECIES WITHIN THE TRANSECT LINES

3.3.1 *Stylophora pistillata*

Stylophora pistillata is poorly represented in Cockle Bay. It is a small polyped species that is intolerant of Cockle Bay's silty conditions.

In Geoffrey Bay this species is distributed on the lower seaward slope of the reef (Fig. 9.1). Loya (1976), describes *Stylophora pistillata* as an *r* strategist, able to maintain itself in unstable environments (by having a high growth rate, good regeneration potential, short lifespan, and high population turnover). Loya found that when competition for space occurs, this species is out-competed by others. Its lack of ability to compete for space may explain its presence only on the lower reef slope.

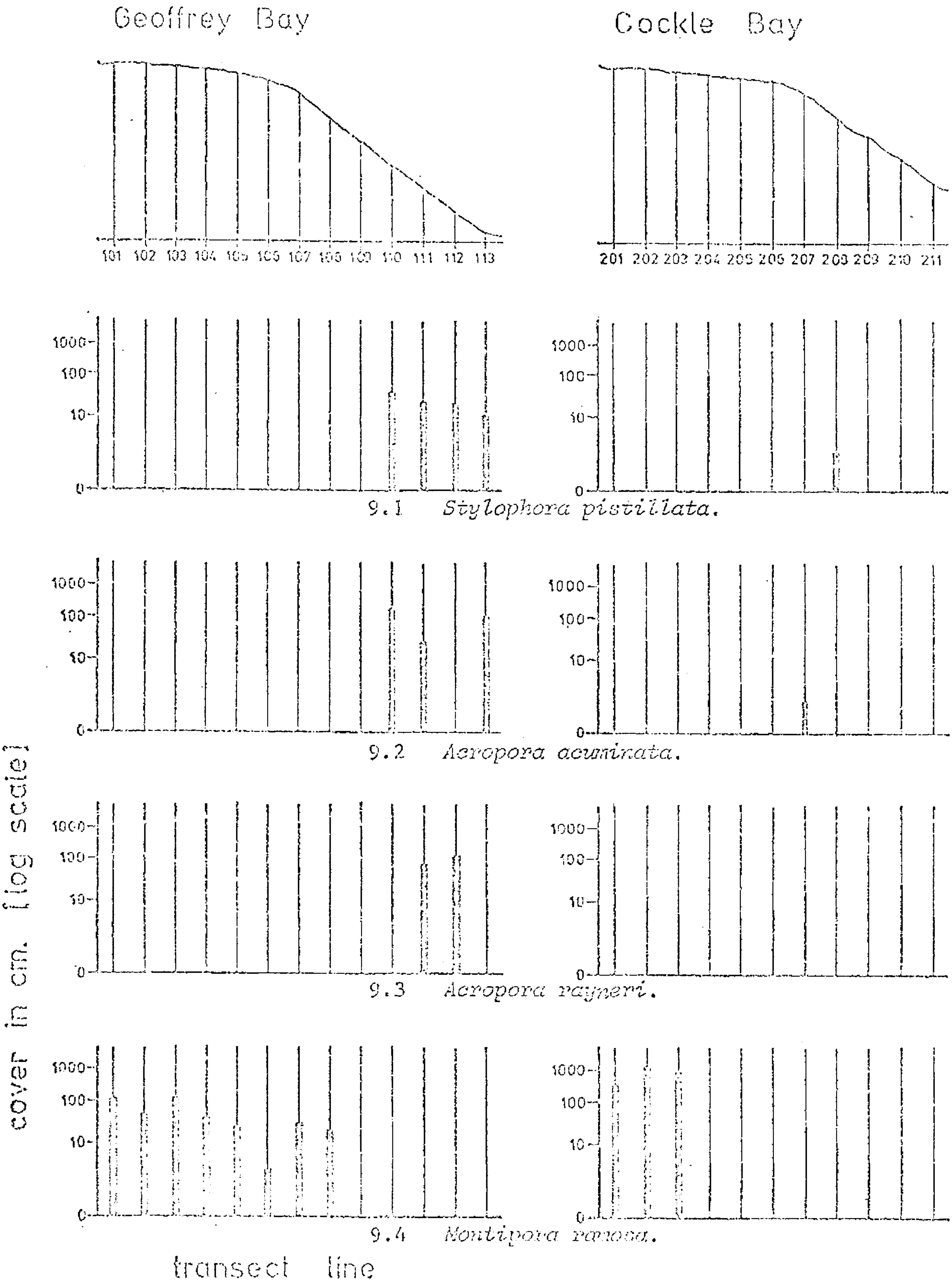
3.3.2 *Acropora* species

10 species of *Acropora* were recorded in Geoffrey Bay; only one colony of one species in Cockle Bay. Distributions of the two most prominent species, with respect

FIGURE 9

Distributions of various species within the Geoffrey Bay transect lines, (Graphs of cover in cm on each 30m transect line) in relation to diagrammatic profiles of the reefs.

9.1 *Stylophora pistillata*
9.2 *Acropora acuminata*
9.3 *Acropora rayneri*
9.4 *Montipora ramosa*
9.5 *Montipora* sp. D (foliose)
9.6 *Montipora* sp. E (foliose)
9.7 *Pachyseris speciosa*
9.8 *Goniopora tenuidens*
9.9 *Porites solida*
9.10 *Porites lobata*
9.11 *Porites australiensis*
9.12 *Favia favus*
9.13 *Goniastrea aspera*
9.14 *Platygyra sinensis*
9.15 *Symphyllia recta*
9.16 *Turbinaria auricularis*

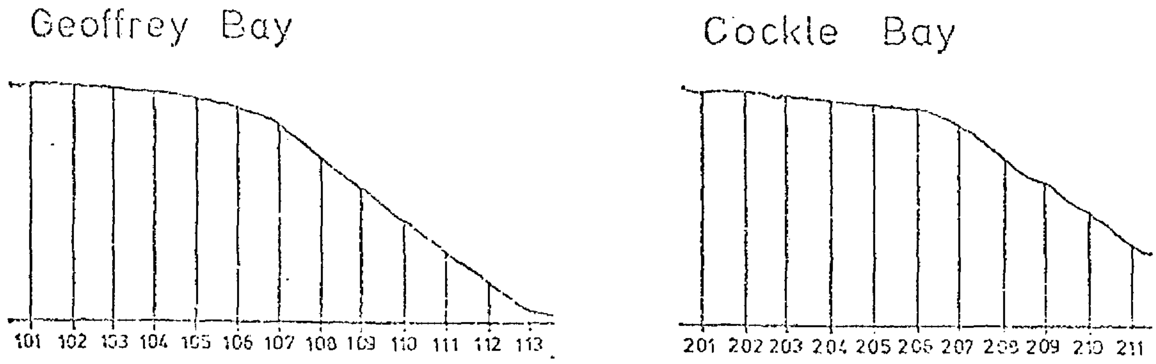


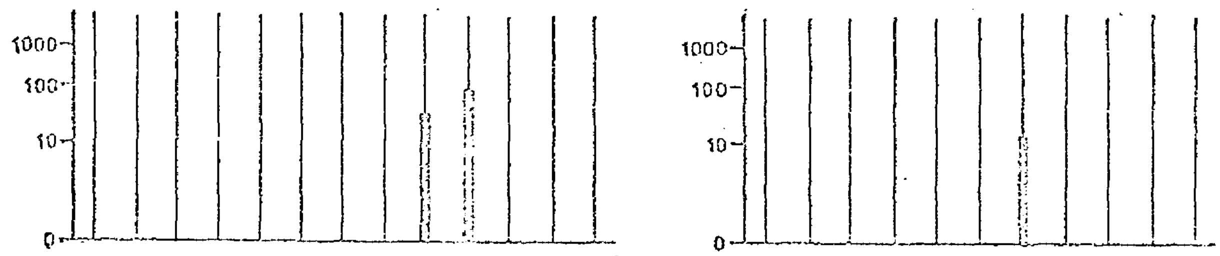
9.1 *Stylophora pistillata.*

9.2 *Acropora acuminata.*

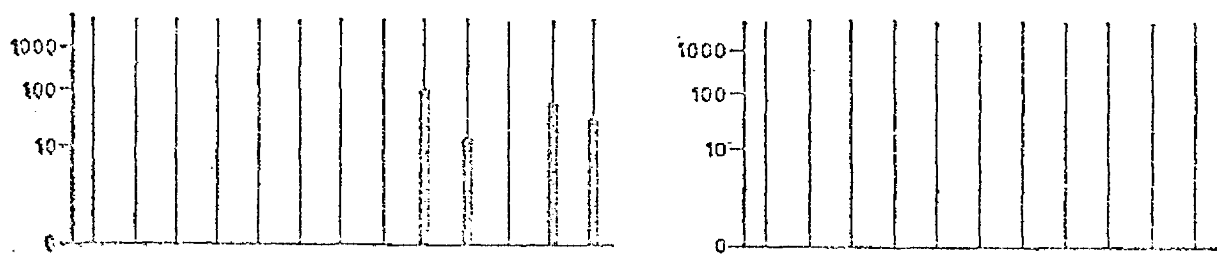
9.3 *Acropora rayneri.*

9.4 *Montipora ramosa.*

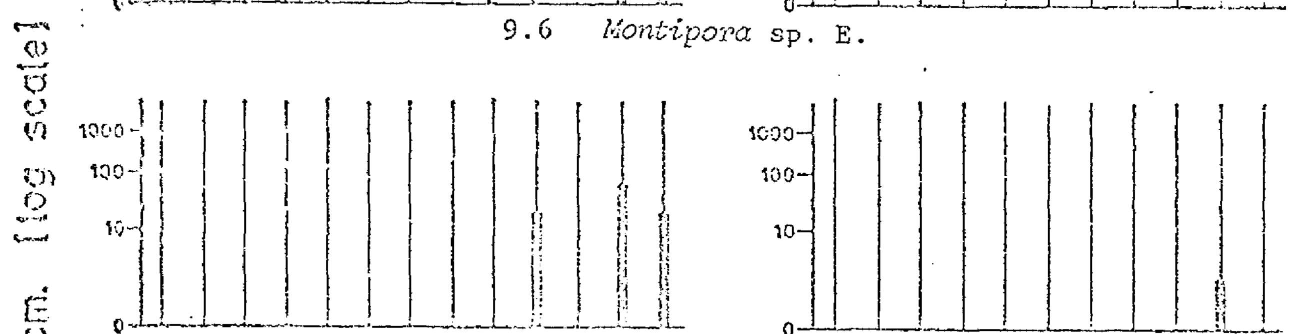




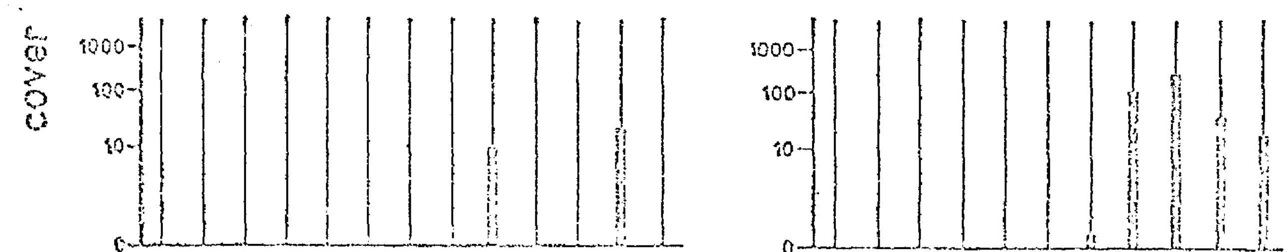
9.5 *Montipora* sp. D.



9.6 *Montipora* sp. E.

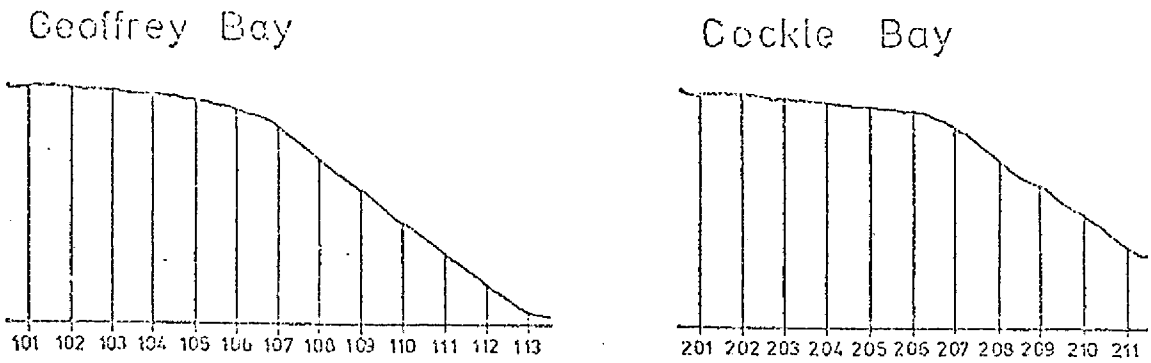


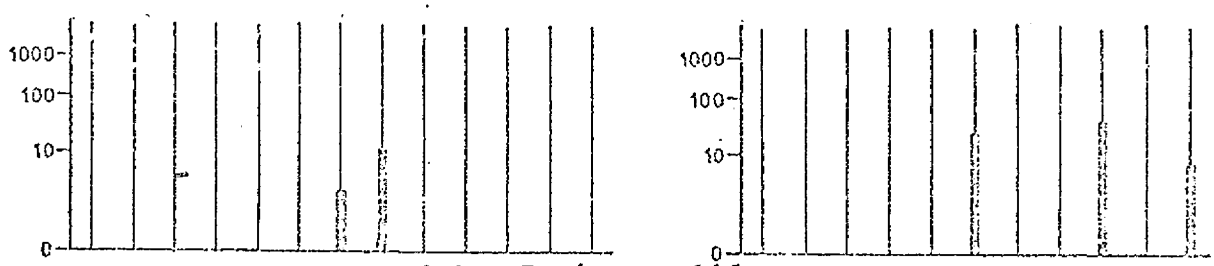
9.7 *Pachyseris speciosa.*



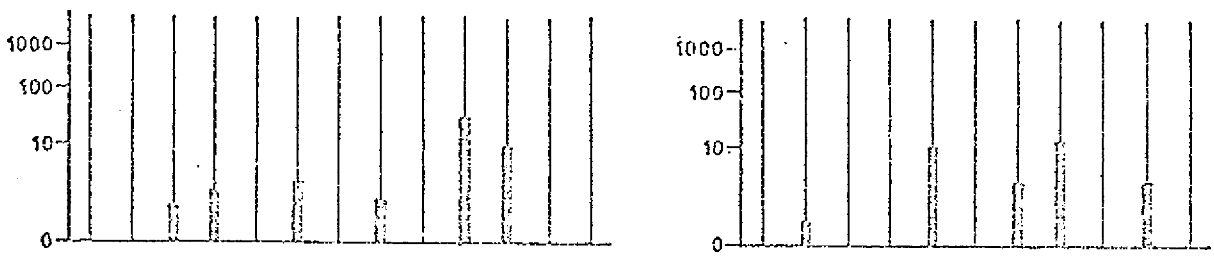
9.8 *Goniopora tenuidens.*

transect line

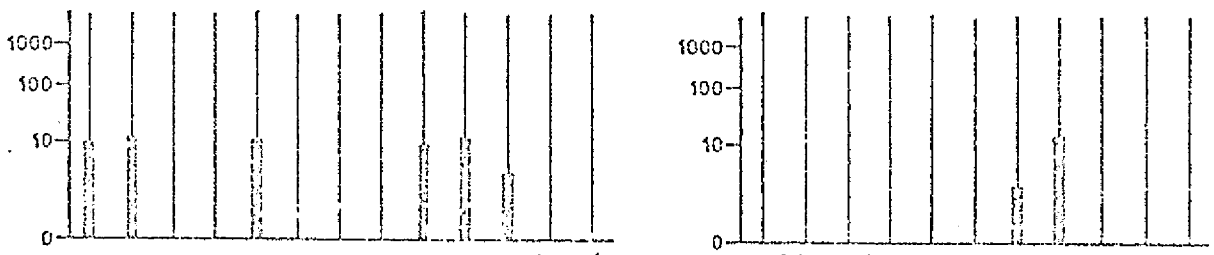




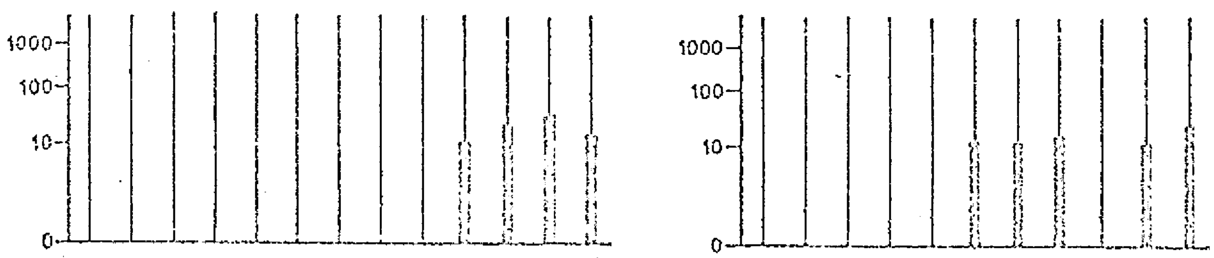
9.9 Porites solida.



9.10 Porites lobata.



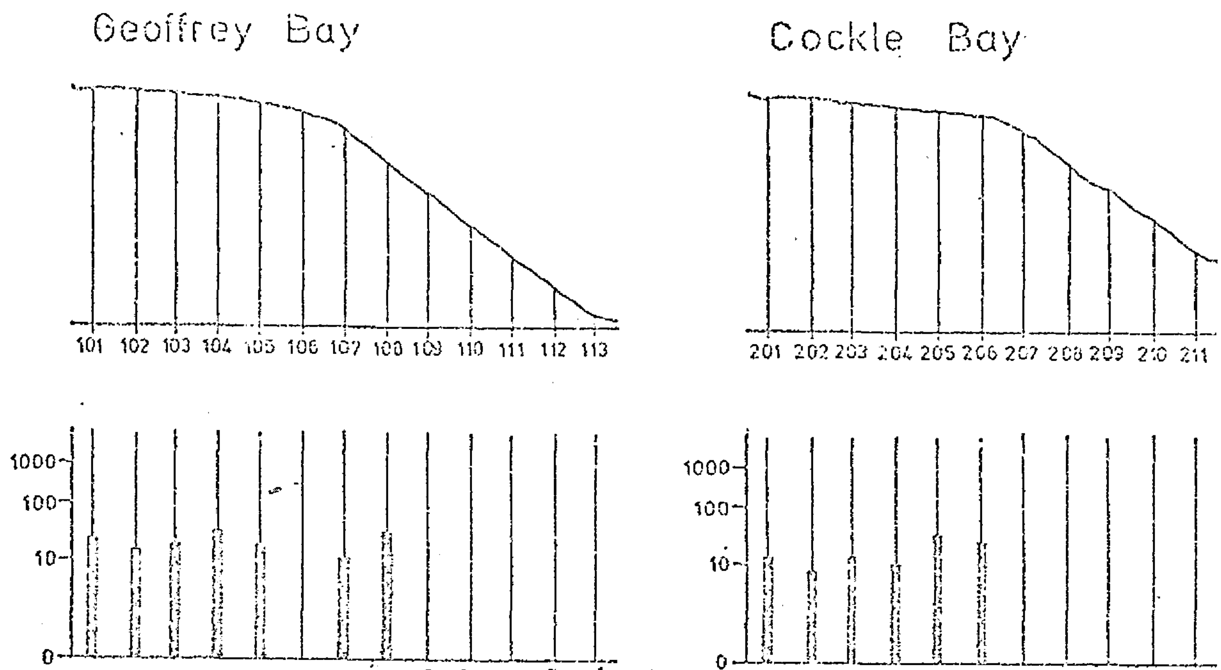
9.11 Porites australiensis.



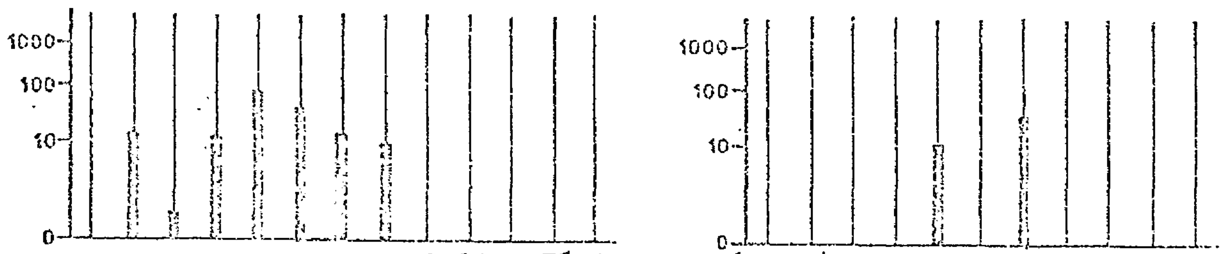
9.12 Favia favus.

transect line

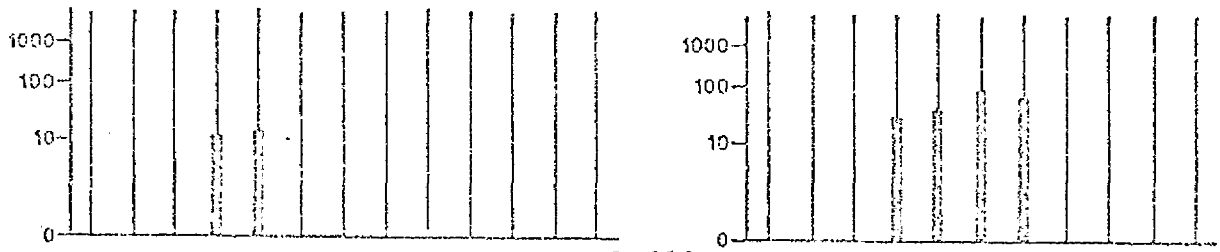
cover in cm. [log scale]



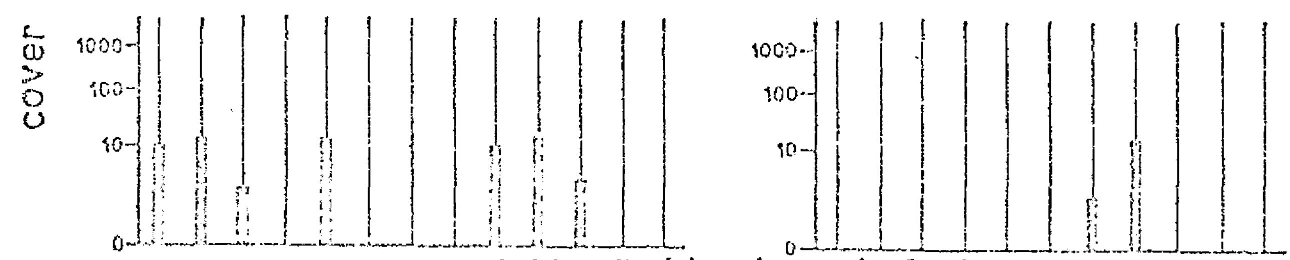
9.13 *Goniastrea aspera.*



9.14 *Platygyra sinensis.*



9.15 *Symphyllia recta.*



9.16 *Turbinaria auricularis.*

transect line

to cover, (*A. acuminata* and *A. rayneri*) are given (Figs. 9.2 and 9.3). All the 10 *Acropora* species are typically distributed on the middle and lower slope of the Geoffrey Bay reef.

Acropora is not generally found in heavily sedimented situations (e.g. Cockle Bay). The slope area where *Acropora* is present in Geoffrey Bay is the steepest part of the reef. Corals thus situated may be less prone to the effects of siltation (Loya, 1972).

Branching *Acropora* species also require moderate water agitation (see discussion of reef schemes of Pichon and Rosen, section 1.3.3), which explains their presence on the reef slope of Geoffrey Bay.

3.3.3 *Montipora ramosa*

In both Geoffrey and Cockle Bays, *Montipora ramosa* is the species with the highest recorded cover. In Cockle Bay it densely covers very large areas of the inner reef flat (Fig. 9.4). It was recorded as covering 21%, 43% and 32% of lines 201, 202 and 203 respectively. These were the highest recorded percentage covers of any single species on any of the transect lines.

In Geoffrey Bay *Montipora ramosa* is abundant on the inner reef flat, but also extends as far as the reef crest area, although with reduced cover.

On the inner reef flat areas the attachment bases of this species are densely packed and many branches interlock. This means that values obtained from the line transect survey for numbers of individuals of *Montipora ramosa* are more representative of the number of "beds" of this species. Branch lengths, measured from the attachment bases to the extreme tips, rarely exceed 10cm, implying that the actual average colony size is small (about 10cm diameter).

Much of the reef flat areas of Geoffrey and Cockle Bays has a non-stabilized substrate composed of shifting coral rubble. *Montipora ramosa* is the only species which is able to become abundant in these unstable areas. Other species only reach any significant level of cover and colony size where there is a firm substrate for attachment.

From work done on the reef flat of Nelly Bay and elsewhere, M. Yamaguchi (personal communication) has found that *Montipora ramosa* exhibits an extremely fast growth rate and exceptional powers of regeneration. He also thinks that these species may not reproduce sexually, but increase in numbers of individuals by regeneration of whole colonies from broken fragments. Yamaguchi suggests that *Montipora ramosa* is able to maintain high cover on reef flat areas with non-stabilized substrate because of its fast growth rate and ability to regenerate from broken fragments.

Because of the sheltering of Cockle Bay the rubble substrate is probably not shifted around by wave and swell action as much as in Geoffrey Bay. This might explain the much higher coverage of *Montipora ramosa* on the inner reef flat of Cockle Bay.

3.3.4 Foliose *Montipora* species

5 Foliose *Montipora* species were recorded in Geoffrey Bay, and 2 in Cockle Bay. Distributions of *Montipora* sp.D and *Montipora* sp.E are given in Figure 9.6. All 5 species are present on the reef slope transects only.

The sheets or leaves of foliose *Montipora* species often form a funnel shape. This colony configuration may be adopted to optimize light utilization. A funnel configuration however is definitely sub-optimal where high sedimentation rates prevail. This may explain why fewer species and lower cover of foliose *Montipora* species were recorded in Cockle Bay.

3.3.5 *Pachyseris speciosa*

The distribution of *Pachyseris speciosa* (Fig. 9.7) is typical of many of the delicate foliose species with small polyps (e.g.*Oxypora lacera*). The sensitivity of such corals to siltation explains their general paucity in Cockle Bay.

3.3.6 *Goniopora tenuidens*

Goniopora tenuidens is the most prominent species with respect to cover on the reef slope area of Cockle Bay (Fig. 9.8). Some very large colonies (greater than 1.5m in diameter) were recorded. The polyps of *Goniopora tenuidens* are long and thin and extend during the daytime as well as at night. By remaining continually distended it passively avoids accumulation of sediment on the polyp. Active tentacular action is also likely.

Adaptations to survive in silty conditions allow *Goniopora tenuidens* to attain large colony sizes and to dominate the reef slope area of Cockle Bay.

3.3.7 *Porites* species

Distributions of *Porites solida* and *P. lobata* are given in Figures 9.9 and 9.10. Both species are distributed throughout the reef areas. Colony sizes on the reef flat are generally small, 3 to 4cm. However, colonies up to 1m in diameter are present on slope areas.

Polyps of *Porites* are able to actively reject sediment particles by tentacular manipulation (Hubbard & Pocock, 1972). *Porites* species are thus able to withstand silty conditions.

The distribution of *Porites australiensis* is given in Figure 9.11. This species is similarly distributed, with smaller colonies on the reef flat than on the slope. There is, however, a distinct area of "microatolls" of *P. australiensis* on the inner reef flat in Geoffrey Bay (transects 101, 102 and 103). Microatolls develop when a coral (especially *Porites* species) is sufficiently well adapted to the reef flat environment to attain a large colony size. Upward growth of the colony is limited by exposure during low tides. Thus most growth is oriented to horizontal increase in colony size. Death of the top part of the colony often occurs, and in this manner an atoll-shaped colony is developed.

3.3.8 Faviidae

The distribution of three particularly abundant Faviid species, *Favia favus*, *Goniastrea aspera* and *Platygyra sinensis* are given in Figures 9.12, 9.13 and 9.14. *Favia favus* is only found on the reef slopes, whereas *Goniastrea aspera* and *Platygyra sinensis* are more typical of the outer reef flat and crest.

The abundant faviid species have fairly similar distributions and cover in both Geoffrey and Cockle Bays, although there is a greater number of less important species in Geoffrey Bay. This again reflects the greater selectivity of species caused by the severity of the environment in Cockle Bay.

3.3.9 *Symphyllia recta*

In both Geoffrey and Cockle Bays *Symphyllia recta* is particularly important in the outer reef flat and crest areas (Fig. 9.15). On the outer reef flat, colonies are often distributed around the edges of pools which remain partly filled at low spring tides. Nearer the upper slope, large spherical colonies are more common, expecially in Cockle Bay.

3.3.10 *Turbinaria auricularis*

Distributions in Geoffrey and Cockle Bays of *Turbinaria auricularis* are given in Fig. 9.16. This species is distributed from the outer reef flat down to the base of the slope.

Colony size recordings varied from 1cm to 45cm. On the reef slopes there were some well developed stacked plate colonies. Many recordings of this species, however, were of small colonies, 2 to 5cm in diameter. These smaller colonies were often attached to species of coral rubble partly buried in sediment.

3.4 ANALYSIS OF TRANSECT CHARACTERISTICS

Values for the number of species, number of genera, percentage coral cover, number of colonies, mean, maximum and minimum colony size, the standard deviation from the mean colony size and the Shannon and Weaver diversity indices H'c and H'n, are given for each 30m transect line in Table 5 (Geoffrey Bay) and Table 6 (Cockle Bay).

3.4.1 Geoffrey Bay

There is a greater number of species and genera on the reef slope transects than on the reef crest or reef flat transects, i.e. there is an increase in number of species when moving horizontally from the inner reef flat to the reef crest and vertically (with increasing depth of water) from the reef crest to the base of the reef slope.

TABLE 5

Transect line data for Geoffrey Bay.

Transect line number	Number of genera	Number of species	Percentage coral cover	Number of colonies	Average colony size (in cm)	Standard deviation from average colony size	Minimum colony size (in cm)	(species number to which size value corresponds)	Maximum colony size (in cm)	(species number to which size value corresponds)	Shannon and Weaver Diversity Index H'c	Shannon and Weaver Diversity Index H'n
101	3	3	5.73	20	8.60	4.59	1	(008)	19	(876)	0.773	0.886
102	4	5	44.80	15	9.60	5.03	2	(796)	19	(796)	1.287	1.287
103	5	7	5.80	20	8.70	3.94	2	(796)	15	(876)	1.001	1.400
104	7	9	5.93	25	7.12	3.77	2	(513)	14	(274)	1.669	1.504
105	5	5	6.27	20	9.40	5.40	2	(796)	22	(796)	1.360	1.400
106	6	7	4.00	14	8.57	4.20	3	(796)	17	(727)	1.440	1.451
107	7	8	3.93	14	8.43	4.61	4	(186)	21	(009)	1.812	1.909
108	6	10	5.23	26	6.04	4.25	2	(009)	18	(797)	1.879	1.977
109	12	20	20.56	32	20.56	17.86	6	(886)	83	(897)	2.609	2.853
110	17	24	35.23	46	22.98	20.15	2	(516)	115	(885)	2.823	2.981
111	13	30	24.07	46	15.69	12.30	1	(805)	65	(781)	2.950	3.202
112	18	20	24.03	40	18.03	14.15	2	(556)	65	(781)	2.531	2.442
113	13	19	26.13	35	22.40	22.40	2	(880)	107	(890)	2.373	2.773

TABLE 6

Transect line data for Cockle Bay.

Transect line number	Number of genera	Number of species	Percentage coral cover	Number of colonies	Average colony size (in cm)	Standard deviation from average colony size	Minimum colony size (in cm)	(species number to which size value corresponds)	Maximum colony size (in cm)	(species number to which size value corresponds)	Shannon and Weaver Diversity Index H'c	Shannon and Weaver Diversity Index H'n
201	2	2	21.63	35	18.54	28.72	2	(186)	163	(876)	0.121	0.293
202	3	3	43.17	73	17.74	19.08	1	(876)	90	(876)	0.053	0.145
203	2	2	32.90	26	37.96	115.04	3	(876)	606	(876)	0.087	0.271
204	3	3	2.50	5	15.00	10.04	6	(186)	33	(274)	0.942	1.055
205	9	11	8.70	19	13.74	11.44	3	(757)	47	(797)	2.079	2.132
206	6	8	14.23	33	12.94	12.22	3	(875)	65	(274)	1.799	1.670
207	15	19	16.83	50	10.10	10.01	1	(745)	50	(796)	2.349	2.634
208	10	15	14.17	41	10.37	10.00	2	(889)	46	(009)	2.193	2.197
209	6	8	23.80	29	24.62	27.35	3	(879)	114	(879)	2.182	1.597
210	10	11	5.73	18	9.56	9.88	2	(516)	44	(879)	2.064	2.293
211	10	13	8.50	25	9.45	7.34	2	(009)	29	(762)	2.156	2.191

The number of species on the reef flat is probably controlled by regularly occurring extremes of environment, due to the effects of tides, and occasional "catastrophic" changes, due to the influence of weather. The distribution of numbers of species is similar to that found by Loya (1972). Although reduction of light intensity with depth generally has an effect on species numbers (Wells, 1957), low light intensities are unlikely to affect the number of species at even the deepest of the Geoffrey Bay transects (9m), despite very poor average water clarity. Loya (1972) suggested a limit of 30m as the depth at which species numbers start being limited by light intensity at Eilat (where average water clarity is exceptionally high).

There is a higher percentage cover of live coral on the reef slope transects than on the reef flat and reef crest. This increase in coral cover with depth is probably caused by the same factors as the increase in numbers of species with depth (i.e. because of extremeness of environment on the reef flat). The lower limit of coral cover is reached at the base of the slope where the flat muddy bottom of the Bay provides no suitable substrate for coral growth.

The number of colonies, the average colony size and the maximum colony size are all markedly greater on the reef slope transects than on the reef flat and reef crest transects. Again these differences can be explained by the increase in environmental stability with depth. The minimum colony size, unlike the maximum colony size, shows no pattern of change with depth. Thus an increase in range of colony size with depth is reflected in the high values for standard deviation from the mean colony size, in the reef slope transects.

The Shannon and Weaver diversity indices H'c and H'n also show an increase with depth. Again it is, as one would expect, due to the increase of environmental stability with depth. Loya (1972) found at Eilat that the highest values of H'c and H'n were recorded on the steepest sections of the reef slope. He suggested that this was because settling sediment is spread over a wide area where the substrate is steep. It is interesting to note that the two indices, H'c (calculated on cover proportions of each species) and H'n (calculated on the proportions of numbers of individuals of each species), have markedly similar values throughout the transects. This reflects the fact that the increases in species number, number of colonies, percentage cover and colony size with depth, closely follow each other.

3.4.2 Cockle Bay

As in the Geoffrey Bay transects there is an increase in the number of species with depth. The absolute number of species per transect in each area of the reef, however, is lower than in Geoffrey Bay, reflecting the fact that the total number of species is less in Cockle Bay.

The inner reef flat transects (201, 202 and 203) show high percentage cover values, due mainly to the dense beds of *Montipora ramosa*. Also the problem of definition of individuals of *Montipora ramosa* previously mentioned (section 3.3.3), confuses the values for numbers of colonies and average colony size for these transects.

Apart from the inner reef flat which is so dominated by a single, well adapted species, the other reef flat transects (204 to 207) have lower percentage cover values than most of the reef slope transects, although this is less marked than in Geoffrey Bay.

There is no clear pattern of changes in number of colonies, average colony size or maximum colony size, as is shown in Geoffrey Bay. Nevertheless, there are increases in the Shannon and Weaver diversity indices from the inner reef flat to the reef slope. The values of H'c and H'n do not follow each other as closely as they do in Geoffrey Bay. This is probably because of the lack of any clear pattern of increase in number of colonies and colony size with depth.

In Geoffrey Bay the differences in the values of the transect characteristics between the reef flat and crest area, and the reef slope area, can be explained by the fact that the reef flat is more environmentally extreme than the subtidal slope. The whole of Cockle Bay, however, can be regarded as environmentally extreme, due to the ever present and dominant influence of high sedimentation rates. This also explains why the differences between the reef areas, with respect to the characteristics discussed, are less marked in Cockle Bay than in Geoffrey Bay.

3.5 CLUSTER ANALYSIS OF TRANSECTS

Figures 10 to 15 are hierarchical classifications (presented as dendrograms) of the transects for Geoffrey Bay, Cockle Bay and both bays combined.

The nodes on the horizontal axes are labelled with the transect numbers. The vertical axes bear the scale of the dissimilarity measure.

When interpreting such dendrograms, it must be remembered that the absolute positions of transects on the horizontal axis are irrelevant. It is the relative positions and the levels at which transects or groups of transects are fused with others which are important. The

FIGURE 10

The 13 Geoffrey Bay transects classified on the <u>cover</u> values of each of the 69 species attributes.

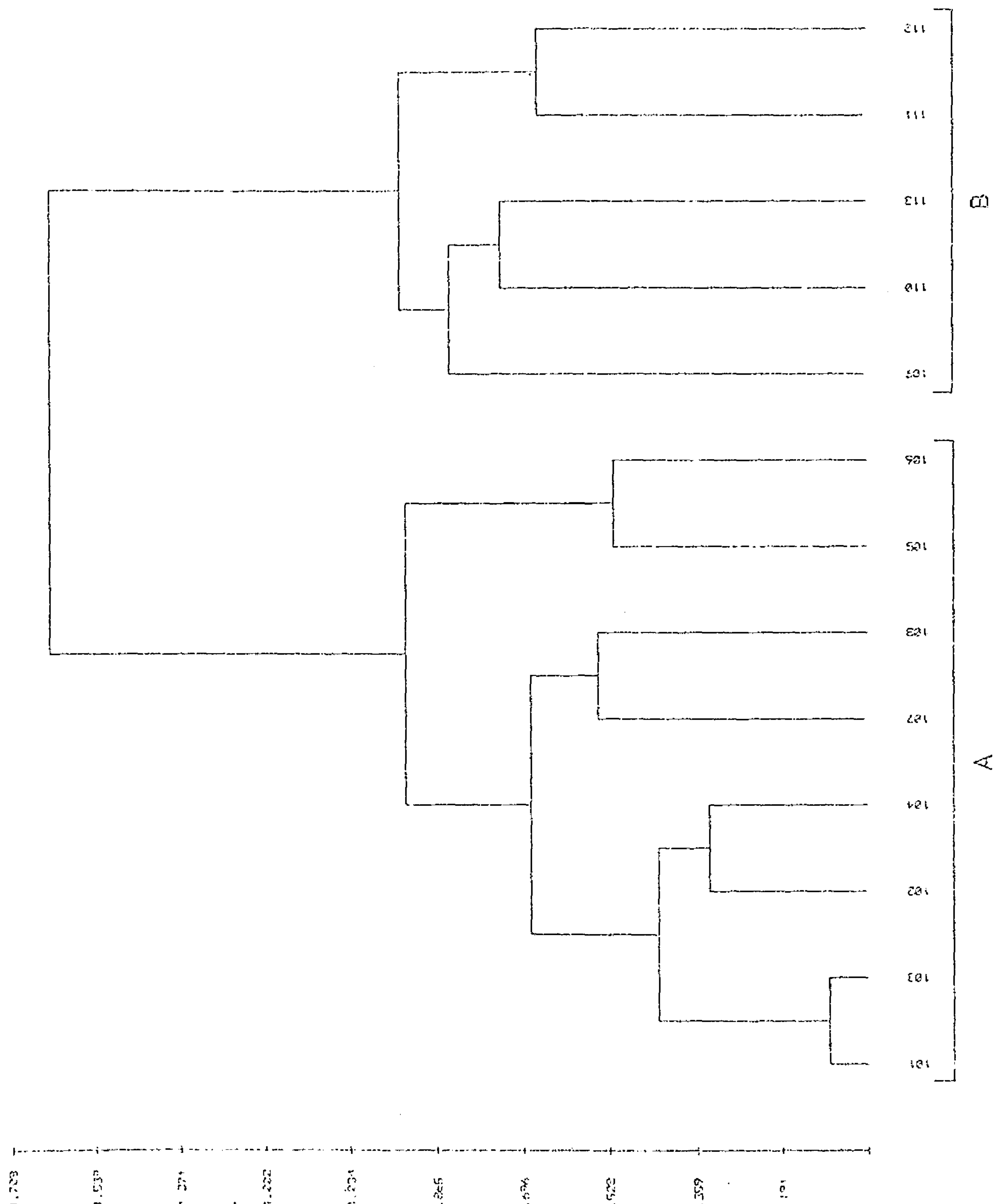

B
A

FIGURE 11

The 13 Geoffrey Bay transects classified on the <u>colony number</u> values of each of the 69 species attributes.

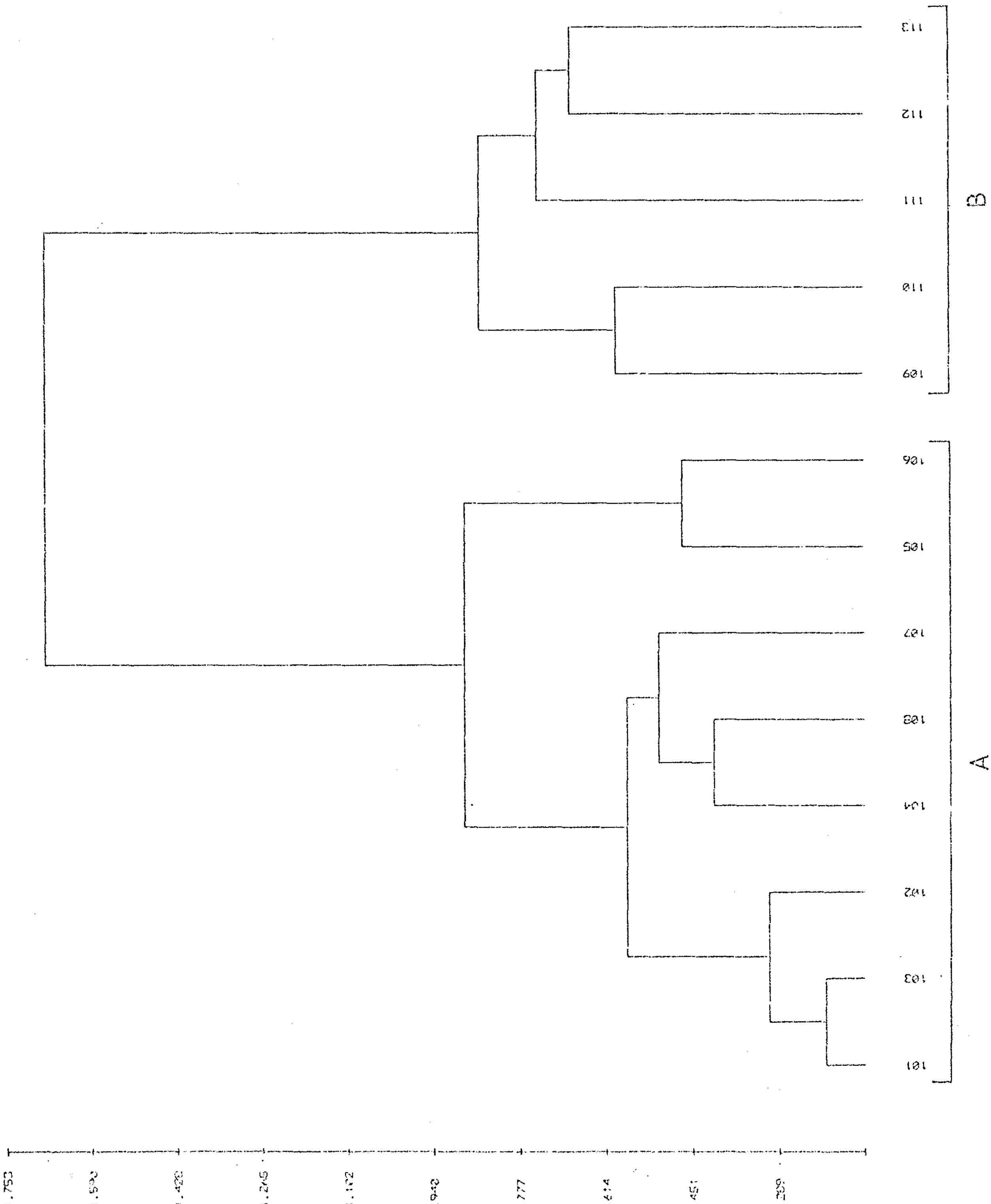

113
112
111
110
109
B
106
105
107
108
104
102
103
101
A
1.753
1.590
1.428
1.265
1.102
.940
.777
.614
.451
.289

FIGURE 12

The 11 Cockle Bay transects classified on the <u>cover</u> values of each of the 42 species attributes.

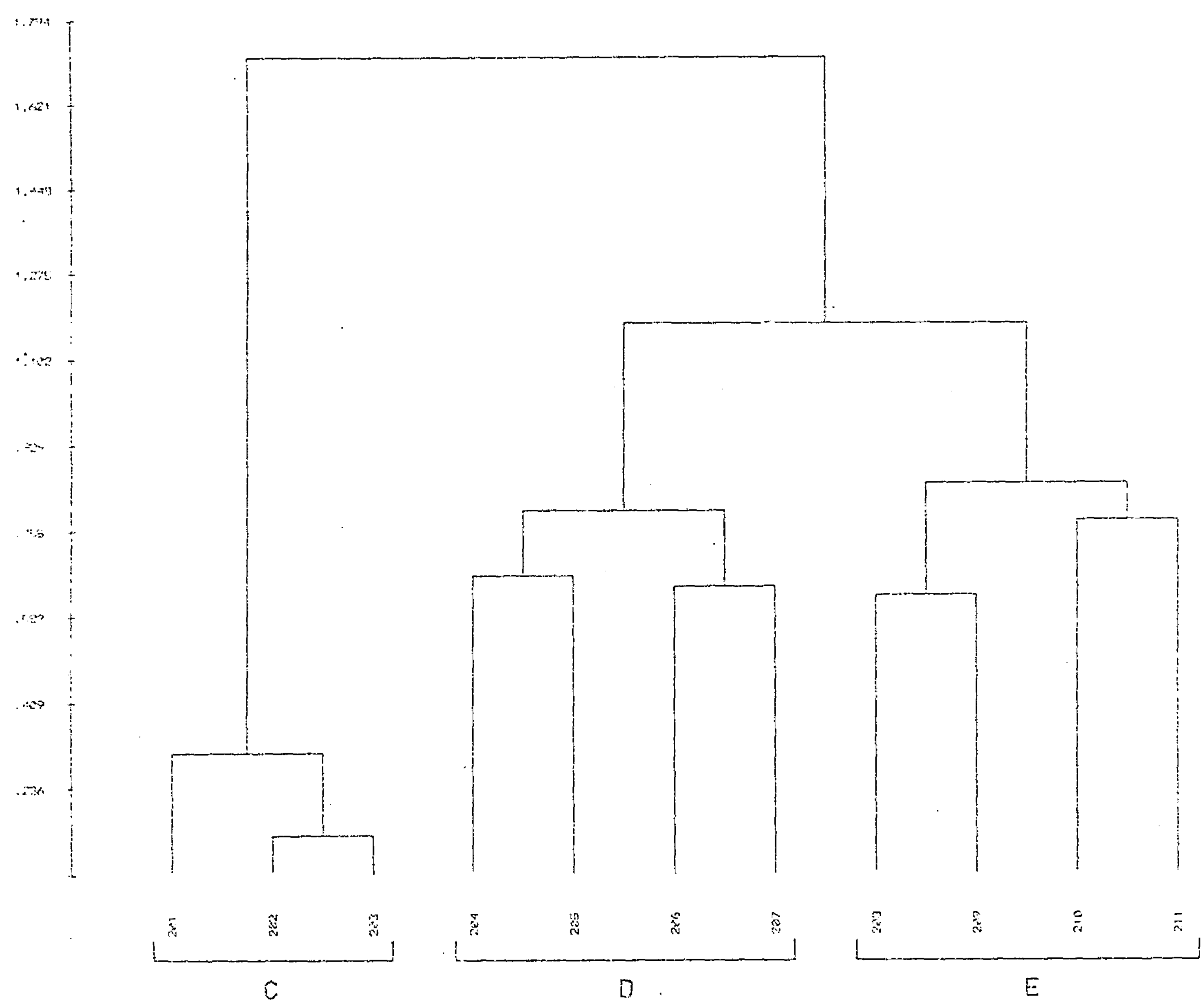

1,621
1,449
1,276
.236
201
202
203
204
205
206
207
208
209
210
211
C
D
E

FIGURE 13

The 11 Cockle Bay transects classified on the colony number values of each of the 42 species attributes.

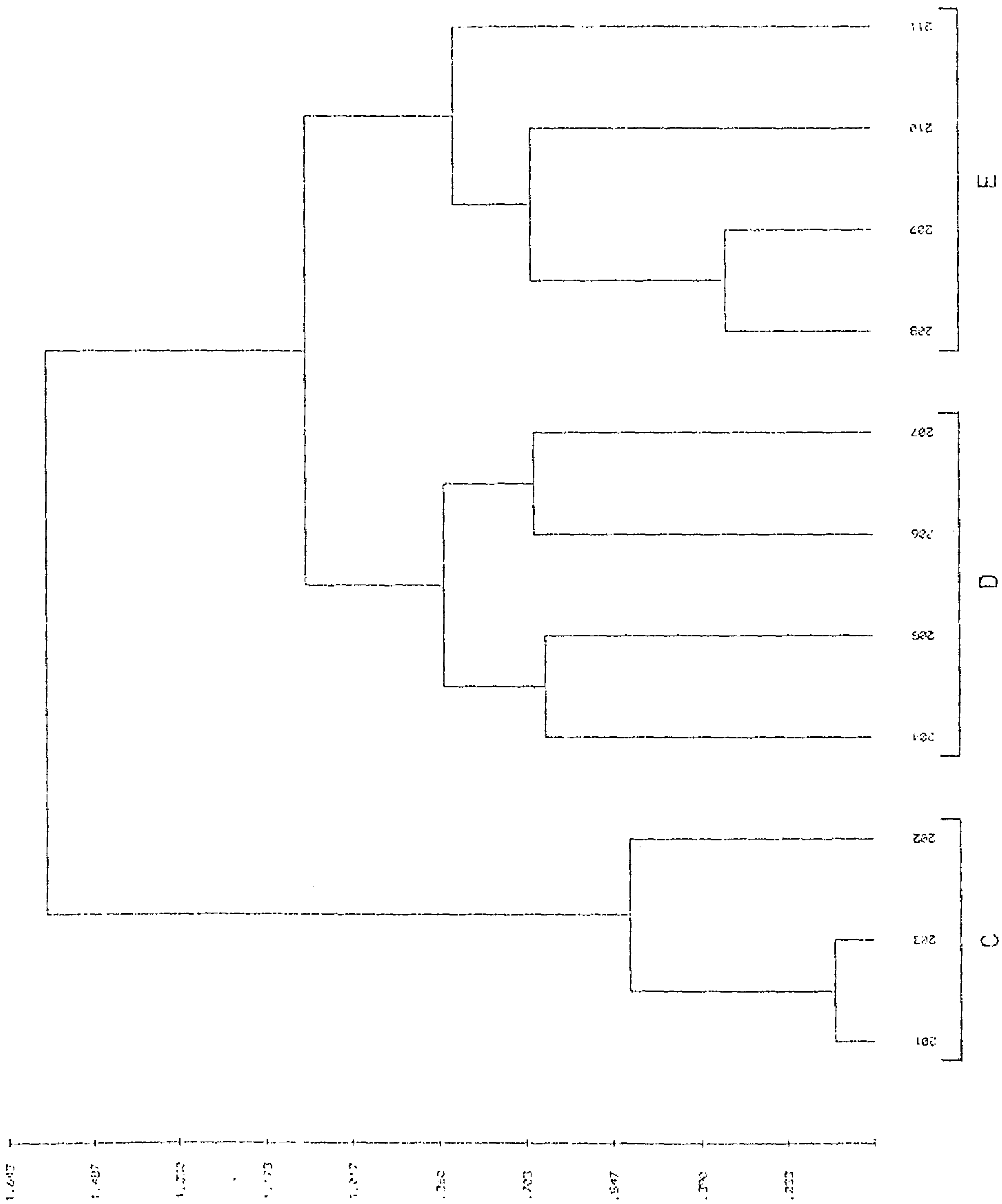

E
D
C

FIGURE 14

All 24 transects from both bays classified on the _cover_ values of each of the 78 species attributes.

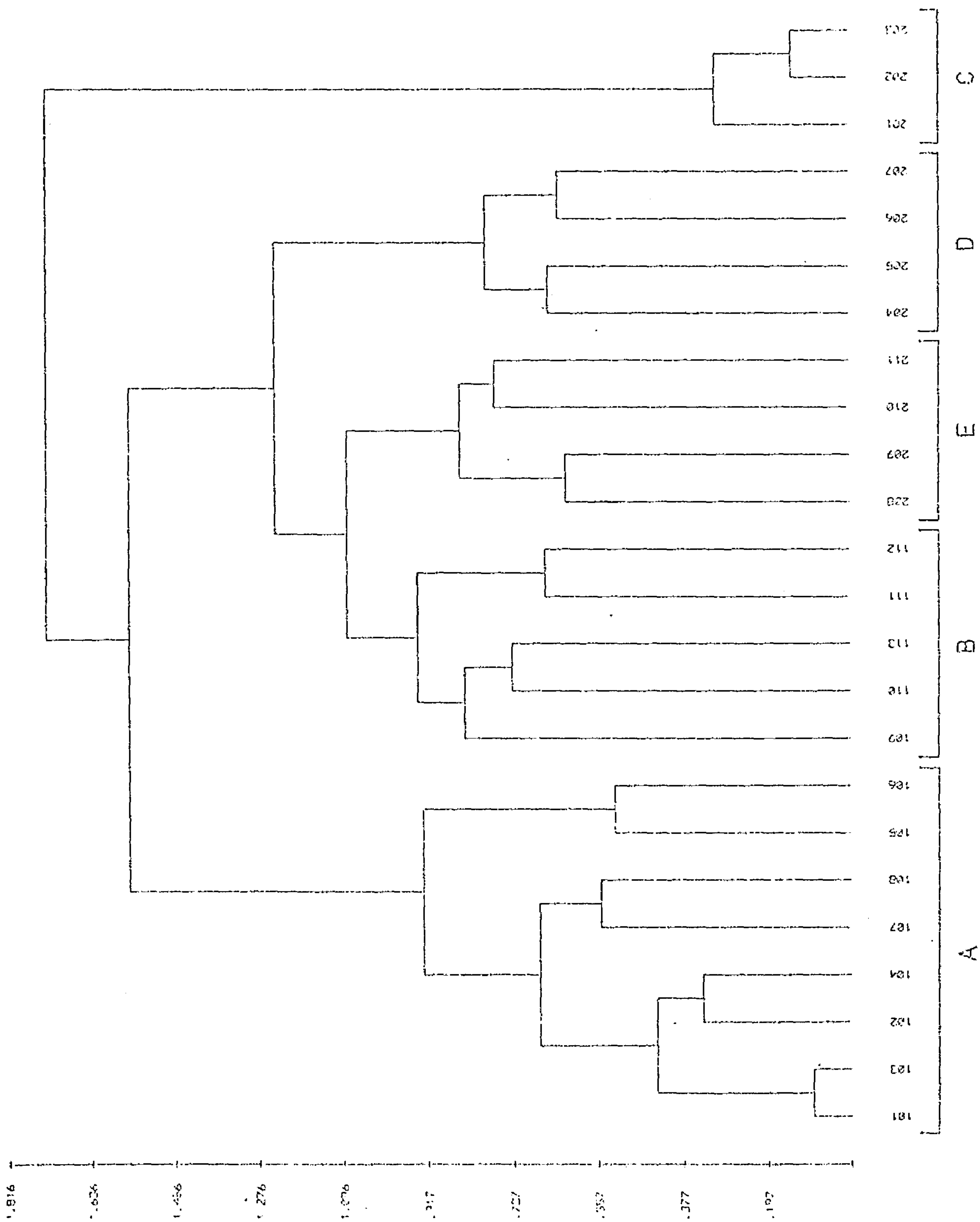
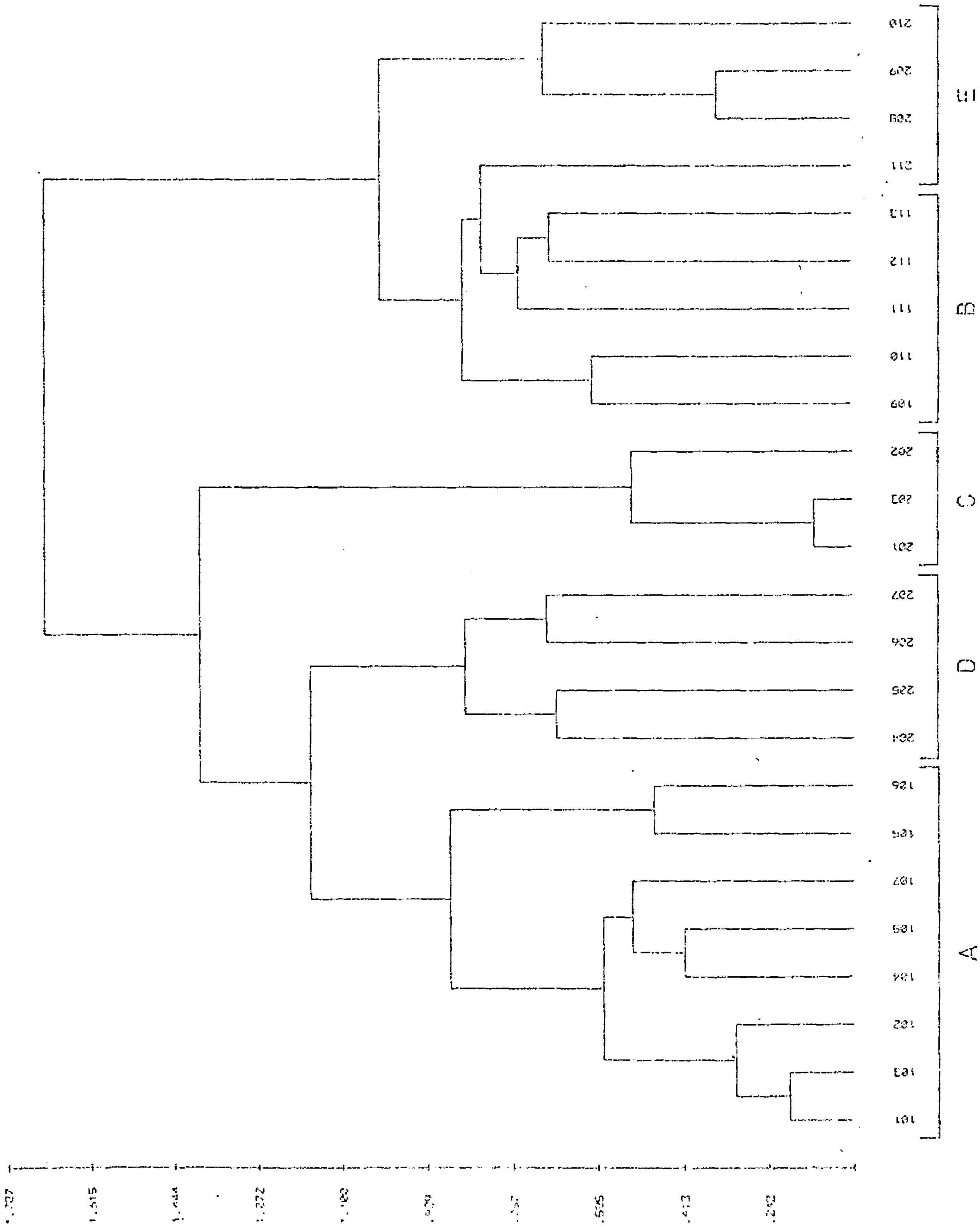

C
D
E
B
A

FIGURE 15

All 24 transects from both bays classified on the <u>colony number</u> values of each of the 78 species attributes.


210
209
208
211
113
112
111
110
109
202
203
201
207
206
205
204
E
B
C
D
A

transects fused at the lowest level are the least dissimilar (or most similar). The species which cause particular groups to cluster together are listed as dominant species of each zone (section 3.6).

3.5.1 Geoffrey Bay Transects

Both the cover matrix classification (Fig. 10) and the abundance matrix classification (Fig. 11) for Geoffrey Bay show a clear grouping of the transects into two clusters or groups: "A" the reef flat and crest transects (101 to 108) and "B" the slope transects (109 to 113).

It is noticeable that the point dividing the two groups (between transects 108 and 109) is exactly the same as the division previously characterized by changes in values of the transect characteristics (section 3.4). Within the clusters there are further subdivisions into pairs and groups of three transects. With so few transects, however, it is difficult to characterize these sub-groupings.

3.5.2 Cockle Bay Transects

In the Cockle Bay classifications (Figs. 12 and 13) there are three main clusters: "C" the inner reef flat transects (201, 202 and 203), "D" the outer reef flat and crest transects (204 to 207) and "E" the slope transects (208 to 211). The inner reef flat transects are well separated from the rest. This is as a result of the isolation of individuals with outlying values by the Bray-Curtis metric measure. In this case the outlying values are of *Montipora ramosa*. This effect of the dissimilarity measure, however, merely accentuates the fact that the inner reef flat transects of Cockle Bay are a quite distinct group.

As previously mentioned (section 1.4), at the present stage in the development of the use of classification as an aid to interpreting ecological data, it is not possible to accept a particular classification without comparing its results with the results of more traditional analyses. The results of classification of transects, and other findings already discussed (section 3.4), are entirely complementary. Each of the clusters of transects shown in the dendrograms have their own distinctive species composition, dominant species, diversity indices, and number and size of colonies. In the simple cases of these particular individual reefs, the classification of transects is only backing up what it is possible to find out without the use of multivariate analysis. A use of classification likely to provide unexpected insights, is for the classification of transects from different reefs.

3.5.3 All Transects

Figures 14 and 15 are dendrograms from classifications of all the transects surveyed in Geoffrey and Cockle Bays.

In all cases the transects, clustered together in the classifications of transects for each of the two individual Bays, remain in the same groupings as the combined Bays classifications. This means that the "between-transect" similarities within each cluster are greater than the similarities between transects from an equivalent area on the other reef. The reef slope transects of each Bay (groups "B" and "E"), however, are linked together at a lower level than either is linked with other groups from the same reef. This implies a greater "between-group" similarity of the reef slope transects of different reefs, than the similarity between the reef slope and other groups (for instance the reef flat), from the same reef.

In both the combined Bays classifications (cover and number of colonies) "C", the group of inner reef flat transects of Cockle Bay, forms a separate cluster, with fusion to other clusters only at a high level of dissimilarity. Again this extreme isolation can be attributed to outlying values of *Montipora ramosa*, enhanced by the Bray-Curtis measure. This group is not at all closely linked with transects from a similar position in Geoffrey Bay, which reflects a markedly different ecological structure of the two zones.

The only difference between the two combined Bays classifications is the linkage of "D" (the group of outer reef flat and crest transects of Cockle Bay) with other clusters. In the abundance Matrix classification (Fig. 15), the group is most closely linked with "A" (the reef flat and crest transects of Geoffrey Bay). In the cover matrix classification (Fig. 14) "C" is most closely linked with "B" and "E" (the reef slope transects).

3.6 ZONATION PATTERNS WITHIN THE COMMUNITY

Both reefs, from the lower limits of coral growth (the bases of the reef slopes) to the landward limits of coral growth (the landward limits of the inner reef flats) can be regarded as being single coral reef "communities". These communities can be subdivided into various "zones" on the basis of the evidence already discussed. The term "zone" has been used in a wide variety of contexts with different definitions, and often without any significance as far as ecological units are concerned.

For the purposes of this study the zones described are subdivisions of the reef communities which can be defined on the basis of the following characteristic parameters:

- Percentage coral cover
- Colony size
- Number of species per transect
- Species diversity.

Each zone has its own characteristic species composition, spatial distribution of species and dominant species.

The "zones" are related to the following environmental factors (which in turn determine particular values of the ecological parameters of each zone):

- Strength of water movement
- Substrate nature and substrate slope
- Sediments and sedimentation
- Exposure by tides and related variations of temperature and salinity.

3.6.1 Geoffrey Bay

Two zones can be described for the Geoffrey Bay reef community:

The Reef Flat and Crest Zone (transects 101 to 108)

a. Environmental characteristics:
   - a gradient of decreasing strength of water movement from the reef crest to the inner reef flat
   - substrate of solid concreted coral rock, with areas of sand and areas of non-stabilized coral rubble which gets shifted around by wave action during storms
   - substrate slope, horizontal or nearly horizontal
   - coarser sediments than on the Reef Slope Zone

- regular, periodic emersion during low spring tides and exposure to desiccation and extremes of salinity and temperature

b. Ecological characteristics:

- low percentage coral cover (3.93% to 6.27%)
- small average colony size (6.04cm to 9.40cm)
- low number of species per transect (3 to 10)
- lower values of H'c and H'c than on the Reef Slope Zone because of low species numbers
- dominant species: *Montipora ramosa* - especially on areas with non-stabilized substrate, *Goniastrea aspera* and *Platygyra sinensis* throughout, *Porites australiensis* micro-atolls on the inner reef flat, and *Symphyllia recta* on the outer reef flat and crest
- other less dominant species include: *Goniastrea favulus, Platygyra pini, Porites solida, Porites lobata* and *Turbinaria auricularis*

<u>The Reef Slope Zone</u> (transects 109 to 114)

a. Environmental characteristics

- a gradient of decreasing strength of water movement from the crest to the base of the reef slope
- solid steep substrate with pockets of fine sediment
- never exposed during low tides, so not subjected to the same range of extremes of temperature and salinity as the Reef Flat and Crest Zone

b. Ecological characteristics:

- high percentage of coral cover (20.56% to 35.23%)
- large average colony size (15.69cm to 29.28cm)
- high number of species per transect (19 to 30)

- higher values of H'c and H'n than on the Reef Flat and Crest Zone
- dominant species: *Acropora rayneri*, *Acropora acuminata* and *Montipora* sp.E (foliose)
- other species include: 9 further species of *Acropora*, other foliose *Montipora* species, *Turbinaria auricularis*, *Pachyseris speciosa*, *Favia favus*, *Stylophora pistillata* and *Cyphastrea serailia*.

3.6.2 Cockle Bay

For the Cockle Bay community three major zones are suggested by the data.

The Inner Reef Flat Zone (transects 201 to 203)

a. Environmental characteristics:
   - very little water movement
   - flat, non-stabilized coral rubble substrate (this is shifted around by wave and swell action to a lesser extent than in Geoffrey Bay)
   - exposed during low spring tides and subjected to desiccation and extremes of temperature and salinity

b. Ecological characteristics:
   - high percentage cover (21.63% to 43.17%)
   - small average colony size, but with large beds of *Montipora ramosa*
   - only 2 or 3 species per transect
   - very low values of H'c and H'n due to low species numbers and low equitability
   - complete domination by *Montipora ramosa*
   - only other species are *Goniastrea aspera* and *Porites lobata*

Outer Reef Flat and Crest Zone (transects 204 to 207)

a. Environmental characteristics:
- zone in Cockle Bay with most water movement (There is, however, weaker water movement than on the equivalent position in Geoffrey Bay)
- flat and near-flat solid substrate with sandy pockets
- coarser sediments than on the Reef Slope Zone
- at least the upper part of the zone is exposed during low spring tides

b. Ecological characteristics:
- lower percentage cover than on the Inner Reef Flat Zone (2.5% to 16.83%)
- average colony size 10.1cm to 15.0cm
- 3 to 19 species per transect
- higher species diversity values (H'c and H'n) than on the Inner Reef Flat Zone due to higher number of species and greater equitability
- dominant species include: *Platygyra sinensis*, *Lobophyllia hemprichii*, *Turbinaria auricularis* and *Porites lobata*

Reef Slope Zone (transects 208 to 211)

a. Environmental characteristics:
- little water movement
- steep substrate
- heavy sedimentation with fine, high clay content sediment
- not exposed during low tides

b. Ecological characteristics:
- similar percentage cover to the Outer Reef

Flat Zone (5.78% to 23.80%) (This is much lower than on the equivalent zone in Geoffrey Bay)

- average colony size 9.45cm to 24.62cm
- number of species per transect (8 to 15) and values of H'c and H'n are similar to the Outer Reef Flat and Crest Zone
- dominant species: *Goniopora tenuidens*
- other species include: *Porites mayeri*, *Favia favus*, *Turbinaria auricularis* and *Merulina ampliata*

4 GENERAL CONCLUSIONS

The reef communities of Geoffrey Bay and Cockle Bay are subdivided into the following zones:

Geoffrey Bay

Zone 1 - Reef Flat and Crest Zone
Zone 2 - Reef Slope Zone

Cockle Bay

Zone 1 - Inner Reef Flat Zone
Zone 2 - Outer Reef Flat and Crest Zone
Zone 3 - Reef Slope Zone

The characteristic ecological parameters of each zone directly reflect the influence of the prevailing environmental factors.

The two communities differ both environmentally and ecologically. Cockle Bay is less exposed and more heavily sedimented (especially on the Reef Slope Zone) than Geoffrey Bay. The relative extremeness of the environment of Cockle Bay is reflected in the smaller number of species and lower species diversity of corals than in the Geoffrey Bay community. Loya (1976a) found a similar difference in species number and diversity when comparing a heavily sedimented community with a less sedimented community on the fringing reefs of Puerto Rico.

It is possible to relate the growth forms of the dominant species of each zone of the two communities to the synthetic models of Rosen (1971, 1975) and Pichon (1973) (refer to section 1.3.3). In particular the dominant growth forms of each zone reflect the strength of water movement in the manner put forward by Rosen and by Pichon. The only exception to this is the dominance of *Montipora ramosa* on reef flat areas with non-stabilized substrate. But, as has been pointed out (section 3.3.3), *Montipora ramosa* is the only species that is sufficiently well adapted to maintain high coverage in such areas, by way of active regeneration.

The Reef Slope Zone of the Geoffrey Bay community is dominated by branching *Acropora* species. According to Rosen's and Pichon's models, this reflects moderate water movement. The Reef Flat and Crest Zone of Geoffrey Bay is dominated by the massive species, *Goniastrea aspera*, *Platygyra sinensis* and *Symphyllia recta*. In Cockle Bay, the Outer Reef Flat and Crest Zone is dominated by *Symphyllia recta* and *Goniastrea aspera*, and the Reef Slope Zone is dominated by *Goniopora tenuidens*. Thus all the zones except the Reef Slope Zone of Geoffrey Bay are dominated by massive species. These zones correspond to Rosen's *Porites* assemblage and Pichon's zone-type dominated by species with massive growth form. This reflects reduced strength of water movement.

No areas of either reef are sufficiently exposed to wave action for development of a zone corresponding to Rosen's *Pocillopora* assemblage and Pichon's zone-type dominated by species with thick and short digitations (*Acropora humilis* for instance).

A general comparison of the community structure and zonation patterns of these two Magnetic Island reefs with other published studies on fringing reefs is difficult. Although there is a great wealth of literature on high island and coastal fringing reef morphology and ecology, there have been few studies of similarly sheltered and sedimented reefs in the Indo-Pacific.

Morphologically the Magnetic Island reefs differ from many other reefs that have been studied. In particular, the vertical extent of the communities is small (the reef slopes extend to 10m in Geoffrey Bay and only 4m in Cockle Bay). This compares with lower depth limits of 50m at Tuléar, Malagasy (Pichon, 1971), 30m at Eilat, Red Sea (Loya, 1972) and 50m at Mauritius, Mascarene Archipelago (Faure & Montaggioni, 1976). Furthermore, there is no formation of a lagoon or moat area in either Geoffrey Bay or Cockle Bay, as has been described at Mauritius and other islands of the Mascarenes (Faure, 1975, Faure & Montaggioni, 1975). Morphologically, perhaps, the most similar reefs recently studied are those at Mahé, Seychelles (Lewis, 1968; Braithwaite, 1971 and Rosen, 1971) where the reef flats on the exposed side of the island extend approximately 500m from a sandy beach, and the reef slopes extend to a muddy sand base at 10 to 15m (Braithwaite, 1971). At Mahé there is a similar clear division of the coral community into fore reef, reef edge and back reef with no lagoon or moat development. The details of the zonation and assemblage organization, however, are quite different from Magnetic Island; at Mahé there is greater development of seagrass beds and exposed *Pocillopora* and *Acropora* assemblages (Braithwaite, 1971).

Many of the fringing reefs for which studies have been published are from open ocean island localities and show features determined by far greater exposure than is found at Magnetic Island; such as the exposed *Pocillopora* and *Acropora* assemblages at Mahé (Braithwaite, 1971). Of the fringing reefs that have been studied, the most comparable to Magnetic Island in terms of exposure and possibly sedimentation are : the N.W. side of Maer Island, Murray Islands (Mayer, 1918), Gaua, New Hebrides (Baker, 1925) and the Bay of Batavia (Umbgrove, 1940). Unfortunately these early studies do not include any quantitative surveys. Furthermore the descriptions are limited to the reef flat and crest areas only.

At all three of these areas, inner reef flat zones of *Montipora ramosa* are described. Abe (1937) also describes such a zone at Iwayama Bay, Palao. The position and degree of shelter of these *Montipora ramosa* zones is directly comparable to the Inner Reef Flat Zone of Cockle Bay, and the *Montipora ramosa* dominated areas of the Reef Flat and Crest Zone of Geoffrey Bay. Baker (1925) also found a dominance of *Porites (fragosa)* on some areas of the reef flat at Gaua, and describes a *Goniastrea (pectinata)* zone on the extreme reef edge. Mayer (1918) describes the outer reef edge and slope at Maer Island as being dominated by branching *Acropora* and *Montipora* (presumably foliose). Thus there are some similarities between these reefs and the reefs of Geoffrey and Cockle Bays. Detailed comparison, however, is difficult because of the lack of quantitative data and descriptions of the reef slope areas.

In conclusion it seems that the general pattern of zonation defined for these Magnetic Island reefs is, on a world-wide basis, characteristic of fringing reef communities in very sheltered and heavily sedimented conditions.

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APPENDIX I

List and descriptions of computer programs used for data processing:

FRED. F4 - Written by Brad Cooper (Computer Centre, James Cook University) and the author to replace Dr Terry Done's program, COLINA.F4.
- Converts the raw data to a list of transect numbers followed by cover readings for each species on that line.

SUBMAT. - Written by Terry Done and adapted by the author.
- Draws from data files made by FRED.F4 to create rectangular matrices of total cover and numbers of colonies of each species on each line.

COVA. F4 - Written by Terry Done and adapted by the author.
- Plots centred histograms of cover distribution of chosen species on all transect lines.

SPESUM - Written by Terry Done and adapted by the author.
- Makes a summary table of data for each species.

COLISA. F4 - Written by Terry Done and adapted by the author.
- Makes a summary table of information about each transect line.

APPENDIX 2

Details of the procedure used for determining sediment particle size distributions:

(1) The whole sediment sample (300ml) was air dried in an oven at 70^{o} for 12 hours.

(2) The sample was gently ground using a pestle and mortar to separate conglomerated particles.

(3) A sub-sample of 50g was removed (see Carver, 1971, p.52 for details).

(4) The sub-sample was shaken well and soaked for at least 12 hours in 100ml of Calgon solution (4g per litre of Sodium hexa meta phosphate). This was to disperse the clay fractions.

(5) The sub-sample was washed through a stack of sieves with about 1 litre of water. Sieves with the following mesh diameters were used:

2.057×10^{-3}m
4.547×10^{-4}m
2.515×11^{-4}m
6.350×10^{-5}m

(6) Each sieve and its contents were oven dried and the trapped sediment was weighed.

(7) The suspension which was washed through all the sieves was placed in a settling column 45cm long by 5cm diameter.

(8) The column was left to stand for 60 mins maintained

at a temperature of 21^{o}.

(9) The top 5cm of suspension was removed by pipette.

(10) (8) and (9) were repeated twice.

(11) The suspension remaining in the column (a) and the removed suspension (b) were each dried and weighed. These gave values for the size classes:

$$6.3 \times 10^{-5}m > (a) > 4.0 \times 10^{-6}m$$
$$4.0 \times 10^{-6}m > (b)$$

APPENDIX 3

Details of coefficients used for graphical computation of mean, skewness and sorting of sediment samples:

Mean

$$\text{Mean} = (\phi\,10 + \phi\,30 + \phi\,50 + \phi\,70 + \phi\,90) / 5$$

McCammon (1962)*

Sorting

$$\text{Sorting} = (\phi\,85 + \phi\,95 - \phi\,5 - \phi\,15) / 5.4$$

McCammon (1962)*

Skewness

$$Sk\phi = [\phi\,25 + \phi\,75 - 2\,(\phi\,50)] / 2$$

Krumbein & Pettijohn (1938)*

Where ϕx is the xth percentile interpolated from a graph of grain size range (in ϕ units) plotted against cumulative percentage weight in each grain size group.

Conversion of linear grain sizes to the ϕ scale was done using a table given by Page (1955).

* References cited by Carver (1971).