JCU ePrints

This file is part of the following reference:

Muffley, Richard S. (1981) ***Benthic fauna of a tropical sandy shore in the Townsville region.*** **Masters (Research) thesis, James Cook University**.

Access to this file is available from:

http://eprints.jcu.edu.au/17035

JAMES COOK UNIVERSITY

INTRODUCTION

Research into the fauna and dynamics of the fauna of tropical sandy shores throughout the world has been limited. Dexter (1972, 1974, 1976) has done preliminary work in Panama, Costa Rica and Colombia, and Mexico and also in North Carolina (Dexter, 1969). Pearse *et. al.* (1942), Rodriguez (1959), Holland and Polgar (1976), Holland and Dean (1977), Saloman and Naughton (1977, 1978), Dauer and Simon (1976), Simon and Dauer (1977), and Patterson (1974) have been responsible for most of the work in southern North America and the Caribbean.

Two classical works from the Gold Coast and Inhaca are those of Gauld and Buchanan (1956) and MacNae and Kalk (1962). Other important works include those of Pichon (1967) at Madagascar, Ansell *et. al.* (1972), Trevallion *et. al.* (1970), and McIntyre (1968) in India, Vohra (1971) at Singapore, Jones (1979) in Malaysia, and Morton and Challis (1969) in the Solomon Islands.

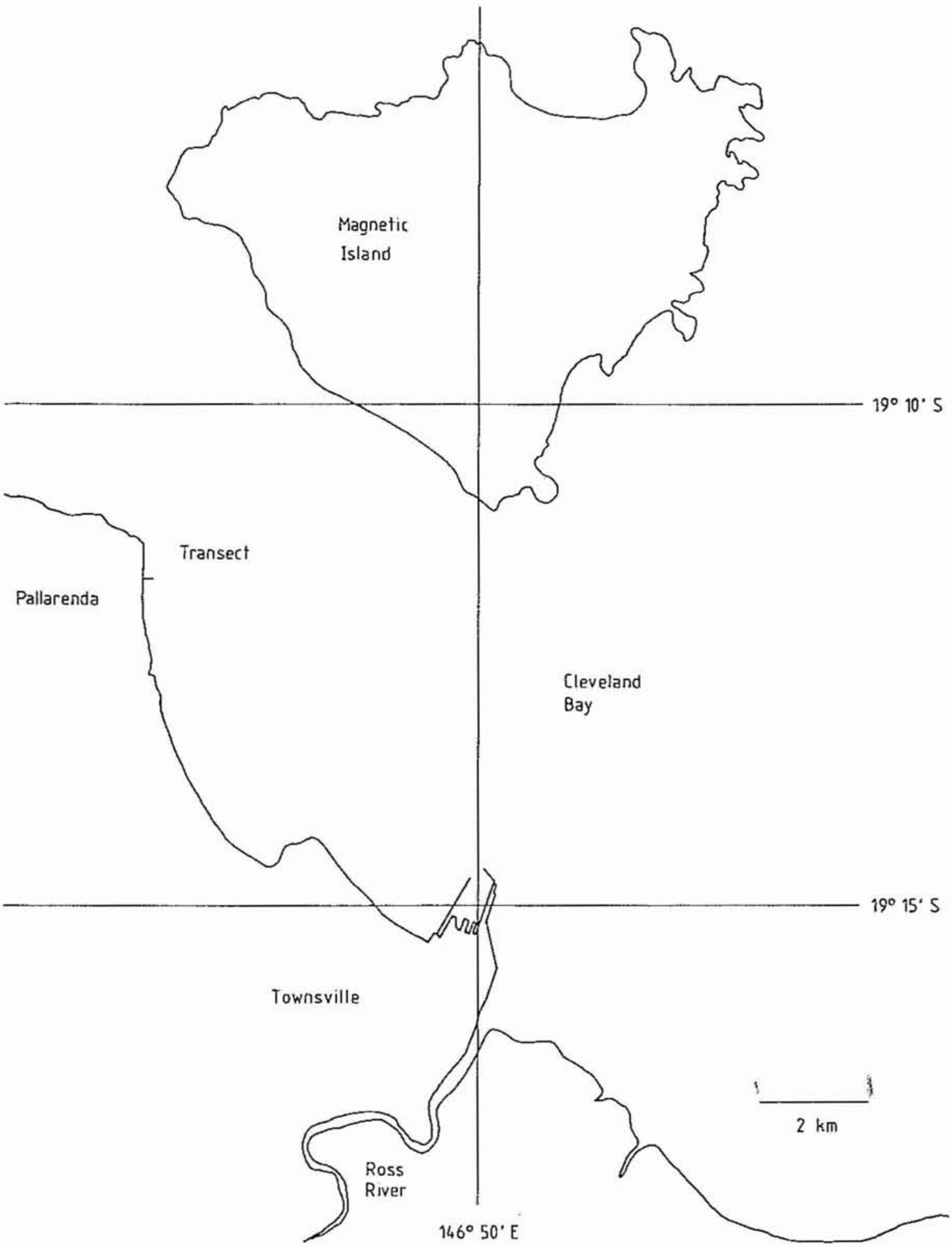
On the Australian coasts little is known of the fauna of northern shores and the eastern shores are cursorily treated by Knox (1963) and Dakin (1976). Gibbs (1979) worked on the shore above reef flats at Low Isles and surrounding islands and Green (1968) observed predator-prey interaction of selected species on a beach in Morton Bay near Brisbane.

Research programs based on a time sequence are available but are not common. Holland and Polgar (1976) have done a very useful ecological study on the yearly sequence of species on a sand bar in North Carolina, and Dexter (1979) has observed the species changes for a year in Panama. Other time series studies include Whitlatch (1977), Simon and Dauer (1977), Bloom, Simon, and Hunter (1972), Johnson (1970), and Vohra (1971).

The purpose of this study at Pallarenda was to find which species live in and on a tropical eastern Australian beach, and to record the variations in species composition for a period of one year.

Pallarenda beach (19° 12' S, 146° 47' E) is located at the northwestern end of Cleveland Bay near Townsville, Queensland (see Figure 1). The beach is open to the east and therefore is subjected to unimpeded wave action which is directed from the southeast for much of the year. The tidal pattern is semidiurnal (Easton, 1970) with significant diurnal inequality (Kenny, 1979), and the spring tidal range in this area is approximately 4.0 meters (Kenny, 1979). Kenny (1974) has found the mean temperatures of surface waters in Cleveland Bay to be between 21.8 °C in the winter and 31.2 °C in the summer. Ross River, which enters Cleveland Bay 10 kilometers southeast of Pallarenda beach, is the main source of freshwater in the bay. Rainfall in the area averages 111 centimeters per year and approximately 70 % of the annual total fall is in the period of January to March (Kenny, 1974), though within this period, heavy falls are usually recorded in periods of one to two days.

Figure 1. A map of the western side of Cleveland Bay. The transect location at Pallarenda is marked.


Magnetic
Island
19° 10' S
Transect
Pallarenda
Cleveland
Bay
19° 15' S
Townsville
2 km
Ross
River
146° 50' E

SPECIES INFORMATION

Following is a complete list of the animals found in the seasonal collections of this study.

POLYCHAETES

Saccocirrus
Polygordius
Perinereis vallata
Other Nereids
Pisione oerstedi
Armandia intermedia
Opheliid (n.g. n.sp.)
Goniadopsis
Ceratonereis erythraeensis
Spionid C
Dispio A
Scolelepis B
Prionospio
Malacoceros
Scolelepis C
Spiophanes
Orbinia
Scoloplos (Leodamus)
Scoloplos (Scoloplos) normalis
Naineris cf. grubei
Syllis (Langerhansia)
Glycera A
Glycera B
Glycera cf. americana
Diopatra
Magelona
Phyllodoce
Lumbrinereis
Euchone

Sthenelais
Sigalion
Amphictene
Pista typha
Capitellidae
Maldanidae Euchymeninae
Pisionidens indica
"Onuphis sp 4"
cf. Platynereis

BIVALVES

Mesodesma altenae
Donax faba
Tellina (Cadella) semen
Dosinia kaspiewi
Strigilla tomlini
Epicodakia
Tellina (Macomona) australis
Tellina (Angulus) lanceolata
Montacutona
Mactra dissimilis

GASTROPODS

Solidula cf. sulcata
Polinices conicus
Polinices didymus
Isanda coronata
Hastula plumbea
Eulimid
Nassarius
Polinices A

CRUSTACEA

Megalops Larva
Pseudolana brevimargine
Scopimera inflata
Sphaeromidae
Diogenes avarus
Ostracods (Leuroleberis)
Callianassa australiensis
Gastrosaccus cf. dakini
Ogyrides
Peneid B

Taneid B
Albunea symmysta
Matuta
Platyischnopus
Urohaustorius
Choncholestes
Atylus
Amphipod C
Microprotopus
Amphipod E
cf. Gondogeneia
cf. Exoidiceros
Orchestia
Elamenopsis cf. lineata
Portunidae
Philyra
Cumacea

MISCELLANEOUS

Oligochaete B
Nemerteans (Carinoma)
Patinapta cf. ooplax (Echinodermata)
Enteropneust
Arachnoides placenta (Echinodermata)
Edwardsia elegans (Coelenterata)
Paraplagusia guttata (Teleostei)
Goby

Many of the species in the study are not identified beyond a generic name and several do not have a generic name. When a generic name is given, it refers to a single species and should be written more correctly with "sp." following the generic name. Throughout the text of this thesis the inclusion of "sp." would be cumbersome and so it has been ommitted. Some species are identified only by a broader taxonomic name (eg. Opheliid (n.g. n.sp.)), but only one species is indicated by one taxonomic or general heading. If more than one species exists for a particular genus, then an alphabetic character will follow the generic name (eg. Glycera A and Glycera B). Some species which have only one species for the genus cited may also have an alphabetic character following the generic name (eg. Dispio A and Amphipod C). This has occurred as other species in the genus or group have been given specific identification.

Further comments relating to these incompletely identified specimens may be found in Appendix D.

MATERIALS AND METHODS

PHYSICAL SURVEY

LOCATION OF STATIONS

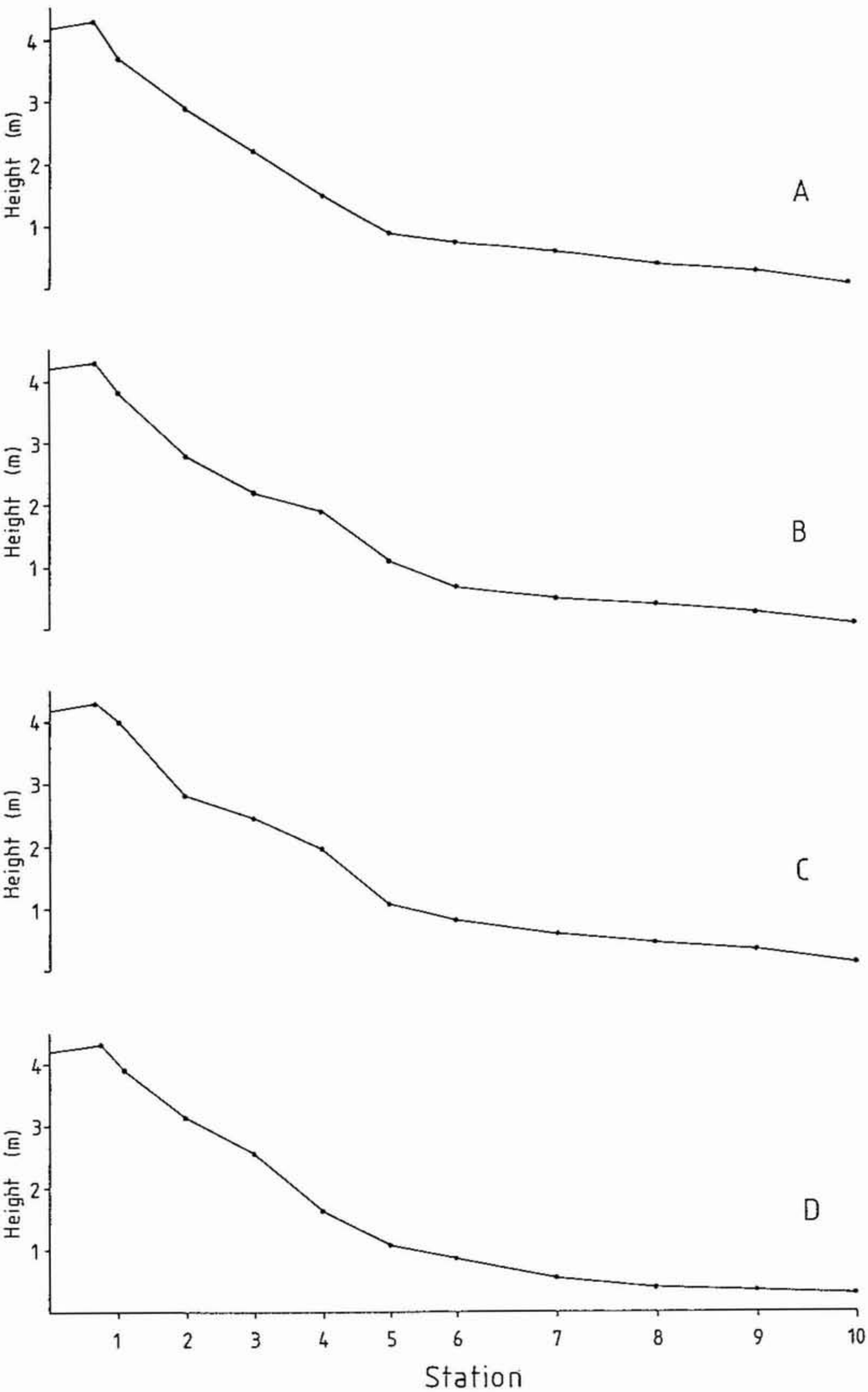
A transect, which ran from above the highest tide to below the mean low water spring tide, was oriented perpendicular to the shoreline at Pallarenda. To facilitate regular reestablishment of the transect, the line was located as an extension of an existing fence line, (see Figure 2 and Table 1). This fence formerly protected the entrance to the Commonwealth Quarantine Station which can be identified on locality maps (see Australian Survey Corps, Department of Lands: Australia 1:50,000, Magnetic 8259-1). Stations were placed consecutively along the transect with the most landward station (station 1) located immediately seaward of the dune vegetation at the top of the beach. Successive stations 2, 3, 4, 5, and 6 were placed at 10 meter intervals down the beach from station 1 and stations 7, 8, 9, and 10 were fixed at 15 meter intervals. Below station 7 patches of seagrass were found. In order that a new variable would not be introduced into the sampling, these seagrass areas were avoided. If a station was positioned in seagrass, the location was moved laterally to a situation at least one

Table 1. Elevation of stations (meters above datum).

	STATION									
	1	2	3	4	5	6	7	8	9	10
August 1977	3.6	2.9	2.2	1.5	.9	.7	.6	.4	.3	.1
November 1977	3.8	2.8	2.2	1.9	1.1	.7	.5	.4	.3	.1
February 1978	4.0	2.8	2.5	2.0	1.1	.8	.6	.5	.3	.1
May 1978	3.9	3.2	2.5	1.6	1.1	.8	.6	.4	.2	.1

Figure 2. Station elevations of each seasonal transect.

A August 1977
B November 1977
C February 1978
D May 1978



Height (m)
A
B
C
D
1
2
3
4
5
6
7
8
9
10
Station

meter from the vegetation.

PROFILE

Seasonal elevations of stations were determined with a Sokkisha Automatic Level B-2 reading a Brookeades standard metric rod. A base elevation was determined by reading from the sea level on a calm day at the time of the predicted low tide. The elevation of the low tide reading is given in the Official Queensland Tide Tables of 1977 (Anonymous, 1977). All other elevations given are relative to the low tide reading.

SALINITY AND TEMPERATURE

Collections of seawater for salinity determinations were taken. As there was a layer of surface water oozing from the steeper portion of the beach and flowing over the remainder of the beach, a bank of sediment was shovelled to form a dam to keep water out of a central area at each station. The enclosed area was then dug to between 10 and 20 centimeters depth and the resulting hole was allowed to fill with interstitial water. A clean glass collecting bottle was rinsed once from this water and then filled. A sample of seawater was collected at low tide from 15 to 25 centimeters depth for comparison with the interstitial water sample. Early determinations were made using silver nitrate titration methods, but later an electronic inductively coupled salinometer (AutoLab Model 601K IIIB) was used. Silver nitrate titration determinations and inductive salinometer readings from the same samples were compared (see Table 2) and showed differences of less than 2.0 %.

Temperature data was recorded using a mercury-filled glass thermometer. The thermometer was inserted five centimeters into the sediment for station recordings and held one meter above the beach in the shade for air temperature readings. The seawater temperature was taken at low tide from 15 to 25 centimeters depth.

SUBSTRATE

PARTICLE SIZE

Sediments were collected at each station for determination of calcium carbonate content and for granulometric analysis. A length of P.V.C. tubing with a 3.75 centimeter internal diameter was pressed 10 centimeters into the substrate. The tube with the core sample was removed and each core was placed in a labelled plastic bag. The samples were allowed to air dry for several days and then transferred to paper bags and oven dried at 100 ^{o}C until no further weight loss could be detected.

The sediment was separated into grain size classes using a battery of Endecott sieves with a Wentworth scale of mesh sizes as given in Table 3. Before sieving commenced, each sample was weighed on a Sartorius pan balance. Sediment was then worked through the sieves under a flow of fresh water and then oven redried. Following drying,

Table 2. Comparison of silver nitrate titration and inductive salinometer methods in determining salinity (‰).

STATION	SALINOMETER	SILVER NITRATE	PERCENT DIFFERENCE
4A	36.7	36.3	1.10
4B	32.9	32.4	1.54
5	34.3	34.3	0.00
6	35.1	34.9	.57
Sea Water	36.1	35.5	1.69

Table 3. Phi values and their corresponding metric measurements (after Krumbein and Pettijohn, 1938).

Wentworth Grade Scale (mm)	Phi Value	Wentworth Nomenclature
		Granule
2.000	- 1.0	
		Very Coarse Sand
1.000	0.0	
		Coarse Sand
.500	1.0	
		Medium Sand
.250	2.0	
		Fine Sand
.125	3.0	
		Very Fine Sand
.063	4.0	
		Silt and Clay

the sieves with the sediment were placed on a mechanical shaker which continued the sieving for five hours. The weight of each fraction was determined. These weights summed were then subtracted from the weight of the entire sample and the difference was attributed to the fraction with size less than 0.063 millimeters which was lost through the sieves. In order to permit statistical treatment of granulometric data the mesh size for each sediment fraction was converted from the geometric pattern of the Wentworth scale to an arithmetic series. This was done by calculating a phi (ϕ) value, where

$$\phi = -\log_2 \text{grain size (mm)}$$

as explained by Krumbein (1934). Graphic display and subsequent granulometric calculations are facilitated by the phi notation. Four parameters can be used to describe a sediment sample. They are mean grain size, kurtosis, skewness, and standard deviation. Mean grain size and standard deviation (sorting coefficient) are most useful in describing sediment for biological work and the equations used in determining these values are given below.

$$\text{mean} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$\text{S.D.} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

where $\phi 16$ is the phi value at 16 % of the accumulated sediment, $\phi 84$ is the phi value at 84 % of the accumulated sediment, and so on.

The degree of sorting of the sediment is measured by the spread of the sediment size classes around the mean class size. In well sorted material a greater proportion of the sediment is contained in a few adjacent size classes, than in a more poorly sorted sediment sample. The spread is measured in phi units per standard deviation unit and a low value indicates good sorting, while a high value signifies poorer sorting. This value is referred to as the coefficient of sorting in this thesis and should not be confused with the sorting coefficients of numerical classification.

Graphical parameters were determined by a computer analysis program. In order to use the program, phi values and the weight of the corresponding sand fraction were inserted. The program operates not only on the cumulative quartile percentages (see Buchanan and Kain, 1971), but also on the phi values of the 5 and 95 percent accumulation (see Folk, 1961). Since the silt-clay fraction was not separated further, it was necessary to estimate the phi value beyond which only an insignificant proportion of the sample would remain. After considering all samples a phi value of 8 was selected to represent this value.

CALCIUM CARBONATE

In order to determine the proportion of calcium carbonate in the sediment samples the following procedure was established. Before beginning the sieving in the granulometric analysis, two small subsamples of sediment were removed and placed in glass beakers of known weight. These samples were dried for two hours at 65 ^{0}C and the weights of the samples were determined. A solution of 1.0 M HCl was added in excess and the mixture was covered and allowed to stand overnight. The following morning the sample was filtered through Whatman 1 filterpaper and oven dried until no change in weight could be detected. The weight of the acid treated samples was determined and compared with the weight prior to treatment. The loss in weight was attributed to the loss of calcium carbonate. The average calcium carbonate fraction for each station is given in Table 4.

BIOLOGICAL SAMPLING

Preliminary testing was carried out in order to determine the extent of sampling required for various aspects of the program. Discussion of the preliminary analyses follows the presentation of the general methods used in collecting the benthic organisms for this study.

Table 4. Percentage of calcium carbonate in each sample.

	STATION									
	1	2	3	4	5	6	7	8	9	10
August 1977	7.11	8.96	10.67	10.35	10.12	8.74	7.33	6.57	8.55	7.81
November 1977	4.76	5.40	18.38	14.44	12.86	11.19	8.96	7.66	6.30	6.89
February 1978	5.17	11.94	9.83	10.36	14.56	12.22	5.26	6.39	6.80	7.25
May 1978	4.82	13.65	22.03	14.01	10.77	8.62	5.77	8.06	6.03	4.60

METHODS

COLLECTION OF FAUNA

Spring tides on Pallarenda Beach do not expose every station during each month of the year. Although monthly samples were collected, only seasonal samples were used in the analysis for this study. These samples were taken from the beach when there was maximum exposure, and all the stations could be sampled. The season-month correspondence was

winter - August 1977

spring - November 1977

summer - February 1978

autumn - May 1978

Only the data collected for these periods are included in RESULTS. The data from other monthly samples are given in Appendix A.

A metal cylinder circumscribing 0.2 square meter was pressed 10 centimeters into the substrate and the sandy contents within the ring were dug out by hand and placed in a large bucket. Carried to the water's edge, the sample was worked through a wire sieve, with a square mesh side measuring 1.2 millimeters, by puddling the sieve containing a small portion of the sample sediment in the sea. As each portion was cleaned, the residue was placed in a plastic storage container and the sediment was covered with seawater. To this an excess amount of a solution made of the vital stain erythrosin B and seawater was added. After a minimum of thirty minutes, concentrated formalin was added to make the preservative solution approximately 10 % seawater formalin.

The labelled containers were then stored until they were sorted. Sorting the specimens from the sand was done by hand. The sample was placed over a 1.0 millimeter mesh screen and the erythrosin B and formalin solutions were washed from it with freshwater. Portions of the washed sediment were placed in a white enamelled tray and searched by hand for the stained organisms. Specimens were placed in vials with 70 % alcohol for later identification and counting.

EVALUATION OF SAMPLING METHODS

STATION PLACEMENT

The upper portion of the beach (approximately 40 meters) was characterized by a steep physical gradient (see Figure 2) and large particle size of the sediment (see Table 11), while the lower beach (approximately 80 meters) was relatively flat and the sediment grain size was relatively small. There was a sharp boundary delimiting the beach areas of small grain size and low slope gradient and those of coarse grain and steep slope, and this boundary is referred to as the spring horizon in this thesis. This boundary between these areas was distinct and there was little or no gradation of slope or sediment size characteristics. Stations 1 through 4 were located in the upper beach, and stations 6 through 10 were placed in the lower beach. Station 1 was in a position on the beach which was rarely inundated by seawater. Only when sea conditions were rough and there were extreme high spring tides were the sediments at this station covered. At all other times the substrate at station 1 was disturbed only by people visiting the beach.

Station 2 also received little seawater inundation. The wave action from the high spring tides washed this station.

Stations 3 and 4 were regularly wet by each tidal cycle.

The stations of the lower beach remained immersed during neap tidal cycles, and during months when spring tides were not extreme, stations 9 and 10 were not exposed.

The spring horizon moves perpendicular to the beach contour several meters dependent upon the hydrodynamics of the sea (see also section DISCUSSION: ABIOTIC FACTORS). Station 5 was positioned very near to the spring horizon. Because of its position and because of the mobility of the spring horizon, this station was sometimes sampled as a part of the upper beach and sometimes as a part of the lower beach. Stations 1 and 2 were not sampled regularly. At each of the remaining stations monthly samples were taken during the period of spring tides. The number of samples taken at each station was increased sometime after the sampling program was begun. Table 5 indicates the number of samples taken for each month. Lack of sampling at lower stations in certain months was due to these stations not being exposed at low tide.

The manner in which sample sites are positioned on a sand beach depends upon the disposition of the sampler and the underlying purposes or hypotheses of the study. Sometimes a single station is used to represent the faunal structure (Holland and Polgar, 1976; Holland and Dean, 1977). In studies where stations are located within obvious biotopes, the importance of recognizable ecological factors have been anticipated (Pichon, 1967). This is most marked in studies which locate

Table 5. Number of 0.2 square meter subsamples collected at each station.

STATION	F	M	A	M	J	J	A	S	O	N	D	J	F	M
	MONTH													
2	1	1	1	1	0	0	0	1	.5	0	0	.5	.5	0
3	1	1	1	1	1	1	3	3	3	3	3	3	3	3
4	1	1	1	1	1	1	3	3	3	3	3	3	3	3
5	1	1	1	1	1	1	3	3	3	3	3	3	3	3
6	1	1	1	1	1	1	3	3	3	3	3	3	3	3
7	1	1	1	1	1	1	3	3	3	3	3	3	3	3
8	0	0	0	1	2	4	3	3	3	3	3	3	3	3
9	0	0	0	1	1	4	3	0	0	3	3	3	3	3
10	0	0	0	0	1	4	3	0	0	3	3	3	3	3

stations at particular tidal heights (Vohra, 1971; Jawed and Khan, 1974; Dexter 1979), which presuppose immersion or emersion time is of primary importance in governing the distribution of organisms. When there is reason to believe that particular environmental features dominate the control of the benthic structure, this approach to positioning of stations may be desirable, however, as virtually nothing was known of the influences which control distributions of species on the north Queensland shores, a program that anticipated specific influences was not attempted in this study. As most environmental features of a sandy shore have a downshore gradient, it is logical to sample on a line parallel to the gradients, and this was done. However, to avoid emphasizing a particular feature, stations were placed at a constant horizontal distance on the transect each month. This approach has been used by previous workers (Colman and Segrove, 1955; McIntyre, 1968; Dwivedi et. al., 1973; Wharfe, 1977).

Homogeneity in benthic structure at consecutive points running parallel to the shore cannot be assumed. In this study no attempt was made to determine lateral shore variability of fauna, however, work by Dauer and Simon (1975) suggests that a transect method, such as the one described for this study, is satisfactory, because reasonable homogeneity along a shore on the beach does exist.

Seagrass areas, which were often found on the lower end of the beach, were not sampled. Reise (1977) compared the macrofauna of seagrass beds and mudflats and found the species composition to be similar, but the densities and abundances were higher in the seagrass. He attributed the differences to the protection offered by the seagrass to prey species. He identified major predators as small crabs, a species of shrimp, and a goby. Similar predator species were represented in the Pallarenda samples. Therefore, collections from Pallarenda seagrass habitats were not made.

Algal plants were widely separated and rarely did a thallus lie within a sample area. If this did happen, the sample area was moved laterally until the thallus was excluded. Epiphytic animals were not introduced into the samples. The floral species found on Pallarenda beach are presented in Appendix B.

AREA AND DEPTH OF SAMPLE

As sample size may influence the incidence of particular species in a sample, tests of relative abundance related to sample sizes were made and compared. Samples were collected from stations 8, 9, and 10, because these stations showed the greatest number of species in preliminary investigations. The individuals of the species at these stations were spatially more widely separated than species at other stations, implying that they require the greatest area of sampling. Station "3 + 5" meters which is 5 meters down the transect from station 3 (placing it midway between stations 3 and 4), was included for completeness, as it was assumed to be representative of the condition in the coarse sand of the upper beach. Four 0.2 square meter samples were taken and in the analysis these were summed in such a way as to give the maximum number of species present in 0.2, 0.4, 0.6, and 0.8 square meter samples. Using the number of species present in the 0.8 square meter sample as the maximum, a proportion of the maximum can be determined for each of the lesser incremental areas. The resulting data are listed in Table 6 and the cumulative curves are given as Figure 3.

The vertical depth of sampling was determined by stratigraphic sampling at five stations. The top layer was two centimeters thick and the second layer was four centimeters. The deepest layer was four centimeters thick giving samples a total depth of ten centimeters. The specimens of each layer were identified and the number of species in each layer was noted. The results are given in Figure 4. In summary it may be stated that at each more seaward station, a greater proportion of the species were found in the upper six centimeters of the sample. Figure 5 (and Table 7) shows the trend of finding previously unsampled species by digging a deeper sample, and reveals that there was a marked decrease in the number of previously unrecorded species found in deeper layers. In the accumulated data half of the species recorded in the samples were found in the upper two centimeters of the substrate, and 87 % of the species were found in the upper six centimeters. In the coarse sediment of stations 3 and 4 a higher proportion of the species were found somewhat deeper in the sediment than at the stations of the lower beach.

The results obtained in the analysis of the area to be sampled indicate that with three replicates of 0.2 square meter each (i.e. a 0.6 square meter sample), at least 95 % of the collectable species may be expected in the sample, therefore beginning in August 1977 three subsamples were taken at each station. It was then possible to sum the data from the three subsamples into a single sample. This method

Table 6. Cumulative percentage of species present in progressively larger samples.

	Percentage of Species Present in the Following Sampled Areas (m)			
Station	0.2	0.4	0.6	0.8
3 + 5 m	67	89	100	100
8	63	89	100	100
9	57	81	95	100
10	52	81	95	100

Figure 3. Species area curves. The curves were determined from collections made on 29 July 1977 at four sites on the transect.

A Station 3 + 5 meters
B Station 8
C Station 9
D Station 10

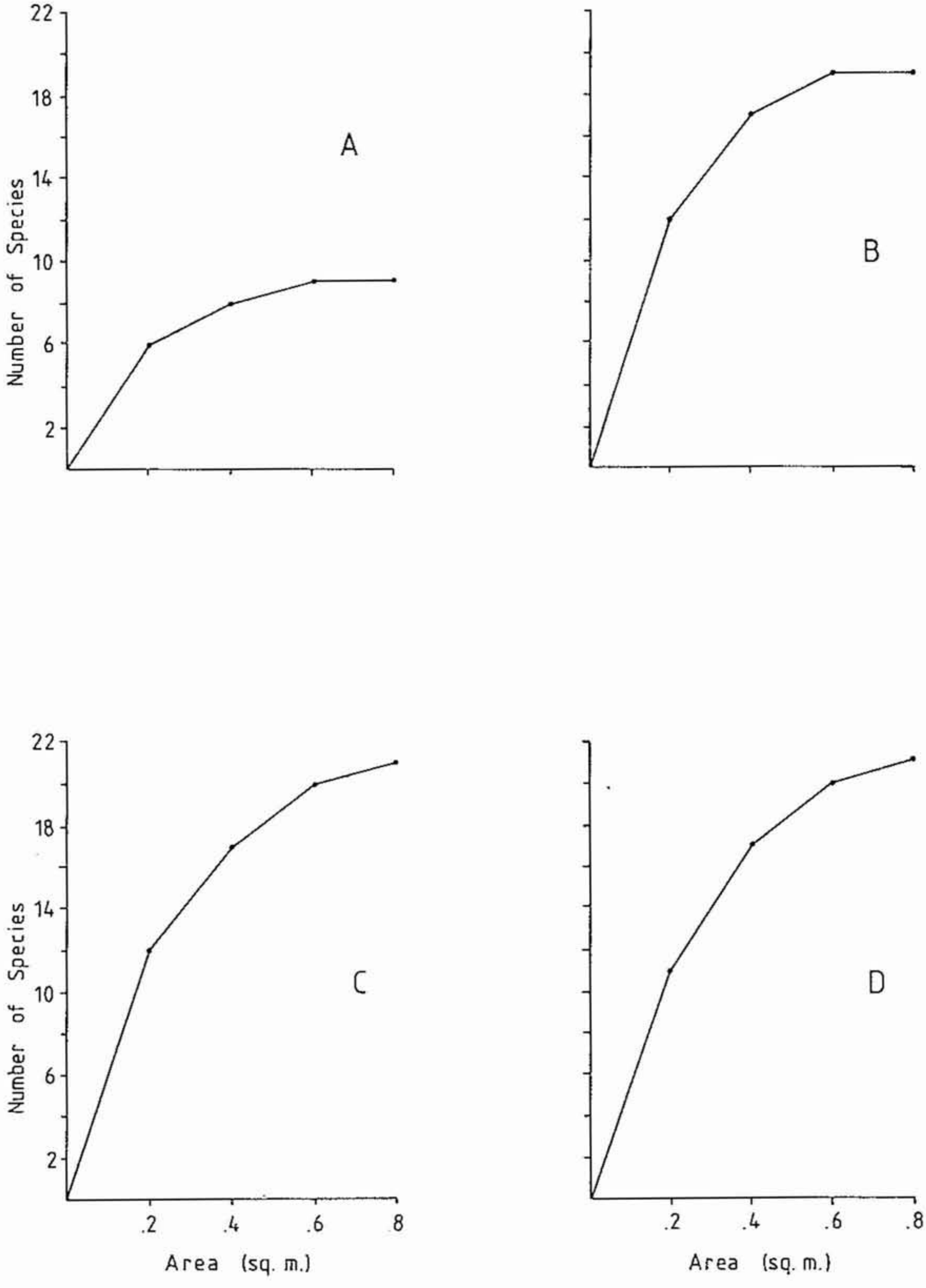
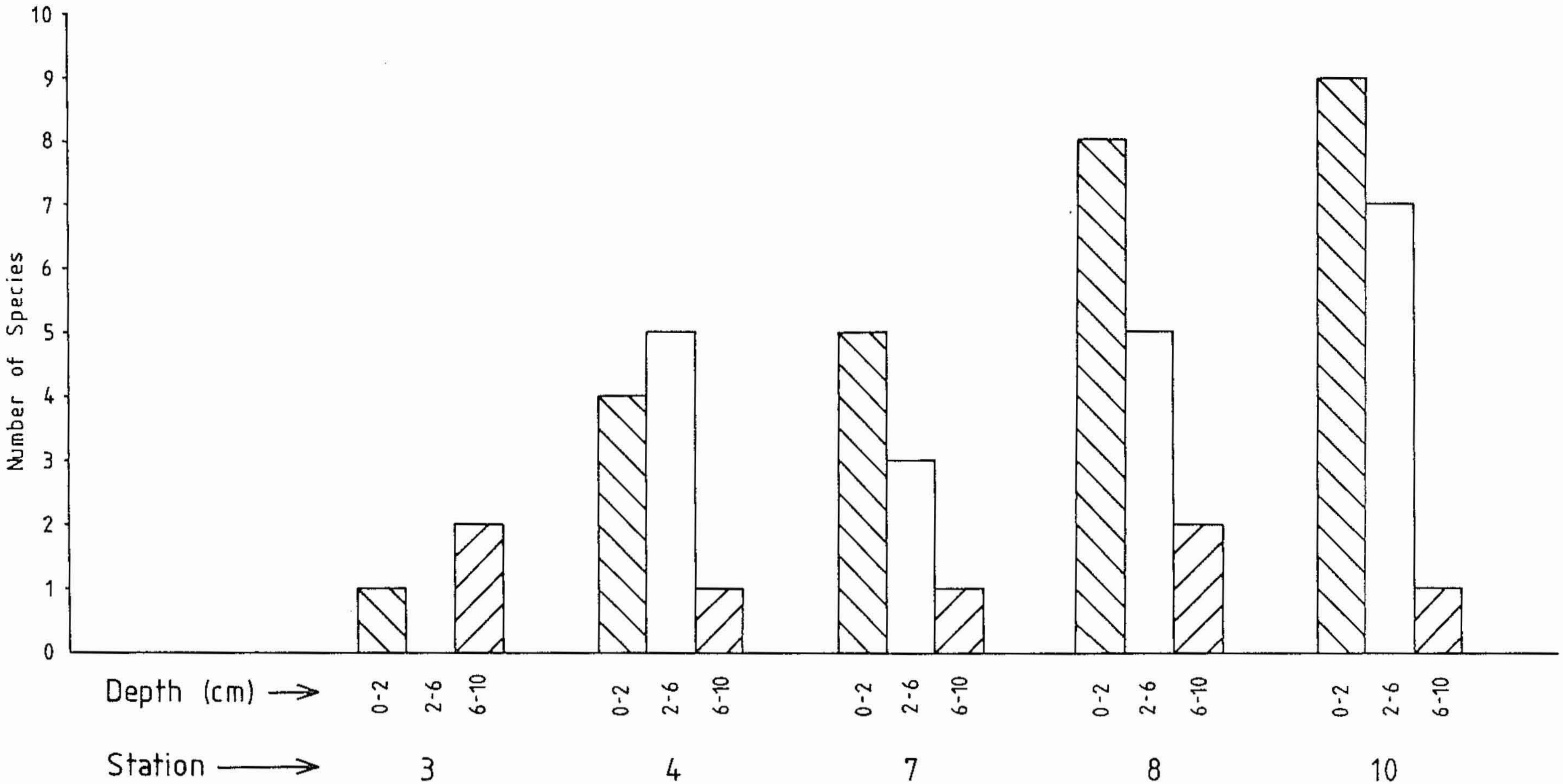

A
B
C
D
Number of Species
Number of Species
22
18
14
10
6
2
22
18
14
10
6
2
.2
.4
.6
8
.2
.4
.6
.8
Area (sq. m.)
Area (sq. m.)

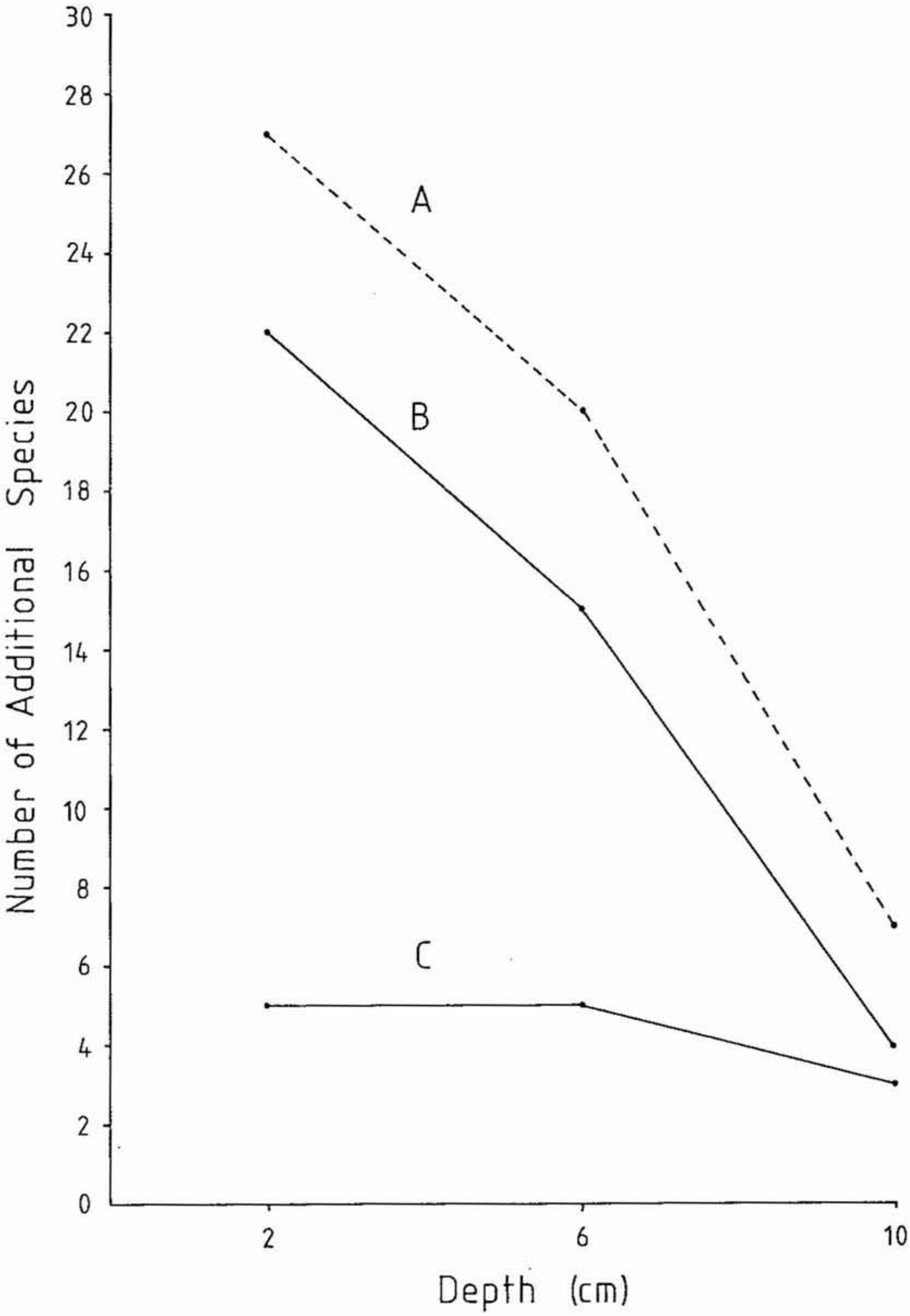
Figure 4. Number of species found in each stratigraphic layer at each of five stations. The samples were taken on 20 June 1978.



Number of Species
0
1
2
3
4
5
6
7
8
9
10
Depth (cm) →
0-2
2-6
6-10
Station →
3
4
7
8
10

Figure 5. Number of additional species collected from succesively deeper layers. The samples were taken on 20 June 1978.

A All Stations
B Stations 7, 8, and 10
C Stations 3 and 4



Number of Additional Species
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
A
B
C
2
6
10
Depth (cm)

Table 7. Additional species found in successively deeper sample layers (measured in centimeters).

	DEPTH					
	0 - 2		2 - 6		6 - 10	
	Number of Species	Cumulative % of Total	Number of Species	Cumulative % of Total	Number of Species	Cumulative % of Total
A*	27	50	20	87	7	100
B	22	54	15	90	4	100
C	5	38	5	77	3	100

A, B, and C as in Figure 5

permits analysis of variation within a sample.

The data indicate that ten centimeters is an appropriate depth for each sample. It was considered that endofaunal species might have been nearer the surface when covered by the tide than when exposed (Vader, 1964). Johnson (1967a) could find no evidence of vertical migration of organisms in a beach related to tidal regime. No effort was made in this study to test this consideration, but in an attempt to ensure capture of otherwise deeper living species, and to maintain consistency, all sampling was done as the falling tide uncovered each station.

Tests for species capture, dependent upon both area and depth of sample, indicate that in general larger samples than those taken by other workers were desirable (see table below). Time and effort requirements influence, or determine, the sampling size and methods in a research program.

Study	Area Sampled/ Station (m^2)	Area Sampled/ Transect (m^2)	Volume Sampled/ Month (litre)
Dexter (1969)	.5	3.0	150
Croker (1977)	.12	.72	72
Holland and Polgar (1976)	1.0	1.0	200
Vohra (1971)	.22	1.33	66.7
Whitlatch (1977)	.012	.2	39
Trevallion *et. al.* (1970)	.1	1.2	192
This study	.6	4.8	480

preliminary testing in this study indicated that the amount of sampling done was necessary to adequately collect the species present at the beach at Pallarenda.

MESH SIZE

An assesment of species captured by different mesh sizes was made (see Reish, 1959). Samples from stations 6, 7, and 8 were washed through a stack of three sieves with diminishing mesh sizes. The top sieve had a mesh of 1.2 millimeters, the middle mesh was 1.0 millimeters, and the bottom was 0.5 millimeters. Table 8 shows the percentage of species first found in the sample starting with the 1.2 millimeter mesh.

From the data it is evident that a high proportion of species were found only on the 0.5 millimeter mesh sieve, however, if the three stations were grouped, as though they were replicates from a single station, the percentage distribution from the samples is

1.2 mm	1.0 mm	0.5 mm
72.7 %	4.5 %	22.7 %

Other than harpacticoid copepods, every species collected on the 0.5 millimeter mesh sieve was collected in the regular sampling program, that is, the major difference between specimens on the 1.2 millimeter mesh and those on the 0.5 millimeter mesh was that the latter were primarily small individuals of species captured on the larger mesh sieve. Only 4.5 % of the species escaped the 1.2 mm mesh and were

Table 8. Species captured on different mesh sizes.

	Mesh (mm)		
STATION	1.2	1.0	0.5
6	55.6	16.6	27.8
7	62.5	12.5	25.0
8	53.8	15.4	30.8

captured on the 1.0 mm mesh, and though a higher species capture could be expected from a 0.5 mm mesh collection sieve, logistical constraints prevented its use.

For uniformity with many other sandy shore works (see Vohra, 1971; Ansell et. al., 1972; Jawed and Khan, 1974; Holland and Polgar, 1976) a 1.0 millimeter mesh would be preferred rather than the unconventional 1.2 millimeter mesh which was used. However, at the initiation of the sampling program such a sieve was not available. Other mesh sizes have been used. Pichon (1967) sampled using a 2.0 millimeter mesh and McLachlan (1977), following his own testing, chose a 1.5 millimeter mesh "because it was easier to operate in the field." Due to energy and time limitations, both in the field and in the laboratory, the 1.2 millimeter mesh was deemed part of a more satisfactory sampling technique than a 0.5 millimeter mesh. It was believed that the sampling program was better served with the mesh size compromised in favour of a larger area for the samples at each station.

NUMERICAL ANALYSIS

All computations were done using a Digital DEC-1091 computer system.

SPECIES DIVERSITY

The Shannon-Weiner species diversity index (H') was computed on species abundance for transects as a whole, as well as selected segments of the transects. The index was computed using logarithms to the base 2.

Pielou evenness (Pielou, 1977) was determined for the same species units as those for which the species diversity index was prepared.

The equations for Shannon-Weiner diversity and for equitability are given in Krebs (1978). These values were determined using a computer program prepared by the author.

ANALYSIS OF VARIANCE

Oneway analysis of variance computations were executed through the Statpack Statistical Package (STP) (prepared by R. Houchard of Western Michigan University in 1974) which is present on the James Cook University computer system.

CLASSIFICATION

Numerical classification of the species data was performed using the Bray-Curtis dissimilarity index and the flexible sorting strategy with beta set at -0.25. The Clustan 1C version (Wishart, 1978) was used to provide this classification. Clustering was done on the raw data with no reductions or transformations.

CLASSIFICATION VERSUS ORDINATION

Application of numerical methods to the numeric distribution of species was made for two reasons. 1) A simplified representation of the benthic structure was desirable and 2) such methods may have suggested structural features which were not otherwise easily recognizable. These are two of several common reasons for utilization of numeric analysis (Orloci, 1975).

In choosing numeric methods there are many alternatives to consider. Most of these are considered in texts such as Sneath and Sokal (1973), Clifford and Stephenson (1975), and Orloci (1975). Ordination and classification are different approaches to condensing entities into ecological groupings. Sneath and Sokal (1973) write

> There are not satisfactory methods for telling from the similarity matrix itself whether clustering or ordination is most appropriate . . . . .

However, in theory there are properties of the respective approaches which better suit them for data of a particular type. If a worker prefers to perceive an assemblage as a fundamental unit, as in a community concept, classification better suits the needs in simplifying distribution according to Lambert and Dale (1964), but if the worker's vision of species distribution is one of a continuum, that is, based on individual species, ordination will best indicate the distributional discontinuities. McIntosh (1967) accepted this division, though he anticipated that future techniques in both methods may cause this belief to be reexamined. Orloci (1975) also agrees that theoretically ordination and classification are quite distinct, but he has found that when utilized together, there appears little difference between the products of the two.

For a comparison of the community (or fundamental unit) concept and the continuum (or individualistic) concept see Krebs (1978) and for a more detailed account see Whittaker (1962). For a working definition of "continuous" Lambert and Dale (1964) attribute the following to W.T. Williams.

> If we have a set of sites such that for every site in the group there is at least one other site with which it has one or more species in common, and if this group cannot be divided into two or more groups such that all the sites of any one group have no species in common with those of another, then the vegetation may be said to be continuous.

The necessity for choosing one method over the other is somewhat clouded. Though there seems to be some theoretical basis for making a choice, the practical application does not always prompt the same choice. Webb et. al. (1967) tried several clustering methods and found that major features were elucidated by all of them. However, finer distinctions of known ecological importance were better summarized by classification than by ordination. Sneath and Sokal (1973) report that Rohlf (1968) ordinating with Principal Component Analysis noted that representation of groups was poorest when the analysis was examining the distance between close neighbours, that is, again, the finer detail is not well distinguished by ordination.

A further potential limitation of ordination derives from the condensation of groupings from hyperspace to two or three dimensional space. Though the groupings may be distinct in hyperspace, it is possible that, as they are projected onto fewer and fewer axes, they may come to overlap, thereby losing their visual uniqueness (Orloci, 1975).

Finally, Orloci (1975) provides a note of caution in rigorously accepting one method over another.

> . . . . . ordinations and classifications should be thought of not as some preferential strategies, associated with rigid assumptions, but rather, as techniques which among other techniques of data analysis can help the user to accomplish certain objectives.

There appears uncertainty and non-conformity of opinions over the usage of these two methods. For this reason both methods with a variety of options to each were undertaken in this study in an effort to meet the objectives planned for numerical analysis. It was felt that classification provides the simplest representation of structure. Additionally, classification methods adequately suggest ecological interactions which can be investigated using the raw data. Discussion related to the methodologies considered for classification techniques follows.

SIMILARITY INDEX AND SORTING STRATEGY

The methods of determining the measurement of the similarity of the entities being classified were examined for their suitability in fulfilling the objectives of this study. The methods were the measure commonly referred to as the Bray-Curtis measure and the Canberra Metric measure. Both of these produce a measure of dissimilarity, rather than similarity, and are described in relevant texts.

The Canberra Metric and Bray-Curtis methods are different in their approach to establishing the dissimilarity matrix. The Canberra Metric measure has a low sensitivity to high abundance species. It, therefore, gives a relatively greater importance to the rarer species. The Bray-Curtis index is influenced by highly dominant species.

Both methods have specific disadvantages. Canberra Metric relies upon the rarer species to define the organismic structure. By the nature of the distribution of these species, they were always poorly sampled in this study which means that each dissimilarity matrix formed using the Canberra Metric was dependent upon a poorly sampled section of the species collection. Ephemeral species may be present in large numbers and so "swamp" the more stable, constantly present species (Grassle and Grassle, 1974) in the Bray-Curtis matrix. Unless the ephemeral species are periodic in occurrence the usefulness of the Bray-Curtis measure is reduced, as its effectiveness to predict the ecological structure is impaired.

The Canberra Metric measure was not used for the reason stated above. However, the disadvantage of the Bray-Curtis method was not manifested with the Pallarenda samples. As will be seen, only one species numerically "swamped" the samples and then only in the season when juveniles of that species were settling. Application of the Bray-Curtis method showed that it was the most suitable measure to fulfill the objectives set for numerical classification.

Several sorting strategies were considered for use with the Bray-Curtis dissimilarity matrix. They were furthest neighbour, nearest neighbour (nearest neighbour sorting strategy should not be confused with the nearest neighbour computations that are produced from each of these sorting methods), group average, median, and flexible (see Clifford and Stephenson, 1975).

Furthest neighbour sorting has been found to produce an excessive number of groups (Clifford and Stephenson, 1975), and this was judged to be the situation when applied to data from this study. Groupings were formed which had small numerical differences from other groups formed, making ecological interpretation difficult.

At the other extreme, nearest neighbour sorting yielded clusters with an excessive amount of chaining (sites being added one at a time to a larger grouping), and failed to construct groupings which were evident from the data.

Group average sorting produced a classification similar to that of the flexible method, but the groups formed were less distinct. The similarity is not surprising, since an analysis from the flexible strategy used is similar to an analysis using group average (Clifford and Stephenson, 1975).

Flexible sorting was done with beta set at -0.25 which has become standard for ecological use of this strategy (Clifford and Stephenson, 1975). The dendrogram produced using flexible sorting with the Bray-Curtis measure of dissimilarity on the information collected in this study best satisfies the objectives set for the numerical classification.

RESULTS

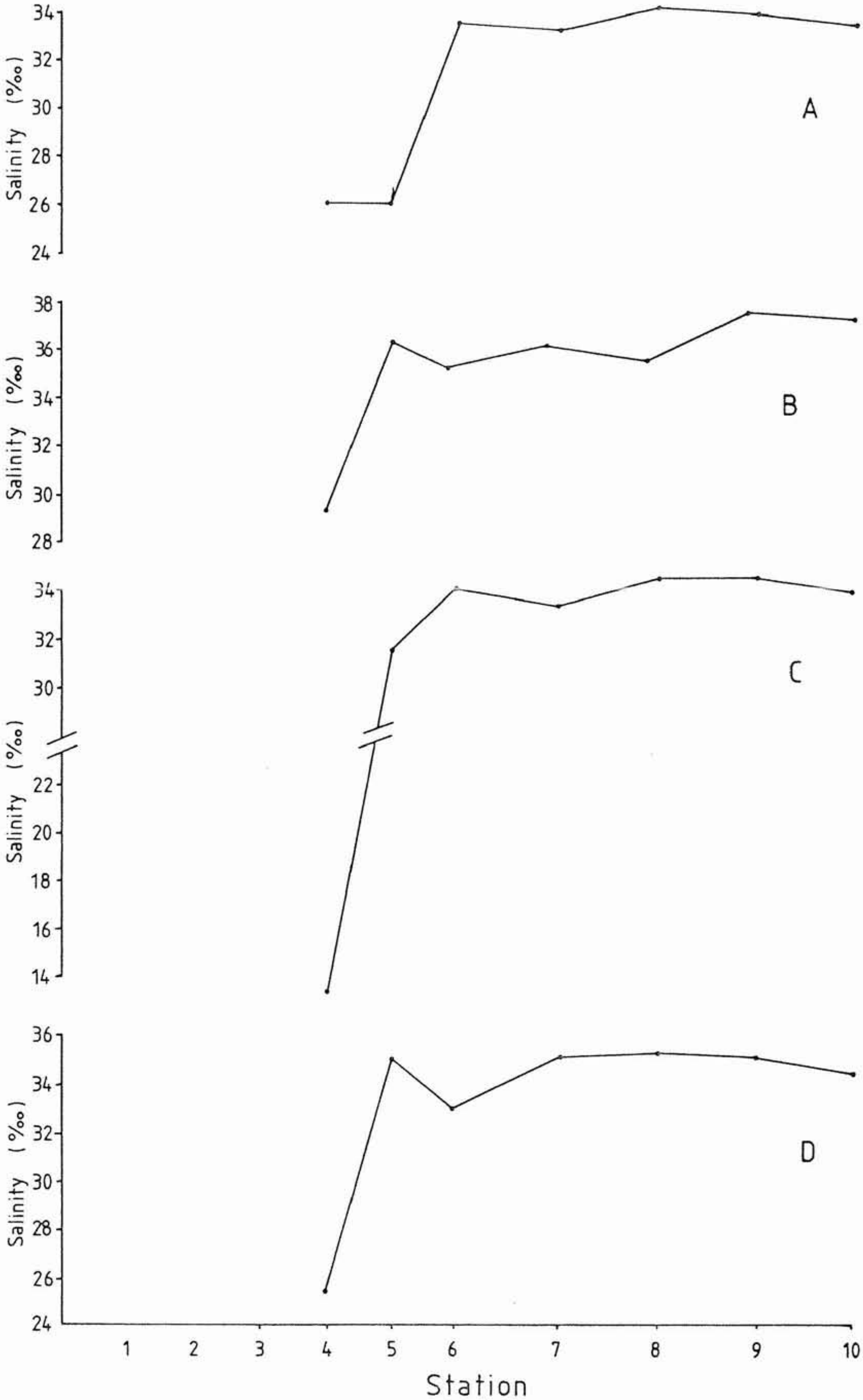
SALINITY AND TEMPERATURE

The salinity between stations 6 and 10 remained relatively equal at each station and consistent throughout the year. The salinity at the higher stations, most notably stations 3 and 4, generally was much lower than at the lower stations during each sampling period. Subsurface water often reached the surface at station 4 and sometimes at station 3. This water contained much less salt than the seawater. See Figure 6 and Table 9. Once on the surface this water flowed freely down the beach and over the lower stations at low tide. This water flow was usually widely dispersed over the lower beach, but occasionally it formed into distinct channels. If channels to the sea formed, many of the lower stations were exposed to the air, however, the more usual situation was that the flow covered the lower stations.

The salinity data, collected once a month, do not reflect average values for each month, but instead are indicative of the salinity only at the time the information was collected. However, when the data are compiled, these readings suggest the yearly range of salinity (see Archibald and Kenny, 1980).

Figure 6. The salinity determined at each station for each season.

A August 1977
B November 1977
C February 1978
D May 1978



Salinity (‰)
A
B
C
D
Station
1
2
3
4
5
6
7
8
9
10

Table 9. Salinity (p.p.t.) at each station from which samples were collected.

	STATION										
	1	2	3	4	5	6	7	8	9	10	Sea
August 1977				26.2	26.1	33.8	33.4	34.3	34.1	33.7	32.6
November 1977				29.5	36.7	35.5	36.5	35.9	38.0	37.6	36.7
February 1978				13.4	31.5	34.1	33.3	34.5	34.5	34.0	30.0
May 1978				25.5	35.1	33.0	35.2	35.4	35.2	34.6	35.2

Similarly, temperature data were collected once a month and so will not show the general temperature trend for the month (see Kenny, 1974). Relating to this problem during the summer months (October through March) tides were such that the sampling had to be done at night. Therefore, summer temperatures were taken at night and winter temperatures were taken during the day. Figure 7 depicts a comparison of day and night temperatures for February 4, 1978. It appears that the difference between day and night temperatures is less at the lower stations, though more critical sampling is necessary. At stations 2 and 3 the difference was between 5 and 6 ^{o}C, at station 4 it was approximately 4 ^{o}C and at station 5 the difference was only 2 ^{o}C.

Temperatures between stations 5 and 10 were relatively constant, though they appear to have been slightly higher at stations 9 and 10 (see Figure 8 and Table 10). In the summer, when sampling was at night, stations 2, 3, and 4 were notably cooler than the others. Similarly, this was the case in August when winter temperatures were not particularly high.

SUBSTRATE

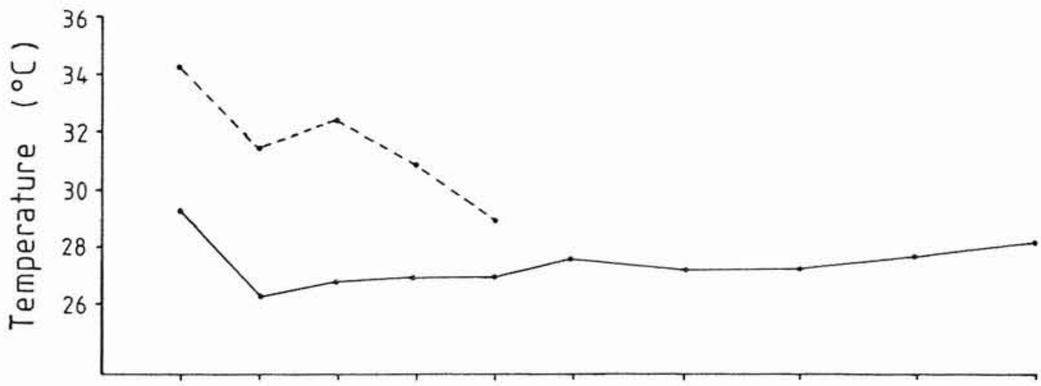
Figure 9 (also see Tables 11 and 12) shows that the particle size at the stations on the upper beach was greater than the particle size at the stations of the lower beach. Stations 3 and 4 had a mean grain size between 0.34 mm and 0.83 mm, while the mean grain size of particles at stations 6 through 10 was in the range 0.07 mm and 0.23 mm. The grain size at station 5 was influenced by the mobile nature of the spring

Figure 7. Temperatures taken during the day and during the night from the same site. The temperatures were measured on 4 February 1978.

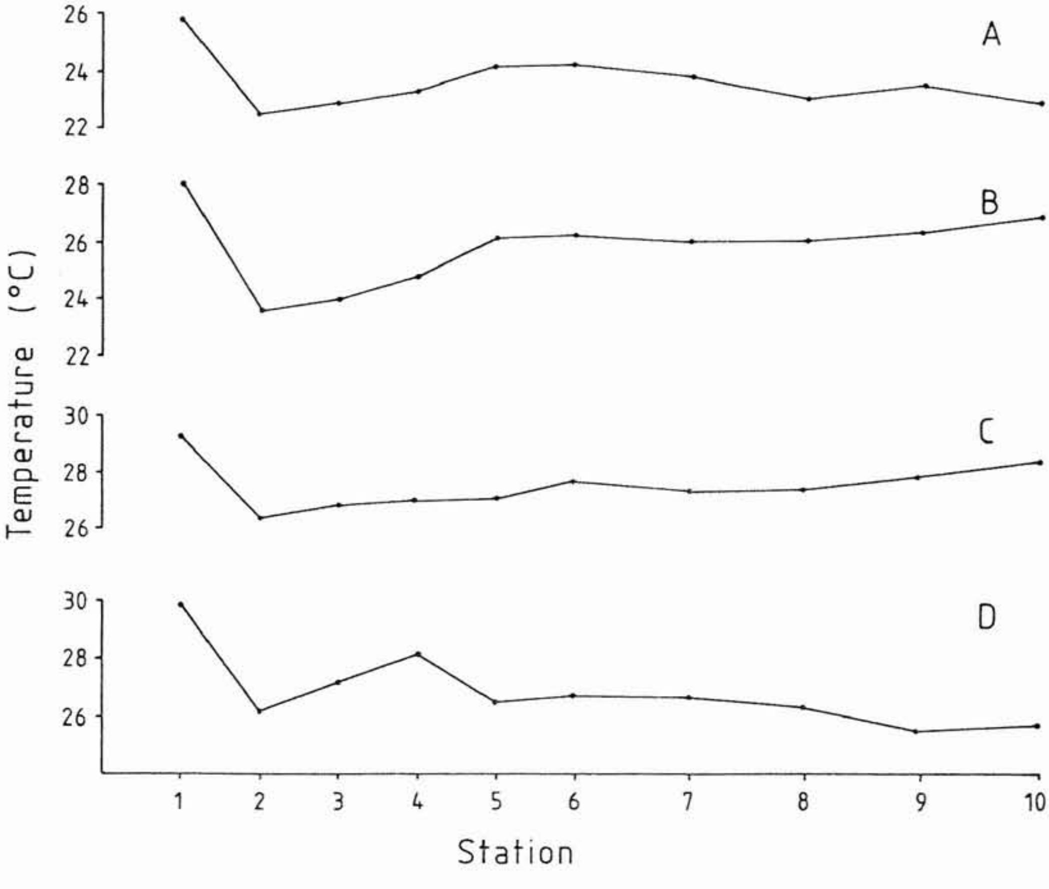
Day Temperature: broken line
Night Temperature: solid line

Figure 8. The temperatures determined during the seasonal sampling.

A August 1977
B November 1977
C February 1978
D May 1978



36
34
32
30
28
26
Temperature (°C)



A
B
C
D
26
24
22
28
26
24
22
30
28
26
30
28
26
Temperature (°C)
1
2
3
4
5
6
7
8
9
10
Station

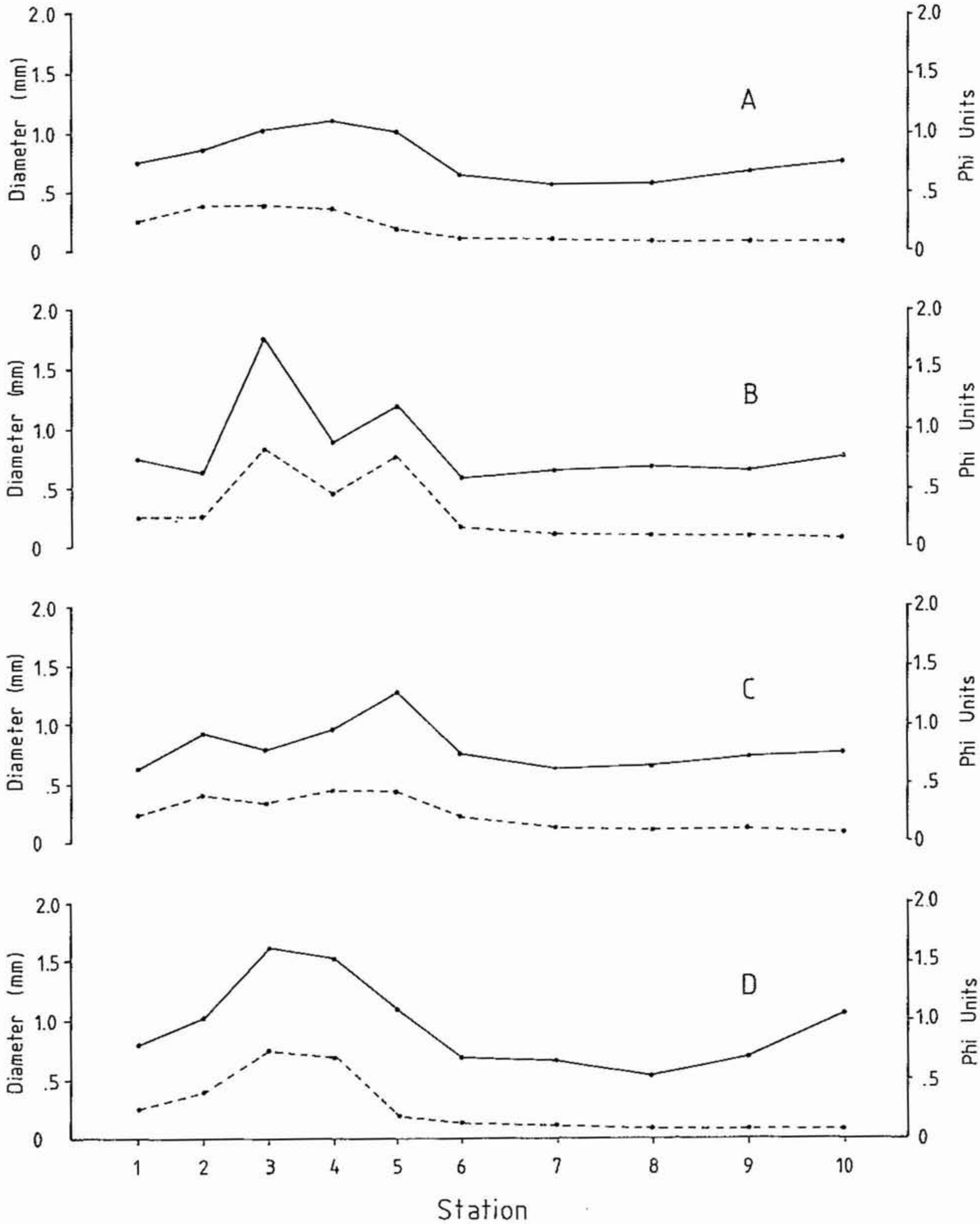
Table 10. Temperature (Centigrade) data.

	STATION											
	1	2	3	4	5	6	7	8	9	10	Sea	Air
August 1977	25.9	22.5	22.9	23.3	24.2	24.2	23.8	23.0	23.5	22.9	23.2	23.0
November 1977	28.0	23.7	24.0	24.8	26.5	26.6	26.2	26.3	26.5	27.0	25.5	25.5
February 1978 (night)	29.4	26.4	26.8	27.0	27.1	27.7	27.4	27.4	27.8	28.3	27.8	27.2
February 1978 (day)	34.6	31.5	32.5	30.8	29.0						30.7	31.0
May 1978	29.9	26.1	27.2	28.1	26.5	26.7	26.7	26.3	25.5	25.7	24.3	28.2

Figure 9. Mean grain size and sorting coeeficient for sediments.

Mean Grain Size: broken line
Sorting Coefficient: solid line

left Y-axis: Mean Grain Size (mm)
right Y-axis: Sorting Coefficient in phi units as defined by Krumbein (1934)



A
B
C
D
Diameter (mm)
Phi Units
2.0
1.5
1.0
.5
0
1
2
3
4
5
6
7
8
9
10
Station

Table 11. Mean grain size of sediment at each station for each sample period.

	STATION									
	1	2	3	4	5	6	7	8	9	10
August 1977	.262	.382	.400	.365	.198	.124	.103	.097	.089	.088
November 1977	.261	.265	.833	.462	.778	.174	.127	.117	.112	.087
February 1978	.244	.407	.341	.453	.447	.233	.136	.111	.101	.089
May 1978	.251	.431	.731	.685	.200	.145	.109	.094	.087	.069

Table 12. Sorting coefficient of sediment at each station for each sample period.

	STATION									
	1	2	3	4	5	6	7	8	9	10
August 1977	.752	.865	1.035	1.117	1.014	.657	.576	.577	.677	.759
November 1977	.751	.632	1.778	.898	1.198	.594	.651	.682	.653	.776
February 1978	.635	.933	.796	.959	1.285	.738	.633	.718	.733	.765
May 1978	.801	1.043	1.627	1.534	1.100	.691	.667	.537	.695	1.060

horizon. In November and February the spring horizon had moved below station 5 and the mean grain size at the station was closer to those of stations 3 and 4 than to the mean size at stations of the lower beach. In November and February the mean grain sizes at station 5 were 0.78 and 0.45 mm, respectively. In the autumn and winter the spring horizon had moved above station 5 and the sediment parameter values were nearer to the sediment measurements of the stations of the lower end of the transect. In both of these seasons the mean grain size at station 5 was 0.20 mm.

Below the spring horizon the influence of the coarse sand on the size class structure of the sediment gradually diminished. Stations 9 and 10 sometimes had a comparatively high silt-clay fraction of more than 10 %.

Figure 9 shows that the best sorting was at stations 6, 7, and 8, and from station 6 to station 10 there was a gradual decrease in the degree of sorting in all seasons. The sediment of the lower beach is more poorly sorted at each successive seaward station. The figure also shows that the upper beach was usually more poorly sorted than any of the lower beach stations and seasonally it was more variable in the degree of sorting.

FAUNA

AUGUST

The upper two stations (stations 3 and 4) were characterized by an exclusive group of species which did not occur at the lower six stations (see Table 13). The nereids, though present at station 3, were primarily residents of station 4, as were three other worms, Pisione oerstedi, Goniadopsis, and the archiannelid, Saccocirrus. The distribution of Donax faba extended across both of these upper stations, but it was found in greatest abundance at station 4. Though Mesodesma altenae was found in abundance at station 3, the most common organism at this station was Pseudolana brevimargine.

Both Urohaustorius and Opheliid (n.g. n.sp.) were found regularly and abundantly only at station 5 and can be considered definitive species of this station. Glycera A had its most abundant distribution at this station. Callianassa australiensis juveniles were found in large numbers at station 5. Diogenes avarus was quite abundant at this station, but was also well distributed downshore. Platyischnopus was found only at station 5. Many of the species which occur at the lower stations, were evident at station 5. Glycera B was an important species between stations 5 and 10 and Choncholestes became progressively more abundant at downshore stations, reaching its maximum in the sampled area at station 10. Solidula cf. sulcata and Tellina (Macomana) australis, and Arachnoides placenta were major contributors to the number of individuals on the lower beach.

Table 13. Number of individuals of each species at each station in August 1977.

August 1977

	STATION							
	3	4	5	6	7	8	9	10
Pseudolana brevimargine	27							
Mesodesma altenae	24	5						
Donax faba	21	71						
Perinereis vallata	2	24						
Other Nereids	1	26						
Pisione oerstedi		24						
Goniadopsis		7						
Saccocirrus		3						
Solidula cf. sulcata		1	1	1	7	3	8	2
Callianassa australiensis			59		2			
Urohaustorius			20					
Arachnoides placenta			16	11	13	5	6	12
Glycera A			16	2		1		
Diogenes avarus			15	1	1		1	6
Scolelepis B			5	2				
Opheliid (n.g. n.sp.)			4					
Glycera B			3	9	3	6	2	1
Nemerteans (Carinoma)			3	2	2	3	2	4
Amphipod C			3					
Eulimid			2		2	1	2	
Platyischnopus			2					
Chonchlestes			1	2	2	6	6	11
Ceratonereis erythraeensis			1	1				
Polinices conicus			1	1				

Table 13 continued.

Scoloplos (Scoloplos) normalis	1					
Tellina (Macomona) australis		3	6	4	1	3
Dispio A		3	2			
Armandia intermedia		2				
Dosinia kaspiewi		1	2	1	5	3
Albunea symmysta		1		2		2
Isanda coronata		1				
Elamenopsis cf. lineata		1				
Gastrosaccus cf. dakini			4	2		1
Naineris cf. grubei			1			1
Strigilla tomlini			1			
Amphictene				1	1	
Diopatra				1		1
Scoloplos (Leodamus)				1		
Lumbrinereis				1		
Euchone				1		
Sthenelais				1		
Pista typha				1		
Ogyrides				1		
Mactra dissimilis					3	
Tellina (Angulus) lanceolata					1	
Spiophanes						2
Magelona						1
Sigalion						1
"Onuphis sp 4"						1
Tellina (Cadella) semen						1
Hastula plumbea						1
Philyra						1

NOVEMBER

Pseudolana brevimargine was found in equal numbers at stations 3 and 4 in this month, and its range was extended to station 5. Several species were found in the lower portion of the upper beach. Donax faba was distributed between stations 4 and 5, as was the largest portion of Mesodesma altenae individuals. The ~~worms~~ annelids, Saccocirrus, Goniadopsis, Pisione oerstedi, and Syllis, were found only at station 5, and again, Callianassa australiensis was abundant at station 5, as was Glycera A. Urohaustorius and Opheliid (n.g. n.sp.) were absent. Platyischnopus, Glycera A, and Scolelepis B were found concentrated in the upper portion of the lower beach (stations 5, 6, and 7), while others extended throughout the lower beach (Tellina (Macomana) australis, Glycera B, Mactra dissimilis, and Matuta). Amphipod C was confined to station 6 and Choncholestes became progressively more abundant at stations 8, 9, and 10. Tellina (Cadella) semen and Sthenelais were abundant in the lower portion of the transect. Microprotopus, Strigilla tomlini, and Ogyrides were other important species between stations 6 and 10.

In November more species (67) were collected than during any other month (see Table 14), but there were many species that were present in low abundance. Twelve species occurred at either station 9 or 10 and of those twelve, nine were represented by one individual only (see DISCUSSION: RARE SPECIES).

Table 14. Number of individuals of each species at each station in November 1977.

November 1977

	STATION							
	3	4	5	6	7	8	9	10
Pseudolana brevimargine	28	28	2					
Mesodesma altenae	11	289	2014	2				
Perinereis vallata	3	18						
Other Nereids	1	9	1					
Donax faba		81	53					
Megalops Larva		4						
Scolelepis C		3						
Dosinia kaspiewi		1		2	1	3	1	5
cf. Gondogeneia		1		1	2	4	2	1
Pisione oerstedi			52					
Callianassa australiensis			19	1	1			
Glycera A			12	9	2			
Goniadopsis			10					
Platyischnopus			8	18	4	1		
Scolelepis B			7	8	1			
Saccocirrus			7					
Syllis (Langerhansia)			7					
Amphipod C			6					
Ceratonereis erythraeensis			4	3		1		
Arachnoides placenta			2	206	35	21	5	7
Gastrosaccus cf. dakini			2	1			2	

Table 14 continued.

Armandia intermedia	2	1				
Polygordius	1					
Polinices didymus	1					
Sphaeromidae	1					
Mactra dissimilis		8	19	30	26	6
Glycera B		7	20	19	21	6
Matuta		4	1	4	3	1
Strigilla tomlini		3	5	10	4	
Nemerteans (Carinoma)		3	2	7	4	5
Solidula cf. sulcata		2	5	3		1
Phyllodoce		2				
Tellina (Macomona) australis		1	4	6	5	2
Ogyrides		1	3	2		5
Hastula plumbea		1	2	1		
Polinices (small)		1	1	4	3	
Diogenes avarus		1	1	1	2	7
Isanda coronata		1	1			
Scoloplos (Leodamus)		1		1	1	
Microprotopus			17	19	2	5
Naineris cf. grubei			2		1	
Epicodakia			1	1		
Enteropneust			1	1		
Chonchlestes				7	38	50
Dispio A				3	3	
Tellina (Cadella) semen				2	11	2
Tellina (Angulus) lanceolata				2	1	
Malacoceros				1	1	
Spionid C				1		
Ostracods (Leuroleberis)				1		
Portunidae				1		
Philyra				1		
Prionospio					4	
Sigalion					2	1
Amphictene					2	1
Orbinia					1	1

Table 14 continued.

Magelona	1	
Polinices conicus	1	
Edwardsia elegans	1	
Goby	1	
Sthenelais		4
Montacutona		2
Diopatra		1
Maldanidae Euchymeninae		1
Peneid B		1
cf. Exoidiceros		1
Paraplugusia guttata		1

FEBRUARY

As noted above, for August and November, the species composition at stations 3 and 4 remained relatively the same in February (see Table 15). However, in February all the cirolanids were located at station 4. *Polygordius* was the more abundant archiannelid, as the *Saccocirrus* maximum had moved to station 5. The nereids and *Donax faba* were most common at station 4, but *Mesodesma altenae* was absent from this station and in much lower abundance than in November. *Pisione oerstedi* was found only at station 4, as was a single individual of *Patinapta* cf. *ooplax*. *Syllis*, *Goniadopsis*, Opheliid (n.g. n.sp.), and *Urohaustorius* contributed heavily to the collections from station 5. *Glycera* A was numerically important at station 5, but occurred in greater numbers at station 6. The major contributors between stations 6 and 10 included *Tellina* (*Macomana*) *australis*, *Arachnoides placenta*, *Mactra dissimilis*, and *Solidula* cf. *sulcata*. *Albunea symmysta* was moderately common, particularly at station 9, but *Glycera* B was less abundant than in previous seasons. *Choncholestes* was concentrated at the lower end of the transect.

MAY

The nereids and *Donax faba*, though present at both station 3 and station 4, were more abundant at the latter (see Table 16). Station 4 was the sole site of *Pisione oerstedi*, *Goniadopsis*, *Pisionidens* cf. *indica*, and *Patinapta* cf. *ooplax*. *Pseudolana brevimargine* was found at both the upper two stations, so that no species distribution pattern

Table 15. Number of individuals of each species at each station in February 1978.

February 1978

	STATION							
	3	4	5	6	7	8	9	10
Donax faba	12	25	2	1				
Other Nereids	3	7						
Perinereis vallata	1	4						
Armandia intermedia	1	1	2					
Mesodesma altenae	1		3	6				
Megalops Larva	1							
Polygordius		17						
Pseudolana brevimargine		12						
Pisione oerstedi		9						
Saccocirrus		2	7					
Diogenes avarus		1		3	5	2	6	5
Oligochaete B		1						
Patinapta cf. ooplax		1						
Gastrosaccus cf. dakini			10			1		1
Syllis (Langerhansia)			9					
Glycera A			5	11				
Urohaustorius			3					
Matuta			1	1				2
Opheliid (n.g. n.sp.)			1					
Goniadopsis			1					
Taneid B			1					
Arachnoides placenta				14	26	24	33	31
Nemerteans (Carinoma)				3			3	3
Tellina (Macomona) australis				2	8	6	9	1

Table 15 continued.

Dispio A	2	3	1		
cf. Gondogeneia	2	1			
Dosinia kaspiewi	2		1		2
Platyischnopus	2				
Glycera B	1	3	3		
Polinices conicus	1	1	2		
Scolelepis B	1	1			
Strigilla tomlini	1		2		
Albunea symmysta	1		1	5	2
Microprotopus	1				2
Enteropneust	1				1
Scoloplos (Leodamus)	1				
Mactra dissimilis		3	2	5	2
Solidula cf. sulcata		2	2	2	1
Chonchlestes			2	4	1
Atylus			2		1
Glycera cf. americana			1		
Diopatra			1		
Ostracods (Leuroleberis)			1		
Orchestia			1		
Paraplugusia guttata			1		
cf. Platynereis				4	
Capitellidae				1	1
Naineris cf. grubei				1	
Cumacea				1	
Epicodakia					1
Tellina (Angulus) lanceolata					1
Nassarius					1
Polinices (small)					1

Table 16. Number of individuals of each species at each station in May 1978.

May 1978

	STATION							
	3	4	5	6	7	8	9	10
Other Nereids	6	20						
Donax faba	5	167						
Pseudolana brevimargine	3	5						
Oligochaete B	2							
Perinereis vallata	1	26						
Mesodesma altenae	1		1					
Scopimera inflata	1							
Pisione oerstedi		22						
Goniadopsis		14						
Nemerteans (Carinoma)		3		1	8	1	2	3
Pisionidens indica		3						
Patinapta cf. ooplax		3						
Scolelepis B		1	7	3				
Syllis (Langerhansia)		1	1					
Opheliid (n.g. n.sp.)			37					
Glycera A			11	5	1			
Ceratonereis erythraeensis			7					
Arachnoides placenta			5	21	19	12	27	27
Mactra dissimilis			5	6		6	1	2
Urohaustorius			5					
Platyischnopus			2	4				
Matuta			2					
Amphipod E			2					
Tellina (Macomona) australis			1	3	1	6		

Table 16 continued.

Solidula cf. sulcata	1	1		3	1	1
Megalops Larva	1	1		1		
Glycera B	1		2	2		
Amphipod C	1					
Diogenes avarus		5	4	8	3	3
Ogyrides		3	4	2	2	5
Polinices (small)		2				
Dispio A		1	3		1	
Dosinia kaspiewi		1	1			2
Microprotopus		1			3	
Tellina (Cadella) semen		1				
Polinices didymus		1				
Gastrosaccus cf. dakini			2	2	5	6
Hastula plumbea			2	1	2	1
Albunea symmysta			1	1		
Scoloplos (Leodamus)			1			
Lumbrinereis			1			
cf. Gondogeneia				3		
Chonchlestes				2		2
Strigilla tomlini				2		
Atylus				1		1
Spionid C				1		
Diopatra				1		
Ostracods (Leuroleberis)					6	
Capitellidae					1	
Enteropneust					1	
Goby						4
cf. Platynereis						1
Tellina (Angulus) lanceolata						1
Eulimid						1
Peneid B						1

emerged which clearly separated station 3 from station 4. Oligochaete B and Scopimera inflata were found only at station 3, but are not major contributors to the number of individuals of the area. Station 5 was distinguished by the presence of Urohaustorius and especially by numerous individuals of Opheliid (n.g. n.sp.). Scolelepis B, Ceratonereis erythraeensis, Amphipod C, Glycera A, and Platyischnopus each remained geographically high in this lower portion of the intertidal. Mactra dissimilis, Arachnoides placenta, Diogenes avarus, and Ogyrides were widely distributed and easily found throughout the lower stations across the flat. Gastrosaccus cf. dakini and Tellina (Macomana) australis also were prevalent in this area. Glycera B showed neither the abundance nor the breadth of distribution which it had exhibited in other seasons. Choncholestes was again found at the lower intertidal stations, as in November and February.

SPECIES NOT REGULARLY SAMPLED

Most species listed in Tables 13 - 16 and Appendix A were abundant and common enough to appear regularly in the samples, but there also occurred species which, though less obvious, need to be recognized.

It was not possible to collect several of the species which inhabit the beach at Pallarenda, as they live too deep to be sampled by the regular sampling method.

Callianassa australiensis was found in a belt at the lower end of the coarse sand of the upper beach. The presence of this species was indicated by a small conical mound at the surface above each individual.

Table 17. Number of individuals of each species at each station for the combined four seasonal samples.

August 1977
November 1977
February 1978
May 1978

	STATION							
	3	4	5	6	7	8	9	10
Pseudolana brevimargine	58	45	2					
Donax faba	38	344	55	1				
Mesodesma altenae	37	294	2018	8				
Other Nereids	11	62	1					
Perinereis vallata	7	72						
Oligochaete B	2	1						
Megalops Larva	1	4	1	1		1		
Armandia intermedia	1	1	4	3				
Scopimera inflata	1							
Pisione oerstedi		55	52					
Goniadopsis		21	11					
Polygordius		17	1					
Saccocirrus		5	14					
Patinapta cf. ooplax		4						
Nemerteans (Carinoma)		3	3	9	12	11	11	15
Scolelepis C		3						
Pisionidens indica		3						
Scolelepis B		1	19	14	2			
Syllis (Langerhansia)		1	17					
Diogenes avarus		1	15	10	11	11	12	21
Solidula cf. sulcata		1	2	4	14	11	11	5

Table 17 continued.

Dosinia kaspiewi	1		6	4	5	6	12
cf. Gondogeneia	1		3	3	7	2	1
Callianassa australiensis		78	1	3			
Glycera A		44	27	3	1		
Opheliid (n.g. n.sp.)		42					
Urohaustorius		28					
Arachnoides placenta		23	252	93	62	71	77
Platyischnopus		12	24	4	1		
Ceratonereis erythraeensis		12	4		1		
Gastrosaccus cf. dakini		12	1	6	5	7	8
Amphipod C		10					
Mactra dissimilis		5	14	22	38	35	10
Glycera B		4	17	28	30	23	7
Matuta		3	5	1	4	3	3
Eulimid		2		2	1	2	1
Amphipod E		2					
Tellina (Macomona) australis		1	9	19	22	15	6
Chocholestes		1	2	2	17	48	64
Polinices conicus		1	2	1	2	1	
Polinices didymus		1	1				
Scoloplos (Scoloplos) normalis		1					
Sphaeromidae		1					
Taneid B		1					
Dispio A			6	8	4	4	
Ogyrides			4	7	5	2	10
Strigilla tomlini			4	6	14	4	
Polinices A			3	1	4	3	1
Microprotopus			2	17	19	5	7
Albunea symmysta			2	1	4	5	4
Scoloplos (Leodamus)			2	1	2	1	
Isanda coronata			2	1			
Phyllodoce			2				
Hastula plumbea			1	4	2	2	2
Enteropneust			1	1	1	1	1
Tellina (Cadella) semen			1		2	11	3

Table 17 continued.

Elamenopsis cf. lineata	1				
Naineris		3		2	1
Epicodakia		1	1		1
Lumbrinereis		1	1		
Diopatra			3		2
Atylus			3		2
Ostracods (Leuroleberis)			2	6	
Tellina (Angulus) lanceolata			2	2	2
Spionid C			2		
Amphictene			1	3	1
Malacoceros			1	1	
Sthenelais			1		4
Philyra			1		1
Paraplagusia guttata			1		1
Glycera cf. americana			1		
Euchone			1		
Pista typha			1		
Orchestia			1		
Portunidae			1		
cf. Platynereis				4	1
Prionospio				4	
Sigalion				2	2
Capitellidae				2	1
Goby				1	4
Orbinia				1	1
Magelona				1	1
Cumacea				1	
Edwardsia elegans				1	
Spiophanes					2
Montacutona					2
Peneid B					2
Maldanidae Euchymeninae					1
"Onuphis sp 4"					1
Nassarius					1
cf. Exoidiceros					1

The opening to burrows of the ghost crab, *Ocypode*, revealed the distribution of this crab. Most of these burrows are situated above the high water line of the most recent high tide, but burrow openings were found as low as station 3 when the tide had fallen. Ten specimens of *Ocypode* were collected, and all were of the species *Ocypode ceratophthalma*.

The upper limit of the most recent high tide was demarcated by pieces of wood, algae, and other deposited debris. The sand beneath these pieces in the strand line remained moist and cool and provided a habitat for the amphipod *Talorchestia*.

Other important species with a distribution pattern, which did not allow collection by the regular sampling procedure, were found at the lower beach stations. These were *Diopatra*, *Balanoglossus*, *Flosmaris*, and *Paracondylactis dawydoffi*.

Diopatra was evenly distributed from station 6 to the lowest observed tide level, and was easily located. The characteristically 'scruffy' tube of *Diopatra* descends several ~~feet~~ one meter into the substrate, and it was not possible to collect an entire specimen of this polychaete. The range of the enteropneust extended from between stations 6 and 7 to station 10, but was in its greatest abundance between stations 8 and 9. These animals were readily located by the presence of the characteristic casts of deposited sediment on the beach surface. The proboscis of *Balanoglossus* are positioned approximately one meter below the surface, consequently, an entire animal was not collected. The base of *Paracondylactis dawydoffi* may be situated at a depth of three-quarters of a meter which allows the animal to be readily dug from the sand.

This anemone was found throughout the region between station 5 and station 10, but was not found as frequently as either Diopatra or the enteropneust. Flosmaris is a shallow burrowing anemone which was collected more often than Paracondylactis dawydoffi, but not regularly enough to give an indication of its density and distribution. It existed between stations 6 and 10 and the majority of individuals occurred in the region near stations 8 and 9. Each of these four species referred to above was large and sedentary with some feature which made its presence conspicuous, and therefore, it was easy to recognize that they were missing or inadequately represented in the samples.

Evidence on the beach surface of other deep living species existed and diggings were made for some of these. The head of a species of Mesochaetopterus was taken, but an echiurid which was present was not collected. Stomatopod burrows were dug, but no specimens were collected, however, in digging one of these burrows four individuals of the galleomanid bivalve, Devonia, a known commensal of stomatopods (Lock, personal communication), were found.

Several additional species were found irregularly, but little is known of their spatial or their temporal distribution in the area. These species include Philine angasi, Atripina, Aphrodite (not Aphrodite australis), Astropecten granulosa, and Camposcia rugosa. Astropecten granulosa was sparsely distributed, but was found during each season. Philine angasi and Atripina were found only during the winter months, however, their discovery requires careful searching and they may have been overlooked on many occasions. Both of these species were located very near the low tide line, and may have been more abundant in the subtidal habitat, where no sampling was undertaken. *Camposcia rugosa* is a majid crab and was found only at the low tide mark, and only where much algae (particularly *Solieria* and *Chondria tenuiesima*) was present. These two algal species make up nearly all of the decoration of the crab.

FLORA

The flora found on Pallarenda beach are given in Appendix B. A more complete account of the algae of this area may be found in Ngan and Price (1979).

MATHEMATICAL ANALYSES

DIVERSITY

Species diversity values (H') computed for the entire transect of each month are displayed in Figure 10. Though the index value drops to 2.45 in November, it is otherwise between 4.00 and 5.00.

Isolation of the equitability component from the diversity index shows the same pattern on Figure 10 as shown for H'. In November the value is low (.40), but in other seasons the values are between .70 and .80.

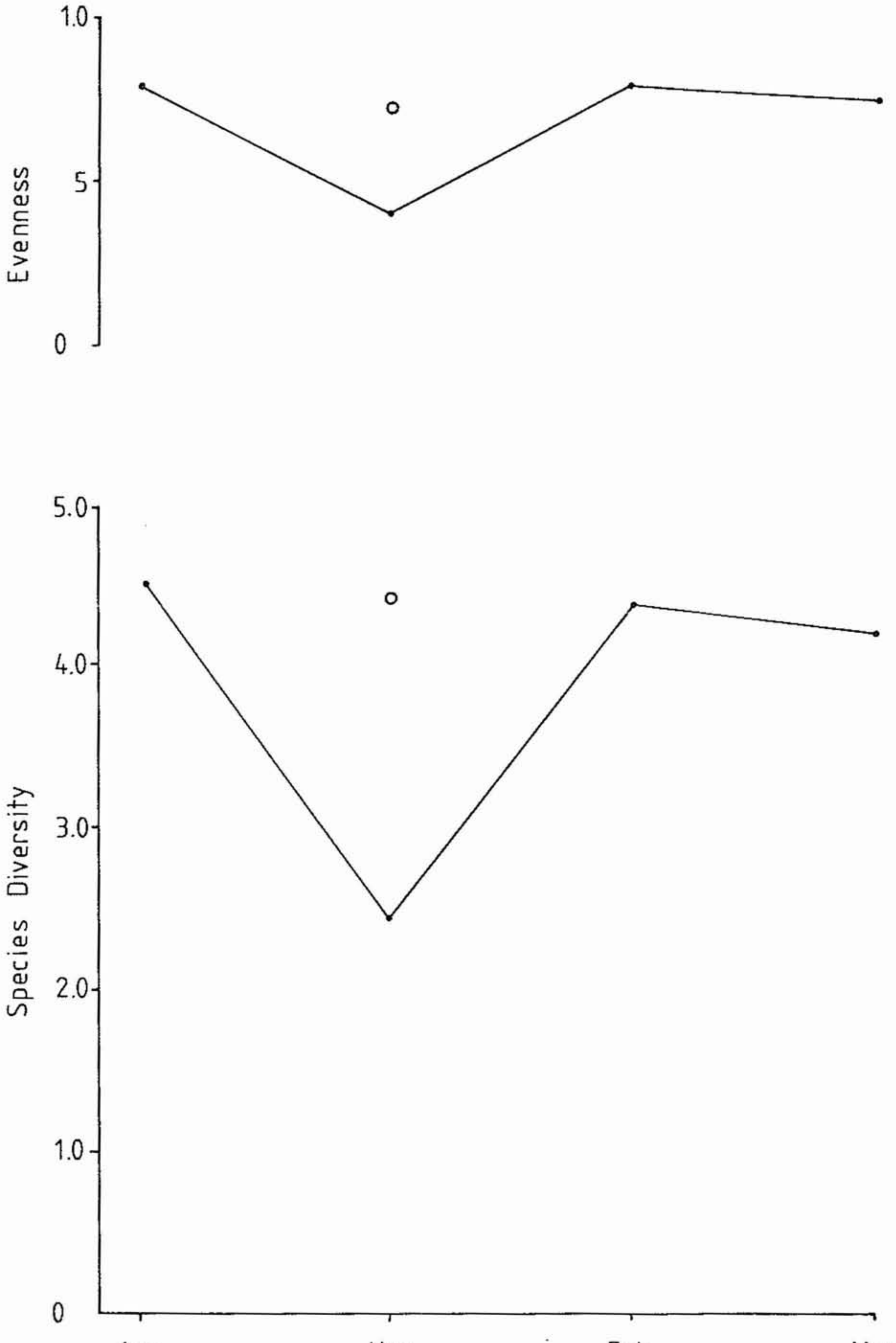
Table 18. Number of species, diversity, and evenness.

Stations	Aug 1977	Nov 1977	Feb 1978	May 1978
Number of Species				
3 - 4	9	9	13	14
5	17	20	12	17
6 - 10	39	53	38	37
3 - 10	52	67	53	55
Diversity				
3 - 4	2.57	1.67	2.76	2.09
5	2.96	.72	3.12	3.04
6 - 10	4.12	3.83	3.56	3.75
3 - 10	4.54	2.45	4.37	4.20
3 - 10*		4.43		
Evenness				
3 - 4	.81	.53	.75	.55
5	.72	.17	.87	.74
6 - 10	.78	.67	.68	.72
3 - 10	.80	.40	.76	.73
3 - 10*		.78		

3 - 10* *Mesodesma altenae* not included in the computation.

Figure 10. Shannon-Weiner species diversity and the evenness index for the seasonal collections.

O The value obtained if Mesodesma altenae is not included in the calculation.


1.0
5
0
Evenness
5.0
4.0
3.0
2.0
1.0
0
Species Diversity
Aug
Nov
Feb
May
Sample

The number of species, the species diversity, and the evenness were calculated for each month and are given in Table 18. Though the diversity values tended to be lowest at stations 3 and 4 and highest at stations 6 through 10, there is no obvious pattern for the equitability values of the four seasonal samples.

NUMERICAL CLASSIFICATION

The dendrogram in Figure 11 was generated from the relationships of all species collected in the four seasonal samples. Two major groups are evident and are composed of the stations of the lower beach and the stations of the upper beach group plus the intermediate station 5. Though the intermediate station is combined with the upper beach group, it maintains its own identity within the division.

On the dendrogram of the 91 seasonal species the evident groups have been identified (Figure 12). These groups are formed from units which were created from observable ecological organization.

Group A. Station 3 of each season is similar to station 3 of every other season in such a manner that all of them are organized into a group. One station which seems incongruous in the group is station 4 of February (February 4). Examination of the species captured in the February 4 sample reveals why it is clustered with this group. Pseudolana brevimargine is a species typically found at station 3, but in February it was also found at station 4 (refer to Figure 16). See Tables 13 - 16 and the nearest neighbour table in Appendix C.

Figure 11. Clustering of sites using the 91 species collected from the samples of the year. The month and the station of each collection are given.

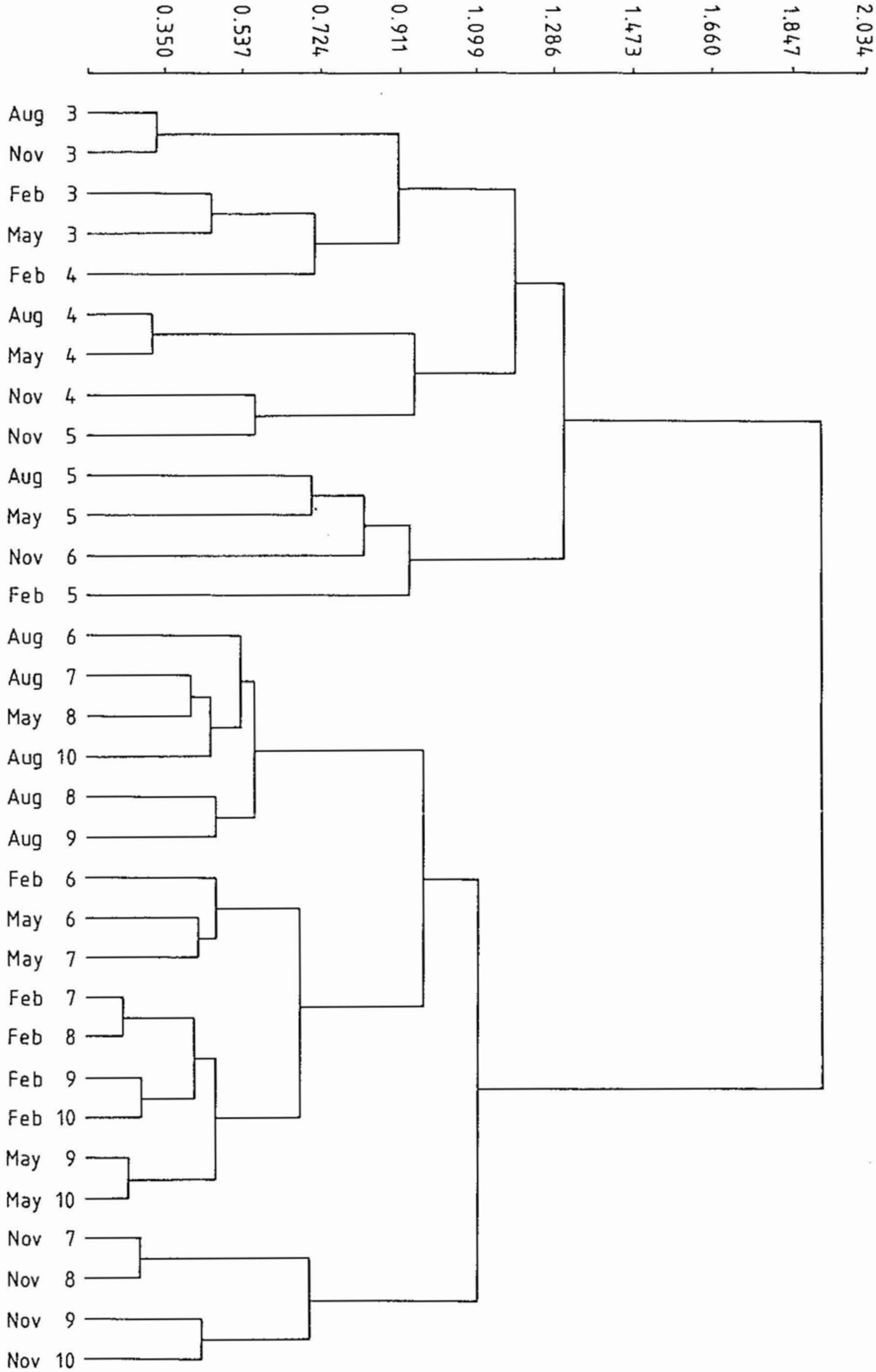
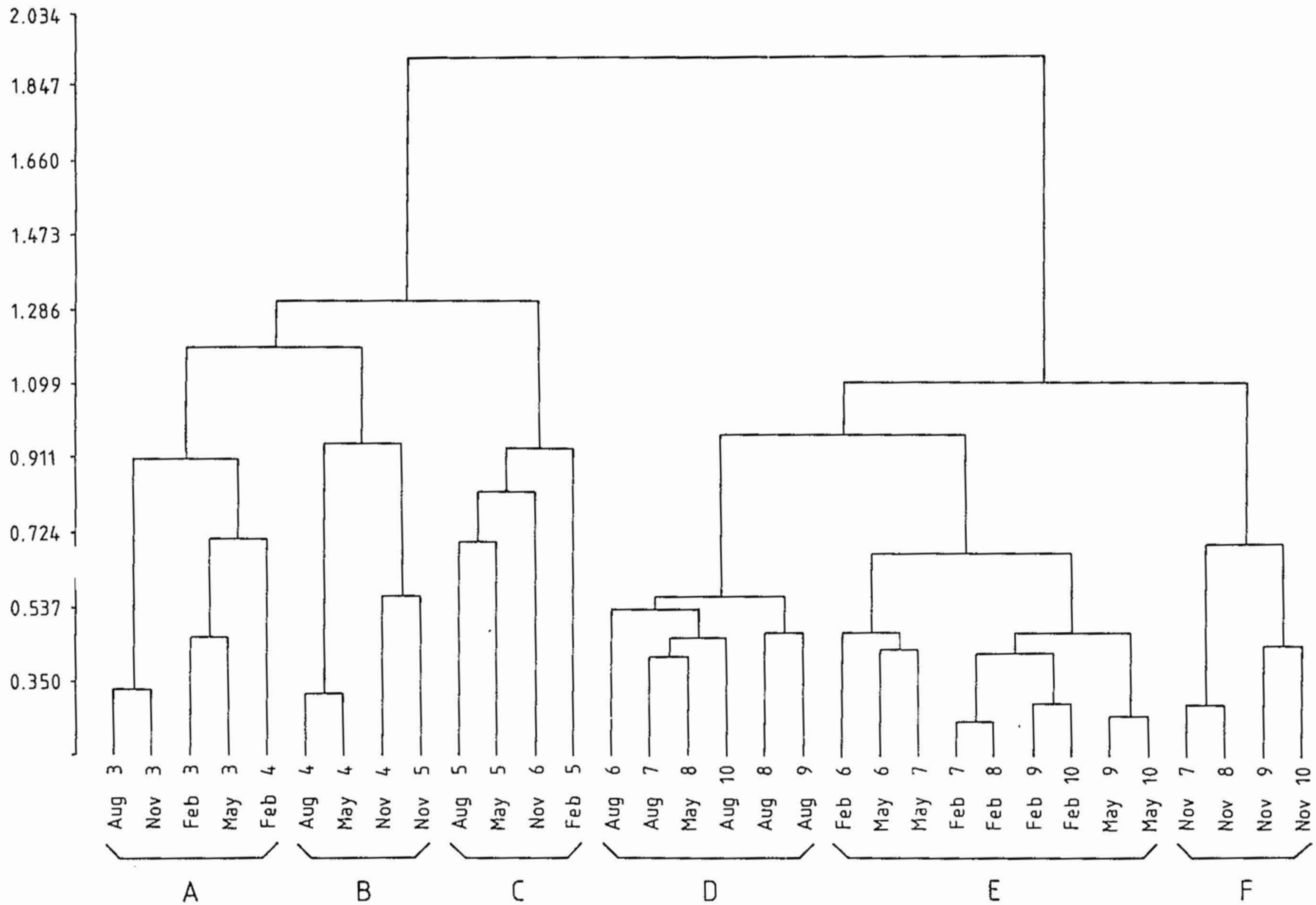

0.350
0.537
0.724
0.911
1.099
1.286
1.473
1.660
1.847
2.034
Aug 3
Nov 3
Feb 3
May 3
Feb 4
Aug 4
May 4
Nov 4
Nov 5
Aug 5
May 5
Nov 6
Feb 5
Aug 6
Aug 7
May 8
Aug 10
Aug 8
Aug 9
Feb 6
May 6
May 7
Feb 7
Feb 8
Feb 9
Feb 10
May 9
May 10
Nov 7
Nov 8
Nov 9
Nov 10

Figure 12. Identification of six clusters of sites on Figure 11. The month and the station of each collection are given.



2.034
1.847
1.660
1.473
1.286
1.099
0.911
0.724
0.537
0.350
Aug 3
Nov 3
Feb 3
May 3
Feb 4
Aug 4
May 4
Nov 4
Nov 5
Aug 5
May 5
Nov 6
Feb 5
Aug 6
Aug 7
May 8
Aug 10
Aug 8
Aug 9
Feb 6
May 6
May 7
Feb 7
Feb 8
Feb 9
Feb 10
May 9
May 10
Nov 7
Nov 8
Nov 9
Nov 10
A
B
C
D
E
F

Group B. As with group A, this group is a collection of the samples of a single station (station 4) for each season, except February, and it also includes November 5. In November the spring horizon was below station 5, and this caused the station to be sampled as a part of the coarse-sand upper beach. As a result, many of the species collected were those generally found at station 4 (particularly Donax faba and Mesodesma altenae). This is sufficient to link November 5 with station 4 from other seasons.

Group C. As the spring horizon had moved lower in November, station 6 became positioned immediately below it and assumed a species composition, which usually was found in station 5 samples, therefore it is not surprising to find November 6 clustered with station 5 from the other three seasons in Group C. Within the group there is very little cohesion, as none of the members clustered very close to any other member (see nearest neighbour table in Appendix C).

Why this group is more similar to groups A and B is not understood. As noted earlier, many of the species of station 5 were found throughout the lower beach, and, in fact, the nearest neighbours of the stations in Group C are generally stations of the lower beach. However, Group C is so dissimilar to every other group, that it can only be considered independent.

Group F. The clusters of the stations of the lower beach are made by the stations of a particular time, and the most seasonally definitive group is composed of November stations.

Group E. The lower beach stations of the adjacent summer and autumn seasons describe Group E. It appears that if May 9 and May 10 were more similar to the May 6 and May 7 portion of this group an essentially May group and a February group could be recognized. However, there is no indication from either the nearest neighbour information or the species present at each station data, that such would occur, therefore the group composition is formed by the combination of both seasons.

Group D. The lower beach stations of August plus May 8 constitute group D, but if May 8 is placed with its nearest neighbour it would be moved to group E. There it would consolidate the February-May alliance, leaving group D as a tighter August-only group.

DISCUSSION

ABIOTIC CONDITIONS

Many factors have been suggested as influencing distribution of species in the sandy intertidal. Sediment type and grain size have been identified by Holland and Dean (1977) as determining intertidal assemblages. However, there is doubt that grain size alone is sufficient to characterize a beach. Organic (Dahl, 1953) and hydrodynamic conditions (Croker, 1977; Holland and Dean, 1977) reflected by sediment parameters have been recognized as influencing distributions. Air and water temperatures (Dahl, 1953; Johnson, 1965) and the action of ice in polar regions (Dahl, 1953, Broad, 1976) have also been noted as affecting distributions, but it is likely that wave action has the greatest overriding influence on the beach distribution of organisms (Dahl, 1953; Pichon, 1967; Saloman and Naughton, 1978).

Figure 2 shows that the beach below station 5 has a gentle fall, with a gradient approximately 1 meter vertical for 80 horizontal meters. This gentle reach had a mollifying effect on incoming waves and dissipated the wave energy with only a small amount of sediment disruption. As the tide changed, the water flowed gently and there was little hydrodynamic action. In this manner fine particles settled out of the water column and little disturbance of sediment on the bottom occurred. Disturbance at lower stations was further reduced by the lesser emersion of these stations during the lunar cycle. Therefore, the low energy of the tidal water enabled the maintenance of a high silt-clay sediment fraction which was well sorted at station 10. Station 9 was more exposed to developing waves and was less affected by the silt-clay fraction, consistently having a slightly higher mean grain size than found at station 10. Similarly station 8 was less well sorted and had a slightly larger mean grain size than either of the stations below. Station 7 continued the trend. The most severe water activity occurred at or near stations 5, 4, and 3, enabling the water column by its turbulence to suspend coarser particles. As this coarse material settled out of the water column, the nearer stations received most of the deposit. Therefore station 6 received a greater proportion of it than station 7, and as a result, it was more poorly sorted than at station 7.

The percentage of fine sand present on a beach affects the species present in several ways. Burrowing ability, the content of organic material, and oxygen concentration have each been related to the size of the sand grains (Brafield, 1978). Though oxygen concentrations may be lower in the lower beach than in the upper beach, species in the lower region are covered for a greater proportion of the time by oxygen laden water and oxygen is available from the water column. The consolidation of sediment, which was enabled by a higher proportion of fine sand, permitted the establishment of sedentary forms such as the anemones, *Diopatra*, *Amphictene*, and the enteropneust.

The stations that were above the spring horizon were on a much steeper gradient than those below, and it is on this gradient that the incoming waves break. As a result, the sand was well washed and the mean grain size was much higher than on the flats area. Station 1 and, to a lesser extent, station 2 were not regularly washed by breaking waves. The surface sediment at station 1 was primarily transported to the station by wind that bore the lighter fraction, thus reducing the mean grain size.

Station 5 was located above the spring horizon during November and February and was below it in May and August. During the summer months wave action becomes more severe due to weather conditions over the sea. The increase in wave action transports sediment seaward (King, 1972) and this phenomenon is responsible for shifting the spring horizon.

The constancy of granulometric parameters below station 5 makes it impossible to relate changing benthic structure to sediment conditions. Species above station 5 probably are tolerent of a range of granulometric conditions and of comparatively severe wave action (see Newell, 1970). The action of waves on the upper beach was relatively harsh on the animals present, but its severity was generally constant and these animals have adapted to it. Even though it was constant, its severity caused it to be more important than any other physical factor to species present.

Brafield (1978) has reported that temperatures within a beach vary less than those of the air and water above. Johnson (1965) found that temperatures in the upper centimeter of an exposed site on a beach may have a range three times greater than those to which a subtidal individual of the same species is exposed. In this study the interstitial temperatures have been found to be within a few degrees of the air and water temperatures.

Throughout the year the region below station 6 was uncovered only once a day during the spring tides. Because of the nature of the tidal regime in North Queensland, the lower beach was not exposed during the day in the hot summer, but was uncovered only during the night. In the cooler winter months the reverse was the case. Exposure was during daylight and during the cold winter nights the stations were covered. It is during exposure that the most extreme fluctuation from seawater temperature occurred. Measurements in both summer and winter show the sediment temperatures at low tide differed by less than 3 °C from seawater temperatures.

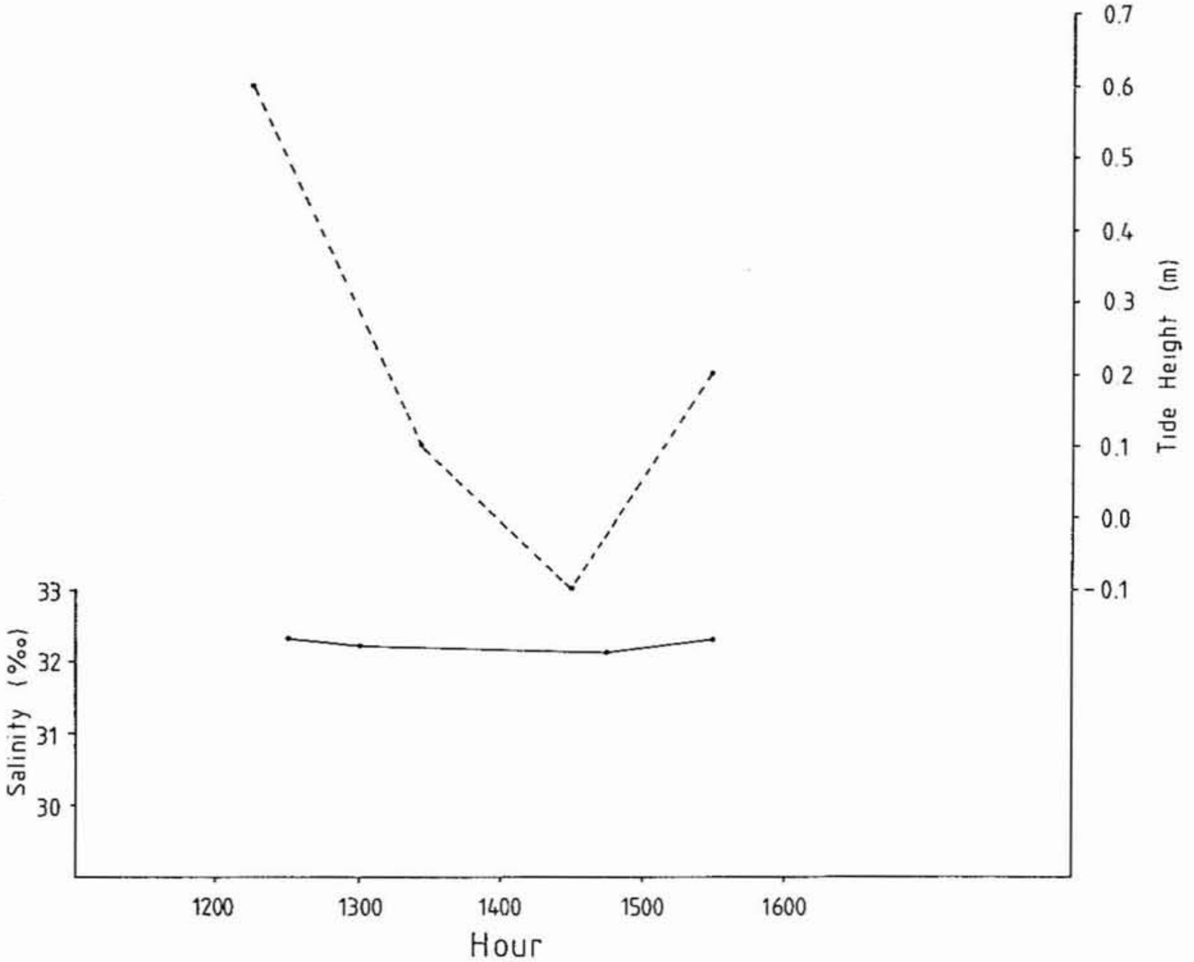
Summer temperatures at the stations on the upper beach were modified by the effects of evaporative cooling. In this way temperatures were within 6 °C of wintertime temperatures at the same stations, and did not reflect the 10 °C difference which Kenny (1974) found for surface water in Cleveland Bay. It is, therefore, not likely that the daily temperature variation had a significant impact on the species present. However, the seasonal temperature variation may have a bearing on the expression of some stage of the life history of many species. Eltringham (1971) suggests that temperature is likely to govern life cycles of intertidal organisms which have periodic spawning. *Mesodesma altenae*, *Callianassa australiensis*, and *Mactra dissimilis* were observed to be seasonal spawners and gastropods, in general, have been found to reproduce seasonally in this area (Bishop, personal communication). Temperature may be the controlling factor in the spawning of several of the Pallarenda beach species.

The interstitial water maintains relatively constant salinity throughout a low tide period. During the time of emersion surface water of lower salinity flowed over the stations of the lower beach, but there was little mixing between the interstitial water and the surface water. See Figure 13 and Johnson (1967b), Sanders, Manglesdorf and Hampson (1965), and Brafield (1978). Ansell et. al. (1972) cite salinity as being effective in restricting beach populations, though primarily near the mouths of rivers or where there is limited water movement. The constancy of salinity at Pallarenda throughout the year suggests that it had an insignificant bearing on population densities and distributions on the beach. However, on occasions, when Cleveland Bay receives massive freshwater input, as during a cyclone, the accompanying drop in salinity may be expected to cause mass mortality of fauna.

Table 4 indicates that there was relative constancy of calcium carbonate abundance at stations 6 through 10, and that the calcium carbonate content in the lower beach region was lower than in the coarse sand of the upper beach. Most calcium carbonate pieces in this region were small and unidentifiable, but observed larger pieces were always fragments of mollusc shells. That this beach was not surrounded and influenced by reef is evident from the small amount of calcium carbonate found in the Pallarenda samples.

Figure 13. The salinity variation at station 7 during emmersion. The data was collected on 1 June 1977.

Tide Height: broken line
Salinity: solid line



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
- 0.1
Tide Height (m)
33
32
31
30
Salinity (‰)
1200
1300
1400
1500
1600
Hour

STRUCTURE

DISTRIBUTION OF SPECIES

Zonation of species on sandy shores has been found on beaches around the world (Elmhirst, 1933; Dahl, 1953; Pichon, 1967; Mathews, 1967; Wood, 1968; Eltringham, 1971; Vohra, 1971; Carefoot, 1977; Jaramillo, 1978).

Examination of the distribution of the animal species present on the beach showed that three major faunal zones existed. Within two of these zones the species arrangement permits the identification of more detailed benthic structure. The structural regime is depicted in Figure 14.

The tables showing the seasonal samples indicate that there were many species which were found at both station 3 and station 4, and most of these species were not found at any of the other stations. The species, which were common to these two stations, make a well defined faunistic zone at the top of the beach. In November, and to a lesser extent in February, several species found at station 5 were common to the two stations above. Mesodesma altenae and Donax faba and Saccocirrus were the most important of these representatives. It was during these months that station 5 was sampled as a part of the coarse-sand upper beach area, that is, the spring horizon had shifted downshore below this station, and the presence of typically upper beach (stations 3 and 4) species can probably be related to the shift. The uppermost zone was formed of organisms consistently sampled at stations 3 and 4 which, under specific conditions, were also collected at

Figure 14. Zonation scheme at Pallarenda beach with the representative species.

Major zones: solid lines
Subzones: broken lines

Station	
3	Pseudolana brevimargine
4	Donax faba Nereids Pisione oerstedi Saccocirrus
5	Amphipod C Opheliid (n.g. n.sp.) Urohaustorius
6	Ceratonereis erythraeensis Gastrosaccus cf. dakini Glycera A Platyischnopus Scolelepis B
7	
8	Dispio A Glycera B Mactra dissimilis Solidula cf. sulcata Strigilla tomlini Tellina (Macomana) australis
9 10	Albunea symmysta Choncholestes Dosinia kaspiewi Sigalion Sthenelais Tellina (Cadella) semen

station 5.

Within the upper zone, the species arrangement can be loosely determined by plotting the average yearly population centre (see Figure 15). The numbers of individuals of Donax faba and the nereids which were present indicated that station 4 was the typical central site for these species. However, the mobility of Donax species is well known (Wade, 1967; Pichon, 1967), and it is possible that at a different time in the semidiurnal tidal cycle or of the lunar tidal cycle the population centre may have a different location. The upper population range of the Donax and nereid species included station 3, but the major portion of their distribution was a station lower. From the seasonal data it appears that Pseudolana brevimargine was distributed between stations 3 and 4, and individuals of this species were found exclusively at one or the other of these two stations at particular times of the year. Examination of data taken for each month of the year indicates a marked seasonal distribution. Figure 16 shows that nearly all of the individuals collected at station 4 were taken in November and December, but that the species maintained a relatively constant presence and density at station 3. Considered over the entire year, the population centre of Pseudolana brevimargine was positioned topographically above the centres of Donax faba and the nereids. The isopod defined an area of the upper beach that was distinct from the Donax-nereid region.

The pattern found at Pallarenda of a Donax species, nereids, and a species of cirolanid isopod was similar to the arrangement of these forms found by Pichon (1967) in Madagascar and by Gauld and Buchanan (1956) in western Africa. In the West Indies (Wade, 1967) and both the

Figure 15. Relative positioning of the major species of the upper beach at Pallarenda.

◆ indicates the central region of the distribution.

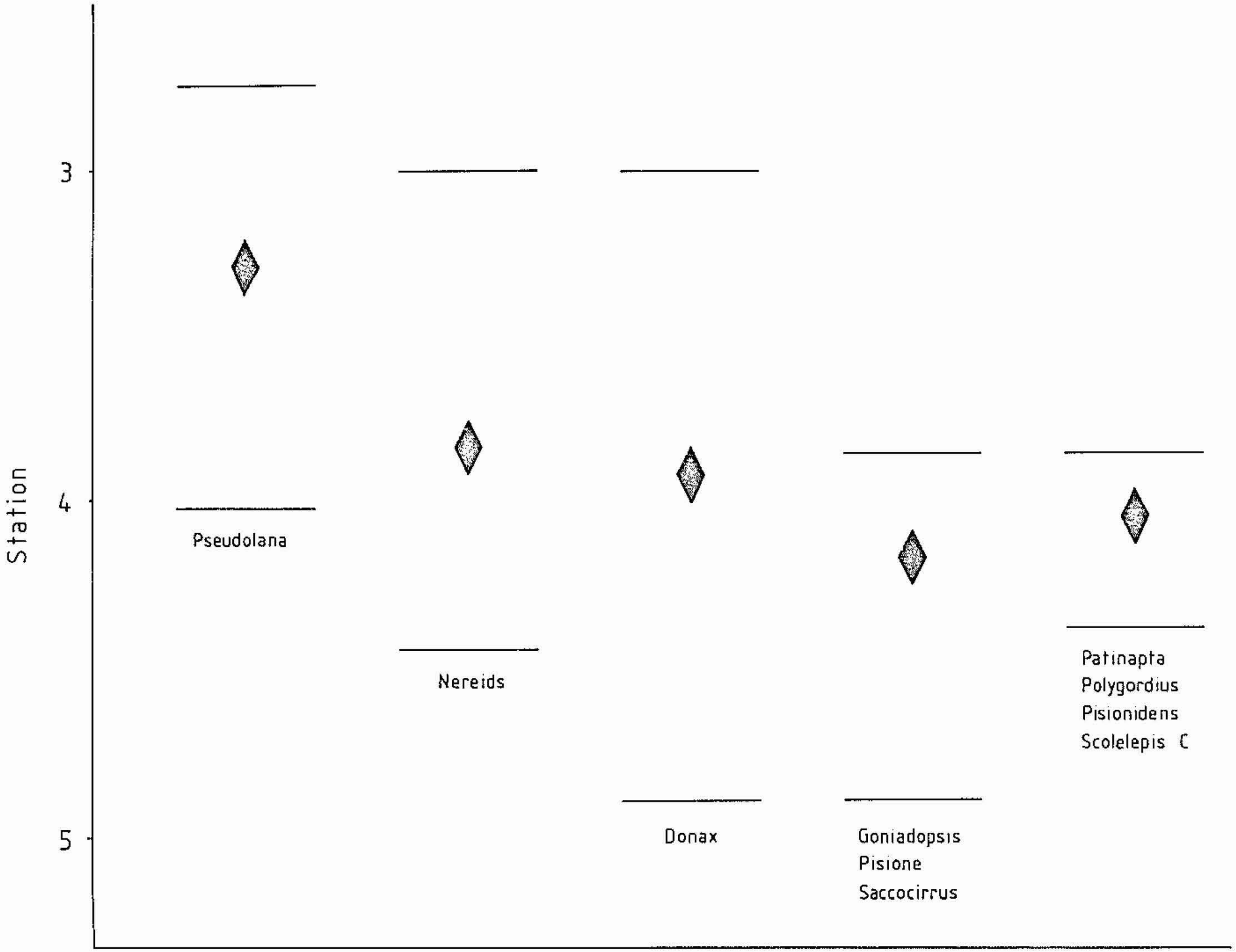
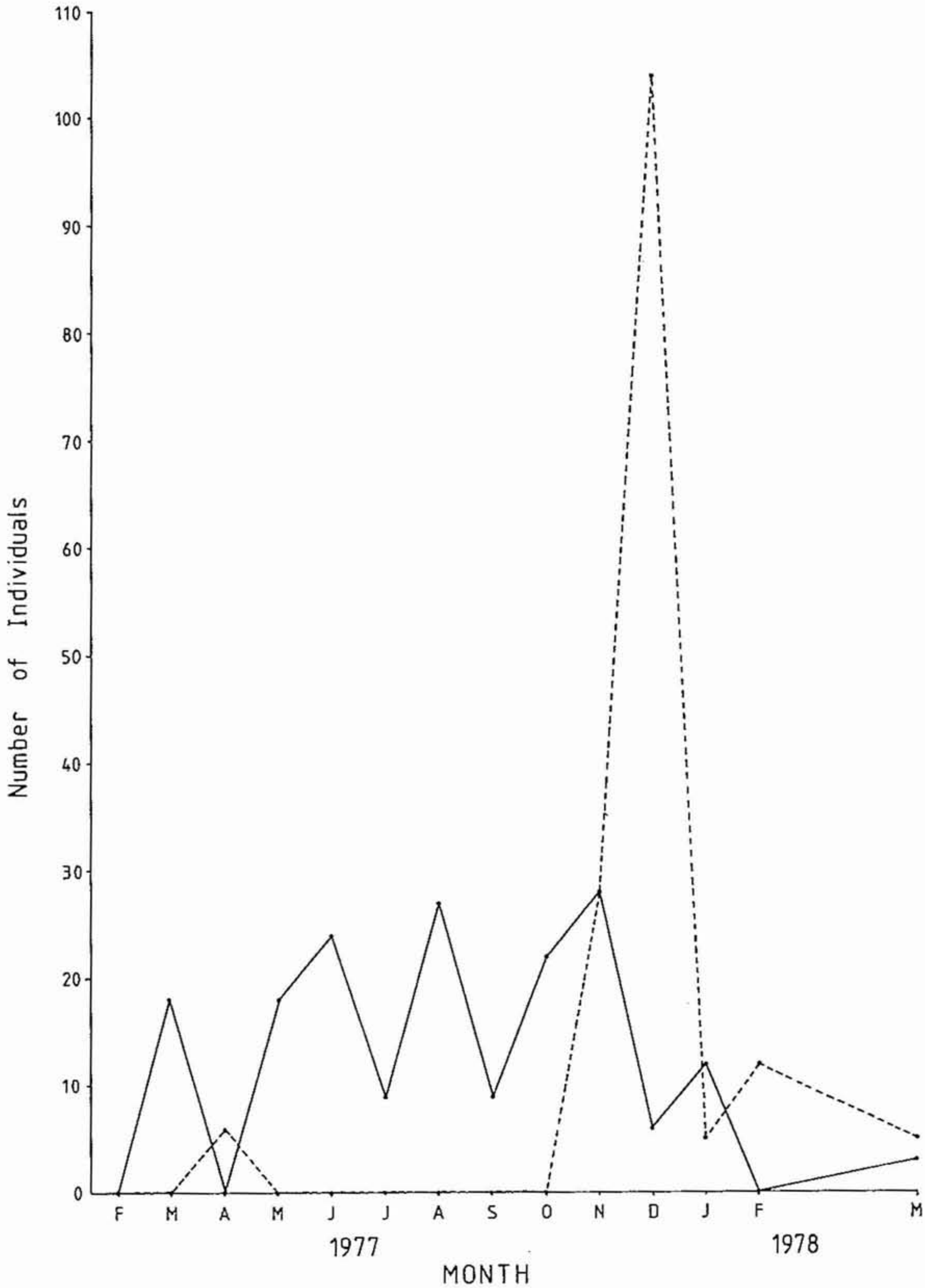

Station
3
4
5
Pseudolana
Nereids
Donax
Goniadopsis
Pisione
Saccocirrus
Patinapta
Polygordius
Pisionidens
Scolelepis C

Figure 16. Number of individuals of Pseudolana brevimargine collected monthly at station 3 and station 4. Values given for the period February through July of 1977 have been multiplied by three, because these collections were three times smaller than the collections of the other months (see Table 5).

Station 3: solid line
Station 4: broken line



110
100
90
80
70
60
50
40
30
20
10
0
Number of Individuals
F
M
A
M
J
J
A
S
O
N
D
J
F
M
1977
1978
MONTH

Atlantic and Pacific coasts of Costa Rica and Colombia (Dexter, 1974) the nereid belt is absent, but a Donax band lies below a cirolanid belt. In each of these cases the relationship occurs in the upper and mid-tidal regions, as it does in the Pallarenda study. In Mozambique (MacNae and Kalk, 1962), the west coast of India (Trevallion et. al., 1970), the east coast of India (McIntyre, 1968), and Singapore (Vohra, 1971) there exists no comparable cirolanid zone, and only at the last two of these four sites was there a nereid grouping. In the Solomon Islands no cirolanids were reported from the wave washed beaches, but Donax was present (Morton and Challis, 1969), while in New Zealand the cirolanids were present on the upper portion of the beaches, but Donax species were absent (Morton and Miller, 1968). Examination of these three faunal groups shows that the upper region of the north Queensland beach was more similar to remote beaches (east and west Africa and the West Indies) than to nearer beaches (east and west India, the Solomon Islands, and New Zealand).

Other species that separate the faunal patterns at stations 3 and 4 were Scolelepis C, Pisionidens indica, and Patinapta cf. ooplax, which, when they occurred, were found only at station 4. There were several species (Saccocirrus, Polygordius, Pisione oerstedi, and Goniadopsis) which indicated faunal similarities between stations 4 and 5, but these species were present at station 5 only when station 5 was sampled above the spring horizon. Otherwise these species groupings should be considered as a part of the Donax-nereid zone as typified by samples from station 4.

Station 5, here recognized as the region immediately below the spring horizon, was the only site where Urohaustorius, Opheliid (n.g. n.sp.), and Amphipod C were found. Species, which were found at other stations, may also be found at station 5, but the regularity and abundance with which these three species were represented in this region of the transect enable them to be used to define this region as a distinct zone.

Station 5 was the upper boundary for several species which were distributed in the area of the lower beach. Only four of these species were present in the greatest abundance of their distribution at this station (Gastrosaccus cf. dakini, Ceratonereis erythraeensis, Scolelepis B and Glycera A). The presence of these species suggests the affiliation of this station 5 area with the lower beach.

Many species in the lower beach were found at each station. Further, a group of species with less extensive distribution in the lower beach was found with upper and lower limits overlapping the limits of neighbouring species, and in this manner were continuous over the entire lower beach. These two species groups can be used to define the lower zone. This zone is comparable to the low water region (the infralittoral of Pichon (1967)). The pattern of distribution of certain species in the lower beach area can be seen to describe three regions. These are 1) species distributed in the upper portion, 2) species distributed in the central region, and 3) species concentrated in abundance near the low tide. This distribution pattern and the species important in describing it are given in Figure 17.

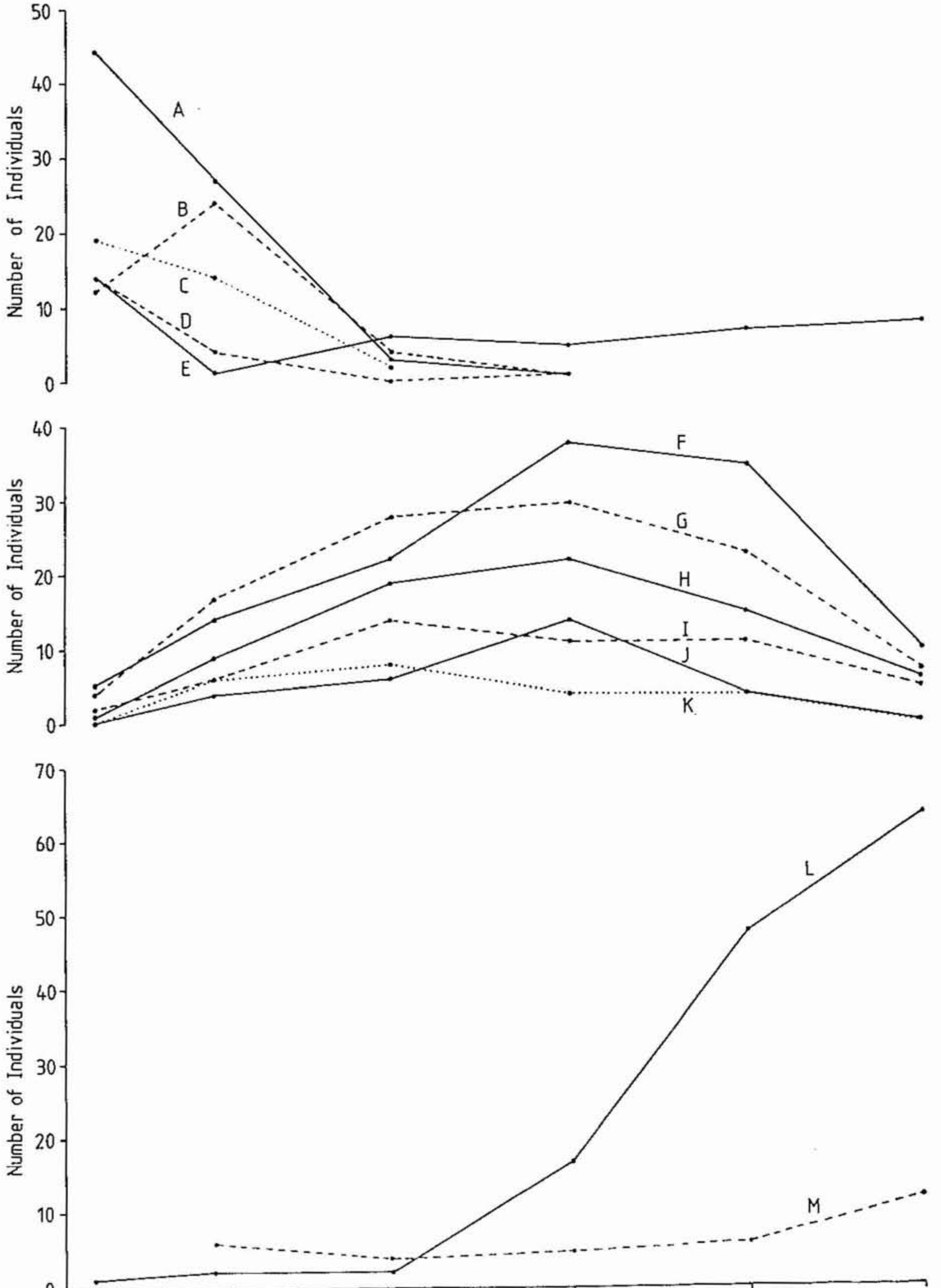
Station 5 provided the most suitable habitat for Scolelepis B, Ceratonereis erythraeensis, Gastrosaccus cf. dakini, and Glycera A in the first of the three regions. The density of Platyischnopus individuals was also highest in the first of the upper range of the lower beach (refer to Figure 17), but its abundance peak is somewhat lower on the transect than the peak for the other four species noted above.

A major change in the average grain size of the sediment at the upper boundary of these species was the feature most probably limiting the upper distribution, but the factors involved in determining the lower limit of the distributions are less easy to designate. Since biological interactions may control these distributions (Connell, 1972; Strauch et. al., 1980), close studies on individual species are necessary. A notable interaction at this boundary is one between two species of Glycera. The lower limit of the distribution of Glycera A corresponds consistently with the upper limit of the distribution of Glycera B. The nature of the interaction is unknown.

In the middle region of the lower beach Glycera B was one of several species which had a relatively low abundance at each end of the range between stations 6 and 10 and a higher abundance at the intermediate stations (refer to Figure 17). Other species in this group were Tellina (Macomana) australis, Solidula cf. sulcata, Strigilla tomlini, Dispio A, and the juveniles of Mactra dissimilis. These juveniles settle primarily in November. The distribution of these species was confined to this region of the intertidal.

Figure 17. Distribution of selected species between stations 5 and 10.

A Glycera A
B Platyischnopus
C Scolelepis B
D Ceratonereis erythraeensis
E Gastrosaccus cf. dakini
F Mactra dissimilus
G Glycera B
H Tellina (Macomana) australis
I Solidula cf. sulcata
J Strigilla tomlini
K Dispio A
L Choncholestes
M Dosinia kaspiewi



Number of Individuals
A
B
C
D
E
F
G
H
I
J
K
L
M
Station

In the lower portion of the lower beach Choncholestes was dominant in the yearly abundance (see Figure 17). Dosinia kaspiewi appeared to be another species showing increased numbers of individuals at the lower end of the transect. Other species tended to have an extended distribution between stations 6 and 10. Of these, several occurred regularly enough to merit attention; these included Sigalion, Albunea symmysta, Tellina (Angulus) lanceolata, Amphictene, and Sthenelais. It is not certain that these species are primarily intertidal species, as no subtidal sampling was done, however, each was regularly represented in samples from the most seaward portion of the lower beach.

COMPOSITION DETERMINED FROM NUMERICAL CLASSIFICATION

The treatment of zonation has generally been based upon limited observation, permitting identification of spatial zonation patterns, but unable to include a temporal perspective. The importance of including time sequences in ecological studies has been discussed by Stephenson (1973), however, though some long term intertidal beach studies have been carried out, little attention has been given to this aspect of zonation.

Figure 12 shows that Groups A, B, and C had a less varied benthic structure at a particular station from one season to another, that is, there was a greater variability between stations within a season than there was between seasons within a station. The groups made from lower beach stations indicate the opposite. In that area there was greater variability in structure between seasons and not between stations. It appears from the clustering that each station of the upper beach and station 5 maintained a species structure that was more consistent temporally whereas, stations of the lower beach had a composition, which was more similar by season than by station.

Whitlatch (1977) also found that when clustering intertidal sample sites of Barnstable Harbor, the clusters that formed were composed of sites from the same season. By continuing the analysis he found that important species in each of the groups were undergoing reproductive activity during the season assigned to the cluster. He concluded that several factors may influence the formation of seasonal abundance patterns, but that recruitment was a major influence. In addition to Whitlatch, Ansell et. al. (1972) and Holland and Polgar (1976) have emphasized the importance of recruitment in the determination of benthic structure.

In November the greatest number of species occurred and also the most juveniles of species were present, thus giving those species greater numerical importance. They include Tellina (Macomona) australis, Mesodesma altenae, Arachnoides placenta, Mactra dissimilis, and Callianassa australiensis. Though most of these species were present for the entire year, their high number of individuals in November causes the stations of November to form an exclusive group. Ansell et. al. (1972) found that the greatest number of species in western India occurred shortly before the monsoon season and at that time the most marked zonation of species occurred. They were able to relate these features to patterns of recruitment. Only the obvious cases of recruitment were observed at Pallarenda. Many important species recruit at Pallarenda in the spring, though spawning and settlement (or brooding) is probably not restricted to any one period (Bishop, personal communication). As in India, the wet season begins shortly after this recruitment period in the Townsville region, usually in late December or January, and for many species the pre-wet season period is the most opportune time to carry out the early stages of the life cycle. Further study may identify other reproductive "windows" during the year.

On the Caribbean coast of Panama Dexter (1979) did not observe a change in the zonation pattern during the year, but on the Pacific shore she found zone changes for several species. The changes were typically from a lower position to a higher position and were attributed to upwelling which began in March. Though she did not incorporate the specific species shifts into a broader zonation scheme for the beach fauna as a whole, she was able to use them to show a temporal zone change based on diversity and density. Table 18 shows that the diversity values of each of the three zones described for Pallarenda beach remain similar during the year except for the November period, when there was an abundance of juvenile forms. Unlike Dexter's study, the diversity change at Pallarenda was not caused by the movement into or out of a region, but rather by a large increase in the number of individuals of a few species, and the zonation scheme at Pallarenda described from the diversity analysis (see DISCUSSION: DIVERSITY) is not affected by species movement.

The changes in seasonal abundance for several species caused changes in the importance of the numerically dominant species (see DISCUSSION: DOMINANCE). However, at Pallarenda beach this had little effect on the spatial distribution of the species, as they remain generally constant in their beach position during the year. However, it does create a temporal "blocking" of sites into distinct units when analyzed with the classification techniques used in this study.

COMMUNITY PARAMETERS

DIVERSITY

In the species discussion three beach zones were identified based upon species composition. Shannon-Weiner species diversity was calculated for each of the zones for each season and presented in the RESULTS section. A comparative account of the zones, based on this index, is given below.

At each of the temporal samples Shannon-Weiner diversity is typically lower at the upper level than at either of the two lower levels (see Table 18). In these calculations the large juvenile populations of *Mesodesma altenae* were excluded. In the upper levels three or four species (usually *Perinereis vallata*, *Donax faba*, *Pseudolana brevimargine*, and *Pisione oerstedi*) were represented by distinctly more individuals than other species from the same zone, although almost all species were represented by more than one or two individuals in each collection (exceptions were *Patinapta* cf. *ooplax* and *Pisionidens indica*). Since exceptionally dominant species were not a feature of the upper beach, it follows that the lower diversity in this region is caused by the comparative paucity of species and not by unevenness.

It appears that this region is a very specific habitat to which certain species have become well adapted. Since almost all species present were substantially represented, the primary control of the benthic structure of this zone may be dependent upon the harshness of the physical environment and not upon competitive or predator-prey interactions between species (see Sanders, 1968).

No steep environmental gradients extended from station 6 through station 10 and this feature affected the distribution of abundances. The range of the distribution of species in this area tended to be broader than the range of any species of the upper zone. In this area there were many species which occurred regularly in very low numbers (see Tables 13 - 17) and there were no dominating populations. As the highest diversity values occur when there are many species, each represented by similar numbers of individuals (Pielou, 1977), it is not unexpected that this region had the highest values for H' from the three beach regions identified.

Although the species present and their abundances in the station 5 region ensured that this zone was described as an independent and unique one, the diversity values were usually transitional between the values for the upper and lower beach areas. Only in the months when there was large settlement of Mesodesma altenae (November 1977) did the diversity value fail to fall between the values of the regions on either side of this station (see Table 18). It is evident that there were some species with low abundance values (Solidula cf. sulcata, Ceratonereis erythraeensis, and Polinices conicus) and some which dominated the faunal composition at this station (Mesodesma altenae, Urohaustorius, Opheliid (n.g. n.sp.), and Glycera A). It is this relationship, a compromise of the species conditions of the beach regions above and below which establishes the intermediate diversity value for this area.

The Shannon-Weiner diversity index was applied to the data of this study, because it permits comparisons with conclusions drawn from its usage in other studies. The table below compares the diversity values obtained in some other studies.

Author and Date	Site	Log Base	Pooled H'	Number of Species
Dexter 1979	Panama (Caribbean)	2	1.94	22
Dexter 1979	Panama (Pacific)	2	.96	47
Holland and Polgar 1976	South Carolina	e	1.50 approx	56
Croker 1977	Maine	2	2.46	10
Vohra 1971	Singapore	2	3.13	88
This Study	North Queensland	2	3.56	91

The index of diversity is dependent on the relative dominance of particular species. In the American studies there was one, or sometimes two, highly dominant species noted at each site. In the colder regions amphipods are abundant. In Maine Amphiporeia virginiana may account for between 70 and 95 % of the individuals present (Croker, 1977), and in South Carolina Holland and Polgar (1976) noted the dominance of Acanthohaustorius millsi and Pseudohaustorius caroliniensis which together represented 81 % of the individuals collected. In tropical Panama (Dexter, 1979) an isopod, Excirolana braziliensis, comprised 86 % of the individuals on the Pacific side of the isthmus and 53 % on the Caribbean side.

In tropical north Queensland no species occurs regularly in a dominant pattern as do those of the Americas. Only when Mesodesma altenae juveniles have recently settled (November 1977) does such dominance occur. Mesodesma altenae then makes up nearly 66 % of the numerical abundance. In all other seasons the most dominant species makes up less than 30 % of the sample (Donax faba in August and in May and Arachnoides placenta in February). The numerical importance is spread among several species yielding a relatively high evenness index. Similarly, the dominant species from Vohra's (1971) study at Mata Ikan (Cerithidea cingulata) represents only 44 % of the individuals collected. This species, though dominant, does not overwhelm the collections as do the American dominant species (Croker, 1977; Holland and Polgar, 1976; Dexter, 1979).

Vohra (1971) collected 88 species in his Singapore study and 91 species were collected from Pallarenda in the present work. The American beaches, even those in the tropics, do not show the species richness found in the Australasian region. The evenness of numerical distribution and the species richness are responsible for relatively high species diversity values. Thus, it is not surprising that the diversity values from Mata

Ikan and Pallarenda are similar and are higher than those of the American beaches.

DOMINANCE

The effects on the diversity value created by the dominant species at Pallarenda were caused by different species at different times of the year. Of the five most abundant species (by number of individuals) only Donax faba and Arachnoides placenta occurred in each season. No other species was among the five most abundant for more than two seasons (see Table 19). Twelve different species can be listed among the five most abundant species during the four seasons, and eight of these were present only once. There was a high turnover of dominant species. When the entire year is considered, the dominant species include Donax faba and Arachnoides placenta. Three of the five most abundant are represented as a result of heavy juvenile recruitment at some stage in the year. Mesodesma altenae and Mactra dissimilis were especially dependent upon juveniles for their status. This also applies to Arachnoides placenta, though to a lesser degree, since adults of this species were always prevalent. As dominance was sometimes dependent upon juvenile recruitment, it may be expected that there is a high turnover in the dominant representatives. Fluctuations of dominant species at Pallarenda were partially governed by the life histories of certain species.

Table 19. Dominant species from three studies.

Summer	Autumn	Winter	Spring
Acanthohaustorius millsi	Acanthohaustorius millsi	Acanthohaustorius millsi	Acanthohaustorius millsi
Pseudohaustorius caroliniensis	Pseudohaustorius caroliniensis	Pseudohaustorius caroliniensis	Pseudohaustorius caroliniensis
Trichophoxus epistomus	Heteromastus filiformis	Polydora sp.	Spiophanes bombyx
Spiophanes bombyx	Tellina texana	Spiophanes bombyx	Heteromastus filiformis
Tellina texana	Spiophanes bombyx	Hoploscoloplos fragilis	Monoculodes edwardsi

Holland and Polgar (1976) --- 9 species (South Carolina)

November	February	May	August
Cerithidea cingulata	Cerithidea cingulata	Cerithidea cingulata	Cerithidea cingulata
Clithon oualaniensis	Clithon oualaniensis	Clithon oualaniensis	Clithon oualaniensis
Batillaria multiformis	Diogenes diogenes	Onuphis sp.	Ceratonereis hircinicola ?
Diogenes diogenes	Onuphis sp.	Diopatra neopolitana	Diopatra neopolitana
Cerithium moniliferum	Diopatra neopolitana	Diognes diogenes	Cerithidea coralium

Vohra (1971) --- 9 species (Singapore)

August	November	February	May
Donax faba	Mesodesma altenae	Arachnoides placenta	Donax faba
Arachnoides placenta	Arachnoides placenta	Donax faba	Arachnoides placenta
Callianassa australiensis	Donax faba	Tellina (M.) australis	Opheliid (n.g. n.sp.)
Mesodesma altenae	Chencholestes	Diogenes avarus	Perinereis vallata
Choncholestes	Mactra dissimilis	Polygordius	Other Nereids

This Study --- 12 species (North Queensland)

RARE SPECIES

The percentage of single occurrence species collected in other studies is given in Table 20.

There is no distinct difference between the values found for the Pallarenda results and other areas. However, as has been noted, sampling methods were not suitable to insure an adequate collection of these species. The degree to which the single occurrence species were incidentals or were low density, regular inhabitants is not clear.

Table 20. Percentage of species represented by only one individual.

Site of Collection	Total Species	Percent of Singles	Author
N. Carolina	41	29.3	Dexter (1969)
Panama (Pacific)	39	28.2	Dexter (1972)
Panama (Caribbean)	13	15.4	Dexter (1972)
S. Carolina (summer)	22	9.1	Holland and Polgar (1976)
S. Carolina (autumn)	26	19.3	
S. Carolina (winter)	38	31.6	
S. Carolina (spring)	26	23.1	
S. Carolina (year)	56	34.0	
Korea	26	7.7	Yi (1975)
Britain	39	18.0	Withers (1977)
	49	14.3	
(selected British beaches from the same study ---- number of species is greater than 30)	90	20.0	
	92	19.6	
	37	32.4	
	33	24.2	
	119	16.0	
Auckland N.Z.	55	20.0	Wood (1968)
Florida	43	41.9	Saloman and Naughton (1978)
N. Queensland (summer)	53	34.0	This Study
N. Queensland (autumn)	55	25.5	
N. Queensland (winter)	52	32.7	
N. Queensland (spring)	67	23.9	
N. Queensland (year)	91	17.6	

SUMMARY

1. The species, which exist on North Queensland shores, are not well known. It is anticipated that more than 30 % are undescribed species, and many of these are numerically important species on the beach (Opheliid (n.g. n.sp.), Platyischnopus, Choncholestes, Glycera A, Glycera B, Amphipod C, Ogyrides, Diopatra).

2. It was necessary to sample a larger area and volume than most other studies to ensure an acceptable species capture at each station. A total area of .6 square meter was sampled for each station each season which provided 4.8 square meters sampled on the beach for each sample period.

3. On a diurnal scale the physical factors, which were measured, have little variability. Granulometric parameters of the lower beach particularly have little variation. This is also true of temperature and salinity. Seasonally, there is a much greater range in these factors, especially with temperature and it is probably the long-term variation which influences the species composition.

4. Zonation of species is evident on Pallarenda beach, as it is around the world. Three broad zones are evident and two of these can be broken into lesser zones. The most landward of the three zones is distinguished by Pseudolana brevimargine at the top and several species below, including Donax faba, the nereid polychaetes, Pisione oerstedi, Saccocirrus, Polygordius, and Goniadopsis. The middle zone is identified by three species which occur only there. They are Urohaustorius, Opheliid (n.g. n.sp.), and Amphipod C. The most

seaward of the three zones is broken into three parts. Species of the upper part are Platyischnopus, Glycera A, and Scolelepis B. Several species attain their greatest abundance in the middle region of the lower zone and these include Tellina (Macomana) australis, Mactra dissimilis, Glycera B, Solidula cf. sulcata, Strigilla tomlini, and Dispio A. Choncholestes is obviously a species with its greatest abundance in the lower region, but Albunea symmysta, Dosinia kaspiewi, Tellina (Cadella) semen, Sigalion, and Sthenelais also are typical of this region.

5. Though the major species present are found throughout the year, there is variety in the relative proportions from season to season. Donax faba and Arachnoides placenta are always abundant, but the other dominant species change with each season. Species, which occurred only once in the samples, add further variety to the species composition.

6. Though it is difficult to correlate limiting factors with species present, at least one important pattern is evident. Conditions at each of the stations of the upper beach favour a particular composition of species for the entire year, but on the lower beach limiting factors were broader in the physical area of their influence (from station 6 through station 10) and were seasonal in their effectiveness. This variability of the species composition is spatial on the upper beach, but is temporal on the lower beach.