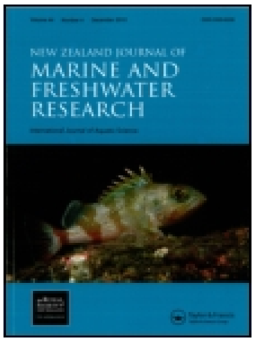

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Associations of benthic foraminifera (Protozoa : Sarcodina) of inner shelf sediments around the Cavalli Islands, north-east New Zealand

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Abstract Census data on foraminiferal tests (live plus dead) from 55 dredge samples (0–41 m depth) of surficial sediments around the Cavalli Islands are analysed by non-hierarchical classification, principal components, and minimum spanning tree techniques. The samples are grouped into 4 associations with 5 subassociations. Characterising species of each association are found by calculating 'association scores' for each species, based on its dominance, fidelity, and relative abundance within each group. The 4 associations are: A. *Elphidium charlottensis* — subassociations A1. *Elphidium charlottensis/Elphidium oceanicum/*(*Virgulopsis turris*), A2. *Elphidium charlottensis/(Elphidium oceanicum/Elphidium simplex)* — in sandy beach gravel or fine to very fine sand in shallow bays (intertidal to 6 m depth) on a sheltered coast; B. *Pileolina zealandica/Cibicides marlboroughensis* — subassociations B1. *Discorbis dimidiatus/Elphidium novozealandicum/Pileolina zealandica*, B2. *Pileolina zealandica/Cibicides marlboroughensis-/Neoconorbina pacifica*, B3. *Cibicides marlboroughensis/Quinqueloculina seminula/Notorotalia olsoni* — widespread in clean, medium to coarse sand or shell gravel in moderately exposed or current-swept locations (5–10 m depth); C. *Planoglabratella opercularis/Pileolina harmeri/ Neoconorbina pacifica*, in shelly, very coarse sand or shell gravel in shallow (6–9 m), strongly current-swept, wave-battered channels; D. *Cassidulina carinata/Bulimina submarginata/Globocassidulina canalisuturata*, in fine to very fine sand in the deeper (29–41 m), northern parts of the Cavalli Passage. Associations A, B, and D, or variants thereof, are recognisable in similar environments elsewhere around northern New Zealand. Associations characterised by abundant plastogammic foraminifera, such as glabratellids and buliminoidids (e.g., C), have not previously been identified around New Zealand and are rare elsewhere. The habit of fusing together in plastogammic pairs during the sexual phase of reproduction appears to be an adaptation to survival in strongly current-swept environments. Species diversity (Fisher β index, Information Function) and Evenness increase regularly with increasing depth. There is also good correlation between these foraminiferal associations and the macrofaunal associations recognised from the same dredge samples.

Keywords Foraminifera; benthic environment; benthos; microbenthos; aquatic communities; zoobenthos; associations; ecological distribution; community composition; Cavalli Islands; coastal zone

INTRODUCTION

57 dredge samples of surface sediment were taken from the inner shelf (0–41 m depth) around the Cavalli Islands during the Offshore Islands Research Group's trip, New Year 1978–1979. The Cavalli Islands (longitude 174°E, latitude 35°S) lie 2–3 km off the east coast of Northland, between the Bay of Islands and Whangaroa Harbour (Fig. 1).

The macrobenthos of Stations 1–47 (Table 1) on the sheltered western side of the islands has been analysed (Grace & Hayward 1980) and 4 associations recognised:

a. *Myadora boltoni–Pectinaria australis* (fine sand, 0–5 m),
b. *Tawera spissa* (shelly, medium to coarse sand, 2–15 m),
c. *Zeacolpus pagoda–Zegalerus tenuis*–juvenile *Tawera spissa* (fine sand to fine shell gravel, 2–30 m), and
d. *Nemocardium pulchellum* (fine to very fine sand, 30–40 m).

This paper describes the benthic foraminiferal associations of 55 of the 57 dredge stations. 6 of the 267 benthic foraminiferal species identified in these samples (taxonomic account in preparation) are new records from New Zealand of subtropical–tropical taxa, presumably carried down here in warm

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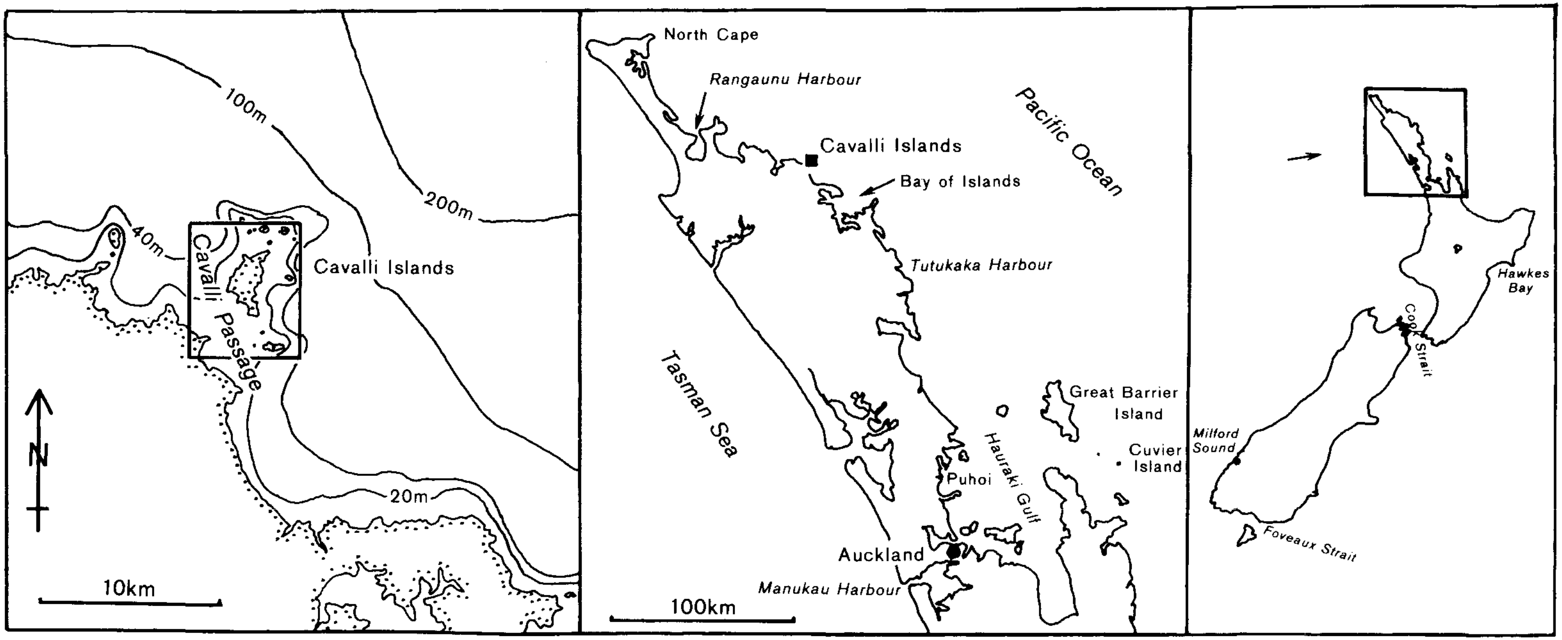


Fig. 1 Map showing the location of the Cavalli Islands study area (left) on the northeast coast of Northland (centre), New Zealand (right).

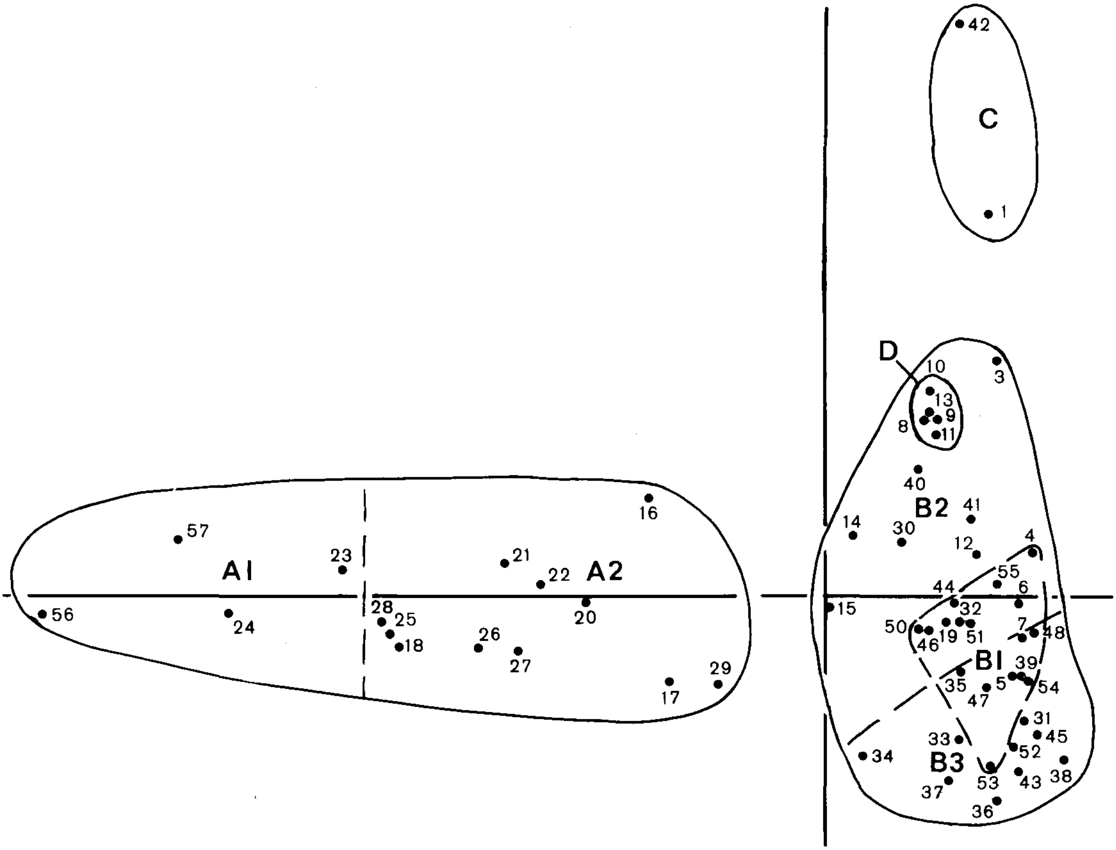


Fig. 2 2-dimensional configuration of samples produced by principal component analysis, with the 7 groupings (associations and subassociations) produced by non-hierarchical classification (Fig. 4a) superimposed.

currents (Hayward 1980). Planktics comprise 0–10% of the foraminiferal faunas and are dealt with elsewhere (Hayward 1979).

Previous studies of the foraminifera of northern New Zealand have concentrated on the fauna of estuaries (Gregory 1973; Topping 1973), enclosed harbours (Hulme 1964; Adams 1979; Brook et al. 1981), or large areas of shelf and bathyal sea floor (Thompson 1975; Hoskins 1978). The only descriptions of faunas from inner shelf environments similar to those encountered around the Cavalli Islands are of 9 samples (0–12 m depth) from the eastern Bay of Islands (Hayward 1981). Other major studies of Recent foraminiferal faunas around New Zealand are those of Vella (1957) in Cook Strait, Lewis (1979) off southern Hawkes Bay, Kustanowich (1964) in Milford Sound, and Hedley et al. (1967) of the *Corallina officionalis* zone at 8 widely distributed localities.

Station numbers 1–47 are those used in macrofaunal studies (Grace & Hayward 1980), and 48–57 are additional stations, mostly east of the islands, that were largely devoid of macrofauna. Station data are given in Table 1. All microfaunal samples are held in the Micropaleontology Section of the New Zealand Geological Survey (catalogue numbers e.g., F201712). Figured specimens have catalogue numbers prefixed by FP.

METHODS

Field

Samples were collected using a small dredge, made from a 1-gallon petrol tin (described by Grace & Whitten 1974), and hand-hauled from a dinghy. Under ideal conditions the dredge sampled approximately 0.075 m^2 to a sediment depth of 6 cm, and held 4500 cm^3. A sample, comprising approximately 200 cm^3 of sediment, was taken from each dredge haul and preserved in 10% ethanol; the remainder was processed for macrofaunal analysis.

Table 1 Physical and biological characteristics of stations around the Cavalli Islands.

Stn no.	NZGS no.	Depth (m)	Foram. assoc.	S	Diversity		E	Macro.† assoc.	Sediment
					α	H			
1	F201712	6	C	42	13	2.85	0.41	(T)	shelly very coarse sand
3	F201714	6	B2	58	21	3.02	0.35	T	shelly very coarse sand
4	F201715	7	B1	45	15	3.10	0.49	T	shelly very coarse sand
5	F201716	10	B1	48	16	3.08	0.45	Z	shelly medium sand
6	F201717	25	B2	59	22	3.52	0.57	Z	shelly very coarse sand
7	F201718	36	B3	64	25	3.42	0.48	N	shelly very coarse sand
8	F201719	41	D	62	23	3.59	0.58	N	slightly muddy very fine sand
9	F201720	41	D	61	23	3.47	0.53	N	slightly muddy very fine sand
10	F201721	34	D	52	18	3.23	0.49	N	fine sand
11	F201722	29	D	65	25	3.71	0.63	(Z, N)	shelly very coarse sand
12	F201723	22	B2	55	20	3.40	0.54	Z	shelly very coarse sand
13	F201724	17	B2	55	20	3.40	0.54	Z	fine shell gravel
14	F201725	10	B2	52	18	3.31	0.53	T	fine sand
15	F201726	2	B2	45	15	3.21	0.55	(M, Z)	fine sand
16	F201727	1	A2	42	13	3.01	0.48	M	fine sand
17	F201728	6	A2	50	17	3.08	0.44	Z	fine sand
18	F201729	6	A2	42	13	2.74	0.37	Z	fine sand
19	F201730	8	B2	54	19	3.22	0.46	T	fine sand
20	F201731	3	A2	52	18	3.16	0.45	M	fine sand
21	F201732	3	A2	47	16	3.02	0.44	M	fine sand
22	F201733	0.8	A2	44	14	2.96	0.44	M	fine sand
23	F201734	1	A1	39	12	2.71	0.39	M	slightly muddy very fine sand
24	F201735	1.8	A1	38	11.5	2.55	0.34	M	fine sand
25	F201736	2.5	A2	45	15	2.87	0.39	M	fine sand
26	F201737	3	A2	50	17	3.01	0.41	(M, Z)	fine sand
27	F201738	3.5	A2	43	14	2.94	0.44	M	fine sand
28	F201739	1.5	A2	51	18	2.87	0.35	M	slightly muddy very fine sand
29	F201740	4	A2	43	14	3.02	0.48	T	fine sand
30	F201741	5.5	B2	47	16	3.44	0.66	T	shelly very coarse sand
31	F201742	7	B3	44	14	3.01	0.46	T	shelly coarse sand
32	F201743	7	B2	61	23	3.42	0.50	T	shelly coarse sand
33	F201744	6.5	B3	45	15	3.05	0.47	T	medium sand
34	F201745	5.5	B3	32	9	2.90	0.57	T	medium sand
35	F201746	6	B3	55	20	3.34	0.51	T	shelly medium-fine sand
36	F201747	4	B3	33	10	2.85	0.52	T	medium sand
37	F201748	6	B3	40	12	2.95	0.48	T	medium sand
38	F201749	7	B3	62	23	3.33	0.45	T	medium sand
39	F201750	8	B3	56	20	3.43	0.55	T	shelly medium sand
40	F201751	10	B2	58	21	3.52	0.58	T	shelly very coarse sand
41	F201752	10	B2	62	23	3.57	0.57	T	shelly very coarse sand
42	F201753	9	C	34	10	2.36	0.31	T	fine shell gravel
43	F201754	9.5	B3	52	18	3.15	0.45	T	shelly very coarse sand
44	F201755	2.5	B2	77	34	3.80	0.58	T	shelly very coarse sand
45	F201756	1	B3	60	22	3.38	0.49	(T)	sandy gravel
46	F201757	10	B2	58	21	3.49	0.57	Z	fine sand
47	F201758	3	B1	48	16	3.13	0.48	Z	medium sand
48	F201759	39	B3	70	28	3.51	0.48	–	shelly pebbly gravel
50	F201761	28	B1	53	19	3.33	0.53	–	shelly very coarse sand
51	F201762	36	B2	48	16	3.26	0.54	–	medium sand
52	F201763	40	B3	51	18	3.22	0.49	–	medium sand
53	F201764	2	B1	39	12	2.92	0.48	–	medium sand
54	F201765	10	B1	40	12	2.97	0.49	–	medium sand
55	F201766	10	B2	65	25	3.72	0.63	–	shelly pebbly gravel
56	F201760	+0.3	A1	30	8	2.00	0.25	–	sandy gravel
57	F201713	0	A1	25	6.5	2.13	0.34	–	fine sand

† Macrofaunal associations: M, *Myadora boltoni–Pectinaria australis*; T, *Tawera spissa*; Z, *Zeacolpus pagoda–Zegalerus tenuis*; N, *Nemocardium pulchellum*

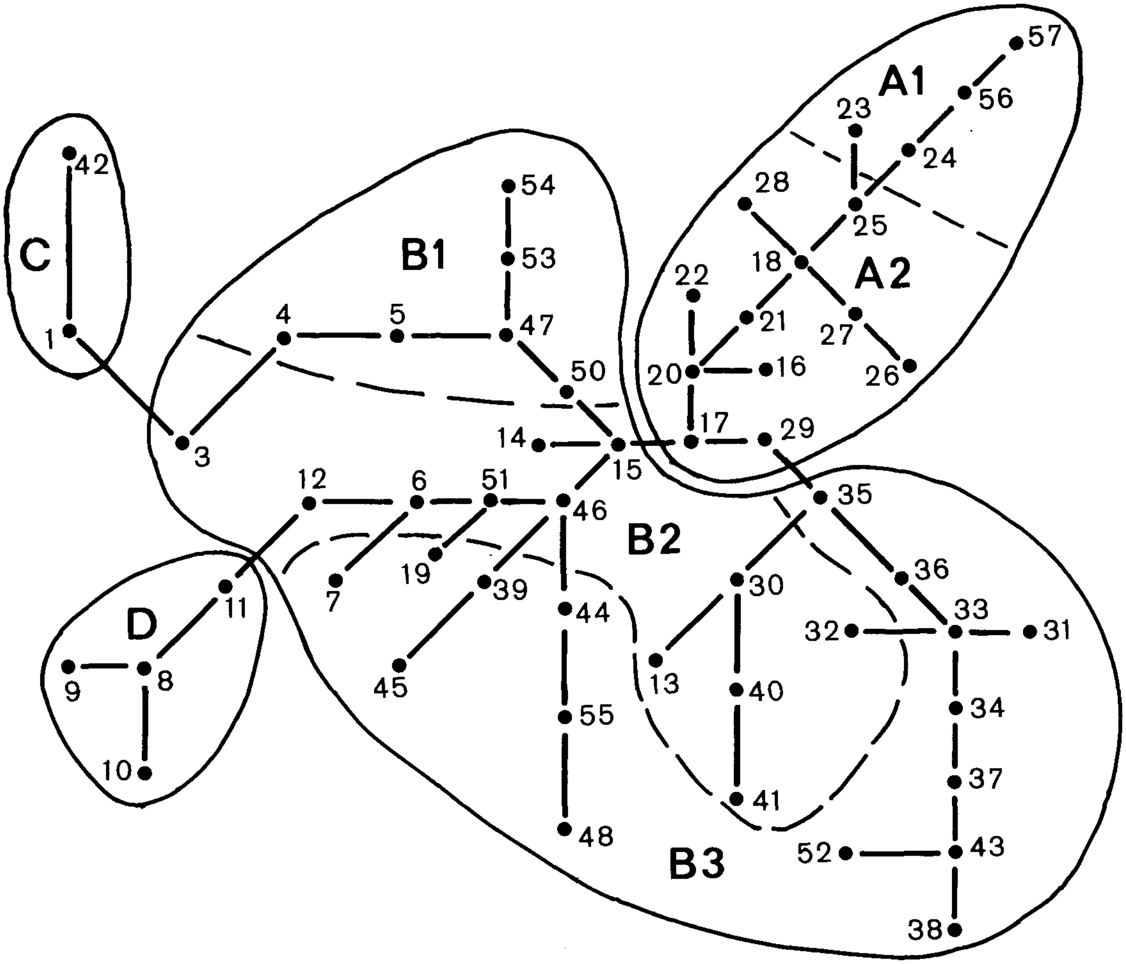


Fig. 3 Configuration of samples produced by minimum spanning tree analysis, with the 7 groupings (associations and subassociations) produced by non-hierarchical classification (Fig. 4a) superimposed.

Laboratory

On return to the laboratory, the samples were stained with a solution of Rose Bengal (a stain for protoplasm commonly used to identify living individuals) and analysed for grain size using sieves. Samples were then processed in 2 ways:

TOTAL (DEAD PLUS LIVE) FAUNA. Each sample was divided up using a microsplitter until the quantity of material left contained approximately 300 benthic foraminifera which were then picked (together with the few planktics present), mounted, identified, and counted.

LIVE FAUNA. A split of 100 cm^3 of sediment was taken from each sample and the foraminifera were concentrated by flotation with carbon tetrachloride. The float was scanned in a dish of water and all red-stained individuals were picked, mounted, identified, and counted. These counts are theoretically of the total live fauna present at the time of sampling, although there is considerable uncertainty as to the accuracy of staining in distinguishing all live foraminifera (Martin & Steinker 1973).

Computer

TOTAL FAUNA. The data consist of counts of 221 species in 55 samples. Because the number of individuals picked was standardised at around 300, the data are more analogous to species proportions than species densities. The data matrix was standardised by converting counts to proportions of sample totals. Several classification and ordination techniques in the GENSTAT statistical package (Alvey et al. 1977) were then applied to the data.

Principal component analysis of the dispersion matrix for species proportions provided a 2-dimensional representation (67% variance) of sample dispositions in the 221-variate hyperspace (Fig. 2). Major influences on the configuration are taxa with large variances, which are strongly dominant in some samples (e.g., *Elphidium charlottensis, Planoglabratella opercularis, Neoconorbina harmeri*).

A minimum spanning tree (Fig. 3) produced by the single linkage cluster analysis routine (similarity computed treating data as quantitatively linear, Alvey et al. 1977) is useful in identifying distortions in the disposition of samples (Fig. 2) due to incomplete representation of variance. It is the shortest connected tree linking all points and indicates, for example, that Sample 13, shown as part of the tight cluster that includes Samples 8, 9, 10, and 11 in Fig. 2, is much closer to Sample 30 in the hyperspace.

Most classificatory techniques used in numerical taxonomy force a hierarchical scheme on the data, regardless of its structure. Hierarchical organisation of clusters is not obvious in the configuration shown in Fig. 2 and centroid and average linkage clustering techniques did not produce readily interpretable classifications.

GENSTAT includes a powerful non-hierarchical strategy ('Classify' directive, Alvey et al. 1977) that proved much more meaningful with the Cavalli data. For a specified number of groups, the technique attempts, iteratively, to optimize a criterion of group homogeneity by transferring samples among groups and testing for improvement. However, there is no guarantee that a global optimum is achieved. The algorithm involves extensive computation and trials were restricted to the sums of squares criterion using the original order of samples.

Non-hierarchical classification was used to divide the samples into 2, 3, 4, 6, 7, and 8 groups and these classifications were then assessed subjectively for mappability, interpretation, and goodness of fit with the principal component and minimum spanning tree plots. All had mappable groupings but those selected as having the most meaningful and natural classifications were the 3 and 7 groups (Fig. 4a, b) and these were adopted for use in interpretation of the foraminiferal fauna.

To assess the role played by dominant and rare species in producing the 7 groups of samples (= faunal associations), the full data were reduced and non-hierarchical classification used to produce 2 further 7 groupings of samples (Fig. 4c, d) based on counts of only the 37 dominant taxa (defined as those comprising 3% or more in at least one sample — Fig. 5 and 6), or presence/absence scores for all taxa.

LIVE FAUNA. Non-hierarchical classification was used to produce two 7 groupings of samples based on full live data standardised as proportions of sample totals, or live data converted to presence-/absence scores for all taxa.

These classifications were compared with the grouping of 7 associations adopted from the total faunal data and are used later in the this paper for interpretation of the foraminiferal distribution.

Association score (Tables 2–8)

To determine which species characterise each of the 7 faunal associations, the 37 dominant taxa in the study (3% or more in at least 1 station) were ranked for each association using a value (association score) calculated to reflect their importance, based on 3 criteria:

DOMINANCE, obtained by ranking the 10 most abundant taxa at each station in the association. 10 points were given to the numerically most abundant taxon, 9 for the second most abundant, and so on until the 10th taxon is given 1 point. The points are summed for each taxon for all stations in the association and presented as a proportion of the maximum possible total.

FIDELITY, or degree to which a taxon is restricted to association expressed as the proportion of stations within the association in which the taxon occurs less the proportion of stations outside the association in which it occurs.

RELATIVE ABUNDANCE, expressed as the mean abundance of the taxon within the association less its mean abundance throughout all the stations.

Dominance values range between 0 and 1, whereas fidelity and relative abundance values each range between -1 and +1.

The Association score, as used here, is defined as

Assoc. score = 5 (2 Dom. + 3 Fid. + 15 Rel. abund.)

Association score values may range between -90 and +100.

Species diversity

Four measures of species diversity — S, α, H, and E were used:

NUMBER OF SPECIES, S, in the station.

FISHER α INDEX, which gives a value relating number of species present to the number of individuals counted (discussed by Murray 1973).

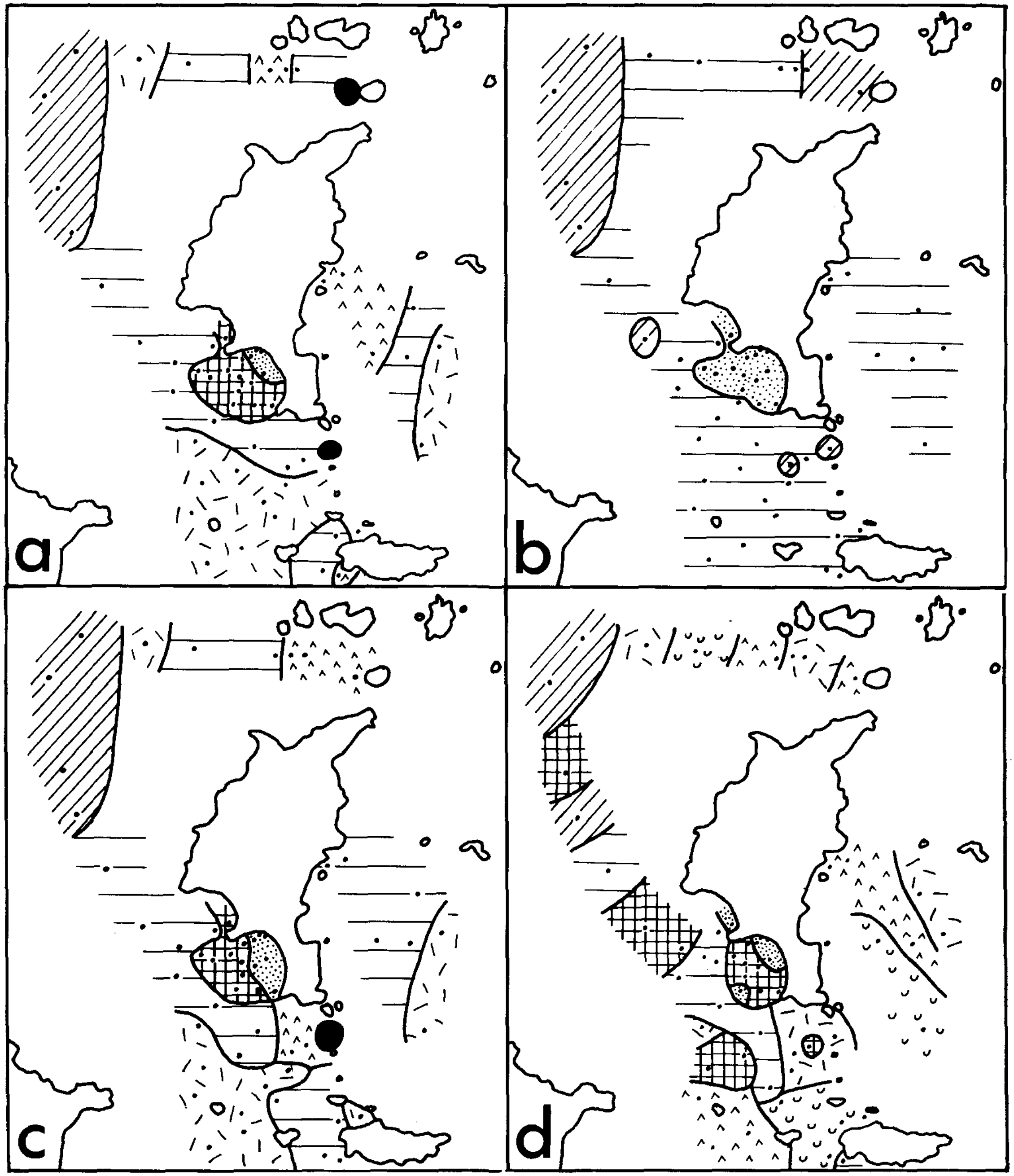


Fig. 4 Groupings produced by non-hierarchical classification applied to a map of sample locations: (a) 7 groups using full census data; (b) 3 groups using full census data; (c) 7 groups using census counts for only the 37 dominant taxa; (d) 7 groups using presence/absence scores for all taxa.

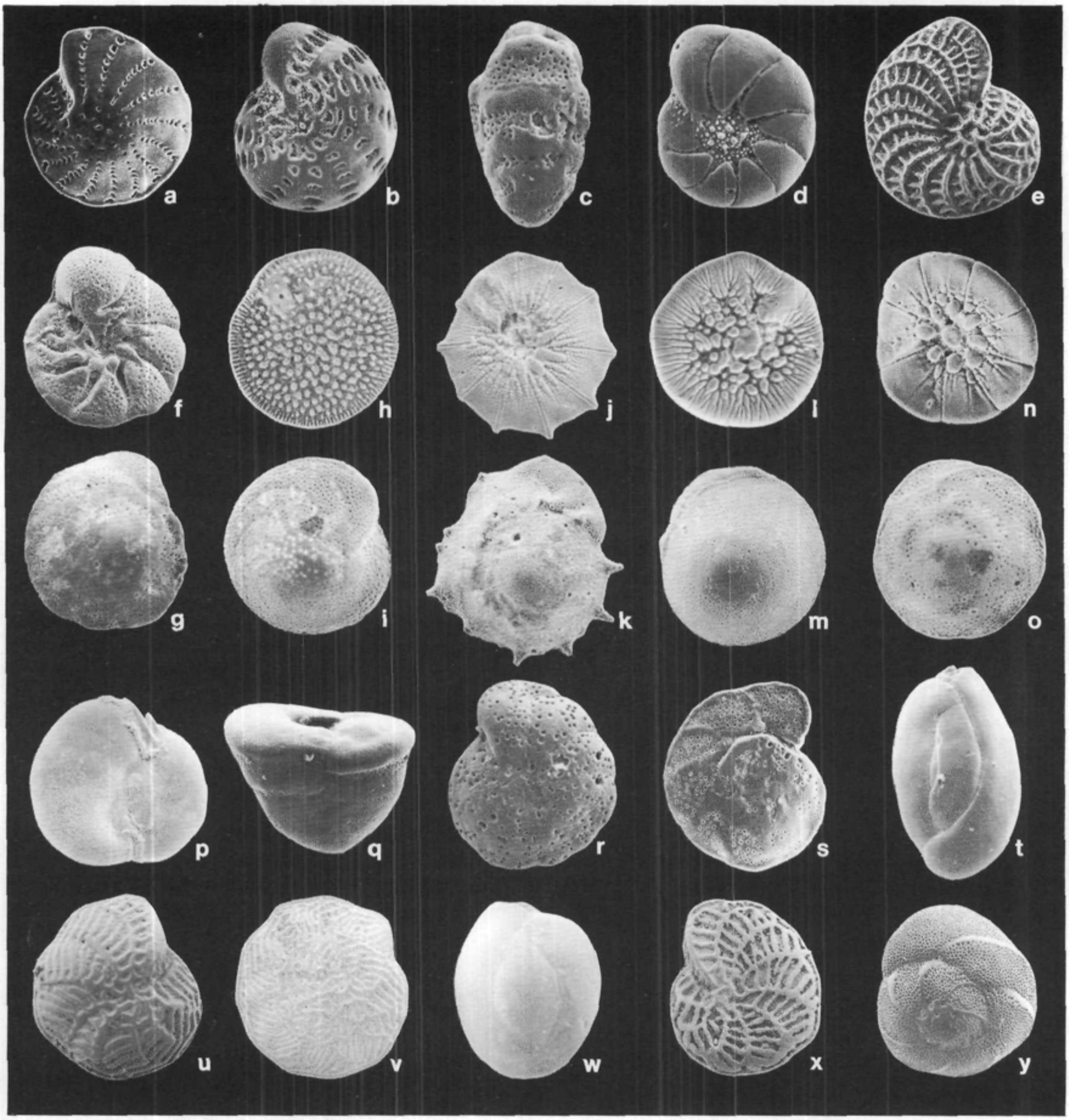


Fig. 5 Dominant foraminifera in Associations A and B around the Cavalli Islands, New Zealand. (a)–(d) characteristic species of Association A, (a) *Elphidium charlottensis* (Vella), FP 3160, F201738, × 60; (b) *Elphidium oceanicum* Cushman, FP 3161, F201732, × 80; (c) *Virgulopsis turris* (Heron-Allen & Earland), FP 3162, F201738, × 100; (d) *Elphidium simplex* Cushman, FP 3163, F201720, × 100. (e)–(k) characteristic species of Subassociation B1, (e) *Elphidium novozealandicum* Cushman, FP 3166, F201745, × 80; (f) *Discorbis dimidiatus* (Jones & Parker), FP 3164, F201715, × 40; (g) *Discorbis dimidiatus* (Jones & Parker), FP 3165, F201715, × 40; (h) *Pileolina radiata* Vella, FP 3167, F201726, × 80; (i) *Pileolina radiata* Vella, FP 3168, F201732, × 100; (j) *Pileolina calcarata* (Heron-Allen & Earland), FP 3169, F201727, × 100; (k) *Pileolina calcarata* (Heron-Allen & Earland), FP 3170, F201750, × 80; (l)–(q) characteristic species of Subassociation B2, (l) *Pileolina zealandica* Vella,FP 3040, F201787, × 90;(m) *Pileolina zealandica* Vella, FP 3040, F201787, × 90; (n) *Pileolina patelliformis* (Brady) FP 3172, F201723, × 80; (o) *Pileolina patelliformis* (Brady) FP 3173, F201723, × 90; (p) *Miliolinella subrotundata* (Montagu) FP 3174, F210729, × 60; (q) *Patellinella inconspicua* (Brady),FP 3175, F201745, × 80; (r)–(y) characteristic species of Subassociation B3, (r) *Cibicides marlboroughensis* Vella, FP 3176, F201741, × 60; (s) *Cibicides marlboroughensis* (Vella), FP 3177, F201740, × 90, (t) *Quinqueloculina seminula* (Linnaeus), FP 3178, F201758, × 50; (u) *Notorotalia olsoni* Vella, FP 3179, F201746, × 50; (v) *Notorotalia olsoni* Vella, FP 3180, F201720, × 30; (w) *Quinqueloculina triangularis* d'Orbigny, FP 3181, F201741, × 45; (x) *Notorotalia depressa* Vella, FP 3182, F201746, × 40; (y) *Rosalina bradyi* (Cushman), FP 3183, F201732, × 35.

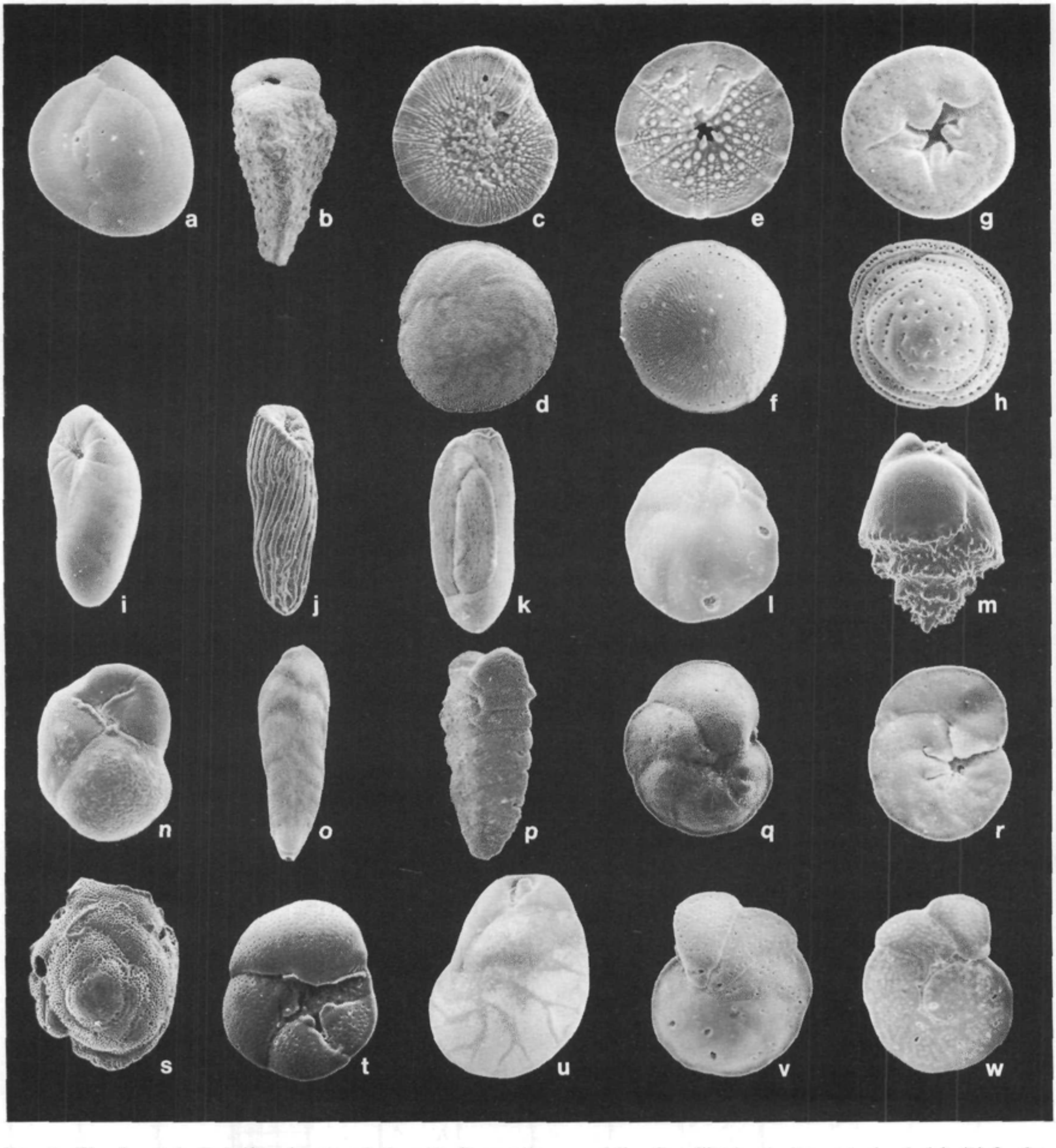


Fig. 6 Dominant foraminifera in Associations B, C, and D around the Cavalli Islands, New Zealand. (a)–(b) further characteristic species of Subassociation B3, (a) *Quinqueloculina suborbicularis* D'Orbigny, FP 3184, F201722, × 70; (b) *Gaudryina convexa* (Karrer), FP 3185, F201759, × 30; (c)–(k) characteristic species of Association C, (c) *Planoglabratella opercularis* (d'Orbigny), FP 3186, F201745, × 50; (d) *Planoglabratella opercularis* (d'Orbigny), FP 3187, F201712, × 70; (e) *Pileolina harmeri* (Heron-Allen & Earland), FP 3188, F201720, × 70; (f) *Pileolina harmeri* (Heron-Allen & Earland), FP 3189, F201720, × 70; (g) *Neoconorbina pacifica* Hofker, FP 3190,F201712, × 70; (h) *Neoconorbina pacifica* Hofker, FP 3191, F201724, × 70; (i) *Buliminoides madagascariensis* (d'Orbigny), FP 3192, F201719, × 80; (j) *Buliminoides williamsoniana* (Brady), FP 3193, F201746, × 70; (k) *Quinqueloculina ariminensis* d'Orbigny, FP 3194, F201714, × 45; (l)–(w) characteristic species of Association D, (l) *Cassidulina carinata* Silvestri, FP 3195, F201719, × 80; (m) *Bulimina submarginata* Parr, FP 3196, F201748, × 90; (n) *Globocassidulina canalisuturata* Eade, FP 3197, F201759, × 120; (o) *Bolivina cacozela* Vella, FP 3198, F201720, × 80; (p) *Textularia ensis* Vella, FP 3199, F201719, × 35; (q) *Hanzawaia bertheloti* (d'Orbigny), FP 3203, F201720, × 80; (r) *Hanzawaia bertheloti* (d'Orbigny), FP 3201, F201720, × 60; (s) *Rosalina irregularis* (Rhumbler), FP 3200, F201741, × 50; (t) *Gavelinopsis hamatus* Vella, FP 3203, F201732, × 100; (u) *Evolvocassidulina orientalis* (Cushman), FP 3204, F201756, × 60; (v, w) *Cibicides* cf. *ungerianus* (d'Orbigny), FP 3205, F201717, × 60.

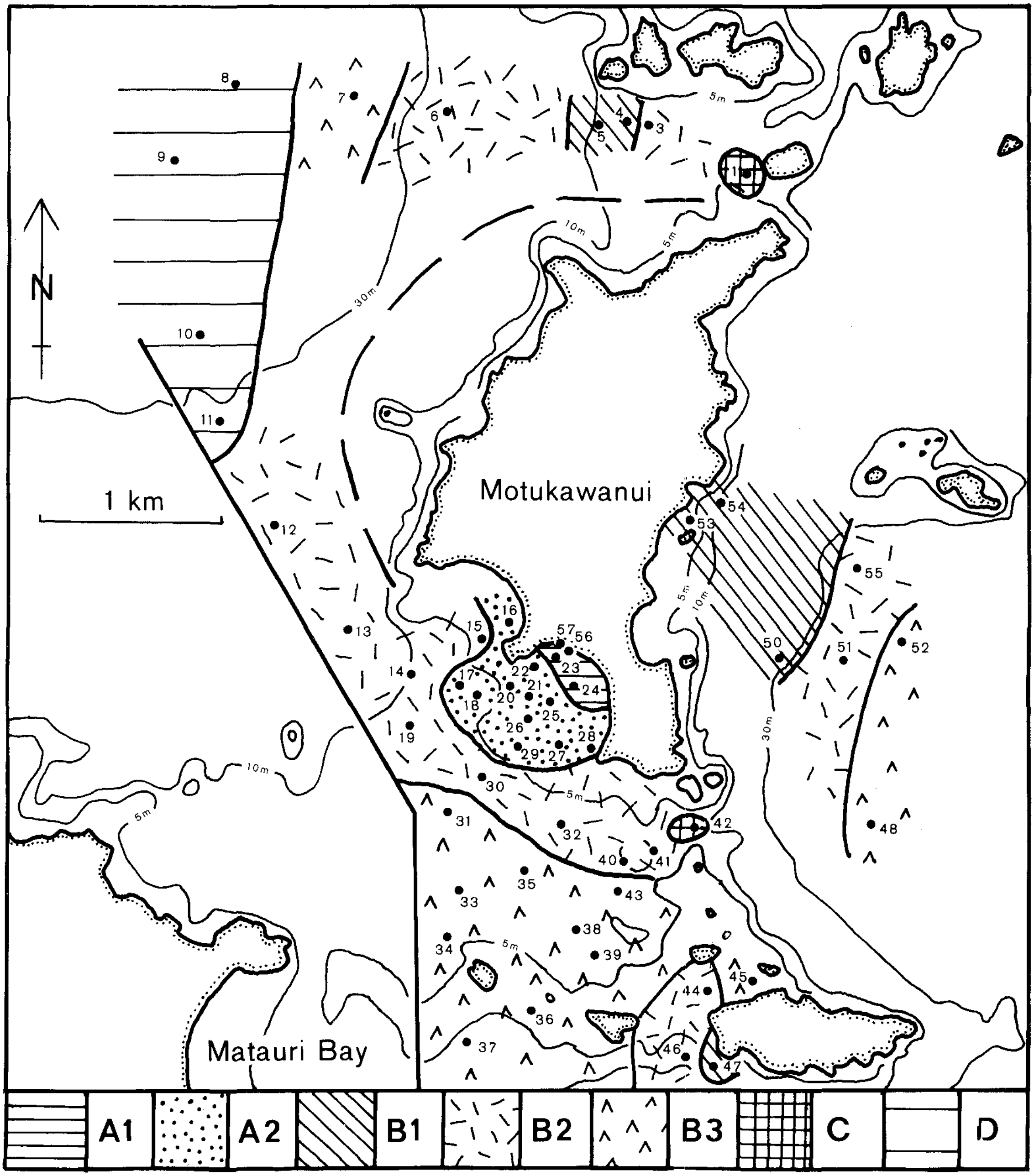


Fig. 7 Station numbers, depth contours, and distribution of 7 groups produced by non-hierarchical classification using full census data.

Table 2 Major characterising species of subassociation A1 (*Elphidium charlottensis/Elphidium oceanicum/Virgulopsis turris*), Cavalli Islands, arranged in order of decreasing Association scores (Assoc. score) calculated from each species Dominance (Dom), Fidelity (Fid.) and Relative abundance (Rel. abund.) in the subassociation (see text for explanation).

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Assoc. score
Elphidium charlottensis	1.00	1.00	0.039	42.6	31.8	34.4
Elphidium oceanicum	0.88	1.00	0.647	11.2	9.8	25.8
Virgulopsis turris	0.05	1.00	0.529	1.2	0.9	9.1
Pileolina harmeri	0.65	1.00	0.019	4.2	0.7	7.3
Neoconorbina pacifica	0.48	1.00	0.019	4.1	0.5	4.7
Cassidulina carinata	0.28	1.00	0.078	2.7	0.2	4.1
Elphidium novozealandicum	0.35	1.00	0.019	2.9	1.0	3.0
Gavelinopsis hamatus	0.20	1.00	0.039	2.8	0.5	3.0

Table 3 Major characterising species of Subassociation A2 (*Elphidium charlottensis/Elphidium oceanicum/Elphidium simplex*). Conventions as in Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Assoc. score
Elphidium charlottensis	1.00	1.00	0.045	26.7	15.9	22.6
Elphidium oceanicum	0.24	0.91	0.636	3.0	1.5	13.1
Elphidium simplex	0.00	1.00	0.682	0.8	0.5	10.6
Pileolina zealandica	0.83	1.00	0.023	7.3	–0.9	8.0
Neoconorbina pacifica	0.60	1.00	0.023	5.4	0.8	6.9
Elphidium novozealandicum	0.54	1.00	0.023	4.8	1.0	6.5
Rosalina irregularis	0.09	0.91	0.318	1.9	0.7	6.2
Quinqueloculina seminula	0.49	1.00	0.045	4.8	–0.3	5.4
Cibicides marlboroughensis	0.64	1.00	0.000	6.4	–3.0	4.1

SHANNON-WIENER INFORMATION FUNCTION

$$H = \sum_{P_i} \log P_i$$

where P_i is the proportion of the ith species (MacArthur & MacArthur 1961; Gibson & Buzas 1973). Unlike S and α, the Information Function places little weight on rarer species. The value of H depends on a combination of the evenness of species counts together to a lesser extent with the number of species present.

EVENNESS, $E = e^H/S$, is a measure solely of evenness of species counts within a station, irrespective of the number of species present (Buzas & Gibson 1969; Hill 1973).

RESULTS AND DISCUSSION

Total foraminiferal associations (dead plus live) (Fig. 7)

ASSOCIATION A — *Elphidium charlottensis*

This group of 15 stations occurs in fine to very fine sand in the shelter of Parapara and Waiiti Bays on the southwest coast of Motukawanui Island. All faunas are characterised by the dominance of *Elphidium charlottensis* (18–51%). This is one of the major clusters generated when non-hierarchical classification was programmed to divide the stations into 3 groups (Fig. 4b). When programmed to produce more than 3 groups, this cluster was split into 2 smaller groups, here termed subassociations.

Subassociation A1 — *Elphidium charlottensis/Elphidium oceanicum/*(*Virgulopsis turris*) Table 2, Fig. 8

Stations: 23, 24, 56, 57 (total 4)
Depth: low-tide beach – 1.8 m (mean 0.6 m)
Sediment: very fine sand, fine sand, and sandy gravel
Wave energy: low – moderate
Macrofaunal associations: *Myadora boltoni – Pectinaria australis* (23, 24), no fauna (56, 57)
Planktic percent of foraminifera: 0–1%.

This subassociation is confined to the shallowest and most sheltered stations (Fig. 7). 3 of the stations are fine to very fine sand and in the fourth the foraminifera occur in the fine sand matrix of the low-tide beach gravel (Stn 56).

The subassociation is characterised by the large dominance of *Elphidium charlottensis* (35–61%) and the secondary dominance of *Elphidium oceanicum* (5–17%). The next most abundant taxa are 3 discorbaceans (*Pileolina harmeri, Pileolina*

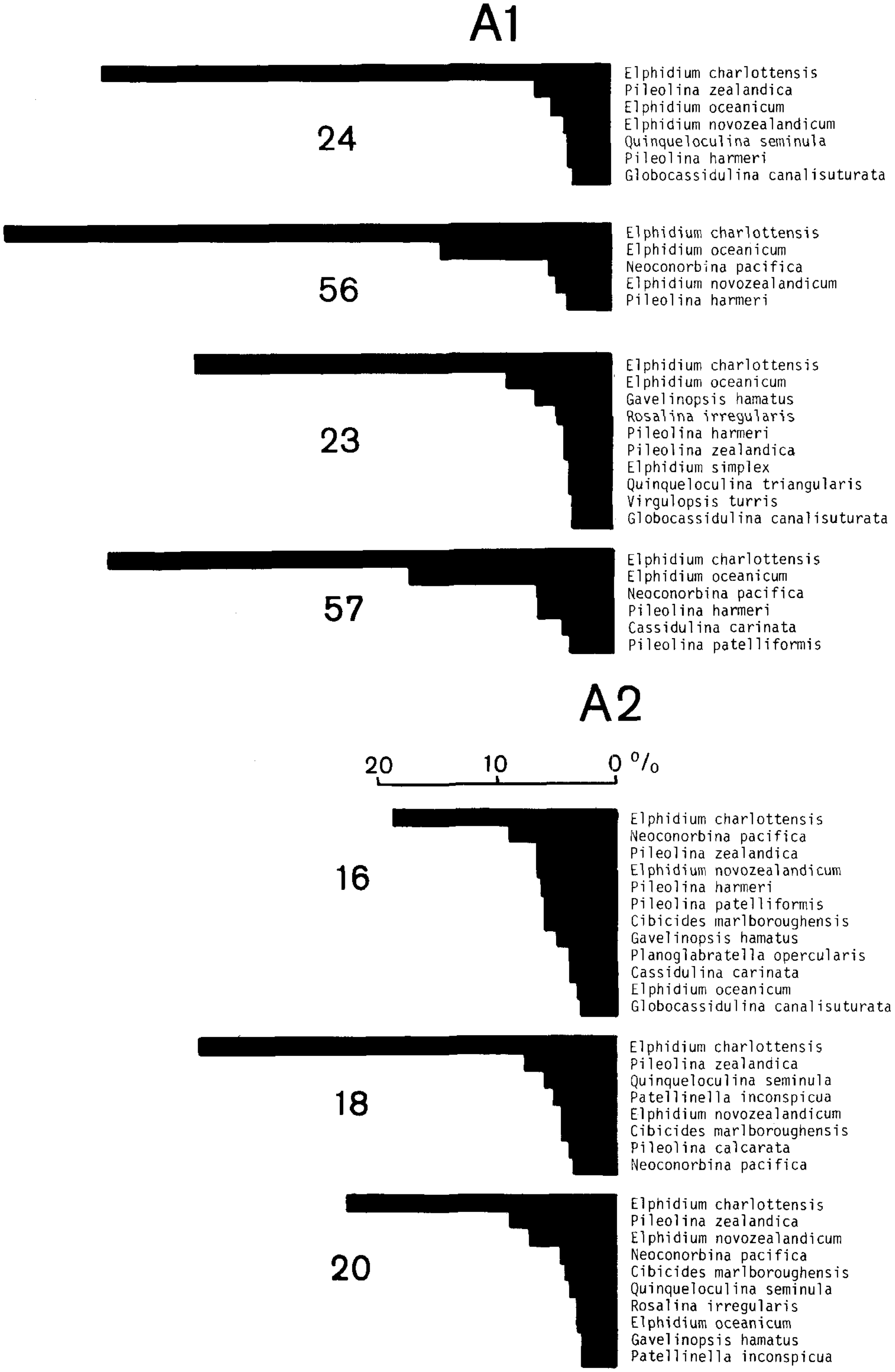
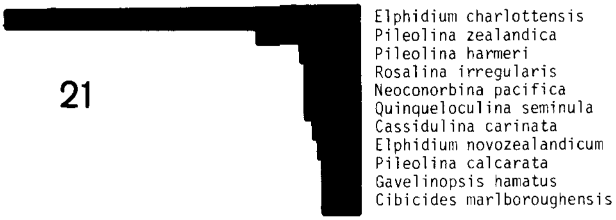


Fig. 8 (above and opposite) Histograms of common species (>3%) in Association A samples.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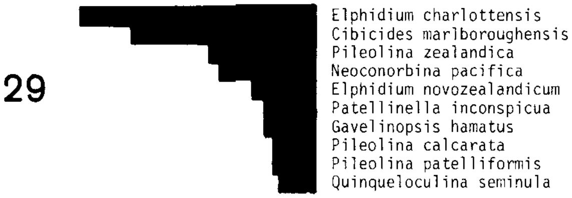
Elphidium charlottensis
Pileolina zealandica
Pileolina harmeri
Rosalina irregularis
Neoconorbina pacifica
Quinqueloculina seminula
Cassidulina carinata
Elphidium novozealandicum
Pileolina calcarata
Gavelinopsis hamatus
Cibicides marlboroughensis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Cibicides marlboroughensis
Pileolina zealandica
Neoconorbina pacifica
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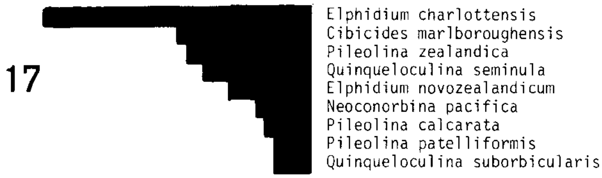
Pileolina calcarata
Pileolina patelliformis
Quinqueloculina seminula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Pileolina zealandica
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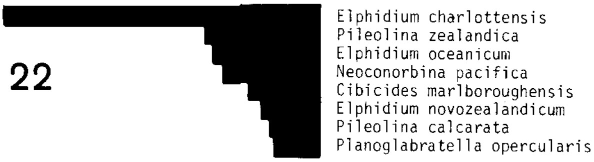
Pileolina calcarata
Pileolina patelliformis
Quinqueloculina suborbicularis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Elphidium charlottensis
Pileolina zealandica
Elphidium oceanicum
Neoconorbina pacifica
Cibicides marlboroughensis
Elphidium novozealandicum
Pileolina calcarata
Planoglabratella opercularis


25
Elphidium charlottensis
Pileolina zealandica
Quinqueloculina seminula
Cibicides marlboroughensis
Gavelinopsis hamatus
Elphidium oceanicum
Pileolina patelliformis
Pileolina harmeri


26
Elphidium charlottensis
Quinqueloculina siminula
Pileolina zealandica
Neoconorbina pacifica
Elphidium novozealandicum
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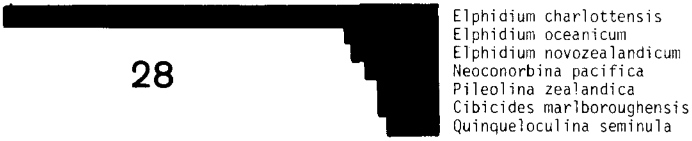
Cassidulina carinata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Elphidium charlottensis
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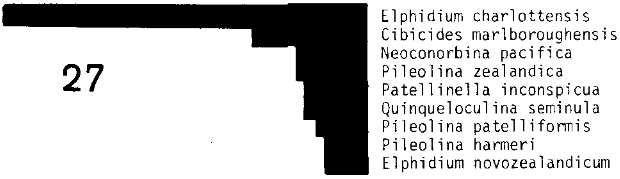
Elphidium novozealandicum
Neoconorbina pacifica
Pileolina zealandica
Cibicides marlboroughensis
Quinqueloculina seminula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Cibicides marlboroughensis
Neoconorbina pacifica
Pileolina zealandica
Patellinella inconspicua
Quinqueloculina seminula
Pileolina patelliformis
Pileolina harmeri
Elphidium novozealandicum

zealandica, Neoconorbina pacifica) all of which are abundant and widespread throughout the study area and therefore have low fidelity, relative abundance, and association scores. Despite its low abundance (0.3–3%), *Virgulopsis turris* has the third highest association score (a result of its high fidelity and relative abundance) and is considered a secondary characterising species of this subassociation.

Subassociation A2 — *Elphidium charlottensis*/(*Elphidium oceanicum*/*Elphidium simplex*) Table 3, Fig. 8
Stations: 16, 17, 18, 20, 21, 22, 25, 26, 27, 28, 29 (total 11)
Depth: 0.8–6 m (mean 3m)
Sediment: fine sand – slightly muddy very fine sand
Wave energy: low – moderate
Macrofaunal association: *Myadora boltoni–Pectinaria australis, Zeacolpus pagoda–Zegalerus tenuis*
Planktic percent of foraminifera: 0–2%.

This subassociation occurs in fine sand (and very fine sand) within the open mouth of Parapara Bay and in the shallows of adjacent Waiiti Bay (Fig. 7). Like A1, it is characterised by the dominance of *Elphidium charlottensis*, though in lower abundance (18–35%). 2 secondary characterising species are recognised (*Elphidium oceanicum, Elphidium simplex*) by their high association scores, which result from their high fidelity values. *Elphidium oceanicum* is far less abundant (mean 3%) in this subassociation than in A1 (mean 11.2%) and is ranked seventh (rather than second) in order of dominance. *Elphidium simplex* is only a minor component of the fauna (0.3–2.3%) but this is the only subassociation in which it occurs consistently. Secondary dominants in the fauna, behind *Elphidium charlottensis*, are (in decreasing order) *Pileolina zealandica, Cibicides marlboroughensis, Neoconorbina pacifica, Elphidium novozealandicum*, and *Quinqueloculina seminula*, all of which are widespread and abundant throughout most of the study area and are characterising species in the adjacent Association B.

DISCUSSION

This *Elphidium charlottensis* association is broadly similar to faunas described from several other parts of eastern Northland. Muddy sand in the lower portion of the Puhoi Estuary (Fig. 1) is dominated by *Elphidium charlottensis* with subdominant *Elphidium simplex, Quinqueloculina seminula, Discorbis dimidiatus*, and *Rosalina* species (Topping 1973). A fauna very similar to A1 occurs in gravelly, very coarse sand at low tide level on the relatively sheltered beach in Urupukapuka Bay, eastern Bay of Islands (stn 30 of Hayward 1981). It has *Elphidium charlottensis* dominant (52%) with subdominant *Elphidium oceanicum, Discorbis dimidiatus*, and *Quinqueloculina seminula*. 3 further samples in the eastern Bay of Islands (stns 27, 36, 40), in very similar environmental settings to Parapara Bay, have faunas classifiable with the A2 subassociation. 2 of these occur in fine sand at 2 m depth within Urupukapuka Bay and the third is in medium sand at low tide level on Otehei Bay beach.

Faunas dominated by the secondary characterising species of A1, *Virgulopsis turris*, with subdominant *Elphidium charlottensis, Elphidium oceanicum*, and several discorbaceans and miliolaceans, occur in very fine sand at 3–10 m depth in the outer part of Tutukaka Harbour (stns 24, 28 of Brook et al. 1981). A fauna dominated by the secondary characterising species of A1, *Elphidium simplex*, with subdominant *Elphidium charlottensis, Elphidium argenteum, Elphidium oceanicum*, and several other species, occurs in slightly gravelly very fine sand in the middle part of Tutukaka Harbour (stn 31 of Brook et al. 1981).

The *Elphidium charlottensis* association appears to be characteristic of the beaches and shallows of sheltered, normal salinity bays and is intermediate in composition between the faunas of the outer parts of enclosed harbours and those of more open and exposed bays.

ASSOCIATION B — *Pileolina zealandica/Cibicides marlboroughensis*

This is the largest group of stations in the study area. They are widespread and usually occur in medium to coarse sand or shell gravel in moderately exposed or current-swept localities. The faunas are characterised by abundant discorbaceans, miliolids (mostly *Quinqueloculina*), and cibicidids.

This is one of the major groups generated when non-hierarchical classification was programmed to divide the stations into 3 clusters (Fig. 4b). When 7 clusters were produced this group (association) was split into 3 smaller groups (subassociations). The 2 most abundant species in each subassociation are *Pileolina zealandica* and *Cibicides marlboroughensis*.

Subassociation B1 — *Discorbis dimidiatus/Elphidium novozealandicum/Pileolina zealandica.* Table 4, Fig. 9
Stations: 4, 5, 47, 50, 53, 54 (total 6)
Depth: 2–28 m (mean 10 m)
Sediment: medium sand and shelly very coarse sand
Wave energy: moderate–high
Macrofaunal associations: *Zeacolpus pagoda–Zegalerus tenuis, Tawera spissa*, or sparse fauna.
Planktic percent of foraminifera: 0–2%.

This subassociation occurs in 3 areas (Fig. 7), usually shallower than the adjacent B2 and B3

Table 4 Major characterising species of Subassociation B1 (*Discorbis dimidiatus/Elphidium novozealandicum/Pileolina zealandica*). Conventions as in Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Assoc. score
Discorbis dimidiatus	0.68	1.00	0.036	8.6	6.4	16.2
Elphidium novozealandicum	0.80	1.00	0.020	10.2	6.4	13.1
Pileolina zealandica	0.85	1.00	0.020	12.5	4.2	12.0
Cibicides marlboroughensis	0.82	1.00	0.000	11.3	1.9	9.6
Pileolina radiata	0.32	1.00	0.204	4.0	2.9	8.4
Pileolina calcarata	0.55	1.00	0.020	6.0	2.9	8.0
Rosalina bradyi	0.07	1.00	0.245	2.1	0.7	4.9
Notorotalia olsoni	0.13	1.00	0.204	2.8	0.6	4.8
Quinqueloculina seminula	0.42	1.00	0.041	5.1	0.1	4.7

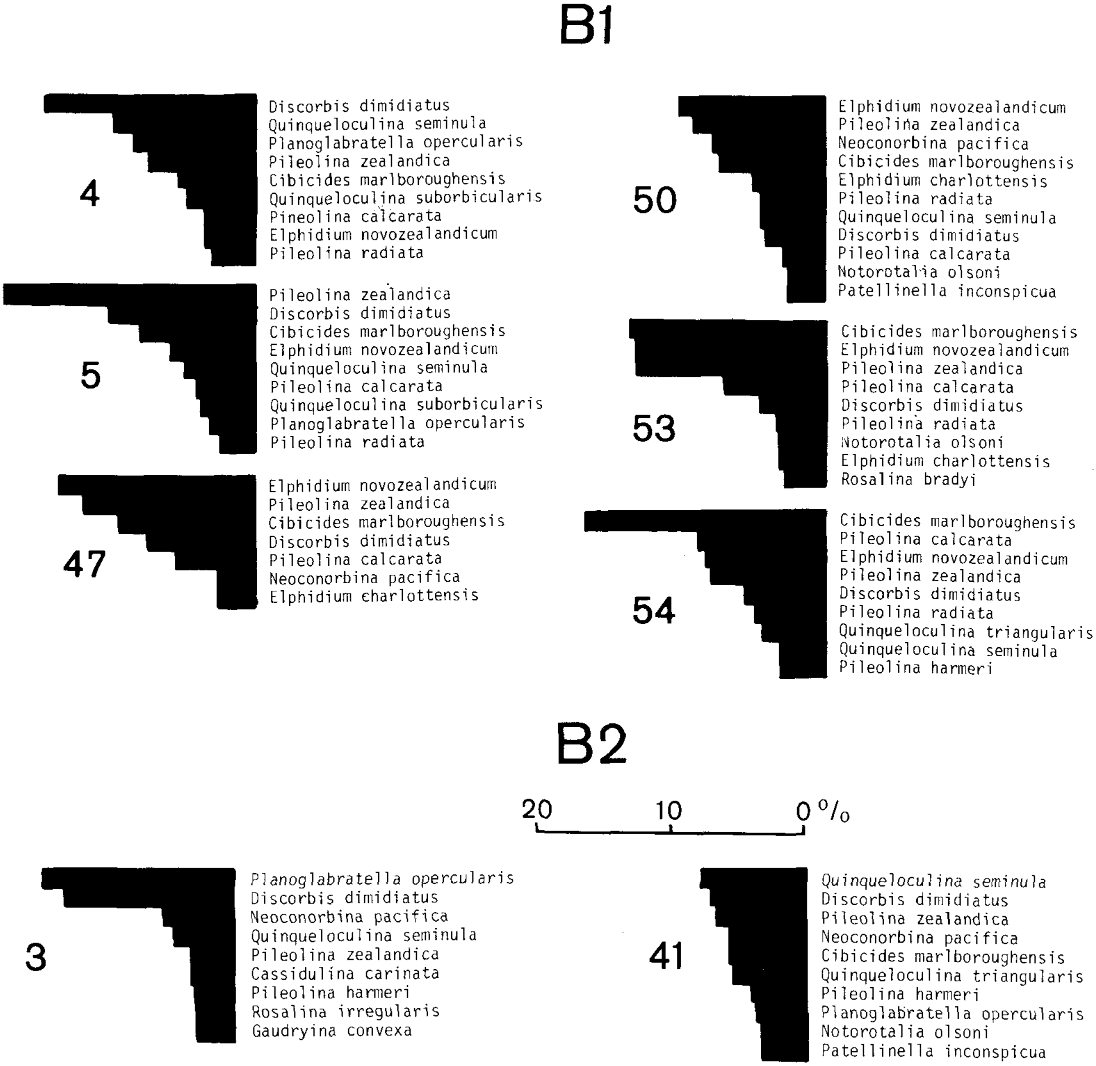
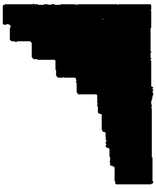


Fig. 9 (above, overleaf, and p. 43) Histograms of common species (>3%) in Association B samples.

15

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Elphidium novozealandicum
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Pileolina harmeri
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Patellinella inconspicua
Quinqueloculina seminula
Pileolina calcarata

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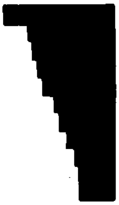
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Quinqueloculina ariminensis
Pileolina patelliformis
Gavelinopsis hamatus
Quinqueloculina suborbicularis

40

Quinqueloculina seminula
Discorbis dimidiatus
Neoconorbina pacifica
Pileolina harmeri
Buliminoides madagascariensis
Elphidium charlottensis
Planoglabratella opercularis
Miliolinella subrotundata
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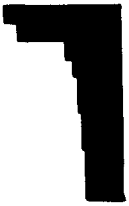
Patellinella inconspicua
Quinqueloculina triangularis
Quinqueloculina ariminensis

44

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Pileolina calcarata
Elphidium charlottensis
Quinqueloculina seminula
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Neoconorbina pacifica
Evolvocassidulina orientali

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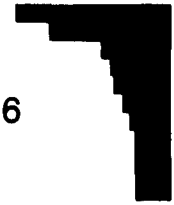
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Pileolina calcarata
Cassidulina carinata
Neoconorbina pacifica
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Patellinella inconspicua
Quinqueloculina seminula
Gaudryina convexa
Planaoglabratella opercularis
Quinqueloculina suborbicularis

14

Cibicides marlboroughensis
Neoconorbina pacifica
Elphidium charlottensis
Pileolina zealandica
Gavelinopsis hamatus
Pileolina harmeri
Planoglabratella opercularis
Patellinella inconspicua
Quinqueloculina suborbicularis
Elphidium novozealandicum
Pileolina patelliformis
Pileolina calcarata

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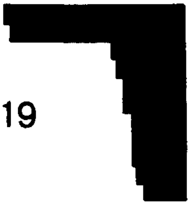
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Pileolina calcarata
Neoconorbina pacifica
Elphidium novozealandicum
Quinqueloculina suborbicularis

55

Pileolina zealandica
Cibicides marlboroughensis
Globocassidulina canalisuturata
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Cassidulina carinata

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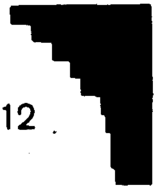
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Pileolina harmeri

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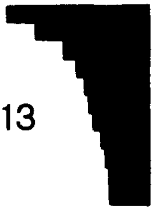
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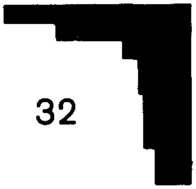
Elphidium charlottensis
Patellinella inconspicua
Quinaueloculina seminula
Quinqueloculina suborbicularis

32

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Quinqueloculina suborbicularis

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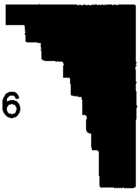
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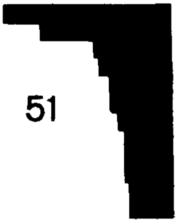
Globocassidulina canalisuturata

51

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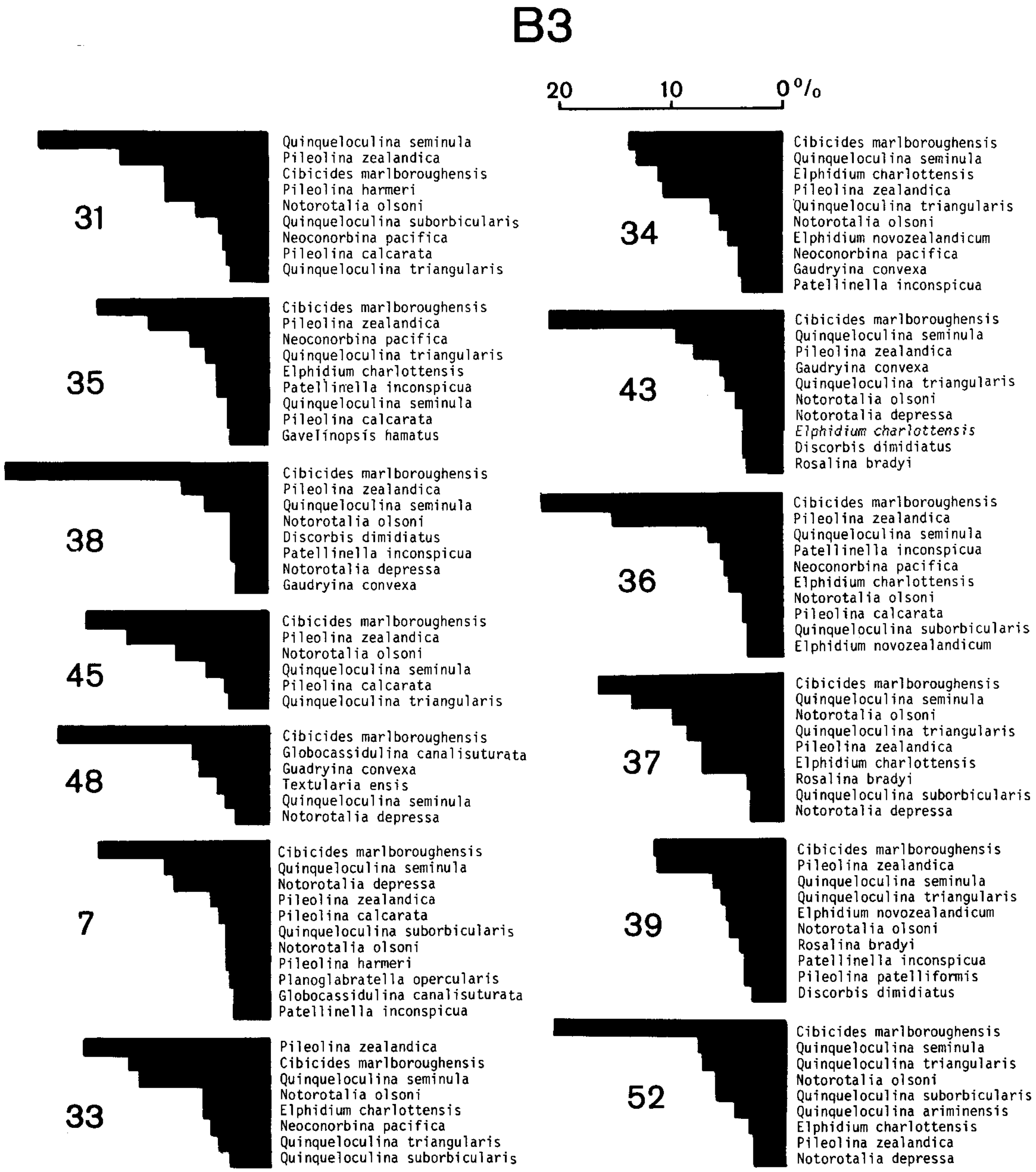
Quinqueloculina suborbicularis



subassociations. Most of the fauna presumably lived in sand in the vicinity of the dredge stations but the primary characterising species, *Discorbis dimidiatus*, was probably transported after death into the clean medium sand of Stations 47, 53, and 54. This species lives epifaunally on fairly stable substrates such as shells, pebbles, and rocky reefs and is often one of the most abundant taxa on intertidal and shallow subtidal rocky areas (Hedley et al. 1967). Stations 47, 53, and 54 are within 50 m of shallow reefs, whereas Stations 4, 5, and 50 contain large shell clasts on which *Discorbis dimidiatus* possibly lived.

The second characterising species, *Elphidium novozealandicum*, is widespread in low abundance throughout the study area but occurs in greatest numbers (4–15%, mean 10%) in this subassociation.

Table 5 Major characterising species of Subassociation B2 (*Pileolina zealandica/Cibicides marlboroughensis/Neoconorbina pacifica*). Conventions as in Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Assoc. score
Pileolina zealandica	0.81	1.00	0.025	9.0	0.8	9.1
Cibicides marlboroughensis	0.78	1.00	0.000	8.7	−0.7	7.3
Neoconorbina pacifica	0.62	1.00	0.025	5.5	1.0	7.3
Discorbis dimidiatus	0.21	0.87	0.192	2.7	0.5	5.4
Pileolina calcarata	0.36	1.00	0.025	3.7	0.6	4.4
Pileolina patelliformis	0.28	1.00	0.050	3.7	1.1	4.4
Pileolina harmeri	0.34	1.00	0.025	3.5	0.1	3.9
Cassidulina carinata	0.21	1.00	0.100	2.8	0.3	3.8
Planoglabratella opercularis	0.19	1.00	0.100	3.3	0.4	3.7

Table 6 Major characterising species of Subassociation B3 (*Cibicides marlboroughensis/Quinqueloculina seminula/Notorotalia olsoni*). Conventions as for Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Assoc. score
Cibicides marlboroughensis	0.98	1.00	0.000	16.7	7.3	15.3
Quinqueloculina seminula	0.80	1.00	0.048	9.0	3.9	11.6
Notorotalia olsoni	0.54	1.00	0.238	5.3	3.1	11.3
Quinqueloculina triangularis	0.43	1.00	0.190	4.5	2.4	9.0
Pileolina zealandica	0.72	1.00	0.024	9.1	0.8	8.2
Notorotalia depressa	0.19	1.00	0.333	2.6	1.4	7.9
Rosalina bradyi	0.07	1.00	0.286	2.1	0.7	5.5
Quinqueloculina suborbicularis	0.20	1.00	0.095	2.4	0.3	3.7
Quinqueloculina ariminensis	0.04	1.00	0.167	1.8	0.5	3.3
Gaudryina convexa	0.17	0.92	0.015	2.5	1.0	2.7

The 2 most abundant species overall in B1 are *Pileolina zealandica* and *Cibicides marlboroughensis* (Table 4).

Subassociation B2 — *Pileolina zealandica/Cibicides marlboroughensis/Neoconorbina pacifica* Table 5, Fig. 9
Stations: 3, 6, 12, 13, 14, 15, 19, 30, 32, 40, 41, 44, 46, 51, 55 (total 15)
Depth: 2–36 m (mean 12 m)
Sediment: fine sand–shelly pebble gravel (mostly shelly very coarse sand)
Wave energy: moderate–high
Macrofaunal associations: *Tawera spissa, Zeacolpus pagoda–Zegalerus tenuis*, or sparse fauna.
Planktic percent of foraminifera: 0–2.5%

This subassociation is widespread around the Cavalli Islands (Fig. 7) at intermediate depths, mostly between 5 and 25 m, and often in places with moderately strong currents. Substrates are usually a mixture of mollusc shells (predominantly *Tawera spissa*) and clean sand, although grain size is quite variable.

The subassociation lacks any characterising species with high association scores. It is named after the 3 most abundant taxa (*Pileolina zealandica, Cibicides marlboroughensis, Neoconorbina pacifica*), although none occur in numbers much greater than their background level throughout much of the study area (i.e., low relative abundance values). This subassociation is notable for the number of discorbaceans with moderately high association scores (e.g., *Discorbis dimidiatus, Pileolina calcarata, Pileolina patelliformis, Pileolina harmeri, Planoglabratella opercularis*). It is very similar in composition to B1 and B3, differing mainly in the slightly lower abundances of *Discorbis dimidiatus, Elphidium novozealandicum, Quinqueloculina seminula*, and *Notorotalia olsoni.*

Subassociation B3 — *Cibicides marlboroughensis-/Quinqueloculina seminula/Notorotalia olsoni* Table 6, Fig. 9
Stations: 7, 31, 33, 34, 35, 36, 37, 38, 39, 43, 45, 48, 52 (total 13)
Depth: 4–40 m (mean 13.5 m)
Sediment: medium sand to sandy gravel and shelly very coarse sand
Wave energy: moderate–high
Macrofaunal associations: *Tawera spissa, Nemocardium pulchellum*, or sparse fauna
Planktic percent of foraminifera: 0–2%.

9 of the stations (31–43) in this subassociation occur on the shallow current-swept shelf (4–10 m)

Table 7 Major characterising species of Association C (*Planoglabratella opercularis/Pileolina harmeri/Neoconorbina pacifica*). Conventions as for Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Comm. score
Planoglabratella opercularis	0.90	1.00	0.075	23.0	20.2	25.3
Pileolina harmeri	0.95	1.00	0.019	21.1	17.6	23.0
Neoconorbina pacifica	0.85	1.00	0.019	10.5	5.9	13.2
Buliminoides madagascariensis	0.35	1.00	0.189	3.6	2.4	8.1
Buliminoides williamsoniana	0.40	0.50	0.142	2.9	2.6	8.1
Quinqueloculina ariminensis	0.35	1.00	0.132	2.8	1.6	6.7
Cibicides marlboroughensis	0.50	1.00	0.000	3.9	–5.5	0.9

southwest of Motukawanui. 3 of the other 4 stations occur in moderately deep water (36–40 m) in more exposed locations northwest and east of Motukawanui (Fig. 7).

The 3 characterising species (*Cibicides marlboroughensis, Quinqueloculina seminula, Notorotalia olsoni*) all occur in their greatest abundances in this subassociation (Table 6). Miliolids are more abundant here than in any of the other associations, with 3 further *Quinqueloculina* species (*Q. triangularis, Q. suborbicularis, Q. ariminensis*) having moderately high association scores. 3 of the less abundant taxa around the Cavalli Islands (*Notorotalia depressa, Rosalina bradyi, Gaudryina convexa*) all have their highest association scores in B3.

DISCUSSION

Foraminiferal faunas broadly similar to this *Pileolina zealandica/Cibicides marlboroughensis* association have been recorded from a number of fairly exposed inner shelf localities around New Zealand. The fauna of 4 samples (13–75 m) in fine sand off North Cape, 90 km northwest of the Cavallis, is dominated by *Cibicides marlboroughensis, Quinqueloculina* spp., *Pileolina* spp., *Cibicides corticatus*, and *Zeaflorilus parri* (Hoskins 1978), and is similar to B3, although *Zeaflorilus parri* is virtually absent from the Cavalli faunas.

The fauna in fine sand at 2–22 m depth in the current-swept entrance to Rangaunu Harbour and shallow parts of exposed Rangaunu Bay (Fig. 1) is dominated by *Pileolina zealandica, Cibicides marlboroughensis, Quinqueloculina seminula, Elphidium novozealandicum, Notorotalia olsoni*, and *Elphidium charlottensis* ("association 3" of Adams 1979) and is therefore remarkably similar to Association B around the Cavalli Islands. Albert Channel in the eastern Bay of Islands is a very similar current-swept environment to the Cavalli Passage and its fauna in sandy gravel at 7 m depth (stns 5, 18 of Hayward 1981) is also very similar to B. Similar faunas are also present in 6 stations (6–37 m) in fine to medium sand in a relatively exposed location off Cuvier Island, 220 km southeast of the Cavallis (Hayward & Grace 1981). The 3 subassociations of the *Pileolina zealandica/Cibicides marlboroughensis* association recognised around the Cavalli Islands are not easily distinguishable in the faunas around Rangaunu, Bay of Islands, and Cuvier.

Faunas akin to B3 and characterised by *Cibicides marlboroughensis, Quinqueloculina seminula*, and *Notorotalia olsoni* occur in clean sand in the outer part of the Hauraki Gulf at 20–55 m depth ("thantotope 1" of Thompson 1975), and at 25 m in shelly coarse sand of the Foveaux Strait oyster beds, around the south of New Zealand (Hornibrook 1952a). In Foveaux Strait *Notorotalia olsoni* is replaced by the closely related *Notorotalia zealandica*.

ASSOCIATION C — *Planoglabratella opercularis/Pileolina harmeri/Neoconorbina pacifica* Table 7, Fig. 10

Stations: 1, 42 (total 2)
Depth: 6 m, 9 m
Sediment: shelly very coarse sand, fine shell gravel
Wave energy: high
Macrofaunal association: *Tawera spissa*
Planktic percent of foraminifera: 0–0.5%.

This association occurs in the 2 most exposed station localities in the study area. Both are in shallow (6 m, 9 m), narrow channels between islands that are swept by strong currents and exposed to the easterly swells that roll in from the Pacific Ocean. Both have coarse sediment which is well suited to the apparently epifaunal habit of the 2 primary characterising species, *Planoglabratella opercularis* and *Pileolina harmeri*. The secondary characterising taxon, *Neoconorbina pacifica*, is reasonably common throughout the area. 2 species of *Buliminoides* (*B. madagascariensis, B. williamsoniana*) have high relative abundances and association scores in this association.

DISCUSSION

Recent foraminiferal faunas similar to Association C have not been recorded previously from around

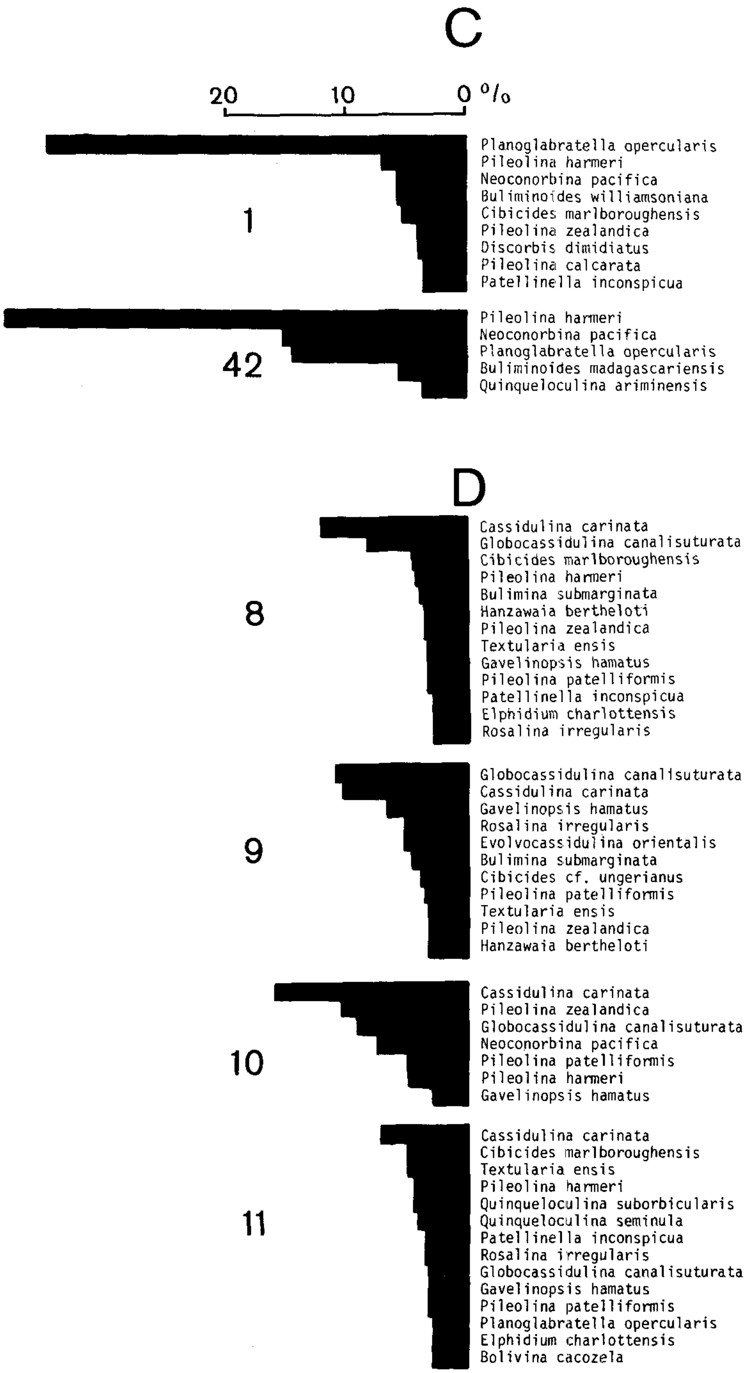


Fig. 10 Histograms of common species (>3%) in Association C and D samples.

Table 8 Major characterising species of Association D (*Cassidulina carinata/Bulimina submarginata/Globocassidulina canalisuturata*). Conventions as for Table 2.

	Dom.	Prop.	Fid.	Abund.	Rel. abund.	Comm. score
Cassidulina carinata	0.98	1.00	0.078	11.6	9.1	17.8
Bulimina submarginata	0.28	1.00	0.725	2.4	2.1	15.3
Globocassidulina canalisuturata	0.73	1.00	0.157	7.9	5.8	14.0
Bolivina cacozela	0.00	0.75	0.672	1.0	0.9	10.8
Buliminoides williamsoniana	0.00	1.00	0.686	0.4	0.1	10.4
Textularia ensis	0.28	1.00	0.353	3.1	2.2	9.7
Rosalina irregularis	0.30	1.00	0.294	3.6	2.4	9.2
Hanzawaia bertheloti	0.18	1.00	0.373	2.5	2.0	8.9
Gavelinopsis hamatus	0.40	1.00	0.039	4.1	1.8	7.7
Pileolina harmeri	0.50	1.00	0.020	4.0	0.5	5.7
Pileolina patelliformis	0.33	1.00	0.039	3.9	1.3	4.9
Evolvocassidulina orientalis	0.20	1.00	0.098	2.9	1.5	4.6

New Zealand, probably because of the rather restricted occurrence of the specialised habitat in which it was found.

The fauna of this association shows an apparently high correlation between strongly current-swept environments and plastogammic reproduction. Foraminifera have assexual and sexual reproductive stages in their life cycle, and in sexual reproduction most release free-swimming or floating gametes into the water. In 3 small families, however, 2 individuals fuse together during sexual reproduction to form a plastogammic pair and gametes are not released into the water. Association C is characterised by the greatest abundance in the study area of plastogammic taxa (e.g. species of *Planoglabratella, Pileolina, Buliminoides*), which appears to confirm the theory that plastogammic reproduction is an adaptation to allow sexual reproduction in such strongly current-swept environments.

ASSOCIATION D — *Cassidulina carinata/ Bulimina submarginata/Globocassidulina canalisuturata* Table 8, Fig. 10

Stations: 8, 9, 10, 11 (total 4)
Depth: 29–41 m
Sediment: slightly muddy very fine sand to shelly very coarse sand
Wave energy: moderate–low
Macrofaunal association: *Nemocardium pulchellum*
Planktic percent of foraminifera: 2.5–10%.

This association is limited in its distribution to deep water (29–41 m) northwest of Motukawanui Island, which is partially sheltered from the northeasterly swells by the northern Cavalli Islands. The substrate is primarily fine to very fine sand, although the shallowest station (Stn 11) is very coarse sand.

Of the characterising species, *Cassidulina carinata* and *Globocassidulina canalisuturata* occur in their greatest abundances in Association D (7.3–16.2% and 3.2–11.0% respectively), whereas *Bulimina submarginata* (0.3–4.6%) has a high fidelity score. *Bolivina cacozela* and *Buliminoides williamsoniana* occur in low abundances but because of their high fidelity have moderately high association scores. *Textularia ensis, Rosalina irregularis, Hanzawaia bertheloti, Gavelinopsis hamatus*, and *Evolvocassidulina orientalis* all have their highest abundances (means 2.5–4.1%) and association scores in this association.

DISCUSSION

Recent foraminiferal faunas dominated by *Cassidulina* and *Globocassidulina* species have not been recorded previously from shelf depths around New Zealand. This association is probably a variant of "thanatotope 2" of Thompson (1975) which is dominated by *Bulimina submarginata* and occurs in fine to medium sand at 25–60 m depth in the outer Hauraki Gulf. Similar faunas dominated by *Bulimina submarginata* are present in fine sand at 40–80 m depth off the east coast of Great Barrier Island (pers. obs.).

Species diversity (Table 9, Fig. 11a, b)

The shallowest subassociation (A1) has the lowest species diversity α of benthic foraminifera in the study area and also the lowest values for Information Function (H) and Evenness (E), resulting primarily from the high dominance and abundance of *Elphidium charlottensis* (Fig. 8). Association C, restricted to current-swept channels, has the second lowest values for α, H, and E, resulting from the abundance of *Planoglabratella opercularis* and *Pileolina harmeri*. Among the remaining associations, there is a gradual increase in diversity and evenness (α, H, and E values) from A2

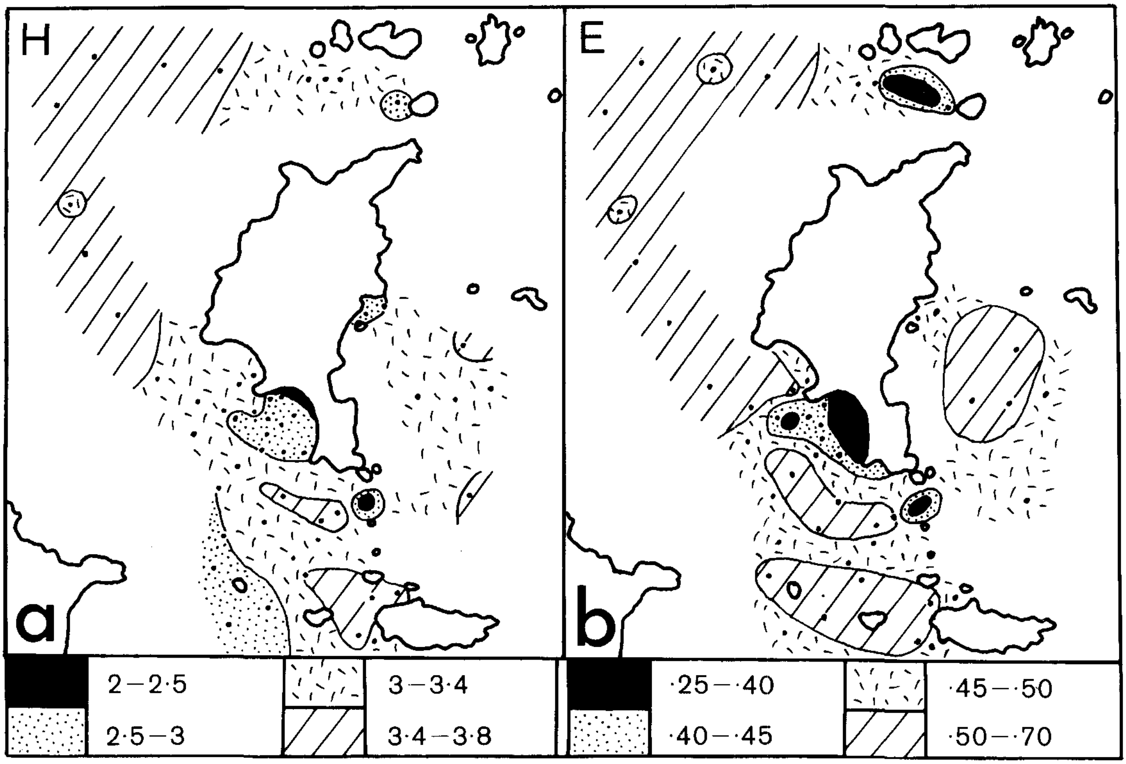


Fig. 11 Maps of the Cavalli Islands area showing: (a) the distribution of Information Function (H) values; (b) the distribution of Evenness (E) values.

Table 9 Mean and range of values for species diversity (Fisher α index), information function (H), and Evenness (E) for the foraminiferal associations recognised around the Cavalli Islands.

	α		H		E	
Association	range	mean	range	mean	range	mean
A1	6.5–12	9.5	2.00–2.71	2.35	0.25–0.39	0.33
A2	13–18	15.5	2.74–3.16	2.97	0.35–0.48	0.43
B1	12–19	15	2.92–3.33	3.09	0.45–0.53	0.49
B2	15–34	21	3.02–3.80	3.42	0.35–0.66	0.55
B3	9–28	18	2.85–3.51	3.20	0.45–0.57	0.50
C	10–13	11.5	2.36–2.85	2.61	0.31–0.41	0.36
D	18–25	22	3.23–3.71	3.50	0.49–0.63	0.56

through B1, B3, and B2 to the deepest association, D, which has the largest mean diversity and evenness.

Around the Cavalli Islands, therefore, there is a general trend of increasing diversity with increasing depth. Similar trends have been recorded elsewhere, but usually over much larger depth ranges. In many parts of the world, there is an observed increasing diversity from shallow depths, moving across the shelf to a maximum around the shelf break or in the upper bathyal at depths of 200–800 m (e.g., Gibson & Buzas 1973; Murray 1973; Hoskins 1978).

The mean values of α, H, and E in Associations B2 and D around the Cavallis are much higher than normally found at inner shelf depths, and are of a similar magnitude to those observed elsewhere in the world at shelf break and upper bathyal depths (e.g., Gibson & Buzas 1973; Hoskins 1978). Species diversity values (α = 28, 34) in several stations around the Cavalli Islands (Table 9) are among the highest recorded anywhere for benthic foraminifera

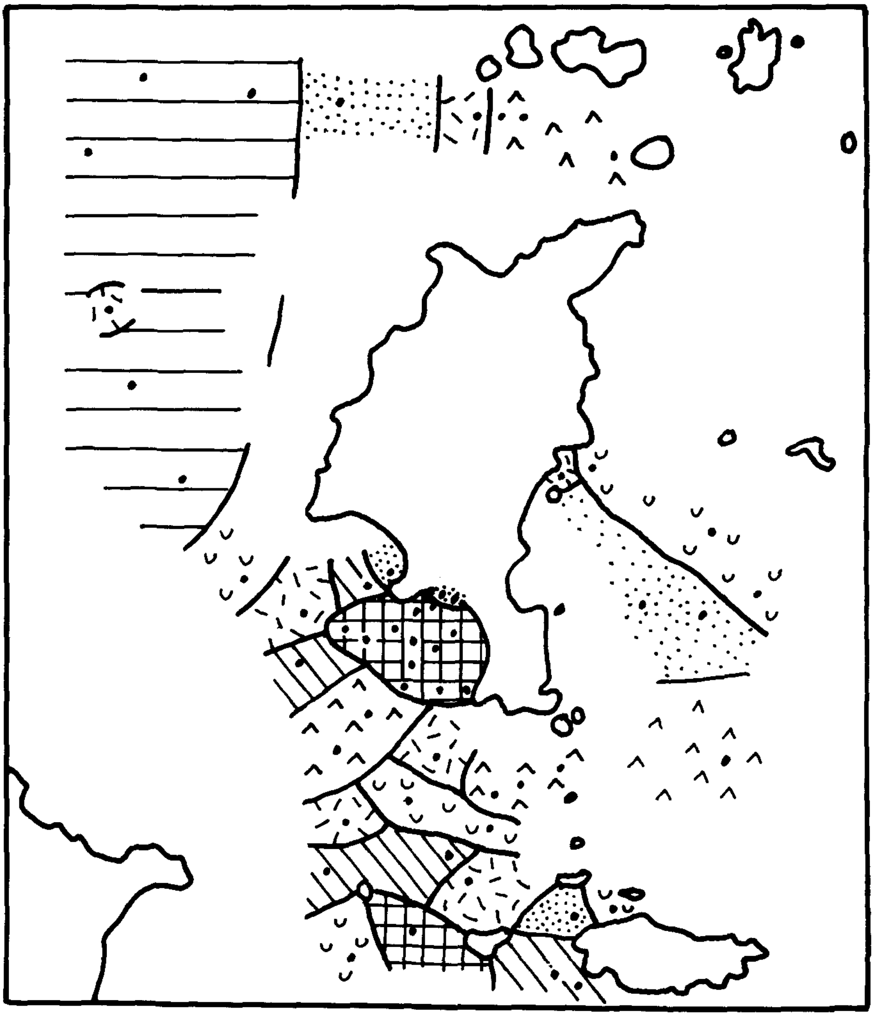


Fig. 12 Distribution of 7 groups produced by non-hierarchical classification of presence/absence scores for all taxa in 'live' census data.

and certainly from such shallow depths. Since these calculations are based on total faunal data and not just live, the high diversity values may be partly a result of postmortem transport and mixing. They possibly also reflect, however, the generally higher faunal diversity of groups in the Indo-pacific region (Stehli & Wells 1971) and the location of the study in the area with the greatest foraminiferal faunal diversity around New Zealand (pers. obs.). The Cavallis lie on the fringe of the southward-moving, warm East Auckland Current (Brodie 1960), which brings to this part of New Zealand shallow water, subtropical and tropical organisms, many of which including foraminifera, do not occur further south (Ayling 1971; Russell 1971; Hayward 1980). In addition, the majority of shallow-water, benthic foraminifera of the temperate zone that occur to the south around the rest of New Zealand are also present off eastern Northland. This unusually high diversity of foraminifera appears to be paralleled in other groups, such as the ostracoda, for Hornibrook (1952b) obtained one of the highest diversities of ostracods ever recorded in a sample off North Cape.

'Live' foraminiferal fauna

Many previous workers (e.g., Martin & Steinker 1977) have expressed concern about the accuracy of Rose Bengal and other stains in determining the presence of protoplasm and thereby identifying live foraminifera. I, too, have serious doubts about the validity of some of the Cavalli 'live' data. The detection of staining in any *Quinqueloculina* is problematical and scores for these are probably too low. Almost every specimen of some trochospiral, agglutinated taxa stained very strongly, and although they were counted as 'live', this determination must be considered doubtful in most instances.

STANDING CROP

Standing crop is a measure of density of live foraminifera and is usually calculated as the number of live individuals (stained red with Rose Bengal) present in the sediments of 10 cm^2 of sea floor. Standing crop in the Cavalli samples ranges from 1.8–57 (in the upper 6 cm of sediment). These values are lower than the average values (50–200) for shelf and marginal marine environments elsewhere in the world (Murray 1973). There is no obvious pattern in the distribution of standing crop values in the Cavalli area. Values do not appear to correlate with the benthic foraminiferal associations, the substrate type or any other variable. The density of live foraminifera appears to be patchy and random. For example the 4 samples in Subassociation A1, all within an area of 200 × 50 m, have standing crops of 19, 53, 17, and 47.

COMPARISON OF 'LIVE' AND TOTAL FAUNAL ASSOCIATIONS

The 'live' data correspond to species densities and vary greatly between samples (e.g., 3 individuals in 2 species to 95 individuals in 38 species). Computer classification techniques applied to this data are greatly affected by the foraminiferal densities, as well as taxonomic composition, although the effect was reduced by standardising the data as proportions of sample totals. Non-hierarchical classification of the 'live' data, using full census counts and presence/absence scores, produced 7 groupings that are mappable in part (Fig. 12) and comparable to the associations recognised from the total (dead + live) data (Fig. 7). The classification produced using presence/absence scores of 'live' taxa is more easily mapped (Fig. 12) than that produced using full census data.

In the 'live', presence/absence classification there is a group of deep-water stations, northwest of Motukawanui (Fig. 12), corresponding in part to Association D (Fig. 7), and a group of sheltered, shallow stations, southwest of Motukawanui, corresponding exactly to Association A. There is also a group of stations located in the narrow, current-swept channels, north and south of Motukawanui, which corresponds with Association C plus many of the stations intermediate in character between B1 and C. The remaining stations (corresponding to most of B) show a haphazard distribution of groupings.

The 'live' foraminifera in Association A stations closely parallel the total faunas, with *Elphidium charlottensis* the single dominant taxon in both. The secondary characterising species of A1, *Elphidium oceanicum*, is also the secondary dominant in the 'live' fauna and *Virgulopsis turris* has the highest fidelity value in both 'live' and total faunas. As with the total fauna, *E. oceanicum* is less abundant in 'live' A2 stations but still has a high fidelity value. *Elphidium simplex*, the third characterising species of A2, is not as abundant in the 'live' fauna as the total.

The 2 characterising species of Association B (*Pileolina zealandica, Cibicides marlboroughensis*) are the first and third most abundant taxa in the 'live' fauna of this association. The 3 characterising species of B1 (*Discorbis dimidiatus, Elphidium novozealandica, Pileolina zealandica*) are the fourth, first, and third most abundant respectively in the 'live' fauna of these stations. The 3 characterising species of B2 (*Pileolina zealandica, Cibicides marlboroughensis, Neoconorbina pacifica*) are the third, fourth, and first most abundant respectively in the 'live' fauna. The 3 characterising species of B3 (*Cibicides marlboroughensis, Quinqueloculina seminula, Notorotalia olsoni*) are the third, sixth, and eighth most abundant taxa in the 'live' fauna but all occur in their greatest 'live' abundances in this subassociation.

In Association C, the 3 characterising species (*Planoglabratella opercularis, Pileolina harmeri, Neoconorbina pacifica*) are the first, third, and fourth most abundant taxa in the 'live' fauna. *Buliminoides williamsoniana*, which has a high fidelity value in Association C total fauna, is more abundant in the 'live' fauna, being the dominant 'live' species in Station 1. 2 of the characterising species of Association D (*Cassidulina carinata, Globocassidulina canalisuturata*) are the most abundant taxa in both total and 'live' faunas. The third characterising species (*Bulimina submarginata*) has very high fidelity values in both faunas. Many of the taxa with low abundances but high fidelity values in the total fauna of D (e.g., *Bolivina cacozela, Hanzawaia bertheloti, Evolvocassidulina orientalis, Loxostomum karrerianum, Bolivina subexcavata*) also occur in small numbers in the 'live' fauna and have high fidelity values.

The observed differences between the total and 'live' data probably result from small-scale patchiness of live foraminiferal faunas, similar to that observed elsewhere (Boltovskoy & Wright 1976 p. 125), and possibly resulting from clumping of offspring during assexual reproduction. Differences may be caused also by seasonal changes in 'live' foraminiferal faunas (Boltovskoy & Wright 1976 p. 33).

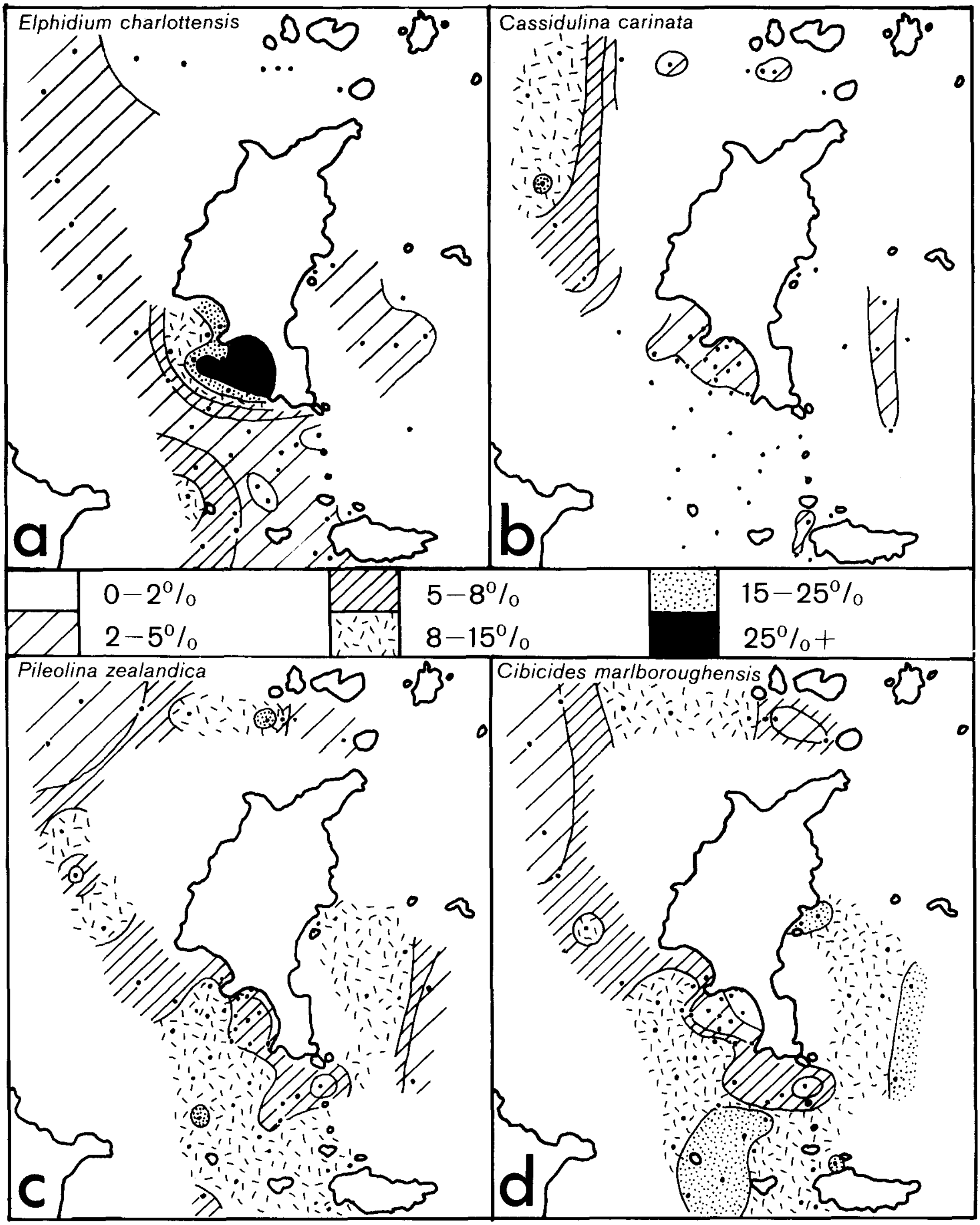


Fig. 13 Maps of the Cavalli Islands area showing distribution and abundance of: (a) *Elphidium charlottensis*; (b) *Cassidulina carinata*; (c) *Pileolina zealandica*; (d) *Cibicides marlboroughensis*.

GENERAL DISCUSSION

Are the associations real?

Do the groupings adopted here represent discrete faunal associations or are they artificially applied to a gradationally changing overall fauna? To answer this, one must look at the nature of the boundaries between associations, especially in areas of greatest sample density, such as southwest of Motukawanui, and also at the distribution of the characterising species.

Association A appears to be a discrete, mappable grouping with fairly sharply defined boundaries. In all the groupings (2–8) generated by non-hierarchical classification (e.g., Fig. 4a, b) based on full census data, this association remained as a coherent unit, although it was subdivided internally when 5 or more groupings were created. In these groupings only 1 station (29) was occasionally lost to the adjacent Association B, and its location lies on the boundary between the 2 (Fig. 7). The tight clustering of stations into Association A relies heavily on the dominance of *Elphidium charlottensis*, which drops off rapidly in abundance outside the mapped area of this association (Fig. 13a). Within A the fauna changes gradationally from the shallowest samples characterised by abundant *Elphidium oceanicum* (Fig. 14a) and the rare *Virgulopsis turris*, with its high fidelity, to faunas further offshore containing increasing proportions of taxa that characterise the adjacent association B.

Association D, confined to deep water, also appears to be a fairly discrete mappable association, judging from the faithful clustering together of all its 4 stations in all the non-hierarchical classification groupings produced. The boundary between B and D appears fairly distinct and its 2 most abundant, characterising species (*Cassidulina carinata, Globocassidulina canalisuturata*) rapidly decrease in abundance upslope away from Association D (Fig. 13b and 14b).

Associations A and D are also discrete clusters on the minimum-spanning-tree representation (Fig. 3) and principal component plot (Fig. 2), although D requires the third dimension to separate it from Association B.

The boundaries between Associations B and A and B and D are fairly sharp, but that between B and C is gradational. Association C, characterised by abundant *Planoglabratella opercularis* (Fig. 14d) and *Pileolina harmeri*, is considerably different from the majority of Association B, characterised by *Pileolina zealandica* (Fig. 13c) and *Cibicides marlboroughensis* (Fig. 13d). The boundary delineating the 2 associations is not sharp and many of the computer groupings placed combinations of the stations adjacent to the boundary (3, 4, 40, 41) in Association C, together with the 2 'core' stations, 1 and 42 (Fig. 4a–d). The fauna within Association B is quite variable, and mappable gradations occur. The groupings produced by non-hierarchical classification and other computer methods showed no consistent subdivision of Association B and the subassociations recognised here are certainly not discrete faunal assemblages.

The 2 well-defined, discrete associations (A, D) occur in the 2 least-exposed areas in the study area, and it is quite likely that the strong wave energy and currents that affect the areas of B and C result in more post-mortem mixing of the faunas, thereby obscuring the discrete nature of C and possibly any good subassociations within B. The 'live' fauna classification tends to confirm this (Fig. 12).

It would appear therefore that A, B, C, and D are discrete faunal associations, in that they have various preferred frequencies of many of the dominant taxa. They are not particularly discrete however in terms of overall taxonomic composition, in that they have many taxa in common. It would also appear that within A and B there are significant, mappable, gradational changes in the faunas that can be arbitrarily subdivided into recognisable subassociations.

Factors affecting the distribution of associations

An assessment of the factors that might be responsible for the observed pattern of foraminiferal distribution is highly speculative. The location of this study in a confined area with a relatively small depth range and offshore away from the effects of freshwater runoff, eliminates most variation within many of the physical and chemical factors (e.g., salinity, pH, water chemistry) that could affect foraminiferal distribution.

Foraminiferal associations (Fig. 7) correlate fairly well with the distribution of sediments (Fig. 15) but not so exactly as to indicate that substrate is the prime factor responsible for foraminiferal distribution. It appears more likely that the degree of exposure to current and wave energy is the main factor influencing the distribution both of foraminifera and of sediments.

In the study area strong currents sweep across the shallows in the Cavalli Passage (between the islands and the mainland) and also pour through the narrow channels between the individual islands. Thus those areas that are most strongly current-swept are in the narrow channels and shallow shelf areas (less than 10 m deep), north and south of Motukawanui (mostly coarse shelly sand and gravel, Associations B and C). The areas least affected by currents are the shallow bays (mostly fine sand, Association A) and deeper areas (mostly fine sand, Association D).

In the study area, the largest swells come from the east and northeast, and in storms probably affect

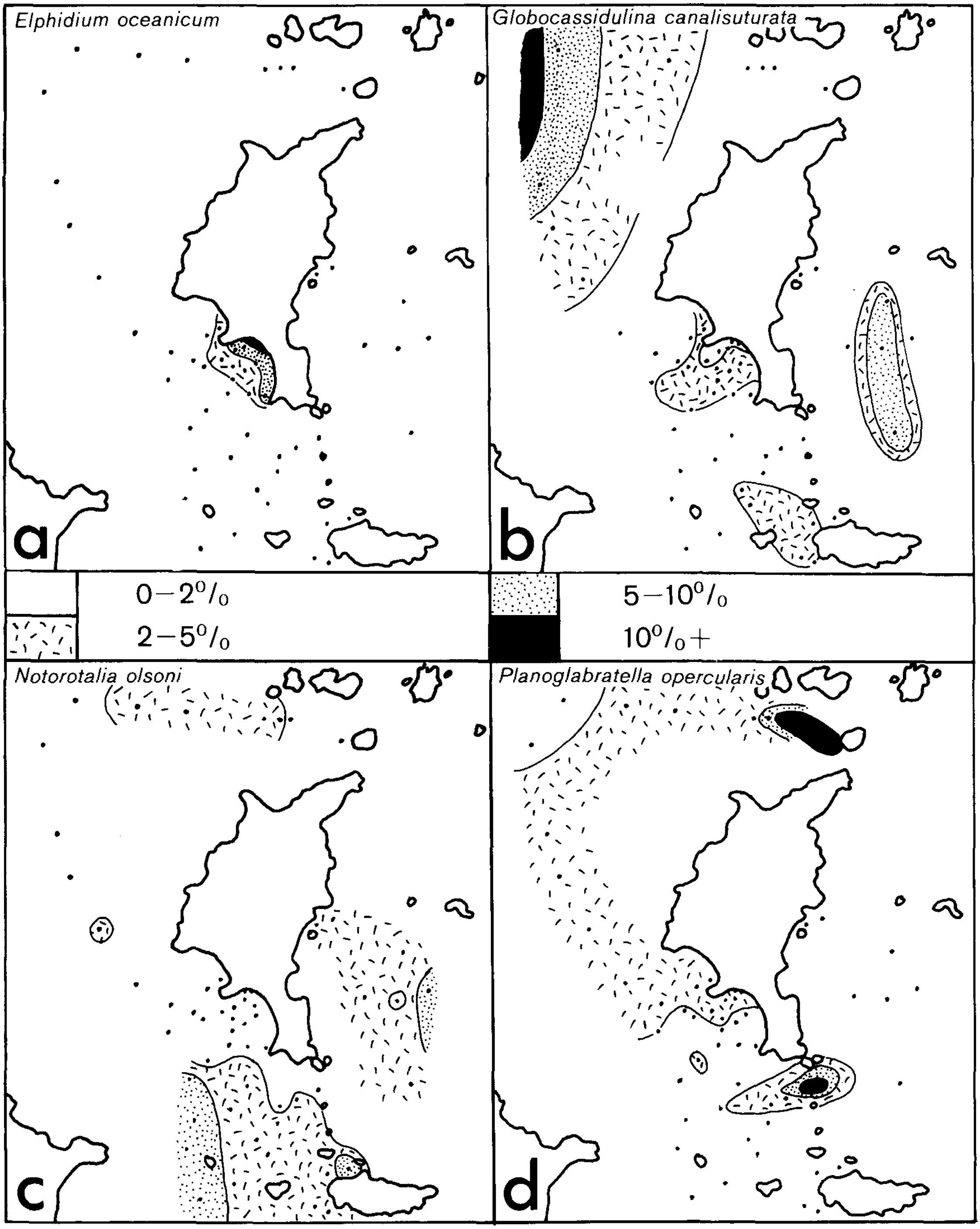


Fig. 14 Maps of the Cavalli Islands area showing distribution and abundance of: (a) *Elphidium oceanicum*; (b) *Globocassidulina canalisuturata*; (c) *Notorotalia olsoni*; (d) *Planoglabratella opercularis*.

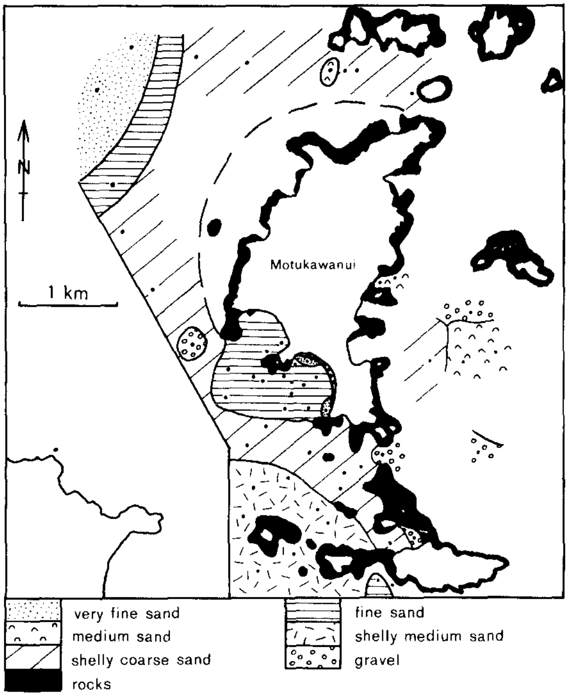


Fig. 15 Distribution of sediment types around the Cavalli Islands.

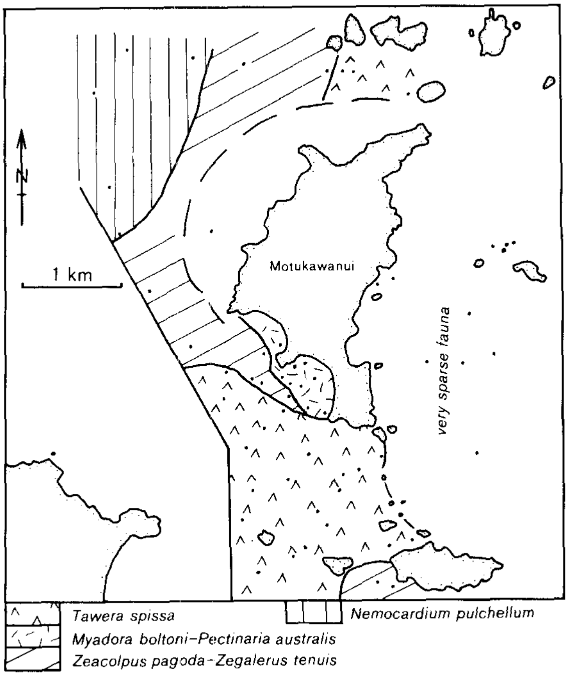


Fig. 16 Distribution of benthic macrofaunal communities around the Cavalli Islands (Grace & Hayward 1980).

bottom sediments at depths in excess of 40 m. Thus those areas most exposed to wave energy lie off the east coast of Motukawanui (mostly clean medium to coarse sand, Association B) and in the entrances to narrow channels to the north and south (coarse sediment, Association C). Less severe swells from the north funnel down the Cavalli Passage, but even in storms are unlikely to greatly affect bottom sediments over 30 m deep. A triangular area of fine to very fine sand off the southwest coast of Motukawanui (Fig. 15) is sheltered from these northerly swells and also the easterly swells that pass through the narrow channel to the south. It is to this sheltered triangle that Association A is restricted.

To summarise, Association C occurs in clean, unstable, coarse sediments in narrow channels exposed to the strongest currents and greatest wave attack. Association B (especially B1 and B2) also occurs in areas of strong wave and current energy with clean, fairly unstable, medium to coarse sand or gravel substrates. Associations A and D occur primarily in fine to very fine, sometimes slightly muddy, sand, in areas most sheltered from strong currents and large waves.

Other factors (such as light intensity, temperature, food resources, and hydrostatic pressure) that may vary rapidly with depth possibly also play a part in determining foraminiferal distribution, especially as Associations A and D both appear to inhabit sheltered areas with similar fine substrates.

Comparison with macrofaunal associations (Fig. 16)

4 major macrofaunal associations were recognised in the area by Grace & Hayward (1980). Live macrofaunal material was very sparse and sometimes absent from stations east of Motukawanui, and these were excluded from the analysis.

There is a remarkably high correlation between macrofaunal and foraminiferal associations — *Myadora boltoni–Pectinaria australis* and Association A, *Nemocardium pulchellum* and Association D, and *Tawera spissa* and Associations B and C.

A separable macrofaunal association (comparable to C) was not recognised in the current-swept channels. The area covered by the foraminiferal Association B was divided into 2 distinct macrofaunal associations (Fig. 16) — *Tawera spissa* and *Zeacolpus pagoda–Zegalerus tenuis*. The *Zeacolpus–Zegalerus* association is considered to be a fringe variant of the *Tawera spissa* association and its distribution overlaps the boundary between the foraminiferal Associations A and B.

Overseas comparisons

There have been few if any studies elsewhere in warm temperate to subtropical regions with a similar range of sheltered to exposed environments in open marine conditions, with which to compare the Cavalli faunas.

Comparisons at the species level are almost impossible because of the proliferation of taxonomic names that are applied locally in various parts of the world without rigorous, monographic studies of the different genera. A few of the Cavalli's species are recognised consistently world-wide (e.g., *Hanzawaia bertheloti, Quinqueloculina seminula, Miliolinella subrotundata, Rosalina bradyi, Planoglabratella opercularis*) and several others are known to be endemic to the New Zealand or Australasian regions (e.g., *Notorotalia depressa, N. olsoni, Pileolina harmeri*), but the cosmopolitan or endemic character of the majority is indeterminable at present (e.g., *Bulimina submarginata, Elphidium* spp., *Cibicides marlboroughensis, Pileolina zealandica, Globocassidulina canalisuturata*).

At the generic level, the Cavalli faunas are similar to warm temperate or subtropical, inner shelf faunas elsewhere. These are generally dominated by a combination of *Elphidium, Ammonia, Quinqueloculina, Discorbis, Buliminella,* and *Buccella* (Boltovskoy & Wright 1976).

Faunas of beaches and adjacent shallow water, in both exposed and protected situations in many parts of the world, generally have 1 or more species of *Elphidium* among the 5 or so dominant taxa (Murray 1973). Only rarely (e.g., Puerto Deseado Beach, Argentina — Boltovskoy 1963) has *Elphidium* been recorded as the single dominant, as in the Cavallis' Association A.

Some of the dominant genera in Association B (e.g., *Cibicides, Quinqueloculina, Neoconorbina, Discorbis,* and *Rosalina*) are commonly among the codominants of faunas in exposed or partly exposed, near-shore sediments (0–20 m depth) in other parts of the world, e.g., northeast coast, North America (Todd & Low 1961), southern California (McGlasson 1959; Uchio 1960), Bay of Bengal (Vedantam & Subba Rao 1970), and New South Wales (Albani & Johnson 1976). However, other genera, abundant overseas in coarse nearshore sediments (e.g., *Ammonia, Bolivina, Miliolinella, Nonionella*), are uncommon at the Cavallis but frequent around many other parts of New Zealand, for reasons unknown. Glabratellid genera (e.g., *Pileolina, Planoglabratella*), among the dominants of Associations B and C at the Cavallis, seldom figure predominantly in faunas described elsewhere, possibly because few studies have looked at similar coarse sediments in current-swept environments.

The characteristic genera (e.g., *Cassidulina, Bulimina, Globocassidulina*) of Association D, in the deeper, usually finer-grained localities around the Cavallis, are often among the suite of dominants in overseas faunas in muds and fine sands at mid to outer shelf depths (40–200 m). Other genera (e.g., *Bolivina, Hanzawaia, Nonionella, Siphouvigerina*) co-dominant in these overseas faunas (e.g., McGlasson 1959; Frerichs 1970, Vendantam & Gubba Rao 1970), are only minor constituents of Association D.

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REFERENCES

Adams, A. G. 1979: Recent foraminifera and sediments of Rangaunu Harbour and inner Rangaunu Bay, Northland. Unpublished M.Sc. thesis, University of Auckland.

Albani, A. D.; Johnson, K. R. 1976: Resolution of foraminiferal biotopes in Broken Bay, New South Wales. *Journal of the Geological Society of Australia 22* : 435 – 446.

Alvey, N. G. et al. 1977: GENSTAT. A general statistical program. Statistics Department, Rothamsted Experimental Station, UK.

Ayling, A. M. 1971: Unpublished submissions of the Environmental Defence Society Inc. for a Declaration of a Marine Reserve at the Poor Knights Islands.

Boltovskoy, E. 1963: The littoral foraminiferal biocoenoses of Puerto Deseado (Patagonia, Argentina). *Contributions to the Cushman Foundation for Foraminiferal Research 14* : 58 – 70.

Boltovskoy, E.; Wright, R. 1976: Recent foraminifera. The Hague, Dr W. Junk.

Brodie, J. W. 1960: Coastal surface currents around New Zealand. *New Zealand journal of geology and geophysics 3* : 235 – 252.

Brook, F.; Grace, R. V.; Hayward, B. W. 1981: Soft-bottom benthic faunal associations of Tutukaka Harbour, Northland, New Zealand. *Tane 27* :69 – 92.

Buzas, M. A.; Gibson, T. G. 1969: Species diversity: benthonic foraminifera in western North Atlantic. *Science 163* : 72 – 75.

Frerichs, W. E. 1970: Distribution and ecology of benthic foraminifera in sediments of the Andaman Sea. *Contributions to the Cushman Foundation for Foraminiferal Research 21* : 123 – 147.

Gibson, T. G.; Buzas, M. A. 1973: Species diversity: Patterns in modern and Miocene foraminifera of the eastern margin of North America. *Geological Society of America, bulletin 84* : 217 – 238.

Grace, R. V.; Hayward, B. W. 1980: Macrobenthos of the Cavalli Islands, northern New Zealand. *Tane 26* : 189 – 209.

Grace, R. V.; Whitten, R. 1974: Benthic communities west of Slipper Island, north-eastern New Zealand. *Tane 20* : 5 – 20.

Gregory, M. R. 1973: Benthonic foraminifera from a mangrove swamp, Whangaparapara, Great Barrier Island. *Tane 19* : 193 – 204.

Hayward, B. W. 1979: Planktic foraminifera in surface sediments around the Cavalli Islands, northern New Zealand. *Tane 25* : 149 – 155.

——— 1980: New records of warm-water foraminifera from north-eastern New Zealand. *Tane 26* : 183 – 188.

——— 1981: Foraminifera in nearshore sediments of the eastern Bay of Islands, northern New Zealand. *Tane 27* : 123–134.

Hayward, B. W.; Grace, R. V. 1981: Soft-bottom macrofauna and foraminiferal microfauna off Cuvier Island, northeast New Zealand. *Tane 27* : 43 – 54.

Hedley, R. H.; Hurdle, C. M.; Burdett, I. D. J. 1967: The marine fauna of New Zealand: intertidal foraminifera of *Corallina officinalis* zone. *New Zealand Oceanographic Institute memoir No. 38.*

Hill, M. O. 1973: Diversity and evenness: a unifying rotation and its consquences. *Ecology 54* : 427 – 432.

Hornibrook, N.deB. 1952a: Appendix: faunal list; east oyster bed. Foraminifera *In:* Fleming, C. A.; A Foveaux Strait oyster bed. *New Zealand journal of science and technology 34B* : 82.

——— 1952b: Tertiary and Recent marine Ostracoda of New Zealand. *New Zealand Geological Survey paleontological bulletin 18.*

Hoskins, R. H. 1978: New Zealand middle Miocene foraminifera: The Waiauan Stage. Unpublished PhD thesis, University of Exeter.

Hulme, S. G. 1964: Recent foraminifera from Manukau Harbour, Auckland, New Zealand. *New Zealand journal of science 7* : 305 – 340.

Kustanowich, S. 1964: Foraminifera of Milford Sound. *In:* Skerman, T. M. *ed.* Studies of a southern fiord. *New Zealand Department of Scientific and Industrial Research bulletin 157* : 49 – 63.

Lewis, K. B. 1979: Foraminifera on the continental shelf and slope off southern Hawke's Bay, New Zealand. *New Zealand Oceanographic Institute memoir 84.*

Macarthur, R. H.; Macarthur, J. W. 1961: On bird species diversity. *Ecology 42* : 594 – 598.

McGlasson, R. H. 1959: Foraminiferal biofacies around Santa Catalina Island, California. *Micropaleontology 5* : 217 – 240.

Martin, R. E.; Steinker, D. C. 1973: Evaluation of techniques for recognition of living foraminifera. *Compass, sigma gamma epsilon 50* : 26 – 30.

Murray, J. W. 1973: Distribution and ecology of living benthic foraminiferids. London, Heinemann Educational Books.

Russell, B. C. 1971: A preliminary annotated checklist of fishes of the Poor Knights Islands. *Tane 17* : 81 – 90.

Stehli, F. G.; Wells, J. W. 1971: Diversity and age patterns in hermatypic corals. *Systematic zoology 20* : 115 – 126.

Thompson, I. C. 1975: Recent foraminifera and superficial sediments of an area of the continental shelf and upper slope east of the North Island, New Zealand. Unpublished MSc thesis, University of Auckland.

Todd, R.; Low, D. 1961: Nearshore foraminifera of Martha's Vineyard Island, Massachusetts. *Contributions to the Cushman Foundation for Foraminiferal Research 12* : 5 – 21.

Topping, R. M. 1973: Benthonic foraminifera from Puhoi Estuary, Auckland, New Zealand. Unpublished BSc (Hons) thesis, University of Auckland.

Uchio, T. 1960: Ecology of living benthonic foraminifera from the San Diego, California, Area. *Cushman Foundation for Foraminiferal Research, special publication 5.*

Vedantam, D.; Subba Rao, M. 1970: Recent foraminifera from off Pentakota, east coast of India. *Micropaleontology 16* : 325 – 344.

Vella, P. 1957: Studies in New Zealand foraminifera. *New Zealand Geological Survey paleontological bulletin 28.*