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Bruce W. Hayward , Chris J. Hollis & Hugh Grenell

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Foraminiferal associations in Port Pegasus, Stewart Island, New Zealand

BRUCE W. HAYWARD
CHRIS J. HOLLIS*
HUGH GRENFELL
Auckland Institute and Museum
Private Bag 92018
Auckland, New Zealand

*Present address: Department of Geology, Utsunomiya University, Utsunomiya 321, Japan

Abstract Census data on benthic foraminiferal tests in 56 seafloor sediment samples (high tide to 45 m depth; slightly brackish to normal marine) in Port Pegasus, south-east Stewart Island, are analysed by cluster analysis. The faunal samples are grouped into six associations: A. *Trifarina angulosa/Textularia proxispira/Miliolinella subrotundata*—current-swept passages and adjacent port; B. *Notorotalia finlayi/Quinqueloculina delicatula/Nonionella flemingi*—muddy fine sand at 22–30 m; C. *Notorotalia zelandica/Elphidium novozealandicum*—sheltered bays at 2.5–26 m; D. *Rosalina bradyi*—shallow subtidal amongst rocky reefs; E. *Ammonia beccarii/Elphidium advenum depressulum/Haynesina depressula*—0.5–6 m, sheltered bays and channels of Cooks Arm; F. *Miliammina fusca*—brackish, intertidal. In the entrance passages and exposed shelf (5–45 m depth) planktics comprise 15–30% of the total foraminiferal tests. Directly inside the passages in Port Pegasus, planktics comprise 30–65% of the fauna. These are dominated by small species that have been swept inshore by the predominant onshore swells and winds and carried into the port by strong tidal currents before settling out of suspension. The small, calcareous tests of benthic *Cassidulina carinata* and *Trifarina angulosa* also have distribution patterns consistent with some current transport into Port Pegasus.

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Keywords Foraminifera; benthic foraminiferal associations; planktic foraminiferal abundances; ecological distribution; post-mortem transport of tests; Port Pegasus; Stewart Island; New Zealand; cluster analysis; association acores

INTRODUCTION

Knowledge of the ecological distribution of shallow-water benthic foraminifera (Protista, Protozoa) has application in both modern and fossil environmental studies. Shallow-water coastal environments are the most polluted marine habitats. Foraminiferal studies provide the potential for a quick, cost-effective method of assessing the impact of pollution on the biota, for monitoring change, and for comparing the modern fauna with that in the unpolluted recent past. Study of foraminiferal distribution patterns also provides an efficient method of investigating water circulation patterns in estuaries, enclosed harbours and bays, and the interplay between the sea and freshwater inflow.

An understanding of modern foraminiferal patterns can be used in interpreting fossil foraminiferal faunas and allow us to make relatively accurate assessments of paleodepth, paleosalinity, and paleoenvironments useful in paleogeographic reconstruction. Fossil shallow-water benthic foraminiferal faunas are of special relevance to modern methods of determining rates of Quaternary uplift, changes in sea levels and climate, and in the study and quantification of Cenozoic cyclothems, sequence stratigraphy and geohistory analysis.

Previous detailed studies of the ecological distribution patterns of shallow-water benthic foraminiferal associations around New Zealand have all been around the coast of the North Island (e.g., Hayward 1982; Hayward et al. 1984; Hayward & Triggs in press). This is the first detailed foraminiferal study of a southern New Zealand coastal situation.

This paper describes the benthic foraminiferal associations in 56 surface sediment samples from

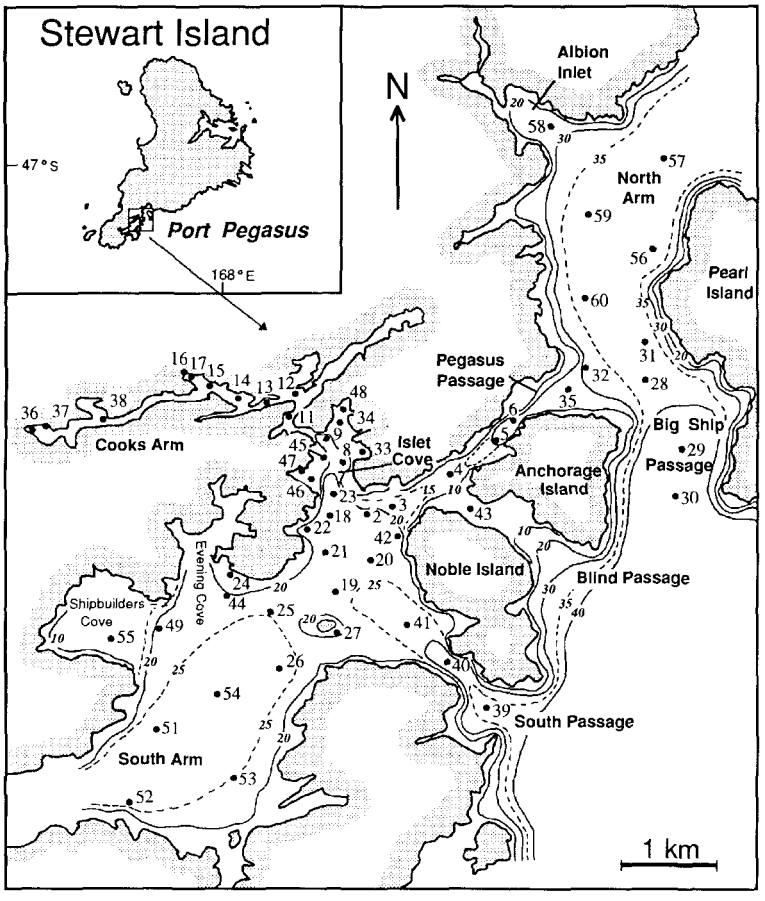

Fig. 1 Foraminiferal sediment sample locations and depth contours in Port Pegasus, southeast Stewart Island, New Zealand.

Port Pegasus (Fig. 1, Appendix 1). The samples come from a broad range of shallow and inner shelf environments (high tide to 45 m depth) extending from the limits of brackish influence in Cooks Arm (Stn 16) through to normal salinity and exposure to the full force of the Subantarctic Ocean at the entrance to Port Pegasus (Stn 30).

Port Pegasus is the southernmost enclosed harbour on Stewart Island (47°10′S, 167°40′E), New Zealand (Fig. 1). This southern part of Stewart Island is uninhabited and the Port Pegasus catchment is largely unmodified native forest, subalpine scrub, and grassland. The elongate harbour (c. 12 by 2 km) is enclosed by several peninsulas and islands, and is divided into two arms (North and South) connected by the narrow, 10–20 m deep Pegasus Passage. The main basin of North Arm (35–40 m deep) is slightly deeper than the main basin of South Arm (25–30 m). Both arms have shallower embayments around their fringes (e.g., Shipbuilders, Evening, and Islet Coves) with rocky shorelines interspersed with small sandy beaches. Several long, winding, narrow inlets snake their way for several km into the hills surrounding Port Pegasus. The most prominent of these is the 5 km long Cooks Arm. It is a narrow, shallow (1.5–3 m deep) channel, swept by strong tidal currents for the seaward 2 km of its length. The upper 3 km is less current-swept, and is mostly fine sand tidal flats and marginal salt marsh with freshwater input from several small streams.

Sediments

Grain size terminology follows Folk (1968). Sediment types at dredge stations are listed in Appendix 1, and their distribution is shown in Fig. 2.

Most of the Port Pegasus sea floor is covered by fine sand or muddy fine sand. The central port

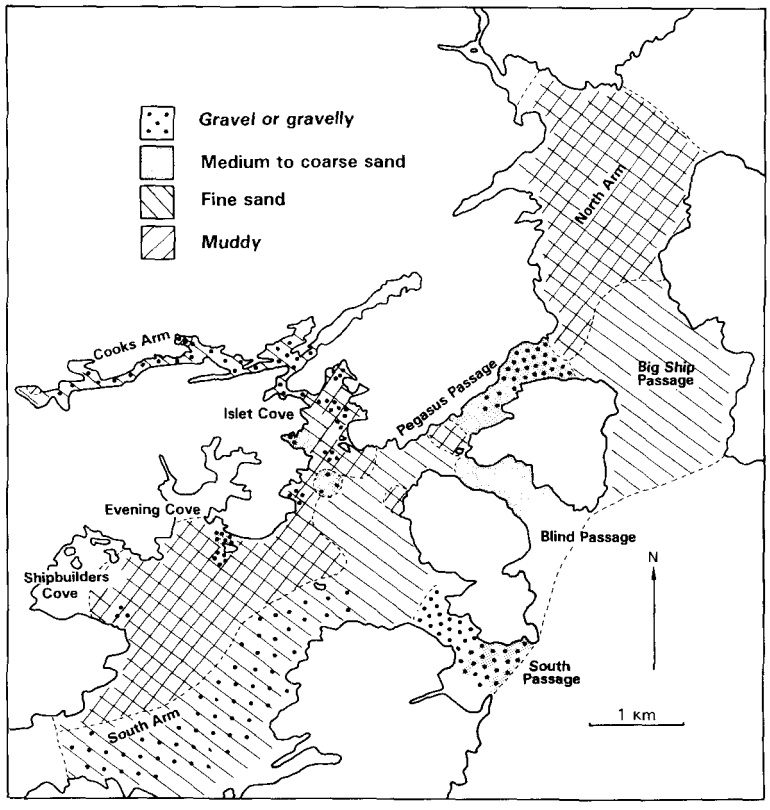

Fig. 2 Simplified sediment distribution map of Port Pegasus study area (based on grain size analysis of present samples).

area and Big Ship Passage is covered with medium to fine sand whereas the landward halves of South Arm and North Arm are mostly covered with muddy fine sand (> 10% mud). Areas of shelly fine sand occur in the seaward half of South Arm. In Cooks Arm pebbly and shelly/pebbly fine sand is present. Sand or shelly/pebbly coarse sand covers the middle of Pegasus Passage and the shallows of Blind Passage. The coarsest sediments are shell/pebble gravel and sandy, shell/pebble gravel in South Passage and in the northern part of Pegasus Passage at water depths of 25–40 m. The Islet Cove area has a wide variety of sediment types ranging from sand and gravelly muddy sand to sandy mud.

METHODS

Field

Samples were collected (by BWH) using a small, 2-litre capacity bucket dredge, hand-hauled from a 4 m aluminium dinghy powered by a 5 h.p. outboard motor or by oars. The sea floor sediment was sampled to a depth of 50–100 mm, in January and February 1989.

Laboratory

Grain size analysis of each sample was by dry sieving (Folk 1968). The mud fraction (< 0.06 mm) was washed away and foraminifera concentrated by floatation with carbon tetrachloride. The dried float from each sample was divided using a microsplitter until the quantity of material left contained approximately 100 benthic foraminifera which were then picked, mounted, identified, and counted. Planktic foraminifera were also picked and counted. The remaining unpicked float from a range of samples was subsequently scanned and specimens of any additional rarer taxa were picked to give a more complete species list (Appendix 2).

In previous studies we have found that picking just 100 benthic foraminifera provides a sufficiently accurate assessment of faunal composition for use in identifying and mapping associations.

All faunas are deposited in the Micropaleontology Section of the Institute for Geological

and Nuclear Sciences (Samples F202271–202329). Figured specimens (Fig. 3, 4) have catalogue numbers prefixed by FP.

Statistical

The data consist of counts of 144 species in 56 samples and is available on request from BWH. The data matrix was standardised by converting counts to proportions of sample totals. Unweighted pair group cluster analysis using arithmetic averages of a Bray-Curtis distance matrix was used to produce a dendrogram classification (Fig. 5) from which sample associations were selected. Similar cluster analysis of a distance matrix produced using Horn's (1966) modified version of Morista's (1959) index for proportions was used to produce a dendrogram classification of abundant species (> 5% in any sample) from which species associations were selected (Fig. 6). Mathematical definitions of the Bray-Curtis and modified Morista coefficients are given in Sneath & Sokal (1973) and Rohlf (1989). The modified Morista index downweights the more abundant species and produces a more realistic clustering of species that commonly occur together. Cluster analyses were computed using the "NTSYS" statistical package (Rohlf 1989).

Association scores

To determine which species characterise each of the six faunal associations, the 144 taxa were ranked for each association using a value (association score) calculated to reflect their importance, based on a combination of five criteria (modified after McCloskey 1970; Grange 1979; and Hayward 1982):

1. **Dominance (Dom)**: the 10 most abundant taxa of each station in an association were scored with most abundant species given a score of 10, the second most abundant a score of 9, and so on. The dominance of a taxon within an association is given by the mean score across all stations.
2. **Fidelity (Fid)**: degree to which a taxon is restricted to an 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.
3. **Abundance (Abund)**: mean abundance of the taxon within the association.
4. **Relative abundance (Rel)**: mean abundance of the taxon within the association less its mean abundance throughout all the stations.
5. **Persistence (Pers)**: proportion of the stations within the association in which the taxon occurs.

The various criteria were weighted and combined to give an empirical association score for each species in each association, with a maximum value of 100 (Appendix 3). Association scores were calculated using the formula:

4 (0.3 Dom + 2 Fid + 0.11 Abund + 0.08 Rel + Pers).

Weightings have been assigned to each criterion to make their values more nearly equal but to give greater weight to some criteria in the following decreasing order: Abundance, Relative Abundance, Dominance, Fidelity, Persistence.

SAMPLE ASSOCIATIONS

The following six sample associations and five subassociations were selected by inspection from the cluster analysis dendrogram (Fig. 5) and their geographic distribution is shown in Fig. 7. The characterising species listed are those having the highest association scores (Appendix 3).

Association A: *Trifarina angulosa/Textularia proxispira/ Miliolinella subrotundata*

Stations: 2,3,4,5,6,19,20,21,22,27,28,29,30,31, 32,35,39,40,41,42,43,56,57,58,59,60 = 26

Dominant species associations: 1, 2

Depth: 3–45 m

Sediment: a broad range from clean gravel to muddy very fine sand (0–36% mud)

This association occurs in the entrance passages to Port Pegasus exposed to the huge swells of the Subantarctic Ocean and in those parts of the Port that are nearest to the passages. The association also occurs in the moderately deep (12–22 m), current-swept Pegasus Passage that links the North and South Arms of Port Pegasus in the lee of Anchorage and Noble Islands. All stations are at depths in excess of 12 m, except Sample 43 which was taken at 3 m in the sand-filled shallows of Blind Passage.

The fauna is dominated by *Trifarina angulosa* (mean abundance 11%), with subdominant *Textularia proxispira, Cassidulina carinata, Quinqueloculina seminula, Miliolinella sub-*

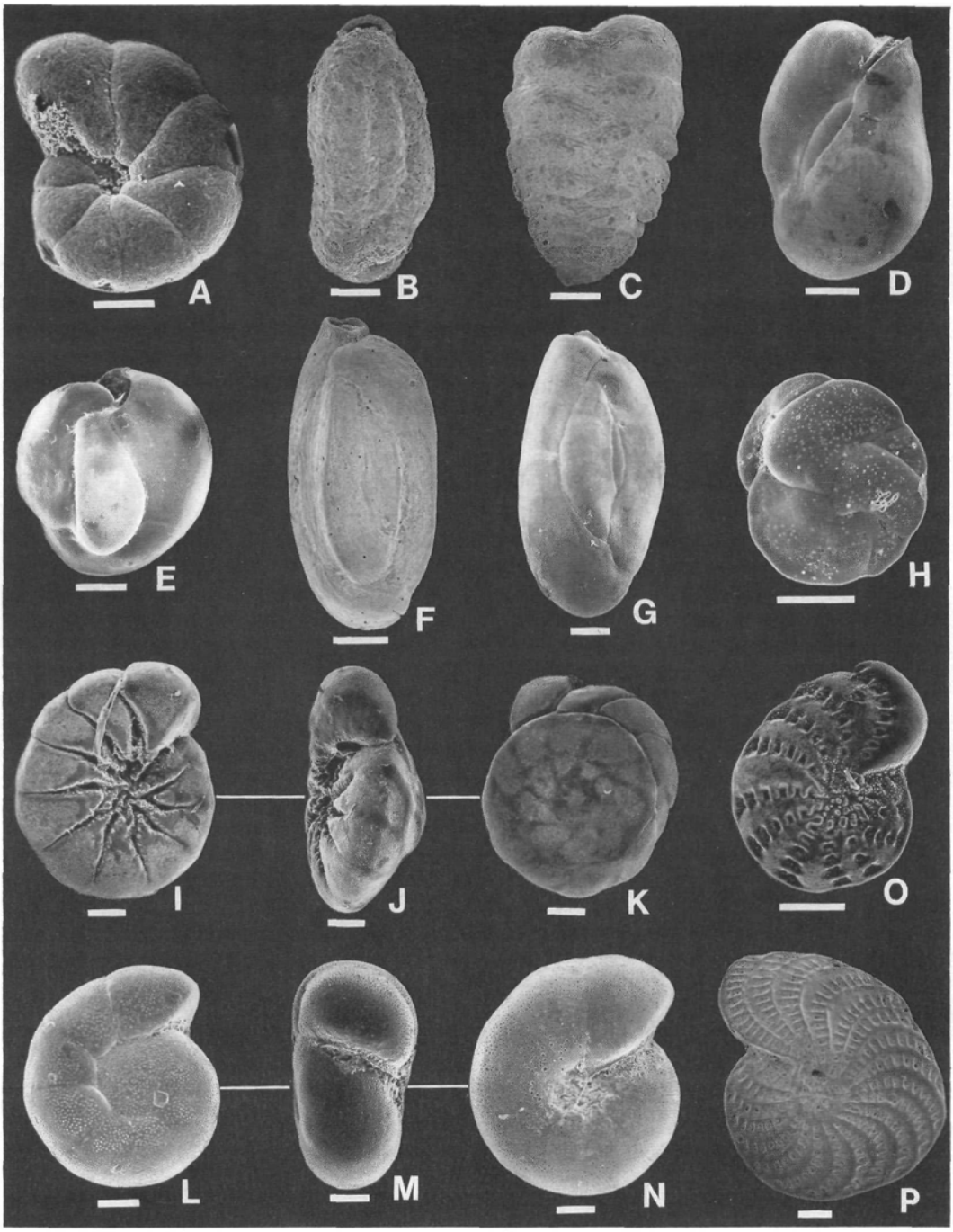

Fig. 3 Scanning electron microscope photographs of characterising and more common species in Port Pegasus. A, *Haplophragmoides wilberti,* Stn 16, FP4056; B, *Miliammina fusca,* Stn 16, FP4057; C, *Textularia proxispira,* Stn 30, FP4058; D, *Miliolinella labiosa,* Stn 14, FP4059; E, *Miliolinella subrotundata,* Stn 30, FP4060; F, *Quinqueloculina delicatula,* Stn 7, FP4061; G, *Quinqueloculina seminula,* Stn 13, FP4062; H, *Cassidulina carinata,* Stn 35, FP4063; I–K, *Ammonia beccarii,* Stn 14, FP4064, 4065; L–N, *Anomalina spherica,* Stn 23, FP4066, 4067, 4068; O, *Elphidium advenum depressulum,* Stn 13, FP4069; P, *Elphidium novozealandicum,* Stn 23, FP4070. Scale equals 0.1 mm.

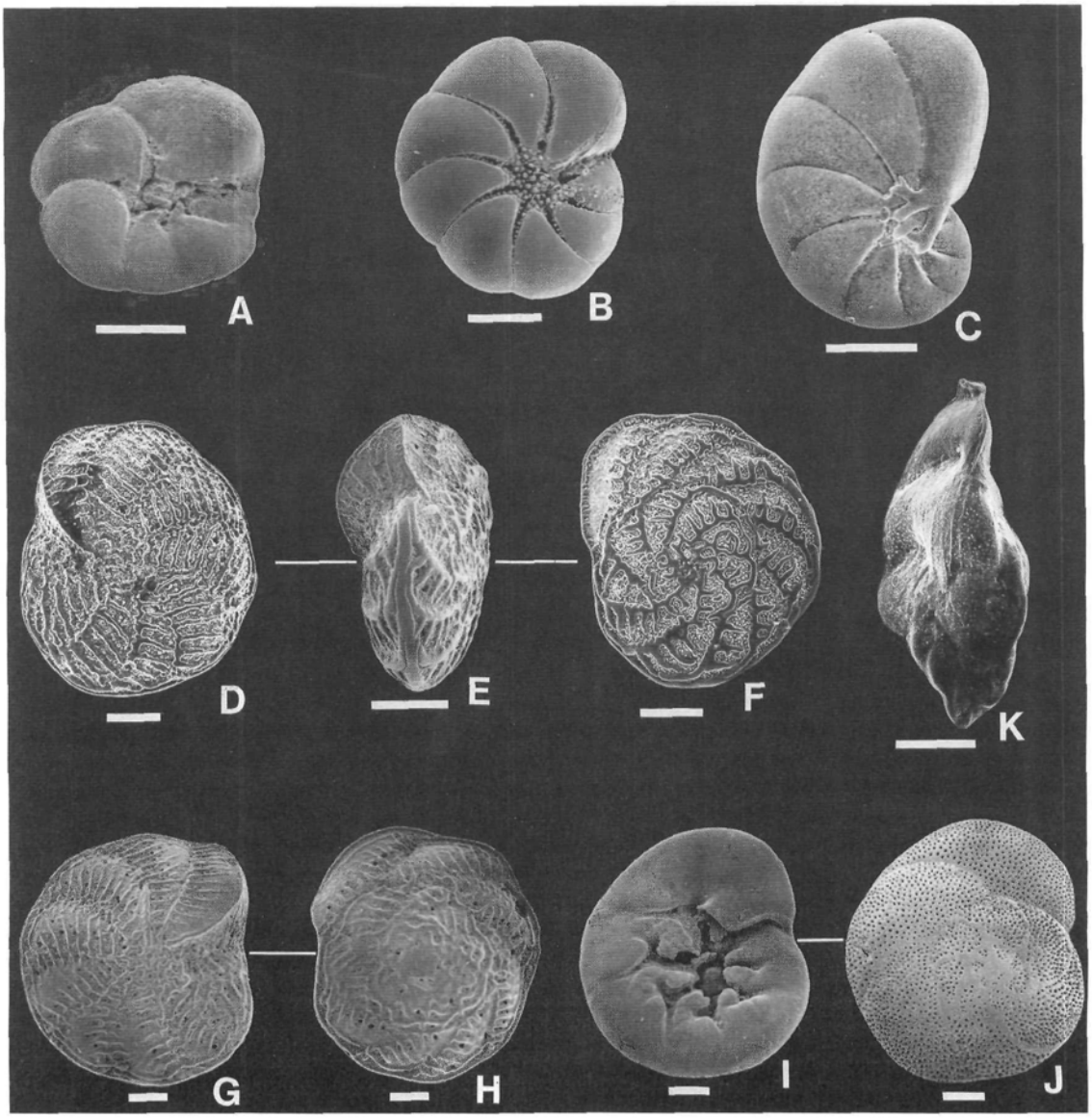

Fig. 4 Scanning electron microscope photographs of characterising and more common species in Port Pegasus. A, *Gavelinopsis lobatulus,* Stn 35, FP4071; B, *Haynesina depressula,* Stn 12, FP4072; C, *Nonionella flemingi,* Stn 51, FP4073; D–F, *Notorotalia finlayi* (D and F, Stn 23, FP4074, 4075; E, Stn 51, FP4076); G–H, *Notorotalia zelandica,* Stn 18, FP4077, 4078; I–J, *Rosalina bradyi,* Stn 47, FP4079, 4080; K, *Trifarina angulosa,* Stn 30, FP4081. Scale equals 0.1 mm.

rotundata, and *Gavelinopsis lobatulus* (each with mean abundances of 4–6%). *T. proxispira* and *M. subrotundata* are characterising species of this association because they have higher fidelity values than the other subdominants.

This association has not previously been recorded from New Zealand waters, probably because of the lack of study of faunas from southern New Zealand. The dominant species, *Trifarina angulosa,* is not known around northern New Zealand. It is recorded as common at slope depths, but not shelf depths, off southern Hawkes Bay (Lewis 1979). This association has elements in common with the widespread inner shelf *Pileolina*

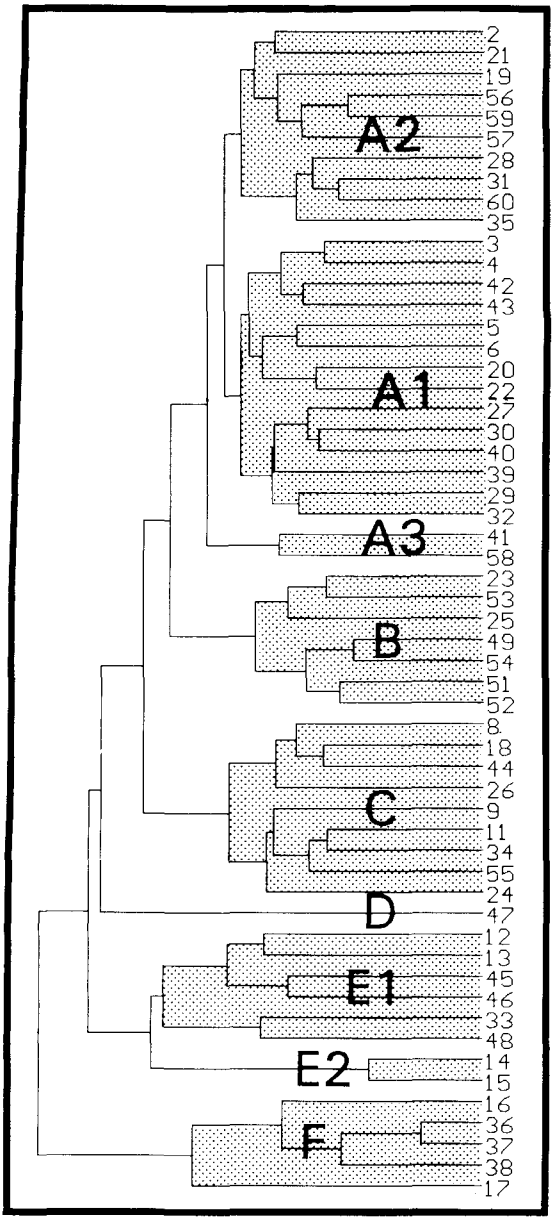

Fig. 5 Dendrogram classifications of Port Pegasus foraminiferal samples produced by cluster analysis using Bray-Curtis distance matrix (Rohlf 1989). The six sample associations (A-F) were selected by the authors, after inspection of the dendrograms.

zelandica–Quinqueloculina seminula–Elphidium charlottensis association and also the common mid shelf *Bulimina submarginata–Cassidulina carinata–Evolvocassidulina orientalis* association, both off northern New Zealand (Hayward 1983; Hayward et al. 1984).

Various associations dominated by *Trifarina angulosa* with subdominant *Cassidulina, Bolivina* and a variety of other genera occur at 60–500 m in muddy sand are recorded from similar subpolar locations in the north and south Atlantic and Pacific Oceans (Murray 1991).

Three subassociations are recognised:

Subassociation A1: *Trifarina angulosa/ Textularia proxispira*

Stations: 3,4,5,6,20,22,27,29,30,32,39,40,42, 43 = 14

Dominant species associations: 1, 2b

Depth: 3–45 m

Sediment: slightly gravelly to gravelly, clean to muddy, very fine to coarse sand or sandy gravel

This subassociation occurs in the most exposed or highest-energy (either wave or current) parts of the study area. It occurs in the main current swept passages, including Pegasus Passage in the lee of the islands.

The fauna is codominated by *Trifarina angulosa* and *Textularia proxispira* with a wide diversity of subdominants that include *Miliolinella subrotundata* and *Pileolina radiata* (both with high fidelity values) and also *Cibicides marlboroughensis, Dyocibicides* sp. and *Rosalina bradyi.* This subassociation differs from the other two in the greater abundance of the latter six species and in its greater diversity and evenness in composition.

Subassociation A2: *Trifarina angulosa/ Cassidulina carinata/ Gavelinopsis lobatulus*

Stations: 2,19,21,28,31,35,56,57,59,60 = 10

Dominant species association: 2a

Depth: 21–40 m

Sediment: clean to muddy, fine to very fine sand, sometimes slightly gravelly

This subassociation occurs inside Port Pegasus in relatively deep, quieter bottom conditions with fine to very fine sand substrates. It occurs in those parts of the port directly inside South and Big Ship Passages.

The fauna is dominated by *Trifarina angulosa* (mean abundance 13%) with subdominant characterising species *Cassidulina carinata* and *Gavelinopsis lobatulus.* Other common species that occur most frequently in this subassociation (high

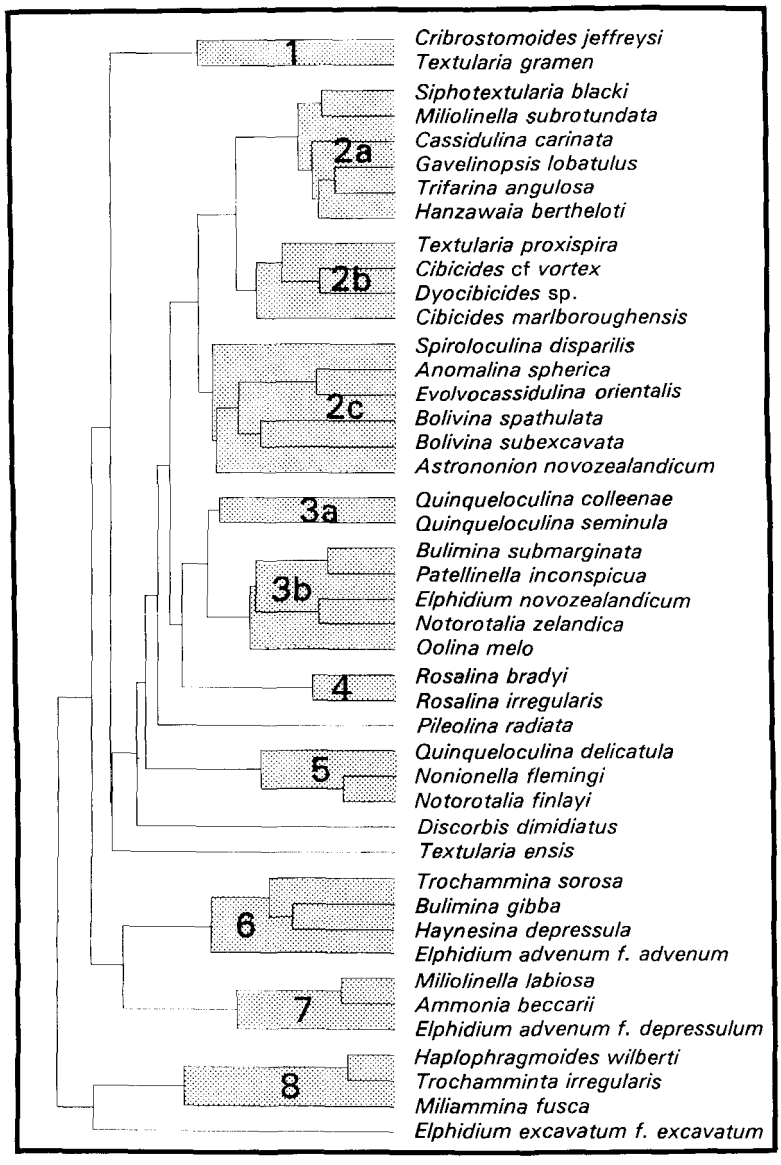

Fig. 6 Dendrogram classification of dominant foraminiferal species (> 5% in any sample) produced by cluster analysis using Horn's (1966) modified version of Morista's (1959) index for proportions (Rohlf 1989). The eight species associations were selected by the authors, after inspection of the dendrograms.

fidelity values) are *Miliolinella subrotundata, Bolivina subexcavata, Hanzawaia bertheloti, Anomalina spherica, Siphotextularia blacki, Bolivina spathulata, Evolvocassidulina orientalis,* and *Textularia proxispira.*

Subassociation A3: *Quinqueloculina seminula/ Anomalina spherica/ Textularia proxispira*

Stations : 41,58 = 2

Dominant species associations: 2c, 3a

Depth: 26–27 m

Sediment: medium to fine sand and slightly gravelly muddy sand

This subassociation occurs in two stations within the area of Association A. One station lies within the South Arm of the port just inside South Passage entrance and the other lies in the entrance to Albion Inlet off North Arm. Both are at a similar depth.

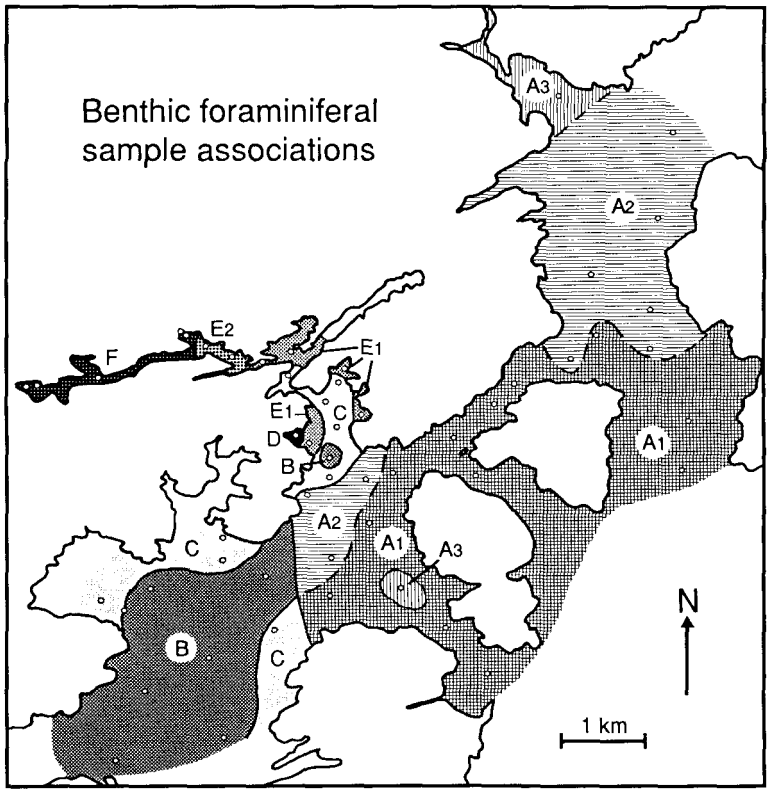

Fig. 7 Distribution of the six benthic foraminiferal sample associations and five sub-associations in Port Pegasus. Association A1 = *Trifarina angulosa/Textularia proxispira*, Association A2 = *Trifarina angulosa/Cassidulina carinata/ Gavelinopsis lobulatus*, Association A3 = *Quinqueloculina seminula/Anomalina spherica/ Textularia proxispira*, Association B = *Notorotalia finlayi/ Quinqueloculina delicatula/ Nonionella flemingi*, Association C = *Notorotalia zelandica/ Elphidium novozealandicum*, Association D = *Rosalina bradyi*, Association E1 = *Elphidium advenum* f. *depressulum/Haynesia depressula*, Association E2 = *Ammonia beccarii*, Association F = *Miliammina fusca*..

The subassociation is dominated by *Quinqueloculina seminula* with subdominant *Anomalina spherica*. Other common species include *Trifarina angulosa, Textularia proxispira, Patellinella inconspicua*, and *Pileolina radiata*.

Association B: *Notorotalia finlayi/Quinqueloculina delicatula/ Nonionella flemingi*

Stations: 23,25,49,51,52,53,54 = 7

Dominant species association: 5

Depth: 22–30 m

Sediment: gravelly to slightly gravelly, muddy to slightly muddy, fine sand (7–35% mud)

This association occurs in the moderate shelter of the South Arm and in one station at a similar depth in the middle of Islet Cove. The fauna is dominated by *Notorotalia finlayi* and also characterised by the subdominants *Quinqueloculina delicatula* and *Nonionella flemingi,* both of which are uncommon outside this association. Other subdominants that are common in other associations are *Anomalina spherica, Quinqueloculina seminula, Trifarina angulosa, Notorotalia zelandica,* and *Patelinella inconspicua.* The less common species *Bulimina submarginata, Loxostomum karrerianum,* and *Elphidium advenum* f. *advenum* occur most frequently in this association.

This association is very similar to faunas with abundant *Notorotalia* spp. and *Nonionella flemingi* recorded from 20–30 m depth in the Marlborough Sounds (Vella 1957) and Port Fitzroy, Great Barrier Island (unpubl. data). *Notorotalia*-dominated associations are not known overseas and both *Notorotalia finlayi* and *Nonionella flemingi* are believed to be endemic to the New Zealand region.

Association C: *Notorotalia zelandica/Elphidium novozealandicum*

Stations: 8,9,11,18,24,26,34,44,55 = 9

Dominant species association: 3b

Depth 2.5–26 m

Sediment: gravelly, clean to muddy fine to coarse sand, sandy gravel or slightly gravelly sandy mud (0–67% mud)

This association mostly occurs in bays (Shipbuilders, Evening, and Islet coves) on the northern, landward side of Port Pegasus. The fauna is dominated by *Notorotalia zelandica* and *Elphidium novozealandicum,* both of which occur in their greatest abundances and frequency in this association. Also common are *Quinqueloculina seminula, Rosalina bradyi, Patellinella inconspicua,* and *Dyocibicides* sp. The less common species *Trochammina sorosa* and *Quinqueloculina colleenae* occur most frequently in this association.

This association is most similar to a fauna dominated by *Notorotalia* spp. and *Elphidium novozealandicum* in 8 m depth in Queen Charlotte Sound (Vella 1957). *Notorotalia*-dominated associations are not known overseas and both *Notorotalia zelandica* and *Elphidium novozealandicum* are endemic to the New Zealand region.

Association D: *Rosalina bradyi*

Stations : 47

Dominant species association: 4

Depth: 0.5 m

Sediment: sandy gravel

This association is only recorded from one station, located in shallow subtidal (0.5 m), sandy gravel amongst weed-covered rocky reefs in Islet Cove. The fauna is dominated by *Rosalina bradyi* with subdominant *Rosalina irregularis,* both of which commonly live on hard rocky substrates and probably dropped off the reefs and into the surrounding sediment.

The only recorded similar fauna from New Zealand has common *Discorbis dimidiatus* and *Rosalina bradyi* and occurs at 5 m in sand adjacent to rocky reefs at the Chickens Islands, Northland (Hayward et al. 1984). A *Rosalina bradyi* association has previously been recognised at around 60 m depth off the Japan coast (Matoba 1976).

Association E: *Ammonia beccarii/Elphidium advenum* f. *depressulum/ Haynesina depressula*

Stations: 12,13,14,15,33,45,46,48 = 8

Dominant species associations: 3a,6,7

Depth: 0.5–6 m

Sediment: gravelly to slightly gravelly, clean to muddy (0–48% mud), fine and medium sand

This association occurs in the shallower fringes of Islet Cove and in the middle stretches of the narrow, tide-swept Cooks Arm at the head of the inlet. The fauna is dominated by *Ammonia beccarii* and *Elphidium advenum* f. *depressulum* with subdominant *Quinqueloculina seminula* and *Haynesina depressula.*

Foraminiferal associations similar to this with strongly dominant *Ammonia beccarii* and subsidiary *Haynesina depressula* and *Elphidium advenum* and *E. excavatum* occur in many shallow sheltered harbour and estuary situations around New Zealand (Hayward & Hollis in press; Hayward & Triggs in press). *Ammonia beccarii*-dominated associations with common associated *Elphidium excavatum* and sometimes *Elphidium advenum* have a cosmopolitan distribution in sheltered harbour and estuarine environments, often with a slightly lowered salinity (Murray 1991).

Two subassociations are recognised:

Subassociation E1: *Elphidium advenum* f. *depressulum/Haynesina depressula*

Stations: 12,13,33,45,46,48 = 6

Dominant species associations: 3a,6,7

Depth: 1.5–6 m

Sediment: gravelly to slightly gravelly, clean to muddy (0–48% mud), fine and medium sand

This subassociation occurs in the shallow subtidal areas of Islet Cove, often amongst rocky reefs, and in the channel of the middle part of Cooks Arm. The fauna is codominated by *Elphidium advenum* f. *depressulum, Haynesina depressula, Quinqueloculina seminula,* and *Ammonia beccarii* (each averages 10–16% of the benthic fauna). The first two of these are far more abundant in this subassociation than elsewhere in the study area and are therefore the characterising species. Also common are *Rosalina bradyi, Elphidium advenum* f. *advenum, Elphidium novozealandicum,* and *Notorotalia finlayi.*

Subassociation E2: *Ammonia beccarii*

Stations: 14,15 = 2

Dominant species association: 7

Depth: 0.5 m

Sediment: gravelly fine sand

This subassociation occurs further up Cooks Arm and in shallower water than E1. The fauna is dominated by abundant *Ammonia beccarii* (55–62%) with subsidiary *Elphidium advenum* f. *depressulum* and *Miliolinella labiosa.* This latter species has by far its greatest abundance and frequency in this subassociation. Faunas with a

similar high abundance of *Ammonia beccarii* and reduced diversity occur in many parts of New Zealand at slightly lowered salinity in sheltered environments (Hayward & Hollis in press). In most of these places, however, the subdominant species is *Elphidium excavatum* s.l. and/or *Haynesina depressula.*

Association F: *Miliammina fusca*

Stations: 16,17,36,37,38 = 5

Dominant species association: 8

Depth: intertidal

Sediment: gravelly, muddy to slightly muddy, fine sand to fine sandy mud (2–84% mud)

This association is restricted to the intertidal upper reaches of Cooks Arm, where the water is often slightly brackish. The fauna is dominated in all stations by abundant *Miliammina fusca.* The characteristically brackish intertidal species *Haplophragmoides wilberti* occurs in the three highest stations (16,36,37) and the species most characteristic of the least saline waters in New Zealand, *Trochamminita irregularis* (Hayward & Hollis in press), is common in Stn 16 in high tidal salt marsh at the mouth of a small stream.

The above three species are common throughout New Zealand in intertidal brackish environments similar to these at the head of Cooks Arm (Hayward & Hollis in press). Several other taxa that are equally common in these environments in other parts of New Zealand (e.g., *Jadammina macrescens, Elphidium excavatum, Trochammina inflata*) are absent or almost absent from this study area. Upper estuarine environments around the world are mostly dominated by *Miliammina fusca* (Murray 1968, 1991; Boltovskoy & Wright 1976). In different regions additional species are sometimes abundant in these low-salinity environments, especially *Haplophragmoides wilberti*, which is abundant in some Australian, European, Caribbean, and South American upper estuarine habitats (Albani 1968; Boltovskoy & Wright 1976; Murray 1991).

SPECIES ASSOCIATIONS

The following six species associations and five subassociations were selected by inspection from the cluster analysis dendrogram (Fig. 6).

Association 1

Species: *Textularia gramen, Cribrostomoides jeffreysi*

Dominant sample association: A1

Distribution: This minor species association occurs in greatest abundance in South Passage, with low background levels in Big Ship and Pegasus passages and in parts of the port close to the open sea. It is probably best regarded as part of Association 2b.

Association 2

Dominant sample association: A

Association 2a

Species: *Miliolinella subrotundata, Cassidulina carinata, Gavelinopsis lobatulus, Trifarina angulosa, Hanzawaia bertheloti*

Dominant sample association: A2

Distribution (Fig. 8): This major species association has a distribution pattern closely paralleling that of sample association A2. Its greatest abundance is within those parts of the two arms of Pegasus adjacent to the main entrance passages and also in Pegasus Passage between the two arms. The species association has a low background abundance in the main entrance passages themselves and also further up the arms and in Islet Cove. A small peak abundance occurs in the upper reaches of Cooks Arm centred around low-tide Stn 17.

Association 2b

Species: *Textularia proxispira, Cibicides vortex, Dyocibicides* sp.

Dominant sample association: A1

Distribution (Fig. 8): This association has its greatest abundance in the exposed South and Big Ship Passages that lead in from the open sea. Association abundance progressively decreases to nothing as one moves into Port Pegasus. The pattern corresponds closely with sample association A1.

Association 2c

Species: *Spiroloculina disparilis, Anomalina spherica, Evolvocassidulina orientalis, Bolivina spathulata, Bolivina subexcavata, Astrononion novozealandicum*

Dominant sample associations: B,A3

Distribution (Fig. 9): This association has a low background abundance throughout both arms of Port Pegasus and in the current-swept passages. Its greatest concentration is in the quieter parts of the arms, away from the influence of the entrance

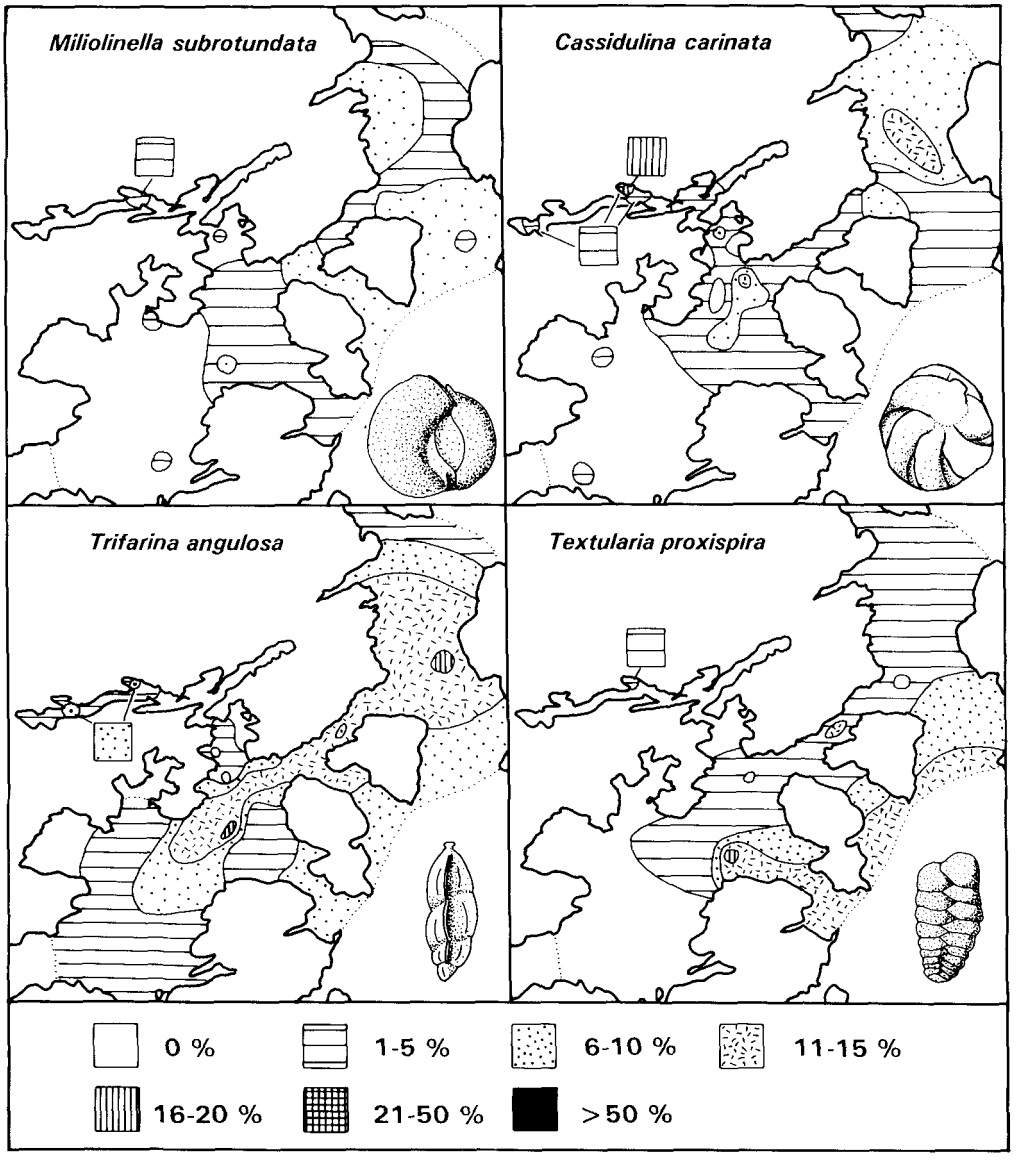

Fig. 8 Contoured abundance distribution maps of the dominant characterising species of Associations 2a and 2b in Port Pegasus.

passages, but hardly extending up into the shallows of any of the sheltered bays.

Association 3

Dominant sample association: C

Association 3a

Species: *Quinqueloculina seminula, Quinqueloculina colleenae*

Dominant sample associations: A3,E1

Distribution (Fig. 9): This association of two *Quinqueloculina* species has an extremely widespread and patchy distribution throughout all of Port Pegasus, the entrance channels and Cooks Arm, except the highest brackish reaches (Association F). The greatest abundances are in the deeper parts of Islet Cove and the subtidal channel of Cooks Arm.

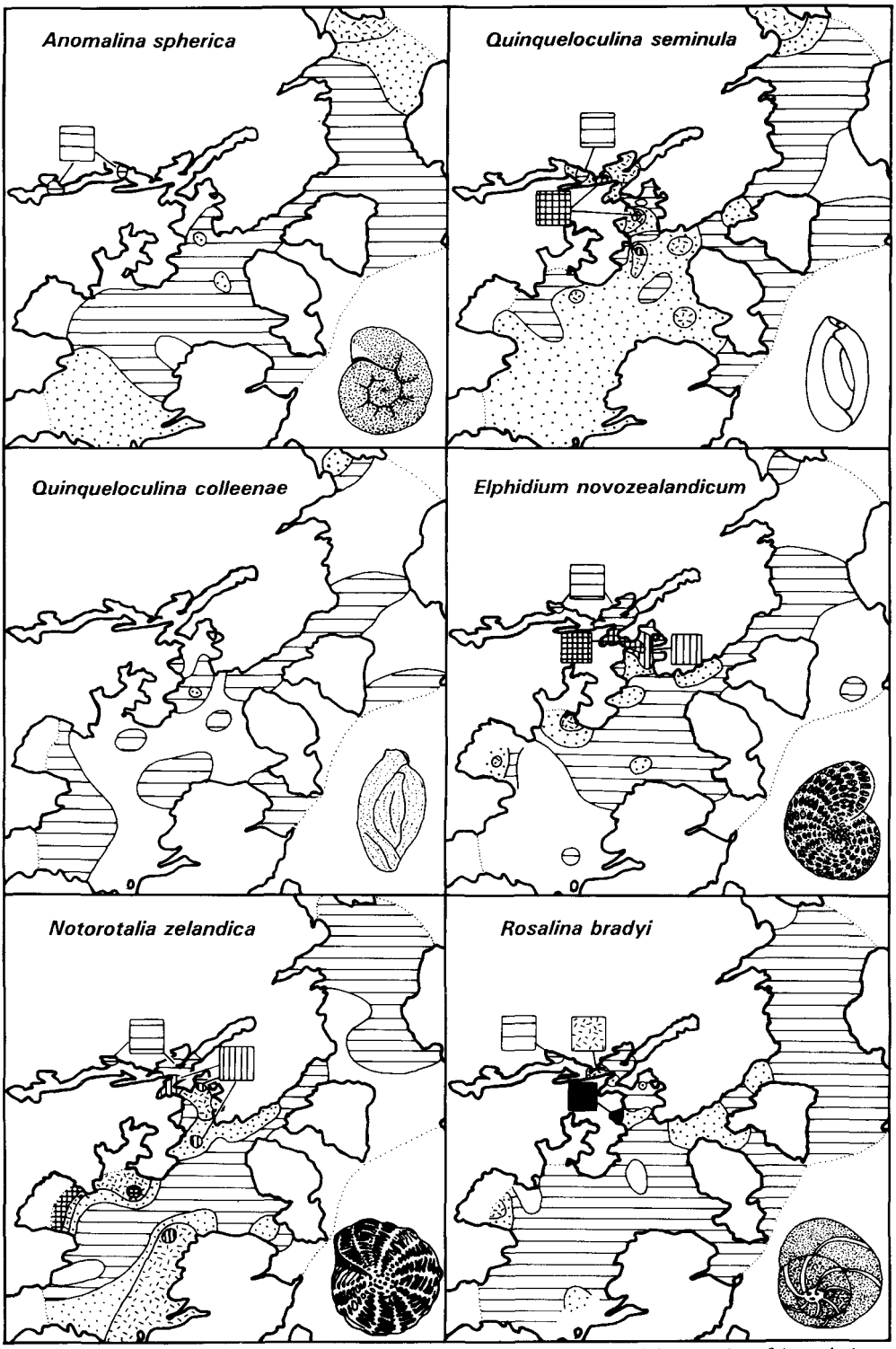

Fig. 9 Contoured abundance distribution maps of the dominant characterising species of Associations 2c, 3, and 4 in Port Pegasus.

Association 3b

Species: *Bulimina submarginata, Patellinella inconspicua, Elphidium novozealandicum, Notorotalia zelandica, Oolina melo*

Dominant sample association: C

Distribution (Fig. 9): This association has a wide distribution throughout Port Pegasus, although it generally does not extend into the upper reaches of Cooks Arm nor out through the passages to the open sea. Its greatest abundance is around the fringes of South Arm and in the central parts of Islet Cove, mimicking the distribution pattern of sample association C.

Association 4

Species: *Rosalina bradyi, Rosalina irregularis*

Dominant sample association: D

Distribution (Fig. 9): These are the characterising species for sample association D and likewise have their greatest concentration in sediments close to rocks in the shallows of Islet Cove. The association has a low background level of abundance throughout most of the Port Pegasus study area.

Association 5

Species: *Quinqueloculina delicatula, Nonionella flemingi, Notorotalia finlayi*

Dominant sample association: B

Distribution (Fig. 10): This association occurs in greatest abundances in those deeper parts of the Port Pegasus arms which are more distant from the open sea. It also occurs in lesser abundance in the deeper central parts of Islet Cove. These are the dominant characterising species for sample association B.

Association 6

Species: *Trochammina sorosa, Bulimina gibba, Haynesina depressula, Elphidium advenum* f. *advenum*

Dominant sample association: E1

Distribution (Fig. 10): This association occurs primarily in the sheltered shallows of Islet and Shipbuilders Coves and also extends up the subtidal channel of Cooks Arm. It closely approximates the distribution of sample association E1. The combination of species has not been recognised elsewhere in New Zealand.

Association 7

Species: *Miliolinella labiosa, Ammonia beccarii, Elphidium advenum* f. *depressulum*

Dominant sample associations: E1,E2

Distribution (Fig. 10): This association has its greatest abundance in the middle reaches of Cooks Arm and in the sheltered shallows around Islet Cove. The species hardly occur outside of this area. This combination of species has not been recognised elsewhere in New Zealand, where more commonly *Ammonia beccarii* and *Haynesina depressula* occur together as a recurring association (e.g., Hayward & Triggs in press).

Association 8

Species: *Miliammina fusca, Haplophragmoides wilberti, Trochamminita irregularis*

Dominant sample association: F

Distribution (Fig. 10): This species association occurs in the brackish, intertidal, upper reaches of Cooks Arm. It is the characterising fauna of sample association F. This association is typical of brackish estuaries and salt marshes throughout most of New Zealand (Hayward & Hollis in press).

Planktic foraminifera (Fig. 11)

Associations

Two planktic foraminiferal associations are recognisable in these Port Pegasus samples. One association is composed primarily of larger tests (adults) of *Globigerina bulloides, Globorotalia truncatulinoides,* and *Globorotalia inflata* with several less common species. This association is largely confined to the most exposed part of the area in the three entrance passages and is presumed to be typical of the fauna occurring along the open coast outside the Port.

The second planktic foraminiferal association is dominantly composed of small tests of *Globigerina quinqueloba, Neogloboquadrina pachyderma,* and other *Globigerina* species with a few small juveniles of other species. This association occurs throughout most of Port Pegasus and up Cooks Arm.

Relative abundance

The tests of planktics comprise 0–65% of the total foraminiferal faunas in this study. The greatest relative abundances of planktics occur in sediments within the North and South Arms of Port Pegasus,

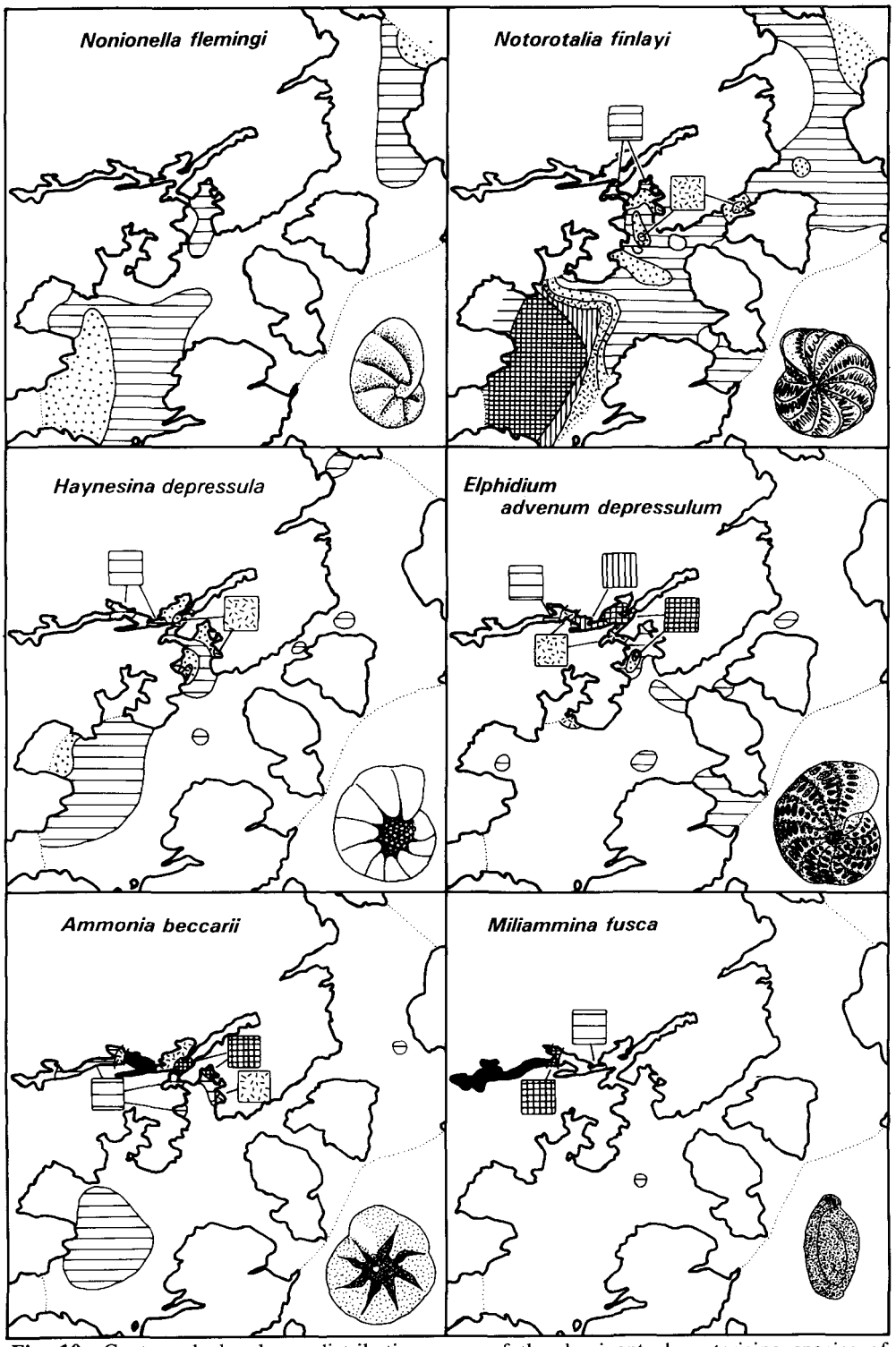

Fig. 10 Contoured abundance distribution maps of the dominant characterising species of Associations 5, 6, 7, and 8 in Port Pegasus.

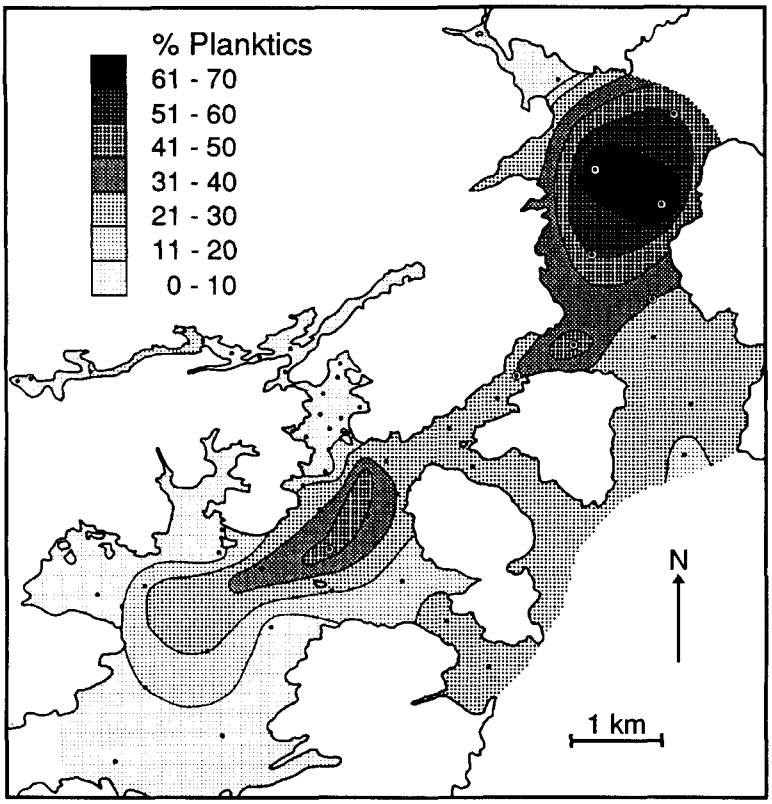

Fig. 11 Contoured map of planktic foraminiferal abundance in the Port Pegasus samples, expressed as a percentage of the total foraminiferal fauna.

with the peaks (65% in North Arm, 45% in South Arm) located directly opposite the main entrance passages (Big Ship and South passages) into the sheltered port. In general the planktic percentages progressively decrease the further one moves into the port (e.g., southwards into South Arm), with values of 0–5% common around the fringes of the port and in its bays. The relatively deep, current-swept Pegasus Passage, between the two arms, has fairly consistent planktic percentages of 25–30%. These are similar to the planktic percentages (15–30%) in the main entrance passages.

Planktic foraminiferal test abundances in the long and narrow Cooks Arm are quite variable. The tidal-current swept channel has low planktic percentages of 0–5%, as do high tidal sediments around the very head of the estuary. However, the three low tidal sediment samples in the upper reaches of Cooks Arm have 10–20% planktics, which is unusually high for a tidal estuary or for a fauna of the *Miliammina fusca* association.

Distribution

Relative abundance of planktic foraminiferal tests in many Port Pegasus samples is extraordinarily high. In most parts of the world and around the New Zealand coast, planktic percentages for inner shelf depths such as these are in the range of 0–15%, rarely up to 25% (e.g., Hayward 1986). In one instance, on the west coast of the North Island of New Zealand, planktic percentages of up to 40% recorded from intertidal sediments are thought to result from concentration of planktic tests by the dominant onshore winds and seas of this area (Hayward 1986). A similar explanation is proposed for the high values in Port Pegasus. The onshore winds and seas of the Subantarctic Ocean outside and around the entrances to the Port are extremely strong and relentless. It is inferred that planktic foraminifera are carried shorewards in the surface waters and smaller tests are swept through the passages into the quieter waters of the North and South Arm basins. Here in the less turbulent

conditions, many planktic tests settle out of suspension and become concentrated in the bottom sediments. The mechanism in Cooks Arm is inferred to be similar, with many small planktics being swept up the narrow channel and only settling out and becoming concentrated where the waters are less turbulent in its upper reaches.

Not only are the planktic abundances within the port unusually high, but apparently the background relative abundance of planktic foraminifera in inner shelf (0–50 m depth) sediments along most parts of this Stewart Island coast outside the port (15–30%) is also well above the norm. The large swells and strong tidal currents sweeping in and out of the Port presumably prevent smaller planktics from settling out of suspension in the entrance channels.

The pattern of relative abundance of planktic foraminifera in Port Pegasus is also highly unusual. In most inner shelf study areas (both open coast and harbours) around the world there is a general decrease in relative abundance with decreasing depth and increasing shelter. There is no such simple pattern in this study. The nearest approximation to this normal trend occurs within South Arm, as one moves southwards into relatively more shelter and shallower water.

RELATIONSHIP OF SAMPLE ASSOCIATIONS TO ENVIRONMENTAL FACTORS

Because of the remoteness of Port Pegasus, there are few quantitative environmental data available that could be used to attempt statistical correlation with the faunal patterns. The sediment grain size analyses conducted for this study show little apparent correlation between grain size or mud content and the faunal associations, with the exception of sample associations A2 and B. Most associations exist in an extremely wide range of sediment substrate types.

Despite the lack of actual measurements, it is quite obvious (by comparison with brackish faunas elsewhere: Hayward & Hollis in press) that somewhat reduced salinity in the middle and upper reaches of Cooks Arm is significant in determining the faunal composition and the distribution of Associations F and E2. All the other associations quite clearly inhabit waters of normal salinity, based on records of these associations elsewhere.

The influence of factors related to depth on the distribution of the different associations is uncertain. There is, however, an observable trend from associations inhabiting shallow, nearshore habitats to those in quieter, deeper water. This trend is:

F	*Miliammina fusca* association: intertidal;
E2, D	*Ammonia beccarii* and *Rosalina bradyi* associations: 0.5 m;
E1	*Elphidium advenum depressulum/ Haynesina depressula:* 1.5–6 m;
C	*Notorotalia zelandica/Elphidium novozealandicum:* 2.5–26 m;
B	*Notorotalia finlayi/Quinqueloculina delicatula/Nonionella flemingi:* 22–30 m;
A2	*Trifarina angulosa/Cassidulina carinata/ Gavelinopsis lobatulus:* 21–40 m.

Association A1 (*Trifarina angulosa/Textularia proxispira)* occurs in a wide depth range of 3–45 m.

Distribution of the various sample associations in Port Pegasus (Fig. 7) shows that the level of exposure to high wave or current energy is a major factor influencing the Pegasus faunas. Association A occurs in the most exposed situations and in high-energy current-swept passages. Association A1 is clearly the most tolerant of high-energy swells and waves on the exposed inner shelf of this part of the Stewart Island coast and it extends through the entrance passages into adjacent parts of the harbour. Association B occurs in a quiet, moderately deep, fine sediment environment within South Arm. Association C appears to tolerate slightly higher-energy environments than B by its occurrence in shallower water and often coarser sediment. Association D seems to be a very specialised association dominated by epifaunal species that attach to rock and drop off into the nearby sediment on death.

POST-MORTEM TRANSPORT OF FORAMINIFERAL TESTS

The distribution pattern of planktic and some benthic species clearly shows that current transport of foraminiferal tests is a major factor in influencing the foraminiferal sample associations in some parts of Port Pegasus. The distribution maps of selected common benthic species (Fig. 8–10) indicate that there is little post-mortem transport of the dominant characterising species in any of the sample associations, except A, or within any of the species associations except 2a, 2c, and perhaps 3a (Fig. 8, 9).

Members of species association 2a (e.g., *Trifarina angulosa, Cassidulina carinata, Miliolinella subrotundata)* have distribution patterns very similar to the planktics. Their greatest abundances are in sediments just inside the main entrance passages to the port, with a second peak in the low tidal upper reaches of Cooks Arm. They also occur in above-average relative abundance in the passages and exposed inner shelf samples. The explanation for this distribution pattern is probably the same as for the planktics. The tests are lifted into suspension by the turbulent conditions or upwelling in the Subantarctic Ocean outside the port and carried in through the passages by strong tidal currents. Once inside Port Pegasus, conditions are much quieter and the tests settle to the bottom. Some tests are swept through South Arm and up Cooks Arm by the strong incoming tide and settle out in the quieter waters in the upper reaches. Further work is required to determine whether these species actually live in the port sediments, or whether all are swept in from outside. Members of species association 2b (e.g., *Anomalina spherica)* are less abundant than 2a species, but also have distribution patterns suggestive of post-mortem current transport.

The tests of species in Associations 2a and 2b are relatively small, thin-walled and calcareous, and prone to transport in suspension. Other species that also live on the exposed shelf (Association 1 and 2b) seem to be less prone to post-mortem transport and have tests made of sand grains (e.g., *Textularia proxispira, T. gramen)* or perhaps thicker calcite walls (e.g., *Dyocibicides* sp.).

The sporadic and patchy distribution pattern (Fig. 9) of *Quinqueloculina seminula* (Association 3a) is hard to explain, but abundance peaks in the middle and upper reaches of Cooks Arm are possibly a result of post-mortem transport of this thicker-walled species that occurs in relatively high abundance around the entrance to Cooks Arm. The odd specimens of *Notorotalia zelandica* and *Elphidium novozealandicum* that occur in the upper reaches of Cooks Arm (Fig. 9) are probably also picked up and transported in from their abundance peaks in and around the mouth.

ACKNOWLEDGMENTS

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APPENDIX 1 Physical characteristics and planktic foraminiferal percentages of Port Pegasus samples.

	Cat. no.[1]	Depth (m)	Grid ref[2]	% Plank	Sediment
2	F202271	21	D49/042202	40	Muddy fine sand
3	F202272	15	D49/044203	25	Slightly gravelly fine sand
4	F202273	12	D49/051206	30	Slightly gravelly muddy fine sand
5	F202274	20	D49/055209	25	Gravelly coarse sand
6	F202275	22	D49/057212	30	Sandy gravel
8	F202277	18	D49/039207	1	Shelly muddy sand
9	F202278	12	D49/032210	5	Shelly muddy fine sand
11	F202280	2.5	D49/033212	5	Gravelly fine sand
12	F202281	1.5	D49/034215	2	Gravelly fine sand
13	F202282	1.5	D49/031213	0	Gravelly medium sand
14	F202283	0.5	D49/028214	0	Gravelly fine sand
15	F202284	0.5	D49/024216	10	Gravelly fine sand
16	F202285	H.T.	D49/022217	3	Gravelly muddy fine sand
17	F202286	L.T.	D49/022217	20	Gravelly muddy fine sand
18	F202287	20	D49/037201	5	Shelly medium to coarse sand
19	F202288	25	D50/038194	45	Muddy very fine sand
20	F202289	24	D50/042196	40	Very fine sand
21	F202290	22	D50/037198	30	Slightly shelly very fine sand
22	F202291	23	D49/035200	20	Gravelly muddy very fine sand
23	F202292	22	D49/038204	10	Gravelly muddy fine sand
24	F202293	6	D50/026195	10	Sandy gravel
25	F202294	25	D50/031191	35	Slightly gravelly muddy very fine sand
26	F202295	26	D50/032185	5	Shelly medium to fine sand
27	F202296	17	D50/038189	20	Shelly medium to coarse sand
28	F202297	38	D49/072215	25	Medium to fine sand
29	F202298	42	D49/076208	30	Medium to fine sand
30	F202299	45	D49/075204	15	Fine sand
31	F202300	36	D49/072220	30	Fine sand
32	F202301	33	D49/066217	30	Slightly gravelly medium to fine sand
33	F202302	6	D49/042208	2	Slightly gravelly muddy fine sand
34	F202303	4	D49/038212	1	Slightly gravelly sandy mud
35	F202304	25	D49/063214	50	Slightly gravelly muddy fine sand
36	F202305	L.T.	D49/004212	0	Fine sand
37	F202306	H.T.	D49/006212	0	Sandy mud
38	F202307	L.T.	D49/013212	10	Gravelly fine sand
39	F202308	37	D50/055181	25	Sandy gravel
40	F202309	34	D50/050186	25	Gravel
41	F202310	27	D50/046190	15	Medium to fine sand
42	F202311	22	D50/045199	30	Slightly gravelly muddy fine sand
43	F202312	3	D49/053202	25	Slightly gravelly coarse to medium sand
44	F202313	23	D50/026193	5	Shelly muddy sand
45	F202314	4	D49/037208	5	Fine sand
46	F202315	3	D49/035205	5	Slightly gravelly sand
47	F202316	0.5	D49/034206	0	Sandy gravel
48	F202317	4	D49/039213	0	Slightly gravelly muddy fine sand
49	F202318	22	D50/019189	20	Slightly gravelly muddy very fine sand
51	F202320	29	D50/019179	10	Slightly gravelly muddy fine sand
52	F202321	30	D50/016171	5	Shelly very fine sand
53	F202322	25	D50/027173	5	Shelly very fine sand
54	F202323	29	D50/025182	20	Slightly gravelly very fine sand
55	F202324	10	D50/013188	1	Muddy sandy shell gravel
56	F202325	39	D49/073230	65	Muddy very fine sand
57	F202326	40	D49/074239	50	Slightly shelly muddy very fine sand
58	F202327	26	D49/062243	5	Slightly gravelly muddy sand
59	F202328	38	D49/066233	65	Muddy very fine sand
60	F202329	36	D49/066225	50	Muddy very fine sand

[1]Catalogue number of Micropaleontology Section, Institute of Geological and Nuclear Sciences Ltd, Lower Hutt
[2]Grid reference on NZMS 260 1:50 000 map series

APPENDIX 2 List of foraminifera identified from Port Pegasus

BENTHICS

Suborder Textulariina

Ammobaculites exiguus Cushman & Brönnimann; Hedley et al. 1967, p. 19, pl. 5, figs. 5a–b.
Ammodiscus sp.
Ammotium cassis (Parker); Loeblich & Tappan 1953, p. 33, pl. 2, figs. 12–18.
Cribrostomoides crassimargo Norman; Wells 1985, p. 582, figs. 7e–f.
Cribrostomoides jeffreysi (Williamson); Murray 1971, p. 23, pl. 4.
Eggerella advena Cushman; Loeblich & Tappan 1953, p. 36, pl. 3, figs. 8–10.
Haplophragmoides wilberti Andersen 1953, p. 21, pl. 4, fig. 7. This paper Fig. 3A.
Miliammina fusca (Brady); Murray 1971, p. 21, pl. 3. This paper Fig. 3B.
Psammosphaera bowmanni Heron-Allen & Earland; Hoglund 1947, p. 49, pl. 4, figs. 1–8.
Psammosphaera fusca Schulze; Hoglund 1947, p. 46, pl. 4, figs. 9–14.
Pseudobolivina antarctica Wiesner; Wells 1985, p. 586, figs. 10a–c.
Reophax arctica Brady; Loeblich & Tappan 1953, p. 21, pl. 1, figs. 19–20.
Reophax scorpiurus Montfort; Emend. Brönnimann & Whittaker 1980, p. 260, figs. 1–7, 12, 17 (see also Loeblich & Tappan 1988, p. 58, pl. 44, figs. 1–3).
Saccammina difflugiformis (Brady); Hoglund 1947, p. 53, pl. 4, fig. 18 (as Proteonina).
Siphotextularia blacki Vella 1957, p. 16, pl. 4, figs. 53–54.
Textularia earlandi Brady; Wells 1985, p. 584, figs. 9G–h.
Textularia ensis Vella 1957, p. 16, pl. 3, figs. 46–47.
Textularia gramen d'Orbigny; Boltovskoy et al. 1980, p. 51, pl. 32, figs. 17–21.
Textularia proxispira Vella 1957, p. 15, pl. 3, figs. 48, 52. This paper Fig. 3C.
Trochammina bartrami Hedley et al. 1967, p. 21, pl. 6, figs. 2a–C, text–figs. 9–10.
Trochammina ochracea (Williamson); Boltovskoy et al. 1980, p. 52, pl. 33, figs. 20–22.
Trochammina sorosa Parr; Hedley et al. 1967, p. 23, pl. 6, figs. 4A–C, text–figs. 11–15.
Trochamminita irregularis Cushman & Brönnimann; Emend. Saunders 1957, p. 4, pl. 2, figs. 3–8.

Suborder Miliolina

Cyclogyra involvens (Reuss); Hedley et al. 1967, p. 24, text–fig. 16.
Miliolinella labiosa (d'Orbigny); Hedley et al. 1967, p. 29, pl. 8, figs. 2a–c. This paper Fig. 3D.
Miliolinella subrotundata (Montagu); Haynes 1973, p. 56, pl. 5, figs. 5, 6, 12, 13. This paper Fig. 3E.
Miliolinella vigilax Vella 1957, p. 21, pl. 7, figs. 124–126.
Nevillina coronata (Millett); Loeblich & Tappan 1988, p. 340, pl. 349, figs. 11–15.
Pyrgo anomala (Schlumberger); Vella 1957, p. 29, pl. 7, figs. 135–136 (as *Biloculina)*
Pyrgo depressa (d'Orbigny); Vella 1957, p. 29, pl. 7, figs. 137, 140.
Pyrgo aff. *ezo* Asano; Vella 1957, p. 29, pl. 7, figs. 138–139.
Quinqueloculina agglutinans d'Orbigny; Hedley et al. 1965, p. 12, pl. 2, figs. 7a–b.
Quinqueloculina auberiana d'Orbigny; Hedley et al. 1967, p. 25, pl. 8, figs. 5a–c.
Quinqueloculina bicostoides Vella 1957, p. 25, pl. 5, figs. 89–92.
Quinqueloculina cliarensis (Heron-Allen & Earland); Murray 1971, p. 61, pl. 22, figs. 1–4.
Quinqueloculina colleenae Vella 1957, p. 25, pl. 5, figs. 86, 93.
Quinqueloculina cooki Vella 1957, p. 25, pl. 5, figs. 82, 83, 87.
Quinqueloculina delicatula Vella 1957, p. 26, pl. 4, figs. 77–79. This paper Fig. 3F.
Quinqueloculina oblonga (Montagu); Murray 1971, p. 63, pl. 73, figs. 4–8.
Quinqueloculina seminula (Linnaeus); Hedley et al. 1965, p. 13, pl. 2, figs. 8a–b. This paper Fig. 3G)
Scutuloris hornibrooki (Vella 1957), p. 21, pl. 7, figs. 127–129 (as *Quinquinella*).
Spiroloculina disparilis Terquem; Vella 1957, p. 27, pl. 6, figs. 122–123.
Triloculina chrysostoma (Chapman); Vella 1957, p. 28, pl. 5, figs. 97–99.
Triloculina insignis (Brady); Hedley et al. 1965, p. 14, pl. 3, figs. 10a–c.
Triloculina trigonula (Lamarck); Boltovskoy et al. 1980, p. 52, pl. 33, figs. 14–16.

Suborder Rotaliina

Acervulina inhaerens Schulze; Hedley et al. 1967, pl. 1, fig. 2.
Ammonia beccarii (Linnaeus); Hayward 1979, fig. 3a; Hornibrook et al. 1989, p. 84, fig. 23, 22. This paper Figs. 3I–K.
Amphicoryna scalaris (Batsch); Barker 1960, pl. 58, figs. 28–31.
Anomalina spherica Finlay; Hornibrook 1968, p. 73, fig. 13 (as *Anomalinoides*). This paper Figs. 3L–N.

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APPENDIX 2 *(Continued)*

Anomalinoides glabrata (Cushman).
Astacolus australis (Chapman).
Astrononion novozealandicum Cushman & Edwards; Hedley et al. 1965, p. 24, pl. 7, fig. 28.
Bolivina cf. *lapsus* Finlay; Hornibrook 1961, p. 73, pl. 10, fig. 184.
Bolivina cacozela Vella 1957, p. 33, pl. 8, figs. 162, 163.
Bolivina compacta Sidebottom; Hedley et al. 1967, p. 30, pl. 9, fig. 3.
Bolivina hornibrooki Collen 1972, p. 374, figs. 1–3.
Bolivina pseudoplicata Heron–Allen & Earland; Hedley et al. 1967, pl. 9, fig. 4.
Bolivina spathulata (Williamson); Hedley et al. 1965, p. 21, pl. 6, fig. 23.
Bolivina cf. *striatula* Cushman; Boltovskoy et al. 1980, p. 18, pl. 3, figs. 9–13.
Bolivina subexcavata Cushman & Wickenden; Hayward & Grace 1981, p. 49, fig. 5c.
Bulimina elongata d'Orbigny; Barker 1960, pl. 51, figs. 1, 2.
Bulimina gibba Fornasini; Barker 1960, pl. 50, figs. 1–4.
Bulimina submarginata Parr; Hayward 1982, fig. 6m.
Buliminella madagascarensis (d'Orbigny); Hayward 1982, fig. 6i.
Cassidulina carinata Silvestri; Eade 1967, p. 429, fig. 2, nos. 5–9. This paper Fig. 3H.
Cibicides cf. *deliquatus* Finlay; Hornibrook et al. 1989, p. 89, fig. 23, nos. 18a, b.
Cibicides lobatulus (Walker & Jacob); Hayward & Buzas 1979, p. 48, pl. 10, figs. 124–126.
Cibicides marlboroughensis Vella 1957, p. 40, pl. 9, figs. 189–191.
Cibicides cf. *vortex* Dorreen; Hornibrook et al. 1989, p. 90, fig. 17, nos. 9a–c.
Cymbaloporetta bradyi (Cushman); Barker 1960, pl. 102, fig. 14.
Dentalina communis d'Orbigny; Barker 1960, pl. 62, figs. 21, 22.
Dentalina guttifera d'Orbigny; Barker 1960, pl. 62, figs. 10–12.
Discorbinella timida Hornibrook 1961, p. 116, pl. 14, figs. 288, 293, 297.
Discorbis dimidiatus (Jones & Parker); Vella 1957, p. 35, pl. 8, figs. 166, 172–174.
Dyocibicides sp. Vella 1957, p. 41, pl. 9, figs. 198–200.
Elphidium advenum f. *advenum* (Cushman).
Elphidium advenum f. *depressulum* Cushman. This paper Fig. 3O.
Elphidium charlottensis (vella 1957), p. 38, pl. 9, figs. 187, 188 (as *Elphidiononion*).
Elphidium excavatum f. *excavatum* (Terquem); Hayward & Hollis in press, pl. 5, figs. 1–5.
Elphidium excavatum f. *clavatum* Cushman; Hayward & Hollis in press, pl. 5, figs. 6–8.
Elphidium excavatum f. *williamsoni* Haynes; Hayward & Hollis in press, pl. 5, figs. 9–12.
Elphidium novozealandicum Cushman; Hedley et al. 1967, pl. 12, fig. 4. This paper Fig. 3P.
Eponides repandus (Fichtel & Moll); Barker 1960, pl. 104, fig. 18.
Evolvocassidulina orientalis (Cushman); Hedley et al. 1967, pl. 12, fig. 5.
Fissurina claricurta Mcculloch 1977, p. 95, pl. 58, fig. 16.
Fissurina contusa Parr; Barker 1960, pl. 60, fig. 3.
Fissurina laevigata Reuss; Barker 1960, pl. 114, fig. 8.
Fissurina lucida (Williamson); Hayward & Triggs in press, fig. 3, no. 17.
Fissurina marginata (Montagu); Hayward & Buzas 1979, p. 57, pl. 16, fig. 207.
Fissurina orbignyana Seguenza; Hayward & Buzas 1979, p. 57, pl. 16, fig. 210.
Fissurina 6 spp.
Fursenkoina schreibersiana (Czjzek); Hayward & Buzas, 1979, p. 58, pl. 17, fig. 212.
Gavelinopsis hamatus Vella 1957, p. 35, pl. 9, figs. 177–180.
Gavelinopsis lobatulus (Parr 1950), p. 354, pl. 13, figs. 23–25 (as *Discorbis*). This paper Fig. 4A.
Glabratella margaritaceus (Earland).
Globocassidulina canalisuturata Eade; Hayward 1982, fig. 6n.
Guttulina austriaca d'Orbigny; Barker 1960, pl. 73, fig. 4.
Guttulina irregularis (d'Orbigny); Cushman & Ozawa 1930, p. 25, pl. 3, figs. 3, 4.
Guttulina yabei Cushman & Ozawa 1929, p. 68, pl. 13, fig. 2, pl. 14, fig. 6.
Gypsina vesicularis (Parker & Jones); Barker 1960, pl. 101, figs. 9–12.
Hanzawaia bertheloti (d'Orbigny); Hayward 1982, fig. 6q–r.
Haynesina depressula (Walker & Jacob); Hayward & Triggs in press, fig. 4, no. 13. This paper Fig. 4B.
Lagena crenata Parker & Jones; Barker 1960, pl. 57, figs. 15, 21.
Lagena flatulenta Loeblich & Tappan; Albani 1968, p. 24, fig. 86.
Lagena sulcata spicata Cushman & McCulloch; Barker 1960, pl. 58, figs. 4–6.
Lagena sp.
Lagenosolenia sp.
Lenticulina antarctica Parr 1950.

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APPENDIX 2 (*continued*)

Lenticulina australis Parr 1950, p. 322, pl. 11, figs. 7, 8.
Lenticulina gibba (d'Orbigny); Barker 1960, pl. 69, figs. 8, 9.
Lenticulina tasmanica Parr 1950.
Loxostomum karrerianum (Brady); Hornibrook 1968, p. 77, fig. 14.
Mississippina concentrica (Parker & Jones); Barker 1960, pl. 105, fig. 1.
Neoconorbina sp.
Nonionella flemingi (Vella 1957), p. 37, pl. 9, figs. 183, 184 (as *Nonion*). This paper Fig. 4C)
Nonionella turgida (Williamson); Barker 1960, pl. 109, figs. 17–19.
Notorotalia finlayi Vella 1957, p. 49, pl. 1, figs. 4, 5, 9, 10. This paper Figs. 4D–F.
Notorotalia zelandica Finlay; Vella 1957, p. 11, 13, 55, pl. 2, figs. 31, 33, 34. This paper Figs. 4G–H.
Oolina hexagona (Williamson); Hayward & Buzas 1979, p. 68, pl. 23, fig. 286.
Oolina lineata (Williamson); Barker 1960, pl. 57, fig. 13.
Oolina melo d'Orbigny; Barker 1960, pl. 58, figs. 28–31.
Oolina tasmanica Parr; Hayward & Triggs in press, fig. 3, no. 18.
Oolina 2 spp.
Oridorsalis umbonatus (Reuss); Hayward & Buzas 1979, p. 68, pl. 24, figs. 295–296.
Patellina corrugata Williamson; Hornibrook 1961, p. 97, pl. 13, fig. 250.
Patellinella inconspicua (Brady); Hedley et al. 1967, pl. 9, fig. 7.
Pileolina radiata Vella 1957, p. 36, pl. 8, figs. 170, 171.
Planoglabratella opercularis (d'Orbigny); Hayward 1982, figs. 6c–d.
Rosalina bradyi (Cushman); Hedley et al. 1967, pl. 1, fig. 3, pl. 11, fig. 2. This paper Figs. 4I–J.
Rosalina irregularis (Rhumbler); Hedley et al. 1967, pl. 11, fig. 3.
Sigmavirgulina tortuosa (Brady); Barker 1960, pl. 52, figs. 31, 32.
Sigmoidella kagaensis Cushman & Ozawa 1928, p. 19, pl. 2, fig. 14.
Sigmoidina silvestri Cushman & Ozawa 1928.
Sigmomorphina lacrimosa Vella 1957, p. 31, pl. 8, figs. 149–151.
Siphonina tubulosa Cushman; Barker 1960, pl. 96, figs. 5–7.
Sphaeroidina bulloides d'Orbigny; Barker 1960, pl. 84, figs. 1–7.
Spirillina vivipara Ehrenberg; Barker 1960, pl. 85, figs. 1–4.
Trifarina angulosa (Williamson); This paper Fig. 4K.
Vaginulina sp.
Vagocibicides maoria (Finlay); Hornibrook 1961, p. 165, pl. 26, fig. 515.

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Globigerina bulloides d'Orbigny; Hayward 1983, p. 64, figs. 2C–E.
Globigerina falconensis Blow; Hayward 1983, p. 64, figs. 2I–K.
Globigerina quinqueloba Natland; Hayward 1983, p. 64, figs. 2O–Q.
Globigerinella aequilateralis (Brady); Hayward 1983, p. 49, figs. 3A–C.
Globigerinita glutinata (Egger); Hayward 1983, p. 70, figs. 3F–H.
Globorotalia hirsuta (d'Orbigny); Hayward 1983, p. 70, figs. 4G–I.
Globorotalia inflata (d'Orbigny); Hayward 1983, p. 70, figs. 4J–L
Globorotalia scitula (Brady); Hayward 1983, p. 70, figs. 4M–O.
Globorotalia truncatulinoides (d'Orbigny); Hayward 1983, p. 71, figs. 4P–R.
Neogloboquadrina pachyderma (Ehrenberg); Hayward 1983, p. 71, figs. 5G–I.
Orbulina universa d'Orbigny; Hayward 1983, p. 70, fig. 5J.

APPENDIX 3 Main characterising species of the six benthic foraminiferal associations recognised in Port Pegasus. Species are arranged in order of decreasing Association Scores (Ass.Sc.) calculated from each species abundance (Abund.), fidelity (Fid.), persistence (Pers.), dominance (Dom.) and relative abundance (Rel.) within each association (see text for explanation).

	Dom.	Pers.	Fid.	Abund.	Rel.	Ass.Sc.
Association A						
Stns.2,3,4,5,6,19,20,21,22,27,28,29,30,31,32,35,39,40,41,42,43,56,57,58,59,60 = 26						
Trifarina angulosa	8.2	1.0	0.48	10.7	5.0	24.0
Textularia proxispira	4.0	0.92	0.70	5.7	2.8	17.5
Miliolinella subrotundata	3.5	0.92	0.72	4.3	2.0	16.2
Cassidulina carinata	4.2	0.88	0.36	5.4	2.2	14.5
Siphotextularia blacki	1.0	0.80	0.73	2.2	1.2	13.9
Gavelinopsis lobatulus	1.8	0.96	0.61	4.7	2.4	13.7
Anomalina spherica	2.5	0.96	0.54	3.7	1.2	13.2
Cibicides marlboroughensis	2.3	0.96	0.57	3.5	1.2	13.1
Dyocibicides sp.	2.0	0.92	0.44	3.3	0.9	11.3
Rosalina irregularis	1.6	0.88	0.43	3.0	1.0	10.5
Pileolina radiata	2.0	0.58	0.52	2.6	1.3	10.4
Quinqueloculina seminula	3.8	0.92	0.04	5.0	–1.3	10.4
Association A1						
Stns.3,4,5,6,20,22,27,29,30,32,39,40,42,43 = 14						
Trifarina angulosa	7.8	1.0	0.35	8.6	2.9	20.9
Textularia proxispira	4.8	0.93	0.51	7.4	4.5	18.2
Miliolinella subrotundata	3.4	1.0	0.72	4.5	2.2	16.6
Cibicides marlboroughensis	4.2	0.93	0.37	5.1	2.8	14.8
Pileolina radiata	3.3	0.71	0.55	3.8	2.5	13.7
Dyocibicides sp.	3.4	0.93	0.28	4.5	2.1	12.7
Rosalina bradyi	3.5	1.0	0.21	4.6	0.1	12.0
Gavelinopsis lobatulus	1.9	0.93	0.42	3.0	0.7	11.3
Cassidulina carinata	2.5	0.93	0.33	3.6	0.4	11.1
Quinqueloculina seminula	3.6	1.0	0.1	5.0	–1.3	10.9
Anomalina spherica	1.7	0.93	0.34	3.3	0.8	10.2
Elphidium novozealandicum	2.7	0.79	0.12	3.3	–0.7	8.6
Notorotalia finlayi	3.0	0.71	0.08	3.4	–2.0	8.8
Notorotalia zelandica	3.5	0.71	–0.06	4.0	–2.1	7.2
Association A2						
Stns.2,19,21,28,31,35,56,57,59,60 = 10						
Trifarina angulosa	9.3	1.0	0.32	13.1	7.4	25.8
Cassidulina carinata	7.2	0.9	0.26	7.8	4.6	19.2
Gavelinopsis lobatulus	4.8	1.0	0.47	6.6	4.3	17.8
Miliolinella subrotundata	4.4	0.9	0.54	4.8	2.5	16.1
Bolivina subexcavata	4.6	0.8	0.37	4.1	2.3	14.2
Hanzawaia bertheloti	2.5	1.0	0.53	4.3	2.9	14.0
Anomalina spherica	2.6	1.0	0.40	3.4	0.9	12.1
Siphotextularia blacki	1.5	0.9	0.61	2.5	1.5	11.9
Rosalina irregularis	2.2	0.9	0.30	3.2	1.2	10.4
Bolivina spathulata	1.3	0.7	0.53	2.4	0.6	9.9
Quinqueloculina delicatula	1.9	0.7	0.38	2.4	0.6	9.4
Evolvocassidulina orientalis	1.5	0.8	0.35	2.3	1.2	9.2
Textularia proxispira	2.6	0.9	0.51	3.5	0.6	7.5
Associationa A3						
Stns. 41,58 = 2						
Quinqueloculina seminula	10.0	1.0	0.1	13.5	7.2	25.1
Anomalina spherica	7.5	1.0	0.35	8.5	6.0	21.6
Textularia proxispira	5.0	1.0	0.47	4.5	1.6	16.3

(*Continued*)

APPENDIX 3 *(Continued)*

	Dom.	Pers.	Fid.	Abund.	Rel.	Ass.Sc.
Pileolina radiata	2.5	1.0	0.73	3.5	2.4	15.2
Trifarina angulosa	5.5	1.0	0.27	4.5	–1.2	14.4
Patellinella inconspicua	4.0	1.0	0.16	4.0	0.9	12.1
Association B						
Stns.23,25,49,51,52,53,54 = 7						
Notorotalia finlayi	10.0	1.0	0.40	24.1	18.7	37.3
Quinqueloculina delicatula	7.1	1.0	0.70	7.7	5.9	23.4
Nonionella flemingi	4.7	1.0	0.65	5.3	4.3	18.5
Anomalina spherica	5.4	1.0	0.38	6.0	3.5	17.3
Trifarina angulosa	3.9	1.0	0.30	5.0	–0.7	13.0
Quinqueloculina seminula	4.7	1.0	0.12	5.6	–0.7	12.8
Loxostomum karrerianum	1.0	0.86	0.80	2.0	1.7	12.5
Notorotalia zelandica	4.4	0.86	0.12	5.3	–0.8	11.8
Patellinella inconspicua	3.4	1.0	0.18	3.6	0.5	11.3
Bulimina submarginata	1.1	1.0	0.42	2.9	1.4	10.4
Elphidium advenum f. *advenum*	2.1	0.57	0.31	2.1	1.0	8.5
Association C						
Stns. 8,9,11,18,24,26,34,44,55 = 9						
Notorotalia zelandica	9.5	1.0	0.30	20.6	14.5	31.9
Elphidium novozealandicum	8.0	1.0	0.36	13.4	9.4	25.4
Quinqueloculina seminula	5.7	0.89	0.01	8.4	2.1	14.9
Rosalina bradyi	4.1	1.0	0.19	4.9	0.4	12.7
Patellinella inconspicua	3.2	1.0	0.19	4.1	1.0	11.5
Dyocibicides sp.	3.7	0.78	0.10	3.7	1.3	10.5
Trochammina sorosa	1.4	0.67	0.34	2.0	1.2	8.1
Elphidium advenum f. *depressulum*	2.2	0.56	0.16	3.4	0.3	7.5
Quinqueloculina colleenae	1.4	0.56	0.22	1.9	0.9	7.0
Association D						
Stn 47						
Rosalina bradyi	10.0	1.0	0.16	54.0	49.5	56.9
Rosalina irregularis	9.0	1.0	0.36	13.0	11.0	26.9
Quinqueloculina seminula	8.0	1.0	0.13	8.0	1.7	18.7
Patellinella inconspicua	7.0	1.0	0.16	4.0	0.9	15.7
Association E						
Stns.12,13,14,15,33,45,46,48 = 8						
Ammonia beccarii	6.8	0.75	0.59	25.5	21.6	34.0
Elphidium advenum f. *depressulum*	7.1	0.88	0.59	16.1	13.0	28.0
Haynesina depressula	6.2	0.88	0.51	8.1	6.0	20.5
Quinqueloculina seminula	5.9	1.0	0.09	12.4	6.1	19.2
Miliolinella labiosa	3.1	0.5	0.44	3.1	2.6	11.4
Trochammina sorosa	1.6	0.63	0.36	2.0	1.2	8.6
Elphidium advenum advenum	3.1	0.38	0.09	3.5	2.4	8.3
Elphidium novozealandicum	2.3	0.75	0.06	3.4	–0.6	7.5
Association E1,E2						
Stns.12,13,33,45,46,48 = 6						
Elphidium advenum f. *depressulum*	6.7	0.83	0.52	15.8	12.7	27.5
Haynesina depressula	7.8	1.0	0.63	10.5	8.4	26.6
Quinqueloculina seminula	6.5	1.0	0.12	15.3	9.0	22.4
Ammonia beccarii	5.5	0.5	0.28	14.5	10.6	20.6
Elphidium novozealandicum	3.0	1.0	0.34	4.5	0.5	12.5

(Continued)

APPENDIX 3 (*Continued*)

	Dom.	Pers.	Fid.	Abund.	Rel.	Ass.Sc.
Trochammina sorosa	2.2	0.83	0.58	2.7	1.9	12.4
Rosalina bradyi	3.2	1.0	0.18	5.5	1.0	12.0
Elphidium advenum f. *advenum*	3.2	0.5	0.23	4.7	3.6	10.9
Notorotalia finlayi	3.2	0.67	0.02	4.2	–1.2	8.2
Association E3						
Stns. 14,15 = 2						
Ammonia beccarii	10.0	1.0	0.78	58.5	54.6	65.5
Elphidium advenum f. *depressulum*	9.0	1.0	0.65	17.0	13.9	31.9
Miliolinella labiosa	8.0	1.0	0.91	9.5	9.0	25.1
Quinqueloculina seminula	4.0	1.0	0.11	3.5	–2.8	10.4
Association F						
Stns.16,17,36,37,38 = 5						
Miliammina fusca	10.0	1.0	0.96	68.6	62.5	73.9
Haplophragmodes wilberti	3.4	0.6	0.60	5.2	4.7	12.7
Cassidulina carinata	4.0	0.8	–0.10	4.2	1.0	8.2
Trochamminita irregularis	1.8	0.2	0.20	4.4	4.0	7.6
Trifarina angulosa	3.2	0.4	–0.37	2.6	–3.1	2.6