

Chatham Island foraminifera (Protista), New Zealand

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(Received 27 January 1999; revised and accepted 2 June 1999)

Abstract

One hundred and twenty-five species of benthic and nine species of planktic foraminifera are recorded from shallow inner shelf (0-35 m) and paralic environments around Chatham Island. This low diversity benthic fauna (c. 30% of New Zealand shallow water fauna) results from the Chathams' long and distant isolation (c. 65 million years, c. 850 km) from the main islands and the low diversity of marine habitats and sediment substrate types present. Cluster analysis of the quantitative counts of the benthic foraminifera in 17 samples allows the recognition of three sample associations: 1. an *Ammonia parkinsoniana* association occurs in the slightly hyposaline, shallow Te Whanga Lagoon; 2. a *Bolivina compacta-Elphidium advenum-Bolivina pseudoplicata* association occurs in the relatively sheltered, shallow Port Hutt embayment; and 3. a *Cibicides dispars-Trifarina angulosa-Trochulina dimidiatus* association in exposed Petre Bay. This latter association is also washed into the small Nairn River Estuary where it drowns out a depauperate brackish water fauna.

Ninety percent of the Chatham Island benthic species also occur widely around mainland New Zealand. Chatham Island is the southernmost extent of range for the remaining 10% of the fauna. Just one species, *Discorbinella deflata*, appears to be endemic to the Chatham Islands today, although it was present around the South Island in the Miocene. The majority of the Chatham fauna appears to have arrived by current dispersal from mainland New Zealand during the Pliocene and Quaternary.

Keywords: Foraminifera - associations - ecological distribution - island biogeography - Chatham Island - New Zealand

Introduction

Foraminifera are microscopic marine Protozoa that live in vast numbers in seafloor sediments and in the plankton. As they grow, they build themselves single or multi-chambered shells of calcite, aragonite or sand grains. Upon death the empty shells are commonly fossilised in the seafloor sediment and have been doing so in similar abundance over the past 100 million years or more. Because of this and their evolutionary succession of forms, foraminifera are one of the most studied and valuable groups of fossils for determining the age of sedimentary rocks and the

paleoenvironments in which they accumulated. Information on the present day ecologic and biogeographic distribution of foraminifera, like that presented in this study, is important in understanding and interpreting the fossil record of their ancestors, and gives us insight into the process of speciation in island habitats.

Previous work

This paper provides the first published records of Recent foraminifera from around the Chatham Islands, although there have been a number of reports on the recent and fossil foraminifera of the Chatham Rise to the west.

Table 1 Chatham Island station and foraminiferal faunal data.

No.	Location	Cat. no. ^{1,2}	Latitude/Longitude	Depth (m)	Substrate	% planktics	Diversity			Association
							α	H	E	
1	Waitangi Bay	L14036	43°56.47'S, 176°33.76'W	10	fine sand	1	15	2.84	0.83	C
2	Nairn River estuary	L14042	43°57.36'S, 176°33.33'W	1.5	fine sand	3	8	2.68	0.88	C
3	2 km W of Kahunene Pt	L14055	43°57.22 S, 176°36.34'W	35	coarse sand	0	4	1.89	0.71	C
4	3 km N of Pt Weeding	L14059	43°54.90'S, 176°34.37'W	25	fine sand	0	9	2.54	0.82	C
5	750 m SW of Red Bluff	L14060	43°54.20'S, 176°33.08'W	12	fine sand	3	8	2.34	0.77	C
6	200 m W of Red Bluff	L14061	43°54.19'S, 176°32.74'W	6	coarse sand	1	11	2.74	0.84	C
7	3.5 km N of Waitangi	L14063	43°54.80'S, 176°32.81'W	11	fine sand	0	12	2.65	0.80	C
8	3 km N of Waitangi	L14064	43°55.51'S, 176°32.64'W	9	fine sand	1	10	2.47	0.78	C
9	Port Hutt	L14083	43°48.53'S, 176°42.43'W	6	fine-medium sand	1	7	2.56	0.85	B
10	Port Hutt	L14084	43°48.60'S, 176°42.48'W	4	fine-medium sand	1	6	2.46	0.85	B
11	Port Hutt	L14085	43°48.54'S, 176°42.44'W	3	fine-medium sand	0	5	2.16	0.78	B
12	Port Hutt	L14086	43°48.49'S, 176°42.37'W	4	fine-medium sand	1	8	2.48	0.81	B
13	Port Hutt	L14087	43°48.53'S, 176°42.43'W	4	fine-medium sand	4	6	2.39	0.84	B
14	Port Hutt	L14088	43°48.78'S, 176°42.46'W	4	fine-medium sand	13	9	2.75	0.88	B
15	Port Hutt	L14089	43°48.82'S, 176°42.49'W	2	fine-medium sand	35	10	2.65	0.83	B
16	Te Whanga Lagoon	L14090	43°51.85'S, 176°31.21'W	2.5	shelly coarse sand	4	2	0.66	0.32	A
17	Te Whanga Lagoon	L14091	43°51.81'S, 176°30.95'W	3.2	weedy coarse sand	10	1	0.54	0.30	A
18*	1 km off Waitangi	F201913	43°56.20'S, 176°33.80'W	13	fine-medium sand					
19*	E of Cape Young	F201914	43°41.00'S, 176°33.00'W	20	shelly sand					

1 Catalogue numbers prefixed by L are held in the Auckland Museum marine department collections.

2 Catalogue numbers prefixed by F are held in the Micropaleontology Collections of the Institute of Geological and Nuclear Sciences, Lower Hutt.

* Qualitative samples only containing additional planktic records.

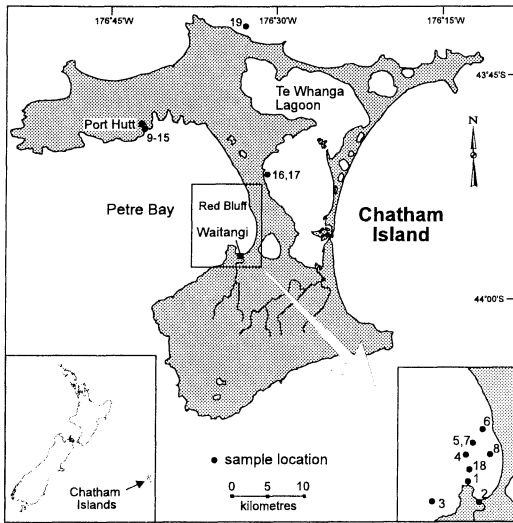


Figure 1 Foraminiferal sediment sample locations around Chatham Island, east of the South Island of New Zealand.

Fossil foraminifera from the Cenozoic rocks of the Chatham Islands were documented by Cole (1962), Scott in Hay *et al.* (1970), Hornibrook in Grindley *et al.* (1977) and most extensively by Hayward, Hornibrook and Strong in Campbell *et al.* (1994).

This study

Here we describe the benthic foraminiferal associations in 17 surface sediment samples from paralic and inner-shelf environments around the largest island of the Chatham Islands group, New Zealand (Fig. 1, Table 1). The Chatham Islands (44°S, 176° 30'W) are located 850 km east of Christchurch, at the eastern end of the Chatham Rise, a major elongate submarine extension of the New Zealand subcontinent. The largest island in the group, Chatham Island, has a maximum width of 57 km measured east to west across the northern end of the island and a maximum length, north to south, of 49 km. Pitt Island, 22 km to the south-east of Chatham, is the only other sizable island in the group.

Character of Chatham Islands marine area

The Chatham Islands lie within the Subtropical

Front (STF) where southward-flowing currents of warm, saline subtropical waters come into direct opposition with cold and less saline, Subantarctic waters (Bradford-Grieve *et al.* 1991, Carter *et al.* 1998). The effect of the STF is apparently evident in the marine faunas living around the Chatham Islands, with cooler water organisms predominating on the southern and west-facing coasts and warmer water organisms on northern and east-facing coasts (Dell 1956, 1960). Analysis of the biological community structure and limited oceanographic measurements also suggest that the STF could be found north or south of the islands on occasions (Knox 1957). Stanton (1997) sought to test whether the STF does indeed move north and south of the islands by using available sea level and sea surface temperature (SST) data. Although he found variability at a variety of scales, there was little evidence for movement of the STF. The SST data range for 1992-94 was 10-15°C (Stanton 1997, fig.1) and the annual mean SST around the Chatham Islands for a 60 month data set range was 12-13°C (Uddstrom & Oien in press). In Te Whanga Lagoon, Chatham Island (Fig.1), temperatures are likely to be seasonally warmer because of the shallow water depth and limited circulation.

Our samples (Fig. 1) come from inner shelf (2-35 m), normal marine salinity environments in Port Hutt (stations 9-15) and Petre Bay (stns 1, 3-8), on the west side of Chatham Island; from one of the few estuaries present - at the mouth of Nairn River in Waitangi township (stn. 2); and from Te Whanga Lagoon (stns 16,17). This limited foraminiferal data set is insufficient to test the biogeographic observations of Dell (1956, 1960).

Port Hutt is an elongate (1 km long), relatively sheltered, south-facing, shallow (2-6 m depth) embayment carpeted by clean, fine-medium quartz sand. Petre Bay is a wide (25 km across), relatively exposed, moderately deep (up to 50 m), west-south-west-facing bay. The floor of much of the deeper, outer part of the bay is

swept clean of sediment by currents or storm waves and is floored by rock. Nearer the shore, it is floored by clean fine to coarse, quartz sand. Nairn Estuary is a small (200 × 20 m), high tidal estuary at the mouth of a small stream (Nairn River) and is filled with fine quartz sand, shells and debris washed in from Petre Bay. Te Whanga Lagoon is a large (15 × 30 km), shallow (up to 4 m), saline lagoon with an intermittently open entrance on the eastern side of Chatham Island. The lagoon is carpeted with an anaerobic mixture of coarse quartz sand and rotting weed.

Geological History

The geologic history of the Chathams has relevance to foraminiferal biogeography discussed below. Although older basement rocks exist, the Chatham Islands may be described as the remnants of late Cretaceous volcanic islands. They appear to have been the locus of thin biogenic and authigenic sediment accumulation around remnant oceanic islands on a marine shelf for much of the time since the late Cretaceous (Campbell *et al.* 1994). The style of sedimentation changed in the late Pliocene with a switch to the accumulation of quartzose sands and peats, which continues to the present day. As such the Chathams have been a relatively shallow submarine extension of the Chatham Rise during the Cenozoic. A disjointed record of foraminifera that lived in shallow-water (shelf) through the Cenozoic in the Chatham Islands area is preserved in patchy outcrops of sedimentary rocks on the present-day islands (Campbell *et al.* 1994).

Methods

Field

Samples were collected using a 10-litre capacity bucket dredge, hand-hauled from a 3 m inflatable dinghy or from a local crayfishing boat during an Auckland Museum field trip to Chatham Island in March 1995. Typically the dredge bites

to a depth of c. 70 mm into the seafloor sediment.

Laboratory

Mud was removed from samples by washing over a 63 mm sieve. Foraminiferal tests from the dried sand fraction were concentrated by flotation with carbon tetrachloride. The dried float from each sample was microsplit to a subsample containing approximately 100 benthic foraminiferal tests. These were then picked, mounted, identified, and counted. From the same subsample planktic foraminifera were also picked and counted. The remaining unpicked float from selected samples was subsequently scanned and specimens of any additional rarer taxa were picked to give a more complete species list (Appendix 2).

Our previous studies have shown that picking just 100 benthic foraminifera provides a sufficiently accurate assessment of faunal composition for use in identifying and mapping associations. The computer programmes employed, below, are primarily influenced by the dominants in each fauna and picks of 100 specimens readily identify these (e.g. Hayward *et al.* 1997a). Larger populations are unnecessary for this type of study.

The Chatham Island specimens and faunas used in this study come from:

a) The Auckland War Memorial Museum, Auckland, New Zealand (formerly Auckland Institute and Museum). Sample catalogue numbers prefixed by L.

b) The New Zealand national collection of foraminifera held by the Institute of Geological and Nuclear Sciences (IGNS), Lower Hutt, New Zealand (formerly New Zealand Geological Survey and DSIR Geology and Geophysics). Sample catalogue numbers prefixed by F; specimen catalogue numbers prefixed by FP (figured and on slides) or by BWH (figured and left on SEM stubs).

A full reference list of identified species encountered in this study has been compiled

(Appendix 1).

Statistical

The data consists of counts of the distribution of 86 species in 17 samples (Appendix 2). 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. 2), 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 obtain a dendrogram classification of 28 abundant species (>5% in any sample), from which species associations were selected (Fig. 2). 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).

Species Diversity

Three measures of species diversity have been calculated for each fauna:

1. **Fisher α index**, $\alpha = N(1-x)/x$, where N is the number of individuals in a sample and x is a constant related to the number of species (see Fig. 125 of Williams 1964). Values of α can be read directly from a graph (Murray 1991, p.319).

2. **Shannon-Wiener Information Function**, $H = -\sum P_i \log_e P_i$, where P_i is the proportion of the i th species (MacArthur & MacArthur 1961; Gibson & Buzas 1973). Unlike α , the Information Function places little weight on rare and very abundant 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.

3. **Evenness**, $E = e^H/S$, is a measure solely of even-

ness of species counts within a fauna, irrespective of the number of species present (Buzas & Gibson 1969, Hill 1973).

Sample Associations

The following three sample associations were selected by inspection from the cluster analysis dendrogram (Fig. 2) and their geographic distribution is shown in Fig. 3. In the discussions the sample associations are related to the species associations, although the species associations are not separately documented.

Association A: Ammonia parkinsoniana

Stations: 16, 17 = 2

Dominant species association: 6 (Fig. 2)

Area: Te Whanga Lagoon

Depth: 0-3 m

Sediment: shelly and weedy coarse sand

Diversity: $\alpha = 1-2$; $H = 0.5-0.7$; $E = 0.30-0.32$

This association has very low species diversity and equitability (E), being dominated exclusively by *Ammonia parkinsoniana* (species association 6, 85-90% of total benthic fauna). Also consistently present in low numbers (1-5%) are *Elphidium advenum* f. *maorium*, *E. excavatum* f. *clavatum* and *Cibicides dispers*.

Similar faunal associations with such a high dominance of *Ammonia parkinsoniana* are known from many places around New Zealand. They occur at shallow subtidal depths (0-5m) and in the lower half of the intertidal zone in channels and tidal mud and sand flats at the seaward end of estuaries and in the upper reaches of harbours and tidal bays, where salinity is just slightly lower than normal marine values (Hayward & Hollis 1994). This occurrence of *Ammonia* association in the slightly hyposaline Te Whanga Lagoon extends the known environments in which it occurs in New Zealand. Conditions in the lagoon are presumably quite similar to the other places where this association occurs.

Associations dominated by *Ammonia*

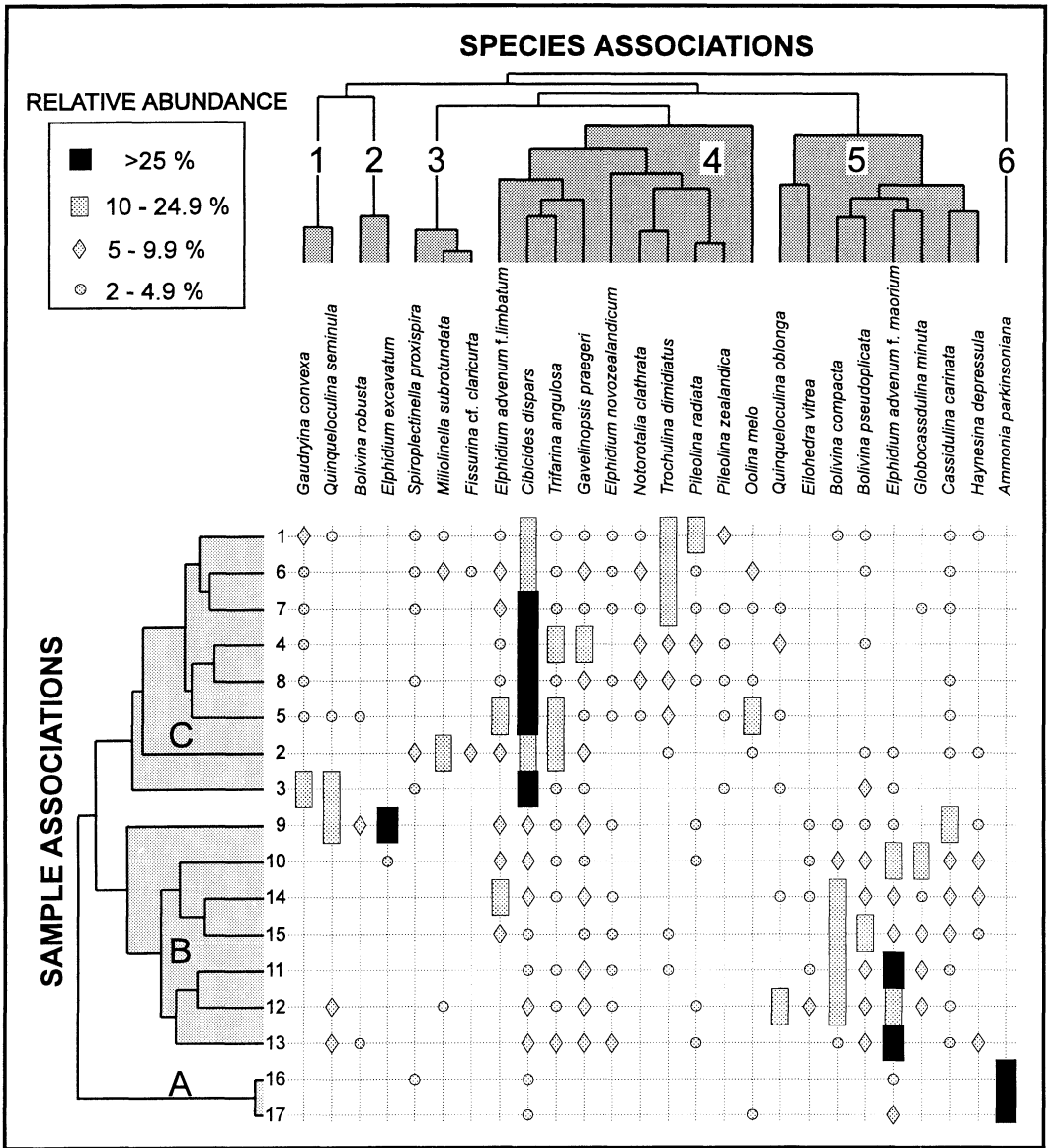


Figure 2 Dendrogram classifications of Chatham Island samples (left) produced by cluster analysis using Bray-Curtis distance, and common species (top) produced by cluster analysis using modified Morista distance (Rohlf 1989). The three sample associations (A-C) and six species associations (1-6) were selected by the authors after inspection of the dendrograms. The relative abundance of each species in each sample is summarised in the chart, produced using the MVSP statistical package (Kovach 1993).

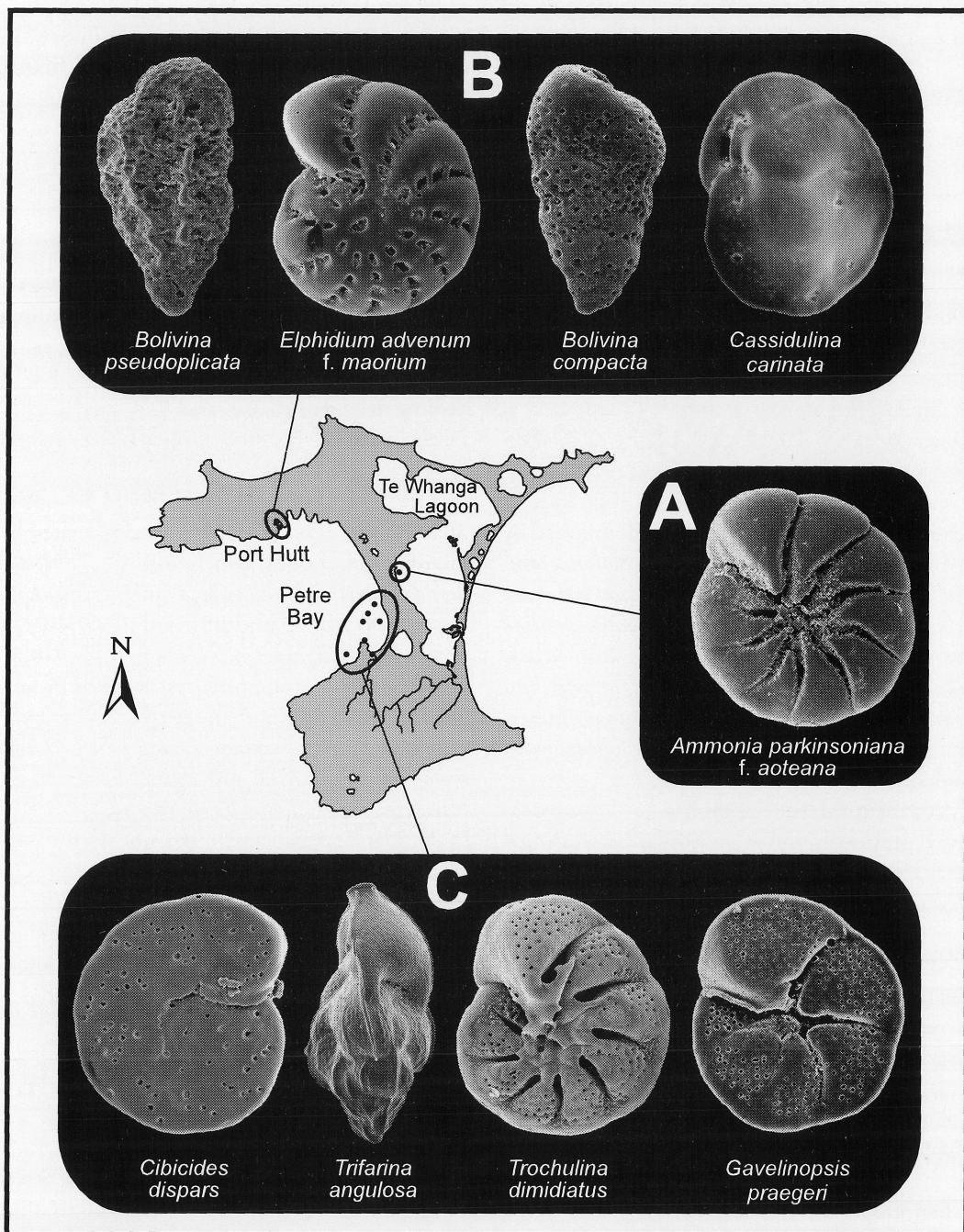


Figure 3 Distribution of the three foraminiferal sample associations around Chatham Island and scanning electron microscope illustrations of the dominant species in each.

parkinsoniana are common throughout the world in marine, hyposaline and hypersaline lagoons and inner shelf environments at depths down to about 25m (Murray 1991). Low diversity faunas such as this are characteristic worldwide of brackish, shallow-water environments.

Association B: Bolivina compacta - Elphidium advenum f. maorium - Bolivina pseudoplicata

Stations: 9-15 = 7

Dominant species association: 4, 3 (Fig. 2)

Area: Port Hutt

Depth: 2-6 m

Sediment: fine to coarse sand

Diversity: $\alpha = 5-10$; $H = 2.2-2.8$; $E = 0.78-0.85$

This association has relatively high species diversity and equitability. It is co-dominated by members of species association 5 - *Bolivina compacta*, *B. pseudoplicata* and *Elphidium advenum f. maorium* with subdominant *Globocassidulina minuta*, *Cassidulina carinata*, *Elphidium advenum f. limbatum*, *Cibicides dispars* and *Gavelinopsis praegeri*. Other frequent taxa mostly limited to this association include *Eilohedra vitrea* and *Haynesina depressula*.

An identical association has not been recognised previously, but it has similarities at the generic level with: the *Bolivina cf. translucens-Textularia earlandi-Bolivina subexcavata* association in muddy very fine sand in the shallow (1-2.5 m) central basin of Pauatahanui Inlet, Wellington (Hayward & Triggs 1994); the *Nonionella flemingi-Bolivina pseudoplicata* association in muddy fine sand in sheltered inner shelf (12-35 m) parts of Port Fitzroy, Great Barrier Island (Hayward & Grenfell 1994); and the *Eilohedra vitrea-Haynesina depressula* association in muddy sand in shallow bays of outer Queen Charlotte Sound (Hayward *et al.* 1997a). These areas and Port Hutt share in common a relatively shallow, sheltered bay environment with a fine sediment substrate. *Elphidium advenum f. maorium* is most common around New Zealand in sheltered environments in slightly brackish

water inside the entrances to harbours and inlets (Hayward *et al.* 1997b). *Bolivina* is known to thrive in muddy, somewhat anaerobic substrates, although more commonly at bathyal depths (Murray 1991).

Association C: Cibicides dispars - Trifarina angulosa - Trochulina dimidiatus

Stations: 1-8 = 8

Dominant species association: 3, 2, 1 (Fig. 2)

Area: Waitangi corner of Petre Bay, including Nairn River estuary

Depth: 1-35 m

Sediment: fine to coarse sand

Diversity: $\alpha = 4-12$; $H = 1.9-2.8$; $E = 0.71-0.88$

This association has relatively high species diversity and equitability. It is co-dominated by members of species association 4 - *Cibicides dispars*, *Trifarina angulosa* and *Trochulina dimidiatus* with subdominant *Gavelinopsis praegeri* and *Elphidium advenum f. limbatum*. Other frequent taxa mostly restricted to this association include *Gaudryina convexa*, *Notorotalia clathrata*, *Pileolina radiata*, *P. zealandica*, *Oolina melo*, *Spiroplectinella proxispira*, *Fissurina cf. claricurta* and *Miliolinella subrotundata*.

An identical association has not been recognised previously, although it has dominant elements in common with: the *Trochulina dimidiatus* association in medium sand in a shallow (5 m), moderately exposed bay at the Chickens Islands, Northland (Hayward *et al.* 1984); a *Cibicides corticatus-Trochulina dimidiatus* association in medium-fine sand in exposed shallows (5-10 m) off Cuvier Island, Bay of Plenty (Hayward & Grace 1981); and the *Trifarina angulosa-Spiroplectinella proxispira* association in fine-coarse sand and gravel in the current- and wave-swept entrance channels (3-45 m) to Port Pegasus, Stewart Island (Hayward *et al.* 1994). The first two of these associations differ from the Chatham association by the virtual lack of *Trifarina angulosa* and the last differs in the lack of *Trochulina dimidiatus*. These areas and Petre

Bay share in common an exposed, sandy, aerobic, inner shelf environment.

The fauna from Nairn River estuary (dominated by obligately marine species such as *Miliolinella subrotundata*, *Cibicides dispars* and *Trifarina angulosa*) is largely derived from offshore and has been carried in by storms and incoming tides. As a consequence it has a greater relative abundance of smaller and less dense shells (e.g. *Miliolinella subrotundata*) than exposed Petre Bay. Probably the only autochthonous species in the estuary fauna are *Miliammina fusca*, *Eggerella advena*, *Elphidium excavatum*, *Elphidium advenum* and *Haynesina depressula*.

At a generic level, a similar association to this occurs off the coast of southern California and Mexico. Here a *Cibicides-Trochulina* association occurs in fine sand at 2-125 m with abundant *Trifarina angulosa* at depths of 60-550 m (McGlasson 1959, Uchio 1960).

Planktic Foraminifera

The relative abundance of planktic foraminiferal tests ranges between 0 and 3% in Petre Bay, 0-13% in Port Hutt and 4-10% in Te Whanga Lagoon.

The presence of planktics in Te Whanga Lagoon probably results from an accumulation over time of planktic tests swept into the lagoon by strong tidal currents when the entrance is open. The slightly inflated values in some Port Hutt samples result from abundant planktic tests being swept into and then trapped in the elongate port. In both situations the tests then slowly sink out of suspension in the enclosed, calmer waters.

The two most common planktics present, *Globigerina falconensis* and *G. quinqueloba*, are both relatively small species that live in neritic water and are also the most common planktics in shallow-water sediments around the rest of northern and central New Zealand (e.g. Hayward & Grenfell 1994). Only a few tests of planktic species that appear to live primarily in

oceanic water (e.g. *Globorotalia inflata*, *G. truncatulinoidea*) have been washed into the shallows around Chatham Island.

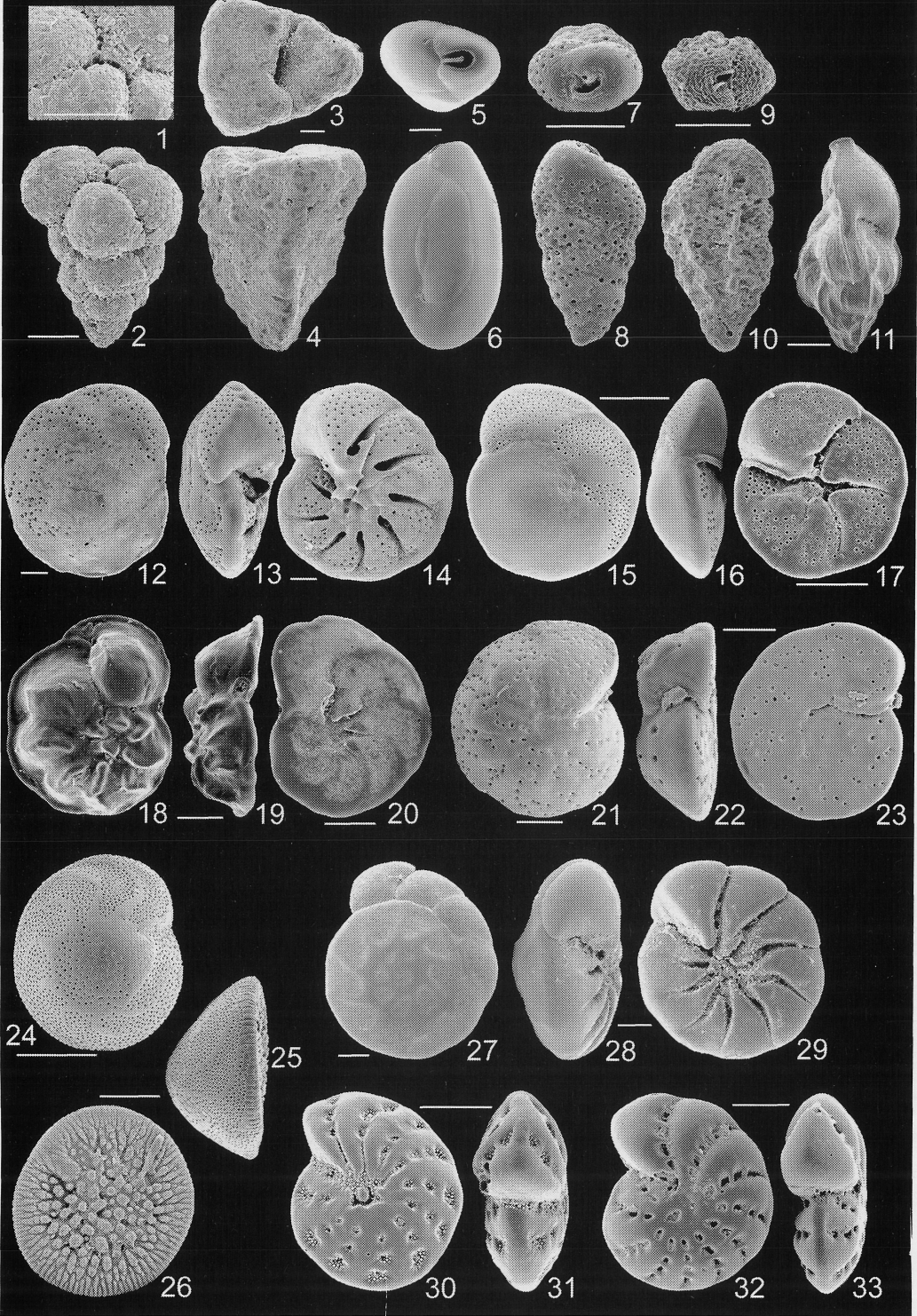
Biogeography

The biogeography of the marine macrofauna and flora of the Chatham Islands has been studied previously (e.g. Finlay 1926, Dell 1960, Knox 1975). There are striking features of the intertidal ecology of the islands which make the Moriorian Province (Powell 1955) as distinct as any in the New Zealand region. They are: 1) the complete absence of many of the commoner species of the mainland shores; 2) the highly characteristic zonation patterns; 3) the mixture of northern and southern species (Aupourian and Forsterian Provinces) and 4) "the peculiar characteristics of the fauna and flora due to the elements missing as much as to those present" (Dell 1960, Knox 1975).

The biogeography of New Zealand shallow-water benthic foraminifera is discussed by Hayward *et al.* (1999). Using Q-mode cluster analysis (Jaccard similarity coefficient) on a New Zealand-wide data set they identified six groups which produce mappable regions, including a Moriorian foraminiferal province, restricted to the Chatham Islands.

Finlay (1926) concluded "the Recent molluscan fauna of the Chatham Islands is not a remnant or an evolution of the Tertiary fauna found there, but a repopulation from the mainland, in post-Pliocene times, but yet not long enough ago for characteristic regional species and subspecies to have evolved". The conclusion that the present-day littoral macrofauna and flora are derived from the New Zealand mainland is supported by oceanic and geological evidence. Ocean currents are known to be favourable for the transport of larvae and epiplanktonic adults from New Zealand to the Chathams (Knox 1960, Carter *et al.* 1998). Inferred shallowing in the Chathams area in the late Pliocene (Campbell *et al.* 1994) probably greatly increased the diversity of intertidal and shallow marine habitats. These may

PLATE 1



have been greatly restricted during much of the Cenozoic, when just a few oceanic islands existed in the area.

Benthic Foraminifera

In this study we record 125 benthic species from paralic and inner-shelf environments around the Chatham Islands. This diversity is low compared with areas of similar size studied in a similar way around the three main islands of New Zealand - e.g. Cavalli Islands, Northland with 221 species (Hayward 1982); northern Great Barrier Island, Auckland with 195 species (Hayward & Grenfell 1994); Port Pegasus, Stewart Island with 144 species (Hayward *et al.* 1994). Some of the lower diversity at Chatham Island may be a result of the less diverse array of sheltered shallow marine habitats and substrates available, but we speculate that marine climate and biogeographic history are the most influential factors.

The southwards decrease in diversity for the New Zealand mainland (304 species north-east North Island, 242 species central New Zealand, 193 species southern South Island - Hayward *et al.* 1999) is largely a result of the presence of a number of warmer-water species with northern-restricted ranges (Aupourian Province). Around New Zealand there appear to be few cooler-water species with southern-restricted ranges (Hayward *et al.* 1999). About 90% of the species recorded from Chatham Island also occur around all three main islands of New Zealand (e.g. *Bulimina marginata*, *Cassidulina carinata*,

Elphidium charlottense, *Haynesina depressula*, *Patellinella inconspicua* and *Quinqueloculina seminula*). The remainder are species that occur around the North Island and have their southern limit in the vicinity of the northern South Island and Chatham Island (e.g. *Gaudryina convexa*, *Bolivina robusta*, *Bolivina spinescens*, *Ehrenbergina mestayerae*, *Mississippina omuraensis*). Two species (*Pseudoflintina triquetra*, *Fissurina cf. southbayensis*) occur off the east coast of the northern North Island (Hayward *et al.* 1999) and at Chatham Island but have not been recorded in between. One southern-restricted species (*Triloculina striatotriconula*) occurs off Chatham and Stewart Islands (Hayward *et al.* 1999).

At Chatham Island we found one endemic species (*Discorbinella deflata*). Although it is currently endemic to the Chatham Islands it occurs in the lower Miocene of Westland, South Island (Finlay 1940). *D. inflata* probably evolved around mainland New Zealand, before dispersing east, and later became extinct there. Additionally of interest is the occurrence in the Nairn Estuary of the cosmopolitan brackish species *Eggerella advena*, which is not known from mainland New Zealand (Hayward & Hollis 1994).

Most of the abundant taxa in brackish and normal marine environments (Hayward *et al.* 1999) around mainland New Zealand are present around Chatham Island but some significant taxa are absent. Although the few brackish environments present were surveyed, *Jadammina macrescens*, *Haplophragmoides wilberti*,

Plate 1 (facing page) Scanning electron microscope photographs of characterising and more common species around Chatham Island. (Scale bar = 100 μm). **Fig. 1-2** *Eggerella advena* Cushman. BWH132/5, L14042, **3-4** *Gaudryina convexa* (Karrer). BWH130/32, L14055; **5-6** *Quinqueloculina oblonga* (Montagu). BWH132/11, L14059; **7-8** *Bolivina compacta* Sidebottom. BWH130/6, L14089; **9-10** *Bolivina pseudoplicata* Heron-Allen & Earland. BWH130/10, L14089; **11** *Trifarina angulosa* (Williamson). BWH130/22, L14060; **12** *Trochulina dimidiatus* (Jones & Parker). BWH132/1, L14061; **13-14** *Trochulina dimidiatus* (Jones & Parker). BWH132/2, L14061; **15-16** *Gavelinopsis praegeri* (Heron-Allen & Earland). BWH132/6, L14059; **17** *Gavelinopsis praegeri* (Heron-Allen & Earland). BWH132/8, L14059; **18-19** *Discorbinella deflata* (Finlay). FP4776, L14036; **20** *Discorbinella deflata* (Finlay). FP4777, L14036; **21** *Cibicides dispars* (d'Orbigny). BWH130/21, L14059; **22-23** *Cibicides dispars* (d'Orbigny). BWH130/18, L14059; **24-25** *Pileolina radiata* Vella. BWH132/12, L14036; **26** *Pileolina radiata* Vella. BWH132/13, L14036; **27** *Ammonia parkinsoniana* (d'Orbigny). BWH130/4, L14091; **28-29** *Ammonia parkinsoniana* (d'Orbigny). BWH130/2, L14091; **30-31** *Elphidium advenum f. limbatum* (Chapman). BWH132/15, L14060; **32-33** *Elphidium advenum f. maorium* Hayward. BWH130/16, L14084.

Trochammina inflata and *Trochammina salsa* were not found. In normal marine environments *Virgulopsis turris*, *Spiroloxostoma glabra* and *Cibicides marlboroughensis* are absent as are *Notorotalia* species, other than *N. hornibrooki* (e.g. *N. depressa*, *N. finlayi*, *N. inornata*, *N. zelandica*). These absences indicate that at least some common mainland species have been unable to successfully disperse eastwards to the Chathams or that suitable habitats do not exist.

A further possible explanation for the low diversity of the Chathams' fauna may lie in the much colder marine conditions that the islands' would have experienced during the numerous Quaternary glacial periods. Evidence in support of this postulate is the presence of the New Zealand endemic species *Pileolina calcarata* (late Oligocene-Recent), in the Chathams Pliocene (Campbell *et al.* 1994). It is not present in our study and appears to have died-off at the Chathams, probably during the colder glacial periods. Its present-day distribution is restricted to the warmer seas off the north-eastern North Island (Hayward *et al.* 1999).

The paucity of shallow-water benthic foraminifera endemic to the Chathams is a little surprising, considering the long period of Cenozoic isolation of the Chathams, separated (even during the peak of the Ice Ages) by 800-1000 km of sea from the rest of New Zealand. Such apparent isolation would usually be thought to cause endemism.

However, assuming that the present current patterns existed in the past (Carter *et al.* 1996), then small juvenile benthic foraminifera would have had plenty of opportunity to be swept in suspension across from shallow-water on the east coast of both the North and South islands. This potential method of trans-oceanic dispersal of shallow-water benthic foraminifera has received little or no study but appears the only logical explanation for the widespread distribution of many species both today and in the past (Hayward *et al.* 1997b). During the many glacial periods in the last few million years (when sea level

was 80-130m lower than today), there would have been several shoals (shallower than 100 m) along the length of the Chatham Rise that may have assisted eastwards dispersal of some shallow-water species.

Among the species present on Chatham Island are three obligate brackish taxa (*Elphidium excavatum* f. *excavatum*, *Eggerella advena* and *Miliammina fusca*). It is unlikely that they would have been carried in suspension and survived transport across the ocean. These cosmopolitan species may have been introduced on the feet of migratory wading seabirds (e.g. Hayward & Hollis 1994).

The fossil foraminiferal faunas of the Chatham Islands are not documented fully enough to accurately determine the times of arrival of the various benthic species from mainland New Zealand. It seems that the majority of the modern fauna are post-Miocene arrivals. Some of the Recent Chatham species (e.g. *Gaudryina convexa*, *Patellina corrugata*, *Astrononion novozealandicum*, *Haynesina depressula*, *Patellinella inconspicua*) are present in the Pliocene and Pleistocene rocks of the Chatham Islands, but none are recorded (so far) in the Oligocene or sparse Miocene Chatham microfaunas (Campbell *et al.* 1994). No species have their recorded earliest fossil occurrence at the Chathams prior to their earliest known occurrence around mainland New Zealand. Some of the Recent Chathams foraminifera with no fossil record on the islands, are presumably fairly recent arrivals as their first occurrence around mainland New Zealand is in the Pleistocene (e.g. *Cibicides corticatus*, *Trochulina dimidiatus*), late Pleistocene (e.g. *Saidovina karreriana*) or Recent (e.g. *Bolivina pseudoplicata*, *Elongobula iphigenaeae*, *Mississippina omuraensis*).

Although the Chathams may look to be a likely place to test models of allopatric speciation or accumulation of diversity through the process of 'archipelago speciation' (cf. Mayr 1970) there is little evidence of it occurring in either the macro- or micro-marine fauna. It seems likely

that the rates of speciation are too slow or that the gene flow from the mainland is strong enough to preclude any new species becoming established. It would appear that shallow-water benthic foraminifera generally form large sympatric populations for which there are ecological, rather than geographical barriers to overcome in terms of speciation.

Planktics

The Chatham Islands sit astride the Subtropical Front - the boundary between the transitional and Subantarctic planktic foraminiferal provinces (Bé 1977, Hayward 1983). All the planktic species recorded here occur in both provinces. Most of the planktics present in our shallow-water samples are neritic species, whereas the species diagnostic of the provinces are more oceanic and are only rarely present in this study. *Globorotalia inflata* is characteristic of the transitional province and is present in only one of our samples. Of the species characteristic of the Subantarctic province, *Neogloboquadrina pachyderma* is moderately common in our samples and *Globigerinita bradyi* is rare. Another abundant species in this cooler water, *Globigerina bulloides*, is absent from our shallow Chatham Island material.

Acknowledgements

We are grateful to Brett Stephenson, Jenny Riley and Chris Hollis for assistance in the field. We thank the Research Centre for Surface and Materials Science, Auckland University, for use of their scanning electron microscope, Kathryn Hayward for assistance with the figures, and Rowan Carter (Auckland University) and Chris Hollis (Institute of Geological and Nuclear Sciences) for reading the draft manuscript and for suggesting improvements.

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Appendix 1

List of foraminifera recorded from Chatham Island, with references to easily accessible published figures that best portray the species as interpreted by us.

Benthic Foraminifera

Suborder Textulariina

- Cribrostomoides jeffreysi* (Williamson). Haynes 1973, pl.2, figs 5-6, pl.8, fig. 9, pl.29, fig. 10, text-fig. 5.
- Eggerella advena* Cushman. Loeblich & Tappan 1953, pl.3, figs 8-10.
- Gaudryina convexa* (Karrer). Hayward & Grenfell 1994, fig. 4.
- Miliammina fusca* (Brady). Hayward & Hollis 1994, pl. 3, figs

5-8.

- Paratrochammina bartrami* Hedley *et al.* 1967, pl. 6, figs 2a-c, text-figs 9-10.
- Reophax* sp.
- Siphotextularia blacki* Vella 1957, pl. 4, figs 53-54.
- Siphotextularia mestayerae* Vella 1957, pl. 4, figs 55-57.
- Spiroplectinella proxispira* (Vella 1957), pl. 3, figs 48, 52.
- Textularia pseudogramen* Chapman & Parr. Yassini & Jones 1995, figs 118,119,123.
- Trochammina* sp.

Suborder Spirillinina

Patellina corrugata Williamson. Hornibrook 1961, p. 97, pl. 13, fig. 250.

Spirillina denticulogranulata Chapman 1907, pl.X, figs 6a-c.

Spirillina vivipara vivipara Ehrenberg. Jones 1994, pl. 85, figs 1-4.

Suborder Miliolina

Cornuspira involvens (Reuss). Hedley *et al.* 1967, text-fig. 16.

Inaequalina disparilis (Terquem). Vella 1957, pl.6, figs 122,123 (as *Spiroloculina*).

Miliolinella subrotundata (Montagu). Haynes 1973, p. 56, pl. 5, figs 5, 6, 12, 13.

Pseudoflintina triquetra (Brady). Jones 1994, pl.8, figs 8,9.

Pyrgo anomala (Schlumberger). Vella 1957, pl.7, figs 135,136 (as *Biloculina*).

Quinqueloculina agglutinans d'Orbigny. Hedley *et al.* 1965, pl.2, figs 7a,b.

Quinqueloculina bicostoides Vella 1957, p. 25, pl. 5, figs 89-92.

Quinqueloculina delicatula Vella 1957, p. 26, pl. 4, figs 77-79.

Quinqueloculina oblonga (Montagu). Yassini & Jones 1995 (as *Triloculina*), figs 188-192, 196-197.

Quinqueloculina parvaggulta Vella 1957, pl. 4; figs 71-73.

Quinqueloculina seminula (Linnaeus). Hedley *et al.* 1965, p. 13, pl. 2, figs 8a-b.

Quinqueloculina suborbicularis d'Orbigny. Vella 1957, p. 23, pl. 6, figs 102-104.

Quinqueloculina subpolygona Parr. Vella 1957, figs 86, 93 (as *Q. colleenae*).

Triloculina striatotrigonula Parr. Jones 1994, pl.4, figs 10a,b.

Triloculina trigonula (Lamarck). Yassini & Jones 1995, figs 200-201.

Suborder Lagenina

Astacolus crepidulus (Fichtel & Moll). Jones 1994, pl. 67, fig. 20.

Fissurina cf. *claricurta* McCulloch 1977, p. 95, pl. 58, fig. 16; Brook *et al.* 1981, fig. 5d.

Fissurina clathrata (Brady). Jones 1994, pl. 60, fig. 4; Yassini & Jones 1995, p.122, figs 454-457.

Fissurina cf. *crucifera* McCulloch 1977, pl. 58, fig. 2.

Fissurina cf. evoluta McCulloch. Hayward & Grace 1981, p. 50, fig. 5e.

Fissurina lucida (Williamson). Hayward & Triggs 1994, fig. 3, no. 17.

Fissurina semialata (Balkwill & Millett). Reid & Hayward 1997, fig. 7k,l.

Fissurina cf. *southbayensis* McCulloch 1977, pl.62, fig. 2.

Fronicularia compta Brady. Jones 1994, pl.65, fig. 19.

Globulina gibba (d'Orbigny). Jones 1994, pl.71, figs 11-12.

Grigelis orectus Loeblich & Tappan. Jones 1994, pl.62, figs 10-12 (as *Grigelis* n.sp.).

Guttulina cf. *regina* (Brady, Parker & Jones). Jones 1994, pl.73, figs 11-13 (as *Globulina*).

Guttulina silvestrii (Cushman & Ozawa). Cushman & Ozawa 1930, figs 6,7.

Guttulina yabei Cushman & Ozawa 1929, pl.13, fig. 2, pl.14, fig. 6.

Laevidentalina filiformis (d'Orbigny). Jones 1994, pl.63, figs 3-5 (as *Dentalina*).

Lagena flatulenta Loeblich & Tappan. Albani 1968, fig. 86.

Lagena laevicostatiformis McCulloch. Albani & Yassini 1989, figs

20-P. (as *L. maccullochae*).

Lagena aff. *spicata* Cushman & McCulloch. Jones 1994, pl. 58, figs 4, 25-6.

Lagenosolenia bradyformis McCulloch 1977, pl. 61, fig. 14.

Lagenosolenia confossa McCulloch 1977, pl.64, figs 7,8.

Lagenosolenia quadrirevertens McCulloch. Brook *et al.* 1981, fig. 5f.

Lagenosolenia strigimarginata Loeblich & Tappan 1994, p.93, pl.161, figs 9,10.

Lenticulina australis Parr 1950, pl. 11, figs 7, 8.

Lenticulina gibba (d'Orbigny). Hedley *et al.* 1965, pl.3, fig. 11; Jones 1994, pl. 69, figs 8, 9.

Oolina borealis Loeblich & Tappan. Boltovskoy *et al.* 1980, pl. 23, figs 7-8.

Oolina caudigera (Wiesner). Jones 1994, text-fig. 11.

Oolina globosa (Montagu). Yassini & Jones 1995, p. 112, figs 369-370.

Oolina hexagona (Williamson). Hayward & Buzas 1979, p. 68, pl. 23, fig. 286.

Oolina lineata (Williamson). Jones 1994, pl. 57, fig. 13.

Oolina melo d'Orbigny. Jones 1994, pl. 58, figs 28-31.

Palliolatella aradisiformis Albani & Yassini 1989, fig. 5F; Yassini & Jones 1995, figs 874-875.

Parafissurina cf. caledoniana McCulloch 1981, pl. 36, figs 4, 6.

Pseudopolymorphina sp.

Suborder Robertinina

Ceratobuliminoides cf. *bassensis* Parr 1950, pl.14, figs 12a-c.

Suborder Rotaliina

Acervulina inhaerens Schulze. Hedley *et al.* 1967, pl.1, fig. 2

Ammonia parkinsoniana f. *aoteana* (Finlay). Hayward & Hollis 1994, pl. 4, figs 1-3.

Anomalinoides sphericus (Finlay). Hornibrook 1968, fig. 13

Astrononion novozealandicum Cushman & Edwards. Hedley *et al.* 1965, p. 24, pl. 7, fig. 28.

Bolivina compacta Sidebottom. Hedley *et al.* 1967, p. 30, pl. 9, fig. 3.

Bolivina pseudoplicata Heron-Allen & Earland. Hedley *et al.* 1967, pl. 9, fig. 4.

Bolivina robusta Brady. Jones 1994, pl. 53, figs, 7-9.

Bolivina spatulata (Williamson). Hedley *et al.* 1965, text-figs 6a-g, pl.6, figs 2a-b.

Bolivina spinescens Cushman 1911, p. 46, fig. 76a-b.

Bolivina subexcavata Cushman & Wickenden. Hayward & Grace 1981, fig. 5c.

Bulimina gibba Fornasini. Jones 1994, pl. 50, figs 1-4.

Bulimina marginata f. *marginata* d'Orbigny. Hayward & Grenfell 1994, fig. 16.

Bulimina marginata f. *acanthia* Costa. Boltovskoy *et al.* 1980, pl.5, figs 10-12 (as *B. marginata*).

Cassidulina carinata Silvestri. Hayward 1982, fig. 6k.

Cibicides corticatus Earland. Vella 1957, pl.9, figs 195-197.

Cibicides disparis (d'Orbigny). Hayward 1982, figs 6v-w (as *C. cf. ungerianus*).

Colonimilesea coronata (Heron-Allen & Earland).). Hornibrook 1961, pl.15, figs 310,311,318.

Conorbella sp.

Discorbinella bertheloti (d'Orbigny). Hayward 1982, fig. 6q-r. Hayward & Grenfell 1994, fig. 24.

Discorbinella complanata (Sidebottom). Hornibrook 1961, pl. 27, fig. 532.

Discorbinella deflata (Finlay). Hayward *et al.* 1999, pl. 14, figs 7-9.
Discorbinella subcomplanata (Parr). Parr 1950, pl.14, figs 1,2.
Discorbinella timida Hornibrook 1961, p. 116, pl. 14, figs 288, 293, 297.
Dyocibicides sp.
Ehrenbergina mestayeri Cushman. Eade 1967, fig. 8, nos 6,7.
Eilobedra vitrea (Parker). Hayward & Grenfell 1994, figs 21-22.
Elongobula iphigenae Revets. Hayward 1982, fig. 6i (as *Buliminoides madagascariensis*).
Elphidium advenum f. *limbatum* (Chapman). Hayward *et al.* 1997b, pl.3, figs 9-17, pl.4, figs 1-10.
Elphidium advenum f. *maorium* Hayward. Hayward *et al.* 1997b, pl.4, figs 11-16, pl.5, figs 1-5.
Elphidium charlottense (Vella). Hayward *et al.* 1997b, pl. 6, figs 13-16, pl.7, figs 1-2.
Elphidium excavatum f. *clavatum* Cushman. Hayward & Hollis 1994, pl. 5, figs 6-8.
Elphidium excavatum f. *excavatum* (Terquem). Hayward & Hollis 1994, pl. 5, figs 1-5.
Elphidium novozealandicum Cushman. Hayward *et al.* 1997b, pl.14, figs 10-14.
Eponides pusillus Parr 1950, pl. 14, figs 16a-c.
Evolvocassidulina orientalis (Cushman). Hayward 1982, fig. 6u.
Gavelinopsis praegeri (Parr). Hayward & Grenfell 1994, fig. 23.
Gavelinopsis sp.
Glauvolutina margaritaceus (Earland). Earland 1933, p.125, pl. 4, figs 23-25 (as *Discorbis*).
Globocassidulina crassa (d'Orbigny). Jones 1994, pl.54, fig.4.
Globocassidulina minuta (Cushman). Eade 1967, fig. 5.2-3.
Globocassidulina producta (Chapman & Parr). Eade 1967, fig. 4, no.5.
Haynesina depressula (Walker & Jacob). Hayward & Hollis 1994, pl. 5, figs 13-16.
Heronallenia pulvinulinoides (Cushman 1915), pl. 6, fig. 3.
Mississippiina omuraensis Shuto 1953, fig. 8d-f.
Neocornobina sp.
Neouuigerina proboscidea (Schwager). Van Morkhoven *et al.* 1986, pl.6.
Nonionellina flemingi (Vella). Vella 1957, pl.9, figs 183,184 (as

Nonion).
Notorotalia hornibrooki Hayward *et al.* 1999 pl.16, figs 31-33.
Patellinella inconspicua (Brady). Hayward 1982, fig. 5q.
Pileolina radiata Vella 1957, p. 36, pl. 8, figs 170, 171; Hayward 1982, figs 5h-i.
Pileolina zealandica Vella. Hayward 1982, figs 5l-m.
Pileolina aff. *patelliformis* (Brady). Hayward 1982, fig 5a-o
Planoglabratella opercularis (d'Orbigny). Hayward 1982, figs 6c-d.
Planulinoides biconcavus (Parker & Jones). Yassini & Jones 1995, figs 887-8.
Rosalina bradyi (Cushman). Hayward 1982, fig. 5y.
Rosalina irregularis (Rhumbler). Hayward 1982, fig. 6s.
Saidovina karrieriana (Brady). Yassini & Jones 1995, figs 649-652.
Sigmavirgulina tortuosa (Brady). Jones 1994, pl. 52, figs 31, 32. Hayward 1980, fig. 5.
Siphogenerina dimorpha (Parker & Jones). Yassini & Jones 1995, fig. 623 (as *Rectobolivina dimorpha pacifica*).
Trifarina angulosa (Williamson) *sensu lato*. Hayward *et al.* 1994, fig. 4K.
Trochulina dimidiatus (Jones & Parker). Hedley *et al.* 1967, p. 33-36, pl. 1, fig. 4, pl. 10, figs 1-3, text-figs 28-43.
Zaeflorilus parri (Cushman). Loeblich & Tappan 1987, pl. 690, figs 8-10.

Planktic foraminifera

Globigerina falconensis Blow. Hayward 1983, figs 2I-K.
Globigerina quinqueloba Natland. Hayward 1983, figs 2O-Q.
Globigerinita bradyi (Wiesner). Hayward 1983, figs 3D-E.
Globigerinita glutinata (Egger). Hayward 1983, figs 3F-H.
Globorotalia crassula Cushman & Stewart. Hayward 1983, p. 70, figs 4D-F
Globorotalia inflata (d'Orbigny). Hayward 1983, figs 4J-L.
Globorotalia scitula (Brady). Hayward 1983, figs 4M-O.
Globorotalia truncatulinoides (d'Orbigny). Hayward 1983, figs 4P-R.
Neoglobobadrina pachyderma (Ehrenberg). Hayward 1983, figs 5G-I.

Appendix 2

Quantitative counts of 100 benthic specimens in each Chatham Island sample. x = not found in count of 100 specimens, but recorded from additional material examined.

Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Cribratomoides jeffreysi</i>	.	x	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Eggerella advena</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Gaudryina convexa</i>	5	.	21	1	4	3	4	1	.	.	.	.	.	.	.	.	.
<i>Miliammina fusca</i>	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
<i>Pavatrochammina barttrami</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.
<i>Reophax</i> sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
<i>Siphotextularia blacki</i>	.	4	x	2	1	2	.	1	.	.	.	.	.	.	.	.	.
<i>Siphotextularia mestayerae</i>	1	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Spiroplectinella proxispira</i>	2	6	1	.	.	1	1	1	.	.	.	.	.	.	.	1	.
<i>Textularia pseudogramen</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Trochammina</i> sp.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Patellina corrugata</i>	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Spirillina denticulogranulata</i>	.	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
<i>Spirillina vivipara vivipara</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.

Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Cornuspira involvens</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Inaequalina disparilis</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Miliolinella subrotundata</i>	3	17	.	.	.	5	.	.	.	.	.	1	.	.	.	.	.
<i>Pseudoflintina triquetra</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Pyrgo anomala</i>	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina agglutinans</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina bicostoides</i>	3	6	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina delicatula</i>	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina oblonga</i>	x	x	3	6	2	3	2	.	.	.	2	10	.	4	5	.	.
<i>Quinqueloculina parvagguta</i>	1	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina seminula</i>	1	3	12	.	1	x	.	3	12	.	3	5	5	.	1	.	.
<i>Quinqueloculina suborbicularis</i>	.	.	.	1	.	4	3	1	.	.	.	.	.	1	2	.	.
<i>Quinqueloculina subpolygona</i>	.	x	1	.	.	x	1	.	.	.	.	.	.	.	.	.	.
<i>Quinqueloculina</i> sp.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Triloculina striatotrigonula</i>	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
<i>Triloculina trigonula</i>	x	x	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Astacolus crepidulus</i>	.	x	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.
<i>Fissurina</i> cf. <i>claricurta</i>	1	7	.	.	3	1	3	.	.	.	.	.	.	.	.	.	.
<i>Fissurina clathrata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Fissurina</i> cf. <i>crucifera</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Fissurina</i> cf. <i>evoluta</i>	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Fissurina lucida</i>	.	.	.	.	x	.	1	.	.	1	.	.	.	.	.	.	.
<i>Fissurina semialata</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Fissurina</i> cf. <i>southbayensis</i>	.	.	.	.	.	.	.	.	2	1	.	1	.	.	.	.	.
<i>Fissurina</i> spp.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.
<i>Fronicularia compta</i>	.	x	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
<i>Globulina gibba</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Grigelis orectus</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Guttulina</i> cf. <i>regina</i>	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
<i>Guttulina silvestrii</i>	.	x	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.
<i>Guttulina yabei</i>	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Laevidentalina filiformis</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lagena flatulenta</i>	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lagena laevicostatiformis</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
<i>Lagena</i> aff. <i>spicata</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Lagenosolenia bradyformis</i>	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
<i>Lagenosolenia confosa</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lagenosolenia quadrirevertens</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lagenosolenia strigimarginata</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Lenticulina australis</i>	1	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
<i>Lenticulina gibba</i>	x	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Oolina borealis</i>	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.
<i>Oolina caudigera</i>	.	x	.	.	.	x	1	.	.	.	.	.	.	.	.	.	.
<i>Oolina globosa</i>	1	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
<i>Oolina hexagona</i>	.	x	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Oolina lineata</i>	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Oolina melo</i>	x	3	.	.	11	5	1	1	.	.	.	.	.	.	.	.	1
<i>Oolina</i> spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.
<i>Palliolatella aradisiformis</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Parafissurina</i> cf. <i>caledoniana</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
<i>Pseudopolymorphina</i> sp.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Ceratobuliminoides</i> cf. <i>bassensis</i>	.	.	.	.	x	.	.	.	.	.	.	.	.	.	x	.	.
<i>Acervulina inhaerens</i>	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
<i>Ammonia parkinsoniana</i> f. <i>aoteana</i>	.	.	.	.	x	x	.	1	.	.	.	.	.	.	.	86	88
<i>Anomalinooides sphericus</i>	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	x	.
<i>Astrononion novozealandicum</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Bolivina compacta</i>	1	x	.	.	.	.	.	3	8	14	19	4	14	15	.	.	.
<i>Bolivina pseudoplicata</i>	1	2	9	1	.	1	.	2	9	6	5	8	9	18	.	.	.
<i>Bolivina robusta</i>	.	x	.	.	1	.	.	6	.	.	.	4	.	.	.	.	.
<i>Bolivina spathulata</i>	.	x	.	1	x	.	.	.	.	.	1	.	2	2	.	1	.
<i>Bolivina spinescens</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.

