New Zealand Aquatic
Environment and Biodiversity
Report No. 6
2006
ISSN 1176-9440

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New Zealand Aquatic Environment and Biodiversity Report No. 6
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Published by Ministry of Fisheries
Wellington
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ISSN 1176-9440

Citation:
Cummings, V.; Thrush, S.; Schwarz, A.-M.; Funnell, G.; Budd, R. (2006).
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New Zealand Aquatic Environment and Biodiversity Report No 6. 67 p.

This series continues the
Marine Biodiversity Biosecurity Report series
which ceased with No. 7 in February 2005.

EXECUTIVE SUMMARY

Cummings, V.; Thrush, S.; Schwarz, A.-M.; Funnell, G.; Budd, R. (2006). Ecology of coastal benthic communities of the northwestern Ross Sea.
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The long-term objective of this programme is to quantify patterns in biodiversity and benthic community structure in the coastal Ross Sea region.

In February 2004 the Italian led 'Victoria Land Transect' (VLT) project aimed to characterise and quantify changes in benthic communities along the Victoria Land coastline. RV *Italica* was to focus on near-shore regions north of Terra Nova Bay, where very little near shore research and diving has been conducted. While we made the most of the limited diving opportunities, our programme of diving was curtailed due to various logistical and safety issues. Thus, our scientific activities were necessarily concentrated in deeper waters (i.e., 100–500 m), which could be sampled directly from RV *Italica*. We visited four locations: Cape Adare, Cape Hallett, Coulman Island and Cape Russell. This sampling of a range of deeper environments along the Victoria Land Coast enabled us to make both latitudinal and depth-related comparisons of the benthic communities and habitats at these north western Ross Sea locations.

The voyage was invaluable in highlighting a number of factors that will influence the structural and functional diversity of shallow water assemblages and habitats in the Ross Sea (e.g., currents, rapid changes in sea ice conditions in the summer, iceberg disturbance, sea water temperature), and provided insight into how the relative importance of different environmental variables structuring near shore benthic communities in the coastal Ross Sea region might change with latitude. The trip provided data on the importance of disturbance to the seafloor associated with icebergs, and the need for information on the spatial and temporal scale of iceberg disturbance to help interpret the patterns in seafloor diversity. While the seafloor shows clear signs of scarring from this type of disturbance, some scars are probably very old. In areas we suspect are prone to high levels of disturbance we still observe far more structurally complex biogenic habitats than are common in temperate regions. Our results indicate differences between the southern-most locations of Cape Russell and Coulman Island, and those further north, that are consistent with higher levels of disturbance and/or earlier successional stages of recovery. In addition, video images of areas of the seafloor around Cape Russell highlight characteristics that are consistent with different iceberg disturbance regimes; e.g., faster growing fauna are more common in an area identified as more impacted based on multibeam imagery.

We found no consistent pattern of sediment grain size, number of individuals and/or taxa, the specific taxa collected, or their functional groups with station depth across locations, and considerable variability was apparent within locations. Interestingly, however, there is a suggestion of a non-linear depth related pattern in the number of macrofaunal taxa, individuals and sediment phaeophytin (a chlorophyll degradation product) found at Cape Adare, Cape Hallett Outside and Cape Hallett Inside only, with highest phaeophytin levels at intermediate depths. The environmental variables most important in explaining the differences in macrofaunal assemblage composition are % fine sand and silt, the ratio of sediment chlorophyll *a* to phaeophytin, and depth; however, these variables explained only a small amount of the variability in assemblage composition (17.3%). It is likely that broader scale environmental factors (e.g., sea ice cover, iceberg disturbance, circulation patterns, local hydrodynamic conditions), and their subsequent affects on factors such as primary production and supply and dispersal of larvae and food, will be major determinants of benthic diversity, and population and community structure. Although, our data set is still limited in terms of the number of sites encompassed, the low correlation found in this study between the infaunal community and the (largely physical) habitat characteristics measured highlights the need for caution when choosing Marine Protected Areas (MPAs) based only on physical variables. Our research highlights the importance of interactions between biological and environmental processes in driving trends in biodiversity. Thus, there is a need to select MPAs based on their functional importance, and to incorporate biogenic habitat complexity into sampling/protection strategies to define and understand

the processes that contribute to seafloor biodiversity. There should also be coordination between management of the Ross Sea toothfish fishery and establishment of Antarctic Specially Managed Areas and Antarctic Specially Protected Areas. This requires data on where and how toothfish spend the various stages of their life cycle to enable preservation of their nursery grounds, species that are important to their sustainability, and vice versa.

Detailed examination of the isotope data collected as part of this project and during previous years' sampling has begun to reveal some very interesting patterns in Antarctic food webs, with changes in the relative importance of different food sources evident with location. There is evidence for shifts in some of the $\delta^{13}C$ and $\delta^{15}N$ signatures which are consistent with predicted differences in supply of open ocean water and ice cover between locations. This supports the findings of our more detailed analysis of the shallow water locations visited previously in McMurdo Sound.

The dives we conducted provided valuable information on the types of habitats we may encounter when we are able sample this region more intensely in the future, and will also be very useful for planning future diving logistics and sampling methods in these different environments. In conjunction with the results of our deeper sampling, we now have some insight into the differences we expect to find as we move along the latitudinal gradient from McMurdo Sound to more northerly locations (e.g., abundance and diversity of macroalgae, biogenic habitats). We hope to continue to address research questions and hypotheses based on these insights and results from other BioRoss research, with future sampling, to more fully understand the relative importance of various environmental drivers and disturbance dynamics in affecting the structural and functional biodiversity of the Ross Sea.

1. INTRODUCTION

The long-term objective of this programme is to provide fundamental information on the structural (biological communities and habitats) and functional (ecological processes and trophic relationships) diversity of Antarctic coastal benthic communities. Antarctica's highly seasonal environmental conditions (e.g., sea ice, light regime) strongly influence primary production sources (e.g., sea ice algae, advected phytoplankton, microphytobenthos, macroalgae) and, subsequently, supply of food to benthic epifauna/macrofauna. Using natural gradients in environmental conditions and productivity along the latitudinal range of the Ross Sea, we will identify key physical variables and primary production pathways driving site-specific patterns in benthic community structure and function.

Our ongoing research of shallow (less than 30 m depth) coastal benthic ecosystems in the Ross Sea aims at improving our current knowledge of Ross Sea coastal biodiversity, both structural and functional. While it is important to assess the structural biodiversity of different habitats and locations (i.e., numbers and kinds of plant and animal species), understanding how the different components of the ecosystem are linked together is vital for making informed predictions about how the biota might respond to environmental change. In the first year of this research (2001–02), we successfully developed a multi-scale sampling strategy, which provides a framework for conducting the first comprehensive comparison of coastal benthic habitats and their associated biodiversity in the Ross Sea. In 2001–02 we implemented this sampling design at two contrasting sites in McMurdo Sound, New Harbour and Cape Evans. In 2002–03 we extended the geographical spread of our sampling further north into the Ross Sea by sampling two new locations, Dunlop Island and Spike Cape. In 2003–04 (the third year of this programme, and the period covered by this report), our aim was to complement and extend the surveys conducted at more southern latitudes in previous years, to the northwestern Ross Sea. Our sampling extent would then cover the entire Victoria Land latitudinal gradient in the Ross Sea, from about 78˚ to about 72˚S.

In February 2004 we participated in the 'Victoria Land Transect' (VLT) project on board RV *Italica*. The voyage visited a number of locations along the Victoria Land coast, and multidisciplinary investigations were conducted at each location. The aim of this voyage was to characterise and quantify changes in benthic communities and water column processes along the whole of the Victoria Land coastline (focusing on offshore areas). Our planned contribution to the joint research programme was to sample shallow water areas using the scuba-based sampling design developed in previous years to investigate the structural and functional diversity of the shallow-water (less than 30 m deep) benthic communities. This sampling was to be carried out from *Italica*'s tender vessel, *Skua*. Unfortunately, for logistical reasons this vessel proved to be largely inoperable, and coastal sea ice conditions were highly variable and unpredictable. Diving was possible on only a few occasions. Consequently, our scientific activities were necessarily concentrated in deeper waters (100–500 m), which could be sampled directly from *Italica*. This extensive sampling of a range of deeper environments along the Victoria Land coast will enable us to make both latitudinal and depth-related comparisons of the benthic communities and habitats at these northwestern Ross Sea locations and eventually those taken on the simultaneous *Tangaroa* voyage overlapping with the northern *Italica* sampling sites.

1.1 Programme Objectives

1. Quantify patterns in biodiversity and community structure in the coastal Ross Sea region.

1.2 Objectives covered by this report

1. *Quantify biodiversity* and benthic and sea ice communities at selected locations in the Ross Sea north of Terra Nova Bay.

2. Describe *ecosystem function* at selected locations in the Ross Sea north of Terra Nova Bay.

2. METHODS

Objective 1. Quantify biodiversity.

During the VLT cruise, RV *Italica* visited the Cape Adare, Cape Hallett, Coulman Island and Cape Russell areas (Figure 1). These locations were chosen prior to the voyage to provide broad geographic coverage of the Victoria Land coastline.

2.1 Deep water sampling from RV *Italica*

Grab and dredge samples

At each location, sampling from RV *Italica* was conducted along a predetermined transect, which was aligned along a depth gradient. Five stations (Stations 1 to 5) were arranged along each transect, at nominal depths of 500, 400, 300, 200 and 100 m, respectively. At each station, three Van Veen grab samples (60 litre volume, 0.2 m^2 surface area) and one Agassiz dredge sample (120 x 50 cm opening, 2 m long net, 8 mm mesh) were collected. Fauna from the dredge samples are being identified and quantified by Italian researchers. Where possible, three grabs were taken at each station, but sometimes only two grabs of sufficient quality were able to be collected due to the cobbled nature of the bottom. Similarly, at some locations, ice conditions were such that fewer than five stations could be sampled. The GPS coordinates of the locations and stations sampled by grab and dredge are given in Appendices 1 and 2, respectively.

Grabs were subsampled by collecting a core (7 cm diameter) to quantify macrofaunal community composition, and surficial sediment scrapes to characterise sediment grain size, organic and chlorophyll *a* content, and stable isotope signature. Core samples were sieved (500 μm mesh) and preserved in 70% isopropyl alcohol. Sediment scrapes were homogenised before being subsampled for chlorophyll *a*, particle size, and organic content analysis. The sediment samples were stored frozen until they could be analysed.

Dredge hauls were sampled for invertebrates and macroalgae. To characterise the trophic status of large epifaunal invertebrates, three individuals of each common taxa were collected from the Agassiz dredge haul. These invertebrates were dissected and the tissues frozen until they could be analysed (see Objective 2 for details of Methods). Macroalgae were identified and assessed for photosynthetic activity via measurements of fluorescence yield, to establish their potential viability. Macroalgae samples were also frozen for later analysis of pigment content and storage products.

Video sampling

Obtaining video footage from deeper areas (100–150 m depth) required modification of the video camera (SplashCam) we had intended to use to sample the shallower dive sites. We extended the cable by splicing another one, and had a frame built to hold the camera and lights and provide some protection for both. The camera was fitted with three lasers, which allows for accurate sizing of habitat features and dominant animals. These images provide information on habitat type and overall biodiversity, and can also be used to make quantitative estimates of the relative abundance, diversity, and size of epibenthic species.

At Cape Hallett and Cape Russell, seafloor transects were videoed from *Italica* or *Skua* by lowering SplashCam to the seafloor, and allowing the boat to drift with the current. Unfortunately, our attempt to collect video footage from Cape Adare was unsuccessful due to strong currents.

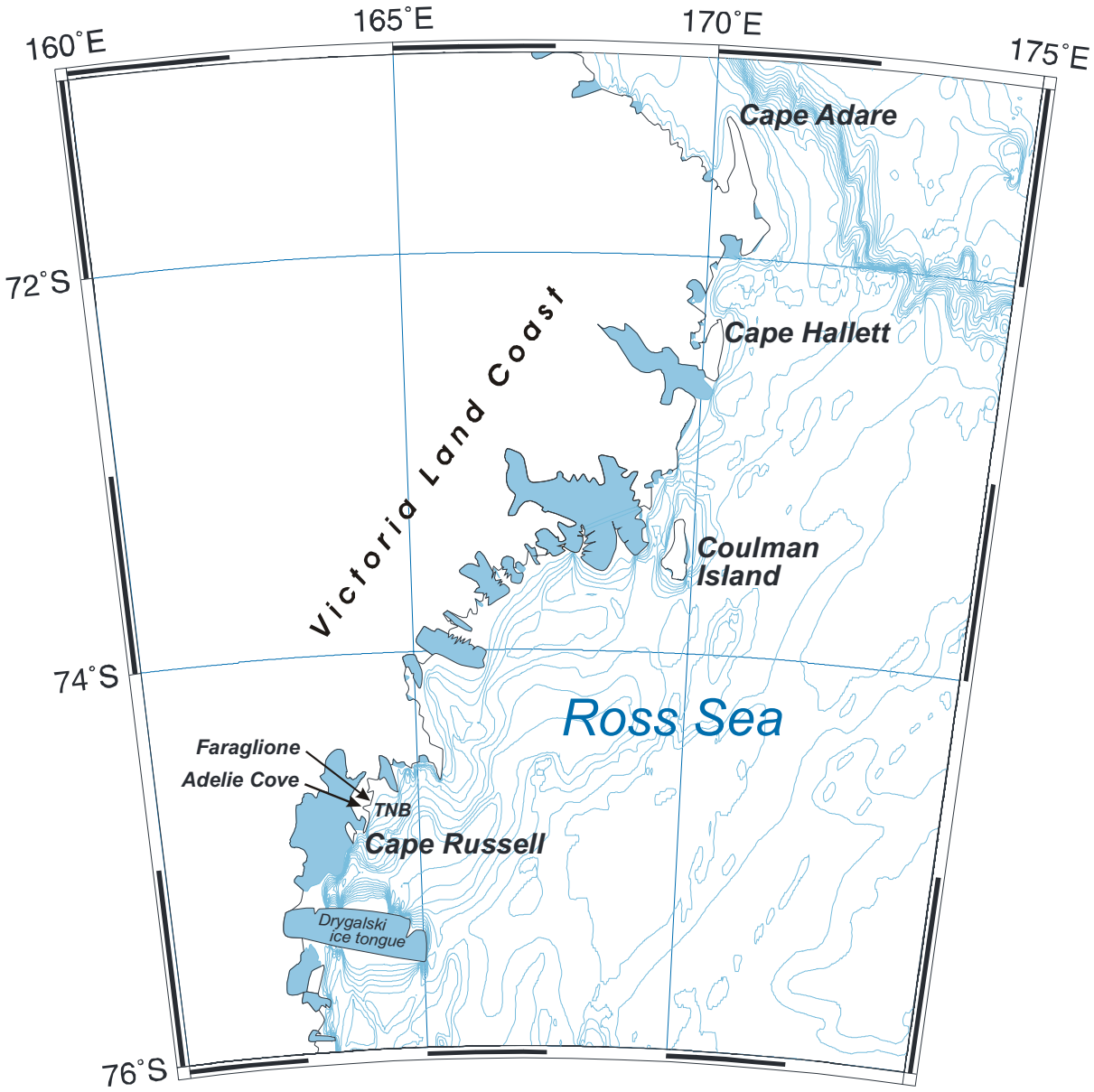

Figure 1: Map of the northwestern Ross Sea, showing the areas sampled as part of the Victoria Land Transect project. TNB, Terra Nova Bay.

2.2 Scuba sampling

Scuba-based survey sampling based on the sampling protocol described in detail in previous reports (Norkko et al. 2002, Cummings et al. 2003) was conducted at one Cape Hallett site. During other dives, sampling concentrated on collection of invertebrates, video transects of the seafloor, and in situ measurements of macroalgae fluorescence. Macroalgae samples were also collected and frozen for later analysis of pigment content and storage products.

2.3 Sample processing and analysis

Macrofauna and sediment samples

Macrofauna core samples were sorted and identified to the lowest taxonomic level practicable. Sediments for particle size analysis were digested in 6% hydrogen peroxide for 48 h to remove organic matter. A Galai particle analyser (Galai Cis – 100; Galai Productions Ltd., Midgal Haemek, Israel) was then used to determine percent volumes for the gravel/shell hash, coarse, medium and fine sand, silt, and clay fractions. The organic matter content of the sediment was measured as loss on ignition (LOI) by drying the sediment at 60 °C for 48 h, followed by combustion at 400 °C for 5.5 h. Chlorophyll *a* was extracted from freeze dried sediments by boiling in 90% ethanol. The extract was measured spectrophotometrically, and an acidification step was included to separate degradation products (phaeophytin) from chlorophyll *a* (Sartory 1982).

Macroalgae

Measurements of fluorescence yield of macroalgae (in situ and in the lab) were made using a submersible pulse amplitude modulated fluorometer (Diving-PAM, Walz). PAM fluorometry allows measurement of the fluorescence yield of chlorophyll under ambient irradiance, and during application of a short pulse of saturating white light. In situ, the principal measurement made using the Diving-PAM was $\Delta F/F_m$' reflecting the effective quantum yield (Y) of photosystem II (PS II). The PAM fibre was held in a specially designed leaf clip to ensure a standard distance from the macroalgal thallus. The fibre and clip were positioned by a diver at about 0.5 cm from the macroalgal frond, and a measurement made of Y. In the laboratory, all measurements on dredged material collected from water too deep for photosynthetically available radiation (PAR) to penetrate were made in darkness, thereby approximating a measure of maximum potential quantum yield (F_v/F_m). [A full explanation of $\Delta F/F_m$' and F_v/F_m were given in appendix 3 of Norkko et al. (2002)]

For in situ measurements, at least 10 measurements of Y were made for a given taxa at the dive depth. In the laboratory, duplicate measurements were made on up to five replicate fronds.

Chlorophyll *a* for both red and brown algae, and chlorophyll *c* for brown algae, were analysed on freeze dried samples using fluorometric techniques following the protocol of Duncan & Harrison (1982).

Video-imagery

Video footage was analysed to estimate abundances of epifauna and flora and substrate type. The single transect videoed during the Cape Hallet dive was analysed as described in previous reports (Norkko et al. 2002, Cummings et al. 2003).

An adaptation of the method used in previous years was used to assess the video footage obtained during this voyage from deeper locations. Briefly, the digital video's of the transects were analysed to estimate the abundance and percent cover of epifauna and flora in a number of frame grabs. Three consecutive frames were 'grabbed' for each example. Within each frame grab, counts were made of the seafloor habitat characteristics (i.e., rock, cobble, pebble, coarse sediment/gravel, sand/mud), to determine the percentage cover of each. Percentage cover of habitat elements such as protruding sponge (which provide additional seafloor structure in their own right) was also assessed. Epibenthic

species composition and abundance of individual fauna (e.g., asteroids, ophiuroids, urchins) and macroalgae were also quantified. Because of the variability in the height of the camera above the seafloor (due to boat movement and currents) the individual frame grabs did not always cover identical areas of seafloor. However, the lasers mounted on the camera allowed us to determine the exact area covered by each frame, and this information was used to adjust the results to a standard quadrat (frame) area. The percentage cover and counts presented here are for a 50 x 50 cm (0.25 m^2) quadrat.

Numerical analysis

Variations in species composition and relative abundance of benthic fauna and flora within and between sites sampled by grab were determined using a combination of univariate (McCullagh & Nelder 1989) and multivariate analytical procedures (Clarke & Warwick 1994, Legendre & Legendre 1998, Warwick & Clarke 2001). Summary statistics (total number of species, total number of individuals, Shannon-Wiener diversity, species evenness, and species richness) were generated using the DIVERSE procedure within PRIMER (Clarke & Gorely 2001).

Spearman's correlation coefficients were used to determine correlations between depth and both number of individuals and number of taxa, using the CORR procedure within SAS (SAS Institute 1999). The same procedure was used to examine relationships between phaeophytin concentrations and both number of individuals and number of taxa.

Similarities and differences between community composition at the different locations and stations were assessed using multidimensional scaling ordinations (MDS) of the untransformed and presence/absence transformed data; these were also conducted using PRIMER. Canonical correspondence analysis (ter Braak 1986, 1987), using untransformed community data, was then used to identify the important environmental factors (e.g., sediment characteristics and depth) driving the observed patterns in community composition.

Objective 2. Ecosystem function

Samples were taken at all sites from each location sampled as part of Objective 1 to determine stable isotope signatures. Samples collected (described in Objective 1), include: tissues of common large epibenthic taxa, surface sediment, microphytobenthos, macroalgae, and detritus. Details of the numbers of samples collected are provided in the Results. In addition, seawater samples were collected from 5 m below the surface (3 samples, each 150 ml) at each location and station to determine the isotopic signature of the seawater (phytoplankton). The seawater was filtered on pre-combusted 2.5 cm GF/C filters, and the filters frozen until they could be analysed.

Frozen samples were freeze dried or oven dried (sea water filters only) before analysis using NIWA's Finnegan Delta-C, continuous flow Mass Spectrometer.

3. RESULTS

Objective 1. Quantify biodiversity

Transect sampling was conducted at Cape Adare (one transect), Cape Hallett (two transects), Coulman Island (one transect), and Cape Russell (one transect). One of the Cape Hallett transects was located close to the cape itself ('Cape Hallett Inside'); the other was further offshore ('Cape Hallett Outside'). The GPS locations of each Van Veen grab and Agassiz dredge sample are given in Appendices 1 and 2, respectively.

3.1 Seafloor sediment characteristics

Organic content and particle size

The sediment organic content and grain size composition are presented in Table 1.

The sediment organic content was less than 3.5% at all stations and locations. Levels were most variable between stations at Cape Adare (0.81–3.43%), and most similar at the Cape Hallett Outside stations (2.08–2.69%) (Table 1). These values are higher than those noted in our previous year's sampling of shallow water McMurdo Sound sites, which were less than 1% at all locations sampled (Cummings et al. 2003). Values of 0.5 to 1.5% C were noted for 270 to 1173 m deep stations in the southwestern Ross Sea by Barry et al. (2003) and, although these values are not directly comparable to our organic content (measured as loss on ignition), they are also considered low.

There was no consistent pattern of sediment grain size distribution with station depth across locations, and considerable variability between sites within locations. Clay content, however, was negligible at all stations/location. Silt levels ranged from very low at Cape Adare (much less than 1%) to about 5% at Coulman Island (Table 1). Because these samples were obtained from grabs, the contribution of the smaller particle size fractions to the total volume of the sediment sample may be underestimated. However, levels of clay in shallow water sediments sampled in previous years, by coring, have also been negligible (i.e., 0.02–0.14%, Cummings et al. 2003).

The grabs collected from the three northernmost locations, Cape Adare, Cape Hallett Outside, and Cape Hallett Inside, generally had higher proportions of gravel than those from Cape Russell and Coulman Island. Cape Adare stations 2 to 5 comprised predominantly gravel and coarse sand (Table 1). Stations 2 to 4 contained a relatively high fraction of gravel (62–69%), with station 1 sediments predominantly coarse sand (74%), and station 5 sediments equal volumes of both gravel and coarse sand (about 40%). The three Cape Hallett Inside stations were mostly fine sand (62–65%) with some gravel (20–26%). Cape Hallett Outside stations 2 to 4 contained high amounts of gravel (60–71%) with 20–26% fine sand, while station 1 comprised similar volumes of fine sand, coarse sand, and gravel (29, 30, and 38%, respectively). Cape Hallett Outside Station 5 was mostly gravel (42%), with a lesser volume of fine and coarse sand (34 and 20%, respectively) (Table 1).

The Coulman Island and Cape Russell sediments were the most heterogeneous of the five locations (Table 1). The two Coulman Island stations had quite similar sediment composition; about half their volume comprised fine sand, with about 23–25% coarse sand. The remainder of the sediment was made up of gravel and silt (Table 1). The two Cape Russell stations were different to each other: over half of the Station 1 sediments were fine sand, with some coarse sand and less gravel. Station 4 comprised similar amounts of coarse sand and gravel, and a slightly higher volume of fine sand (Table 1).

Microphytobenthos

There were differences in levels of microphytobenthos in the sediments between location and depths. Not surprisingly, these deep sites generally have very low levels of chlorophyll *a* (i.e., less than 0.5 μg g^{-1} sediment) (Figure 2). The exception was Cape Russell, where seafloor sediment at 200 and 300 m depth contained 1.5–3.3 μg chlorophyll *a* g^{-1} sediment on average (Figure 2). The amount of phaeophytin (a chlorophyll *a* degradation product) was comparatively high at each location/depth (i.e., 0.1–15.7 μg g^{-1} sediment, recorded at Cape Adare (500 m) and Cape Russell (200 m), respectively; Figure 3), with sediments at all locations having more phaeophytin than chlorophyll *a* by 2 to greater than 10 times. In addition, there is some suggestion of a depth-related pattern in phaeophytin biomass, with highest levels at intermediate depths (Figure 3). As for chlorophyll *a*, levels of phaeophytin were highest at Cape Russell (Figure 3).

As a comparison, sediments obtained from shallow water (less than 30 m) sites in previous years ranged from 0.3 to 9.2 μg chlorophyll *a* g^{-1} sediment while phaeophytin ranged from much less than 1 to 15 μg g^{-1} sediment (Cummings et al. 2003). As for the *Italica* sites, all of these shallow water

locations had more degraded than healthy microphytobenthos (Cummings et al. 2003). The ratio of phaeophytin to chlorophyll *a* observed in Antarctic sediments differs from that noted in temperate New Zealand subtidal areas, where the levels of chlorophyll are generally higher than those of phaeophytin (Cummings, unpublished data). This is probably due to the slow degradation rates evident in the cold Antarctic waters.

Table 1: Sediment grain size and organic content (measured as loss on ignition) at the five locations. Data presented are mean % (± standard error). CA, Cape Adare; CH In, Cape Hallett Inside; CH Out, Cape Hallett Outside; CI, Coulman Island; CR, Cape Russell.

Location	Station	Organic content	Clay	Silt	Fine sand	Medium sand	Coarse sand	Gravel
CA 1	1	1.06 ± 0.39	0.00 ± 0.00	0.02 ± 0.00	3.17 ± 0.92	8.15 ± 0.63	73.90 ± 3.71	14.76 ± 4.26
CA 2	2	3.43 ± 0.48	0.00 ± 0.00	0.05 ± 0.01	4.65 ± 1.82	2.73 ± 1.11	27.05 ± 18.82	65.53 ± 15.88
CA 3	3	1.30 ± 0.24	0.00 ± 0.00	0.04 ± 0.02	5.35 ± 3.06	1.59 ± 0.91	23.62 ± 15.50	69.40 ± 18.40
CA 4	4	2.48 ± 0.44	0.00 ± 0.00	0.09 ± 0.00	6.46 ± 2.17	2.12 ± 0.92	29.39 ± 8.26	61.94 ± 5.17
CA 5	5	0.81 ± 0.15	0.00 ± 0.00	0.12 ± 0.06	16.11 ± 8.55	3.90 ± 1.73	38.70 ± 6.52	41.17 ± 16.68
CH In	2	1.33 ± 0.07	0.01 ± 0.01	2.22 ± 0.62	64.64 ± 15.99	1.41 ± 0.29	5.33 ± 1.21	26.39 ± 17.96
CH In	3	1.18 ± 0.26	0.03 ± 0.02	2.05 ± 0.70	63.54 ± 4.00	2.39 ± 0.63	12.47 ± 5.79	19.52 ± 7.27
CH In	4	1.77 ± 0.35	0.02 ± 0.00	2.80 ± 1.97	61.98 ± 21.46	1.38 ± 0.69	11.16 ± 5.88	22.66 ± 19.19
CH Out	1	2.08 ± 0.20	0.03 ±0 .02	0.71 ± 0.14	28.90 ± 10.35	2.57 ± 1.15	29.65 ± 3.96	38.14 ± 13.75
CH Out	2	2.12 ± 0.77	0.00 ± 0.01	0.63 ± 0.15	20.02 ± 11.95	0.66 ± 0.38	7.64 ± 5.75	71.05 ± 18.24
CH Out	3	2.34 ± 0.26	0.01 ± 0.01	0.70 ± 0.50	25.00 ± 19.06	1.01 ± 0.55	13.44 ± 1.02	59.83 ± 19.11
CH Out	4	2.69 ± 0.06	0.01 ± 0.02	1.02 ± 0.41	26.33 ± 21.01	0.75 ± 0.66	9.13 ± 8.64	62.77 ± 30.70
CH Out	5	2.16 ± 1.03	0.01 ± 0.01	1.65 ± 1.61	33.75 ± 24.01	2.64 ± 1.87	20.39 ± 9.02	41.56 ± 30.35
CI	1	2.03 ± 0.09	0.07 ± 0.02	5.49 ± 1.60	60.83 ± 11.94	2.50 ± 0.34	23.27 ± 7.16	7.84 ± 6.46
CI	2	1.99 ± 0.21	0.03 ± 0.00	4.44 ± 0.37	52.82 ± 3.91	2.78 ± 0.94	25.43 ± 3.08	14.50 ± 6.60
CR	3	0.98 ± 0.17	0.01 ± 0.00	3.02 ± 1.05	56.26 ± 20.62	3.92 ± 1.44	25.28 ± 9.27	11.51 ± 14.09
CR	4	0.76 ± 0.10	0.02 ± 0.01	2.26 ± 1.60	39.38 ± 22.36	2.79 ± 0.83	29.97 ± 9.48	25.58 ± 26.58

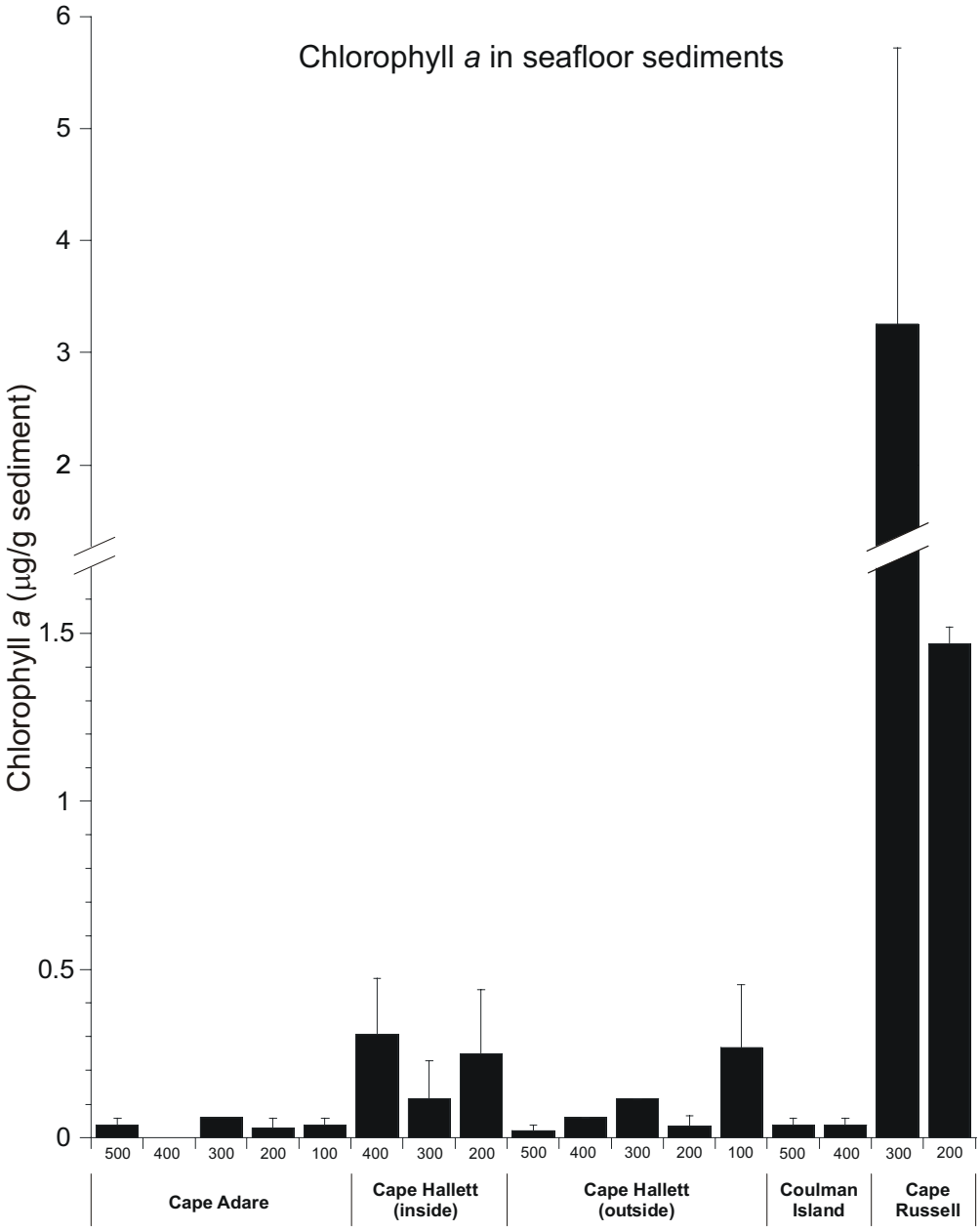

Figure 2: Levels of chlorophyll *a* (mean + standard error) present in seafloor sediments at each depth at each location in February 2004. Depths of 500, 400, 300, 200, and 100 m are targeted depths only (see Methods), and correspond to Stations 1, 2, 3, 4, and 5, respectively.

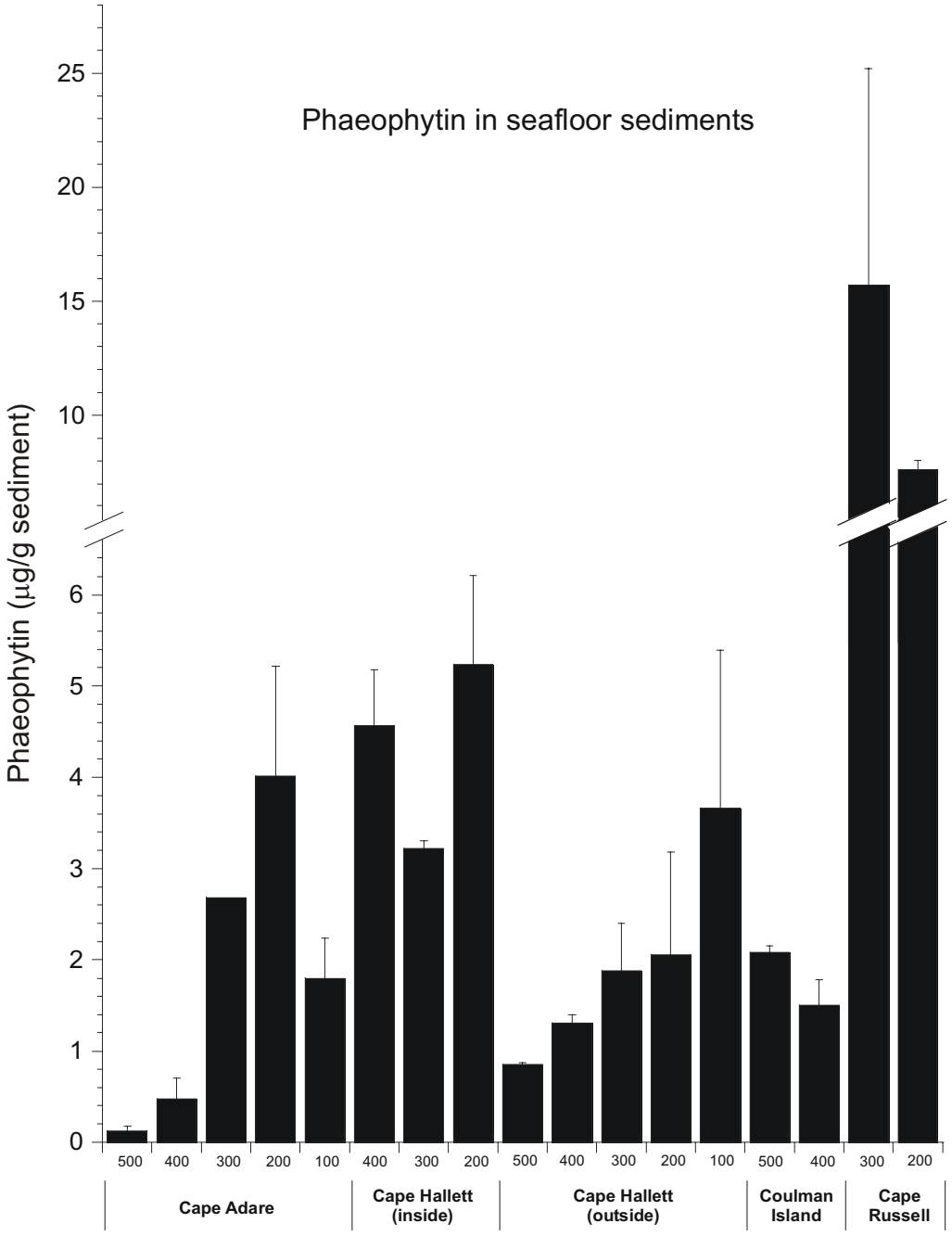

Figure 3: Levels of phaeophytin (mean + standard error) present in seafloor sediments at each depth at each location in February 2004. Depths of 500, 400, 300, 200, and 100 m are targeted depths only (see Methods), and correspond to Stations 1, 2, 3, 4, and 5, respectively.

3.2 Macrofauna

Average numbers of macrofaunal taxa collected in each core ranged from 3 to 21 across all locations and stations (Table 2). The number of taxa was most variable between stations at Cape Adare (4.0–20.5 taxa per core), and most similar between Cape Hallett Outside stations (2.5–8.0 taxa per core). Cape Hallett Outside and Coulman Island stations had the lowest diversity, and the fewest number of individuals, of all locations (less than 11.3 individuals per core; Table 2). The highest numbers of individuals and taxa were found at Cape Adare Station 4 (69.0 individuals, 20.5 taxa per core).

Across all locations, the relationship between number of individuals and/or taxa and depth was weak (Spearman's R = -0.4233, P = 0.0904 for number of individuals; Spearmans R = -0.4140, P = 0.0985 for number of taxa). However, strong differences were noted within locations. For example, at Cape Adare, significantly more individuals and taxa were found at Station 4 (200 m deep) than at Stations 1, 2, and 5 (500, 400, and 100 m deep, respectively; number of individuals: P = 0.0458; number of species: P = 0.0508). Station 4 also had more individuals than Station 3 (300 m deep; P = 0.0458). At Cape Hallett Outside, significantly more individuals were found at the shallowest station (100 m, Station 5) than at the 500–300 m deep stations (stations 1, 2, and 3; P = 0.0542). At Cape Hallett inside (where only the 200–400 m deep stations were sampled) more individuals were found at Station 4 (200 m) than at Station 3 (300 m) (P = 0.0314). There were no significant differences noted for the number of taxa found at stations within either the Cape Hallett outside or Cape Hallett inside locations, and no differences in numbers of individuals or taxa at Coulman Island or Cape Russell (P > 0.05).

Interestingly, the pattern in number of taxa and number of individuals at the Cape Adare, Cape Hallett Inside, and Cape Hallett Outside stations is very similar to the pattern noted in the sediment phaeophytin levels at these stations/locations (compare Figures 4 and 3). There is a significant correlation between both number of individuals and number of taxa and phaeophytin concentration of the sediments across all locations (Spearman's R = 0.6564, P = 0.0042 for number of individuals; Spearman's R = 0.5565, P = 0.0203 for number of taxa). This correlation is being driven by the patterns at Cape Adare and Cape Hallett Outside in particular, where there are highly significant and very strong correlations between phaeophytin concentrations and numbers of individuals and taxa (P < 0.0001; R = 1.00 in all cases). This pattern may be due to the fact that both phaeophytin and macrofauna are time-integrated measures, and there is thus a better matching of macrofauna with phaeophytin than with chlorophyll *a*. These results suggest that the distribution of the benthos in these locations reflects their response to seafloor productivity.

Evenness (Pielou's *J'*) was high at all locations/stations (i.e., 0.9–1.0; Table 2). *J'* is a measure of how evenly the individuals are distributed amongst the different taxa, and these values indicate a lack of numerical dominance (a value of 1.0 indicates all taxa are equally abundant). The Shannon Wiener diversity index (*H'*) is affected by rare taxa, and increases both with increasing numbers of taxa and a more even distribution of individuals amongst taxa. It was highest at sites with high numbers of taxa/individuals: Cape Adare stations 3 and 4, Cape Hallett Inside stations 2 and 4, and Cape Russell Station 4 all had levels greater than or equal to 2.

Examination of the dominant taxa in the macrofaunal assemblage at each station shows differences between locations (Table 3). Cape Adare comprised mostly bivalves and crustaceans (amphipods, isopods, and ostracods), while at Cape Hallett Outside polychaetes are amongst the dominant taxa at all but the shallowest station (100 m, Station 5) (Table 3). In comparison, the dominant taxa at Cape Russell and Coulman Island are polychaetes, nematodes, and oligochaetes. The Cape Hallett Inside assemblages are dominated by a bivalve, crustaceans and polychaetes. The bivalve *Genaxinus debilis* the most abundant species at Stations 2 and 3, does not feature amongst the dominant taxa at any other location (Table 3).

Examination of the distribution of functional groups (i.e., feeding modes) of the common macrofaunal taxa revealed no clear relationship with depth, either across all locations, or within individual locations

($P > 0.05$ in all cases). In addition, closer examination of the composition of the Coulman Island and Cape Russell assemblages did not help elucidate potential reasons for the lack correlation between number of species/individuals and phaeophytin levels at these locations noted above (e.g., absence of a particular functional group). Predator/scavengers and deposit feeders are common at all locations, while suspension feeders are more common at Cape Hallett Outside (Table 3).

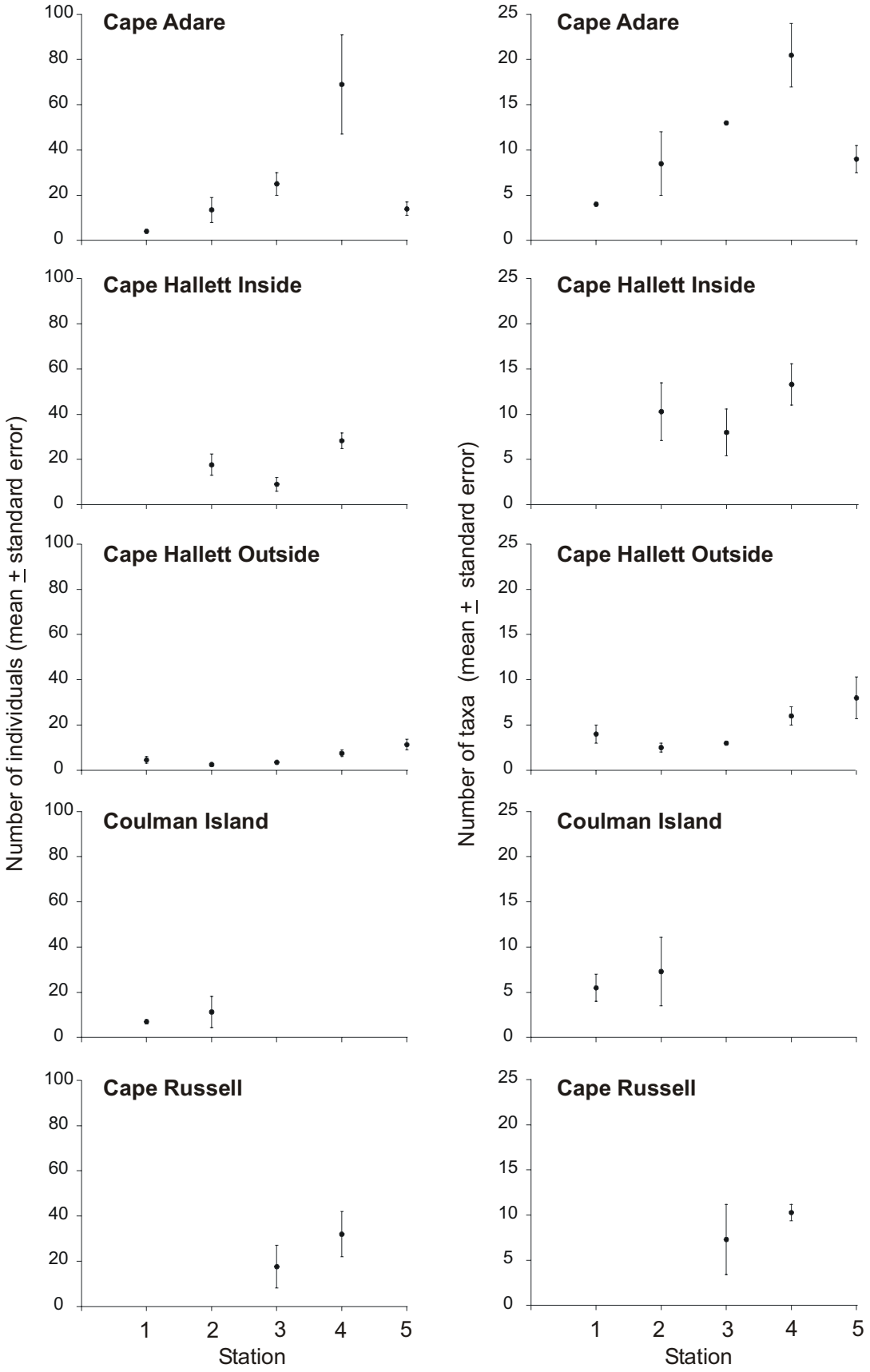

Figure 4: Number of macrofaunal individuals and taxa at each locations and depth (station). Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively.

Table 2: Diversity at the five locations. Data presented are mean ± standard error. n = number of grab samples on which statistics are based.
SW, Shannon Wiener diversity index; CA, Cape Adare; CH In, Cape Hallett Inside; CH Out, Cape Hallett Outside; CI, Coulman Island; CR, Cape Russell;
n, number of grab samples on which statistics are calculated.

Location	Station	n	Number of taxa	Number of individuals	Richness (d)	Evenness (J')	SW (H')
CA	1	1	4.0	4.0	2.2	1.0	1.4
CA	2	2	8.5 ± 3.5	13.5 ± 5.5	2.8 ± 0.9	0.9 ± 0.0	1.9 ± 0.5
CA	3	2	13.0 ± 0.0	25.0 ± 5.0	3.8 ± 0.2	0.9 ± 0.0	2.4 ± 0.1
CA	4	2	20.5 ± 3.5	69.0 ± 22.0	4.8 ± 1.2	0.9 ± 0.1	2.7 ± 0.3
CA	5	3	9.0 ± 1.5	14.0 ± 3.0	3.1 ± 0.4	1.0 ± 0.0	2.1 ± 0.2
CH In	2	3	10.3 ± 3.2	17.7 ± 4.7	3.2 ± 0.9	0.9 ± 0.0	2.1 ± 0.3
CH In	3	3	8.0 ± 2.6	9.0 ± 3.1	3.1 ± 0.7	1.0 ± 0.0	1.9 ± 0.4
CH In	4	3	13.3 ± 2.3	28.3 ± 3.5	3.7 ± 0.8	0.9 ± 0.1	2.2 ± 0.3
CH Out	1	2	4.0 ± 1.0	4.5 ± 1.5	2.0 ± 0.2	1.0 ± 0.0	1.3 ± 0.2
CH Out	2	2	2.5 ± 0.5	2.5 ± 0.5	1.6 ± 0.2	1.0 ± 0.0	0.9 ± 0.2
CH Out	3	2	3.0 ± 0.0	3.5 ± 0.5	1.6 ± 0.2	1.0 ± 0.0	1.1 ± 0.0
CH Out	4	2	6.0 ± 1.0	7.5 ± 1.5	2.5 ± 0.2	1.0 ± 0.0	1.7 ± 0.2
CH Out	5	3	8.0 ± 2.3	11.3 ± 2.4	2.8 ± 0.7	1.0 ± 0.0	1.9 ± 0.3
CI	1	2	5.5 ± 1.5	7.0 ± 1.0	2.3 ± 0.6	0.9 ± 0.0	1.6 ± 0.3
CI	2	3	7.3 ± 3.8	11.3 ± 6.9	2.6 ± 0.9	0.9 ± 0.0	1.6 ± 0.4
CR	3	3	7.3 ± 3.9	17.7 ± 9.4	2.0 ± 1.0	0.8 ± 0.0	1.3 ± 0.5
CR	4	3	10.3 ± 0.9	32.0 ± 10.0	2.8 ± 0.1	0.9 ± 0.0	2.0 ± 0.1

Table 3: Dominant macrofaunal taxa at each location and station. Mean ± standard error. d, deposit feeder; det, detritus feeder; g, grazer; s, suspension feeder; p, predator; sc, scavenger; * could be either, but specific information not available for this species; misc, large group containing a variety of feeding modes. AMP, amphipods; BIV, bivalves; CUM, cumaceans; ECH, echinoderms; ISO, isopods; OST, ostracods; POL, polychaetes. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively.

	Station 1		Station 2		Station 3		Station 4		Station 5	
Cape Adare	*Leptanthuria glacialis* (0.33, 0.41)	ISO d/g*	*Leptanthuria glacialis* (2.50, 2.12)	ISO d/g*	Myodocopid (2.33, 1.78)	OST d*	Myodocopid (13.00, 15.56)	OST d/g*	Ophiuroid 3 (2.00, 1.87)	ECH p/sc
	Lysianassidae (0.33, 0.41)	AMP p/sc	Nematoda (2.50, 2.12)	. misc	Ischyroceridae (1.67, 2.04)	AMP d/g*	*Leptanthuria glacialis* (7.00, 2.83)	ISO d/g*	Ischyroceridae (1.67, 0.41)	AMP d/g*
	Oligochaeta (0.33, 041)	. d	*Philobrya sublaevis* (1.00, 1.41)	BIV s?	Ophiuroid 2 (1.33, 1.63)	ECH p/sc	Ischyroceridae (6.00, 8.49)	AMP d/g*	Ophiuroid 1 (1.67, 1.08)	ECH p/sc
	Glyceridae (0.33, 0.41)	POL p/sc	Myodocopid (1.00, 1.41)	OST d/g*	*Leptanthuria glacialis* (1.33, 1.08)	ISO d/g*			Ophiuroid 2 (1.00, 1.22)	ECH p/sc
			Nucula sp. (1.00, 1.41)	BIV d	*Kiklonana* sp. (1.33, 0.82)	ISO d/g*			*Leptanthuria glacialis* (1.00, 1.71)	ISO d/g*
			Foraminifera (1.00, 1.41)	. misc						
Cape Hallett Outside	*Philobrya sublaevis* (0.67, 0.82)	BIV s?	*Euchone* sp. (0.50, 0.71)	POL s	Ophiuroid sp.1 (1.00, 1.41)	ECH p/sc	Hydroid colony (2.00, 0.00)	. s	Ophiuroid 1 (1.33, 1.08)	ECH p/sc
	Glyceridae (0.33, 0.41)	POL p/sc	Glyceridae (0.50, 0.71)	POL p/sc	Serpulidae 1 (0.50, 0.71)	POL s	Syllinae (1.00, 0.00)	POL p/sc	Hydroid Colony (1.33, 0.82)	. s
	Aricidea sp. (0.33, 0.41)	POL d	Lumbrineridae (0.50, 0.71)	POL p/sc	Syllinae (0.50, 0.71)	POL p/sc	Brachiopoda (1.00, 1.41)	. s	Nematoda (1.0, 1.22)	. misc
	Lumbrineridae (0.33, 0.41)	POL p/sc	Nemertean (0.50, 0.71)	. p	Serpulidae 2 (0.50, 0.71)	POL s			Pycnogonida (1.00, 0.71)	. d
	Galathowenia	POL								

	wilsoni (0.33, 0.41)	s/d*							
	Ophiuroid 1 (0.33, 0.41)	ECH p/sc							
	Ophiuroid 3 (0.33, 0.41)	ECH p/sc							
Cape Hallett Inside	Not sampled		*Genaxinus debilis* (3.00, 1.22)	BIV d	*Genaxinus debilis* (1.33, 0.41)	BIV d	Cumacea 2 (5.33, 4.81)	CUM det	Not sampled
			Oligochaeta (2.33, 2.27)	. d	Phoxocephalidae 2 (1.00, 0.71)	AMP d	*Maldane sarsi antarctica* (4.33, 4.08)	POL d	
			Lumbrineridae (2.00, 0.71)	POL p/sc	*Notoproctus oculatus antarcticus* (1.00, 0.71)	POL d	Oligochaeta (2.33, 2.27)	. d	
							Rhodine sp. (2.33, 2.27)	POL d	
Coulman Island	Cirratulid (1.00, 0.71)	POL p/sc	Nematoda (1.67, 2.04)	. misc	Not sampled		Not sampled		Not sampled
	Spiophanes tcherniai (1.00, 1.22)	POL ?	Oligochaete (1.33, 1.63)	. d					
	Lumbrineridae (0.67, 0.41)	POL p/sc	Lumbrineridae (1.00, 0.00)	POL p/sc					
Cape Russell	Not sampled		Not sampled		Nematoda (4.00,4.90)	. misc	Oligochaeta (7.67,3.34)	. d	Not sampled
					Oligochaeta (3.67, 2.48)	. d	Nematoda (5.00, 1.87)	. misc	
					Maldane sarsi antarctica (2.67, 0.82)	POL d	*Maldane sarsi antarctica* (3.67, 4.49)	POL d	

Assemblage composition

The relationship between macrofaunal assemblage composition at the different stations and locations are illustrated in two dimensions in Figure 5. The closer together the points are on the plot, the more similar their assemblages are.

There is little similarity in macrofaunal assemblage composition across locations at stations of similar depth (Figure 5A). Generally, the assemblages varied considerably within locations (as shown by the wide spacings of like-coloured points), and there was overlap of the different locations. Cape Adare is the most distinct in ordination space, indicating that the macrofaunal assemblages at the five Cape Adare stations are the most similar to one another. Cape Hallett Outside exhibits the highest variability in macrofaunal assemblage composition, while Cape Hallett Inside stations are similar to those from Coulman Island. To isolate the effect of changes in the densities of species from changes in species composition, an ordination was also conducted on the presence/absence transformed data (Figure 5B). While this shows a similar pattern to that of the untransformed MDS, with the exception of one Coulman Island Station 3 sample, there is more overlap and tighter clustering of the Cape Hallett Inside, Coulman Island, and Cape Russell assemblages (Figure 5B), indicating that these communities are comprised of similar taxa (see previous discussion of individual taxa).

Explaining variability in macrofaunal assemblage composition using environmental variables

The MDS plots do not reveal strong differentiation between stations of macrofaunal assemblage composition. To investigate how changes in assemblages were related to various environmental drivers, we use a different ordination technique specifically designed for defining environmental gradients (Figure 6). The environmental variables initially included in this model were sediment 50characteristics (grain size composition, organic content, chlorophyll *a*, phaeophytin, ratio of chlorophyll *a* to phaeophytin) and depth. Of these, the most important in explaining the differences in assemblage composition are percent fine sand and silt, the ratio of sediment chlorophyll *a* to phaeophytin, and depth. However, the overall percentage of community variability explained by this canonical correspondence analysis is low (17.3%), indicating that the environmental factors included in the model are having only a weak influence on macrofaunal assemblage composition.

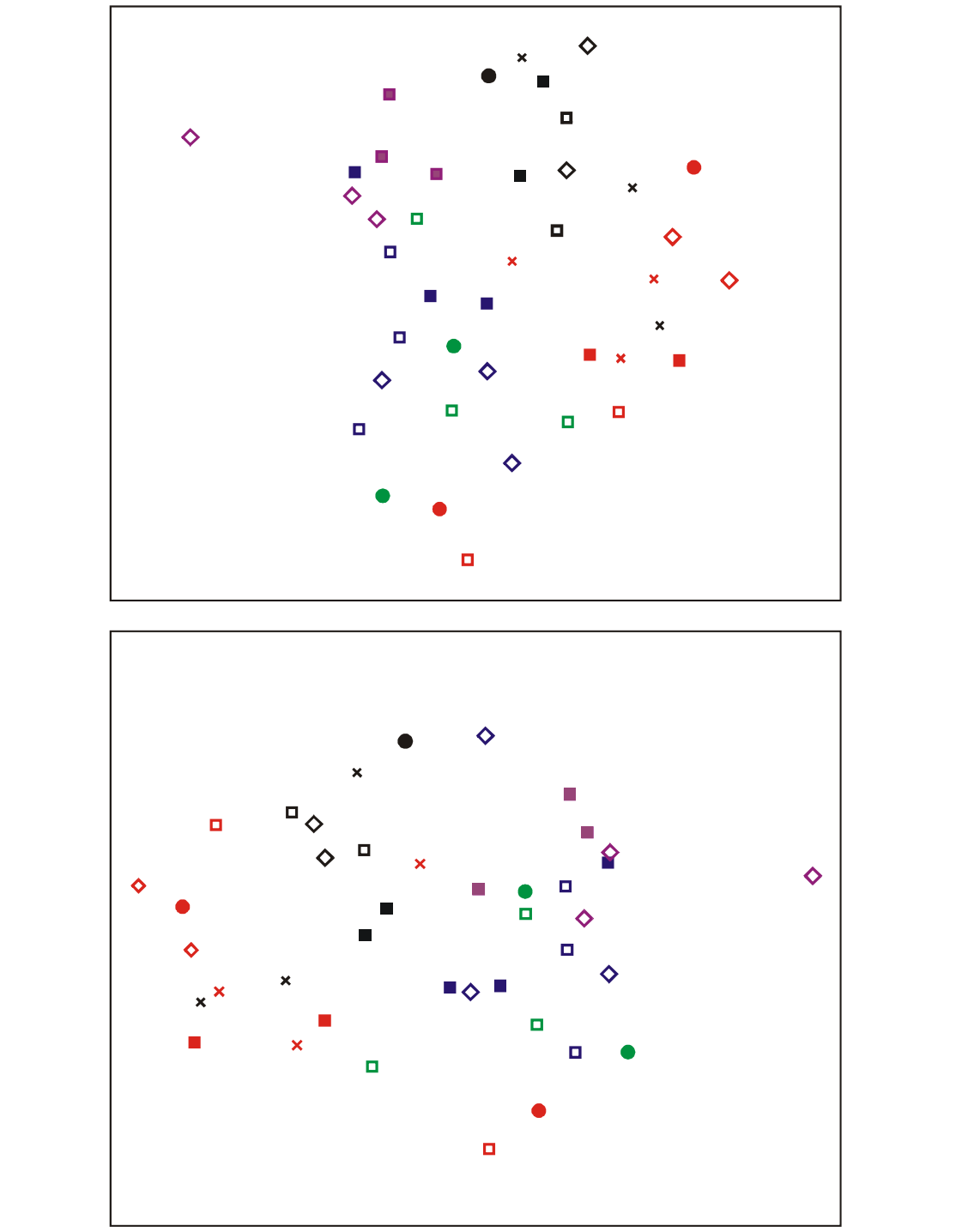

Figure 5: Multidimensional scaling analysis ordination plot showing the similarities in macrofaunal assemblages within and between locations. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively.

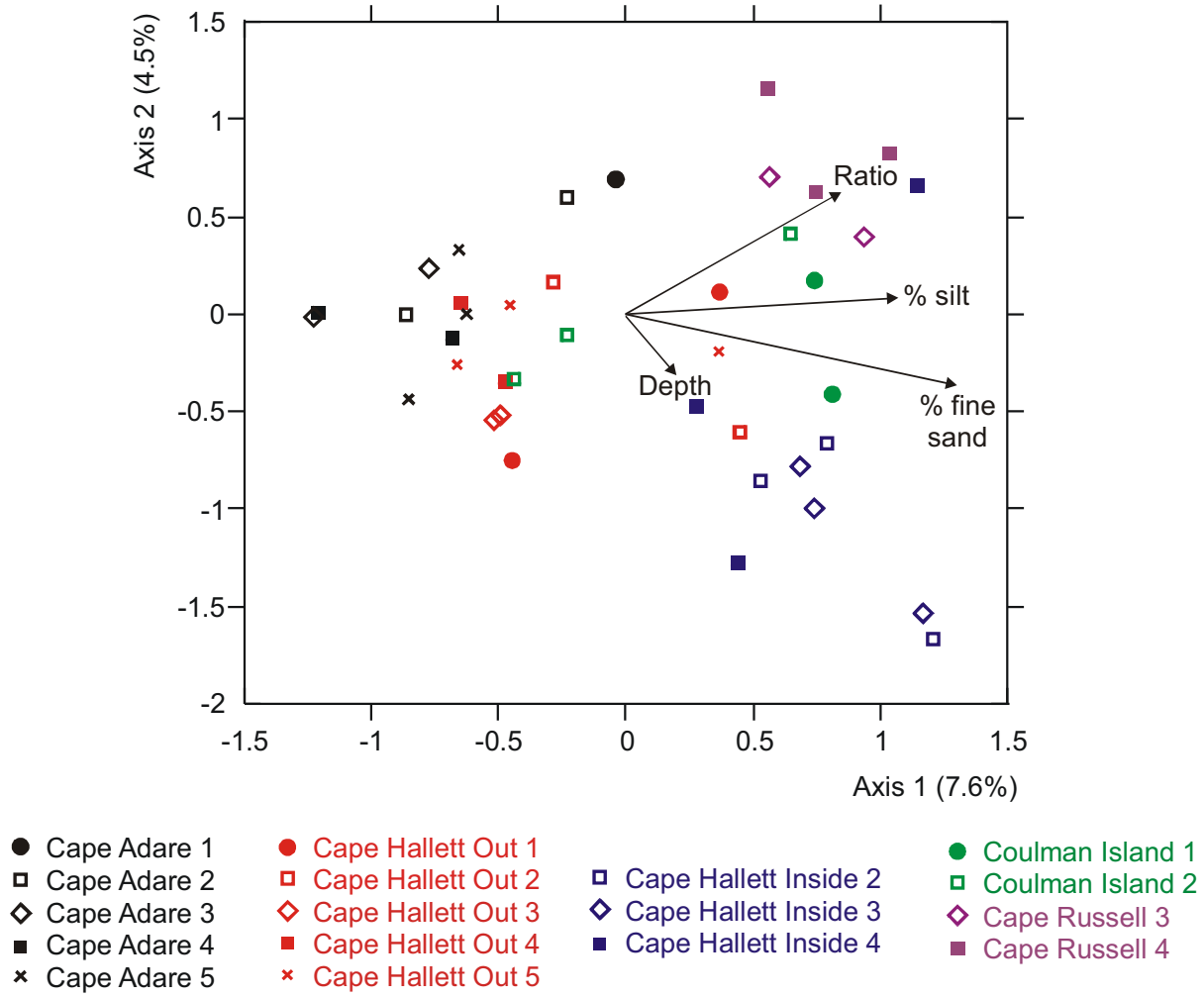

Figure 6: Canonical correspondence analysis ordination plot showing the environmental variables important in explaining the macrofaunal assemblages at each location and station. Ratio = chlorophyll *a*:phaeophytin. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200 and 100 m, respectively.

3.3 Macroalgae

Taxonomic collections and distribution

Nine macroalgal taxa were identified in the samples collected from all depths and locations (Table 4). Demonstrably attached macroalgae could be collected only by scuba diving, and thus our sampling was restricted to depths of less than 20 m. Samples collected from grabs and dredges were assumed to be drift material. Representative samples were preserved on board and identifications have been confirmed by macroalgal taxonomist Dr Wendy Nelson (NIWA, Wellington).

Observations from the Cape Russell video shows extensive coralline growth at depths of 70 to 90 m and 80–100 m (see SplashCam, Section 3.4). Extensive drift *Phyllophora antarctica* and *Iridaea cordata* was evident at the 70–90 m location (primarily associated with urchins, *Sterechinus* sp.) but appeared less abundant at 80–100 m. At the shallower locations (less than 30 m) at Cape Russell, no coralline algae were observed by scuba divers (Table 4). The ecological implications of these drift algae are difficult to assess. Our previous work at Cape Evans indicates that this material is very slowly incorporated into the benthic food chain (Norkko et al. 2002, 2004), due to slow rates of decomposition and high levels of anti-herbivore chemicals (McClintock & Baker 1995, Amsler et al. 1999). However, slightly warmer water temperatures in more northern locations may speed degradation rates and enhance the utility of this material as a food source.

Photosynthetic characteristics

Collected plants appeared to be in various states of photosynthetic competence. Photosynthetic yield values derived from PAM fluorometry under light conditions equivalent to those the plants would have experienced in situ, ranged, for all taxa, from a minimum of 0.004 (indicating no photosynthetic capacity) to a maximum of 0.731 (indicating a high degree of photosynthetic capacity). Both these values were for *Himantothallus grandifolius* at Cape Hallett from depths of 400 m and 18 m, respectively, and are consistent with the deep sample being highly degraded. In situ yield for *Phyllophora antarctica* at depths of 13.5 to 20 m covered a relatively narrow range (0.463 to 0.602) (Table 5). These values are only slightly lower than those measured for attached *Phyllophora* under ice at Cape Evans (0.630 to 0.661; Schwarz et al. 2003) and indicate a healthy, photosynthetically active population.

Table 4: Macroalgae collected by grab, dredge and scuba sampling at each location. For collection depths at each location see Table 2.

Taxa	Cape Adare	Cape Hallett	Faraglione	North of Cape Russell	South of Adelie Cove
Coralline		•	•		
Desmarestia menziezii	•	•			
Himantothallus grandifolius		•			
Iridaea cordata			•	•	•
Palmaria decipiens	•				
Phycodrys antarctica	•	•			
Phyllophora antarctica		•	•	•	•
Plocamium cartilagineum					•
Ulva sp.	•	•			

Chlorophyll *a* contents

Concentrations of chlorophyll *a* varied considerably between samples, ranging from about 50 μg g^{-1} dry weight for *Himantothallus grandifolius* at 400 m, to 900 μg g^{-1} dry weight for *Desmerestia menziezii* at 200 m (Figure 7). For these two large brown macroalgae, concentrations of both chlorophyll *a* and *c* were lowest for drift plants collected from the maximum depth sampled (400 m). The PAM fluorometery indicates that the deep samples were decaying, and this is consistent with reduced chlorophyll contents.

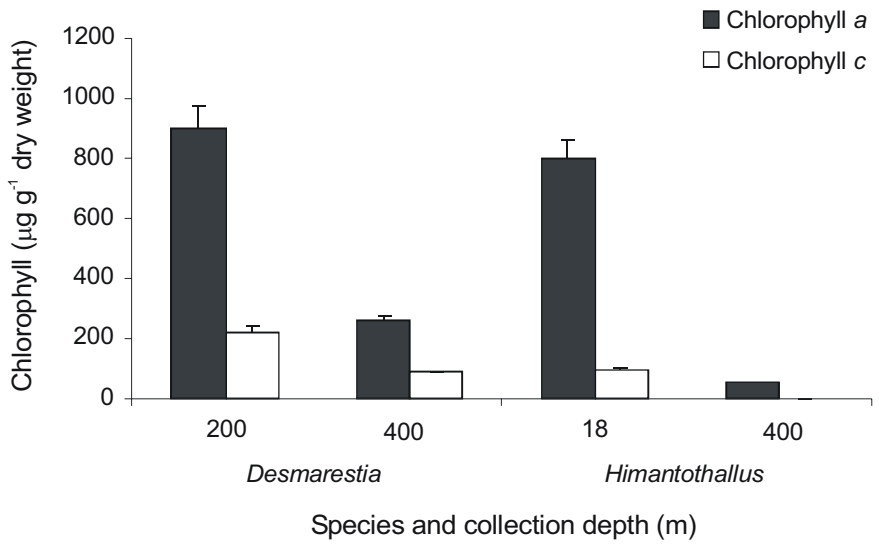

Figure 7. Concentrations of chlorophyll *a* and *c* (mean + standard error, n = 3) in the brown macroalgae *Desmarestia menziezii* and *Himantothallus grandifolius.* Samples were collected in dredge or grab samples from Cape Adare except *Himantothallus* from 18 m, which was collected during a dive at Cape Hallett (see Table 2).

For the red alga *Phyllophora antarctica,* pigment content increased with depth between 13.5 and 20 m (Figure 8). When normalised to fresh weight, concentrations of chlorophyll *a* for *Phyllophora* at depths less than 20 m at Cape Evans were of a similar magnitude to those reported for 16 m in this study (i.e., about 240–355 μg g^{-1} dry wt) (Schwarz et al. 2003). Concentrations for *Phyllophora* from 20 m at Faraglione were about twice those for the same depth from Cape Evans. This may reflect the greater average irradiance at 20 m at Faraglione compared to Cape Evans, making it energetically feasible for the deeper plants to continue to acclimate via increased pigment content.

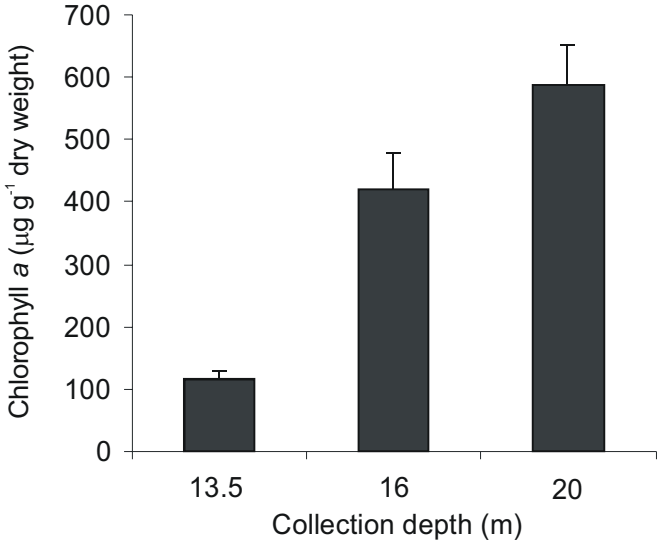

Figure 8: Concentration of chlorophyll *a* (mean ± standard error, n = 3) in the red macroalgae *Phyllophora*. Samples were collected from dive sites north of Cape Russell and at Faraglione.

Table 5: Mean (standard deviation) of $\Delta F/F_m$' approximating *Y* for in situ measurements (less than 30 m; dive sites, n = 10 fronds) and Fv/F_m for dredged material (>30 m; dredge and grab samples, n = 5 fronds). Three different collections of *Phycodrys antarctica* were made from 400 m dredge and grab samples at Cape Hallett.

	Cape Adare		Cape Hallett			Faraglione		North of Cape Russell		South of Adelie Cove	
Taxa	400 m	200 m	400 m	100 m	18 m	20 m	16 m	16 m	13.5 m	20 m	16.5 m
Coralline	-	-	-	-	0.579 (0.03)	-	-	-	-	-	-
Desmarestia menziezii	0.628 (0.06)	0.722 (0.04)	-	-	-	-	-	-	-	-	-
Himantothallus grandifolius	0.669 (0.05)	-	0.004 (0.003)	-	0.731 (0.02)	-	-	-	-	-	-
Iridaea cordata	-	-	-	-	-	0.301 (0.09)	0.463 (0.13)	-	0.455 (0.13)	-	0.430 (0.22)
Palmaria decipiens	0.398 (0.08)	0.242 (0.07)	-	-	0.615 (0.06)	-	-	-	-	-	-
Phycodrys antarctica	-	-	a) 0.39 (0.19) b) 0.454 (0.07) c) 0.403 (0.12)	0.355* (0.15)	-	-	-	-	-	-	-
Phyllophora antarctica	-	-	-	-	0.563 (0.04)	0.528 (0.11)	0.494 (0.10)	0.469 (0.07)	0.602 (0.15)	0.463 (0.24)	0.492 (0.11)
Ulva sp.	-	-	0.601 (0.08)	-	-	-	-	-	-	-	-

* After 5 min in darkness this value had increased to 0.5

3.4 SplashCam

Cape Hallett

Two transects were videoed at Cape Hallett using our splash camera (SplashCam) from *Italica*. GPS locations and depth of each transect (T1 and T2) are given below.

Cape Hallett	Latitude S	Longitude E	Depth (m)
T1 (9/2/04)	72°16.8	170°17.6	97.0
	72°16.7	170°17.3	120.0
	72°16.6	170°16.8	140.0
	72°16.6	170°16.7	143.0
	72°16.6	170°16.7	145.0
	72°16.6	170°16.6	147.0
	72°16.6	170°16.5	150.0
	72°16.6	170°16.5	151.0
	72°16.6	170°16.4	154.0
T2 (17/2/04)	72°17.089	170°17.845	98.8
	72°17.156	170°17.999	102.4
	72°17.167	170°18.073	102.4
	72°17.180	170°18.081	100.8
	72°17.172	170°18.088	100.8
	72°17.179	170°18.082	100.4
	72°17.172	170°18.102	100.8
	72°17.155	170°18.129	101.6
	72°17.101	170°18.197	104.0
	72°17.074	170°18.130	102.8
	72°17.074	170°18.058	104.0

Unfortunately, video from the first transect at Cape Hallett was only partly successful as the ship was drifting too fast. The second Cape Hallett transect shows hydroid dominated communities with some bare patches, perhaps indicative of iceberg scour. The quality of the second video was such that more detailed analysis was not possible.

Cape Russell

Two transects were videoed at Cape Russell on 22/2/04, using SplashCam from RV *Italica*'s tender vessel, *Skua*. The transects were located in areas with contrasting multibeam signatures (as determined by Rikk Kvitek, Seafloor Mapping Lab, Monterey Bay, USA, during this voyage), with Transect 1 located in an area where the signature suggested comparatively less iceberg scour (see Figures 9 and 10). GPS locations of each transect are given below.

Cape Russell	Latitude S	Longitude E
T1	74°50.59	164º01.38
80–100 m	74°50.59	164º01.43
	74°50.59	164º01.45
	74°50.59	164º01.47
	74°50.59	164º01.49
	74°50.59	164º01.50
	74°50.59	164º01.53
	74°50.59	164º01.55
	74°50.59	164º01.56
	74°50.59	164º01.58
	74°50.59	164º01.59
T2	74º50.10	164º03.35
70–90 m	74º50.11	164º03.32
	74º50.12	164º03.30
	74º50.13	164º03.25
	74º50.14	164º03.21
	74º50.15	164º03.18
	74º50.16	164º03.11
	74º50.17	164º03.08
	74º50.17	164º03.05
	74º50.18	164º03.01
	74º50.18	164º02.97
	74º50.18	164º02.96

The video footage from each transect was initially viewed in its entirety, and nominal 'habitat groups' assigned. Examples of these habitat groups along the transects were then characterised as described in the Methods. Transects 1 and 2 were 102 and 241 m long, respectively.

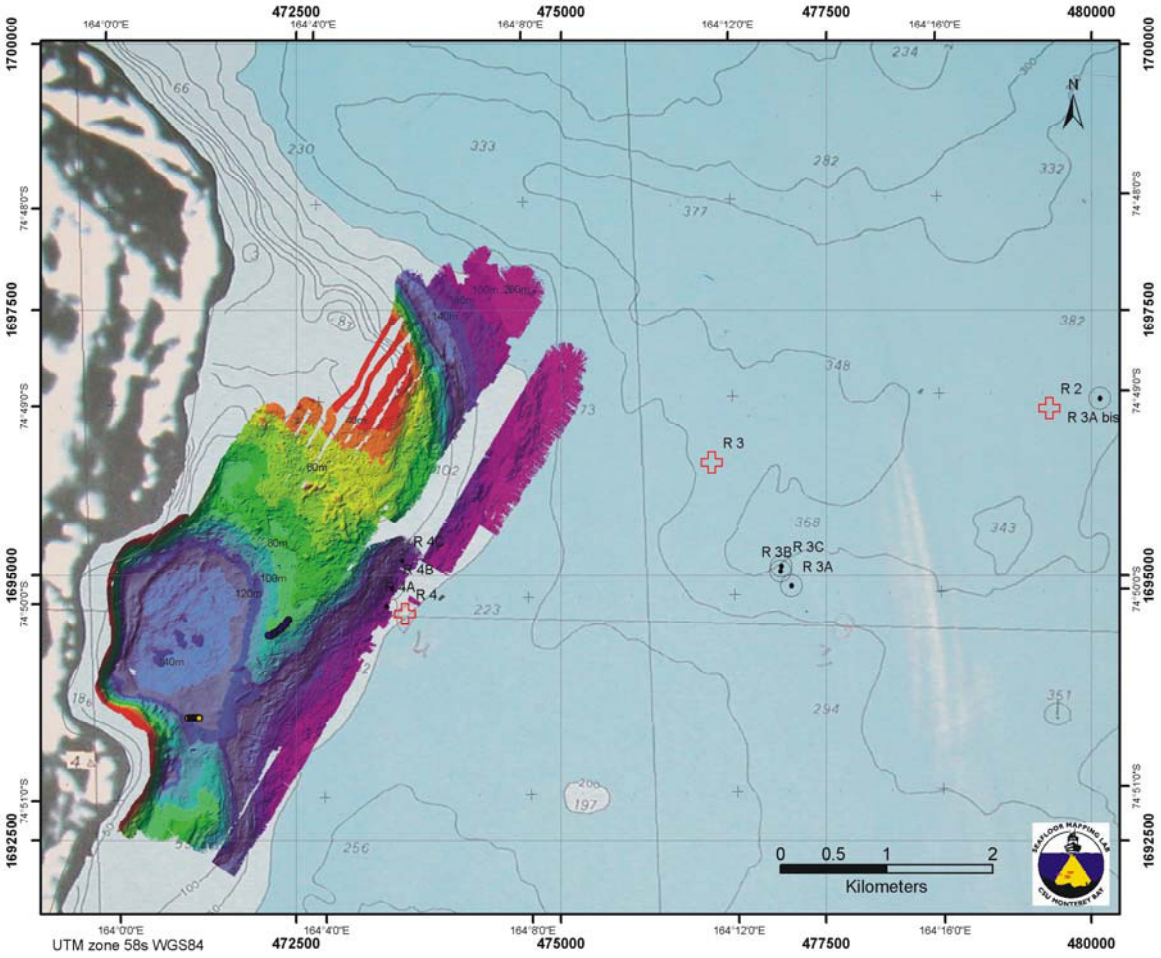

Figure 9. Multibeam imagery of the seafloor off Cape Russell. Locations of Transects 1 and 2 videoed using Splashcam are shown by the series of yellow and black dots, respectively. ***Images courtesy of Rikk Kvitek, Seafloor Mapping Lab, Monterey Bay, US.***

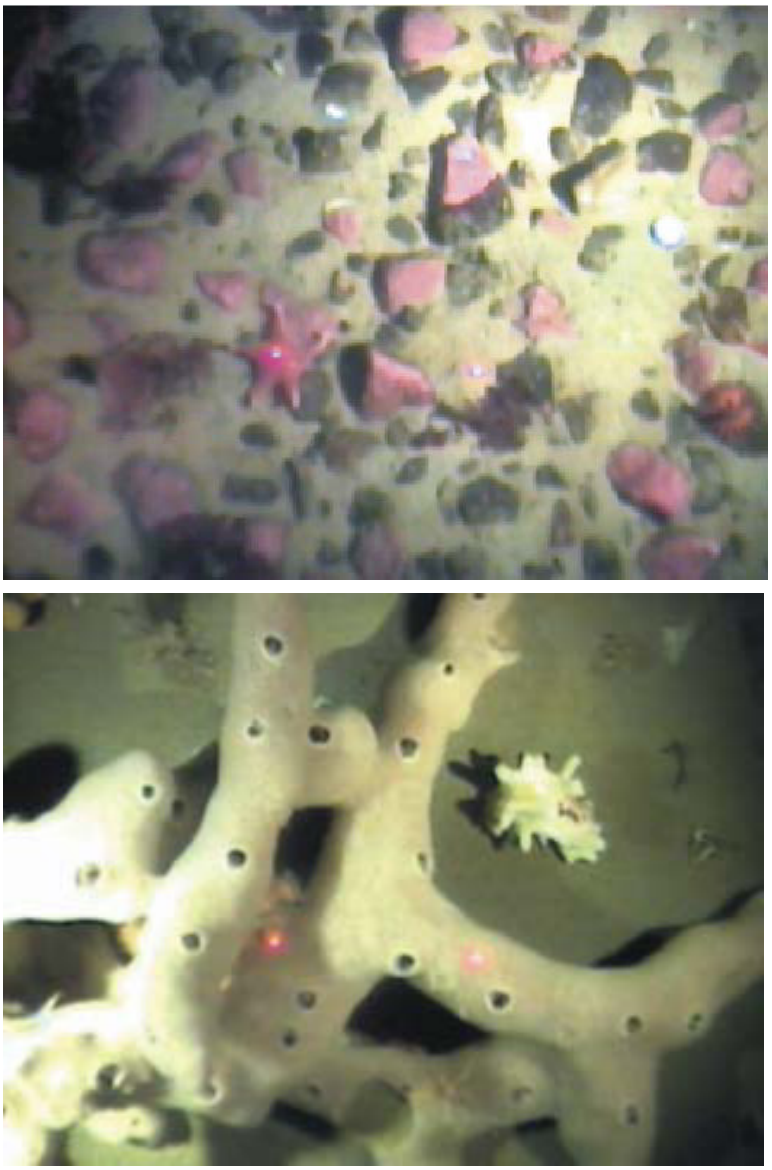

Figure 10: Frame grabs from video footage at Cape Russell, showing seafloor from disturbed area (top), and sponge (bottom). Distance between lasers (red dots) is 12 cm.

The Cape Russell video shows different habitat structure and communities along the two transects (Figure 11 and Table 6). The seafloor along Transect 1 was mostly sand/mud, with varying amounts of rock and cobble (Figure 11A). Within this area, three habitat types were identified: habitat group 1 was about 60% sand/mud, and 40% rock per 0.25 m^2. Habitat group 2 was 98% sand/mud, with a small amount of cobble. Habitat group 3 was about 92% sand/mud, with the balance equal amounts of rock and cobble. In each of the habitat groups along Transect 1, the rock and cobble surfaces were covered with encrusting coralline algae (Figure 11, Table 6). In addition, protruding sponges were common along this transect (5 to 11 individuals per 0.25 m^2). Clumps of red macroalgae (*Phyllophora antarctica* and/or *Iridaea cordata)* attached to the urchin *Sterechinus* were relatively abundant at habitat group 7 (2 clumps and 2 individuals per 0.09 m^2).

Along Transect 2, the seafloor was more variable, with a mixture of different substrates (Figure 11B). Four habitat groups were identified: habitat group 7 was most similar to the Transect 1 habitats, with 88% sand/mud, and a mix of small amounts of rock and pebble (5 and 7.5%, respectively). No encrusting coralline algae were noted in this habitat. Habitat group 4 had equal amounts of sand/mud and pebble (about 35%), with some cobble and coarse sand/gravel. Habitat groups 5 and 6 both contained a mix of all five substrate types: habitat group 5 comprised a combination of rock (42%) and sand/mud (31%), while habitat group 6 was mostly (62%) sand/mud, with 2–15% of the other substrates. Habitat groups 4, 5, and 6 were characterised by 20–30% encrusting corallines.

Apart from the lack of encrusting corallines in habitat group 7, the fauna/flora along Transect 2 were similar in both species composition and abundance. They contained red macroalgae (7–12 clumps per 0.25 m^2), generally attached to *Sterechinus* (7–11 individuals per 0.25 $m^{2)}$); and *Odontaster* (1–3 individuals per 0.25 m^2). Between 1 and 3 individual protruding sponges were also evident in these habitat groups. The ophiuroid *Ophionotus* was relatively abundant in habitat groups 4 and 6 (about 1 individual per 0.25 m^2).

Due to limitations of camera operations by ice, the habitat contrast between transects is potentially confounded by depth changes, with the transect in the region of low scarring (Transect 1) slightly deeper (by 10 m) than the other. Nevertheless, both transects were in 80–90 m water and both contained patches of crustose coralline algae. Sea pens are abundant in two of the three habitat groups along Transect 1, and in habitat group 4 of Transect 2. Gorgonians are found in all habitat groups along Transect 1 in low abundances. *Alcyonium* are found along both transects, although they are more abundant along Transect 2 (Table 6).

Although we were able to collect data only from two locations, the video surveys are consistent with what we might expect under different disturbance regimes and generally conform to predictions of changes in assemblage structure and space occupancy noted from recent studies of iceberg disturbance in the Weddell Sea (Teixido et al. 2002, 2004). The video images highlight characteristics that are consistent with different disturbance regimes; for example, faster growing fauna (such as *Alcyonium*) are more common along Transect 2.

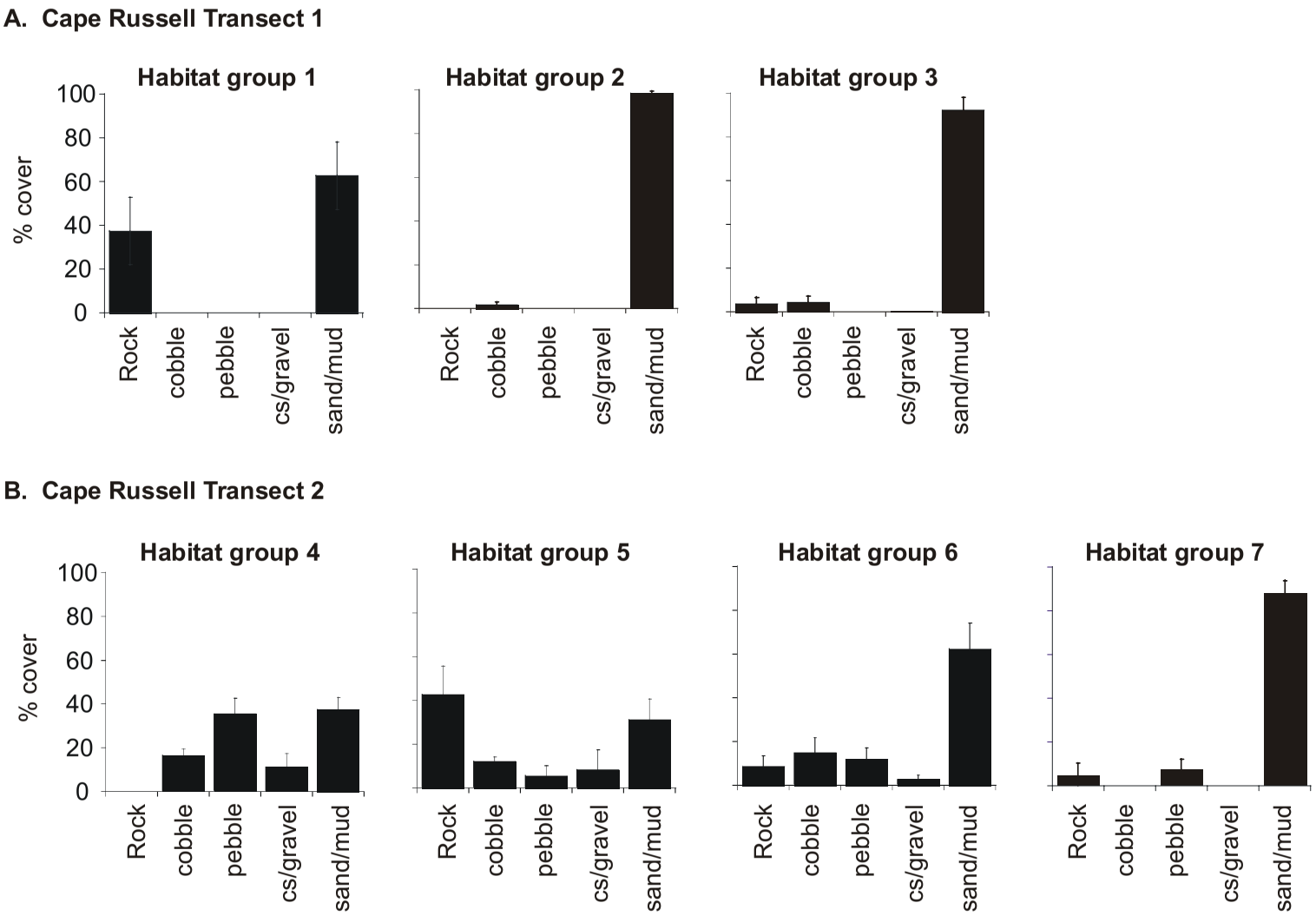

Figure 11: Physical seafloor characteristics of the major habitat groups identified at each video transect at Cape Russell. Multibeam imagery showed evidence of iceberg disturbance in the vicinity of Transect 2, but no disturbance at Transect 1. Transect 1 depth range, 80–100 m; Transect 2 depth range, 70–90 m.

Table 6: Fauna recorded in each habitat group at Cape Russell, from splash cam. Numbers presented are mean (± standard error) 0.25 m^{-2}. * tufts/clumps of macroalgae (*Phyllophora* and/or *Iridaea*). Multibeam imagery showed evidence of iceberg disturbance in the vicinity of Transect 2, but no disturbance at Transect 1. Transect 1 depth range, 80–100 m; Transect 2 depth range, 70–90 m. Classification: cl, class; scl, subclass.

		Transect 1			Transect 2			
Habitat group	Classification	1	2	3	4	5	6	7
% cover								
Coralline (encrusting)	cl. Phodophyceae	35.83 ± 15.86	1.67 ± 1.15	3.13 ± 2.49	24.58 ± 7.10	30.55 ± 12.21	19.03 ± 7.49	-
Number of individuals								
Red macroalgae*	cl. Phodophyceae	1.05 ± 1.15	0.30 ± 0.33	2.40 ± 0.69	9.46 ± 2.81	7.55 ± 1.95	11.91 ± 2.22	7.99 ± 5.00
Sponge (misc. encrusting)		1.05 ± 0.78	-	0.32 ± 0.35	0.30 ± 0.33	-	-	-
Sponge (misc. protruding)		0.70 ± 0.77	-	-	-	0.91 ± 0.68	-	2.50 ± 0.24
Sponge	cl. Demospongiae	0.70 ± 0.77	-	-	-	-	-	-
Sphaerotylus antarcticus								
Sterechinus neumayeri	cl. Echinoidea	0.75 ± 0.52	0.30 ± 0.33	2.40 ± 0.69	11.28 ± 1.90	7.76 ± 1.55	10.78 ± 1.89	7.09 ± 4.34
Odontaster validus	cl. Stelleridea, scl. Asteroidea	-	-	-	1.80 ± 0.41	2.05 ± 0.82	1.61 ± 0.70	2.69 ± 1.90
Asteroida (misc. unid.)	cl. Stelleridea, scl. Asteroidea	-	-	-	-	0.40 ± 0.44	-	-
Ophionotus victoriae	cl. Stelleridea, scl. Ophiuroidea	0.35 ± 0.38	-	-	0.30 ± 0.33	1.15 ± 0.58	0.20 ± 0.22	0.90 ± 1.10
Ophiuroida (misc. unid.)	cl. Stelleridea	2.50 ± 1.09	-	-	0.30 ± 0.33	0.91 ± 1.00	0.20 ± 0.22	-
Sea pens	cl. Anthozoa	4.43 ± 2.58	5.49 ± 2.86	-	7.19 ± 4.21	-	-	-
Alyconium sp.	cl. Anthozoa	0.16 ± 0.17	-	0.61 ± 0.67	-	1.97 ± 0.75	2.01 ± 1.25	0.80 ± 0.97
Gorgonians (misc.)	cl. Anthozoa	1.80 ± 1.51	0.77 ± 0.55	0.32 ± 0.35	-	-	0.34 ± 0.36	-
Anemone (white)	cl. Anthozoa	-	-	-	-	-	0.20 ± 0.22	-
Solitary ascidian (yellow)	cl. Ascidiacea	0.35 ± 0.38	-	-	-	-	-	-
Yellow ascidian	cl. Ascidiacea	0.40 ± 0.44	-	-	-	-	-	-
Ascidian (large)	cl. Ascidiacea	0.70 ± 0.77	-	-	-	-	-	-

3.5 Dredge fauna

The dredge fauna are being identified and quantified by Italian researchers. Table 7 provides a preliminary account of the predominant community type and seafloor substrate, and an evaluation of the faunal diversity at each site. Although further work is needed, it is clear that large emergent epifauna dominate the seafloor in most locations. However, without the type of information available from the video camera, it is not possible to determine whether the seafloor landscape is dominated by epifaunal assemblages, or if it is highly patchy.

Table 7: Predominant substrate and faunal assemblages at each dredge station. CA, Cape Adare; CH In, Cape Hallett Inside; CH Out, Cape Hallett Outside; CI, Coulman Island; CR, Cape Russell. *nd*, not determined. GPS locations of each Station are given in Appendix 2.

Location	Station	Depth (m)	Substrate	Assemblage	Relative diversity*
CA	1	476.0-515.6	Sand, few cobbles	Ophiuroids	Low
CA	2	421.6-430.0	Sand	Stylasterinids	Low
CA	3	305.6-312.0	Sand, rocks	Stylasterinids	Medium
CA	4	223.0-235.0	Sand, cobbles	Ascidians (tube-like)	High
CA	5	120.4-139.0	Sand, cobbles	Ascidians (foliose)	High
CH In	2	388.4-408.0	Mud, cobbles	Gorgonians community	Medium
CH In	3	316.8-369.0	Muddy sand, cobbles	Ascidians (tube-like)	High
CH In	4	196.0	*nd*	Ascidians (botriform)	High
CH In	5	84.4	*nd*	Ascidians (botriform)	High
CH Out	1	537.2-475.0	Mud, cobbles	Bryozoans, gorgonians	Low
CH Out	2	353.2-388.0	Mud, sand	Bryozoans (Flustridae)	High
CH Out	3	246.8-289.0	Sand, cobbles	Bryozoans	High
CH Out	3	258.8	*nd*	*nd*	*nd*
CH Out	4	208.0	*nd*	*nd*	*nd*
CH Out	4	195.0-235.6	Cobbles	Bryozoans (Celleporidae)	High
CH Out	4	218.0	*nd*	*nd*	*nd*
CH Out	5	103.0-105.2	Sand, cobbles	mixed community	High
CI	1	474.0-480.0	Mud, cobbles	Ophiuroids	High
CI	2	372.0-410.0	Mud, cobbles	Pterobrachia	High
CR	2	364.8	*nd*	Bryozoans	Medium
CR	3	307.0-330.0	Sand, cobbles	Gorgonians	High
CR	4	174.0-216.0	Sand, cobbles	Bryozoans, Pterobrachia	Medium

* The diversity indicators in the right hand column were provided by Italian researchers, who are preparing a more quantitative approach to these data

3.6 Scuba sampling

Five scuba dives were conducted at four locations during the voyage. GPS locations of dive sites are given below.

Location (date sampled)	Depth (m)	Latitude S	Longitude E
Cape Hallett (10/2/04)	18.0	72º 18.723	170º 15.229
Cape Hallett (11/2/04)	18.5	72º 18.624	170º 15.369
Faraglione (20/2/04)	18.0–20.0	74º 43.062	164º 06.775
North of Cape Russell (21/2/04)	15.0–17.0	74º 52.350	163º 58.030
South of Adelie Cove (22/2/04)	20.0	74º 50.620	164º 00.576

Cape Hallett

The survey-sampling strategy that was implemented in previous seasons was conducted at one site at Cape Hallett. Video analysis revealed that the dominant epifaunal taxa at this site were *Odontaster validus* and *Sterechinus* sp. Specimens of both were considerably smaller than individuals found at the more southerly locations in previous seasons, and *Sterechinus* individuals were cryptic and difficult to distinguish on the video (being small size camouflaged with gravel). The small size of *Sterechinus* has been previously noted in our comparison between McMurdo Sound and Terra Nova Bay. Small *Sterechinus* were also apparent in our grab and dredge sampling, indicating a possible inverse relationship between density and size along the latitudinal gradient from McMurdo north. There was abundant *Himantothalus grandifolius* (see Section 3.3) slightly deeper than the video transect, but only one holdfast along the video transect. *Himantothalus* fronds prevented the video footage being analysed in several places, as the fronds obscured the underlying seafloor. Generally, the area appeared to be regularly disturbed by drifting pack ice and bergy bits.

The predominant substrate type identified from the video footage was coarse sediment/gravel and pebble (Table 8, Figure 12). Particle size analysis of the samples collected along Transect 1 shows that the sediment consists mostly of gravel (84.41%), with 11.46% fine sand and small amounts of coarse sand (3.46%) medium sand (0.42%), and silt (0.24%). The organic content of this sediment was very low (0.83%). For comparison, in McMurdo Sound (see Cummings et al. 2003), the organic content was similar (i.e., less than 1%), and lower than noted for the deeper sampling sites sampled directly from *Italica* (cf. Table 1).

The few macrofauna core samples collected at this site revealed few species and individuals (less than 1 individual per core on average); nematodes, cirratulid polychaetes, and the small gastropod *Onoba* sp. were found.

Table 8: Summary of the video transect analysis from dives at Cape Hallett and Cape Russell. Numbers presented are % cover or number of individuals (latter indicated by **). Mean ± standard error per quadrat.

	Cape Hallett		Cape Russell	
	T1	T2	T1	Algae
Substrate				
Rock	3.4 ± 2.1	2.4 ± 1.9	-	58.5 ± 7.0
Cobble	9.3 ± 2.5	17.3 ± 4.7	0.3 ± 0.3	4.8 ± 1.8
Pebble	38.1 ± 3.9	46.6 ± 5.7	-	4.2 ± 1.8
Coarse sediment/gravel	49.2 ± 5.4	33.6 ± 4.3	13.6 ± 8.3	4.7 ± 2.0
Sand	-	-	86.2 ± 8.4	-
Iridaea cordata	-	-	-	14.7 ± 3.8
Phyllophora antarctica	-	-	-	13.2 ± 3.5
Fauna/macroalgae*				
*Sterechinus neumayeri***	0.3 ± 0.0	0.4 ± 0.0	-	1.6 ± 0.0
*Odontaster validus***	2.4 ± 0.0	5.2 ± 0.0	9.6 ± 0.3	0.3 ± 0.1
*Laternula elliptica***	-	-	4.0 ± 0.0	-
*Neobuccinum eatoni***	-	-	0.1 ± 0.0	-
Iridaea cordata	-	-	-	13.2 ± 0.5
Phyllophora antarctica	0.2 ± 0.5	-	-	14.7 ± 5.4
Himantothalus grandifolius holdfast	0.1 ± 0.0	-	-	-

**Numbers calculated from total footage, not just along the transect.*

Figure 12: Cape Hallett dive site seafloor, showing cobbly seafloor, the transect line, and the string and weight of video camera. Note the large macroalgae frond in the bottom left hand corner of the top frame.

North of Cape Russell

We were able to obtain limited footage of the seafloor at Cape Russell: one transect was filmed to obtain general seafloor characteristics and another to examine macroalgae. Unlike Cape Hallett, the Cape Russell site was mostly sand (Table 8, Figure 13). *Laternula,* as well as *Sterechinus,* were difficult to detect due to scattered gravelly substrate and macroalgae, respectively. Cape Russell had considerable amounts of *Iridaea cordata* and *Phyllophora antarctica* attached to rocks and boulders.

More detail on the presence and photosynthetic capacity of the macroalgae noted during the Cape Russell dives is described in Section 3.3.

Figure 13: Divers collecting animals and macroalgae at Cape Russell (top).
Note the large fronds of *Himantothallus*. The smaller plates show images of the seafloor: *Iridaea cordata* attached to rocks, and bare sandflats with seastars.

Objective 2. Ecosystem function

A number of samples were collected from each station visited by RV *Italica* to determine carbon and nitrogen stable isotope signatures. This sampling allows us to determine potential differences in food sources of similar species with respect to both latitude (i.e., from Cape Adare in the north to Cape Russell in the south) and depth (i.e., from 500 to 100 m, Stations 1 to 5, respectively).

In this section we compare isotopic signatures across locations and depths/stations separately for: phytoplankton from seawater, sediment + detritus, macroalgae, and selected large epibenthic taxa (i.e., pycnogonids, holothurians, and the urchin *Sterechinu*s spp.). Where appropriate, we also make comparisons with results of our scuba-based isotope sampling conducted at more southerly locations in previous years (Norkko et al. 2002, Cummings et al. 2003).

3.7 Isotope signatures of seawater, sediment + detritus, macroalgae and selected large epibenthic taxa

3.7.1 Seawater (phytoplankton)

Seawater samples represent the isotopic composition of microalgae (phytoplankton) filtered from the seawater at each location. It may also include very fine suspensoids. This material is available to all suspension feeders and represents the 'bottom' of the food web. It may also form a substantial part of the detrital material in the sediment (see below).

The phytoplankton from the Cape Hallett Inside transect had the most reduced nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) signatures of all locations (Table 9, Figure 14). The large variability in the $\delta^{15}N$ isotopic signatures from the stations along the Cape Adare and Cape Hallett Outside transects in particular (Table 9, Figure 14) is suggestive of patchiness in phytoplankton assemblages. This variability may reflect accumulations of phytoplankton at local oceanic or tidal fronts at the time of sampling, which would be consistent with the strong currents and turbulent eddies observed around the capes. However, as only two seawater samples were processed from the Cape Hallett Outside transect, one of which had isotopic signatures very similar to those from the Inside transect and the other very different (Figure 14), the cause of the difference is uncertain and this result should be interpreted with caution. These shifts in the $\delta^{13}C$ or $\delta^{15}N$ isotopic signatures of phytoplankton were not well correlated with latitude or depth.

The isotopic signatures of phytoplankton samples collected from further south (Terra Nova Bay, Spike Cape on the southern Victoria Land coast, and Cape Evans on Ross Island) on previous sampling occasions were all more enriched in $\delta^{13}C$ than the samples obtained during this voyage (Figure 14). This is likely a reflection of more biological processing and recycled nutrient uptake in these locations.

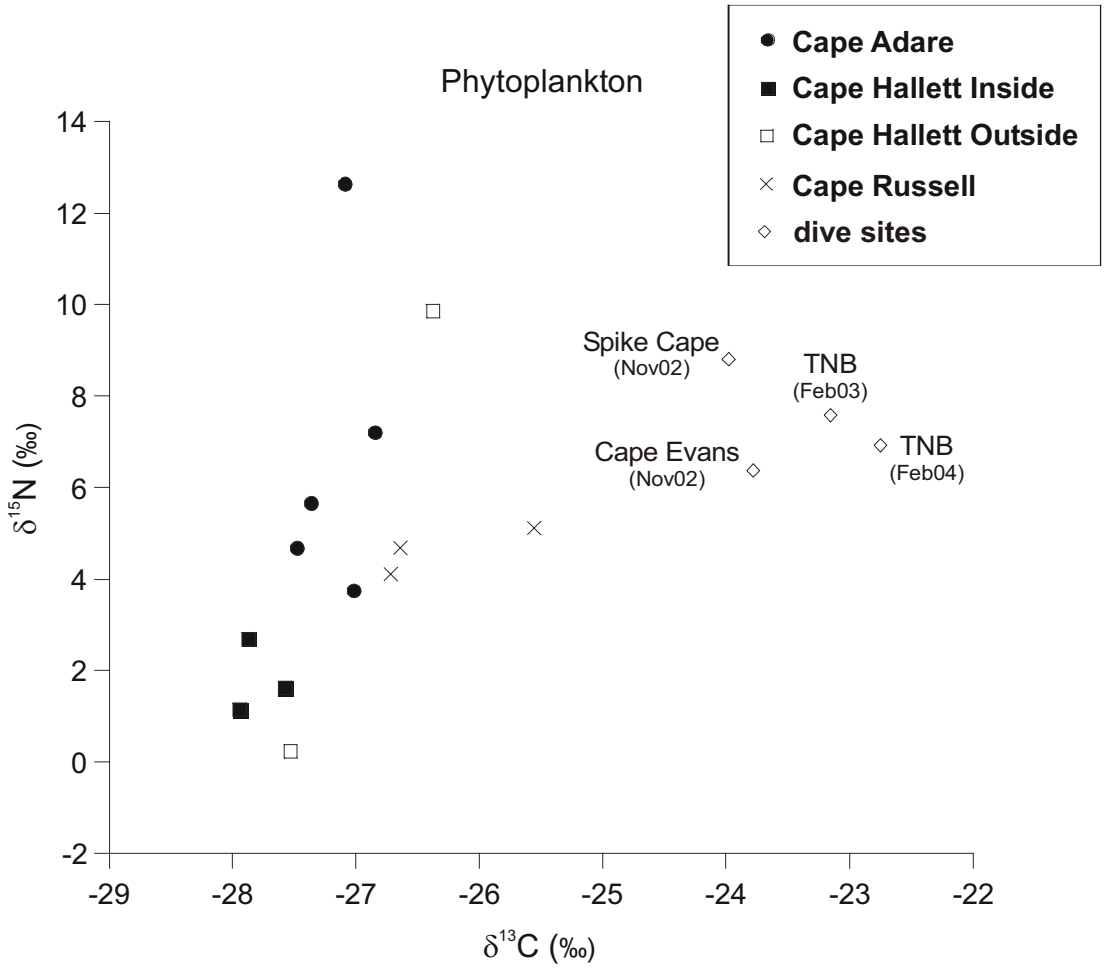

Figure 14: Phytoplankton isotopic distribution (means) from seawater samples at each location sampled from RV *Italica*. See Table 5 for number of samples on which these means are based. Signatures of phytoplankton obtained from shallower locations sampled by scuba in previous years are shown for comparison. TNB, Terra Nova Bay.

Table 9: Mean ($\bar{x}$), range and standard deviation (sd) of $\delta^{13}C$ and $\delta^{15}N$ of seawater samples at the locations and stations (ST.) sampled from *Italica*. CA, Cape Adare; CH In, Cape Hallett Inside; CH Out, Cape Hallett Outside; CR, Cape Russell; n = number of samples.

LOCATION	ST.	Phytoplankton $\delta^{13}C$ (‰)				Phytoplankton $\delta^{15}N$ (‰)				Sediment + detritus $\delta^{13}C$ (‰)				Sediment + detritus $\delta^{15}N$ (‰)			
		$\bar{x}$	range	sd	n	$\bar{x}$	range	sd	n	$\bar{x}$	range	sd	n	$\bar{x}$	range	sd	n
CA	1	-26.84	1.14	0.63	3	7.20	1.89	1.34	2	-9.86	5.8	3.02	3	4.63	-	-	1
CA	2	-27.09	1.36	0.71	3	12.64	0.13	0.09	2	-7.44	2.04	1.44	2	5.51	-	-	1
CA	3	-27.48	0.86	0.46	3	4.67	2.48	1.75	2	-5.30	0.84	0.47	3	4.50	2.04	1.02	3
CA	4	-27.36	0.78	0.39	3	5.65	4.04	2.85	2	-7.30	0.73	0.51	2	3.95	2.11	1.50	2
CA	5	-27.02	0.72	0.40	3	3.74	4.87	2.80	3	-12.40	3.99	2.03	3	3.72	2.48	1.24	3
CH In	2	-27.57	0.35	0.20	3	1.63	0.78	0.55	2	-10.94	1.57	0.90	3	4.27	0.60	0.33	3
CH In	3	-27.94	0.73	0.37	3	1.14	1.05	0.74	2	-9.97	4.09	2.18	3	4.62	1.28	0.65	3
CH In	4	-27.87	0.22	0.12	3	2.68	1.19	0.84	2	-9.37	4.83	2.59	3	4.1	2.39	1.20	3
CH Out	1	-27.53	-	-	1	0.24	-	-	1	-4.7	1.53	0.77	3	4.76	1.05	0.54	3
CH Out	2	-26.37	-	-	1	9.85	-	-	1	-5.52	0.98	0.69	2	5.40	0.96	0.68	2
CH Out	3									-5.21	1.74	1.23	2	5.72	0.22	0.15	2
CH Out	4									-8.03	3.25	2.3	2	4.87	0.19	0.13	2
CH Out	5									-7.66	0.23	0.16	2	4.02	0.13	0.09	2
CR	2	-25.56	0.19	0.36	3	5.11	1.06	0.75	2								
CR	3	-26.72	0.29	0.33	3	4.11	3.50	1.95	3	-22.38	0.14	0.08	3	4.46	2.50	1.31	3
CR	4	-26.64	0.48	0.61	3	4.68	2.89	2.04	2	-14.62	2.28	1.61	2	5.06	0.58	0.23	3

3.7.2 Sediment + detritus

The sediment comprises a mixture of sediment microphytes (algae attached to sediment grains or living in the interstitial spaces between them), faecal pellets of the larger epifauna and macrofauna, sedimenting algae and water column phytoplankton and detritus, and micro-infauna and microbes that consume or decompose the detritus (see Cummings et al. 2003). Sample pretreatment for isotopic analysis was limited to sieving (300 μm mesh) to exclude gravel, coarse sand, and shell fragments, if any. It was not possible to separate the different components of this mixture, and the isotopic signatures measured may reflect the differences in their relative proportions.

There were differences in the $\delta^{13}C$ isotopic signatures of the sediments between the VLT locations, but their $\delta^{15}N$ signatures were quite similar. These differences may be a reflection of location-related differences in phytoplankton blooms that occur earlier in the season, during which large amounts of phytoplankton may be deposited on the seafloor and become incorporated into the sediments as detritus. Similarly, they may reflect differences in the relative proportions of coralline algae incorporated into the sediments (which typically have $\delta^{13}C$ values range from –14 to –5 ‰) (see Cummings et al. 2003). There was no consistent relationship with depth across all locations.

The Cape Hallett Outside transect sediments had the most enriched $\delta^{13}C$ values, while Coulman Island and Cape Russell had the most reduced (Figure 15). At both Coulman Island and Cape Russell, one station is much more reduced in $\delta^{13}C$ than the other (Cape Russell Station 3 (300 m) and Coulman Island Station 1 (500 m)). It is unclear from examining the seafloor sediment composition data why the sediment signatures at these two locations and stations should be so distinct from each other and from the more northern locations sampled from RV *Italica* (see Table 1). Their sediments are more heterogeneous, but not distinctly different from those at all three of the other locations (i.e., they do not contain noticeably higher percentages of any particular grain size fraction).

The $\delta^{13}C$ signatures obtained for sediments collected from the shallower, more southerly locations of our previous scuba based sampling programmes were in the range of the Cape Russell Station 4 and Coulman Island Station 2 sediments; i.e., more reduced than those of the more northern locations, Cape Hallett and Cape Adare (Figure 15). In contrast, the $\delta^{15}N$ signatures were very similar to those of *Italica*'s sampling locations.

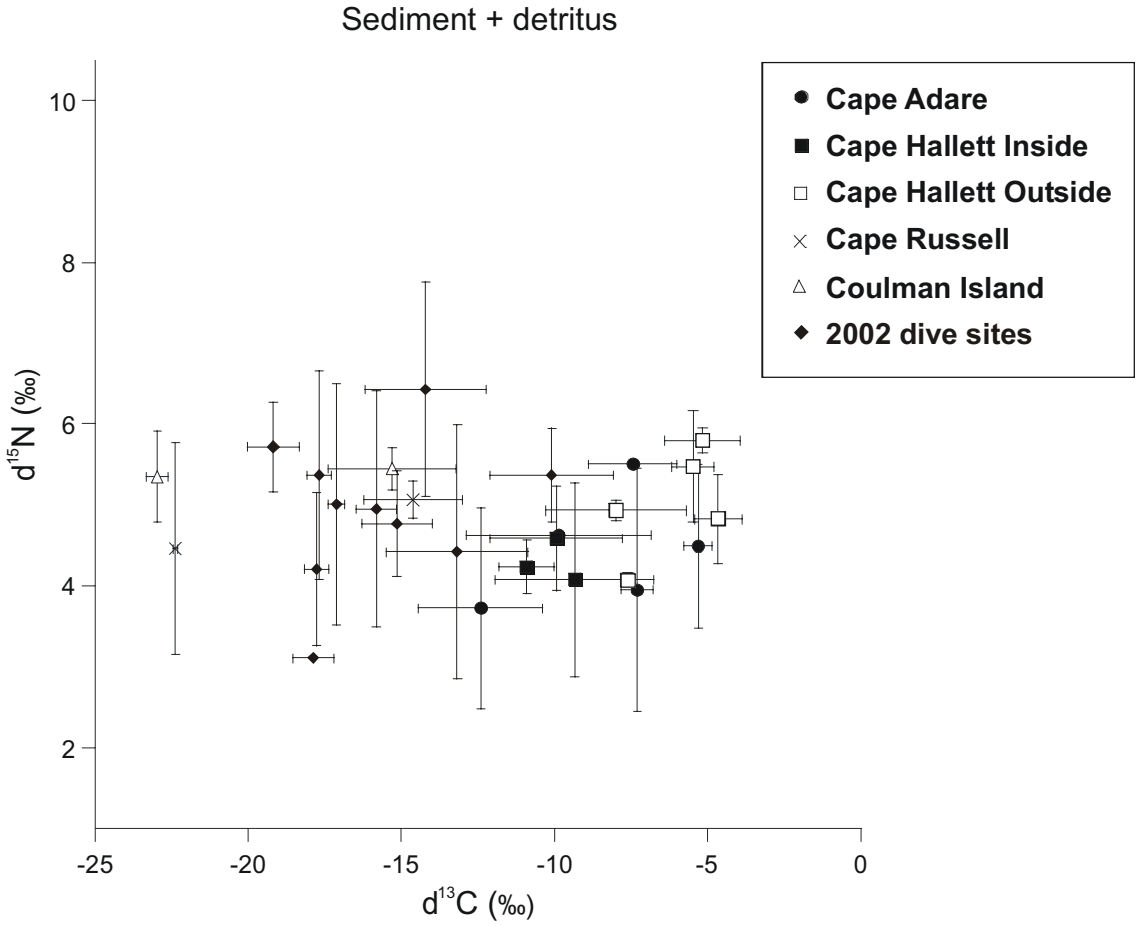

Figure 15: Sediment + detritus isotopic distribution (mean ± standard deviation) from each location sampled from *Italica*, and from the more southerly, shallow dive locations sampled in previous years (i.e., Dunlop Island, Spike Cape, New Harbour, Cape Evans). n, 1 to 3 cores per location.

3.7.3 Macroalgae

Phyllophora antarctica has the most depleted $\delta^{13}C$ isotopic signature of all the macroalgae analysed, and corallines the most enriched (Cummings et al. 2003; Table 10). Signatures of *Phyllophora* collected from Cape Evans and Dunlop Island in 2002 are included in Table 10 for comparison. The data suggest a latitudinal pattern, with more enriched $\delta^{13}C$ values in the south: Cape Evans and Cape Hallett dive, both shallow sites, have the highest and lowest values, respectively (Table 10).

With the exception of the coralline algae, there appears to be a positive correlation between the $\delta^{13}C$ and $\delta^{15}N$ values in the macroalgae, with both isotopes showing proportionally greater enrichment in some species. Interestingly, there are large differences in the isotopic signatures of *Phycodrus antarctica* between Cape Adare (Stations 2 and 4; $\delta^{13}C$: –22 and –23‰, $\delta^{15}N$: 3.22 and 1.72‰, respectively) and Cape Hallett Inside (Stations 2, 4, and 5; $\delta^{13}C$: –36.10 to –35.75‰, $\delta^{15}N$: 0.65 to 0.95‰) (see Table 10). The Cape Hallett *Phycodrus antarctica* isotopic signatures are similar to those of *Phyllophora antarctica,* although the *Phycodrus* are slightly more enriched in $\delta^{13}C$ (Table 10). The reason for the large isotopic difference in this species between these locations is unknown.

Table 10: Mean ($\bar{x}$), range and standard deviation (sd) of $\delta^{13}C$ and $\delta^{15}N$ of macroalgae at stations sampled from *Italica*, and from dive sampling sites in 2002/03 (data from Cummings et al. 2003). CA, Cape Adare; CH, Cape Hallett; CR, Cape Russell; CE, Cape Evans; DI, Dunlop Island. CH In, Cape Hallett inside transects. n, number of samples. **Phyllophora* cleaned of encrusting material

Location	Station	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		$\bar{x}$	range	sd	n	$\bar{x}$	range	sd	n
Palmaria decipens									
CH In	5	-18.22	-	-	1	4.57	-	-	1
Iridaea cordata									
CR	4	-25.87	1.01	0.72	2	3.96	1.79	1.27	2
Kelp									
CA	2	-25.85	-	-	1	2.93	-	-	1
Phycodrus antarctica									
CA	2	-22.43	-	-	1	3.22	-	-	1
CA	4	-23.23	-	-	1	1.72	-	-	1
CH In	2	-36.10	0.94	0.53	3	0.95	0.75	0.38	3
CH In	4	-36.08	0.98	0.49	3	0.79	0.19	0.10	3
CH In	5	-35.75	-	-	1	0.65	-	-	1
Phyllophora antarctica									
CR	2	-37.22	0.42	0.23	3	1.48	1.17	0.65	3
CR	3	-38.24	1.06	0.61	3	2.69	1.50	1.06	2
CR	4	-38.08	0.51	0.27	3	1.21	0.52	0.26	3
CH (dive)		-39.23	0.29	0.16	3	1.00	1.03	0.56	3
CE (dive)	drift*	-36.53	0.50	0.29	3	1.57	1.70	0.88	3
	attached*	-36.85	2.50	1.30	3	-1.08	1.80	1.00	3
DI (dive)	drift*	-37.68	1.30	0.45	9	-0.65	1.40	0.46	9
Himantothallus grandifolius									
CH (dive)		-29.08	1.64	0.85	3	2.90	2.37	1.25	3
Coralline									
CH (dive)		-10.65	0.12	0.09	2	2.98	0.91	0.46	3

3.7.4 Selected large epibenthic taxa

In this section we compare isotopic signatures of three common groups (pycnogonids, holothurians and the urchin *Sterechinus* spp.) across locations and depths (Stations).

Analytical approach

An organism's 'isotopic signature' is typically obtained by drying and grinding the whole animal for analysis. However, as the species chosen for assessing food web linkages in this study are all large and long-lived, and because not all tissues have the same isotopic signature due to tissue-specific fractionation (e.g., Gannes et al. 1997, Lorrain et al. 2002, Schmidt et al. 2004), it was necessary to subsample to obtain $\delta^{15}N$ and $\delta^{13}C$ signatures. The gut and its contents were considered to represent recently ingested food (i.e., 'short term' tissue). We used the more enriched isotopic signatures of a 'long-term' tissue as an integrated measure of all the food sources consumed over a longer period of time (Lorrain et al. 2002). This tissue-specific approach is especially important in the Antarctic environment where the input of food and feeding activity is likely to be pulsed and highly seasonal. For pycnogonids, the body was chosen as the long-term tissue; the integument (body wall) of holothurians, and the test of *Sterechinus* were used.

More specimens than these three groups were collected during the cruise, but due to financial constraints it was not possible to analyse them all. We decided to focus our analyses on a few common groups to identify high level differences within and between locations. Coulman Island individuals were not analysed, because only one of the above taxa were found at both the stations sampled there.

Composition of common groups

The different species of pycnogonids, holothurians, and *Sterechinus* urchins were not distinguished in these analyses, both for the reasons outlined above, and in order to provide sufficient numbers of individuals for location-wide analyses. There was no indication of a depth or location related pattern in the occurrence of the different pycnogonid species, and no depth related pattern in the occurrence of holothurians. The Cape Adare holothurian specimens were all the same type, while the other locations contained a mix of these and other types. There are two species of *Sterechinus* in the Ross Sea: *S. neumayeri* and *S. antarcticus*. The former is generally found shallower (less than 200 m) than the latter, but the two species do co-occur; for example, *S. neumayeri* is reported as occurring at depths from 5 to 640 m (U.S. Antarctic Program 1998). They are very similar morphologically and require microscopic examination to separate them.

Pycnogonids

Pycnogonids (sea spiders) are exclusively marine animals, and most are benthic. Those used in this analysis were small specimens. Adult pycnogonids feed either by sucking the fluids from soft-bodied invertebrates or by browsing on hydroids and bryozoans. Both the body and legs have a chitinous exoskeleton. The body $\delta^{15}N$ signatures were very similar to, although generally more enriched than, that of the legs (Figures 16 and 17). This is contrary to expectations of enrichment between the recently ingested food in the gut and its incorporation into long-term tissue.

For both tissue types, at all locations except Cape Hallett Outside, there is a general pattern of reduced $\delta^{15}N$ values at the shallower stations (i.e., 200 and 100 m deep; Stations 4 and 5, respectively). This is clearly seen in the plots of Station vs. $\delta^{15}N$ for each location (Figure 17). This implies a food source which is either influenced by some function associated with depth, or that there is a different depth-specific food source at each station. As the shifts in $\delta^{15}N$ values are generally not large within location, the differences in pycnogonid signatures could reflect the difference in $\delta^{15}N$ values of nutrients taken by their filter-feeding prey (for example).

Grouping the mean results by similarities in isotopic signature and the reasonable expectation of geographic linkage (see Figure 16), it is apparent that pycnogonids do not feed on one specific prey and that prey may differ by location. Cape Russell data is clearly separate from all other data are implying a local food source, specific to Cape Russell that is not found at the other locations.

Data from Cape Adare imply two main types of prey — one confined to shallow waters and the other to deeper. Of interest, the shallow station data at Cape Adare are similar to most data from Cape Hallett Inside and Outside, suggesting a common prey is shared between these locations. However, in contrast, the deep stations at Cape Adare are very different from the deep stations at Cape Hallett Outside as well as being different from the shallow stations at these locations. This implies some localised prey that do not co-occur between these locations.

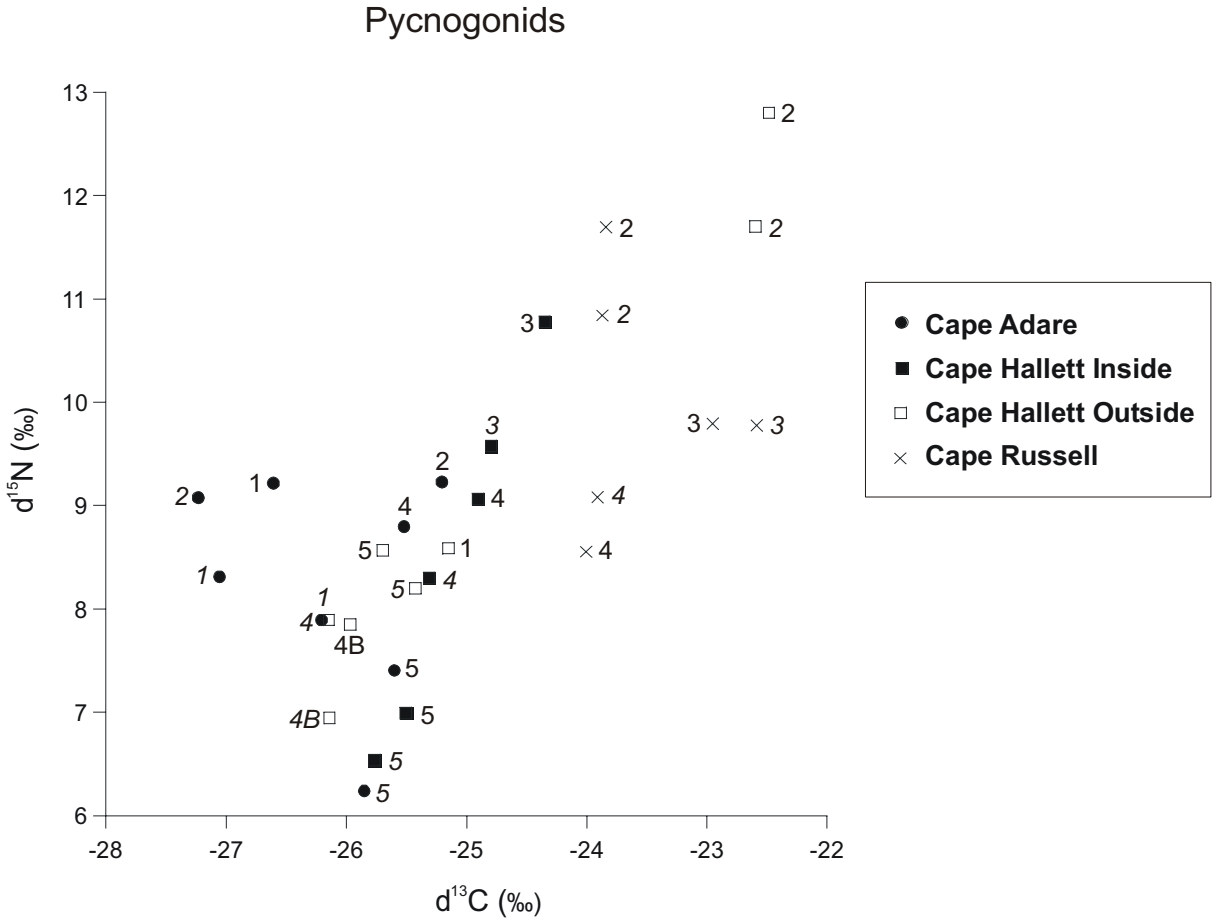

Figure 16: Isotopic distribution (mean) of pycnogonids sampled at each *Italica* location. Numbers in italics = leg tissue, non-italics = body tissue. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively. n, 2–3 individuals per station. To enable easier distinction of station numbers, standard deviations have not been plotted.

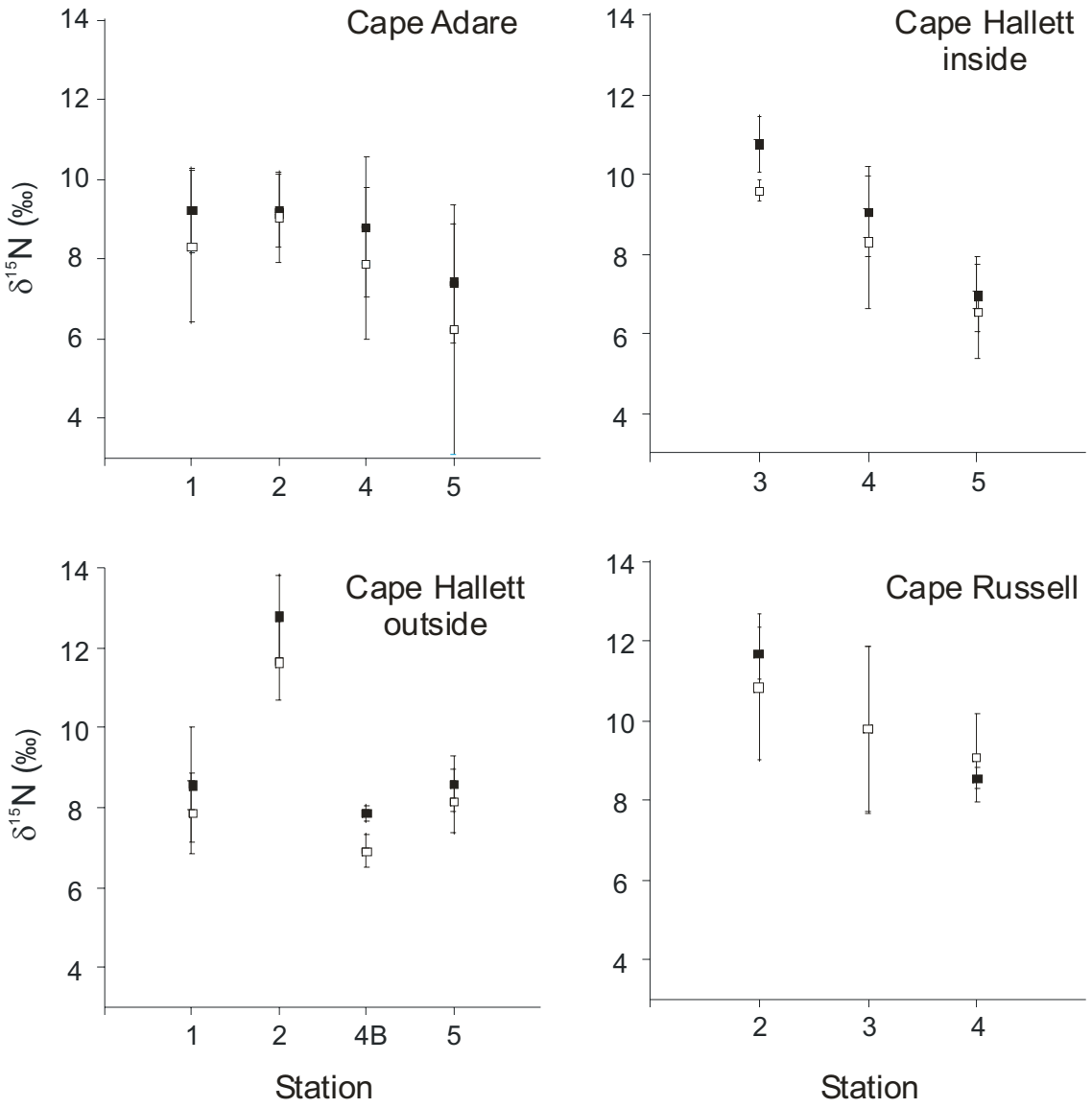

Figure 17: $\delta^{15}N$ distribution (mean ± standard deviation) of pycnogonids sampled at each *Italica* location. Filled squares = leg tissue, hollow squares = body tissue. n, 2–3 individuals per station. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively.

Holothurians

Holothurians feed on detritus, either in suspension or as a deposit (Jarre-Teichmann et al. 1997; U.S. Antarctic Program 1998). Their ecology is not well known (Jarre-Teichmann et al. 1997).

There was no obvious pattern in holothurian isotope signatures associated with location or depth (Figure 18). A possible exception is the Cape Russell holothurians, which appear to be relatively more enriched with $\delta^{13}C$. This lack of pattern is perhaps consistent with the potentially highly variable food source of holothurians (e.g., water masses being advected with currents over large areas).

Gut signatures of holothurians from the three northernmost locations (Cape Adare, Cape Hallett Inside, and Outside transects; range from 1.49 to 5.19 ‰ for $\delta^{15}N$, and –33.09 to –29.38 ‰ for $\delta^{13}C$) were tightly clustered in contrast to the integument (longer term tissue), which was quite variable (Figure 18). This implies that while these individuals were consuming similar trophic-level food sources at all locations at the time of sampling, over the lifetime of the individuals their food is more varied. This perhaps reflects opportunistic utilisation of the most available food resource.

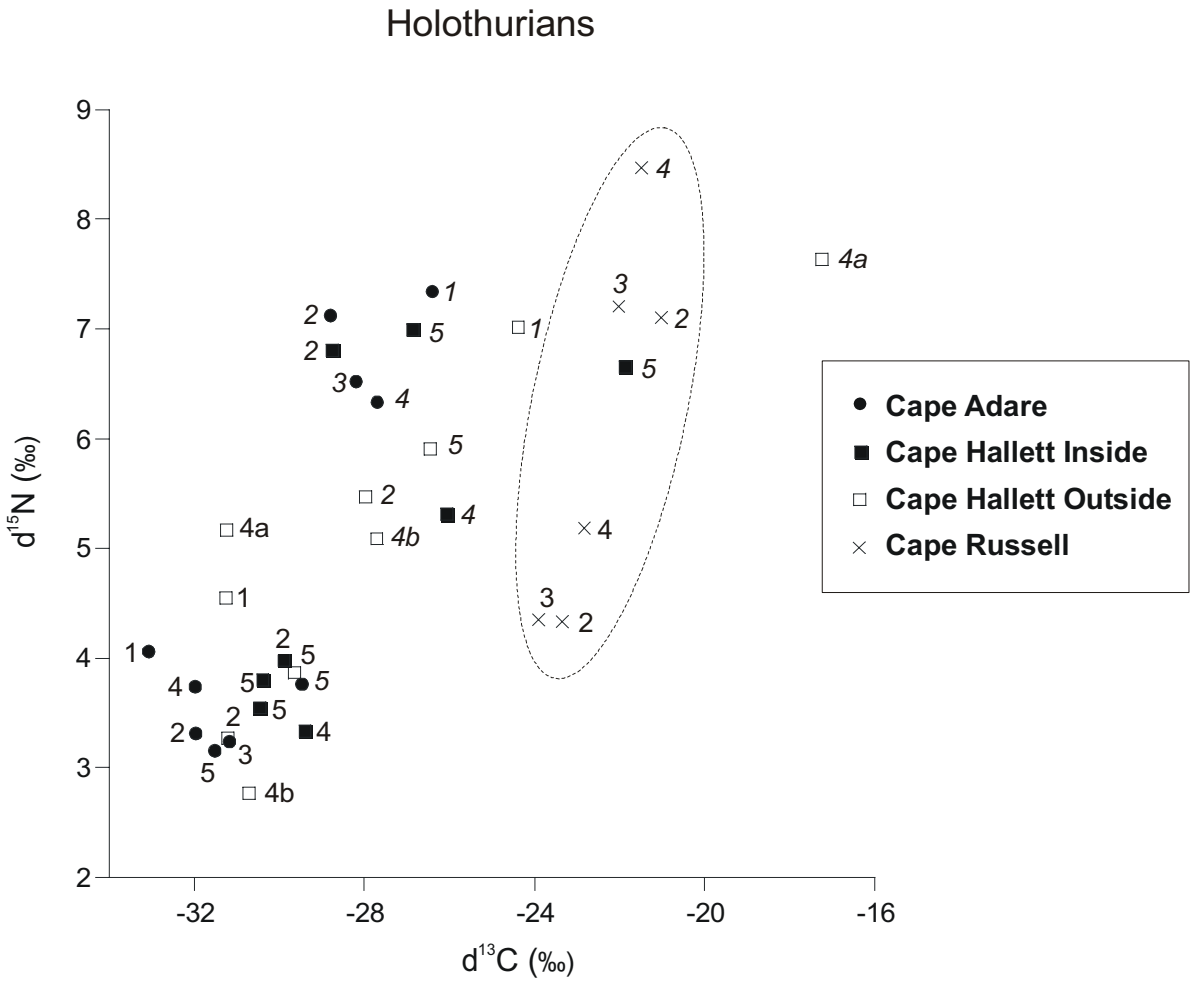

Figure 18. Mean isotopic (‰) distribution of integument (italicised numbers) and gut (non-italicised numbers) of holothurians sampled at each *Italica* location. n, 2–3 individuals per station. Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively. To enable easier distinction of station numbers, standard deviations have not been plotted. Grouping circle encloses all Cape Russell data, demonstrating a possible difference based on geographic separation.

Sterechinus spp.

Sterechinus (urchins) are considered to be omnivorous, and have been reported feeding on benthic diatoms, red algae, seal faeces, detritus, bivalves (*Adamussium*), bryozoans, hydrozoans, polychaetes, amphipods, and forams (Dayton et al. 1970, Stockton 1984, McClintock 1994, and references therein). *Sterechinus* in McMurdo Sound also eat sponges and the macrofauna associated with them (P.K. Dayton, pers comm.).

The large $\delta^{13}C$ signature difference between *Sterechinus* gut and test tissues is consistent with the presence of calcium carbonate precipitation on the test. Acidification to remove the calcium carbonate reduced the $\delta^{13}C$ values from about –6 ‰ to –18‰, but the $\delta^{15}N$ values were unaffected. The $\delta^{15}N$ test and gut values it is apparent that Cape Russell *Sterechinus* have the most depleted isotopic signatures (Figure 19A). In contrast, the $\delta^{13}C$ of the gut tissue from Cape Russell *Sterechinus* was more enriched than at the other locations (Figure 19A).

Overlaying the signatures of the *Sterechinus* from our shallow water dive surveys in previous seasons reveals that individuals from these shallower sites generally have more depleted gut $\delta^{15}N$ isotopic signatures than the *Italica* sampling locations (Figure 19B). Interestingly, the *Sterechinus* from Tethys Bay (Terra Nova Bay) have the most depleted gut $\delta^{15}N$ signatures of all locations, indicating that they are feeding on more nutrient depleted food sources, perhaps consistent with more open ocean food sources and the Terra Nova Bay polynya. With the exception of two of the three sites at Tethys Bay and one at Dunlop Island, the test $\delta^{15}N$ signatures are similar to those of the deeper *Italica* sites (cf. Figures 19A and B).

The reverse latitudinally correlated pattern is true for $\delta^{13}C$, where the gut of *Sterechinus* from all of the more southerly shallow locations except Tethys Bay are more enriched than those from the *Italica* locations (cf. Figures 19A and B).

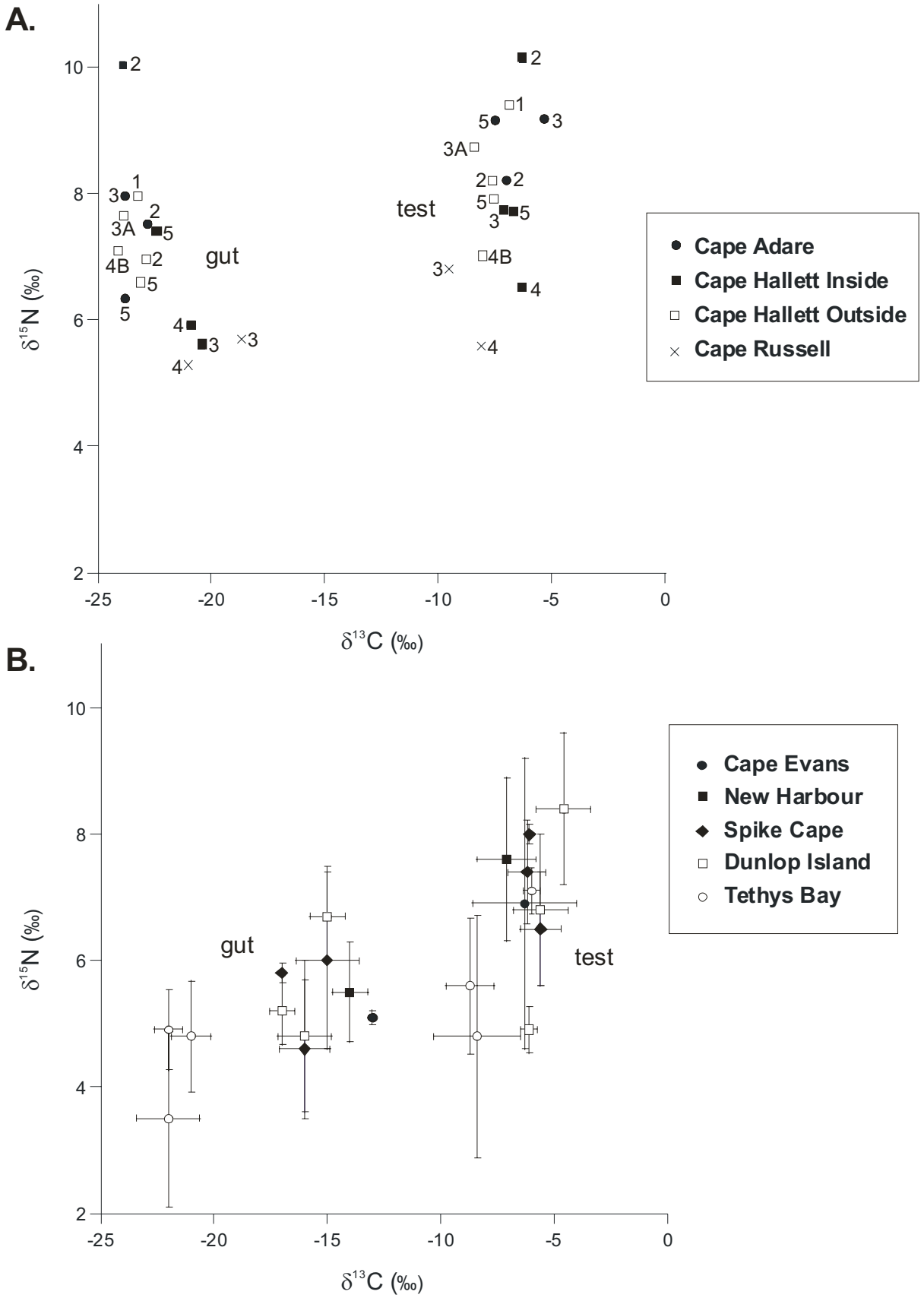

Figure 19: ***Sterechinus.*** **Isotopic distribution (mean ± standard deviation) from A. the *Italica* locations sampled in 2004, and B. the shallower scuba survey locations sampled in the 2002–03 field season. n, 2–3 individuals per station (A) and location (B). Station numbers 1, 2, 3, 4, and 5 correspond to nominal sampling depths of 500, 400, 300, 200, and 100 m, respectively. To enable easier distinction of station numbers, standard deviations have not been plotted on A.**

3.8 General comments on patterns apparent with latitude

The above analysis provides evidence for a latitudinally related shift in $\delta^{13}C$ signatures from more enriched in the south to less enriched in the north. *Sterechinus* gut tissue is more enriched in $\delta^{13}C$ at the further south (McMurdo Sound) locations compared with the *Italica* locations. Holothurians and pycnogonids, which were not collected further south in previous years, were also more enriched in $\delta^{13}C$ at the southernmost location sampled from *Italica*, Cape Russell.

At Cape Russell, the fact that the holothurian gut isotopic signature is very similar to that of the sediment + detritus, but different from that of the phytoplankton (Figure 20) implies that these holothurians are deposit feeders, or that they are feeding on resuspended sediments. In contrast, because of the much more enriched values of the sediment relative to the holothurian gut at Cape Adare (Figure 21), these holothurians are more likely to be suspension feeders at this northernmost location. The relative isotopic signatures of holothurians, phytoplankton, and sediment + detritus at the two Cape Hallett locations suggest a mix of deposit and suspension feeding holothurians (Figures 22 and 23). The isotopic signatures of the phytoplankton at Cape Adare and Cape Hallett do not match those of the holothurians gut signatures (i.e., the isotopic signatures of the gut are more depleted in $\delta^{13}C$) (Figures 21–23); thus it is likely that we did not sample the food these animals were consuming at the time of sampling.

While the intention of the sampling regime was not to define specific food webs, these data give an overview of the degree of similarity between locations separated by several degrees of latitude. Comparisons of gut isotopic signatures suggest that *Sterechinus* from the more northerly locations had food sources more closely associated with phytoplankton, while at Cape Russell the gut signatures were more closely linked with sediment + detritus (Figures 20–23). This is a similar pattern to that found for the gut isotope signatures of holothurians. In combination, these results suggest that the environment around Cape Russell may be a deposition zone (e.g., of sediment and/or detritus), and thus favours detritivores and deposit feeders.

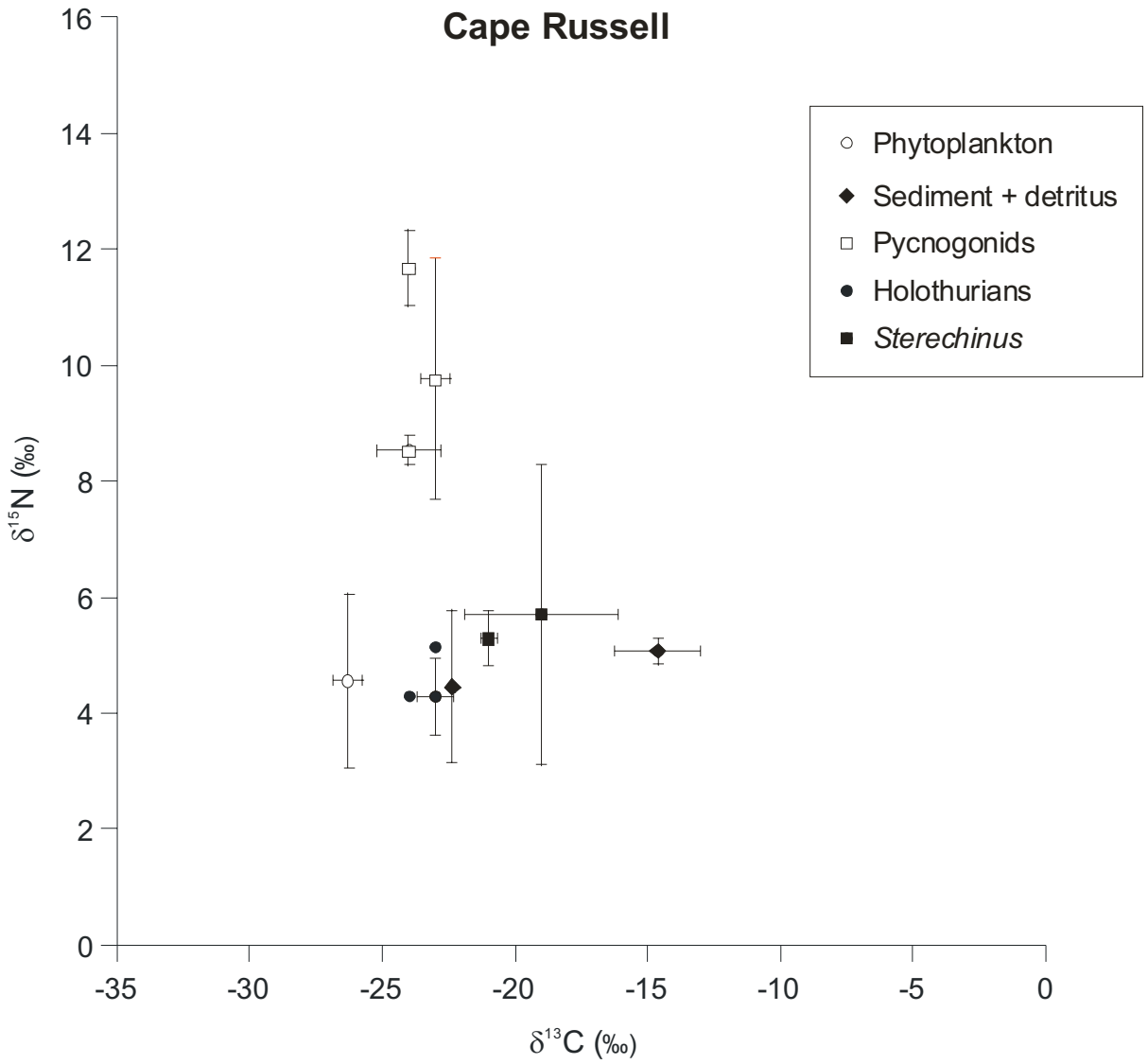

Figure 20: Relationships between isotopic distributions (mean ± standard deviation) of common large epibenthic taxa (gut tissue only), sediment + detritus, and seawater at Cape Russell. For distinction of isotopic distributions with depth/station, see previous figures of individual taxa/sediment.

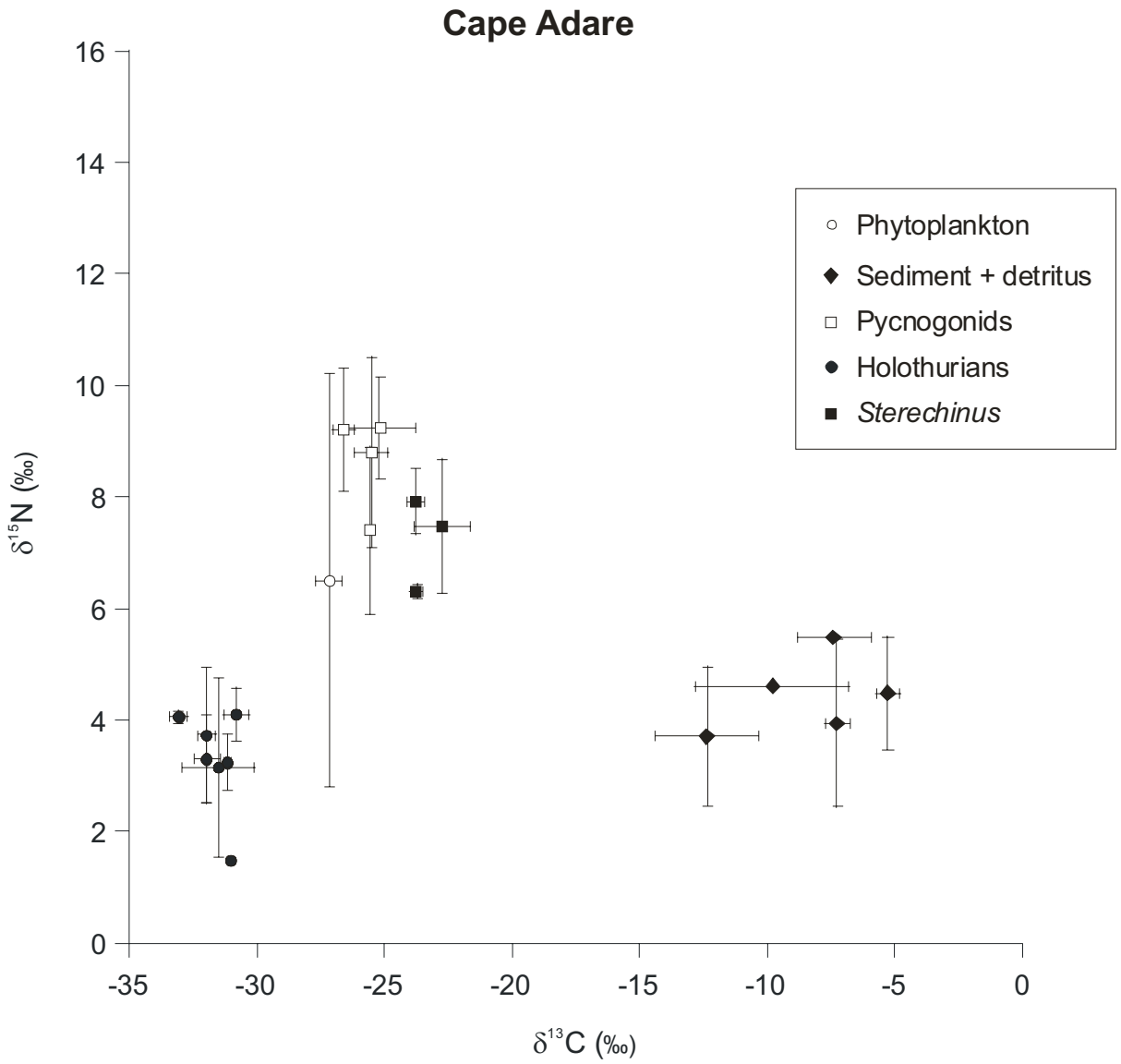

Figure 21: Relationships between isotopic distributions (mean ± standard deviation) of common large epibenthic taxa (gut tissue only), sediment + detritus, and phytoplankton at Cape Adare. For distinction of isotopic distributions with depth/station, see previous figures of individual taxa/sediment.

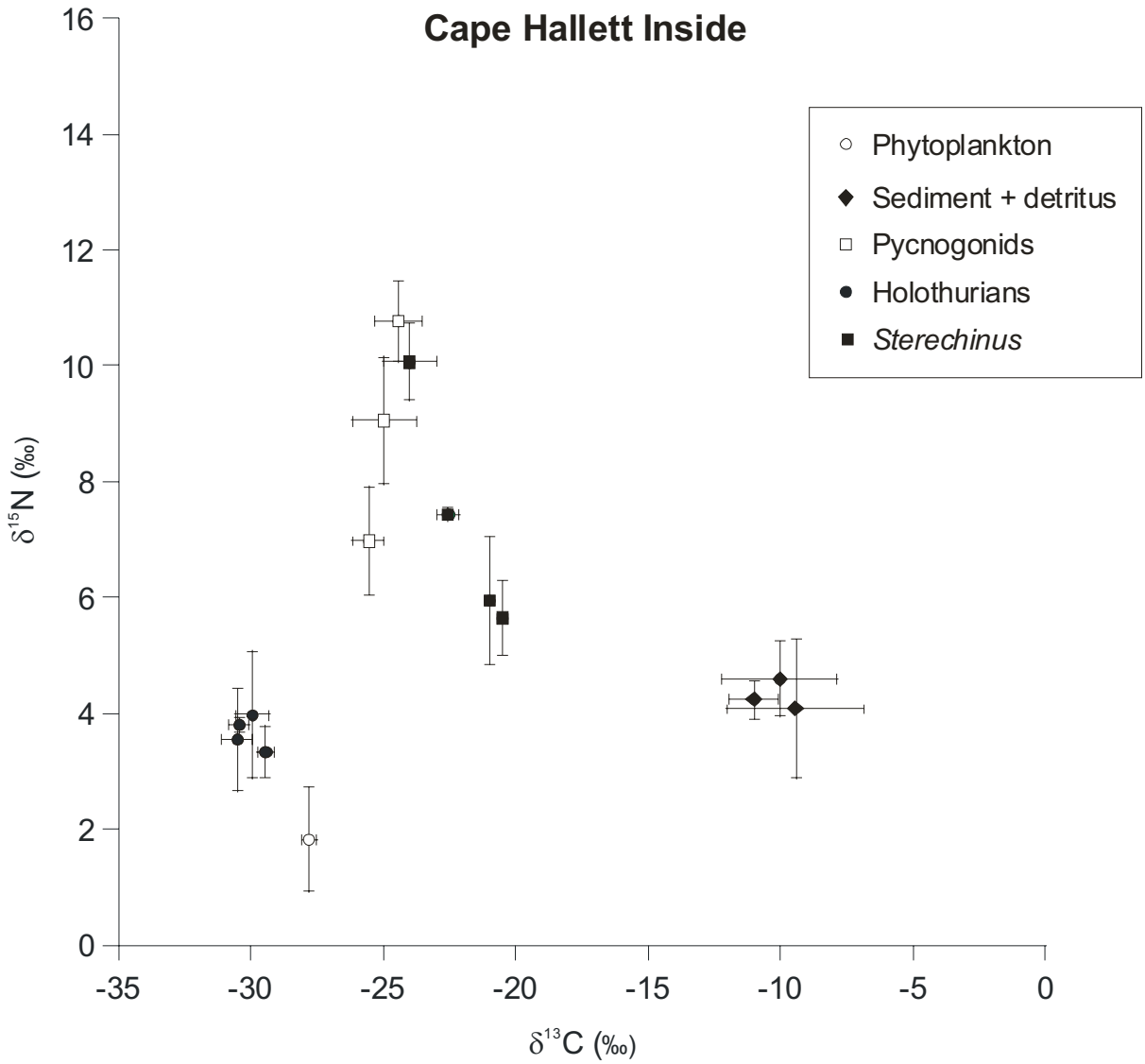

Figure 22: Relationships between isotopic distributions (mean ± standard deviation) of common large epibenthic taxa (gut tissue only), sediment + detritus, and phytoplankton at Cape Hallett Inside. For distinction of isotopic distributions with depth/station, see previous figures of individual taxa/sediment.

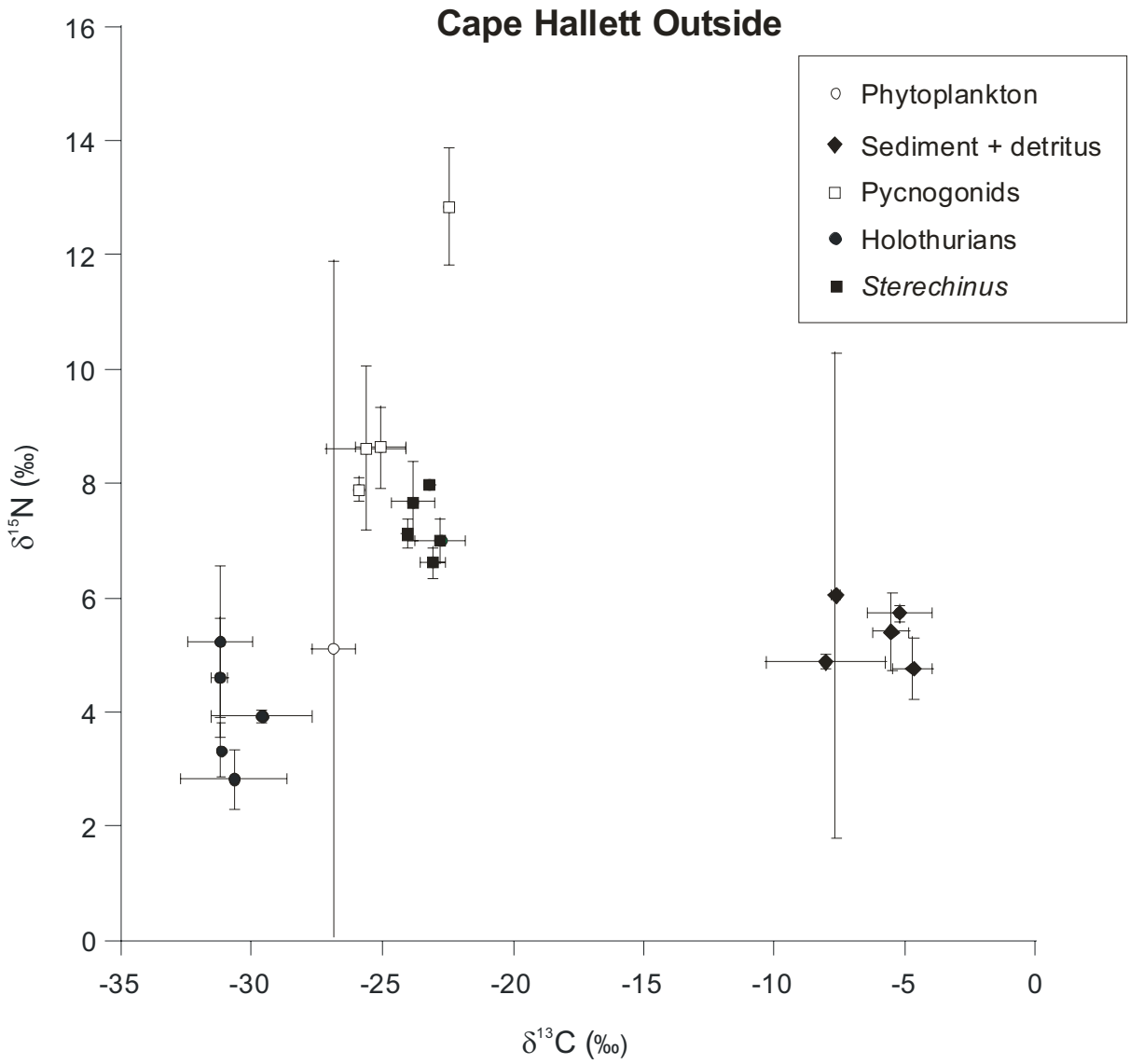

Figure 23: Relationships between isotopic distributions (mean ± standard deviation) of common large epibenthic taxa (gut tissue only), sediment + detritus, and phytoplankton at Cape Hallett Outside. For distinction of isotopic distributions with depth/station, see previous figures of individual taxa/sediment.

4. DISCUSSION

During the voyage we were able to sample a range of deep (100–500 m) environments at four locations along the Victoria Land Coast. Antarctica's continental shelf is deep, and the western coast of the Ross Sea falls away quickly to these sampling depths, so that we can sample stations at 500 m within about 2 km from shore. Although we were unable to implement our diving programme for safety reasons, this deeper water programme provides new data on a previously poorly sampled coast. Our structured sampling of benthic communities provides some insights into the influence of different environmental factors on near-shore benthos. Most importantly, the voyage gave us the opportunity to assess the major differences in benthic communities that exist along the latitudinal gradient from McMurdo Sound to Cape Adare. Iceberg disturbance and very strong coastal currents are dominant factors north of Terra Nova Bay, whereas south of Terra Nova Bay the presence of fast ice and proximity to primary production originating in polynyas becomes increasingly important. Questions about the ecological impacts of iceberg disturbance are obvious. For example, we have little understanding of the frequency of disturbance, or how benthic recovery processes are moderated by localised environmental or intrinsic factors. Benthic species assemblages are diverse and many areas are dominated by large suspension feeding bryozoans, soft corals, sponges, sea pens, hydroids, and gorgonians that create high levels of biogenic structure and habitat complexity. The probable slow growth rates of many of these animals imply that in many areas the frequency of iceberg disturbance is low. Disturbance along the coast from Cape Hallett to Cape Adare may be accentuated as icebergs drifting to the west become entrained in nearshore currents. While understanding this disturbance regime and its ecological consequences is fundamental, this information will also provide valuable insights into other types of disturbance and the potential for resilience on the Ross Sea seafloor.

The Cape Adare macrofaunal assemblage comprises mostly bivalves and crustaceans, while the Cape Hallett Outside assemblage is predominantly polychaetes. In comparison, the dominant taxa at Cape Russell and Coulman Island are polychaetes, nematodes, and oligochaetes. The Cape Hallett Inside assemblages comprise mix of taxa found at the other locations. Contrary to the typical broad-scale pattern that could be expected from sampling over this depth gradient, our analysis does not indicate that depth, sediment particle size, microphytobenthos, or organic content are strong determinants of macrofaunal assemblage structure. Although our analysis demonstrated that the percentage fine sand and silt, the ratio of sediment chlorophyll *a* to phaeophytin, and depth were important in explaining the differences in macrofaunal assemblage composition, these variables explained only 17.3% of the observed changes in composition from one station to the next. It is likely that broader scale environmental factors (e.g., sea ice cover, iceberg disturbance, circulation patterns, local hydrodynamic conditions), and their subsequent effects on factors such as primary production and supply and dispersal of larvae and food, will be major determinants of benthic diversity and population and community structure. Although our data set is still limited in the number of sites encompassed, the low correlation found in this study between the infaunal community and the (largely physical) habitat characteristics measured highlights the need for caution when choosing marine protected areas (MPAs) based only on physical variables. Our research highlights the importance of interactions between biological and environmental processes in driving trends in biodiversity. Thus, there is a need to select MPAs based on their functional importance, and to incorporate biogenic habitat complexity into sampling/protection strategies to define and understand the processes that contribute to seafloor biodiversity. There should also be coordination between management of the Ross Sea toothfish fishery and establishment of Antarctic Specially Managed Areas (ASMAs) and Antarctic Specially Protected Areas (ASPAs). This requires data on where and how toothfish spend the various stages of their life cycle to enable preservation of their nursery grounds, species that are important to their sustainability, and vice versa.

To date, studies of the Ross Sea benthos have tended to focus on the shallow shelf region, often less than 30 m depth. Most of these studies have been conducted in the McMurdo Sound and Terra Nova

Bay regions, with few investigating the fauna of the deeper or more northern waters (but see Barry et al. 2003, Gambi & Bussotti 1999). As well as the RV *Italica*, other voyages have recently studied the benthic communities of deeper areas of the northwestern Ross Sea: RV *Tangaroa*, and the ROAVERRS (Research on Ocean/Atmosphere Variability and Ecosystem Response in the Ross Sea) project. In 2004, *Tangaroa* visited areas from Cape Adare to Cape Hallett, and sampled five across-shelf transects, plus the Balleny Islands, targeting three depth strata (50–250, 250–500, and 500–750 m). Samples from this voyage are still being processed, and the data synthesised. ROAVERRS was a US funded multi-year, multi-cruise project that sampled two areas: along the coast from Cape Adare and Terra Nova Bay, out to 500 m depth; and in the southwest Ross Sea from 300 to 1200 m depth (Barry et al. 2003). Barry et al. (2003) found that the Ross Sea megabenthos (sampled by video) was dominated by suspension feeders (87%), with a smaller proportion of deposit feeders and predators. They also noted that suspension feeders were more abundant in shallow waters, and deposit-feeding taxa increased at the deepest sites. In a recent review, Artnz (1999) also noted that suspension feeders dominated the Ross Sea benthos. The VLT voyage has shown the importance of suspension feeding epifauna from dredges and video images, but this depth-related pattern was not apparent for the macrofauna sampled by grab in our study.

In coastal waters, one consistency that seems to be emerging is the high degree of heterogeneity that benthic communities exhibit. As noted above, this is probably a reflection of local disturbance regimes, larval supply, hydrodynamics, and species that dominate following disturbance, along with changes in the relative proportions of their primary food sources. Benthic biomass is strongly influenced by water column and benthic primary production, through advection of food from elsewhere, sinking of material through the water column, and in situ production (Grebmeier & Barry 1991). Local devastation of benthos by scouring ice and the subsequent recolonisation creates a patchy pattern on the seafloor (Gutt 2001).

Iceberg scouring is amongst the five most significant disturbances that any ecosystem on earth experiences (Gutt & Starmans 2001). There have been a number of studies on the effect of iceberg scouring on seafloor communities in recent years, in the Weddell Sea in particular. Most of these have focused on megabenthos/epifuanal assemblages, but there have been some investigations of macrofauna. Gerdes et al. (2003) studied the impact of iceberg scouring on macrofauna of the high Antarctic Weddell Sea. They found that macrofaunal biomass and taxa richness decreased from undisturbed areas to old iceberg scours to young scours, and that there was a greater variety of taxonomic groups in undisturbed areas. In addition, analysis of polychaetes alone showed a large variety of motile and sessile forms at undisturbed sites, while scours were more impoverished in terms of species richness, abundance, and variety of feeding types and life styles. In shallow areas of the central high Canadian Arctic, (3–15 m) Conlan et al. (1998) noted that macrofaunal communities in undisturbed areas were dominated by predators and suspension feeders, while disturbed areas had a high prevalence of scavengers and deposit feeders. Before the February 2004 RV *Italica* and *Tangaroa* voyages, targeted sampling of areas associated with iceberg disturbance had not been conducted in the Ross Sea. Further detailed analysis of the influence of iceberg scour on benthic biodiversity and species assemblages will be made on the data collected from RV *Tangaroa*.

The video and multibeam imagery collected on the RV *Italica* and *Tangaroa* voyages demonstrate that iceberg scouring is a significant source of topographic variation in the seafloor and emphasise that habitat complexity must be incorporated into sampling strategies to define and understand the processes that contribute to seafloor biodiversity. Effects of iceberg scour on megabenthos vary with the spatial scale of observation (Gutt & Piepenburg 2003). Ideally, a nested sampling design integrating broad-scale acoustic images with video or photo transects and standard grab or core sampling should be employed (Hewitt et al. 2004). Accurately capturing the biotic variability associated with that of the landscape requires a level of precision we were not able to achieve from *Italica*, due as much to very strong currents and drifting pack ice as to technological limitations. Nevertheless, we managed to collect some high quality video images of areas of the seafloor around Cape Russell that we knew from multibeam imagery had been differentially impacted by icebergs.

These images show characteristics consistent with different disturbance regimes; e.g., faster growing fauna (e.g., *Alcyonium*) are more common in the apparently impacted area.

One interesting phenomenon recorded from the Ross Sea is the recovery of apparently healthy macroalgal material from great depth, over 600 m, which was reported as appearing to be living and viable (e.g., Zaneveld 1968, and the 2001 RV *Tangaroa* voyage). Potentially, productivity at depth by macroalgae could be a direct contributor to benthic food webs, given the water clarity and the shade tolerance of macroalgae we have measured further south (Schwarz et al. 2003, 2005). To our knowledge, the measurements of fluorescence made during this voyage are the first such measurements to be made on samples collected from greater than 100 m in the Ross Sea. Although some of the macroalgae collected maintained some photosynthetic capacity, the low values suggest that they were decaying, with reduced chlorophyll contents, suggesting that the retention of photosynthetic capacity is a relic of the time these plants were growing in the photic zone (rather than an indication that they are photosynthetically active at such great depths). This indicates that this primary food source is only an indirect contributor via detrital food pathways.

Detailed examination of the isotope data collected as part of this project (and previous years MFish and FRST sampling) has begun to reveal some very interesting patterns in Antarctic food webs with changes in the relative importance of different food sources evident with location. The pattern apparent from the above analysis provides evidence for shifts in some of the $\delta^{13}C$ and $\delta^{15}N$ signatures which are consistent with predicted differences in supply of open ocean water and ice cover between locations. This supports the findings of our more detailed analysis of the shallow water locations visited previously along the Victoria Land Coast (New Harbour, Spike Cape, Dunlop Island, Terra Nova Bay) and Cape Evans. These sites represent different levels of sea ice cover and proximity to advected primary production in the Ross Sea. Our results indicate some of the omnivorous species became increasingly predatory. The flexibility of this life history trait confers potential stability in food web dynamics, an important attribute of shallow water communities in McMurdo Sound. The detrital pathways used by many benthic species may act to dampen the effects of large seasonal fluctuations in the availability of primary production, particularly that derived from ice algae, benthic diatoms and macrophytes. The limiting relationship between sea ice distribution and in situ primary productivity emphasises the role of connectivity and spatial subsidies of organic matter in fueling the food web.

Although logistics prevented us from implementing our shallow water survey-based sampling during this voyage, the few dives we were able to conduct were valuable. They enabled collections of macrofauna, epifauna, macroalgae, and sediments, along with video footage and still photographs from these northern locations, and thus provided information on the types of habitats we may encounter when we are able to sample this region in the future. This has also been very useful in planning diving logistics (including developing the most suitable methods for sampling these different habitats). In addition, the VLT voyage will yield results additional and complimentary to those presented in this report. In particular, our Italian colleagues Dr Mariachiara Chiantore and Prof. Riccardo Cattaneo-Vietti are processing samples that will provide additional information on epi- and macrofaunal community composition, sediment characteristics (including particle size, and organic, lipid and carbohydrate content).

In future (beyond the time scale of this MFish contract), once the scuba-based survey has been implemented at more locations along the latitudinal gradient of the Ross Sea, meta-analysis will be used to investigate the relative importance of relationships between benthic diversity, local processes (e.g., rate of production, trophic structure), and broader-scale environmental variables (see Thrush et al. 2000, 2001). The VLT voyage has provided valuable information on a number of factors that influence the structural and functional diversity of shallow water assemblages and habitats in the Ross Sea. These include: strong currents (particularly noticeable at Cape Hallett and Cape Adare); rapid changes in sea ice conditions in the summer (e.g., over several hours in some locations); iceberg disturbance; and seawater temperature (e.g., highest at Terra Nova Bay). We now have some insight into the differences evident along the latitudinal gradient from McMurdo Sound to more northerly

locations (e.g., the abundance and diversity of macroalgae were considerably higher in the areas of the northwestern Ross Sea visited on this project, and complex biogenic habitats were also evident). The voyage has also highlighted the need for information on the spatial and temporal scale of iceberg disturbance to help interpret the patterns in seafloor diversity (e.g., sensu Gutt & Piepenburg 2003, Knust et al. 2003). Future research to be conducted in conjunction with Italian and US researchers will address questions dependent on more targeted sampling of the seafloor in the Cape Hallett region where we have information on iceberg scour (from multibeam images taken from *Italica* and *Tangaroa*). In addition, we have been invited to participate in a German-led Census of Antarctic Marine Life (CAML) voyage on board RV *Polarstern* during the International Polar Year (IPY) in 2006–07. *Polarstern* will visit the high latitude Weddell Sea, with plans to sample around and under the recently disintegrated Larsen Iceshelf. This will provide us with a unique opportunity to use methods employed in this and our previous Antarctic research to document the *direct* effects of rapid change in ice conditions on the functioning of key benthic consumers, and will also enable a comparison of functioning of key species between the Weddell and Ross Seas.

Good understanding of the ecological processes that underpin biodiversity in the Ross Sea's coastal regions (continental and islands) is vital in realistically assessing the threats to this environment (e.g., Agardy 2005). These regions are important because they are subject to a variety of anthropogenic threats (e.g., extraction of biological resources, tourism), and are particularly likely to be influenced by climate change/variation. They also provide important resources for seals and penguins, and may be important for the recruitment and growth of juvenile toothfish. The development of toothfish or other fisheries, the potential for bioprospecting or for increased pressure from tourists in coastal regions require consideration of marine protected areas supported by a broader ecosystem-based approach to resource management and conservation in the Ross Sea. Research must extend beyond simplistic trophodynamics models: for example, natural history information on the relationship between toothfish and other species is lacking, as are data on the distribution and habitat use of toothfish over its life cycle.

The pristine nature of much of the Ross Sea offers unique opportunities to study and understand natural ecosystems as yet untouched by man. At present, our understanding of the structure and function of the Ross Sea ecosystem is poor. There are many areas that have not been biologically sampled, and consequently we do not have information as basic as habitat type or species composition. While some areas have been relatively well studied (e.g., McMurdo Sound, Terra Nova Bay), and consequently are better understood, it is unreasonable to expect patterns in these areas will be the same in other locations. More research is required, particularly to enable informed identification and establishment of ASMSs and ASPAs in the Ross Sea. Basing these decisions on a good understanding of how the entire ecosystem functions (e.g., linkages between the different components of the food web), rather than solely on non-biological information (e.g., depth, topography) is especially important in conserving the integrity of the Ross Sea. Such knowledge is also vital in predicting the consequences of change (e.g., removal of top predators, climate variability, tourism). Finally, this lack of detailed information on community dynamics and ecosystem function should not prevent the immediate implementation of MPAs (e.g., Hirshfield 2005): MPAs should be implemented as soon as possible, to avoid adverse impacts on this region occurring, and can be modified in light of scientific information as it becomes available.

5. ACKNOWLEDGMENTS

We thank Riccardo Cattaneo-Vietti and Chiara Chiantore for the opportunity to participate in the VLT voyage, for their patience and support during its execution, and for use of their preliminary data. We also thank the expedition leader Roberto Meloni, PNRA/ENEA staff on board RV *Italica* (especially Nicola la Notte), and the crew of RV *Italica* for being always helpful and cheerful, and for midnight pasta. Finally, thanks to our colleagues on the cruise for stimulating discussions and company.

Thanks to Antarctica New Zealand for their excellent logistical support, and the Ministry of Fisheries BioRoss and NIWA for funding. Thanks also to Jacqui Burgess (MFish) for all her efforts in ensuring our presence on this cruise.

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Appendix 1. GPS location of grab samples collected from each location and station. Stations 1, 2, 3, 4, and 5 correspond to targeted depths of 500, 400, 300, 200, and 100 m, respectively; the actual depths are also given.

Location	Transect	Station	Grab	Depth (m)	Latitude S	Longitude E
Cape Adare		1	1	488.4	71° 16.468'	170° 43.549'
Cape Adare		1	2	478.0	71° 16.664'	170° 42.993'
Cape Adare		1	3	476.4	71° 16.446'	170° 42.621'
Cape Adare		2	1	488.4	71° 16.468'	170° 43.549'
Cape Adare		2	2	476.4	71° 16.446'	170° 42.621'
Cape Adare		3	1	312.8	71° 18.396'	170° 33.215'
Cape Adare		3	2	308.0	71° 18.168'	170° 32.534'
Cape Adare		3	3	312.0	71° 18.107'	170° 32.485'
Cape Adare		4	1	223.6	71° 18.982'	170° 29.920'
Cape Adare		4	2	234.4	71° 18.615'	170° 29.348'
Cape Adare		5	1	124.4	71° 19.382'	170° 26.833'
Cape Adare		5	2	133.6	71° 19.131'	170° 26.849'
Cape Adare		5	3	136.0	71° 19.056'	170° 26.834'
Cape Hallett	inside	2	1	400.0	72° 17.182'	170° 11.736'
Cape Hallett	inside	2	2	406.8	72° 17.169'	170° 11.573'
Cape Hallett	inside	2	3	414	72° 17.017'	170° 10.775'
Cape Hallett	inside	3	1	312.8	72° 17.456'	170° 12.314'
Cape Hallett	inside	3	2	330.0	72° 17.415'	170° 12.270'
Cape Hallett	inside	3	3	369.2	72° 17.146'	170° 12.348
Cape Hallett	inside	4	1	266.0	72° 17.506'	170° 12.536'
Cape Hallett	inside	4	2	228.0	72° 17.756'	170° 12.247'
Cape Hallett	inside	4	3	152.8	72° 17.699'	170° 12.862'
Cape Hallett	outside	1	1	494.8	72° 15.936'	170° 27.804'
Cape Hallett	outside	1	2	525.6	72° 15.709'	170° 27.778'
Cape Hallett	outside	1	3	530.8	72° 15.649'	170° 28.631'
Cape Hallett	outside	2	1	475.2	72° 16.140'	170° 27.657'
Cape Hallett	outside	2	2	377.2	72° 16.588'	170° 26.483'
Cape Hallett	outside	2	3	332.8	72° 16.738'	170° 26.007'
Cape Hallett	outside	3	1	261.2	72° 17.151'	170° 25.883'
Cape Hallett	outside	3	2	246.0	72° 17.280'	170° 25.810'
Cape Hallett	outside	4	1	195.2	72° 17.201'	170° 23.414'
Cape Hallett	outside	4	2	231.6	72° 16.798'	170° 24.225'
Cape Hallett	outside	5	1	103.2	72° 17.973'	170° 19.768'
Cape Hallett	outside	5	2	105.6	72° 18.017'	170° 19.869'
Cape Hallett	outside	5	3	106.8	72° 18.052'	170° 19.971'
Coulman Island		1	1	480.8	73° 24.344'	170° 21.389'
Coulman Island		1	2	478.8	73° 24.340'	170° 21.489'
Coulman Island		1	3	480.8	73° 24.302'	170° 21.539'
Coulman Island		2	1	372.8	73° 21.975'	170° 05.622'
Coulman Island		2	2	375.2	73° 21.996'	170° 05.443'
Coulman Island		2	3	380.8	73° 21.712'	170° 05.512'
Cape Russell		3	1	307.2	74° 49.964'	164° 13.095'
Cape Russell		3	2	322.0	74° 49.890'	164° 12.885'
Cape Russell		3	3	329.0	74° 49.865'	164° 12.907'
Cape Russell		4	1	174.0	74° 50.038'	164° 05.254'
Cape Russell		4	2	156.4	74° 49.951'	164° 05.367'
Cape Russell		4	3	135.2	74° 49.812'	164° 05.568'

Appendix 2. GPS location of dredge samples collected from each location and station. Stations 1, 2, 3, 4, and 5 correspond to targeted depths of 500, 400, 300, 200, and 100 m, respectively; the range of the actual depth sampled is also given.

Location	Transect	Station	Depth (m)	Latitude S	Longitude E
Cape Adare		1	476.0-515.6	71° 15.560'	170° 42.252'
Cape Adare		2	421.6-430.0	71° 17.384'	170° 39.201'
Cape Adare		3	305.6-312.0	71° 18.781'	170° 33.523'
Cape Adare		4	223.0-235.0	71° 18.457'	170° 28.978'
Cape Adare		5	120.4-139.0	71° 18.726'	170° 25.362'
Cape Hallett	inside	2	388.4-408.0	72° 17.186'	170° 29.999'
Cape Hallett	inside	3	316.8-369.0	72° 17.067'	170° 13.125'
Cape Hallett	inside	4	196.0	72° 17.174'	170° 14.048'
Cape Hallett	inside	5	84.4	72° 17.261'	170° 17.905
Cape Hallett	outside	1	537.2-475.0	72° 15.572'	170° 28.375'
Cape Hallett	outside	2	353.2-388.0	72° 17.528'	170° 29.430'
Cape Hallett	outside	3	246.8-289.0	72° 17.510'	170° 26.162'
Cape Hallett	outside	3	258.8	72° 17.447'	170° 26.429’
Cape Hallett	outside	4	195.0-235.6	72° 17.234'	170° 23.934
Cape Hallett	outside	4	218.0	72° 18.213'	170° 26.039'
Cape Hallett	outside	5	103.0-105.2	72° 16.915'	170° 17.094'
Coulman Island		1	474.0-480.0	73° 24.706'	170° 23.118'
Coulman Island		2	372.0-410.0	73° 22.763'	170° 06.948'
Cape Russell		2	364.8	74° 49.084'	164° 18.132'
Cape Russell		3	307.0-330.0	74° 49.335'	164° 11.590'
Cape Russell		4	174.0-216.0	74° 50.079'	164° 05.607'