Chapter 1

Introduction

1.1 The Antarctic marine environment

The Antarctic continent lies in the centre of the world oceanic system, surrounded by the Southern Ocean. The circumpolar circulation of the Southern Ocean isolates Antarctica and its seas from the warm water systems and air masses of lower latitudes promoting its extreme cold climate.

The current climate of Antarctica began to develop with the breaking up of the Gondawanan super-continent (Kemp 1981). Extensive ice has been present in Antarctica and in adjacent seas since the late Eocene (~38 mya) (Arntz et al. 1994). There have been many advances and retreats of ice over the continent. By the beginning of the Pliocene (5.3-1.6 mya) an isolated Antarctic ecosystem had evolved (Arntz et al. 1994). Sea surfaces cooled from the mild 15°C in the Cretaceous to the present range of 2°C to -1.8°C (Clarke 1990).

The development of the Antarctic climate is paralleled by the evolution of the Antarctic marine benthos. Constant low temperatures, the presence of ice and massive seasonal differences in available daylight are environmental conditions that evolved gradually. The slow pace with which these conditions changed allowed the organisms now present in the Antarctic to adapt to them (Clarke 1990). The isolation of the Antarctic continent and repeated glaciation lead to the theory that the present day shallow water benthic fauna has evolved from deep water species that recolonised these habitats in periods of glacial retreat (Arntz et al. 1994).

Today 97.6% of the Antarctic continent is covered by ice (Drewry 1983). The vast weight of the polar ice cap has depressed the continental plate so that the marine shelf

surrounding Antarctica reaches depths of 800 metres in places (Clarke 1996). Shallow marine benthic environments are rare in Antarctica's nearshore waters and when present they are greatly affected by ice (Barnes 1999; Dayton et al. 1969).

Shallow nearshore marine environments are often adjacent to coastal ice free areas. These ice free areas are commonly chosen as centres of human activity. Increasing human activity in the Antarctic has caused an expansion of the presence of contaminated and polluted sites (Kennicutt.II & McDonald 1996; Naveen 1996) and many of these contaminated sites occur in the shallow marine environment. Pollution impacts on benthic communities have been demonstrated in nearshore Antarctic environments at Arthur Harbour, Anvers Island (Kennicutt et al. 1995; Kennicutt et al. 1992; Kennicutt et al. 1991); Casey (Stark 2000; Stark & Riddle 2003; Stark et al. 2004); King Edward Cove, South Georgia (Platt 1978); and McMurdo Sound (Conlan et al. 2004; Kennicutt et al. 1995; Lenihan & Oliver 1995; Lenihan et al. 1990).

The presence of contaminants in the Antarctic benthic environment is a very recent occurrence. While the benthos is well adapted to the seemingly harsh environmental conditions that characterise Antarctic locations, the capacity of these organisms to endure pollution is largely unknown.

1.2 Ecology of Antarctic shallow water benthic environments

Small bodied epifaunal and infaunal assemblages have been investigated in several locations around the Antarctic continent, peninsula and maritime islands. At all locations crustaceans form an important component of these assemblages, often dominating locally in biomass, abundance and diversity (Blazewicz & Jazdzewski 1996; Everitt et al. 1980; Gambi 1994; Jazdzewski et al. 1991; Li et al. 2001; Richardson 1976; Richardson 1975; Stark 2000). Other faunal groups that are well represented locally in these communities include polychaetes and molluscs. Substratum type, sediment features, food availability

and ice disturbance have been identified as the basic environmental factors that influence the occurrence of Antarctic shallow water benthic fauna.

The presence of ice in Antarctic waters plays a major role in structuring benthic communities by driving successional processes and promoting beta diversity and creating depth gradients and limiting production. While direct physical disturbance is the principle cause of the dramatic shallow water depth gradients observed in Antarctic benthos, the effects of ice on benthic production involves a complex of processes that together determine the light climate of pelagic and benthic habitats and the availability and distribution of organic matter in benthic systems.

Ice scours can occur in the Antarctic benthic environment to depths of 500 m (Gutt et al. 1996) but the physical effects of ice are much more frequent and pronounced in shallow waters. Dayton et al.(1969) and (1970) first described anchor ice formation at McMurdo Sound and the ice related benthic zonation pattern of an impoverished shallow zone (0 – 15 m) with no sessile fauna and only a few motile fauna. Habitats from 15 to 30 m supported assemblages of coelenterates and dense sponge assemblages were present from depth of 33 m. The pattern of an impoverished shallow zone has been observed in many other Antarctic locations although the depth range varies (Picken 1984). In a recent overview Barnes (1999) describes four forms of ice which influence polar nearshore benthic communities. These are the ice foot, ice scour, anchor ice and fast ice.

The ice foot forms where the freezing sea surface meets the shore and shallow subtidal substratum. The area of the ice foot is completely encapsulated in ice during the period of fast ice and affected substrata are only available to benthic fauna during spring and summer. Ice scour results from the grounding of drifting ice against the sea bottom. Grounding ice bergs can plough soft substrata and scrape hard substrata, trample substrata by rocking back and forth crushing the benthos beneath them and change local water movements (Peck et al. 1999). Ice scours can completely remove biota and the full

recovery of benthic communities can be very slow, especially in sessile communities (Gutt et al. 1996). Peck et al.(1999) found motile fauna like amphipods and isopods to return to a scour at Signy Island in 10 days and the meiofaunal community to be similar to nearby unscoured sediments in 30 days but the large bivalves had not returned to the site within 250 days.

In contrast to the other ice forms fast ice can decrease disturbance by reducing wave action and wind driven water circulation and block drifting ice to prevent ice scour (Barnes 1999). The presence of fast ice also has important consequences for the amount of light reaching the benthos. Light levels are affected by ice thickness and snow cover. The ice mediated relationship between light and benthic production has been demonstrated by Dayton et al.(1986) who manipulated light levels reaching the benthos by clearing snow from the sea ice surface at McMurdo Sound and observed an increase in chlorophyll *a* and phaeopigments in the benthos below. In a study of benthic primary production at Signy Island Gilbert (1991) found that microphytobenthos increased rapidly after the sea ice breakout, to reach a peak just prior to the phytoplankton bloom. In addition to *in situ* benthic production planktonic and ice algal primary production also contribute to benthic organic matter through sedimentation (Cripps & Clarke 1998).

Water circulation transports and redistributes organic matter in benthic environments by resuspension and advection (Wainright 1990). Benthic invertebrate distributions are closely related to the availability of organic matter (Dayton et al. 1986). The role of water circulation in determining the distribution of organic matter is seen in McMurdo Sound where extreme differences exist in the density of benthic assemblages between the eutrophic eastern and oligotrophic western sound (Barry & Dayton 1988; Dayton & Oliver 1977a; Dayton & Oliver 1977b). The eastern sound has high seasonal productivity typical of Antarctic waters and supports very high densities of sessile fauna and rich infaunal assemblages. The western sound, bathed in slow moving currents from under the Ross Ice Shelf has few sessile fauna and low densities of infauna. The slow

current regime promotes low productivity at this site by reducing particle flux and by preventing early ice breakout which in turn reduces the amount of light entering the system (Barry & Dayton 1988).

1.3 Protection of the Antarctic environment

The Antarctic environment, including marine waters south of 60°S, is the subject of the international agreement known as the Antarctic Treaty System. The Madrid Protocol (1991) to the Antarctic Treaty details the environmental protection measures that have been put in place to preserve the values of the Antarctic environment as a "natural reserve devoted to peace and science". The Madrid Protocol (1991) stipulates that all existing and future activities carried out within the Antarctic Treaty Area will be planned, conducted and monitored to ensure that environmental values are not degraded. The protocol also states an obligation for responsible parties to clean up existing impacted sites such as abandoned waste disposal sites (Annex III, Article 1). In addition to the Antarctic Treaty System specific locations within the Antarctic Treaty Area are also governed by the national laws of the parties that are conducting operations.

The environmental protection measures of the Madrid Protocol (1991) are achieved through the implementation of Environmental Impact Assessment (EIA) procedures in the planning of activities. Monitoring of relevant environmental variables may also be conducted to ensure that the activities are not degrading the environment (Rothwell & Davis 1997). The use of EIA and the choice of appropriate environmental monitoring variables and target values require an understanding of ecosystem processes to be effective in environmental protection (Champ et al. 1992; Kennicutt 1996). This is especially important in Antarctic systems which have only recently begun to be understood and for which baseline information is often unavailable (Walton & Shears 1994; Zwally 1991).

1.4 Environmental monitoring

It is expected that scientific research can deliver accurate assessments of the state of the environment and provide advice on appropriate guideline values for environmental variables which can then be monitored as part of ongoing management strategies. These research goals can only be met if the studies are conducted with experimental designs that allow relevant questions to be asked within a hypothesis testing framework (Clarke & Green 1988; Peterson 1993; Underwood 1995; 1996; Underwood & Peterson 1988). Appropriate scientific studies should test for differences in relevant variables in adequately replicated and controlled experiments (Clarke & Green 1988; Underwood 1991; 1992; 1994).

The establishment of monitoring programs requires equal rigour. A good monitoring program does not collect as much information as possible about the environment in question but targets specific, relevant and responsive variables that can be measured and compared with known values or guidelines (Segar & Stamman 1986). The targeting of monitoring programs is not only important to the value of the information collected but also to the cost of the program (Kingston & Riddle 1989).

Kennicutt (1996) lists the following criteria for selecting monitoring parameters suitable for use in Antarctic environments. The variables must:

- exhibit changes far in excess of limits of detection;
- be directly relatable to a testable hypothesis;
- be known or establishable above the natural variability;
- give information from which management decisions can be made;
- be able to sustain the monitoring activity;
- be able to be sampled within logistical and time constraints;
- be measurable on samples that can be transported without deterioration or be measurable in the field;

- be amenable to quality assurance procedures including, demonstrable precision, accuracy and reproducibility.

Studies of communities assess a level of biological organisation that reflects the integrated conditions of the environment over time (Warwick 1993). The development of multivariate analyses with hypothesis testing routines such as ANOSIM (Clarke 1993; Clarke & Warwick 1994) allows the distinction of assemblages based on changes in composition and abundance structure. These methods can be applied to ecological experiments designed in a hypothesis testing framework without the constraints of parametric statistical analyses. The comparison of community structure and identification of the species responsible for differences between experimental treatments is a powerful tool in monitoring and understanding the response of complex levels of biological organisation to human induced change.

1.5 Pollutants and biological effects in the marine environment

Analysis of global patterns of marine pollution reveals an overlap between polluted areas and coastal waters overlying shelf areas (Stromberg 1997). These patterns result from eutrophication and pollutant inputs from human activities that are often concentrated in coastal areas. In the Antarctic human populations are sparse but the same pattern of pollution occurrence is seen in coastal marine environments adjacent to human activities. Pollution is a major form of disturbance in marine environments.

The introduction of pollutants to marine environments can have direct toxic effects as water borne contaminants but may also have direct and on-going effects in sediment associated forms and by accumulation in the tissues of biota. Pollution in industrialized and urban areas can increase the concentrations of metals such as zinc, lead, cadmium and copper in coastal sediments to values five or ten times higher than those characteristic of 50 to 100 years ago (Ridway & Price 1987). The distribution and form of

dissolved and sorbed chemicals in sediment and their release back to the water column are a function of sediment resuspension, biological activity (bioturbation) and interstitial mixing, sediment reworking (eg. tides, currents and storms) and burial (Fava et al. 1987). Deleterious effects in biota occur in response to environmental contaminants that are available to biota in toxic forms as particulates or in solution.

The bioavailability of contaminants in marine systems is influenced by the characteristics of the contaminant and by the composition and characteristics of the sediments in the receiving environment. Sediment properties that enhance sorption of contaminants to sediment particles can reduce bioavailability by removing the contaminant from solution and potentially changing its chemical form to a less toxic state (Landrum & Robbins 1990). Trace metals that enter the marine environment can be adsorbed to particulate surfaces, carbonate bound, occluded in iron and/or manganese oxyhydroxides, bound to organic matter, sulphide-bound or dissolved in interstitial water (Tessier & Campbell 1987). Organic carbon can sorb organic compounds and complex metals (Landrum & Robbins 1990). Sediment properties that influence sorption are organic carbon content, particle size distribution, clay type and content, cation exchange capacity and pH.

The sensitivity of benthic invertebrate species to contaminants depends upon the physiology and behaviour of each species. Benthic species may be exposed to contaminants by ingesting sediment, through respiration of contaminated water and by consuming the tissues of organisms that have accumulated contaminants. The degree of exposure will vary with the mode and rate of feeding and the source of water a species uses for respiration (Adams 1987). In soft sediment assemblages the most exposed species are infaunal burrowers that respire interstitial water, followed by infaunal species that extend burrows or tubes or body points to overlying water and epifauna in near continuous contact with sediment (Anderson et al. 1987). Peterson et al.(2003) identified three pathways by which a pollution event could cause long-term impacts to populations. These are: direct acute physical or toxicological impacts; direct sublethal impacts such as

reduced growth or reproductive success; and indirect effects including trophic and interaction cascades.

On the Antarctic continent the two main areas that have been studied to examine the effects of pollution on Antarctic marine benthic communities are Winter Quarters Bay at McMurdo Sound (United States) and in the nearshore waters at Casey Station (Australia). In Winter Quarters Bay the effects of contamination have been demonstrated at molecular, histological and community levels. Studies of the demersal fish *Trematomus bernacchii* from Winter Quarters Bay have found elevated levels of enzymes required for the breakdown of PAH and PCBs (Miller et al. 1999), and increased occurrence of histological anomalies including periductal inflammation and necrosis of the liver, X-cell disease, epithelial hyperplasia, lamellar fusion and aneurysms of the gills (Evans et al. 2000). Change in the structure and distribution of infaunal communities at contaminated sites has been demonstrated at McMurdo Sound (Conlan et al. 2004; Lenihan 1992; Lenihan & Oliver 1995; Lenihan et al. 1990) and at Casey (Stark & Riddle 2003; Stark et al. 2004; Stark et al. 2003; Stark et al. 2005).

1.6 Disturbance induced change in benthic communities

Pickett and White (1985) define disturbance as a discrete event that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment. The magnitude, frequency and extent of a disturbance may reverse or reset community successional processes (Norkko et al. 2006) and community responses to repeated disturbances may differ from their response to a single disturbance. The identity, life-history and abundance of organisms that initiate and facilitate the early stages of recovery are predicted to have far reaching implications for the outcome of successional processes (Whitlatch et al. 1998). In polar environments benthic organisms commonly exhibit slow growth, seasonal productivity and brooding habits which make these communities slower to recover from disturbances and potentially more sensitive (Chapman & Riddle 2005).

The majority of investigations of the disturbance effects of marine pollution have been conducted on soft sediment communities. For soft sediment communities Pearson and Rosenberg (1978) described a general pattern of change in the community variables total number of species, total abundance and biomass along a gradient of organic enrichment. In their model species number, abundance and biomass all initially increase with organic input. At the ecotone point species number drops and abundance rises reflecting an increase in the number of individuals from opportunistic species. Along the gradient, biomass declines as the larger bodied, long lived species are lost from the assemblage and replaced with smaller opportunists. At very high levels of enrichment abiotic conditions are reached. This generalised succession model has been found to hold for physical disturbance (Rhoads & Germano 1986) and to apply generally for disturbed sublittoral communities (Heip 1995).

In a review of the effects of dredged material disposal on soft sediment communities Bolam and Rees (2003) describe the role colonising species play in reworking sediments to enhance oxygenation, and other sediment properties which then become attractive to other fauna. The initial pioneers are small tube dwelling polychaetes and small bivalves that begin reconditioning of surficial sediments. The pioneers overtime get replaced with larger, longer lived and deeper burrowing species e.g. ampeliscid amphipods and shallow-dwelling bivalves (in subtropical estuary (Santos & Simon 1980)), which continue to change the sediment conditions. Further succession within the assemblage includes an increased presence of deeper dwelling taxa such as "conveyor belt feeders" like maldanid polychaetes and echinoderms. The life habitats of these fauna increase water content and add oxygen to sediments. This model has been shown for various disturbances to soft sediment habitats including hypoxia, red tides, organic pollution, oil spills, dredging and for defaunated sediments (reviewed in Bolam and Rees (Bolam & Rees 2003)).

Studies of the sessile communities of hard substrata, the infauna of soft sediments and the motile fauna associated with marine algae reveal that recruitment and community development processes are fundamentally different between the assemblages of these habitats (Underwood & Chapman 2006). These differences result from divergent habitat utilisation and life strategies of the fauna that comprise the communities within each habitat type. The life habits of motile fauna of hard substrata also dictate different routes of exposure to contaminants in comparison to infauna as these organisms are not in continual contact with sediments and do not respire interstitial water but are more exposed to particulate and dissolved contaminants in the water column.

The role early successional fauna of pollutant disturbed habitats play in reconditioning the habitat and reducing contaminant effects are expected to differ in hard substratum communities from the processes that have been described for soft sediment communities. An example of this is seen in the *Durvillaea antarctica* holdfast community of Macquarie Island. Smith and Simpson (1995) describe the importance of one species of burrowing isopod as a primary space provider in the holdfast habitat. In sites that were contaminated with oil this species is absent from old (pre-oil spill) tunnels in the holdfasts. The abandoned tunnels had often become loaded with sediment. The holdfast community at oiled sites had polychaete species that were not present in control locations or that occurred in much higher abundances at the polluted sites. These polychaete species do not act in the same way as the burrowing isopod in creating space and maintaining low sediment loads in the holdfast so these old tunnels are not recolonised by the fauna that were there before the oil spill. Isopods returning to the site created new tunnels, leaving the old tunnels abandoned.

1.7 Marine motile epifaunal assemblages

Small bodied motile invertebrate fauna are a crucial component of marine ecosystems. They contribute significantly to productivity themselves (Edgar & Moore 1986; Taylor

1998a), but can also influence the productivity and occurrence of other organisms. In shallow waters motile invertebrates have been shown to both negatively impact macrophyte growth through direct grazing by mesoherbivores (Arrontes 1999; Poore 1994) and to promote plant productivity by controlling fouling epibionts (Jernakoff & Nielsen 1998; Mancinelli & Rossi 2001). Elements of the motile fauna also function to process detritus (Brawley 1992; Edgar & Moore 1986), recycling the nutrients bound up in this organic debris.

Benthic motile fauna, especially crustaceans, are well known as a primary food resource of demersal fish in shallow marine systems (eg. seagrass communities (Edgar 1994b; Edgar & Shaw 1995), drift vegetation (Shaffer et al. 1995), macroalgal communities (Taylor 1998a)). Studies in Antarctic shallow water systems reveal that nearshore demersal fish species rely heavily on benthic motile fauna with small crustaceans being a dominant part of the diet for at least a part of the life cycle or seasonally (Barrera-Oro & Casaux 1991; Richardson 1975; Vacchi et al. 1994).

Small motile fauna can actively structure benthic communities through interactions of motile taxa with juveniles and settling larvae of other taxa. Osman and Whitlatch (1995a) found predation by microgastropods on newly settled ascidians to dramatically change ascidian recruitment patterns on settlement panels. Habitat disturbance created by the amphipod *Pontoporeia* reworking sediments influences soft sediment community composition in the Baltic sea by smothering larval *Macoma balthica* bivalves (Elmgren et al. 1986), which are dominant in areas were *Ponotporeia* is not present in high abundance (Olafsson et al. 1994).

Assemblages of small motile fauna are known from many marine habitats including corals, sponges, echinoderms, soft sediments (as infauna and epifauna), the fronds and holdfasts of marine algae, seagrass communities and artificial substrata that mimic these habitats. Table 1.1 lists examples of some of these studies.

As habitats for macrofauna marine algae and seagrasses (collectively macrophytes) represent a very diverse group. Obvious differences exist between macrophyte species in morphology, chemical composition and habit. Most macrophytes are limited to shallow depths (<100m) where light levels are sufficient for photosynthesis and where suitable substrata exist for attachment (Price 1990). Factors which have been directly associated with animal distributions within macrophyte assemblages include epiphyte presence and abundance, plant morphology, depth, hydrodynamic regime and nutrient supply in the water column (Edgar 1983a, 1983b; Taylor 1998b). It is generally agreed that marine invertebrate phytal assemblages do not show the host specificity that is seen between invertebrates and plants in terrestrial systems (Edgar 1983b; Taylor 1998a). Edgar (1983) suggests that this may be due to the fact that the animals do not depend directly on the host plant or its products for food resources but rely on particles in the water column.

1.8 The use of artificial substrata in ecological studies

Artificial substrata are defined here as inert materials deployed in an environment to act as unoccupied habitat. They are used to investigate the biological assemblage that recruits to the substratum. Artificial substrata have been used in many forms in aquatic environments throughout the world and in habitats as varied as underground (Vervier 1990) and above ground rivers (Casey & Kendall 1996), intertidal areas (Anderson & Underwood 1994), shallow subtidal habitats and deep sea environments (Turner 1973). Artificial substrata are most familiar in marine studies in the form of settlement panels but geometrically complex substrata have also been extensively used.

The advantages artificial substrata provide to experimental design in ecological studies have been noted by many authors (Bourget et al. 1994; Cairns 1982; Gee & Warwick 1996; Martin-Smith 1993; Myers & Southgate 1980; Pugh 1996; Underwood & Anderson 1994). Artificial substrata provide a standardised collection method which is

controlled for habitat variables such as structural complexity, composition and available surface area. In studies of the assemblages that recruit to artificial substrata the investigator accurately knows the age of the assemblage and can observe the assemblage during its early successional stages. Having control over the positioning of artificial substrata in the environment permits specific ecological questions to be asked by manipulating exposure of the substrata to environmental variables such as depth, duration and timing of deployment and distance from source populations or contaminated sites.

Historically the marine use of artificial substrata in ecological studies focused on understanding and preventing the development of fouling communities (Osman 1977; Schoener & Schoener 1981). Studies of 'fouling' communities have been conducted using settlement panels to collect assemblages of sessile organisms and have investigated various ecological processes including: seasonality of recruitment (Stanwell-Smith & Barnes 1997; Underwood & Anderson 1994), larval settlement and post-settlement survival (Hurlbut 1992), predation and competition (Osman & Whitlatch 1995a; 1995c, 1996), large scale hydrodynamic effects (Archambault & Bourget 1999) and the role of habitat complexity (Bourget et al. 1994). The fauna that recruit to settlement panels are predominantly suspension feeders with planktonic larval development (Gee & Warwick 1996). These animals are mostly ascidians, bryozoans, sponges, barnacles, sessile polychaetes and non-burrowing bivalves.

Studies of geometrically complex artificial substrata have employed such diverse objects as rope fibre habitats (Edgar 1991), artificial seagrass (Bell & Hicks 1991; Virnstein & Curran 1986) and pot scourers (Gee & Warwick 1996; Kendall et al. 1996; Myers & Southgate 1980; Pugh 1996; Rule & Smith 2005; Schoener 1974; Smith & Rule 2002). While some sessile taxa do recruit to these substrata, geometrically complex substrata target motile fauna like errant polychaetes, gastropods and the peracaridean crustacean groups: amphipods, isopods, and tanaids. The assemblage collected by these substrata is dominated by grazers and deposit feeders that often have direct benthic development

(Gee & Warwick 1996). The assemblages attracted to complex substrata and the interactions that occur within them are fundamentally different from those occurring in assemblages of sessile communities. The natural history (including life cycle, reproductive biology, feeding guilds, body size distribution, and life form) of the organisms comprising the assemblage has important consequences for community development, structure, stability, persistence and response to change.

The standardised structure and maneuverability of artificial substrata that makes them appealing for ecological experiments is also valuable for environmental monitoring studies. For the information collected from studies employing artificial substrata to be useful in environmental management the species collected by the substratum must adequately represent the local natural communities and be sensitive to changes in local conditions.

Studies of several different types of complex substrata from various locations demonstrate that they do sample most elements of the local invertebrate fauna (eg: nylon scourers and algal turf, Ireland (Myers & Southgate 1980); artificial seaweed, Hawaii (Russo 1990); rope fibre habitats, Australia (Edgar 1991)) and that these assemblages are sensitive to local variation in environmental conditions (Edgar 1991; Edgar & Klump 2003). In contrast Smith and Rule (2002) found that nests of three nylon pot scourers attached directly to rocky reefs and deployed on racks 10cm above the rock, sampled a fauna of a very different composition to that observed in kelp holdfasts and algal turfs from the same areas which the artificial substrata were designed to mimic. Smith and Rule (2002) note the importance of determining the best deployment period and time of deployment when using artificial substrata to target specific assemblages that are suitable for monitoring.

The effective use of biological communities in environmental monitoring requires a clear understanding of the processes that structure biological assemblages and the scales at

which these processes operate (Giller & Gee 1987; Wiens 1989). Recruitment experiments sample communities through the settlement and migration of individuals into the sampling unit. For the individuals to be present in the sample at the time of collection they must also have survived in the sampling unit in co-existence with the other individuals in the sample. The biology of each species within the assemblage will influence its capacity to encounter the habitat, select it and survive within it. Interpretation of community data for use in monitoring must be made in the context of the limitations recruitment processes place on individuals reaching the assemblage and the role biotic interactions play in shaping the assemblage.

1.9 Aims of this study

The overall objective of this study was to assess the suitability of ASUs made of nylon mesh pot scourers for use in biological monitoring of Antarctic nearshore waters.

Experiments were conducted to address the following questions:

- Which taxa recruit to the ASUs and what are their abundance distributions within the ASU assemblage?
- Does the colour of the scourers influence the ASU assemblage?
- What size ASUs most efficiently sample the available fauna to adequately represent taxa and in sufficient abundances to allow robust data analyses?
- How does the timing and duration of deployment influence the ASU assemblage?
- What timing and period of deployment is required to sample a stable ASU assemblage that is repeatable and representative of the taxa available to the ASU?
- On what spatial scales does the ASU assemblage naturally vary?
- How does the ASU assemblage vary on spatial and temporal scales within a known contaminated site?

Table 1.1. Examples of studies of epifaunal assemblages from natural and artificial substrata.

Habitat type	Study Location	Authors
Brown algae		
Acrocarpia paniculata	Bruny Island, Australia	Edgar (1983a)
Carpoglossum confluens	Bruny Island, Australia	Edgar (1983a)
Carpophyllum flexuosum	Goat Island Marine Reserve, New Zealand	Kingsford and Choat (1985)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Carpophyllum maschalocarpum	Goat Island Marine Reserve, New Zealand	Kingsford and Choat (1985)
	Goat Island Marine Reserve, New Zealand	Taylor (1998b)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Carpophyllum plumosum	Goat Island Marine Reserve, New Zealand	Kingsford and Choat (1985)
Carpophyllum plumosum var. *capillifolium*	Goat Island Marine Reserve, New Zealand	Taylor (1998a)
	Goat Island Marine Reserve, New Zealand	Taylor (1998b)
	Goat Island Marine Reserve, New Zealand	Taylor (1998c)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Caulocystis cephalornithos	Bruny Island, Australia	Edgar (1983a)
Colpomenia peregrine (HA)	Port Jackson, Australia	Poore et al.(2000)
Cystophora moniliformis	Bruny Island, Australia	Edgar (1983a)
Cystophora retroflexa	Bruny Island, Australia	Edgar (1983a)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Cystophora torulosa	Bruny Island, Australia	Edgar (1983a)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Cystoseira nodicaulis	El Truhán Inlet, Spain	Vejo (1999)
Desmarestia menziesii	Lützow-Holm Bay, East Antarctica	Takeuchi and Watanabe (2002)
Desmarestia chordalis	Casey, East Antarctica	Grainger (2004)
Dictyopteris acrostichoides (HA)	Port Jackson, Australia	Poore et al.(2000)
Dictyota dichotoma (HA)	Port Jackson, Australia	Poore et al.(2000)
Dilophus marginatus (HA)	Port Jackson, Australia	Poore et al.(2000)
Ecklonia radiata	Bruny Island, Australia	Edgar (1983a)
	Goat Island Marine Reserve, New Zealand	Taylor (1998a)
	Goat Island Marine Reserve, New Zealand	Taylor (1998b)
	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Ecklonia radiata (holdfasts)	Solitary Islands Marine Park, Australia	Smith (1996)
	Solitary Islands Marine Park, Australia	Smith and Rule (2002)

Ecklonia radiata (holdfasts)	Solitary Islands Marine Park, Australia	Smith et al.(1996)
Fucus vesiculosus	North east New Zealand	Anderson et al.(2005)
Halopteris pseudospicata	El Truhán Inlet, Spain	Vejo (1999)
Homosira banksii	Bruny Island, Australia	Edgar (1983a)
Landsburgia quercifolia	Bruny Island, Australia	Edgar (1983a)
Lessonia variegata	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Padina crassa (HA)	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Padina sp.	Port Jackson, Australia	Poore et al.(2000)
Sargasssum bracteolosum	Several locations in Australia	Edgar (1994a)
Sargasssum decipiens	Bruny Island, Australia	Edgar (1983a)
Sargasssum fissifolium	Bruny Island, Australia	Edgar (1983a)
Sargasssum sinclairii	Magnetic Island, Australia	Martin-Smith (1994)
	Goat Island Marine Reserve, New Zealand	Kingsford and Choat (1985)
Sargasssum verruculosum	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Sargassum linearifolium	Bruny Island, Australia	Edgar (1983a)
Sargassum muticum	Port Jackson, Australia	Poore et al.(2000)
	Friday Harbour, America	Norton and Benson (1983)
Sargassum serratifolium	El Truhán Inlet, Spain	Vejo (1999)
Sargassum spp.	Mukaishima Island, Japan	Mukai (1971)
	Australia and Japan	Edgar (1994a)
Sargassum vestitum (HA)	Brook, Great Palm and Fantome Islands, Australia	Edgar and Klump (2003)
Seirococcus axillaris	Port Jackson, Australia	Poore et al.(2000)
Xiphophora chondrophylla	Bruny Island, Australia	Edgar (1983a)
Zonaria diesingiana (HA)	Goat Island Marine Reserve, New Zealand	Taylor and Cole (1994)
Zonaria sp.	Port Jackson, Australia	Poore et al.(2000)
Zonaria sp. and *Lobophora* sp. turf	Bruny Island, Australia	Edgar (1983a)
Zonaria spp.	Port Jackson, Australia	Kennelly and Underwood (1985)
Zonaria turneriana	Several locations in Australia	Edgar (1994a)
	Bruny Island, Australia	Edgar (1983a)
Red algae		
Anotrichum sp.	Bruny Island, Australia	Edgar (1983a)
Ceramium sp.	Goat Island Marine Reserve, New Zealand	Taylor (1998a)
Chondrus crispus	Isles of Scilly, Great Britain	Gee and Warwick (1994)
Gacilaria verrucosa	Lesina Lagoon, Italy	Mancinelli and Rossi (2001)
Gigartina stellata (C G)	Bantry Bay, Ireland	Myers and Southgate (1980)
Gracilaria tikvahiae	Indian River Lagoon, America	Virnstein and Curran (1986)

Hemineura frondosa	Bruny Island, Australia	Edgar (1983a)
Jeannerettia lobata	Bruny Island, Australia	Edgar (1983a)
Laurencia pinnatifida	Isles of Scilly, Great Britain	Gee and Warwick (1994)
Laurencia pinnatifida (C G)	Bantry Bay, Ireland	Myers and Southgate (1980)
Lomentaria articulata	Isles of Scilly, Great Britain	Gee and Warwick (1994)
Lomentaria articulata (C G)	Bantry Bay, Ireland	Myers and Southgate (1980)
Palmaria decipiens	Casey, East Antarctica	Grainger (2004)
Peyssonnelia gunniana and *Hildenbrandia prototypus*	Port Jackson, Australia	Kennelly and Underwood (1985)
Phacellocarpus labillardieri	Bruny Island, Australia	Edgar (1983a)
Plocamium angustum	Bruny Island, Australia	Edgar (1983a)
Thamnoclonium clariferum	Bruny Island, Australia	Edgar (1983a)
Coralline turf assemblage	Okakari Point Marine Reserve, New Zealand	Taylor (1998a)
Green algae		
Caulerpa brownii var. *selaginoides* (A)	Kiakoura, New Zealand	Fenwick (1976)
Caulerpa geminate	Bruny Island, Australia	Edgar (1983a)
Caulerpa trifari	Bruny Island, Australia	Edgar (1983a)
Cladophora feredayi	Bruny Island, Australia	Edgar (1983a)
Cladophora rupestris	Isles of Scilly, Great Britain	Gee and Warwick (1994)
Penicillus capitatus (C)	Punta Ostiones, Puerto Rico	Stoner (1985)
Ulva expansa	Bodega Harbour, America	Everett (1994)
Ulva sp.	Bruny Island, Australia	Edgar (1983a)
Seagrasses		
Amphibolis griffithii	Perth, Australia	Jernakoff and Nielsen (1998)
Amphibolis spp. and *A. antarctica*	Several locations in Australia	Edgar (1994a)
Heterozostera tasmanica	Several locations in Australia	Edgar (1994a)
	Western Port, Australia	Edgar et al.(1994)
Posidonia australis and *P. sinuosa*	Several locations in Australia	Edgar (1994a)
Posidonia sinuosa	Perth, Australia	Jernakoff and Nielsen (1998)
Thalassia testudinum	Indian River Lagoon, America	Virnstein and Curran (1986)
Thalassia testudinum (Cop)	Tampa Bay, America	Walters and Bell (1994)
Thalassia testudinum meadows	Galeta, Panama	Heck and Wetstone (1977)
Thalassia testudinum, Syringodium filiforme and *Halodule wrightii*	Apalachee Bay, America	Greening and Livingston (1982)
Zostera marina	Several locations in Australia	Edgar (1994a)
	Western Port, Australia	Edgar et al.(1994)

Drifting macrophtyes		
Carpophyllum flexuosum	New Zealand waters	Kingsford and Choat (1985)
Carpophyllum maschalocarpum	New Zealand waters	Kingsford and Choat (1985)
Carpophyllum plumosum	New Zealand waters	Kingsford and Choat (1985)
Laurencia poiteaui	Florida Bay, America	Holmquist (1994)
Sargasssum sinclairii	New Zealand waters	Kingsford and Choat (1985)
Mixed macrophytes	Several locations in Australia	Edgar (1994a)
Vegetation mat dominated by *Fucus* sp. with *Nereocystis leutkeana*, *Zostera* sp. and woody debris (C)	San Juan Archipeligo, America	Shaffer et al.(1995)
Sponge		
Antho chartacea (A)	Botany Bay, Australia	Poore et al.(2000)
Callyspongia sp. 1 (A)	Botany Bay, Australia	Poore et al.(2000)
Callyspongia sp. 2 (A)	Botany Bay, Australia	Poore et al.(2000)
Callyspongia sp. 3 (A)	Botany Bay, Australia	Poore et al.(2000)
Cymbastela concentrica (A)	Botany Bay, Australia	Poore et al.(2000)
Halichondria sp. (A)	Botany Bay, Australia	Poore et al.(2000)
Holopsamma laminaefavosa (A)	Botany Bay, Australia	Poore et al.(2000)
Iotrochopsamma arbuscula (A)	Botany Bay, Australia	Poore et al.(2000)
Mycale sp. (A)	Botany Bay, Australia	Poore et al.(2000)
Phorbas sp. (A)	Botany Bay, Australia	Poore et al.(2000)
Phoriospongia c.f. *kirki* (A)	Botany Bay, Australia	Poore et al.(2000)
Polymastia sp.	Goat Island Marine Reserve, New Zealand	Taylor (1998a)
Rhaphoxya sp. (A)	Botany Bay, Australia	Poore et al.(2000)
Corals		
Pocillophora damicornis (DC)	Pearl Islands, Panama	Abele (1979)
Pocillophora verrucosa (C)	Great Barrier Reef, Australia	Preston and Doherty (1994)
Soft corals		
Capnella gaboensis (A)	Botany Bay, Australia	Poore et al.(2000)
Echinoderms		
Arbacia punctata	Tampa Bay, America	Bell and McClintock (1982)

Echinaster sp.	Tampa Bay, America	Bell and McClintock (1982)
Lytechinus variegatus	Tampa Bay, America	Bell and McClintock (1982)
Sterechinus neumayeri	Casey, Antarctica	Richards (unpublished) (1998)
Demersal pelagic		
Coral reef lagoon – emergence and re-entry traps, net tows	Heron Island, Australia	Jacoby and Greenwood (1988)
Mud shelf – suprabenthic sled with plankton nets and above bottom otter trawl (GA)	Baie des Chaleurs, Quebec	Sainte-Marie and Brunel (1985)
Sand with areas of boulders and macroalgae – net tow (PC)	Gulf of Maine, America	Grabe (1996)
Sediment in *Thalassia testudinum* seagrass bed – emergence trap (HC)	Tampa Bay, America	Walters and Bell (1986)
Subtidal sandflat – emergence trap	Dansante Island, Mexico	Alldredge and King (1980)
Hard substrata		
Bare rock/coralline paint	Okakari Point Marine Reserve, New Zealand	Taylor (1998a)
Sedimentary habitats		
Intertidal sand flat	Bodega Harbour, United States	Everett (1994)
Silt in under kelp canopy	Port Jackson, Australia	Kennelly and Underwood (1985)
Soft sediment	Several locations in Australia	Edgar (1994a)
	Western Port, Australia	Edgar et al.(1994)

Artificial substrata		
Bottle brushes	Ancona Port, Adriatic Sea	Mirto and Danovaro (2004)
'Nyleska' nylon scourer (Ac)	Husvik Harbour, South Georgia	Pugh (1996)
'Scotchbrite' nylon scourer (Ac)	Husvik Harbour, South Georgia	Pugh (1996)
APU – filamentous, tanikalon rope fibre	Brook, Great Palm and Fantome Islands, Australia	Edgar and Klump (2003)
Artificial Plant Unit (APU) – foliose, polyethelene sheet strips	Brook, Great Palm and Fantome Islands, Australia	Edgar and Klump (2003)
Artificial seagrass clumps (ASG), polypropylene ribbon	Indian River Lagoon, America	Virnstein and Curran (1986)
Artificial Substratum Units (ASU) – three nylon-mesh pan scourers on rock	Solitary Islands Marine Park, Australia	Smith and Rule (2002)
Artificial Substratum Units (ASU) – three nylon-mesh pan scourers on aluminium racks	Solitary Islands Marine Park, Australia	Smith and Rule (2002), Rule and Smith (2005)
Artificial Substratum Units (ASU) – four nylon-mesh pan scourers	Penwith, Great Britian	Gee and Warwick (1996)
	Isles of Scilly and Penwith, Great Britian	Kendall et al.(1996)
Nylon-mesh pan scourers – flat (C G)	Bantry Bay, Ireland	Myers and Southgate (1980)
Nylon-mesh pan scourers – spheroid (C G)	Bantry Bay, Ireland	Myers and Southgate (1980)
Seagrass mimic, polypropylene ribbon (Cop)	Pauathanui Inlet, New Zealand	Bell and Hicks (1991)

Chapter 2

General Methods

2.1 Study Area

2.1.1 Windmill Islands region

The Windmill Islands region is a 40 by 15 km area along the Antarctic coast that consists of several peninsulas, nunataks and small islands. The rocks of this region are a layered sequence of schists, gneisses and migmatites intruded by a charnockite and a porphyritic granite (Blight & Oliver 1982). The region is uplifting at a rate of 5-6m per 1000 years (Goodwin 1996).

Apart from the islands and exposed peninsulas of the Windmill Island region this area of the continental coastline is composed of ice cliffs which form the coastal margin of Law Dome (Goodwin 1996). Law Dome rises to 1395m, approximately 120km southeast of the Windmill Islands and gives the area around Casey Station a generally light wind regime with only a weak katabatic signature (Turner & Pendlebury 2004).

Strong blizzards occur regularly during the winter, typically every eight to ten days and less frequently during summer. Storm force wind events are commonly from a stable easterly direction and can last from 12 hours to three or four days. These wind events keep a semi-permanent polynya in the eastern part of Vincennes Bay and can clear the sea ice in the outer part of Newcombe Bay at any time of year (Turner & Pendlebury 2004).

The shallow marine benthic environment of the region consists of poorly sorted glacial till overlying bedrock, creating an uneven terrain of small shelves, benches and small basins with a surface mosaic of muddy/sand, gravel, cobbles and boulders (Stark et al. 2004). Circulation in Newcombe Bay is generally very slow with variable direction but responds to strong wind events, during periods of open water, which drive surface waters in an easterly direction and create a net flow of oceanic water into the bay (Tate et al. 1998). Tidal currents are low and the tidal range is slightly less than two metres (Tate et al. 1998).

There have been three human settlements in the Windmill Islands region. Wilkes Station was established on the Clark Peninsula by the United States in 1957 and was handed over to Australia in 1959. Wilkes was occupied until 1969 when operations were moved to 'Old' Casey, a replacement station that had been constructed on the Bailey Peninsula. 'Old' Casey was occupied until 1989 when the current Casey Station was opened. The new Casey Station is located about 500m southwest of 'Old' Casey. Deprez et al.(1999) found twenty contaminated sites associated the operation of the two Casey stations and note that there are many potentially contaminated sites associated with the Wilkes station. Figure 2.1.1 shows the location of Casey Station in reference to the Antarctic content and surrounding southern hemisphere continents.

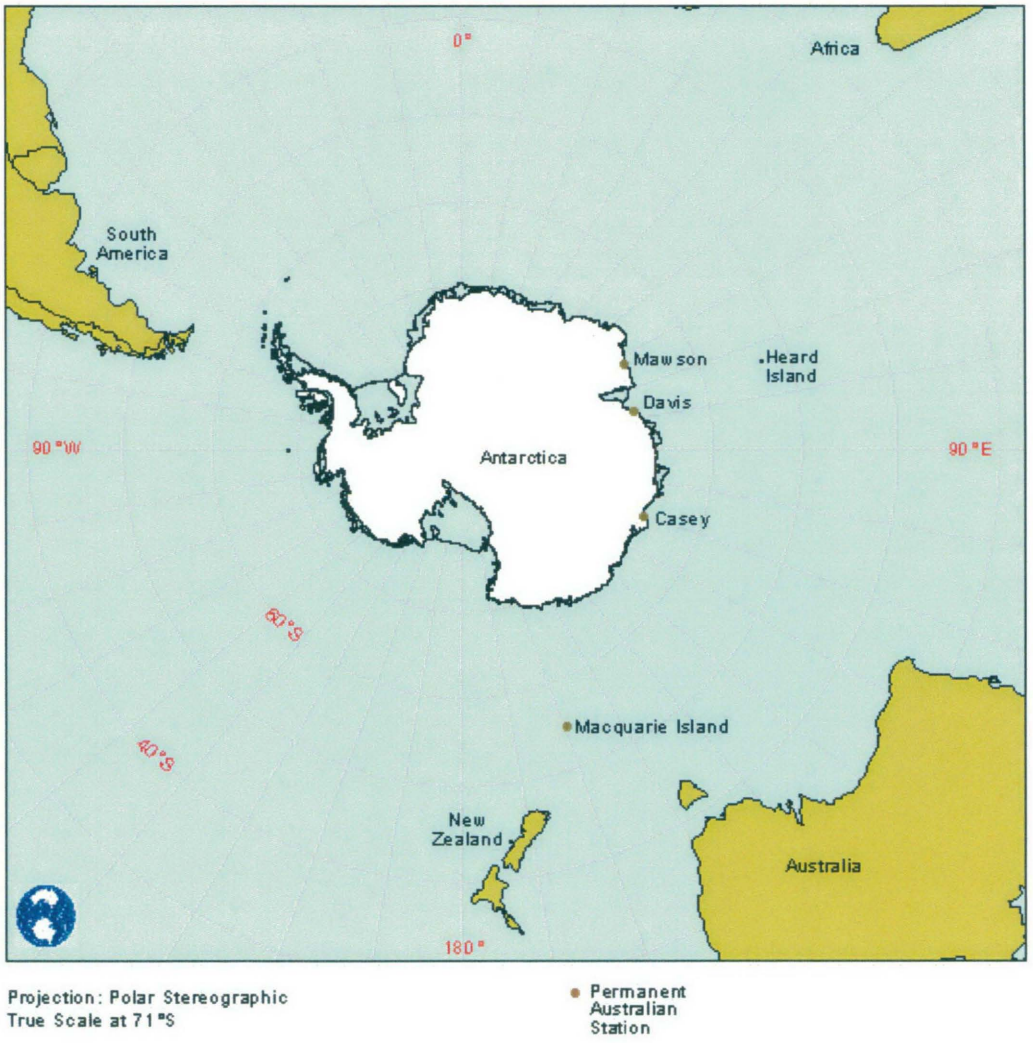

Figure 2.1.1. Antarctica showing location of Casey Station. (Image produced by the Australian Antarctic Data Centre, Australian Antarctic Division, Department of Environment and Heritage, Commonwealth of Australia, July 2000.)

2.1.2 Casey Station

Casey Station (Fig 2.1.2) is located on the Bailey Peninsula and houses a winter population of 15 to 20 people from around April to October and a summer population of up to 70 people from around November to March. Casey is also the closest station to the newly established ice runway that receives aircraft bringing people from Hobart to the continent to visit Casey and to transport them to Australia's other two continental stations Mawson and Davis.

Figure 2.1.2. Casey Station (photograph by Grant Dixon curtesy of Australian Antarctic Division).

2.2 Sampling Locations

The samples used in this study were collected from the shallow marine waters near Casey Station in Brown Bay, Newcombe Bay, O'Brien Bay and Penney Bay. Brown bay is a known contaminated site (Snape et al. 2001). The other locations were chosen as control locations. Sampling locations within each site were chosen using information from divers where available to minimise variation between the sites and in areas with a depth range at low tide of 12-14m meters.

2.2.1 Brown Bay

Brown Bay is the receiving environment for melt water and entrained sediment from Thala Valley, the location of the disused waste dump of Old Casey station. Impacts on

Brown Bay have resulted from the run off of heavy metal leachates from the Thala Valley tip site, and also from the dumping of rubbish from the tip site into the bay. The Thala Valley tip site was in use from 1965 to 1986 and received domestic, scientific, photographic, engineering and construction waste materials from Old Casey Station (Deprez et al. 1999). In 1994 it was estimated that 1800m^3 of waste was present at the site. In the 1995/96 summer 150 tonnes of waste was removed from the site and transported back to Australia. This disturbance of the tip site caused a pulse of contaminated sediment to be washed into Brown Bay in the following summer melt. In the 2003/04 summer the remaining contaminated sediment was removed from the Thala valley tip. Figure 2.2.1 shows Brown Bay and Thala Valley in 2002. Note the drainage channel that has been dug to divert melt water from passing through the contaminated site.

Figure 2.2.1. Brown Bay showing Thalla Valley tip site in 2002 showing channel dug to divert melt water from contaminated tip bed.

2.2.2 Newcombe Bay

Newcombe Bay (Fig 2.2.2) is the large bay directly north of Bailey Peninsula and Casey. Brown Bay is located within Newcombe Bay. Within Newcombe Bay there are several reefs and islands. The bay has shallow waters around most of its shores and reaches depths greater than 100m in the centre of the bay.

2.2.3 O'Brien Bay

O'Brien Bay (Fig 2.2.3) is the large bay directly south of Bailey Peninsula. Sites in O'Brien Bay have been used as control sites in previous benthic studies of contaminant effects. The bay is steep sided and very deep with some shallow shelves on northern and southern sides of the bay. High ice cliffs from around most sides of the bay and can collapse into the bay during summer. There is fast ice at the eastern edge of the bay.

Figure 2.2.2. Newcombe Bay showing ice caught on rocky reefs in foreground.

Figure 2.2.3. Corniced ice cliffs along the north east wall of O'Brien Bay during summer.

2.2.4 Penney Bay

The Penney Bay (Fig 2.2.4) site is the most distant sampling location from Casey. Penney Bay is a large bay between the southern islands Herring, Ford and Holl and the Browning Peninsula 20 km south of Casey.

Figure 2.2.4. Penney Bay.

2.3 Sampling Unit

2.3.1 Artificial substratum unit (ASU)

The substratum used in this study is made from three nylon mesh pot scourers (TUF brand) that are held tightly together with a plastic cable tie. The ASU is a substratum with a high surface area and an intricate internal space with a large interstitial volume. The ASUs were attached to plastic prawn crates that were weighted down with sealed plastic bags of heat treated blue metal dust. The blue metal dust was heated to 170°C for 2 hours to sterilize it to meet Antarctic quarantine procedures. Figure 2.3.1 shows the ASUs during deployment. The ropes attached to the tray hold a line and float. Lines were set to hold the float 6m under the water surface so the tray could be relocated from the surface.

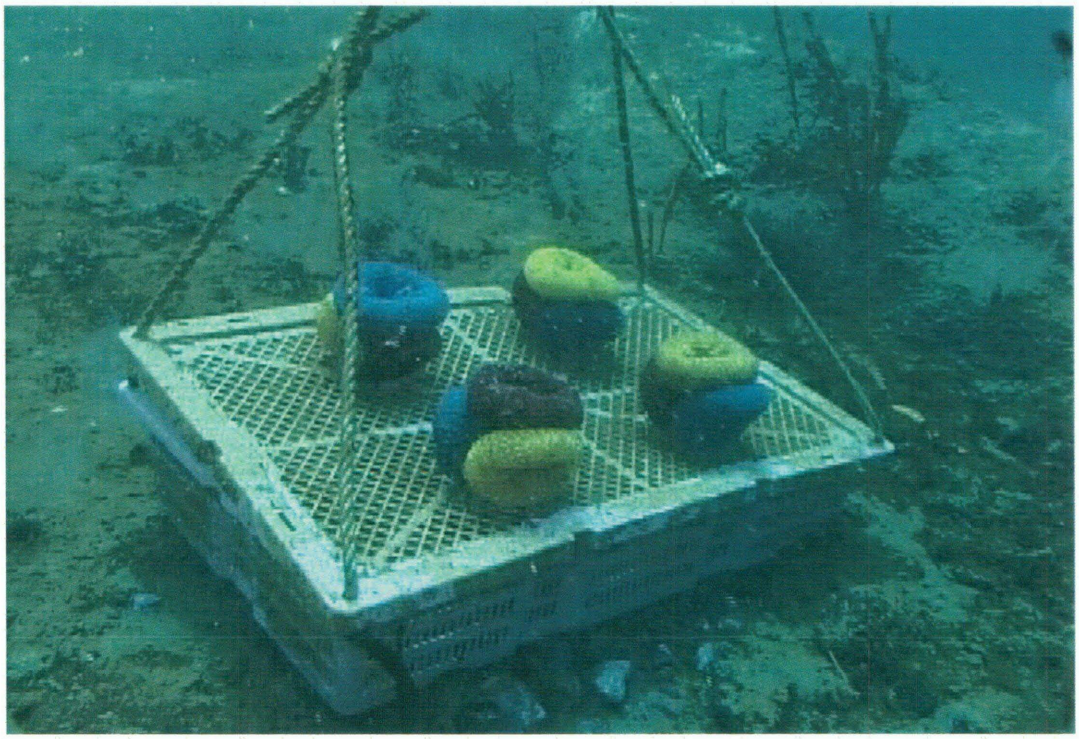

Figure 2.3.1. Four Artificial Substratum Units (ASUs) *in situ.*

2.4 Study Design

2.4.1 Deployed experiments

Unit Size Experiment

This experiment was designed to determine the optimum size ASU for use with Antarctic shallow water benthos, that would adequately sample the available taxa and in sufficient abundances for analyses. The size of the ASUs was varied by using different numbers of scourers. Five size treatments were investigated: one, two, three, six and nine scourers. Sixteen replicate samples were deployed for each size treatment. This experiment was deployed at a site in Newcombe Bay at 12-14m depth for one year.

Temporal Variation Experiment

This experiment was designed to investigate how the ASU assemblage changed over short time periods during the summer and to observe the effect of the timing of deployment on the development of the ASU assemblage. The experiment was deployed in three stages in four week blocks from the first opportunity of open water

(Table 2.4.1). Sixteen replicate samples were deployed for each temporal treatment and all samples were deployed at a site in Newcombe Bay at 12-14m depth.

Table 2.4.1. Details of deployment timing and temporal treatments in temporal variation experiment.

Stage	Deployment Time	Temporal Treatments
1	First open water	4 weeks, 8 weeks, 12 weeks, 1 year
2	+ 4 weeks from stage 1	4 weeks, 8 weeks, 1 year
3	+ 4 weeks from stage 2	4 weeks, 1 year

Depth Experiment

This experiment was designed to investigate how the ASU assemblage varied with depth. Trays were deployed at 12, 18, 24, and 30 m depth at a site in Newcombe Bay for one year. Sixteen replicate samples were deployed for each depth.

Spatial variation and contamination response

The spatial variation experiment was designed to investigate natural variability in the ASU assemblage and to compare the assemblage between three control sites, Newcombe Bay, O'Brien Bay and Penny Bay, and two known impacted sites, Brown Bay and Wilkes. ASUs were deployed in a fully nested design to assess variation within sites at spatial scales of 1 m between trays, 10 m between plots of trays and 100 m between groups of plots (Fig 2.4.1) and to compare the assemblage between sites which were 1 km to 18 km apart. Four replicate ASUs were deployed on each tray. All ASUs were deployed at 12-14 m depth for one year.

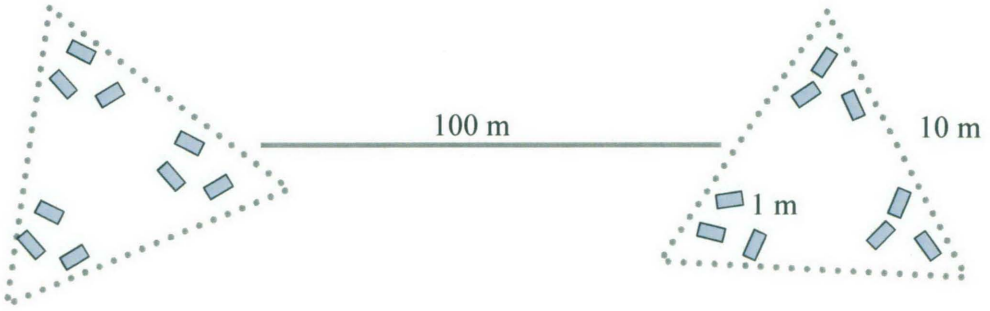

Figure 2.4.1. Spatial variation experiment within site deployment plan.

2.4.2 Experiments retrieved and final designs

More than half of the trays that were deployed were lost, moved or damaged during the deployment period. Mid to late summer retrievals were also hampered by the plankton bloom which reduced visibility of the subsurface buoys. The losses greatly affected the experimental designs of all experiments. The depth experiment was completely lost. For the other experiments specific losses and final experimental designs are detailed in each chapter. Figure 2.4.2 shows some images of damaged and disturbed trays.

Figure 2.4.2. Trays and ASUs damaged and disturbed by ice.

2.5 Field Methods

2.5.1 Deployment and collection of ASUs

ASUs were attached to each tray with plastic cable ties. The trays were filled with 20 kg sealed plastic bags of heat treated blue metal dust and were set with a subsurface buoy 6 m below the water surface. The trays were deployed and collected from the water surface using ropes to lower the trays into position. They were retrieved by attaching a surface line to the subsurface buoy and hauling the tray to the surface with the assistance of a winch and davit fixed to the rigid floor of the zodiac (Fig 2.5.1). The surface lines were attached by lowering a loop of rope over the buoy and pulling it tight. The loop of rope was lowered with the aid of a metal half hoop fitted with c-shaped brackets to hold the loop open. Pulling on the rope once it was in position around the buoy released the rope from the brackets allowing the loop to close around the rope below the buoy.

The ASUs were removed from the tray before the tray was pulled through the water surface. A fine mesh (<0.5mm) bag was placed around the ASU on the submerged tray and the ASU was then cut from the tray (Fig 2.5.2).

Figure 2.5.1. Raising trays using on-board manual winch and davit.

Figure 2.5.2. Removing ASUs from trays.

2.5.2 Collection of marine sediments

Marine sediment samples were collected by divers from the ASU deployment locations in Brown Bay, Newcombe Bay and O'Brien Bay to assess heavy metal concentrations and sediment particle size distribution. Penney Bay could not be sampled as it was outside of the safe operating area for the divers.

2.6 Sample Processing

2.6.1 ASU macrofauna

Samples were fixed in 10% formalin and seawater for a minimum of 24 hours and then transferred to 70% ethanol. After fixing, the samples were sieved through a nest of 1 mm, 0.5 mm and 63 μm sieves. The 1mm fraction of the sample was sorted with the aid of a dissecting microscope. All individuals were identified to the lowest possible taxonomic level and counted. Material retained on the 0.5mm sieve was not sorted due to time constraints.

Macrofauna were identified with the aid of published references and expertise where available. A full taxa list is presented in Appendix 1. Key taxonomic references are listed in Appendix 2. Some taxa were only identified to major groups including ascidians, copepods, nematodes, and sponges. The spirorbid and polynoid polychaetes were only identified to family level.

This study has focused on the motile elements of the ASU assemblage although some sessile taxa (e.g. spirorbid polychaetes, ascidians and sponges) were included. Bryozoans were also present in the ASUs but were impossible to score as they were broken into small fragments during sample processing.

Females of the tanaids *Nototanis dimorphus* and *Nototanais antarcticus* are very hard to distinguish from each other and formed the bulk of all tanaids found in the samples. For analysis the female tanaids were divided into the two species on the basis of the proportional presence of the males of each species in the sample.

2.6.2 ASU sediment

Material retained on the 63 μm sieve was comprised mostly of fine particulate matter. This material was dried in an oven at 80°C and weighed as ASU sediment.

2.6.3 ASU debris

For each ASU the non-faunal material present in the sample was scored as debris on a presence/absence basis. Common debris elements included algae, urchin spines and shell, bivalve shell, bryozoans, gravel chips and an organic composite of diatoms and fine particulate matter. The occurrence of bryozoans in the ASUs may be as debris that has washed into the ASUs or as settling larvae that have attached and grown within the ASU. The sorting process breaks up bryozoans attached to the scourers making it hard to distinguish between living and dead organisms, so they were included in the debris.

2.6.4 Marine sediment

Chemical analyses

Heavy metals in marine sediment samples were extracted using a 4 hour acid digest of 1 gram of dry sediment in 20 mls of 1 molar hydrochloric acid following the method described in Snape et al.(2004). Sediment samples were prepared for digestion by separating the 2 mm fraction by sieving and then oven drying this fraction. Following digestion the supernatant was diluted to 100 ml with distilled water and analysed using ICP-MS by the Central Science Laboratory, University of Tasmania. This method is a partial digest and has been found to be more appropriate for describing biologically available metals in marine sediments than total digests which also measure geogenic metals in the sediment (Riddle et al. 2001; Riddle et al. 2003; Snape et al. 2004).

2.7 Data Analyses

2.7.1 Multivariate methods

Patterns in community structure were investigated using multivariate analyses of the community abundance data using PRIMER software (Plymouth Marine Laboratory 1994). Bray-Curtis similarity matrices were produced using fourth root transformed abundance data to reduce the weighting of abundant species on the analysis (Clarke & Warwick 1994). In some cases a presence/absence transformation was also applied to the data to investigate taxa distributions only. Ordinations were produced by PRIMER using a nonparametric multidimensional scaling technique (nMDS). The significance of the relationships within and between treatment groups were investigated using analysis of similarities (ANOSIM). The role of specific species in producing the observed patterns in the nMDS ordination was investigated using similarity percentages (SIMPER) analysis.

2.7.2 Univariate methods

Analyses of univariate data including diversity measures, abundances and sediment variables were conducted using various ANOVA models. The details of these are described in each chapter for the analyses reported in those chapters. Prior to analysis all univariate data were tested for normality by examining normality plots and for homogeneity of variance using Levene's test and by plotting the standard deviation against the mean. Data were transformed to improve normality and homogeneity of the variance as needed. Transformations used are noted in each case in later chapters. The main transformations used were natural logarithm ($x' = (\ln x+1)$), and square root transformation ($x' = \sqrt{(x+0.5)}$). Univariate analyses were conducted using Minitab software and data preparation was done using Microsoft Excel.

The standard diversity measures used in this work were:

Total number of individuals (N)

Total number of species (S)

Shannon-Wiener's diversity index (H')

$H' = -\Sigma(p_i \ln(p_i))$, where p_i is the proportion of the ith species

Pielou's Evenness (J)

$$J = H'/\ln(S).$$

Diversity measures were calculated using PRIMER (DIVERSE) routine.

All the graphs presented in the thesis have been created using SigmaPlot 2001.

All position data was collected with a handheld GPS using datum WGS84.

Chapter 3

Pilot Study I: ASU Design

3.1 Introduction

To assess the effectiveness of ASUs as a tool for monitoring biodiversity and community response to environmental change the limits the substratum itself places on recruitment and development of the assemblage potentially available to the ASU must be understood. The efficiency of ASUs as a monitoring tool must also be optimised by determining the best unit size to meet the needs of a biological effects study.

The nylon mesh pot scourers used in this study create a substratum with a high surface area and an intricate internal space with a large interstitial volume. This gives a large surface area available for the settlement of epiphytes and attachment of fauna and their habitat modifications, such as the tubes built by tanaids and terebellids. The number of scourers used in each ASU will change the habitat size, the relative surface area and both total volume and interstitial volume. Colour is another physical aspect of the ASU that may influence recruitment of fauna to the units. The scourers used in this study were in three colours: red, blue and yellow.

Geometrically complex substrata are known to target small motile fauna. Experiments using these type of substrata have collected high abundances of small crustaceans, especially amphipods (Gee & Warwick 1996; Jacobi & Langevin 1996; Kendall et al. 1996; Moore 1985). Polychaetes and small gastropods are also common in these assemblages. Sessile fauna such as tube building polychaetes, bryozoans and ascidians also recruit to these substrata (Jacobi & Langevin 1996; Smith & Rule 2002). The intricate nature and small size of the internal spaces of the ASU limit the potential size and shape of the fauna that can move within the ASU and consequently the types of fauna that are able to exploit the habitat. This effect has been noted in studies of the assemblage inhabiting *Ecklonia radiata* holdfasts (Smith 1994).

Complex substrata in the form of nylon pot scourers have been used to study intertidal fauna at South Georgia by Pugh (1996) (mites only) and by Davenport and Stevenson (1998). Both studies found that the scourers were suitable for collecting macrofauna. Lower shore scourers at South Georgia were colonised by amphipods, ostracods, harpacticoid copepods, mites (acari), bivalves and littorinid gastropods (Davenport & Stevenson 1998). Gobin and Warwick (2006) used scourers to collect subtidal polychaete and nematode assemblages at Signy Island as part of a latitudinal study of species diversity. They report colonisation of the scourers by polychaetes, amphipods, copepods, isopods, asteroids, decapods, gastropods, ascidians, bivalves and some less abundant pycnogonids and anthozoans. Smith (pers. comm.) trialed the use of scourers to sample shallow subtidal fauna at Macquarie Island but most of the units were rapidly lost from the deployment locations due to heavy surge and were unable to be collected.

Colour has been recognised as an important cue in habitat selection of spirorbid polychaetes on intertidal boulders in Sydney, Australia (James & Underwood 1994) where it was found that the worms actively selected white panels over black panels. Spirorbid polychaetes are one of the dominant taxa in the ASU assemblage. Preferential settling of spirorbids to the light coloured yellow scourers in the present study would influence the effective recruitment area of ASUs made of several colour scourers and could influence the distribution of other taxa that respond to the presence of the worms.

Habitat size is an important factor influencing diversity, composition and the relative abundance of species in natural communities. Ecological explanations that have been proposed for the existence of species-area relationships include increased habitat diversity in larger areas, equilibrium processes in island biogeography theory and habitat disturbance regimes, but none of these explanations have found unequivocal support in empirical investigations (Connor & McCoy 1979; McGuinness 1984). Within a specific sampling regime the examination of species number and abundance patterns in differing sample sizes is a valuable tool for determining optimum sample size and number to meet the purposes of the study (Gray 1981; Kilburn 1966).

Sampling techniques that are to be used in a monitoring program must adequately sample the fauna of the area of interest but also be limited to the most efficient and cost-effective methods. Analysis of species distribution and abundance data to detect a potential environmental change requires that sufficient samples are collected to allow the fauna of an area to be represented in the samples and also to assess the variability of their occurrence (Andrew & Mapstone 1987; Fairweather 1991).

The following studies were conducted to test for effects of substratum colour on recruitment and to assess the influence of unit size on the structure of the recruited assemblage. These factors are related as a colour preference in recruitment could reduce the effective recruitment size of ASUs composed of different colour scourers. The information from these experiments was collected to determine the most suitable design of the ASU for use in biological monitoring in the Antarctic shallow marine environment.

3.2 Methods

These experiments were deployed in the northwest corner of Newcombe Bay at 66°16.19'S and 110°33.66'E. All samples were deployed, collected and processed following the general methods as described in Chapter 2 to collect species composition and abundance data and to measure the amount of sediment collected by each ASU.

3.2.1 Effects of substratum colour on recruitment to the ASUs

Twenty-four single scourers were deployed on six weighted plastic trays, 8 of each colour red, blue and yellow. Colours were randomly chosen for each tray. Four scourers were attached to each tray with plastic cable ties. The trays were deployed at 13m depth for just over one year from 28/2/01 to the 13/3/02. Unfortunately only three of the six trays were able to be retrieved. The others were lost from the site during the deployment period, most probably entrained in ice and dragged into deep water. This reduced the number of scourers for each colour to five red, three blue and four yellow.

Analyses

A nMDS ordination based on a fourth root transformed Bray-Curtis similarity matrix was used to assess similarity in abundance patterns across taxa in the assemblage. A nMDS

ordination based on a presence/absence similarity matrix was also made to look for any patterns of colour preference by taxa. Tests for significance between colour groups were conducted using ANOSIM.

One-way ANOVAs were used to test for colour effects in species richness (S), total number of individuals (N), Shannon-Wiener diversity (H') and Peilou's evenness (j') between colour treatments. Prior to analysis data were tested for normality and homogeneity of variance and transformed as needed.

3.2.2 Effects of unit size on recruitment to the ASUs

Five unit sizes were investigated in this experiment. ASUs made of one, two, three, six and nine scourers were used (Fig 3.2.1.). Units were deployed on the 3rd of March 2002 and collected on the 27th and 28th of February 2003.

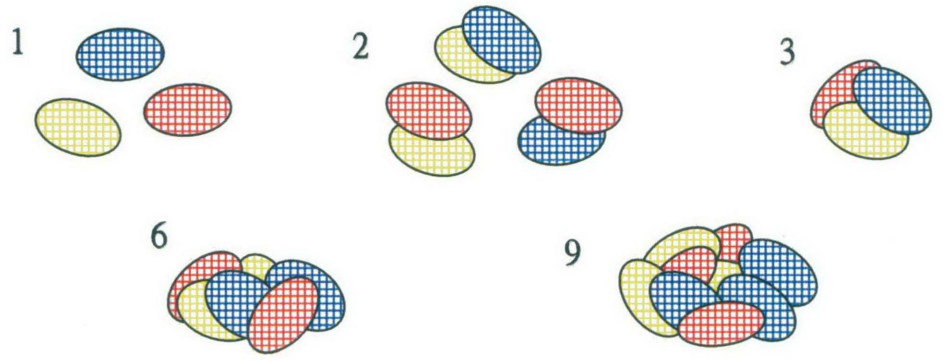

Figure 3.2.1. Number of scourers used in size treatments for unit size experiment.

16 replicates were deployed for each size treatment. ASUs of one, two and three scourers were deployed on weighted plastic trays with four ASUs per tray. Due to the larger size of the six and nine scourer ASUs only two of these units were deployed on each tray. The single scourer ASUs from the colour experiment were also used in this experiment.

Unfortunately only fourteen of the twenty-eight trays were retrieved. The others were lost from the site during the deployment period, most probably entrained in ice and dragged into deep water. This reduced the total number of samples from 64 to 41. Seven of the nine scourer units were retrieved, six of the six scourer units, 16 of the two scourer units and 12 of

the single scourer units. No three scourer units were retrieved from this experiment. Two of the two scourer samples were removed from the analysis as they had been covered by another tray throughout the deployment period.

Analyses

One-way ANOVAs were used to test for differences in species richness (S), total number of individuals (N), Shannon-Wiener diversity (H) and Pielou's evenness (J') between unit size treatments. Prior to analysis data were tested for normality and homogeneity of variance and transformed as needed.

The index of multivariate dispersion was used to investigate variability in assemblage composition among the unit size treatments. To remove the effects of differing sample size across the treatments six samples were randomly selected from each treatment group for use in the analysis.

3.3 Results

3.3.1 Effects of substratum colour on recruitment to the ASUs

Overall the 12 single scourers collected 6726 individuals from 37 taxa. 4500 of these individuals are the gastropod *Skenella paludinoides.* The average number of individuals collected in each scourer was 533 (n=12, SEM=100.85). The average number of taxa collected in each scourer was 14.71 (n=12, SEM=0.67). No grouping by colour is seen in the MDS of 4^{th} root transformed abundance data (stress=0.11) or in the MDS of presence/absence data (stress=0.16) (Figures 3.3.1 and 3.3.2). One-way ANOSIM test of fourth root transformed abundance data found no significant differences between colour groups (Global R= -0.165, p=0.94). One-way ANOSIM for presence/absence data found no significant difference between colour groups (Global R= -0.161, p=0.96).

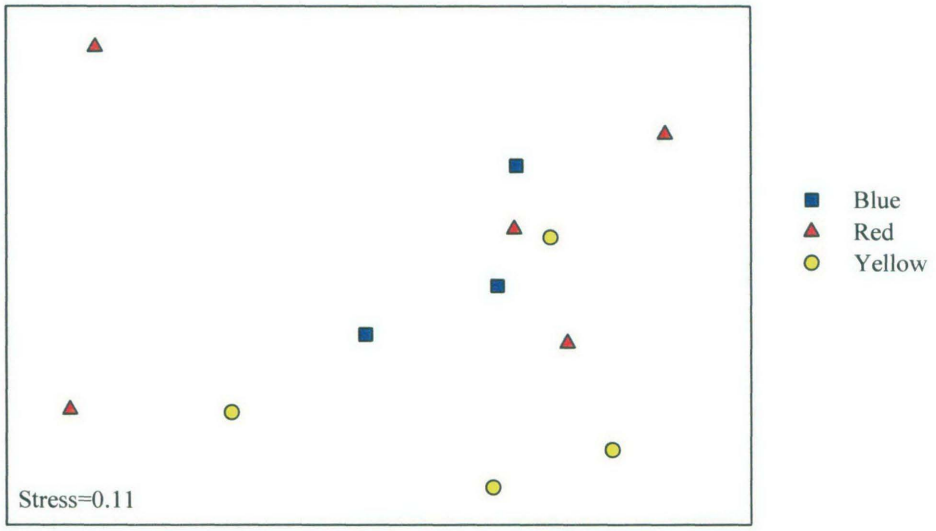

Figure 3.3.1. nMDS ordination for colour treatments based on Bray-Curtis similarities from fourth root transformed abundance data (blue n=3, red n=5, yellow n=4).

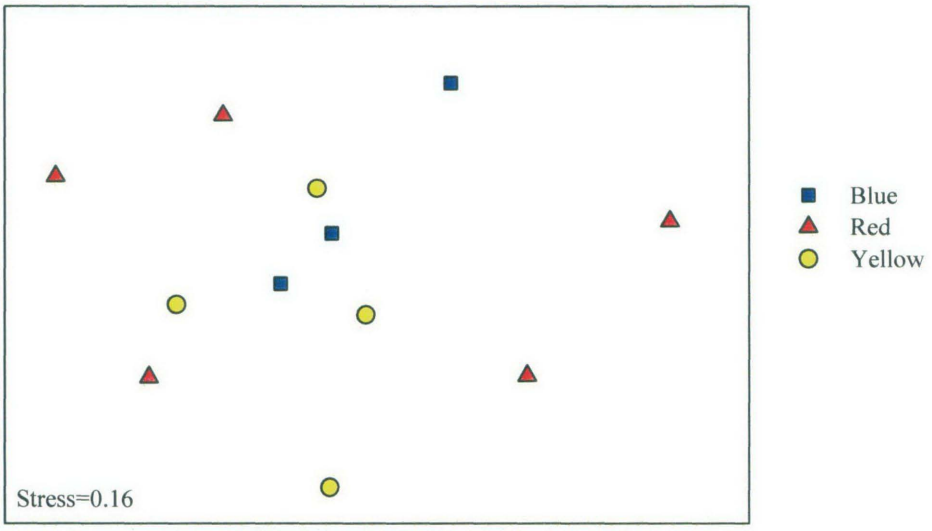

Figure 3.3.2 nMDS ordinations for colour treatments based on Bray-Curtis similarities from presence/absence data (blue n=3, red n=5, yellow n=4).

No significant differences were found in one-way ANOVA tests for colour effects in species richness (S), total individuals (N), Pielou's Evenness (j') or Shannon-Wiener (H'). p-values are presented in Table 3.3.1.

Table 3.3.1. p-values for ANOVA tests of univariate diversity statistics for colour experiment.

Diversity Statistic	ANOVA
	p-value
Species Richness	0.762
Total Individuals	0.483
Peilou's Evenness	0.960
Shannon-Wiener diversity	0.932

3.3.2 Effects of unit size on recruitment to the ASUs

Small amounts of sediment were collected by the ASUs during deployment (Fig 3.3.3). The amount of sediment collected in the ASUs increases with increasing unit size. The dashed line on Figure 3.3.3 is the sediment weight predicted from a one to one linear increase of the mean sediment weight collected by single scourer units. The expected line falls slightly above the mean values for the larger units. This may reflect a small effect of reduced surface area of larger units which reduces the 'catch area' for collecting particles settling from the water column.

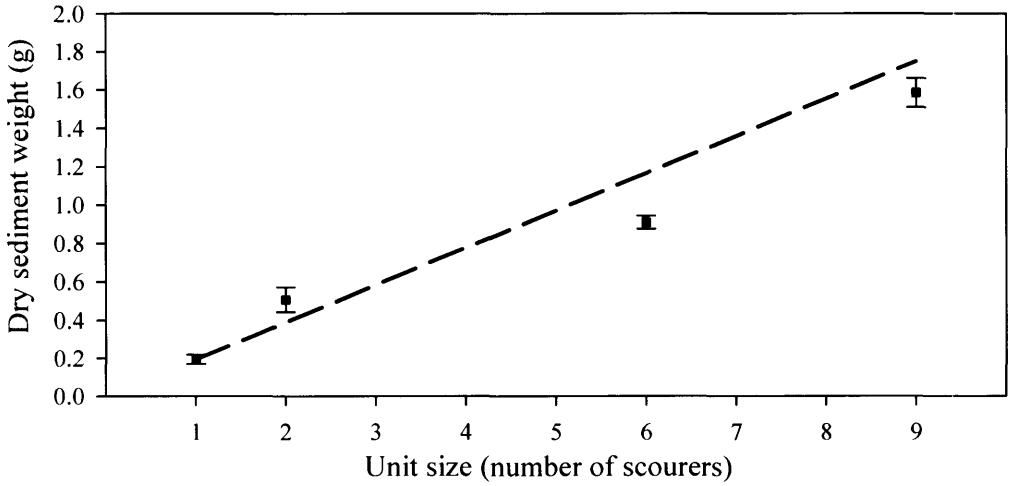

Figure 3.3.3. Entrained sediment in ASUs for unit size treatments (1(n=12), 2(n=14), 6(n=6), 9(n=7)).

In the unit size experiment overall 33451 individuals from 55 taxa were collected. In all unit sizes crustaceans were the most diverse group (31 taxa overall) followed by the gastropods (11 taxa overall). The gastropods *Skenella paludinoides* and *Laevilitorina antarctica* were the most abundant taxa in most samples. A spirorbid polychaete was also commonly abundant and present in most samples. Number of taxa and mean abundance within the major taxonomic groups is presented in Table 3.3.2. The "Other taxa" group includes turbellarians, nematodes, nemerteans and bivalves.

Table 3.3.2. Taxonomic summary and mean abundance for major taxonomic groups in unit size experiment.

	#1 (n=12)		#2 (n=14)		#6 (n=6)		#9 (n=7)		All (n=39)
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Total Individuals	533.00	100.85	605.29	66.54	1031.00	80.46	1723.57	263.32	
Taxa	14 17	0.67	17.21	0.61	20.83	0.79	26.86	0.83	
Crustaceans	69.83	7.63	117.29	16.28	127.67	16.69	394.43	73.01	
Gammarids	36.92	4.69	81.21	13.02	81.00	12.30	262.14	60.11	
Isopods	14.58	3.42	14.00	3.74	26.33	3.73	86.86	13.61	
Tanaids	1.42	0.62	21.00	1.60	20.17	5.19	42.43	6.09	
Other Crustacea	0.33	0.19	1.07	0.59	0.17	0.17	3.00	0.69	
Polychaetes	21.67	3.37	37.93	6.64	59.50	7.96	99.14	17.09	
Gastropods	433.83	95.38	430.71	65.10	831.17	80.05	1300.57	224.30	
Echinoderms	3.83	0.89	8.93	2.30	2.50	0.89	1405.71	232.01	
Other taxa	3.83	0.98	10.43	2.22	10.17	1.85	25.57	7.22	
Total individuals	6726		8474		6186		12065		33451
Total taxa	37		37		36		46		55
Crustacean taxa	19		20		18		26		31
Polychaete taxa	2		2		2		3		3
Gastropod taxa	9		9		9		10		11
Echinoderm taxa	3		1		2		1		3
Other taxa	4		5		5		6		7

Patterns of taxa occurrence for ASUs arranged in rank order of increasing number of taxa for each unit size treatment are plotted in Figure 3.3.4. These plots show total taxa per sample, novel taxa per sample and taxa accumulation. For all unit sizes while the mean number of taxa is reached within three to seven ASUs, the total number of taxa collected is still increasing with sampling effort. This suggests that the potential total number of taxa that could be sampled by each unit size has not been reached. Despite the low number of samples

the data show that total taxa per ASU is greater in the lager units and that the larger units sample more novel and unshared taxa.

Dominance patterns within the ASUs are similar across all unit sizes. All samples show very high abundances of the gastropod *S. paludinoides*. The abundant species of the assemblage are present in all size treatments. Larger units sample more of the common taxa that occur in low abundance.

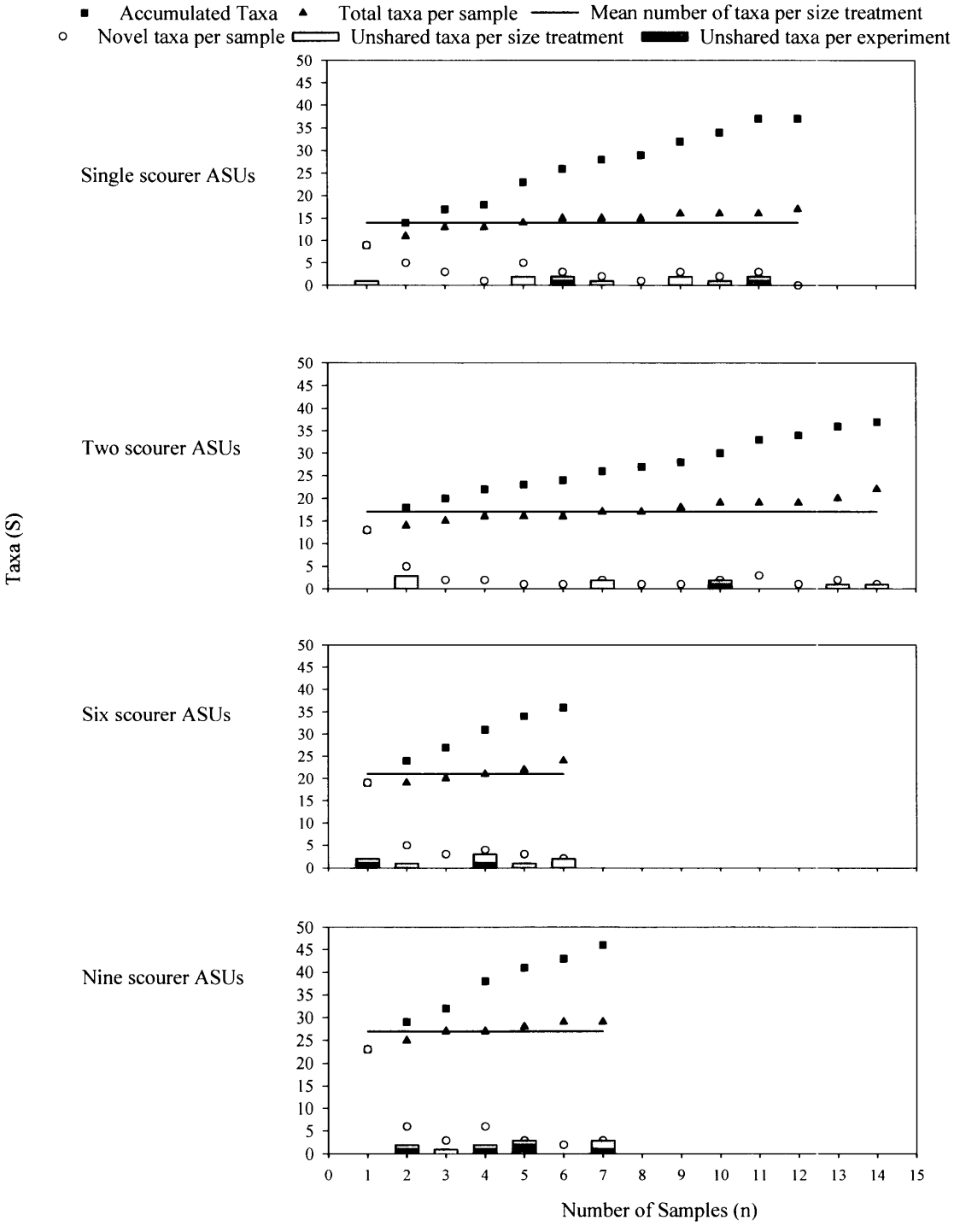

Figure 3.3.4. Patterns of taxa occurrence in unit size treatments showing total taxa per sample, mean number of taxa per size treatment, taxa accumulation per sample within size treatments, novel taxa per treatment and per experiment. One scourer (n=12), Two scourers (n=14), six scourers (n=6), nine scourers (n=7)).

Species accumulation curve with increasing unit size is shown in Figure 3.3.5. Larger samples collected more taxa but the rate of increase in the number of taxa collected by larger units is reduced as unit size increases. The dashed line shows the predicted number of taxa that would be sampled by a three scourer ASU.

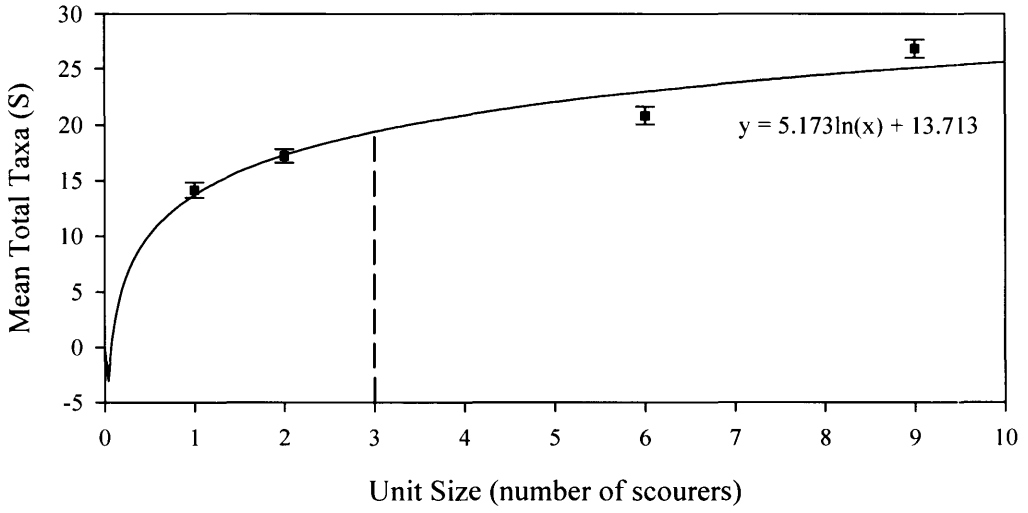

Figure 3.3.5. Species accumulation curve for increasing unit size, showing mean total taxa (S) with standard errors and regression line ($r^2 = 0.91$). One scourer (n=12), Two scourers (n=14), six scourers (n=6), nine scourers (n=7)).

An increase in total abundance is seen with increasing unit size (Fig 3.3.6). This increase is dramatically less than would be expected from a direct linear increase based on the saturation of individuals seen in single scourer units (dashed line).

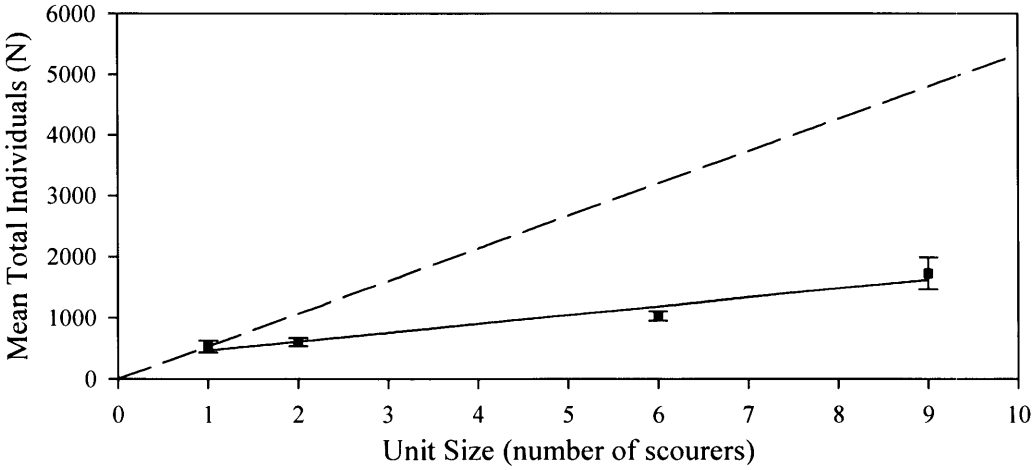

Figure 3.3.6. Mean total number of individuals (N) and standard errors for unit size treatments and expected total individuals. One scourer (n=12), Two scourers (n=14), six scourers (n=6), nine scourers (n=7)).

One-way ANOVAs found species richness and total individuals to be significantly different between unit size treatments, while Shannon-Wiener diversity and Pielou's evenness were not significantly different. p-values and F ratios are presented in Table 3.3.3.

Table 3.3.3. One-way ANOVA results for diversity measures in unit size treatments. df=3,35.

Diversity measure	p-value	F ratio
Species Richness	0.000	48.36
Total individuals	0.000	16.47
Shannon-Wiener diversity	0.356	1.11
Pielou's evenness	0.135	1.98.

To investigate variability in assemblage composition among the size treatment groups the index of multivariate dispersion was used. To remove the effects of differing sample size across the treatments six samples were randomly selected from each treatment group for use in the analysis. The highest dispersion is seen in the single scourer units, followed by the two scourer units, then the nine scourer units, with the six scourer units having the lowest dispersion (Table 3.3.4).

Table 3.3.4. Relative multivariate dispersion for unit size treatments (n=6 for all treatments).

Unit Size	Relative Dispersion
9	0.905
6	0.649
2	1.075
1	1.370

3.4 Discussion

Multivariate analyses found that the faunal assemblage of the ASU was not influenced by the colour of the scourers. These results were also reflected in the univariate diversity measures. No response to colour was seen in either the taxa recruiting to the units or in the abundance distributions of the taxa.

Studies of motile communities in other parts of the world have found habitat complexity to be an important factor influencing recruitment. Habitat complexity has been related to blade density in seagrasses (Stoner 1980), degree of folding in artificial substrata (Jacobi & Langevin 1996) and epiphyte loads (Martin-Smith 1993). For the motile element of the ASU assemblage colour may not be a habitat variable that influences habitat preference. Intrinsic variation in habitat complexity is controlled in ASU experiments.

Many studies report higher species richness and total abundance in larger samples or larger areas of habitat. An increase in the number of species sampled with increasing sample size has been demonstrated in the motile epifaunal assemblages associated with macrophytes (Gunnill 1982). The unit size experiments clearly demonstrate an effect of unit size on the number of taxa and the number of individuals collected by ASUs of differing size. Both species richness and total abundance were significantly greater in larger unit sizes. While the low number of samples successfully collected in this experiment may have diminished the total taxa pool, a reduction in the rate of increase between larger unit sizes was still evident in the species accumulation curves as larger sample sizes approached the asymptote (sensu Ugland et al.(2003)). This suggests that the larger samples collected most of the taxa available to the ASUs during deployment.

Total abundance showed an increase with greater unit size but was less than that predicted from a linear extrapolation of the abundance values from the single scourer units. This pattern may demonstrate the role of animal behaviour in structuring the ASU assemblage and that the fauna are not passively entrained in the ASU habitats but actively choose microhabitat locations within the ASU. It would be expected that sessile suspension feeders would actively settle on the outer surfaces of the ASU. The small bodied motile fauna could actively move through the entire habitat space but would respond to concentrations of resources such as epiphytes or prey species. Studies of phytal communities suggest active habitat choice of dense foliage or highly folded leaves is a predator avoidance response (Martin-Smith 1993). The larger unit sizes have comparatively less external space and a larger internal space and would provide more shelter from predators that could not enter the habitat than the smaller units.

Entrained sediment is an important habitat variable in complex substrata. The particles of organic debris and fine inorganic particulates that settle out of the water column can promote diversity by providing an new resource or act to decrease available space by clogging microhabitat space and blocking light from autotrophs (Hicks 1980). Different amounts of sediment collected by the ASUs could have important consequences for assemblage structure. In this experiment the amount of sediment entrained in the ASUs increased with increasing unit size following a pattern expected from passive entrainment, with a slight reduction in sediment loads in larger units due to their reduced surface area. The results show that the proportional sediment load is not greatly variable between unit size treatments.

Although no three scourer units were retrieved, interpolation of the results of this experiment suggest that a three scourer ASU would adequately sample the fauna of this area. A three scourer unit is preferred over single or two scourer units to reduce inherent variability associated with small sample size. Many of the additional taxa that recruited to the ASUs of six and nine scourers were low abundance species and rare species. Thoroughly sampling these species is important for describing total diversity for a region but is not necessarily required to make an accurate assessment of the state of health of the marine benthic

macrofaunal communities in an environmental change study. In multivariate community analyses of benthic macrofaunal assemblages using data transformations other than presence/absence the rare and low abundance species do not have much weight in the analyses (Clarke & Warwick 1994).

Based on these results a three scourer ASU adequately samples the available taxa. ASUs composed of three scourers have been used in all further experiments.

Chapter 4

Pilot Study II – ASU Deployment

4.1 Introduction

The experiments reported in the previous chapter show that an ASU comprised of three scourers will adequately sample the motile faunal assemblage at Casey. The experiments reported in this chapter investigated the timing and duration of deployment on the structure of the ASU assemblage.

When using passive recruitment sampling methods the influence of time on biological assemblage structure must be taken into account. The sampling regime of a monitoring program should target a stage of community development where the composition of the assemblage is relatively stable and at a time where the organisms that make up the assemblage occur in sufficient frequency and abundance to allow robust analyses of the data. Tailoring the monitoring program to sample a recognisable assemblage structure is a key part of successfully identifying and qualifying natural and anthropogenic environmental conditions that cause changes in the distribution and abundance of species (Kennicutt 1996). Targeting a stable assemblage structure is also important for logistical reasons as it defines the timing of deployment and collection of samples. Experiments using nylon mesh pan scourers similar to those used in this study have commonly used deployment periods of five months (Gee & Warwick 1996; Kendall et al. 1996; Rule & Smith 2005; Smith & Rule 2002). Gee and Warwick (1996) recommended a deployment period of one year for the nylon pan scourers in polar localities.

Many of the processes occurring throughout the development of natural communities have elements that are temporally dependant. Temporal control can function over very large scales, such as in the seasonal hydrodynamic processes that influence planktonic larval availability in a marine embayment (Gaines et al. 1985), and also on small scales, as seen in the sequential recruitment of a species that is attracted to a habitat by the presence of another (eg. settlement of the serpulid *Hydroides elegans* induced by particular bacterial biofilms but not by the availability of clean surfaces (Unabia &

Hadfield 1999)). Sequential recruitment patterns have also been related to changes in the habitat structure created by space being occupied (Osman 1977), the bodies of recruited individuals increasing habitat complexity (Jacobi & Langevin 1996) and direct interactions between residents and new recruits - including predation (Andre et al. 1993; Osman & Whitlatch 1995a), disturbance (Olafsson et al. 1994) and chemical inhibition (Osman & Whitlatch 1995b).

Temporal variation in the motile epifaunal assemblages associated with macrophytes has been investigated in temperate and tropical marine environments. These studies have found that motile fauna rapidly colonise both defaunated plants (Martin-Smith 1994; Taylor 1998c) and artificial plant mimics (Virnstein & Curran 1986). Studies of seasonal variation in the motile epifaunal assemblages of marine algae in temperate waters found a peak in total abundance during spring and summer that coincides with a peak in epiphytic algal biomass (Edgar 1983b; Taylor 1998b). In a study of three species of brown algae in New Zealand Taylor (1998b) found that while total epifaunal abundance showed a seasonal change the species composition of the assemblage remained constant over time. There are currently no published studies of temporal variation in motile epifaunal assemblages from Antarctic waters.

The development of Antarctic sessile assemblages has been thoroughly investigated at Signy Island (Barnes 1995; Barnes 1996, 2000; Barnes & Arnold 2001; Barnes & Clarke 1995; Stanwell-Smith & Barnes 1997) and on the Antarctic Peninsula (Bowden 2005). These studies record low colonisation rates in comparison with sessile communities of lower latitudes and year round recruitment. Low colonisation rates have also been reported from settlement panels deployed in Terra Nova Bay (Amato et al. 1990; Relini & Amato 1991).

The experiments reported here were conducted to assess the influence of deployment duration and the timing of deployment on the assemblage that recruits to the ASUs and to determine the most effective deployment period for the use of ASUs in a monitoring program for Antarctic shallow water benthos. Experiments were designed to assess short

term recruitment patterns during summer and to assess community development on longer time scales.

4.2 Methods

These experiments were deployed in a small embayment at the eastern edge of Newcombe Bay at 66°16.40'S and 110°33.83'E . All samples were deployed, collected and processed following the general methods described in Chapter 2 to collect species composition and abundance data.

Many trays were lost from those deployed in the original experiment described in Chapter 2. Due to the heavy loss of trays during the first season the experiment was repeated in the second year. Again many of the trays were lost. During the final season some trays from earlier deployments that had been hidden by the plankton bloom were rediscovered. From the trays that were successfully retrieved two four week summer deployment periods and several longer term deployments of 44 to 46 weeks, 92 to 94 weeks and 107 weeks have been analysed.

Twelve ASUs that were deployed for four weeks from the beginning of December 2002 and eight ASUs that were deployed at the beginning of January 2003 for four weeks have been used to assess short term recruitment to the ASUs. Trays were deployed in 12-14 m depth.

The ASUs used for analyses of long term deployments had been originally deployed for short term recruitment experiments in previous years. Their discovery and collection in the final year of the study allowed the long term treatments to be included. A result of the unplanned nature of this experiment is the large difference in sample size for each of the treatment groups. The number of ASUs from each deployment period is presented in Table 4.2.1.

Table 4.2.1. Details of deployment periods and sample numbers for long term deployments.

Treatment Group	Deployment Duration	Number of ASUs
Winter only	44 weeks; 31/2/02 to 5/12/02	4
	45 weeks; 4/2/02 to 19/12/02	4
	46 weeks; 4/2/02 to 23/12/02	12
Two winters	92 weeks; 28/2/01 to 5/12/02	4
	94 weeks; 28/2/01 to 18/12/02	4
Two winters + summer	107 weeks; 5/12/00 to 23/12/02	8

Analyses

nMDS ordinations based on a fourth root transformed Bray-Curtis similarity matrices were used to assess similarity in abundance patterns across taxa in the assemblage between deployment treatments. Tests for significance between deployment groups were conducted using ANOSIM. SIMPER analysis was used to determine which taxa were contributing most to differences between deployment groups.

The univariate diversity measures (total individuals (N), total taxa (S), Pielou's Evenness (J) and the Shannon-Wiener diversity index (H')) were tested for differences between the two summer treatments and between the long term deployments using one way ANOVAs. Prior to analyses data were tested for normality and homogeneity of variance.

4.3 Results

The ASUs deployed in these experiments overall collected 20247 individuals from 76 taxa (Table 4.3.1). Crustaceans are the most diverse group in all temporal treatments.

A total of 21 taxa (n = 12) were sampled in December and 16 taxa (n = 8) in January. The occurrence of taxa was more variable in December and abundances were much lower. *S. paludinoides* was the only taxa to occur in all samples during December. In January four taxa were present in all samples – *Antarctogenia macrodactyla*, *Munna c.f. maculata*,

Nototanias antarcticus and *S. paludinoides*. These taxa were also present in all ASUs from the longer deployments.

A great increase in the number of taxa and number of individuals was found in the longer deployments. In the 44-46 week deployments individuals of *S. paludinoides* and *A. macrodactyla* are the most abundant taxa. This pattern continues in the 92-94 week deployment but polychaetes, mostly spirorbids, dominated the assemblage and crustacean abundances were greater than the molluscs. The 107 week deployments collected much lower abundances of spirorbids and *S. paludinoides* than expected from the trends seen in the shorter deployments.

Plots of the standard diversity measures (Total taxa (S), Total individuals (N), Pielou's Evenness (J) and the Shannon-Wiener diversity index (H')) against time are shown in Figure 4.3.1. Species richness and total individuals follow the same pattern of increase with increasing deployment time up to the 90+ deployment, dropping at 107 weeks. Evenness is lowest in the 90+ deployment due to the high abundance of spirorbids and other super abundant taxa in this treatment, although these differences are not significant. Shannon's diversity increases with time.

Table 4.3.1. Taxonomic summary for temporal deployments. Summer only deployments - December (n=12) and January (n=8); long term deployments – 44-46 weeks (n=20), 92-94 weeks (n=8), 107 weeks (n=8).

	December (n=12)		January (n=8)		44-46 weeks (n=20)		92-94 Weeks (n=8)		107 weeks (n=8)		Overall
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Total Individuals	50.17	14.01	94.88	12.06	301.95	24.37	1179.50	143.11	426.38	60.30	
Total Taxa	8.17	0.69	8.38	0.63	20.80	0.69	31.88	1.93	26.13	1.49	
Crustaceans	13.33	1.95	24.63	4.75	104.35	17.03	368.38	60.42	177.63	39.02	
Gammarids	7.92	1.49	6.63	0.98	73.00	10.88	236.88	43.76	129.00	25.99	
Isopods	2.92	0.43	7.00	1.73	12.60	1.58	48.13	10.42	20.88	5.22	
Tanaids	2.42	0.50	11.00	3.62	16.70	7.71	79.50	15.14	24.38	8.15	
Other Crustaceans	0.08	0.08	0.00	0.00	2.05	0.36	3.88	0.79	3.38	1.07	
Polychaetes	2.50	0.82	1.63	0.96	25.20	2.94	485.75	42.97	80.38	8.47	
Molluscs	32.17	13.18	67.50	11.24	161.90	11.30	293.50	49.37	144.00	49.14	
Echinoderms	0.33	0.14	0.00	0.00	4.30	1.06	16.25	6.42	9.75	3.36	
Other Taxa	1.83	0.51	1.13	0.35	6.20	1.05	15.63	1.86	14.63	3.23	
Total Individuals	602		759		6039		9436		3411		**20247**
Total Taxa	21		16		47		55		49		**76**
Crustacean Taxa	12		9		23		22		21		**36**
Gammarid Taxa	3		3		10		9		6		**16**
Isopod Taxa	6		4		8		9		10		**13**
Tanaid Taxa	2		2		1		2		1		**2**
Other Crustaceans	1		0		4		2		4		**5**
Polychaete Taxa	1		1		7		10		8		**12**
Mollusc Taxa	5		5		10		13		10		**15**
Echinoderm Taxa	1		0		2		5		3		**6**
Other Taxa	2		1		5		5		7		**7**

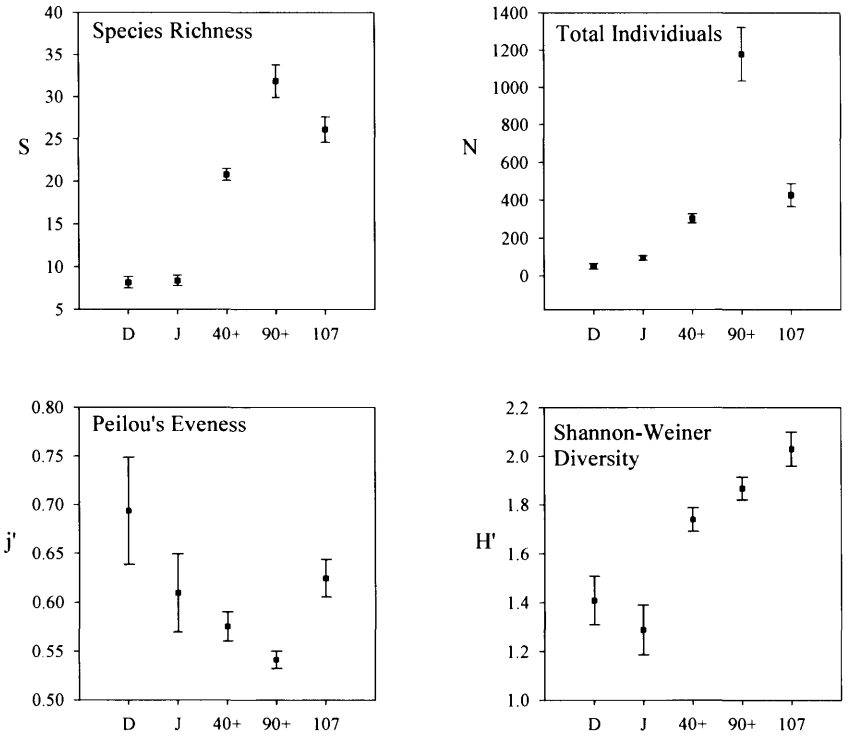

Figure 4.3.1. Mean diversity measures for temporal treatments (D= December (n=12); J =January (n=8); 40+ = 44, 45 and 46 weeks (n=20); 90+ = 92 and 94 weeks n=8; 107 weeks n=8).

p-values for one way ANOVA tests between the two summer treatments and between the long term deployments are presented in Table 4.3.2. With the exception of Evenness all diversity measures are significantly different between the long term deployments. Diversity measures are not significantly different between the summer deployments with the exception of total individuals (N) which is greater in January.

Table 4.3.2. p-values for one way ANOVAs for standard diversity measures between summer deployments and between long term deployments.

Diversity measure	Summer deployments	Long term deployments
S	0.837	0.000
N	0.037	0.000
j'	0.279	0.21
H'	0.425	0.005

The nMDS ordination of all the temporal samples shows clear separation of the short term, summer only deployments and the longer term deployments (Figure 4.3.2). While there is some overlap in the summer deployments each of the long term deployment treatments is discrete on the MDS.

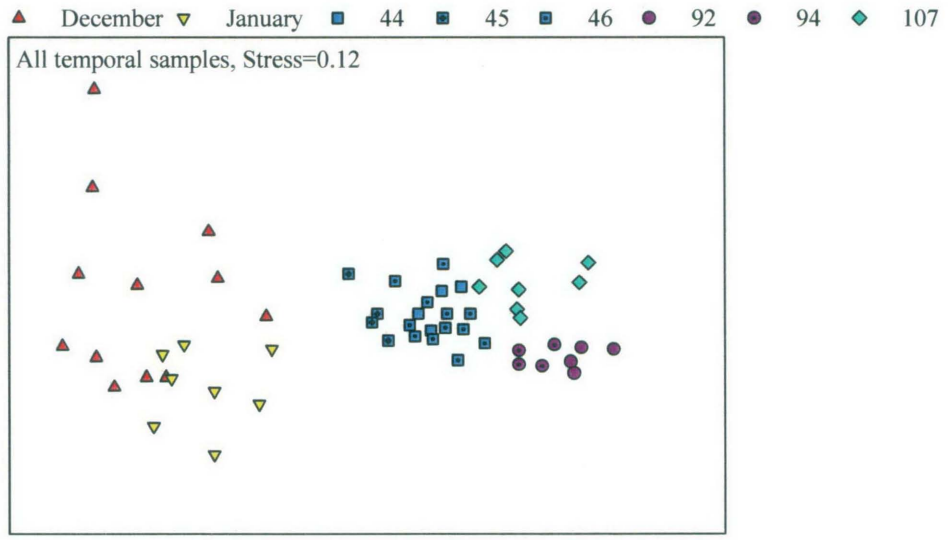

Figure 4.3.2. nMDS ordination for all temporal deployments, from Bray-Curtis similarity matrix based on fourth root transformed abundance data (December n=12, January n=8, 44 n=4, 45 n=4, 46 n=12, 92 n=4, 94 n=4, 107 n=8).

The ordination of the December and January deployments is shown in Figure 4.3.3. The January samples show a closer grouping than the December samples, which may suggest greater variability in early summer recruitment.

The ordination of the long term deployments is shown in Figure 4.3.4. While each of the main treatment groups (40+ weeks, 90+ weeks and 107 weeks) are clearly separated the 107 week deployment is more similar to the 40+ treatment than the older 90+ group.

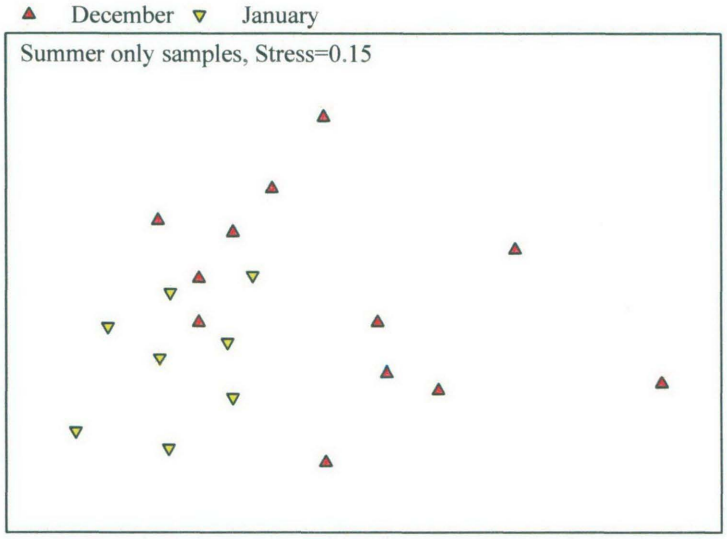

Figure 4.3.3. nMDS ordination for summer only deployments, from Bray-Curtis similarity matrix based on fourth root transformed abundance data (December n=12, January n=8).

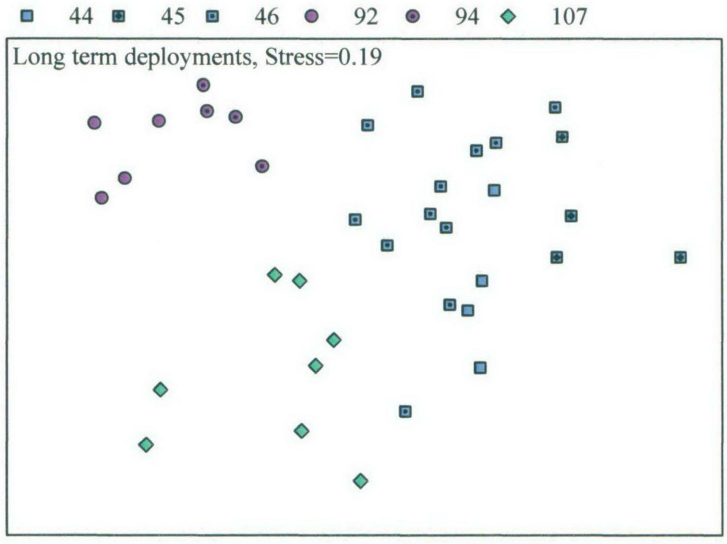

Figure 4.3.4. nMDS ordination for long term deployments, from Bray-Curtis similarity matrix based on fourth root transformed abundance data (44 n=4, 45 n=4, 46 n=12, 92 n=4, 94 n=4, 107 n=8).

Results of one-way ANOSIM tests of within treatment groups are presented in Table 4.3.3. All within treatment groups were found to be significantly different. ANOSIM tests also returned significant results for differences between the seasonal groups (Global R 0.727, p-value=0.001). Global R values and p-values for the comparisons of the seasons are presented in Table 4.3.4. Global R values from within season tests were much lower than R values from tests run between the seasonal deployment treatments.

Table 4.3.3. Global R and p-values for ANOSIM tests of within season deployment groups.

Within season deployment groups	**Global R**	**p-value**
44w (n=4), 45w (n=4), 46w (n=12)	0.317	0.005
92w (n=4), 94w (n=4)	0.313	0.029
December (n=12), January (n=8)	0.146	0.044

Table 4.3.4. Global R values and p-values for seasonal comparisons from one way ANOSIM test.

Seasonal deployment groups comparison		**Global R**	**p-value**
Two Winters	One Winter	0.855	0.001
Two Winters	Summer	0.929	0.001
Two Winters	Two winters + Summer	0.739	0.001
Winter	Summer	0.831	0.001
Winter	Two winters + Summer	0.642	0.001
Summer	Two winters + Summer	0.896	0.001

Average dissimilarity of within season groups is much lower than dissimilarity between the treatment groups (Table 4.3.5). In comparisons of seasonal groups the greatest dissimilarity was found between all of the long term deployments and the summer deployments.

Table 4.3.5. Average dissimilarity values for within season groups.

Within season deployment groups		**Average dissimilarity (%)**
December	January	42.62
44 w	46 w	29.13
44 w	45 w	33.21
46 w	45 w	32.02
92 w	94 w	27.89

SIMPER tables showing mean abundance of species contributing to 50% dissimilarity between season treatments and average dissimilarity are presented in Table 4.3.6.

Table 4.3.6. Results of SIMPER analyses comparing seasonal deployment groups showing average abundance, % dissimilarity and cumulative dissimilarity.

90+ weeks vs 40+ weeks Average dissimilarity = 41.17%				
	90+	**40+**	**Dissimilarity %**	**Cumulative %**
Spirorbidae	462.25	18.6	7.68	7.68
Ascidian	8.75	0.1	4.74	12.42
Nototanais antarcticus	76.45	16.7	3.7	16.12
Cymnodocella tubicauda	8.25	0.35	3.49	19.61
Antarctogenia macrodactyla	228.63	71.4	3.03	22.65
Isopod sp.9	3.38	0.35	2.97	25.62
Haplocheira plumosa	5.88	0.55	2.86	28.48
Munnid sp.	6.13	1.7	2.75	31.22
Terribellidae	6.38	0.65	2.73	33.95
Ophiura crassa	15.75	3.85	2.53	36.48
Flabelligera sp.2	1.88	0	2.5	38.98
Syllid sp.2	1.88	1.65	2.3	41.28
Bivalve sp.3	1.25	0	2.27	43.55
Onoba turqueti	12.75	3.55	2.24	45.79
Copepoda	1.88	0.3	2.1	47.89
Gnathia polaris	2.75	1.3	2	49.89
Austrosignum c. f. grande	2.63	0.4	2	51.9

90+ weeks vs Summer Average dissimilarity = 69.06%				
	90+	**Summer**	**Dissimilarity %**	**Cumulative %**
Spirorbidae	462.25	2.15	8.51	8.51
Antarctogenia macrodactyla	228.63	7.1	5.04	13.55
Onoba gelida	19.88	0.15	4.26	17.81
Nototanais antarcticus	76.45	4.6	4.13	21.94
Onoba sp.	23.25	0.25	4.03	25.97
Ascidian	8.75	0	3.82	29.78
Polynoidae	7.25	0	3.57	33.35
Ophiura crassa	15.75	0.2	3.51	36.86
Skenella paludinoides	225.38	41.55	3.32	40.18
Gastropod sp.9	4.63	0	3.11	43.29
Terebellidae	6.38	0	2.68	45.97
Munna c.f. antarctica	6.13	0.15	2.67	48.64
Isopod sp.9	3.38	0	2.66	51.31

40+ weeks vs Summer

Average dissimilarity = 56.25%

	40+	Summer	Dissimilarity %	Cumulative %
Onoba gelida	8.9	0.15	6.04	6.04
Onoba sp.	6.15	0.25	5.47	11.5
Spirorbidae	18.6	2.15	5.3	16.8
Antarctogenia macrodactyla	71.4	7.1	5.24	22.04
Skenella paludinoides	136.35	41.55	4.68	26.72
Polynoidae	2.25	0	4.67	31.39
Syllid sp.2	1.65	0	3.95	35.34
Ophiura crassa	3.85	0.2	3.92	39.26
Nototanais antarcticus	16.7	4.6	3.79	43.05
Hesionidae	1.3	0	3.71	46.76
Onoba turqueti	3.55	2.7	3.43	50.19

90+ weeks vs 107 weeks

Average dissimilarity = 37.78%

	90+	107	Dissimilarity %	Cumulative %
Spirorbidae	462.25	69.88	4.91	4.91
Skenella paludinoides	225.38	106.5	3.52	8.44
Nemertean	4.38	2.75	3.24	11.68
Isopod sp.9	3.38	0.13	3.1	14.78
Nematoda	0.5	6.63	2.85	17.63
Haplocheira plumosa	5.88	8.25	2.71	20.34
Syllid sp.2	1.88	3.25	2.64	22.98
Nototanais antarcticus	76.45	24.38	2.57	25.55
Gastropod sp.9	4.63	0.5	2.5	28.05
Terebellidae	6.38	1.25	2.47	30.52
Flabelligerid sp.2	1.88	0	2.46	32.99
Sebidae sp.1	0.75	1.5	2.31	35.29
Scleroconocha sp.	2	1.25	2.21	37.5
Bivalve sp3.	1.25	0.13	2.08	39.59
Munna c.f. antarctica	6.13	4.5	2.05	41.64
Austrosignum c.f. grande	2.63	0.88	2.02	43.66
Syllid sp.1	1	0.75	1.91	45.57
Ophiura crassa	15.75	8.75	1.89	47.46
Antarctogenia macrodactyla	228.63	117	1.89	49.35
Gnathia polaris	2.75	3.63	1.88	51.23

40+ weeks vs 107 weeks
Average dissimilarity = 37.67%

	40+	107	Dissimilarity %	Cumulative %
Ascidian	0.1	3.75	4.93	4.93
Nemertean	4.45	2.75	4.41	9.34
Skenella paludinoides	136.35	106.5	3.96	13.3
Cymnodocella tubicauda	0.35	2.75	3.69	16.98
Spirorbidae	18.6	69.88	3.55	20.54
Haplocheira plumosa	0.55	8.25	3.46	24
Nematoda	1.5	6.63	3.3	27.3
Munna c.f. antarctica	1.7	4.5	3.25	30.54
Ophiura crassa	3.85	8.75	3.11	33.66
Nototanais antarcticus	16.7	24.38	2.79	36.44
Copepoda	0.3	1.5	2.78	39.22
Scleroconocha sp.	1.45	1.25	2.72	41.95
Sebidae sp.1	0.4	1.5	2.57	44.52
Onoba turqueti	3.55	5.13	2.57	47.09
Laevilitorina antarctica	3.45	1.38	2.47	49.56
Onoba gelida	8.9	20.13	2.42	51.98

Summer vs 107 weeks
Average dissimilarity = 66.24%

	Summer	107	Dissimilarity %	Cumulative %
Spirorbidae	2.15	69.88	6.23	6.23
Onoba gelida	0.15	20.13	5.37	11.6
Antarctogenia macrodactyla	7.1	117	5.03	16.63
Onoba sp.	0.25	8.38	4.35	20.99
Ascidian	0	3.75	4.08	25.06
Polynoidae	0	3.25	3.88	28.94
Ophiura crassa	0.2	8.75	3.72	32.66
Syllid sp.2	0	3.25	3.71	36.37
Nototanais antarcticus	4.6	24.38	3.32	39.69
Gnathia polaris	0.1	3.63	3.28	42.97
Nematoda	0.05	6.63	3.23	46.2
Skenella paludinoides	41.55	106.5	3.1	49.3
Munna c.f. antarctica	0.15	4.5	3	52.29

Two strong abundance responses can be seen in the development of the ASU assemblage. The taxa that create these patterns are described as 'persistent pioneers' and 'secondary settlers'. The persistent pioneer species are present in the short term deployments and persist in the longer term deployments to occur in high abundance. A second group which becomes prominent in the longer term deployments as common medium and low abundance species are the secondary settlers. It is also worth noting that the abundance

patterns of the secondary settlers do not follow the decline at 107 weeks seen in all of the persistent pioneers. Differences in the abundances of these two groups of taxa and the increased occurrence of rare and low abundance species in the longer term deployments are the main causes of difference in ASU assemblage structure between the temporal treatments. Mean abundance of selected taxa from these groups are shown in Figures 4.3.5. and 4.3.6.

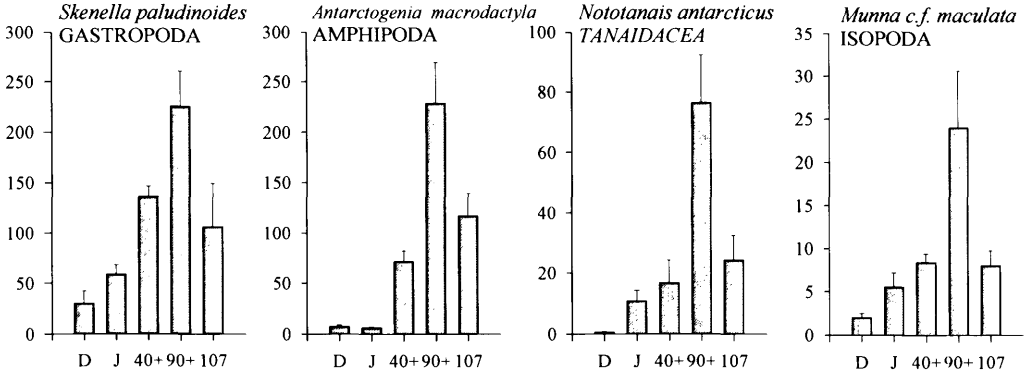

Figure 4.3.5. Mean abundance and standard errors for persistent pioneer species (D= December (n=12); J =January (n=8); 40+ = 44, 45 and 46 weeks (n=20); 90+ = 92 and 94 weeks n=8; 107 weeks n=8).

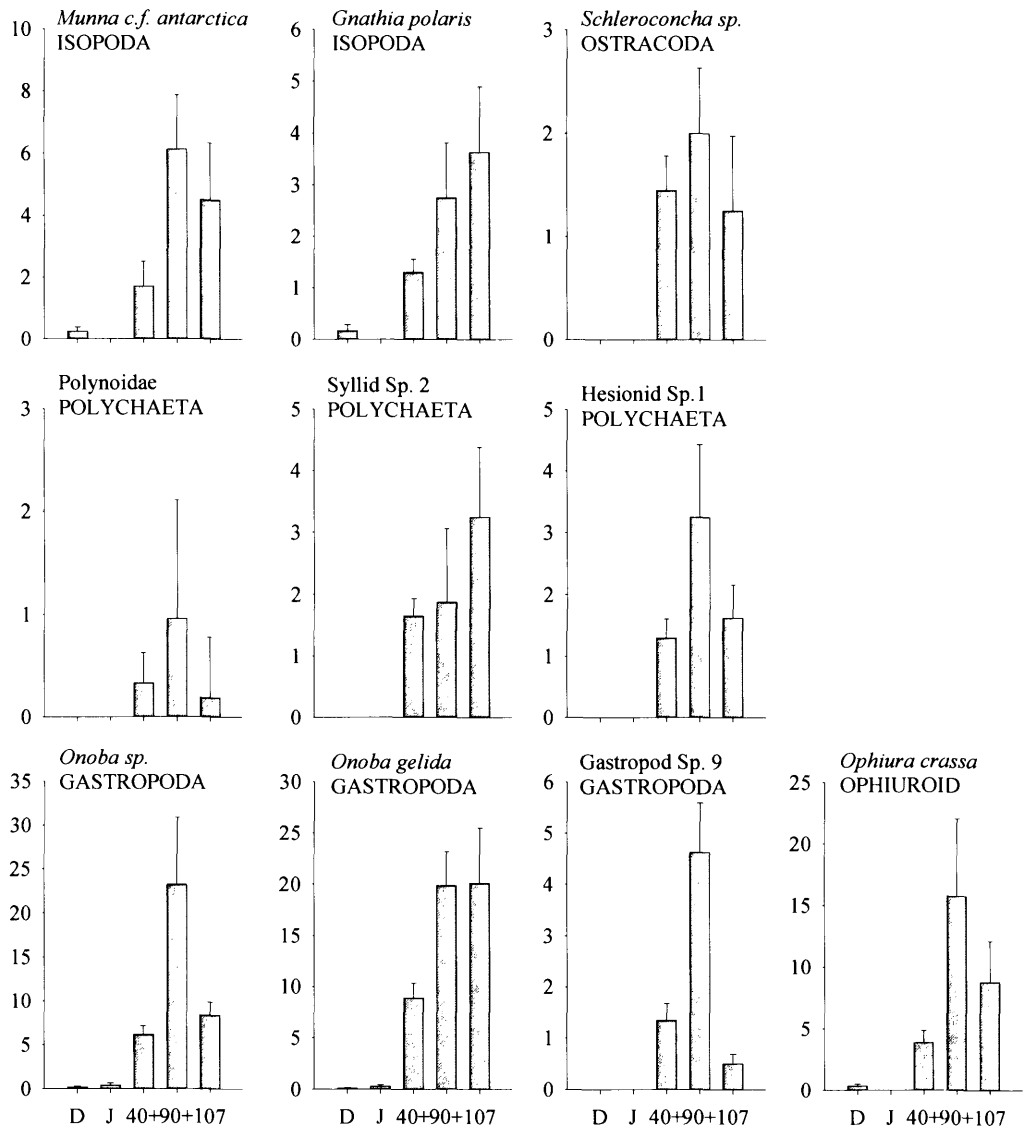

Figure 4.3.6. Mean abundance and standard errors for secondary settlers (D= December (n=12); J =January (n=8); 40+ = 44, 45 and 46 weeks (n=20); 90+ = 92 and 94 weeks n=8; 107 weeks n=8).

4.4 Discussion

The results of these experiments show that both the timing and duration of deployment influence the structure of the faunal assemblage recruiting to the ASUs. The low number of taxa, low abundance and high variability observed in the short term, summer only deployments, make deployments of this duration unsuitable for monitoring use. ASUs deployed over winter collected much greater numbers of taxa and in higher abundance and show less variability and are thus more suitable for monitoring. The trend of increase in taxa and abundance was continued in the ASUs deployed for a second winter but was not upheld in the longest deployment which spanned two winters and a summer. All of the longer deployments show grouping by trays in the ordinations which implies that small scale spatial variation is also important in shaping the ASU assemblage.

The four week summer deployments both collected an average of eight taxa but the number of individuals was almost doubled in the January deployment. The taxa that recruited in these short term deployments were all highly motile taxa. The higher number of individuals and more consistent occurrence of taxa collected in the four week January deployment compared to the four week December deployment may reflect a greater availability of these taxa in the environment during January. This may be a response to increased primary production following sea ice breakout and increased day length. Increased abundance of crustaceans corresponding to a peak of epiphyte abundance during summer has been reported in phytal assemblages in temperate locations (Edgar 1983b; Taylor 1998b).

There is a sequence of community development in the ASU assemblage which shows an increased abundance of 'persistent pioneer' species from the short term summer deployments to the 92-94 week deployment and recruitment of 'secondary settlers' in longer term deployments, which become a stable element of older assemblages. Three peracaridean crustaceans are among the persistent pioneers. The increased abundance of these taxa in the longer deployments is contributed to by reproduction within the habitat. The massive increase of spirorbids in the 92-94 week deployment may reflect gregarious settling of this species. This behaviour is known in other members of this group (Toonen

& Pawlik 2001). The high variability in spirorbid recruitment between treatments may be further explained by differences in larval supply over small spatial scales within the site.

Studies of marine assemblages recruiting to artificial substrata in tropical and temperate locations have used deployment periods ranging from several days to over a year. The small bodied motile fauna associated with seagrasses have been sampled at abundances similar to nearby natural seagrasses on artificial plants in two to four days in New Zealand (Bell and Hicks 1991) and in four to eight days in Florida (Virnstein and Curran 1986). Mitro and Danovaro (2004) found bottle brushes deployed to sample meiofauna on shallow soft sediment in the Adriatic Sea reached carrying capacity in four to six days. Recruitment and development of benthic assemblages is much slower in Antarctic waters and longer deployment times are required to adequately sample the fauna. There is a lack of comparable data from similar communities in Antarctic regions.

The recommended deployment period for ASUs for a standard monitoring procedure should include an over winter deployment and late summer collection to target a stable period in the assemblage development and to collect taxa in sufficient abundances for data analyses. A deployment period of one year is optimal in considering available sampling time and effort. Year long deployment is also practical from a logistical perspective in that access to the sites is only possible during the summer open water period.

Chapter 5
Spatial variation and contamination response in the ASU assemblage

5.1 Introduction

The pilot study experiments have established that ASUs of three scourers have an optimal deployment period of one year. This deployment period is logistically practical and allows the recruited assemblage to develop to a degree of richness and abundance suitable for analysis. The experiment reported in this chapter assesses spatial variation in the ASU assemblage and is an initial investigation of a potential contamination response in assemblage collected at the contaminated site Brown Bay.

Describing the distribution and abundance of organisms and understanding the processes that determine these patterns are fundamental goals of ecology (Andrew & Mapstone 1987). Processes that structure biological communities function over a range of spatial scales from across climatic regions to within microhabitats (Barry & Dayton 1991). The scale at which measurements of variation in species abundance and community structure are made have important consequences for the ability of an investigation to identify patterns and related processes (Bishop et al. 2002; Wiens 1989). Nested sampling designs have been recommended to allow unconfounded estimates of variation for each scale of investigation within an experimental design (Andrew & Mapstone 1987; Green 1979; Underwood 1981). In spatially nested designs successively smaller scales are nested within the scale above (eg samples collected within 1 m from plots 10 m apart within sites 100 m apart). These designs give appropriate replication to estimate the contribution of each scale to the total variation among samples within the largest scale (Morrisey et al. 1992) and so the information needed to identify the scales at which ecological processes are acting (Thrush et al. 1994).

Smith and Rule (2005) found that the assemblage recruited to their ASUs in the Solitary Islands, Australia, varied over all spatial scales from ten and one hundred metres within

islands and kilometres between islands. At the largest scales distinct assemblages were observed and different taxa were numerically dominant between the islands. Significant differences in the abundance patterns of the major taxonomic groups contributed to differences on the sampling scales investigated within islands. Edgar and Klump (2003) found significant differences in the motile assemblage recruiting to artificial plant units between islands in the Great Barrier Reef, but that assemblages within islands were the same.

Stark (2000) found significant variation in soft sediment communities at Casey on scales of 10 m, 100 m and kilometres and that the soft sediment communities were patchy, with taxa often confined to one plot or site within a location. Grainger (2004), in a preliminary study of epifauna associated with macroalgae found significant variation in assemblage composition between all sites which ranged from two to approximately 10 km apart.

Quantifying natural variability as part of a biological effects study informs the investigator of the power of their tests and ultimately their ability to reliably detect differences resulting from anthropogenic change (Osenberg et al. 1994; Underwood 1994). Comparisons of impacted and reference sites are used in post-impact studies where no information from the impacted site prior to the pollution event is available. The need to use references sites adds sources of natural variation to the investigation. To ensure that the differences detected between control and impact sites are related to the impact being investigated and do not merely reflect local variation, the use of multiple controls is recommended (Glasby 1997; Underwood 1992). Reference or control sites should be chosen to be similar to the impact site in every way except for the impact (Glasby & Underwood 1998).

The aims of this experiment were:

- To describe natural variability in the ASU assemblage on spatial scales of 1m to 200 m within sites and on scales of 1 to 18 km between sites.
- To assess differences in the ASU assemblage between control and impacted sites.

- To assess the suitability of ASU assemblage for monitoring.

5.2 Methods

Study Design

Spatial variation in the ASU assemblage was investigated using a nested sampling design which allowed comparison of variation within sites and between sites. This experiment was also designed as a planned contrast between three control sites – Newcombe Bay, O'Brien Bay and Penney Bay, and a known impacted site Brown Bay.

Trays were originally deployed in a fully nested pattern with two groups of nine trays 100 m apart within each site. Within each group of nine trays the trays were arranged in groups of three, 1 m apart, at each point of a 10 m triangle (refer to Chapter 2 Fig 2.4.1). Unfortunately all of the trays were disturbed and moved from their original positions and many were lost. From the trays that were collected from each site six were selected that appeared the least disturbed, were the closest together and from the smallest depth range (Table 5.2.1.). Disturbance of the trays was evident by drag marks in the sediments around the tray and also in the state of the tray and ASUs. Some trays were covered in sediment, and in some cases the ASUs were filled with black anoxic sediments. On other trays the ropes attached to the buoy lines were tangled or moved and some trays also showed signs of being crushed.

Table 5.2.1. Details of selected tray positions within sites in spatial variation experiment.

Site	Distance between trays (m)	Depth range (m)
Brown Bay	10 – 40	12-14
Newcombe Bay	5 – 100	13-19
O'Brien Bay	10 – 60	15-20
Penney Bay	5 – 200	15-17

Trays were deployed between the 12th and 22nd of February 2001 and collected approximately one year later between the 7th and 27th of February 2002. All ASUs were deployed, collected and processed following the general methods described in Chapter 2.

The occurrence of taxa in the ASU assemblage is compared to other macrofaunal assemblages known from previous work at Casey. Data were available for soft sediments

(Stark 2000; Stark et al. 2004; Stark et al. 2005) and tiles (with permission of Jonny Stark), macroalgae (Grainger 2004) and the fauna associated with the debris covering urchin *Sterechinus neumayeri* (Richards 1998).

Site Sediment Variables

Six sediment samples were collected from Newcombe Bay, O'Brien Bay and Brown Bay to measure metal concentrations. Stark (2003) found increased heavy metal concentrations in the sediments of Brown Bay, adjacent to the Thala Valley waste disposal site where heavy metal contamination has been documented by Snape (2001). The sediment samples for the present study were collected by the Human Impacts Research Program Dive Team. Penney Bay could not be sampled as this site was 20km from Casey and outside of the safe operating area for the divers. In most locations within the study area marine sediments were present only as a shallow surface layer, rarely more than 5cm deep (personal observation from divers). To collect sufficient sediments for analysis from each site the surface sediments were scraped from two 2 m by 2 m plots approximately 50 m apart. The location of these plots was centered on the original deployment position of the ASUs at each site. The sediments from each plot were scooped from the surface into 3 L acid washed plastic containers. The large samples from each plot were thoroughly mixed and then separated into three separate samples for analysis. This sampling method is not intended to describe small scale variation in the sediments but provide a site description of the heavy metals present in the sediments.

Heavy metals in the marine sediment samples were extracted using a 4 hour acid digest of 1 gram of dry sediment in 20 mls of 1 molar hydrochloric acid following the method described in Snape et al.(2004). Sediment samples were prepared for digestion by separating the less than 2 mm fraction by sieving and then oven drying this fraction. Following digestion the supernatant was diluted to 100 ml with distilled water and analysed using ICP-MS by the Central Science Laboratory, University of Tasmania.

Analyses

Multivariate and univariate analyses were used to investigate the macrofaunal abundance data and diversity indices following the methods described in Chapter 2. Fourth root transformed abundance data was used in the multivariate analyses to create Bray-Curtis similarity matrices for MDS ordinations, ANOSIM and SIMPER analysis. Data transformations of univariate data including sediment metal concentrations, ASU sediment weights, diversity indices and abundance data were used as required to improve normality and homogeneity of variance to meet the assumptions of parametric analyses. Data transformations that were used are noted in the results in each case.

Asymmetrical ANOVAs were constructed to test for differences between control and impacted sites by combining the two way nested ANOVA of all sites and the two-way nested ANOVA of only the control sites (after Glasby (1997)). Details of mean squares calculation and degrees of freedom for these ANOVAs are provided in Table 5.2.2.

Table 5.2.2. Details of construction of asymmetrical ANOVA to compare control sites with impacted site.

ANOVA 1: All sites. Three control sites and one impacted site.				
Variation source	**df**	**Sum of Squares**	**Mean Square**	**F ratio - versus**
Site	3	A	A/3	Tray(Site)
Tray(Site)	20	B	B/20	Residual
Residual	72	C	C/72	
Total	95			
ANOVA 2: Control sites only.				
Variation source	**df**	**Sum of Squares**	**Mean Square**	**F ratio - versus**
Site	2	a	a/2	Tray(Site)
Tray(Site)	15	b	b/15	Residual
Residual	54	c	c/54	
Total	71			
Asymmetrical ANOVA: Control vs Impact.				
Variation source	**df**	**Sum of Squares**	**Mean Square**	**F ratio - versus**
Site	3	A	A/3	Tray(Site)
Impact vs Controls	1	A - a	A - a	Between Controls
Between Controls	2	a	a/2	Tray(Site) - Controls
Tray(Site)	20	B	B/20	Residual
Tray(Site) – Impact	5	B – b	(B – b)/5	Residual
Tray(Site) – Controls	15	b	b/15	Residual
Residual	72	C	C/72	
Total	95			

Because the trays were moved during deployment the influence of depth and distance on the average dissimilarity between trays within sites was investigated using regression analysis. For each pair of trays within sites the difference in depth and distance between the trays was calculated. The relative depth of trays within sites was calculated as the difference between each pair of trays using positive numbers for a greater depth of the second tray and negative numbers for shallower depths. Distances between trays were measured using plots of GPS point locations taken for the trays at the time of collection. GPS data was plotted using ArcView 3.2. Average dissimilarity values were calculated by SIMPER analysis.

5.3 Results

5.3.1 Sediment chemistry

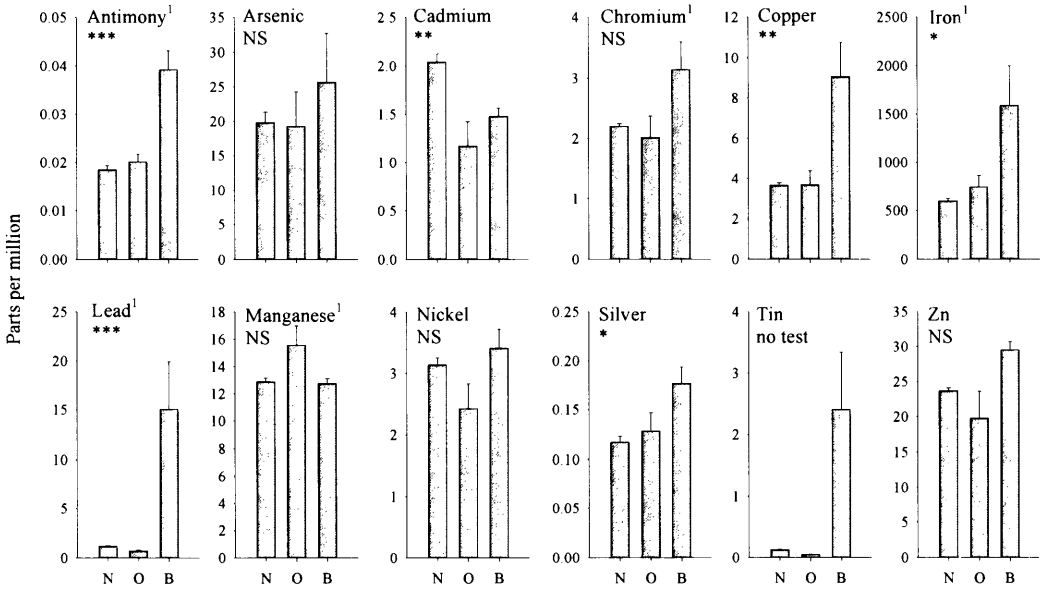

Figure 5.3.1. Mean concentration (ppm) of metals in sediments showing significance of one-way ANOVA tests between sites (n = 4). NS - not significant; *, **, *** - significant at 0.05, 0.1, and 0.001 respectively. N = Newcombe Bay, O = O'Brien Bay, B = Brown Bay. [1] Data log transformed for analysis.

The Brown Bay sediments had significantly higher levels of antimony, copper, iron, lead and silver than sediments from the Newcombe Bay and O'Brien Bay sites (Fig 5.3.1).

The increased concentration of these metals is related to contamination from the Thala Valley tip. Tin was also much higher in Brown Bay but the data were unsuitable for statistical testing as no transformations would correct normality or heterogeneity of variance. Cadmium was significantly higher at the Newcombe Bay site. High levels of Cadmium can occur naturally and have been reported in other locations at Casey.

5.3.2 Physical variables of the ASUs

Small quantities of debris and sediment were entrained in the ASUs during deployment (Fig. 5.3.2 and 5.3.3). Debris items that were found in many of the ASUs included fragments of bryozoans, algae, bivalve and urchin shells and urchin spines and an organic composite of diatoms and fine particulate matter. The ASUs deployed in Brown Bay also commonly collected fragments of anthropogenic debris including charcoal, plastic, metal, glass and rubber.

Algae occurred less commonly in the Penney Bay ASUs while urchin spines and shell fragments were much more common. In several cases *Sterechinus neumayeri* individuals were on the trays when they were collected at this site and in O'Brien Bay. The occurrence of gravel was higher in Penney Bay and Brown Bay.

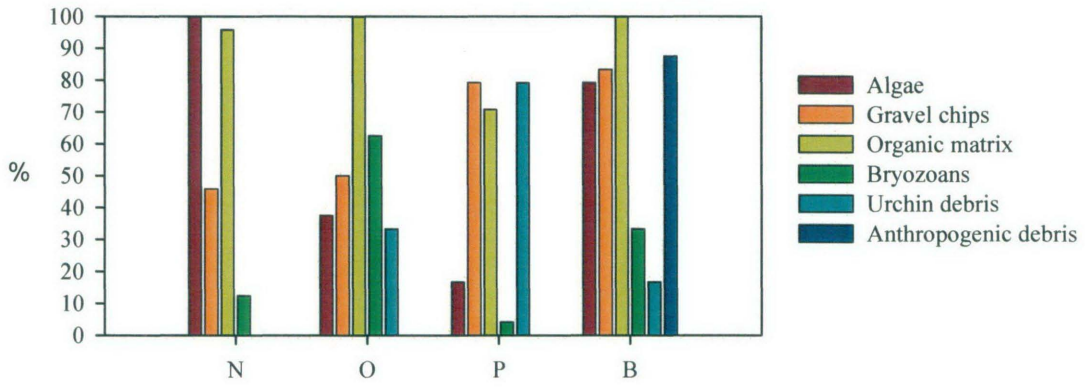

Figure 5.3.2. Percentage occurrence of debris types in ASUs (n=24). N = Newcombe Bay, O = O'Brien Bay, P = Penney Bay, B = Brown Bay.

All ASUs collected small amounts of sediment. ASU sediments consisted mostly of fine particulate matter, sometimes with silt and sand components. High sediment weights were found in some ASUs from Brown Bay and may be attributed to ice disturbance of the trays. When the trays are pushed along the sea bed by ice the surface sediments encountering the leading edge of the tray pile up and can cover the surface of the tray and fill the ASUs. Trays that were covered in sediment were not used in analysis. Benthic disturbance by ice would also locally resuspend sediments contributing to higher sedimentation. Another source of sediment in Brown Bay is the melt stream from Thala Valley which drains a large catchment including the lower half of Casey Station and the wharf road which is maintained during the summer by filling with crushed rock.

Sediment weights were very highly significantly different between sites ($F = 9.86$, $df = 3,92$; $p = 0.000$). Tukey's test found all pairwise comparisons to be significantly different except between Newcombe Bay and Brown Bay and between O'Brien Bay and Penney Bay (family error rate = 0.5, individual error rate = 0.01).

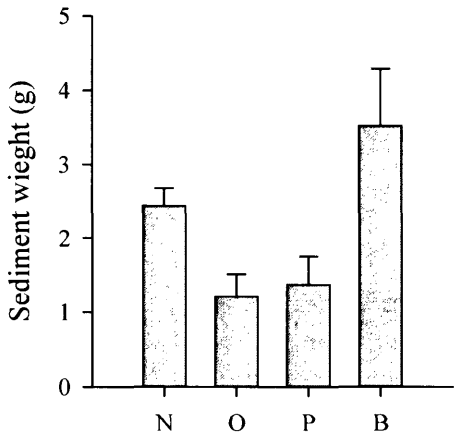

Figure 5.3.3. Mean ASU sediment weight (g) and standard error for sites in spatial variation experiment (n=24). N = Newcombe Bay, O = O'Brien Bay, P = Penney Bay, B = Brown Bay.

5.3.3 Biotic variables

In this experiment overall 50159 individuals were collected from 87 taxa. Many of the taxa that occur in the ASUs are also known from other habitats at Casey (Table 5.3.1).

Table 5.3.1. ASU taxa shared with other habitats from Casey. S = soft sediments, A = algae, T = tiles, U = *Sterechinus neumayeri*.

Group	Name/Code	Family	S	A	T	U
Annelida						
Polychaeta	Spirorbidae	Spirorbidae	x	x	x	x
	Polynoidae	Polynoidae	x	x		x
	Syllid Sp.1	Syllidae	x			x
	Syllid Sp.2	Syllidae				x
	Hesionidae	Hesionidae	x			x
	Terebellidae	Terebellidae				x
	Flabelligerid Sp.1	Flabelligeridae				x
	Capitellidae	Capitellidae	x			
	Orbinidae	Orbinidae	x			
	Dorvilleid Sp.1	Dorvilleidae	x			
	Dorvilleid Sp.2	Dorvilleidae	x			
	Dorvilleid Sp.3	Dorvilleidae	x			
	Maldanidae	Maldanidae	x			
Arthropoda						
Chelicerata						
Acarina	Acarina		x	x	x	x
Pycnogonida	Pycnogonida		x	x		x
Crustacea						
Amphipoda	*Haplocheira plumosa*	Aoridae	x		x	x
	Antarctogenia macrodactyla	Eusiridae		x		x
	Seba sp.	Sebidae				x
	Orchomene pinguides	Lysianassidae	x	x	x	x
	Orchomene franklini	Lysianassidae	x	x	x	x
	Schraderia gracilis	Eusiridae	x	x	x	x
	Eusirid Sp.2	Eusiridae				x
	Methalimedon nordenskjoldi	Exoedicerotidae	x	x	x	
	Heterophoxus videns	Phoxocephalidae	x			
	Lilleboria c.f. georgiana	Liljeborgiidae	x			
	Paroediceroides sinuatus	Paroediceroides	x			
Isopoda	*Munna c.f. maculata*	Munnidae	x	x	x	x
	Munna c.f. antarctica	Munnidae	x	x	x	
	Cymnodocella tubicauda	Sphaeromatidae	x	x	x	x
	Paramunna rostrata	Paramunnidae	x	x	x	x
	Santia mawsoni	Janiriidae				x
	Austrosignum grande	Paramunnidae	x	x	x	x
	Gnathia polaris	Gnathiidae	x	x	x	x
	Desmosoma sp.	Desmosomatidae	x		x	
	Santia charcoti	Santiidae	x	x	x	x
	Austrofilius furcatus	Januridae	x	x	x	x
	Arcturus sp.	Arcturidae	x			x
Leptostraca	Leptostraca		x			
Ostracoda	Ostracod Sp.1		x		x	
	Doloria sp.	Cupridinidae	x			
	Scleroconcha sp.	Philomedidae	x	x		
Tanaidacea	*Nototanais dimorphus*	Nototanidae	x	x	x	x
	Nototanais antarcticus	Nototanidae	x	x	x	x

Table 5.3.1 continued.

Echinodermata						
Asteroidea	Asteroid Sp.1					x
	Asteroid Sp.2					x
Echinoidea	Echinoidea					x
Holothuroidea	Holothuroidea		x			x
Ophiuroidea	*Ophiura crassa*		x	x	x	x
Mollusca						
Bivalvia	Bivalve Sp. 1		x		x	
Gastropoda	*Skenella paludinoides*	Cingulopsidae	x	x	x	x
	Laevilitorina antarctica	Littorinidae	x	x	x	x
	Onoba sp.	Rissoidae				x
	Onoba turqueti	Rissoidae	x	x	x	x
	Onoba gelida	Rissoidae	x		x	x
	Gastropod Sp.9		x		x	
	Submarginata sp.	Trochidae	x	x	x	
	Gastropod Sp.11		x		x	
	Trophon longstaffi	Muricidae	x		x	
Opisthobranchia	Opisthobranchia		x	x		
Other Phyla						
Ascidacea	Ascidacea					x
Nematoda	Nematoda		x	x	x	x
Nemertea	Nemertea		x	x	x	x
Turbellaria	Turbellaria			x		x

Mean abundance and total taxa for the major taxonomic groups collected at each site are presented in Table 5.3.2. The Newcombe Bay site had the most taxa with 62 in total (Mean=25.13, SE=1.37) and the greatest abundance, contributing 55% of all individuals collected in the experiment. Crustacea were the most diverse group at all sites, followed by molluscs.

The species *S. paludinoides* (Gastropoda), *N. antarcticus* (Tanaidacea) and spirorbid polychaetes are dominant taxa at all sites but the relative contribution of these taxa differs at each site (Table 5.3.3). The massive relative increase in *S. paludinoides* in Penney Bay is accompanied with a drop in abundance of crustaceans and polychaetes at this site.

Table 5.3.2. Mean abundance with standard error and total taxa in major taxonomic groups for sites in spatial experiment (n=24). Other Crustacea include copepods and ostracods. Other Taxa include the groups acarina, pycnogonida, planaria, nemertea, nematoda, ascidiacea and porifera.

	Brown Bay		Newcombe Bay		O'Brien Bay		Penney Bay		All
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Total Individuals	396.67	51.55	1149.13	117.24	275.83	31.03	268.33	20.78	
Taxa	20.00	1.50	25.13	1.37	17.13	0.94	15.21	0.84	
Crustacea	118.42	13.12	473.83	117.43	69.42	15.62	27.83	4.61	
Amphipoda	43.29	5.71	100.83	23.85	14.33	4.30	3.96	1.53	
Isopoda	23.63	4.88	179.58	50.70	12.58	2.71	4.04	0.98	
Tanaidacea	45.92	7.35	185.25	50.85	41.33	9.45	12.67	2.30	
Other Crustacea	5.58	1.30	8.17	3.06	1.17	0.45	7.17	1.31	
Polychaeta	153.88	25.35	272.38	59.02	75.21	17.61	26.46	2.72	
Mollusca	119.83	20.86	362.25	67.91	123.13	18.72	207.79	19.91	
Echinodermata	1.54	0.62	0.50	0.33	2.42	0.86	0.33	0.16	
Other Taxa	3.00	0.68	40.17	7.63	5.67	0.97	5.92	0.81	
Total Individuals	9520		27579		6620		6440		50159
Total Taxa	56		62		58		50		87
Crustacea	29		33		27		22		42
Amphipoda	13		14		11		5		18
Isopoda	11		14		10		10		17
Tanaidacea	2		2		2		2		2
Other Crustacea	3		3		4		5		5
Polychaeta	7		8		11		9		13
Mollusca	10		11		11		10		17
Echinodermata	5		3		5		4		6
Other Taxa	5		7		4		5		9

Table 5.3.3. Contribution of dominant taxa to total mean abundance (n=24).

Dominant taxa	Contribution to total mean abundance (%)			
	Brown	Newcombe	O'Brien	Penney
Skenella paludinoides	22.34	23.57	36.01	65.56
Nototanais antarcticus	6.25	13.71	14.63	4.50
Spirorbids	32.25	23.15	24.26	7.52

Figure 5.3.4 shows mean percentage abundance for the major taxonomic groups and contribution by the highly abundant species *Skenella paludionoides* (Gastropoda), *Nototanias antarcticus* (Tanaidacea), *Munna* c.f. *maculata* (Isopoda), *Antarctogenia macrodactyla* (Amphipoda) and spirorbid polychaetes within the major groups. Polychaetes, mostly spirorbids, dominate the Brown Bay assemblage. Crustaceans dominate the Newcombe Bay assemblage. Molluscs, contributed mostly by *S.*

paludionoides, dominate both O'Brien and Penney Bay. This effect is greater in Penney Bay where the abundance of crustaceans and polychaetes is lower.

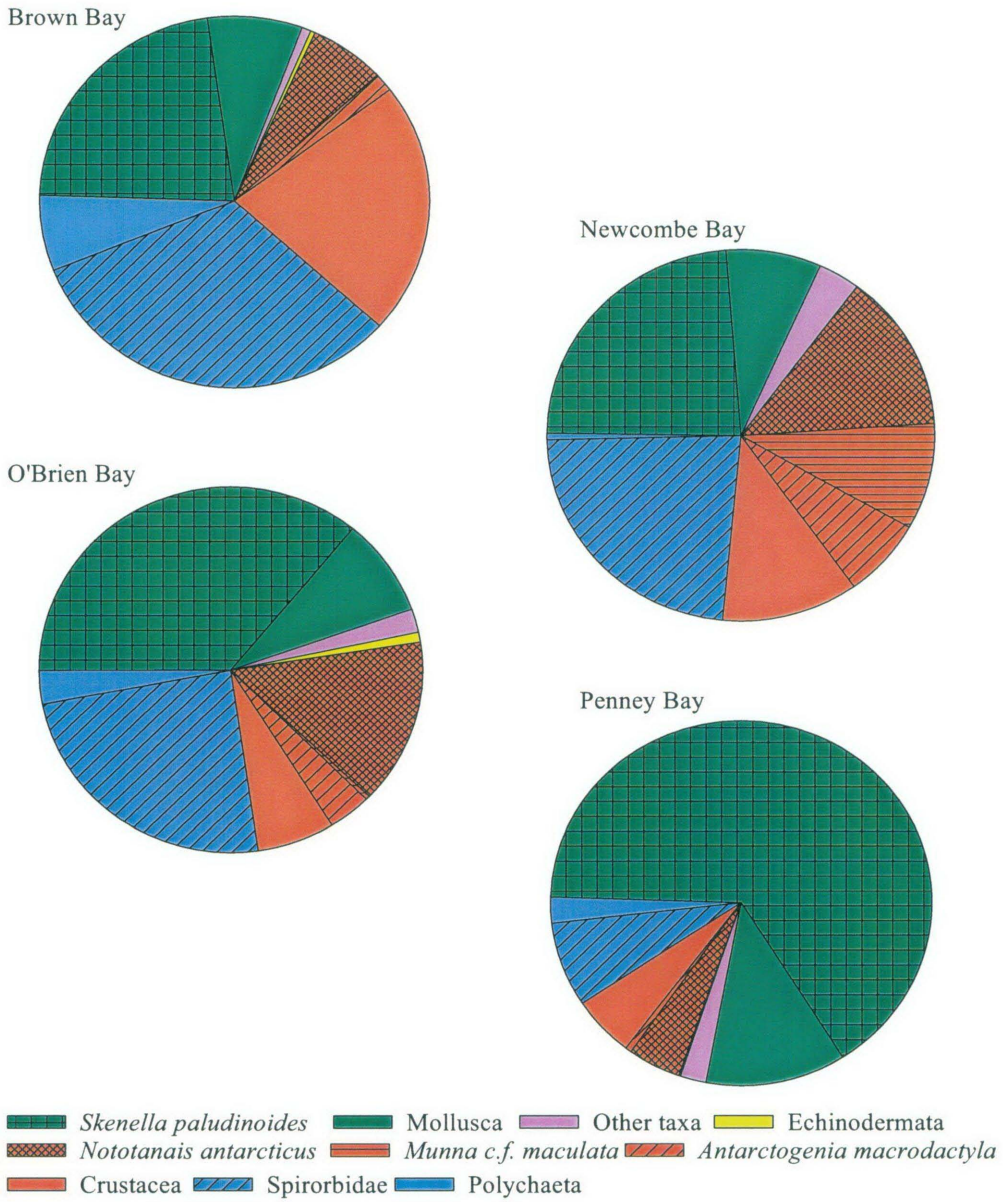

Figure 5.3.4. Site dominance as percentage abundance for major taxonomic groups and showing contribution of the most abundant taxa (n=24).

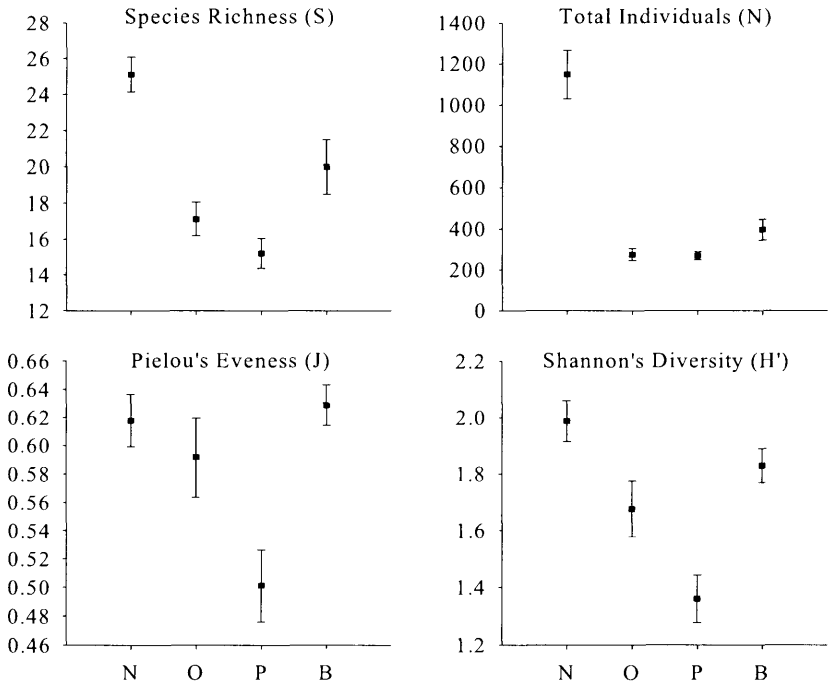

Figure 5.3.5. Standard diversity indices for sites (n=24). N = Newcombe Bay, O = O'Brien Bay, P = Penney Bay, B = Brown Bay.

Species richness (S), total individuals (N) and Shannon's diversity index (H') are all greatest at the Newcombe Bay site (Fig 5.3.5). Brown Bay has greater species richness than both O'Brien Bay and Penney Bay. This pattern is reflected in the total individuals. Evenness is similar for Newcombe Bay, O'Brien Bay and Brown Bay but much lower for Penney Bay. Penney Bay also has the lowest diversity. ANOVA tests found significant differences between sites for all of the diversity indices except evenness.

The MDS ordination (Stress = 0.16) of the species data shows the samples arranged in distinct site groups (Fig 5.3.6). The Brown Bay ASUs have the greatest spread in the ordination space, indicating a higher level of dissimilarity between ASUs within this site. Newcombe and Brown Bay ASUs show some overlap with each other. The O'Brien Bay ASUs overlap all other sites. Separation of the Newcombe and Brown Bay ASUs from all of the Penney Bay ASUs and all but three of the O'Brien Bay ASUs is also evident. The

Brown Bay samples had the greatest relative dispersion (1.305) followed by O'Brien Bay (1.15), Penney Bay (0.828) and Newcombe Bay (0.716) with the least.

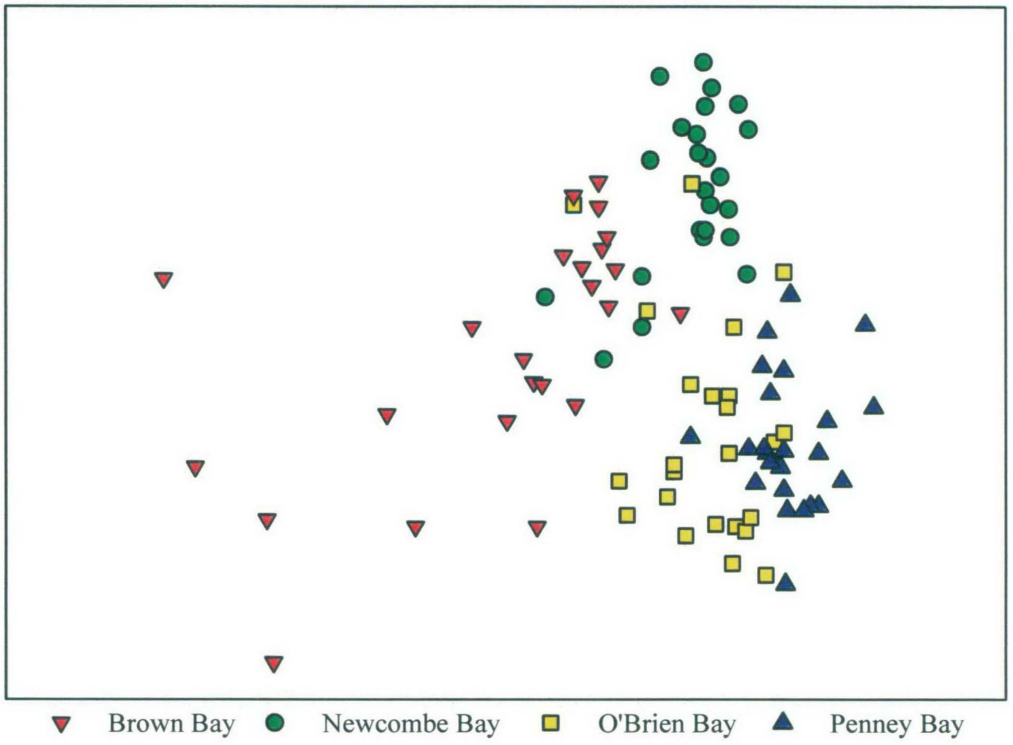

Figure 5.3.6 nMDS of ASU fourth root transformed species abundance data for sites in spatial variation experiment.

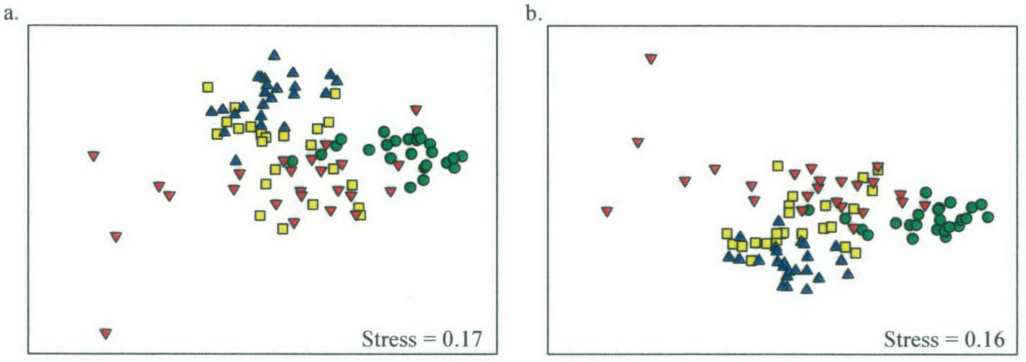

Figure 5.3.7. nMDS ordinations of fourth root transformed abundance data at taxonomic resolution of class (a) and phyla (b) for sites in spatial variation experiment.

Ordinations of the data grouped by class and by phlya retain all of the sites as distinct except O'Brien Bay which strongly overlaps both Penney Bay and Brown Bay (Fig 5.3.7). All further multivariate analysis will be based on the species (taxa) data which provides clearer definition of the site groups.

A two-way nested ANOSIM was conducted between the sites with trays nested within sites. This test found significant differences between trays across all sites (Global R= 0.469, p=0.001) and between all sites (Global R=0.702, p=0.001). All sites are significantly different in pairwise comparisons (Bonferoni corrected p-value=0.0083) (Table 5.3.4). The significant result of the test between all trays suggests important differences occurring within sites. Despite this high variation within sites differences occurring at the site level are still detectable and significant. The greatest differences in R values are between Newcombe and Penney Bay, followed by Brown and Penney Bay. The R value is lowest between O'Brien and Penney Bay.

Table 5.3.4. Results from two-way nested ANOSIM.

Comparison	R	p-value
Newcombe vs O'Brien	0.769	0.004
Newcombe vs Penney	0.970	0.002
Newcombe vs Brown	0.563	0.002
O'Brien vs Penney	0.470	0.002
O'Brien vs Brown	0.680	0.002
Penney vs Brown	0.833	0.002

The contributions to average dissimilarity for selected taxa between sites are presented in Table 5.3.5. The high abundance taxa of Newcombe Bay contribute most to differences between this site and all others. The isopod *Cymnodocella tubicauda* was the most important species in differentiating Newcombe Bay from the other sites. O'Brien Bay had a much weaker identity with different species being important in each comparison. With the exception of the copepods and the gastropod *Skenella paludinoides* O'Brien Bay has a higher abundance of the common taxa in comparison to Penney Bay. When compared with Brown Bay most of the difference is due to a lower abundance of the

dominant Brown Bay species - *Nototanias dimorphus* (Tanaidacea), *Heterophoxus videns*, *Orchomene franklini* (Amphipoda), and spirorbid and orbinid polychaetes - which are also important in separating Brown Bay from Penney Bay. Mean abundances of selected taxa and significance of one-way ANOVA tests betwee sites are presented in Figure 5.3.8. All taxa except *Onoba turqueti* are significantly different between sites.

Table 5.3.5. Contribution to average dissimilarity for selected species from SIMPER analysis (n=24).

Taxa		O	P	B
Antarctogenia macrodactyla AMPHIPODA	N	3.60	5.12	3.87
	O	-	4.41	2.80
	P		-	2.51
Orchonomene franklini AMPHIPODA	N	0.82	0.65	2.67
	O	-	0	3.89
	P		-	4.07
Schraderia gracilis AMPHIPODA	N	4.12	3.47	2.75
	O	-	2.37	2.02
	P		-	2.28
Heterophoxus videns AMPHIPODA	N	1.15	0.63	3.44
	O	-	1.21	4.60
	P		-	5.03
Munna c.f. maculata ISOPODA	N	2.76	4.40	3.00
	O	-	4.11	2.85
	P		-	2.99
Cymnodocella tubicauda ISOPODA	N	6.86	7.37	6.21
	O	-	1.30	1.03
	P		-	
Austrosignum grande ISOPODA	N	3.11	3.78	1.74
	O	-	3.35	2.77
	P		-	3.21
Nototanais dimorphus TANAIDACEA	N	4.57	4.52	0
	O	-	1.50	5.44
	P		-	5.35
Nototanais antarcticus TANAIDACEA	N	3.19	3.87	4.05
	O	-	3.43	3.67
	P		-	3.14
Doloria sp. OSTRACODA	N	0	0	2.60
	O	-	0	3.27
	P		-	3.22

Taxa		O	P	B
COPEPODA	N	1.77	2.45	1.51
	O	-	5.98	0.87
	P		-	4.24
Spirorbidae	N	4.04	5.09	3.91
	O	-	3.48	4.48
	P		-	4.54
Polynoidae	N	1.50	1.26	2.23
	O	-	2.24	2.50
	P		-	3.43
Orbinidae POLYCHAETA	N	0	0	3.34
	O	-	0.79	4.54
	P		-	4.39
Dorvilleidae POLYCHAETA	N	2.09	0	0
	O	-	3.52	2.34
	P		-	0
Skenella paludinoides GASTROPODA	N	3.11	2.40	3.87
	O	-	3.56	3.78
	P		-	4.37
Laevilitorina antarctica GASTROPODA	N	5.57	3.84	4.51
	O	-	4.11	2.41
	P		-	2.12
Onoba turqueti GASTROPODA	N	2.83	2.28	1.51
	O	-	3.36	3.56
	P		-	2.83
Nemertea	N	4.46	4.63	3.56
	O	-	2.12	1.83
	P		-	1.67
Tubellaria	N	2.86	2.82	2.35
	O	-	0	0
	P		-	0

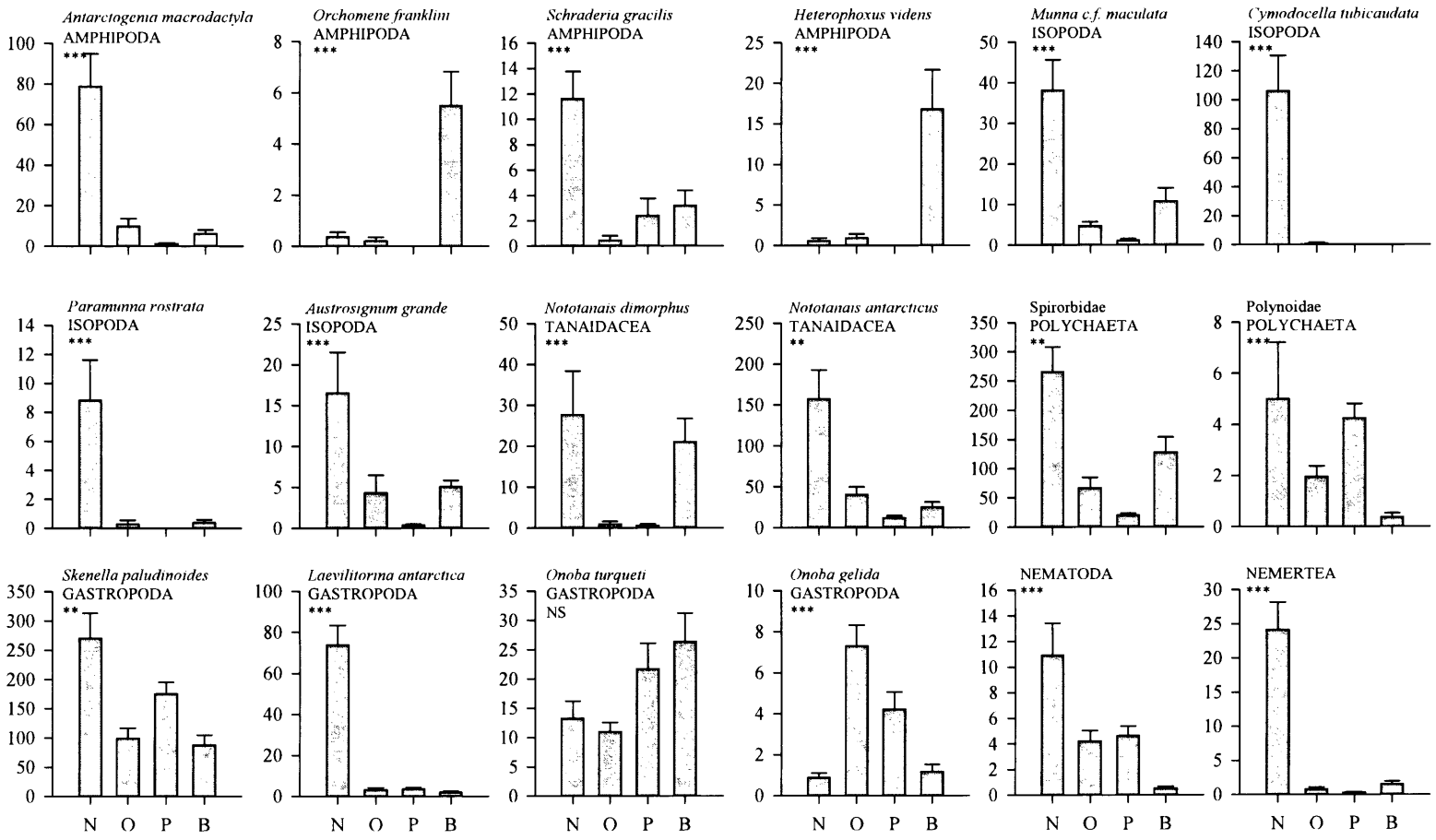

Figure 5.3.8. Mean abundance of selected taxa for sites showing significance of one-way ANOVAs between site groups (n=24). NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively. All data log transformed except *S. paludinoides* which was square root transformed. N = Newcombe Bay, O = O'Brien Bay, P = Penney Bay, B = Brown Bay.

Comparison of impacted and control sites

A one-way ANOSIM test comparing controls with the impacted site found significant differences (Global R = 0.485, p = 0.001). Asymmetrical ANOVAs were constructed to compare the known impacted site Brown Bay with the control sites for the diversity indices and abundance data of selected taxa (Table 5.3.6). In all cases except for the amphipod *Heterophoxus videns*, the test comparing controls to the impacted site were not significant. In all cases except for nematodes and polynoid polychaetes, trays within sites were significantly different.

Table 5.3.6. Asymmetrical ANOVAs comparing control vs impact treatments for diversity indices and selected taxa. Total individuals (N) all taxa except *S. paludinoides* log transformed. *S. paludinoides* square root transformed.

Diversity statistics		Species Richness (S)			Total Individuals (N)			Pielou's Evenness (j)			Shannon's Diversity (H)		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**
Site	3	447.0100	5.9091	**	10.2771	11.3821	***	0.0805	2.8447	NS	1.7141	4.1267	*
Impact vs Controls	1	12.9200	0.0195	NS	1.0771	0.0724	NS	0.0618	0.6877	NS	0.4291	0.1821	NS
Between Controls	2	664.0550	10.1697	**	14.8771	20.3215	***	0.0898	2.5063	NS	2.3565	4.6557	*
Tray(Site)	20	75.6480	4.8190	***	0.9029	4.4175	***	0.0283	3.8462	***	0.4154	5.2162	***
Tray(Site)-Impact	5	106.7000	6.7971	***	1.4154	6.9249	***	0.0056	0.7666	NS	0.1430	1.7953	NS
Tray(Site) -Control	15	65.2973	4.1596	***	0.7321	3.5817	***	0.0358	4.8727	***	0.5062	6.3565	***
Residual	72	15.6979			0.2044			0.0074			0.0796		
AMPHIPODA		*Antarctogenia macrodactyla*			*Schraderia gracilis*			*Heterophoxus videns*					
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**			
Site	3	39.9607	10.8880	***	16.5118	8.5154	***	19.8048	10.9345	***			
Impact vs Controls	1	8.6615	0.1558	NS	0.2148	0.0087	NS	58.0606	85.7679	**			
Between Controls	2	55.6104	14.8475	***	24.6604	14.7886	***	0.6770	1.1308	NS			
Tray(Site)	20	3.6702	6.0820	***	1.9391	3.3266	***	1.8112	4.0192	***			
Tray(Site)-Impact	5	3.4444	5.7079	***	2.7537	4.7241	***	5.4490	12.0915	***			
Tray(Site) -Control	15	3.7454	6.2067	***	1.6675	2.8608	***	0.5986	1.3284	NS			
Residual	72	0.6034			0.5829			0.4506					
ISOPODA		*Mumna c.f. maculata*			*Cymnodocella tubicauda*			*Paramunna rostrata*			*Austrosignum grande*		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**
Site	3	27.8522	8.9336	***	88.4660	39.5511	***	10.8711	8.4550	***	18.1841	8.5372	***
Impact vs Controls	1	0.1401	0.0034	NS	33.3330	0.2873	NS	1.4435	0.0926	NS	3.6755	0.1445	NS
Between Controls	2	41.7083	19.8231	***	116.0325	39.0638	***	15.5849	9.4469	**	25.4384	10.1723	**
Tray(Site)	20	3.1177	5.7581	***	2.2368	11.7056	***	1.2858	3.8636	***	2.1300	4.6165	***
Tray(Site)-Impact	5	6.1587	11.3745	***	0.0360	0.1884	NS	0.1939	0.5825	NS	1.0177	2.2058	NS
Tray(Site) -Control	15	2.1040	3.8859	***	2.9703	15.5447	***	1.6497	4.9573	***	2.5008	5.4201	***
Residual	72	0.5415			0.1911			0.3328			0.4614		
TANAIDACEA		*Nototanais dimorphus*			*Nototanais antarcticus*								
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**						
Site	3	40.5692	23.1149	***	23.1607	4.5680	**						
Impact vs Controls	1	43.6138	1.1170	NS	15.7072	0.5842	NS						
Between Controls	2	39.0470	19.9318	***	26.8875	5.3681	**						
Tray(Site)	20	1.7551	2.0276	**	5.0702	6.8583	***						
Tray(Site)-Impact	5	1.1434	1.3209	NS	5.2547	7.1079	***						
Tray(Site) -Control	15	1.9590	2.2632	*	5.0087	6.7751	***						
Residual	72	0.8656			0.7393								

POLYCHAETA		Spirorbidae			Polynoidae		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Site	3	27.2860	5.3773	**	7.7541	13.9532	***
Impact vs Controls	1	0.0981	0.0024	NS	18.4803	7.7291	NS
Between Controls	2	40.8799	14.9661	***	2.3910	3.3475	NS
Tray(Site)	20	5.0743	6.1750	***	0.5557	1.7165	NS
Tray(Site)-Impact	5	12.1026	14.7279	***	0.0801	0.2473	NS
Tray(Site) -Control	15	2.7315	3.3240	***	0.7143	2.2062	*
Residual	72	0.8217			0.3238		

GASTROPODA		*Skenella paludinoides*			*Laevilitorina antarctica*			*Onoba turqueti*			*Onoba gelida*		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**	**MS**	**F**	**p**
Site	3	249.3700	4.1385	**	53.9491	23.5755	***	1.4770	0.4620	NS	10.2784	8.5113	***
Impact vs Controls	1	328.9400	1.5695	NS	25.3844	0.3720	NS	1.3562	0.8822	NS	8.6807	0.7837	NS
Between Controls	2	209.5850	3.7097	*	68.2315	25.0005	***	1.5374	0.6831	NS	11.0773	7.8508	**
Tray(Site)	20	60.2560	4.7584	***	2.2884	7.1656	***	3.1970	5.1944	***	1.2076	2.6577	**
Tray(Site)-Impact	5	71.5340	5.6490	***	0.9658	3.0243	*	6.0359	9.8070	***	0.5976	1.3151	NS
Tray(Site) -Control	15	56.4967	4.4615	***	2.7292	8.5460	***	2.2507	3.6569	***	1.4110	3.1053	***
Residual	72	12.6632			0.3194			0.6155			0.4544		

OTHER TAXA		Nematoda			Nemertea		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Site	3	14.6854	19.8637	***	34.6862	18.4544	***
Impact vs Controls	1	33.5841	6.4140	NS	4.8531	0.0978	NS
Between Controls	2	5.2361	5.5291	*	49.6028	25.2898	***
Tray(Site)	20	0.7393	1.6806	NS	1.8796	6.8832	***
Tray(Site)-Impact	5	0.1162	0.2642	NS	1.6341	5.9845	***
Tray(Site) -Control	15	0.9470	2.1527	*	1.9614	7.1828	***
Residual	72	0.4399			0.2731		

Variation in the ASU assemblage within sites

MDS ordinations for each of the sites show some grouping of the ASUs by trays (Fig 5.3.9). Each of the sites has a set of ASUs outside of the main group that corresponds to a tray.

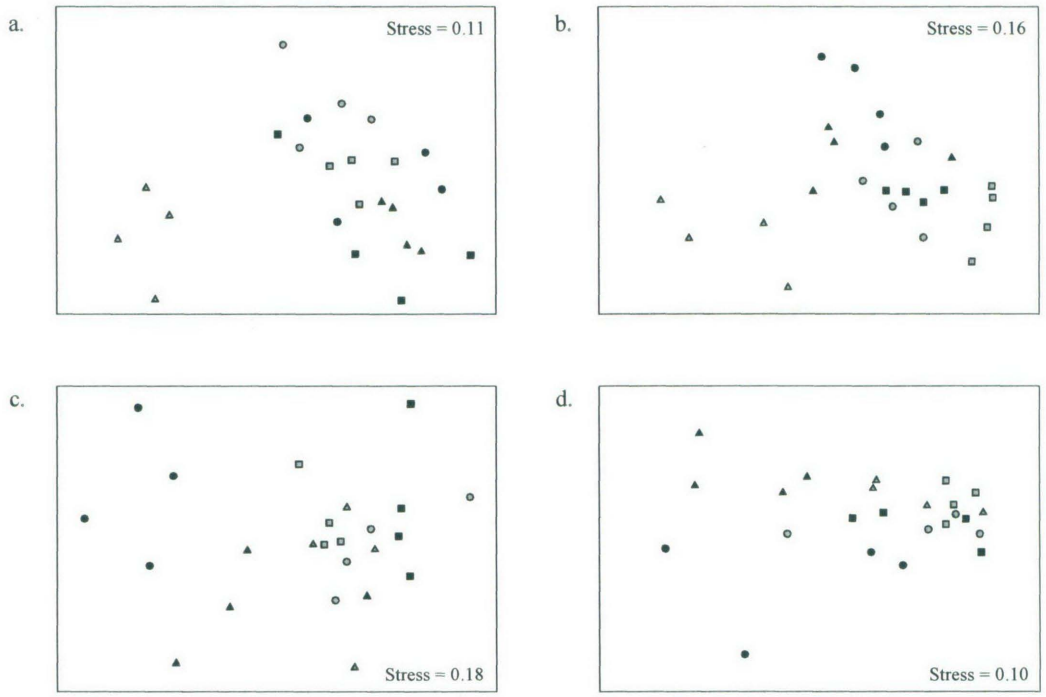

Figure 5.3.9. MDS ordinations of fourth root transformed abundance data for sites showing ASUs from trays as different symbols. a. Newcombe Bay, b. O'Brien Bay, c. Penney Bay, d. Brown Bay.

One-way ANOSIM tests were conducted to test for differences between tray groups within each site (Table 5.3.7). Significant differences were found between trays at all sites. In these tests only 35 permutations are possible. Due to the limitations the number of permutations places on the ANOSIM procedure for testing significance, results that have a p-value of 0.057 are taken as significant (Rule 2004). Penney Bay had the least number of significantly different tray comparisons, followed by Brown Bay.

Table 5.3.7. One-way ANOSIM tests and pairwise comparisons within sites. Significant R values are in bold text.

Newcombe	**2**		**3**		**4**		**5**		**6**	
Global R= 0.606	R	p	R	p	R	p	R	p	R	p
1	0.188	0.257	**0.375**	0.029	**0.375**	0.057	0.146	0.229	**1**	0.029
2	-	-	**0.292**	0.029	**0.719**	0.029	**0.448**	0.029	**0.906**	0.029
3			-	-	**0.906**	0.029	**0.802**	0.029	**1**	0.029
4					-	-	**0.500**	0.029	**0.99**	0.029
5							-	-	**1**	0.029
O'Brien	**2**		**3**		**4**		**5**		**6**	
Global R= 0.613	R	p	R	p	R	p	R	p	R	p
1	**0.802**	0.029	**0.479**	0.057	**0.781**	0.029	**0.885**	0.029	**1**	0.029
2	-	-	**0.563**	0.029	0.188	0.143	**0.573**	0.029	**0.958**	0.029
3			-	-	0.167	0.200	**0.698**	0.029	**0.854**	0.029
4					-	-	0.385	0.086	**0.823**	0.029
5							-	-	**1**	0.029
Penney	**2**		**3**		**4**		**5**		**6**	
Global R= 0.289	R	p	R	p	R	p	R	p	R	p
1	**1**	0.029	**0.531**	0.029	**0.917**	0.029	**0.865**	0.029	**0.813**	0.029
2	-	-	**0.375**	0.057	-0.031	0.543	-0.063	0.686	0.115	0.143
3			-	-	0.198	0.200	0.094	0.314	0.021	0.429
4					-	-	0	0.486	0.031	0.429
5							-	-	0.167	0.143
Brown	**2**		**3**		**4**		**5**		**6**	
Global R= 0.368	R	p	R	p	R	p	R	p	R	p
1	**0.292**	0.057	0.344	0.114	0.208	0.143	**0.552**	0.029	**0.427**	0.029
2	-	-	**0.729**	0.029	0.073	0.200	0.281	0.114	0.250	0.143
3			-	-	**0.719**	0.029	**0.990**	0.029	**0.677**	0.029
4					-	-	**0.271**	0.057	0.115	0.200
5							-	-	**0.427**	0.057

Influence of tray positions within sites

Regression analysis of relative distance between trays and average dissimilarity did not find significant relationships at any of the sites. Regressions of relative depth found significant relationships at Newcombe Bay (r^2 = 0.553, p = 0.001) where trays were collected over a depth range of 10 to 19 m and Penney Bay (r^2 = 0.309, p = 0.031) where trays were collected over a depth range of 14 to 17 m. At both sites average dissimilarity decreased with increasing depth (Fig. 5.3.10). These regressions explain 55% of the variation in dissimilarity at Newcombe Bay and only 31% of the variation at Penney Bay.

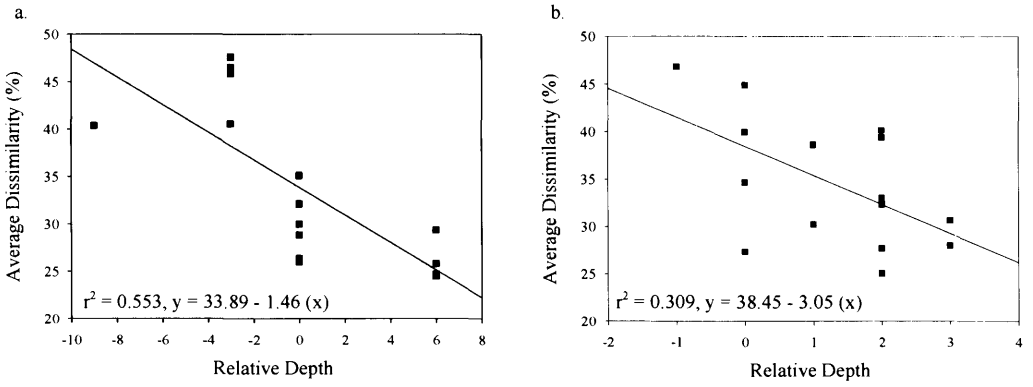

Figure 5.3.10. Regression line of average dissimilarity from SIMPER tray comparisons and relative depth for a. Newcombe Bay and b. Penney Bay.

The average similarity of ASUs from the trays deployed in Newcombe Bay ranged from 70.50% to 83.38%. Taking the average dissimilarity contribution of taxa in the significant tray comparisons 50% of the dissimilarity is explained by 17 taxa. In most cases variation between trays may be attributed to differences in the abundances of the common taxa. Tray 6 has a strong presence of *Orchomene pinguides* which is not seen in the other trays. Tray 6 also has low abundances of the *A. macrodactyla*, *M. maculata*, *C. tubicadua*, *N. antarcticus*, *S. paludinoides*, *L. antarctica* and nemerteans. These taxa are present in most of the other trays in high abundance.

Mean abundance of selected taxa and significance of one-way ANOVA tests between trays for each site are presented in Figure 5.3.11, 5.3.12, 5.3.13, 5.3.14.

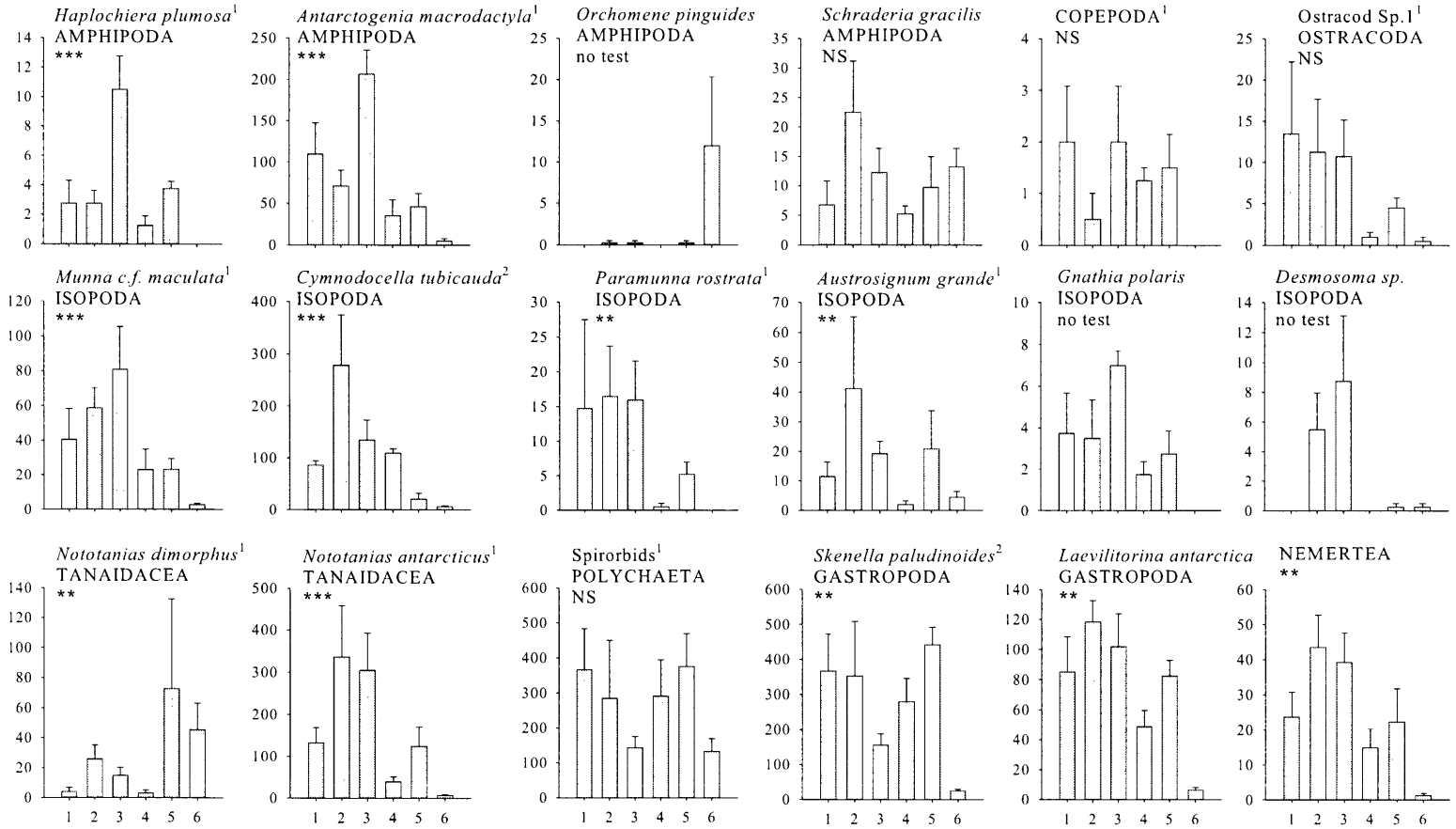

Figure 5.3.11. Mean abundance per tray (n = 4) of selected taxa for Newcombe Bay and significance of one-way ANOVA tests between trays. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively. [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA.

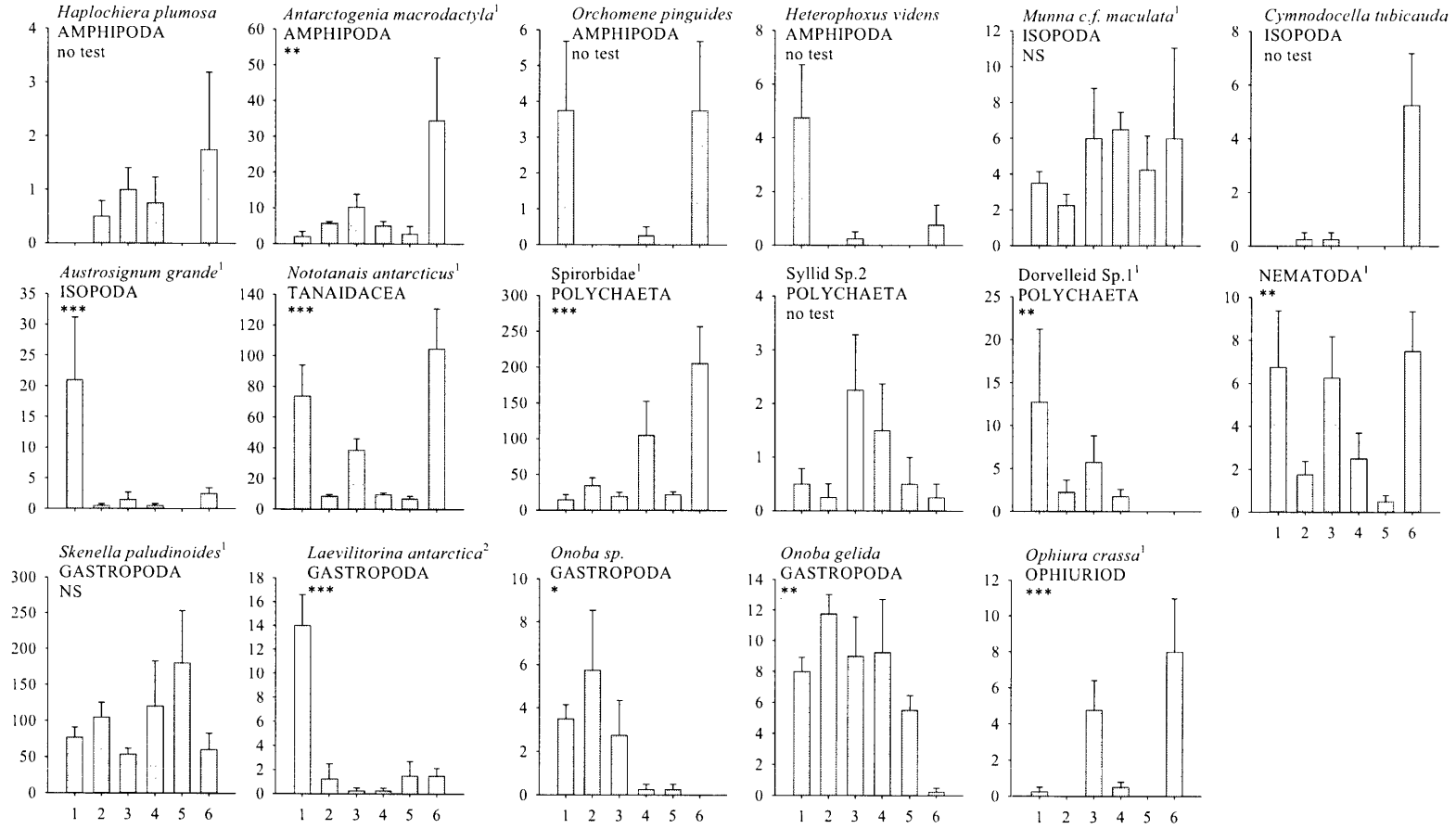

Figure 5.3.12. Mean abundance per tray (n = 4) of selected taxa for O'Brien Bay and significance of one-way ANOVA tests between trays. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively. [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA.

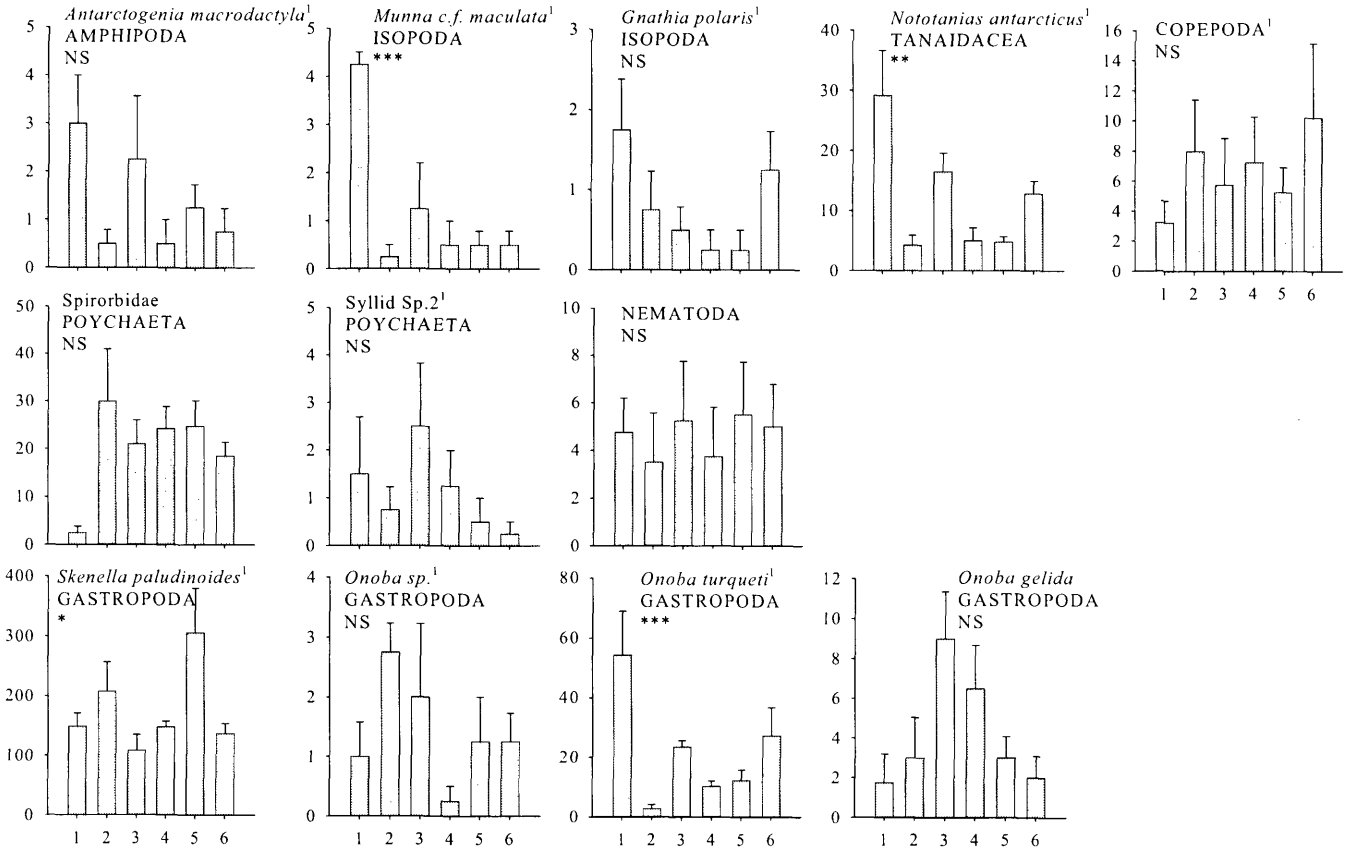

Figure 5.3.13. Mean abundance per tray (n = 4) of selected taxa for Penney Bay and significance of one-way ANOVA tests between trays. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively. [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA.

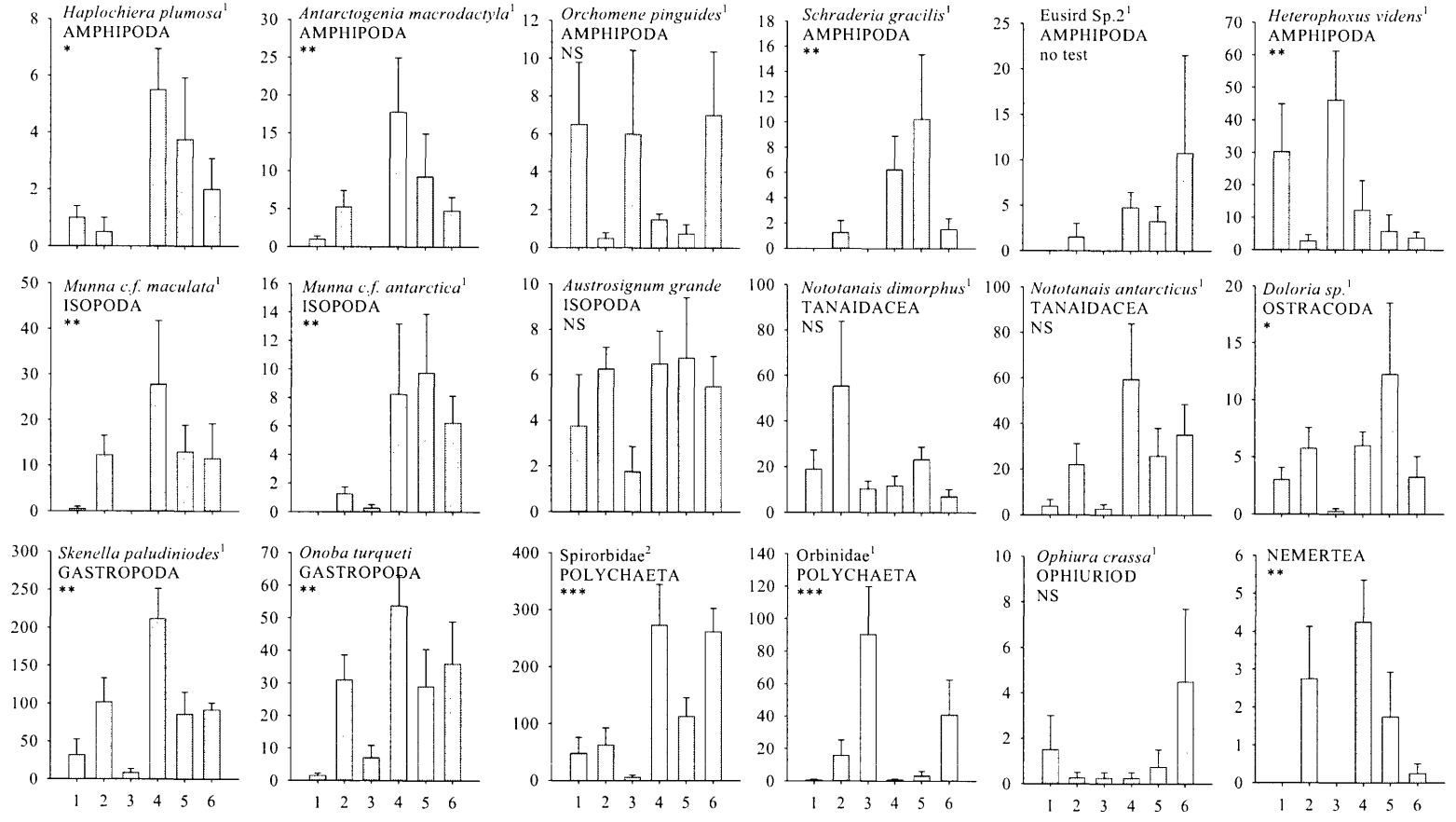

Figure 5.3.14. Mean abundance per tray (n = 4) of selected taxa for Brown Bay and significance of one-way ANOVA tests between trays. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively. [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA.

Within O'Brien Bay the average similarity of the trays ranged from 62.62% to 74.32%. At this site 17 taxa also explain 50% of the dissimilarity between the trays. Tray 6 has very low abundances of *Onoba gelida* and relatively high abundances of *A. macrodactyla*, *C. tubicauda* and *N. antarcticus*.

Average similarity of trays from Penney Bay ranged from 64.59% to 76.79%. At this site 50% of the dissimilarity between trays is described by only 13 taxa. Tray 1 was significantly different from all other trays at the site and is separated by high abundances of *M. maculata*, *N. antarcticus* and *Onoba turqueti*, and low abundances of spirorbid polychaetes.

Within Brown Bay the average similarity of the trays ranged from 46.99% to 72.71%. Eleven taxa describe 50% of the dissimilarity between trays. The most important taxa that discriminate between trays are spirorbid polychaetes, *S. paludinoides*, orbinid polychaetes, *M. maculata*, *N. antarcticus* and *H. videns*.

5.4 Discussion

The ASU assemblage is described for the first time for four locations in the Casey region. The ASUs sample a diverse fauna with highly variable abundance patterns among individual taxa. Many taxa that occurred in the ASU assemblage have been previously recorded in studies of hard substrata, macroalgae (Grainger 2004) and sediments (Stark 2000; Stark & Riddle 2003) and from the fauna associated with the urchin *Sterechinus neumayeri* (Richards 1998). Motile assemblages of macroalgae and hard substrata reported from other Antarctic locations also have a similar structure to the ASU assemblage and contain many of the same taxa. Some epifaunal components of soft sediment assemblages described for Antarctic locations are also present in the ASUs.

Species comparisons with other studies are limited by the level of detail that macrofaunal studies are reported in the literature as results are often described at higher taxonomic levels. The restricted understanding of taxonomic knowledge in this study also reduces the scope of this comparison. Despite these limitations some taxa found in the ASUs have

also been reported in shallow benthic habitats from other Antarctic locations including: Lutzholm Bay, East Antarctica (Takeuchi & Watanabe 2002), Davis (Everitt et al. 1980), Terra Nova Bay (Gambi 1994; Gambi & Mazzella 1991), McMurdo Sound (Conlan et al. 2004), Anvers Island (Richardson 1976), King George Island (Arnaud et al. 1986; Jazdzewski et al. 1991) and Signy Island (Thurston 1972).

The amphipod *Haplocheira plumosa* has been reported from algae in Lutzholm Bay and from Signy Island. *Orchomene franklini* is known from sediments at King George Island and from Davis. *Schraderia gracilis* has been reported in algae at Lutzholm Bay and Signy Island and is also known from sediments at Anvers Island and King George Island. *Methalimedon nordenskjoldi* is known from sediments at Anvers, King George and Signy Islands and from Davis. *Heterophoxus videns* has been reported in sediments from Anvers and Signy Island, McMurdo Sound and Davis. *Paroediceroides sinuatus* has been recorded at Anvers Island.

The isopod *Munna maculata* is reported from soft sediments at Anvers Island. *Munna antarctica* is known from Anvers Island, Terra Nova Bay and Davis. *Paramunna rostrata* has been recorded at King George and Anvers Islands and at Terra Nova Bay. *Austrofilius furcatus* has also been reported at Terra Nova Bay. *Austrosignum grande* is known from soft sediments at McMurdo Sound.

Nototanias dimorphus has been found on algae at King George Island and Terra Nova Bay and also in soft sediments at Anvers Island and McMurdo Sound. *Nototanias antarcticus* has been found on algae at King George Island and in sediments at Davis.

The gastropods *Skenella paludinoides*, *Laevilitorina antarctica*, *Onoba turqueti* and *Onoba gelida* are known from algae at Terra Nova Bay and from mixed substrata at King George Island. *S. paludinoides* is also reported on algae at Lutzholm Bay.

In the present study the ASU assemblage was dominated by *Skenella paludinoides*. The taxa *Antarctogenia macrodactyla*, *Austrosignum grande*, *Nototanais antarcticus*, *N.*

dimorphus and spirorbid polychaetes were also dominant but showed greater variability between sites. Distinct assemblages occur at each site and show significant variation within sites at the community level and in the abundance patterns of individual taxa.

The 'species' level MDS shows grouping of the ASUs by sites and separation of O'Brien and Penney Bay from Newcombe and Brown Bay. There is also separation of the contaminated site Brown Bay from the other sites. Newcombe and Brown Bay are only one kilometre apart and both sites are within the same larger bay. It is interesting that O'Brien Bay and Penney Bay, sites that were 16 km apart, show the most overlap in the ordination. This suggests that important habitat differences may exist between the northern sites and the two southern sites O'Brien and Penny Bay. O'Brien Bay has three ASUs that overlap with two northern sites. This may reflect some spatial relatedness of this site to Newcombe and Brown Bay. Separation of Brown Bay from the other sites may be related to contamination but interpretation of this effect is confounded by the high sediment loads in the Brown Bay ASUs. Sedimentation is higher in Brown Bay and tray disturbance was observed to cover some trays with sediment, pushing sediment into the ASUs.

Sedimentation creates important subhabitats in structurally complex substrata and has been shown to effect the composition of the inhabitant assemblages in natural and artifical algal turfs (Myers & Southgate 1980; Olabarria & Chapman 2001), in kelp holdfasts (Smith 1996; Smith & Simpson 1995) and in ASUs similar to those used in this study (Smith & Rule 2002). The source, quality and quantity of sediments entering the ASUs has important consequences for the effects they will have on the assemblage. Sedimentation rates at Newcombe Bay, O'Brien Bay and Penney Bay were much lower than at Brown Bay and was mostly diatomaceous material settling from the water column. In Brown Bay sediment sources during summer could include terrestrial soils in run off that may also have carried a contaminant load from the Thala Valley tip site. The deposition of terrigenous sediments will change food quality of sediments and the physical properties of the sediment water interface (Lohrer et al. 2004). The Brown Bay ASUs were also exposed to burial by marine sediments during tray disturbance and these

sediments may also have carried contaminants. Different species would be affected in different ways by burial in sediments. Tube building epifaunal suspension and deposit feeders are most susceptible to burial, while large polychaetes with well developed proboscis and parapodia more likely to survive (Powilleit et al. 2006). Motile fauna suited to an open habitat would probably abandon the ASU if they survived the burial event.

Disturbance and loss of trays during deployment has been a major problem throughout this study. Movement of the trays altered the spatial arrangement and completely changed the original experimental design. It also introduced a source of variation from the varied depth of trays and an unknown effect of tray movement and frequency of disturbance. No correlation was found between dissimilarity and distance between trays but depth effects were found at Newcombe Bay and Penny Bay. Disturbance of the trays is also related to the high sediment levels in the ASUs from Brown Bay.

Comparisons of ASUs between the control sites and the impacted site returned mixed results. Multivariate tests did detect differences between the treatments but univariate tests of diversity measures and abundance data for selected taxa were not significant except for *Heterophoxus videns*, whose abundant presence in the ASUs at Brown Bay is most likely related to high amounts of sediment resulting from tray disturbance and higher sedimentation in Brown Bay rather than indicating an impact driven change in community structure. The multivariate analyses may also detect differences from this source as the high abundance of orbinid polychaetes was important in separating Brown Bay from the other sites. Sediment loads are an important habitat variable for motile fauna and the influence of sediment on assemblage structure has been shown in studies of the cryptofauna of coral (Preston & Doherty 1994) and in kelp holdfasts (Smith 1996).

Evidence from the ASU debris component suggests that differences in general habitat structure may exist between the Newcombe Bay sites and O'Brien and Penney Bay. O'Brien and Penney Bay both have lower amounts of algae and more urchin debris and significantly lower ASU sediment values. This could mean that the ASUs deployed in these locations were further from macroalgal source populations. Adjacent habitats have

been shown to be important in determining the motile assemblages recruiting to artificial substrata in other studies (Edgar 1991; Myers & Southgate 1980; Rule & Smith 2005). The lower sediment values may reflect different hydrodynamic regimes as both of these sites are closer to deep water and more exposed to oceanic influences.

The differences in the ASU assemblages of these sites suggests that the ASUs have reflected the natural differences in the presence and abundance of taxa at these sites – but the use of these sites as control locations for Brown Bay may not be appropriate. The great natural differences between O'Brien Bay and Penney Bay in comparison with Brown Bay mean that interpretation of differences in assemblages related to contaminants will be confounded.

High levels of variability among the control sites also confound the ability of univariate tests to detect differences between control and impact treatments. The low power of the asymmetric ANOVA compounds this problem and in this study was made worse by the loss of replicates from each site. This result highlights importance of choosing suitable control sites for use in environmental change studies (see Glasby and Underwood (1998)).

The biological effects of contamination at sites near Casey have been demonstrated in benthic diatom communities (Cunningham et al. 2003; Cunningham et al. 2005), soft sediment communities (Stark 2000; Stark et al. 2004; Stark et al. 2003; Stark et al. 2005), and in elevated levels of metal contaminants in the tissues of benthic invertebrates (Duquesne & Riddle 2002). Stark (2003) found that the soft sediment benthic communities at contaminated sites had fewer taxa and lower diversity and that these biological distributions were correlated with metal concentrations and sediment characteristics. Species that were abundant at contaminated sites near Casey had large abundances of captellid (*Capitella* sp.), orbinid and dorvelleid polychaets and opportunistic gammarids.

Soft sediment communities at contaminated sites in McMurdo Sound show reduced numbers of infaunal and epifaunal species and a numerical dominance of opportunistic

polychaetes (Lenihan et al. 1990). Lenihan et al.(2003) illustrate the relationship between specific taxa and different types of contaminants present in McMurdo Sound sediments. The abundance of opportunistic polychaetes is increased in sediments with organic enrichment regardless of metal concentrations. Arthropods and echinoderms decreased with increasing copper concentrations but showed a variable response to organic enrichment. Small subsurface species decreased with high organic loading but large surface deposit feeding species increased. These results demonstrate the importance of the ecological habitat of an organism in determining its exposure to contaminants. In the case of ASUs, the epifaunal habit of species targeted by the ASUs may create an apparent reduced sensitivity of these assemblages to sediment borne contaminants because the fauna are not continually in contact with the sediment and they do not respire interstitial water.

The results of this experiment demonstrate the highly variable nature of the ASU assemblage. The experiment was greatly affected by the loss and disturbance of trays which resulted in severe changes to the original design and also contributed a putatively large but unknown effect of physical disturbance of the trays as they were moved by ice. Despite these limitations the ASUs collected a diverse assemblage which showed strong spatial patterns. Further experiments were conducted in Brown Bay to investigate temporal and small scale spatial variation within the bay and are reported in chapter six.

Chapter 6

ASU assemblage of Brown Bay

6.1 Introduction

The results of the spatial variation experiment reported in the previous chapter demonstrated that the ASU assemblage was highly variable over both small and large spatial scales. Despite this, significant differences were found between sites and between the contaminated site, Brown Bay, and the uncontaminated sites at Newcombe Bay, O'Brien Bay and Penney Bay. The high level of disturbance to the trays deployed in the original spatial experiment changed the spatial scales that could be investigated. In that experiment the nesting of the smaller scales was lost at all sites. As a case study to assess variation within a known contaminated site, experiments were conducted in Brown Bay to assess variation in community structure over small spatial scales, along a depth transect from the inner bay closest to the tip to the outer bay and variation between consecutive years.

Studies of infaunal communities at Casey have shown that assemblages and populations can vary on very small spatial scales (Stark 2000; Stark et al. 2005). Stark (2001) found fauna to vary in abundance and occurrence with taxa often confined to one plot (replicates 20m apart) or one site (replicates 100m apart) within a location. The ASU assemblage is fundamentally different from the infaunal assemblage studied by Stark and his colleagues, but the two assemblages do share taxa. Taxa that are common to both assemblages include several of the ASUs medium and low abundance amphipods, isopods and tanaids, and some gastropod and polychaete taxa. The presence of orbinid polychaetes and the amphipods *Heterophoxus videns* and *Orchomene franklini* in the ASUs was associated with high sediment content (Chapter 5) and these taxa are known infaunal species (Conlan et al. 2004; Oliver & Slattery 1985; Stark 2001). The other shared taxa have an epifaunal habit (Conlan et al. 2004; Stark 2001). The biology and life habits of the taxa comprising the ASU assemblage will determine the processes that structure the ASU assemblage and its inherent variability. These factors will also

determine the sensitivity of the assemblage to the presence of contaminants in the surrounding environment.

The effects of heavy metal and hydrocarbon contamination of sediments at Casey have been shown in a recruitment experiment by Stark et al.(2004). The presence of contaminants in sediments modified recruitment patterns at an assemblage level and among taxa with gammarids, isopods and tanaids generally more abundant in uncontaminated sediments. Stark et al.(2004) found that while the effects of sediment contamination were evident at Shannon Bay and Brown Bay, differences between the two sites were greater than differences between control and contaminated sediments. Many taxa were more abundant at Brown Bay. The recruited assemblages were found to be dependent on surrounding assemblages, known from previous studies (Stark 2000; Stark et al. 2003).

In an extensive study within Brown Bay Stark et al.(2005) described concentrations of heavy metals, sediment particle size distribution and total organic carbon with matched sampling of sediments to study infauna. The sampling was conducted along three transects within the bay from the inner bay closest to the Thala Valley tip to the outer bay joining Newcombe Bay. They found that contaminants were highly variable throughout Brown Bay. A general gradient of decreasing contamination moving away from the tip site was detected but there were also high levels of contamination at some stations. Small scale variation in community patterns were significantly correlated with cadmium, copper, tin and lead and grain size. Within Brown Bay the infauna showed three assemblage patterns corresponding to the inner bay stations, the middle and the outer bay stations. The highly contaminated inner bay samples were the most variable.

The aims of the experiments reported in this chapter were to identify important scales of variation in the ASU assemblage at a known contaminated site. ASUs were also deployed in a transect to assess variation with depth. The repetition of sampling in Brown Bay allowed a comparison of the ASU assemblage between consecutive years.

6.2 Methods

These experiments were deployed in Brown Bay in February 2002 and collected in February 2003, except for the six trays used in the temporal comparison which were from the 2001 spatial variation experiment reported in Chapter 5. Due to logistic constraints the experiments were not able to be repeated at control locations. All ASUs were deployed, retrieved and processed following the general methods described in Chapter 2. Sediment contaminant data was provided by Jonny Stark, published in Stark et al.(2005).

6.2.1 Depth transect

Trays were deployed along a depth transect from the shallow inner bay closest to the Thalla valley tip out to a point in the middle of the bay. Four depths were sampled: five, seven, ten and thirteen metres. At each depth two groups of three trays were deployed with trays in each group one metre apart and the two groups ten metres apart. Due to the natural depth gradient in the bay the distance between the sampling points along the transect varied. The seven metre point was 70 m from the five metre depth. The ten metre point was 40 m from the seven metre point. The thirteen metre point was 100 m from the ten metre point.

Many of the trays were moved during the deployment period. Three trays that remained in the deployment depth and that were the closest together along the transect were selected for analysis, giving twelve ASUs per depth. The movement of the trays changed the distance between trays from each depth introducing a new source of spatial variation. The trays from five metres were one to ten metres apart. The trays from seven metres were five to twenty metres apart. The trays from ten metres were six to eighteen metres apart and the trays from thirteen metres were one to four metres apart.

6.2.2 Spatial variation within Brown Bay

ASUs were deployed in the spatial arrangement described for the original spatial variation experiment (Fig 2.4.1) with two groups of trays 100 m apart and nine trays in each group. The nine trays were arranged in three plots of three trays with plots ten

metres apart and trays within plots one metre apart. This experiment was deployed at thirteen metres depth. One of the groups of nine trays corresponded with the thirteen metre point of the depth transect described above and the data from these ASUs is used in both the depth transect and the spatial variation analyses.

Again trays were moved during deployment, although not as much as in the previous year. Two of the three plots within each group of nine trays were fairly intact and ASUs from these trays were used in analysis. From these trays assessment of variation in the ASU assemblage within Brown Bay on scales of one to seven metres within plots, ten to twenty metres between plots and 100 metres between the two groups was made.

6.2.3 Temporal variation within Brown Bay

The repetition of sampling in Brown Bay on two consecutive years allowed comparison of trays deployed at the same location between years. Six trays, giving 24 ASUs, were selected from the thirteen metre site in the middle of Brown Bay that were closest to the sampling location of trays from the previous year.

Analyses

Multivariate analyses were used to produce nMDS ordinations based Bray-Curtis similarities from fourth root transformed abundance data for each of the Brown Bay experiments. One way ANOSIMs were used for the depth transect and temporal experiment. Bonferroni corrections were used to adjust p values for multiple comparisons. Sequential nested ANOSIM tests were used for the spatial variation experiment to compare trays within plots and to compare plots within groups. SIMPER analyses of fourth root transformed abundance data was used to determine the taxa most important in producing dissimilarity between treatment groups.

One-way ANOVAs were used to test for differences between diversity indices and abundance data for selected taxa between depth treatments along the depth transect and between years in the temporal experiment. A three factor nested ANOVA was used to test between groups in the spatial variation experiment with plots and trays nested within

groups. In this analysis none of the plots within groups were significant and returned p values greater than 0.25. This level of nesting was removed and the analysis was run as a two factor nested ANOVA with trays within groups.

Prior to analysis univariate data were tested for normality and homogeneity of variance and transformed as needed. Log transformations ($x'=\ln(x+1)$) and square root transformations ($x'=\sqrt{(x+0.5)}$) were used and are noted in the results in each case.

6.3 Results

Overall 60078 individuals from 72 taxa were sampled by the 108 ASUs deployed in Brown Bay. In all treatments crustaceans were the most diverse group. Polychaetes and molluscs were the most abundant groups. Table 6.3.1 provides a taxonomic summary and mean abundance for the major taxonomic groups. Note that samples from the 13 m depth transect point are used again as part of the Site 1 2002 samples. The "Overall" summary column in Table 6.3.1 does not include the repeated samples.

Table 6.3.1. Mean total individuals, taxa and abundance for major taxonomic groups and total taxa for depth transect points (n = 12) and spatial variation experiments from 2001 and 2002 (n = 24) for Brown Bay.

Brown Bay	5 m n = 12		7 m n = 12		10 m n = 12		13 m n = 12		Site 1 – 2001 n = 24		Site 1 – 2002 n = 24		Site 2 – 2002 n = 24		Overall n = 108
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Individuals	257.75	36.47	1056.75	99.52	850.17	77.12	405.08	30.41	396.67	51.55	434.13	19.68	590.13	74.85	
Taxa	17.00	0.95	23.00	0.84	19.75	0.99	15.83	0.61	20.00	1.50	16.83	0.55	24.67	1.17	
Crustacea	23.50	3.37	128.92	26.47	121.75	18.63	23.92	2.00	118.42	13.12	32.88	2.63	218.71	33.41	
Amphipoda	4.17	0.89	25.42	4.90	22.42	5.88	10.00	1.32	43.29	5.71	13.29	1.37	59.79	7.79	
Isopoda	17.67	3.06	58.75	12.50	59.75	11.61	8.25	1.28	23.63	4.88	12.42	1.54	31.08	4.83	
Tanaidacea	1.58	0.48	43.50	11.91	38.33	5.37	2.83	0.49	45.92	7.35	5.00	0.78	113.04	21.26	
Other Crustacea	0.08	0.08	1.25	0.33	1.25	0.48	2.83	0.60	5.58	1.30	2.17	0.41	14.79	2.75	
Polychaeta	57.17	11.35	388.75	91.86	204.42	25.99	243.08	17.04	153.88	25.35	265.25	12.59	233.63	40.62	
Mollusca	167.50	26.47	520.42	39.06	511.58	54.93	128.58	13.61	119.75	20.83	124.88	8.45	122.79	15.62	
Echinodermata	0.08	0.08	0.25	0.13	0.67	0.26	0.00	0.00	1.54	0.62	0.08	0.08	7.42	1.87	
Other Taxa	9.50	1.74	18.42	2.99	11.75	3.24	9.50	1.02	3.00	0.68	11.04	0.91	7.58	1.11	
Total Individuals	3093		12681		10202		4861		9520		10419		14163		60078
Total Taxa	38		48		46		40		56		48		51		72
Crustacea	14		22		21		21		29		24		28		34
Amphipoda	5		8		8		7		13		10		9		14
Isopoda	6		9		8		9		11		9		12		12
Tanaidacea	2		2		2		2		2		2		2		2
Other Crustacea	1		3		3		3		3		3		5		6
Polychaeta	11		8		9		10		7		11		6		12
Mollusca	6		10		8		3		9		5		9		12
Echinodermata	1		1		3		0		5		1		3		5
Other Taxa	6		7		5		6		5		7		5		8

6.3.1 Heavy metal concentrations in Brown Bay sediments

Metal concentrations from sediment samples collected in Brown Bay in December 1998 and reported by Stark et al.(2005) are presented in Figure 6.3.1. These data were collected from grid points at locations within twenty metres of the deployment locations of the ASUs in the depth transect and spatial variation experiments.

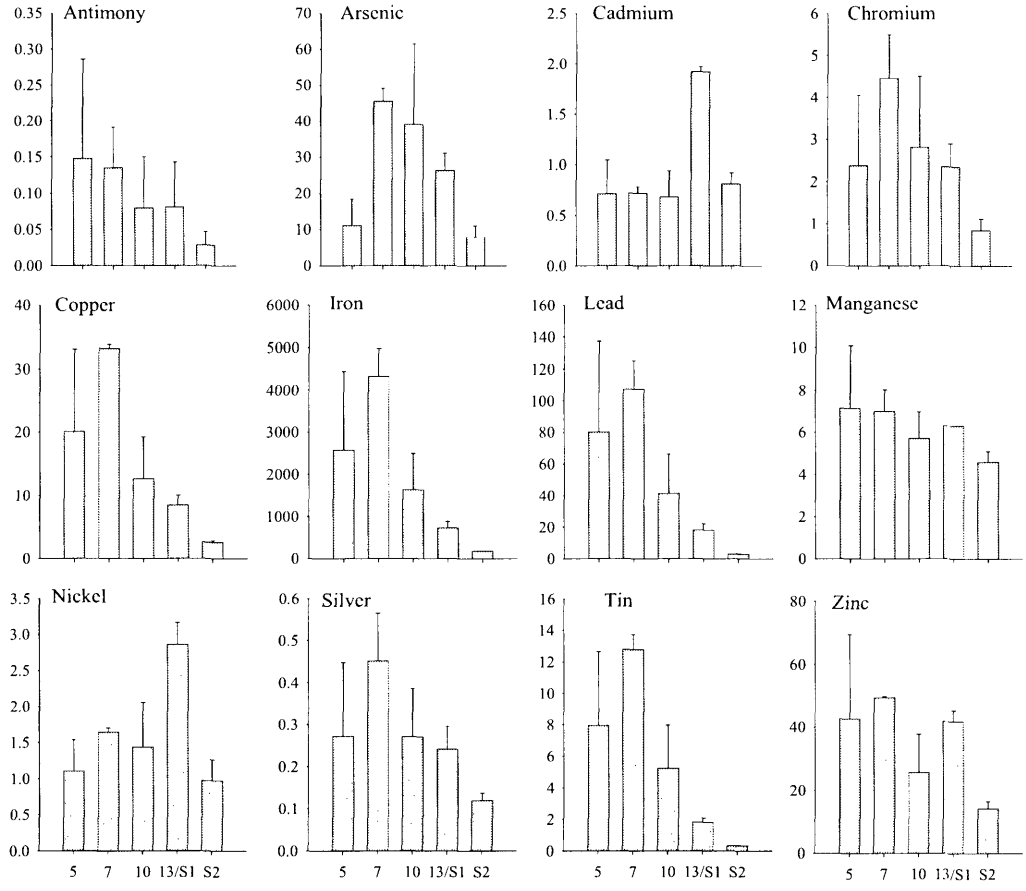

Figure 6.3.1. Metal concentrations in parts per million from sediments in Brown Bay collected by Stark et al.(2005) (n = 2). 5, 7, 10 , 13 depths sampled along transect. S1 and S2 sampling locations of spatial variation experiment.

Stark et al.(2005) described a general gradient of decreasing levels of contamination from the tip source to the outer bay, but also found that contaminant concentrations were highly variable and many 'hot spots' existed throughout the bay. The selected data show a pattern of decrease in concentration from seven to thirteen metres for arsenic,

chromium, copper, iron, lead, silver and tin. All metals show a higher concentration at S1, the spatial variation site in the middle of Brown Bay and end point of the depth transect, than at S2, the spatial variation site located closer to the outer edge of the bay.

6.3.2 Depth transect

Mean Species Richness (S) and mean Total Individuals (N) increased from five metres to peak at seven metres and declined at ten metres and again at thirteen metres (Fig 6.3.2). Mean values for Pielou's Evenness (J) and Shannon-Wiener Diversity (H') were highest at five metres. S, J and H' were all lowest at thirteen metres. N was lowest at five metres. One-way ANOVA tests between the depth treatments returned very highly significant results for all of the diversity measures. Total Individuals data was log transformed for analysis.

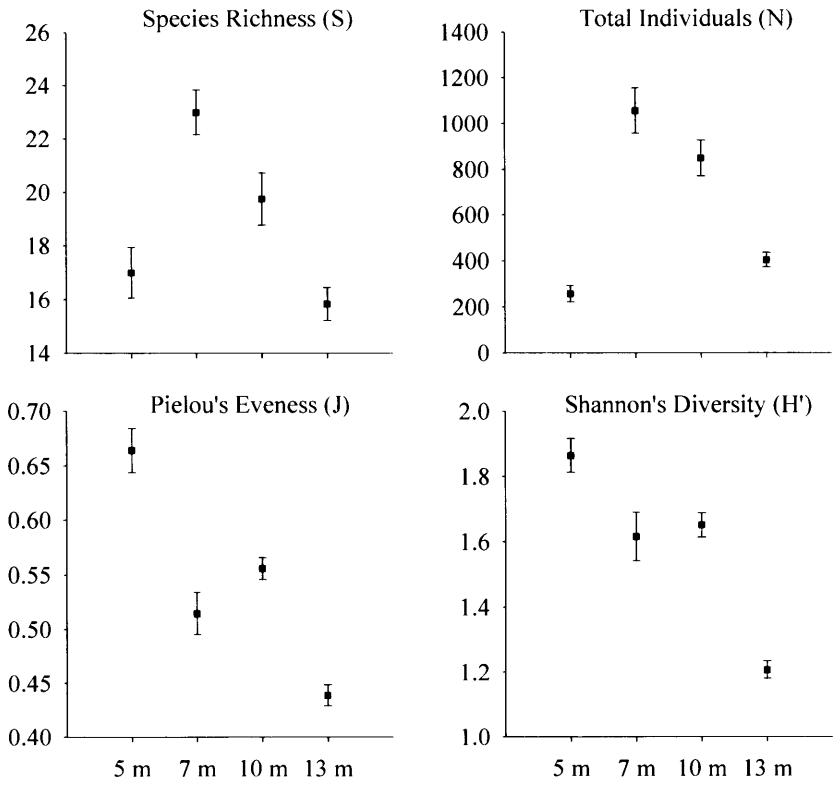

Figure 6.3.2. Mean and standard error for diversity indices along depth transect (n = 12).

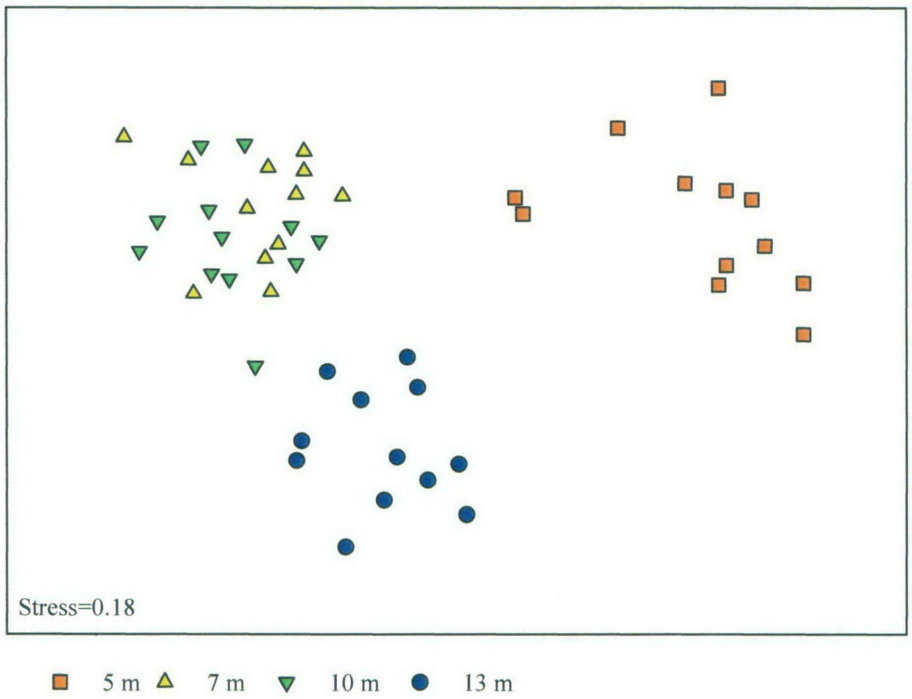

Figure 6.3.3. nMDS ordination for Brown Bay depth transect (n = 12).

The ordination of ASUs from the depth transect shows clear separation of the thirteen metre and five metre ASUs from the seven and ten metre ASUs (Fig 6.3.3). The seven and ten metre ASUs occur as a single group on the ordination and are closer to the thirteen metre group than the five metre group. A one way ANOSIM test between depth treatments was very highly significant (Global R = 0.737, p value = 0.001). All pairwise tests were also significant (Table 6.3.2). The Bonferroni adjusted p value for these multiple comparisons was p = 0.0083. While the ASUs from seven and ten metres were still significantly different the difference was not as great as in the other depth comparisons.

Table 6.3.2. ANOSIM pairwise comparisons of depth treatments (n = 12).

Comparison	Global R	p value
5 vs 7	0.915	0.001
5 vs 10	0.935	0.001
5 vs 13	0.929	0.001
7 vs 10	0.175	0.003
7 vs 13	0.882	0.001
10 vs 13	0.782	0.001

Average dissimilarity was highest in all comparisons with the ASUs from five metres depth (45.97 - 46.45%). This group was separated from the other treatments by very low abundances of common crustacean taxa and lower abundances of the highly abundant taxa including spirorbids, *Skenella paludinoides*, *Nototanais antarcticus*, and *Onoba turqueti*. The occurrence of two dorvilleid polychaetes and a terebellid polychaete at five metres also contributed to separation of the shallow site. In comparison with the ASUs from thirteen metres the abundance of *O. turqueti* was very high in the shallow group. *O. turqueti* reached extremely high abundances in the seven metre ASUs (maximum of 272 individuals) not seen in any other treatment or location throughout the study.

The average dissimilarity between the seven and ten metre ASUs was much lower (29.21%) and was contributed to mostly by relatively small differences in the abundances of taxa occurring at similar levels in both groups. The most important taxa differing between the seven and ten metre groups were spirorbids and *O. turqueti*.

The thirteen metre ASUs had much lower abundances of the common abundant taxa from the seven and ten metre ASUs, especially *O. turqueti* which had a mean abundance of 10 individuals. Mean abundance and significance of one way ANOVA tests between the depth treatments are presented in Figure 6.3.4.

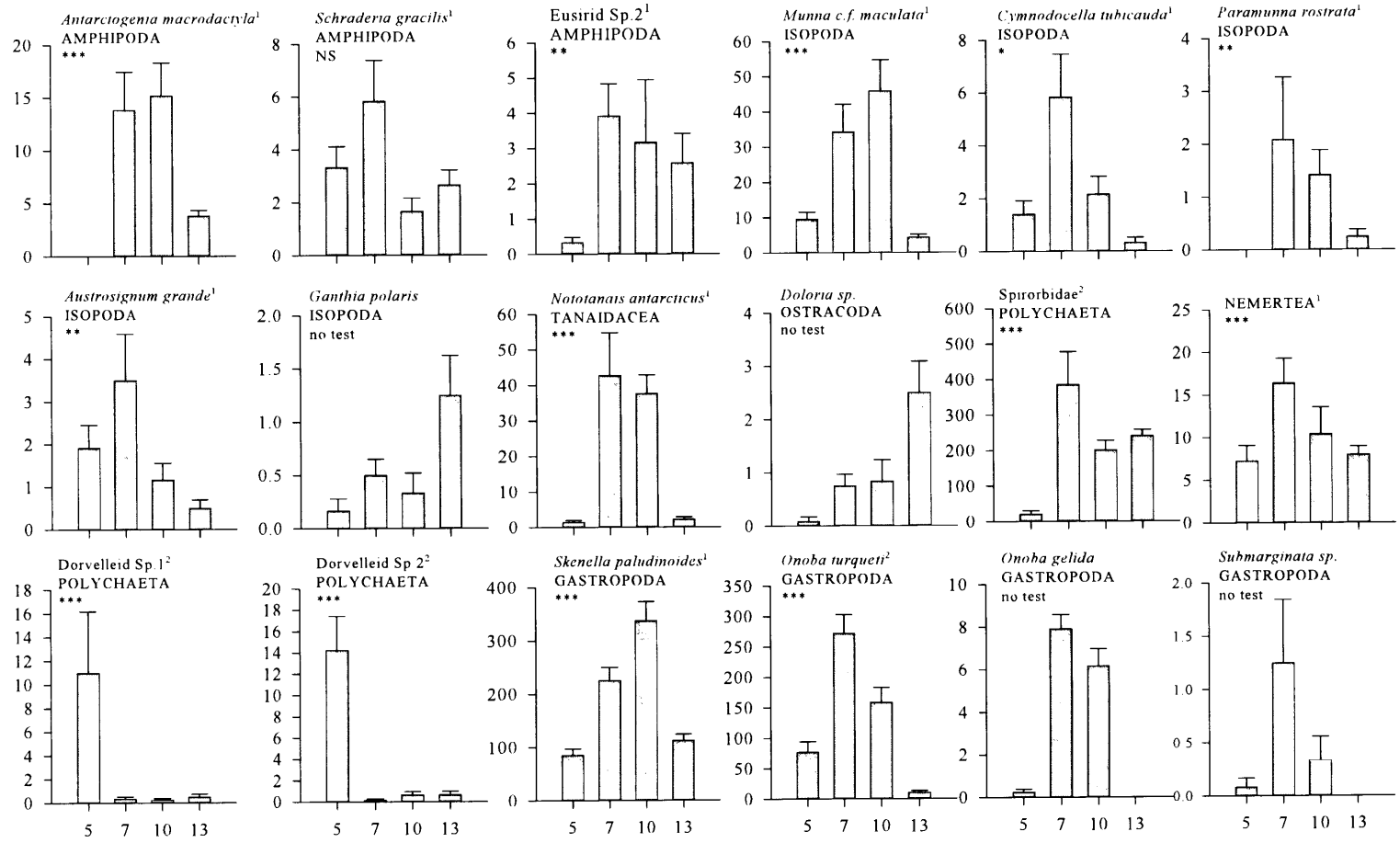

Figure 6.3.4. Mean abundance, standard errors and significance of one way ANOVA test between depths for selected taxa (n = 12). [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively.

6.3.3 Spatial variation within Brown Bay

All of the diversity measures are lower in both plots at group one than group two. Group one also shows less variance than group two. Species Richness (S), Pielou's Evenness (J) and Shannon-Wiener Diversity (H') were all significantly different between sites but not between groups within sites (Fig 6.3.5). Total Individuals (N) was not significantly different between groups or between plots within groups.

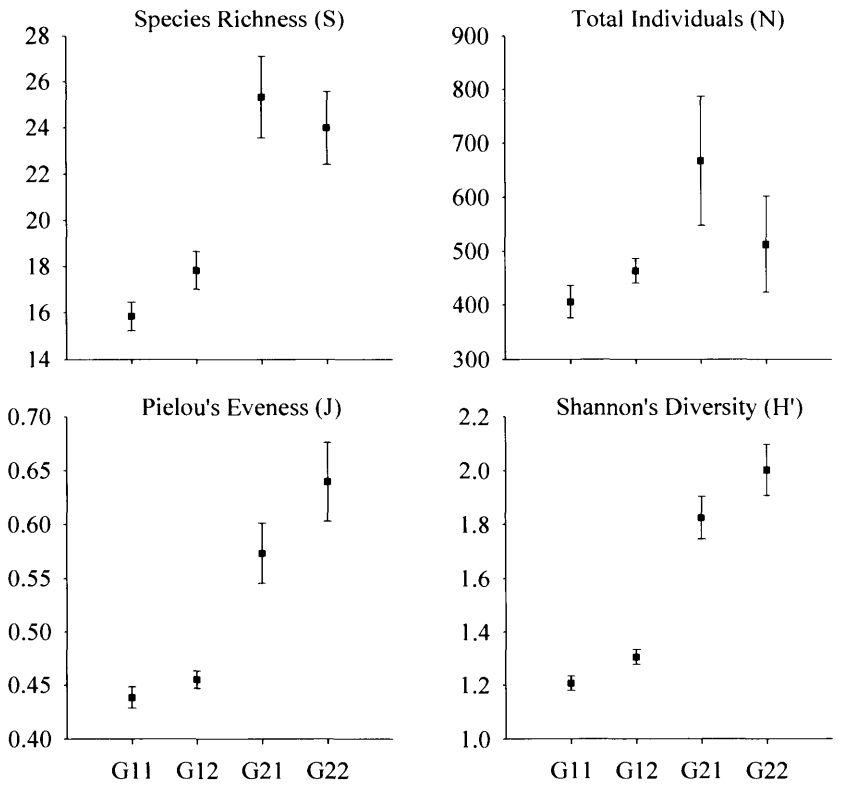

Figure 6.3.5. Mean and standard errors for diversity indices for plots within groups in Brown Bay spatial variation experiment (n = 12). G11 and G12 equal Group1, Plot 1 and Group 1, Plot 2 respectively. G21 and G22 equal Group2, Plot1 and Group2, Plot2 respectively.

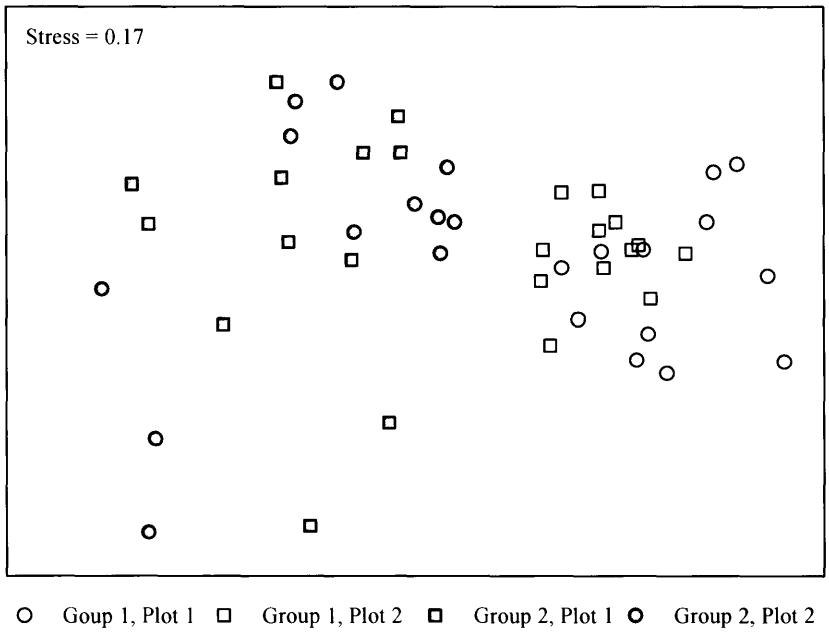

Figure 6.3.6. nMDS ordination of ASUs in Brown Bay spatial variation experiment showing groups 100 m apart and plots within groups 10 m apart (n = 12).

The MDS ordination of the ASUs retrieved from the Brown Bay spatial variation experiment show a clear separation of the two groups (100 m apart) while some overlap is seen between the plots (10 m apart) within each group (Fig 6.3.6). Group two, the outer site) shows a much greater spread in the ordination indicating a higher level of dissimilarity between ASUs at this site. Two way nested ANOSIM tests between plots were run separately for each group and found that in group one (inner site) trays were not significantly different (Global R = 0.043, p = 0.28) but plots were significantly different (Global R = 0.333, p = 0.001). At group two trays were significantly different (Global R = 0.553, p = 0.001) but plots were not (Global R = -0.111, p = 0.80). A two way ANOSIM test comparing the two groups and trays within groups found significant differences between trays (Global R = 0.318, p = 0.001) and between the two groups (Global R = 0.724, p = 0.002).

Average dissimilarity between plots one and two in group one was 28.69% and was due to small differences in the abundance of taxa common to both plots. At group two the average dissimilarity between plots was higher (37.03%) and created by large differences in the abundance of spirorbids, *S. paludinoides* and *N. antarcticus*. There were also differences in the occurrence of *O. turqueti*, *C. tubicauda* and an ophiuroid between the plots. The average dissimilarity between the two groups was 42.68%. Abundances of *N. antarcticus* were much lower at group one and *H. videns*, *Ophiura crassa*, *Orchomene pinguides*, *A. grande* and *Haplocheira plumosa* had a lower occurrence in ASUs from this group. Most of the difference between the two groups is generated by small differences in the abundance of common medium to low abundance taxa. ASU sediment levels are greater at site two (Fig 6.3.7) and may be related to greater movement of trays at this site. Sediment levels are related to the observed taxa patterns with sediment associated taxa increased at this site.

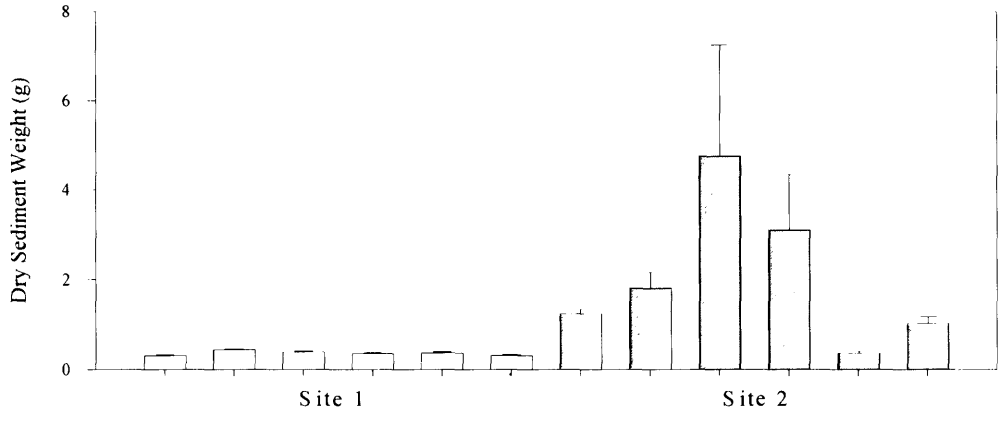

Figure 6.3.7. ASU sediment weight for trays deployed in 2002 spatial variation experiment (n = 4).

Three way nested ANOVAs were conducted for selected taxa to test for differences between sites, between groups within sites and between trays within groups. In all cases no significant differences were found between groups within sites. Two way nested ANOVAs were then run to test for differences between sites and between trays within sites. The significance of these test results and details of data transformations are presented with the abundance data in Figure 6.3.8.

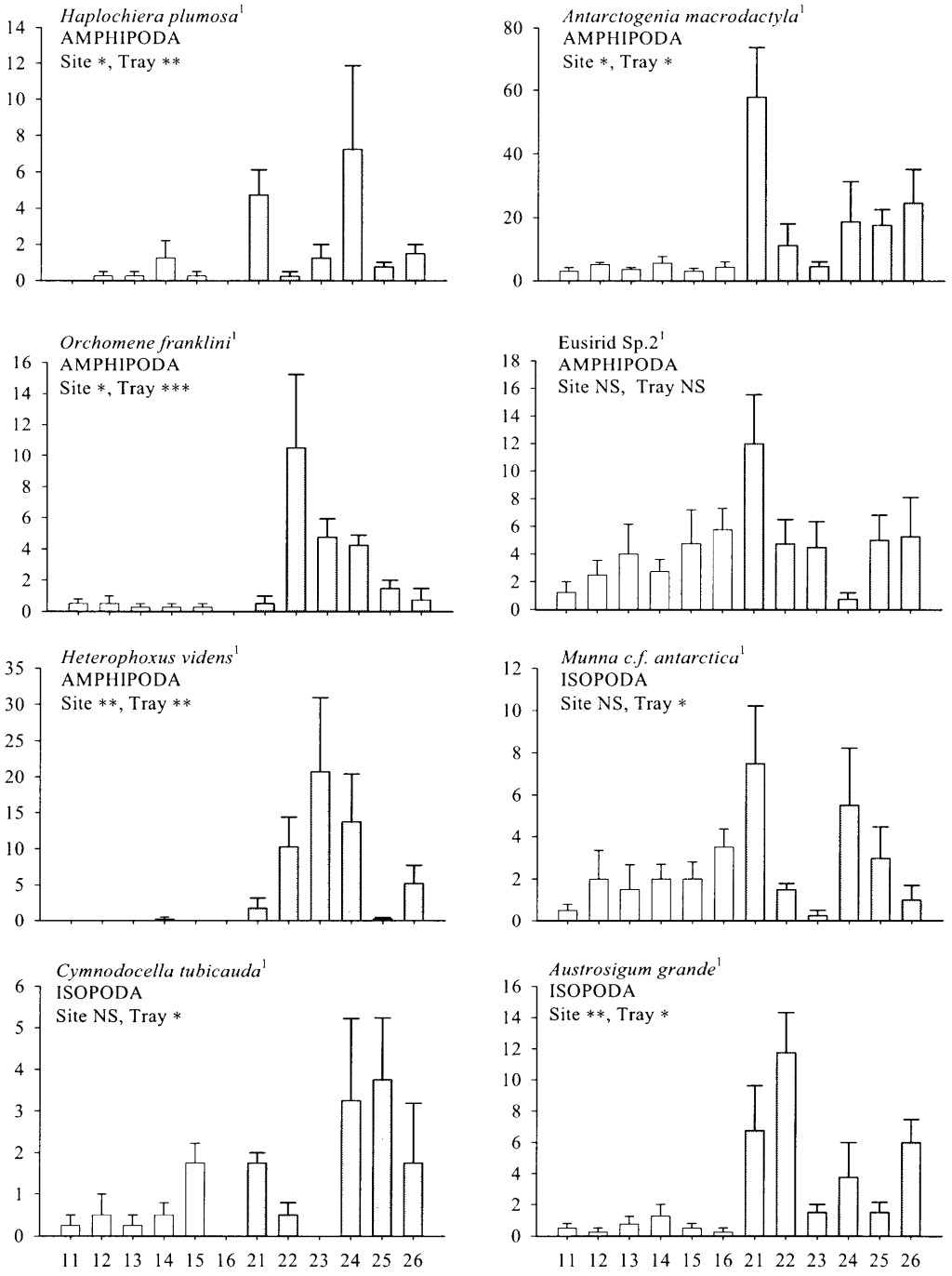

Figure 6.3.8. Mean abundance, standard error and significance of two way nested ANOVA comparing groups and trays within groups for selected taxa in Brown Bay spatial variation experiment (n = 4). [1] Data ln(x+1) transformed for ANOVA. [2] Data$\sqrt{(x+0.5)}$ transformed for ANOVA. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively.

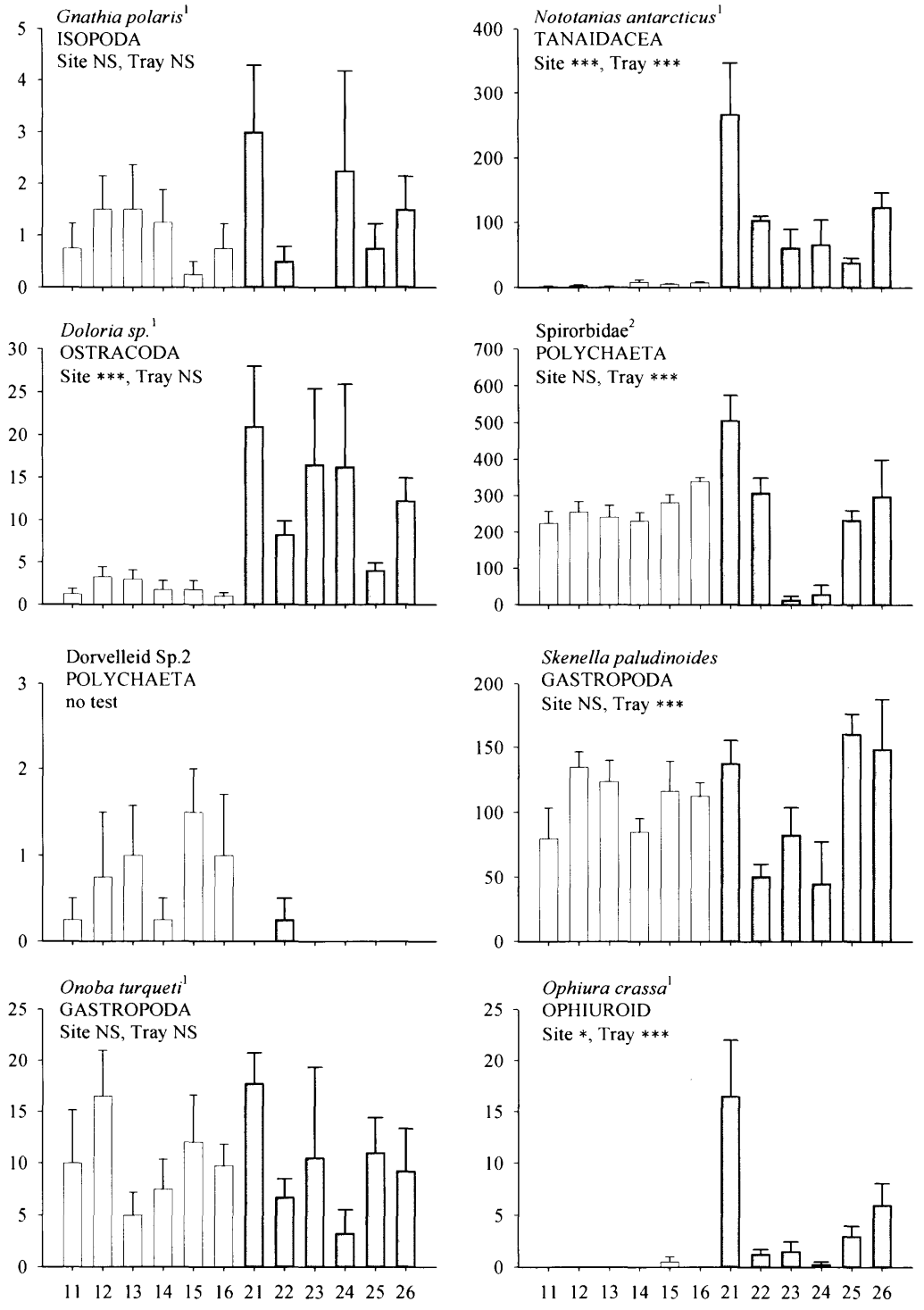

Figure 6.3.8 continued.

6.3.4 Temporal variation within Brown Bay

Mean Species Richness (S), Pielou's Evenness (J) and Shannon-Wiener Diversity (H') are all greater in 2001 (Fig 6.3.9). Mean Total Individuals (N) is greater in 2002 but within the variability of the 2001 value. Variability is greater in 2001 for all diversity measures. One way ANOVAs found no significant differences between years for S ($p = 0.053$) or N ($p = 0.501$). H' and J were significantly different between years.

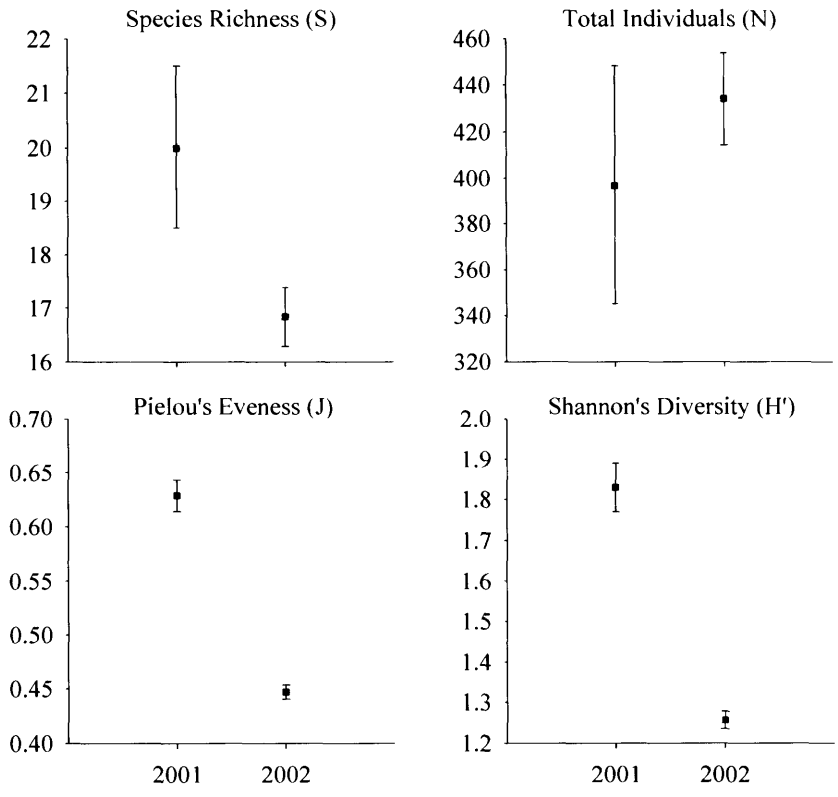

Figure 6.3.9. Mean and standard errors for diversity indices for temporal comparison between 2001 and 2002 in Brown Bay (n = 24).

The two year groups are discrete on the nMDS ordination (Fig 6.3.10). The ASUs from 2001 are very dispersed in the ordination space indicating a high level of variation in this group compared to the ASUs from 2002. A one way ANOSIM test found significant differences between years (Global $R = 0.582$, $p = 0.001$).

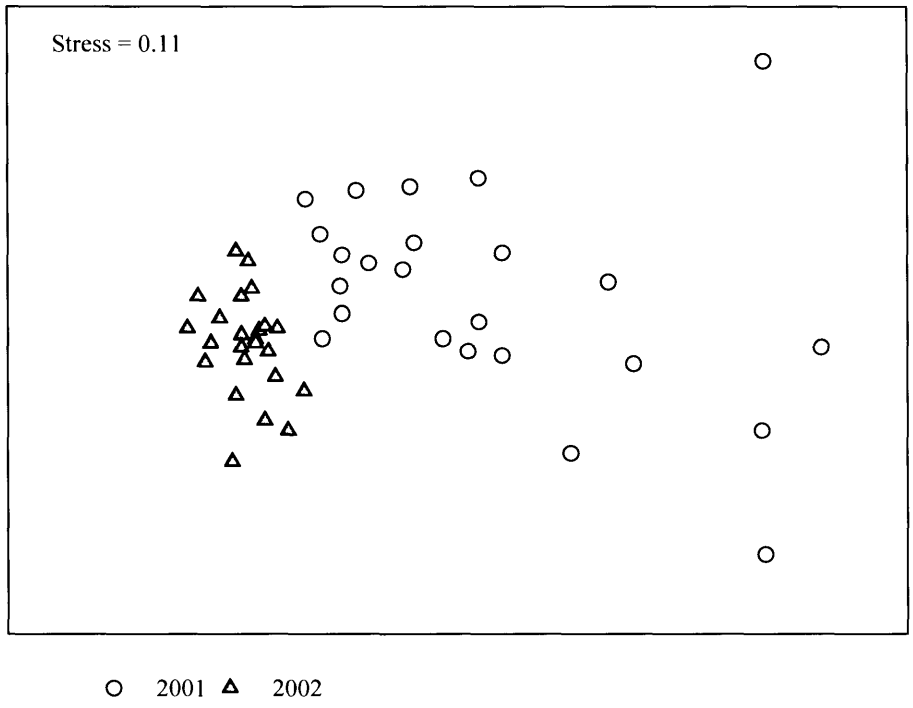

Figure 6.3.10. nMDS ordination of ASUs from Brown Bay in 2001 and 2002 (n = 24).

The average similarity between trays is much greater in 2002, 71.89% compared to 53.22% in 2001. ASUs from 2001 have high abundances of several taxa that are known to be associated with soft sediment habitats. These taxa include *Orchomene pinguides*, *O. franklini*, *Heterophoxus videns* and orbinid polychaetes. Mean abundance for selected taxa and significance of one way ANOVA tests between years are presented in Figure 6.3.11. The presence of these taxa is related to higher levels of sediment that accumulated in the ASUs deployed through 2001, most probably through tray movement and pushing through the surrounding surface sediment. Mean sediment weights for trays from each year are presented in Figure 6.3.12. The change in the nature of the ASU habitat with accumulated sediment confounds the ability of this comparison to detect interannual variation in the ASU assemblage.

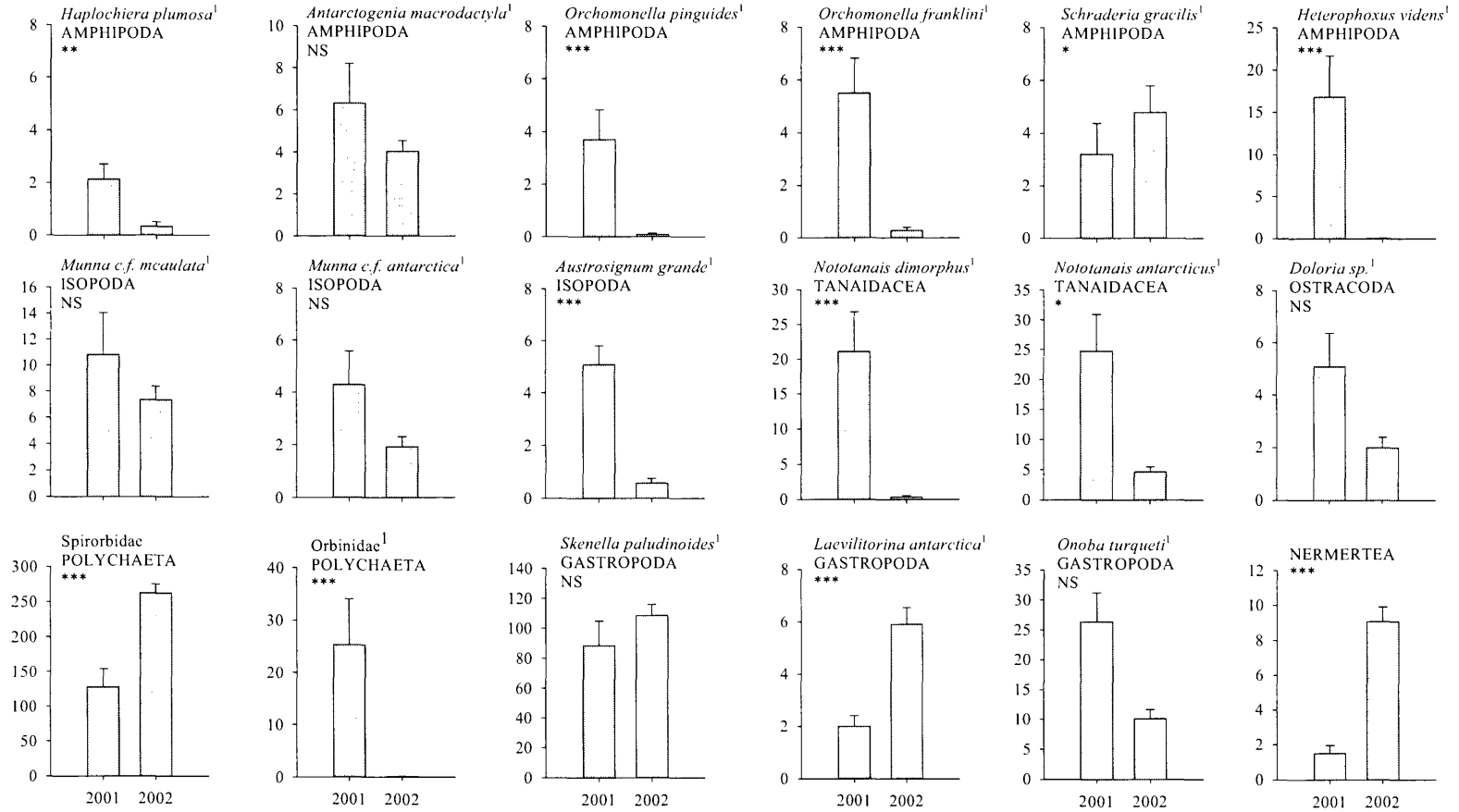

Figure 6.3.11. Mean abundance, standard errors and significance of one way ANOVA test between 2001 and 2002 for selected taxa (n = 24). [1] Data ln(x+1) transformed for ANOVA. [2] Data $\sqrt{(x+0.5)}$ transformed for ANOVA. NS - not significant; *, **, *** - significant at 0.05, 0.01, and 0.001 respectively.

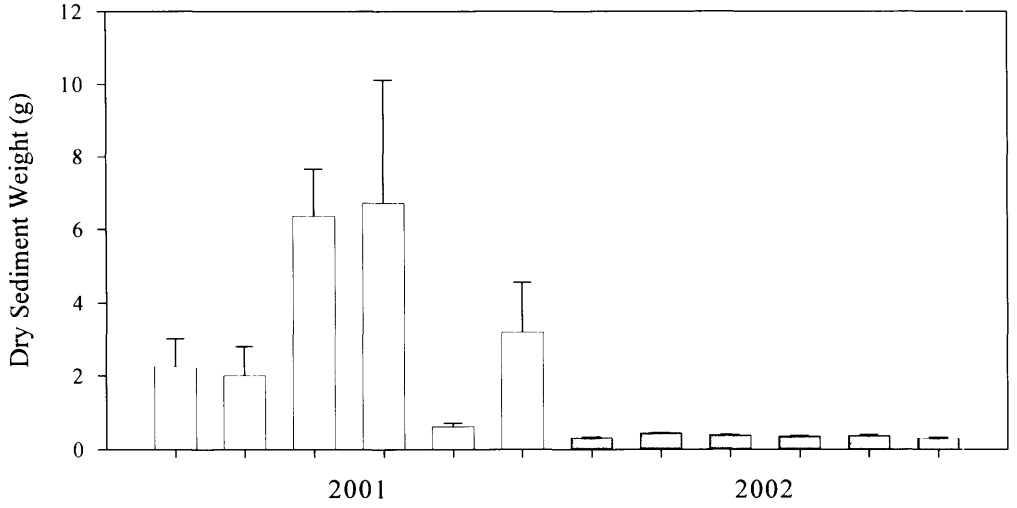

Figure 6.3.12. ASU sediment weight for trays deployed in 2001 (no shading) and 2002 (shaded) (n = 4).

6.4 Discussion

The ASU assemblage of Brown bay is highly variable on spatial scales as small as ten meters, with depth and between years. Brown Bay is a contaminated site and without the repetition of these experiments in control locations (due to logistical constraints), the observed patterns of variation can not be clearly separated from potential contaminant effects. In their study of the Brown Bay infauna Stark et al.(2005) could not separate depth effects from contaminants but did find that the infaunal communities in Brown Bay overall were correlated with the concentrations of metal contaminants and fine fraction sediments.

Stark et al.(2005) described the distribution of contaminants in Brown Bay sediments and found that they had a patchy distribution in the bay with a general gradient of decreasing contamination from the inner bay closest to the tip site to the outer bay. The effects of contaminants on biota vary with the form of the contaminant, that is, if the contaminant is present in the water or is bound to sediments. In a study of the effects of copper on soft sediment assemblages Stark (1998) found that filter feeding sabellid polychaetes were reduced more quickly in treatments with a copper solution added to the water compared

to treatments were the copper solution was added to the sediment. This highlights the importance of the life habit of species in determining the extent of exposure to contaminants. The ASU assemblage is dominated by motile taxa with an epifaunal habit. The ASU taxa would be expected to have lower exposure to sediment bound contaminants than taxa that live in constant contact with the sediments, but may be more sensitive to contaminants in the water column.

The community patterns along the depth transect are similar to the grouping found by Stark et al.(2005) with an inner, middle and outer assemblage. In the ASUs the shallow five metre assemblage showed reduced abundances of common crustacea, gastropods and spirorbids but high abundance of dorvilleid and terebellid polychaetes. In the middle assemblage *Onoba turqueti* was unusually abundant. While the assemblages from seven and ten metres were very similar, they were distinct from the deeper thirteen metre ASUs. The similarity between the seven and ten metre ASUs may also reflect spatial differences as these sites were closest together along the transect. The strong difference between the shallowest ASUs and those from greater depths may also be related to ice effects which are well documented in Antarctic shallow marine environments (reviewed in Dayton (1990), Arntz et al.(1994) and Barnes (1999)). Within Brown Bay the ASU assemblage varied significantly with depth. While this pattern may also be related to contaminants in the Brown Bay sediment this finding has important implications for the deployment of the ASUs and emphasises the need to standardise depth.

The successful collection of the spatial variation experiment allowed examination of small scale patterns of variation in the ASU assemblage. Significant variation in community structure was found at all scales, although this varied between the two groups. In the group closer to the middle of Brown Bay and associated with higher contaminant levels but also lower ASU sediment loads, trays approximately two metres apart were not significantly different, but plots approximately ten metres apart were. In the outer group, closer to Newcombe Bay and with lower contaminants, variation between trays was much greater and plots were not significantly different.

Sediment levels were greater in the trays from the outer bay. Higher sediment loads may cause the significantly higher abundances of the sediment associated crustacea *Heterophoxus videns* and *Orchomene franklini* at the outer site. In addition to a response to ASU sediment loads a pattern possibly related to contamination is suggested by the reduced abundance of other crustacean taxa and the echinoderm *Ophiura crassa* at the inner site. This pattern is consistent with observations of contaminated sediment assemblages at McMurdo Sound (Lenihan et al. 2003a). In another study Lenihan et al.(2003b) found that abundant polychaetes and low numbers of arthropods were associated with combined organic enrichment and toxic contamination. The absence or reduced abundance of taxa may reflect and avoidance response by taxa to contaminated sediments. Avoidance behaviour in amphipods has been demonstrated for heavy metals (Swartz et al. 1982) and for PAH contaminated sediments (Kravitz et al. 1999). The concentration of contaminants that causes avoidance behaviour is often lower than the lethal concentration of a contaminant, but avoidance by a species is equivalent to population extinction in the contaminated area (Lopes et al. 2004).

Taxa that were not significantly different between the two groups in the spatial variation experiment included the gastropod *Skenella paludinoides* and spirorbid polychaetes. Both taxa showed more variability at the outer site. The high abundance of these taxa throughout the study indicates that they are highly dispersive and able to rapidly colonise new habitats. These taxa may be recruiting from sources outside of Brown Bay and their use of the outer surface of the ASUs may mean they are less sensitive to contamination in surrounding sediments or to sediments accumulating in the ASU. *Onoba turqueti* also showed no significant difference between sites, this along with its high abundance in the middle section of the depth transect, may support the idea that this species is pollution tolerant.

Results from the comparison of ASUs deployed in 2001 and 2002 indicated significant differences which were potentially influenced by differences in ASU sediment loads between years and differences in disturbance to the trays. The 2001 group had higher

abundance of sediment associated taxa including the crustacean taxa described above and orbinid polychaetes.

The potential influence of sediment loads on the ASU assemblages is again demonstrated in the comparison of the 2001 ASUs with high sediment weights with the undisturbed trays from 2002 which collected very little sediment. These observations provide strong evidence that the ASU assemblage is sensitive to sediment loading. The amount of sediment present in an ASU greatly changes the microhabitat structure of the ASU and therefore influences the assemblage that recruits to the unit.

Chapter 7

General Discussion

This discussion presents a summary of findings from the study and recommendations for the use of ASUs for environmental monitoring in Antarctic shallow marine environments. This study was the first to employ ASUs to sample shallow water macrofauna in Antarctic continental waters and the first study globally to evaluate ASUs for use in environmental monitoring of pollution effects. Throughout the study disturbance and loss of sampling units during deployment created problems with the integrity of experimental designs and sample retrieval. Further development of the set up of the sampling unit and deployment and collection methods is recommended to control these impacts. Future research into the processes shaping the ASU assemblage is suggested.

Initial investigation of the design of the ASU and optimum deployment period found that a three scourer ASU deployed for one year adequately sampled the available fauna. The fauna sampled by the ASUs was dominated by the gastropod *S. paludinoides* and spirorbid polychaetes. Crustaceans were the most diverse group in the ASU assemblage at all sites. Many of the taxa collected in the ASUs have been previously recorded at Casey from soft sediment communities and in the epifauna of the algae *Palmaria decipiens* and *Desmarestia menziesii*. The common taxa are also known from studies of macrofaunal assemblages from sediments and algae in other shallow Antarctic locations. This finding supports the idea of a single continental Antarctic biogeographic province (sensu Hedgepeth (1969)) for common shallow water amphipods, isopods and gastropods.

Distinct assemblages recruited to the ASUs deployed at each of the study sites around the Windmill Islands. The dominant taxa in the assemblage were similar across all sites but abundance ranges and the occurrence of less abundant species differed between sites. Diversity measures, faunal patterns and debris from the ASUs suggest that important differences exist between the northern sites Newcombe Bay and Brown Bay and the southern sites O'Brien and Penney Bay. O'Brien and Penney Bay are steep sided and adjacent to deep water. These bays may have fewer shallow areas suitable for macroalgae

or for the development of sediment beds, which are known as habitat for many of the taxa that recruited to the ASUs. Newcombe Bay and Brown Bay are within the same larger bay which has several shallow embayments and reef systems within it. The Windmill Islands have had a continual occupation by Adelie penguin colonies dating back 9000 years (Emslie & Woehler 2005). The long-term presence of penguin colonies is likely to have acted as a source organic matter to the water column and sediments in adjacent shallow areas.

Multivariate analyses found significant differences in the ASU assemblage within all sites, created by the highly variable recruitment of individual taxa. Analyses of the univariate diversity indices and abundance patterns of selected taxa also demonstrated significant differences within sites. These patterns of significant spatial variation at both large (kilometres) and small scales (100 to 10s of meters) have also been found in similar ASUs deployed in the subtropics (Rule & Smith 2005). Variation within sites is likely to reflect small scale differences in natural habitats and source populations adjacent to the sampling units. The composition of surrounding habitats and resident fauna strongly influence the colonisation of newly available habitats such as artificial substrata (Mirto & Danovaro 2004; Myers & Southgate 1980; Norderhaug et al. 2002; Rule & Smith 2005). For example, Rule and Smith (2005) found that ASUs deployed next to a large sand patch collected a very different assemblage compared to ASUs anchored within a rocky reef. The ASU close to the sand patch collected more polychaetes while sessile taxa, bivalves and decapods were reduced.

For the first time ASUs have been evaluated to assess their effectiveness in detecting pollution effects. Brown Bay is a known contaminated site in the Windmill Islands and the ASU assemblages from this site were compared with control sites at Newcombe Bay, O'Brien Bay and Penney Bay. Comparisons of the impacted and control sites showed that they were significantly different at the community level. Univariate tests of diversity indices and selected taxa did not detect differences between control and impacted sites with the exception of *Heterophoxus videns* which was more abundant at the impacted site. Although these results suggest a response to pollution, they are confounded by the

sediment loads in the ASUs at Brown Bay. Taxa that occurred in high abundance at the Brown Bay site are known from other studies to be associated with sediments.

Further investigations at Brown Bay demonstrated significant small scale variation in the ASU assemblage within the bay which is influenced by depth, contamination and ASU sediment loads. The assemblage patterns in the ASUs were similar to those described for infauna by Stark et al. (2005) with three distinct assemblages corresponding to inner, middle and outer bay locations.

The effects of pollution on motile marine macrofauna are not well known. The fauna of kelp holdfasts have been studied to investigate effects of organic pollution in the subtropics and in the subantarctic (Smith & Simpson 1992; Smith 1994; Smith 2000; Smith & Simpson 1993) These studies found that the motile assemblages were highly variable and responded strongly to natural environmental variation such as wave exposure and sediment loading. The mechanisms and intensity of exposure of motile epifauna to environmental contaminants are likely to differ from those of infauna traditionally used to model pollution effects in marine benthic communities. Identifying and quantifying these differences requires new research.

Disturbance and loss of sampling units by ice scour and entanglement has been a problem throughout this study. Any sampling method that requires the deployment and recollection of experimental units in the marine environment is exposed to the risk of losing units. This is particularly true for experiments deployed in the highly disturbed shallow marine environment of the Antarctic. The year long deployment, which includes the autumn freeze and spring melt periods of frequent ice movement, increases the chance of the ASUs being disturbed by ice at some point during the deployment. Disturbance of sampling units changed the experimental designs and the ability of the original spatial variation experiment to adequately assess small scale variation in the ASU assemblage. Disturbance of the sampling units also introduced sources of variation by changing deployment depth, distances between units and increasing sediment loads.

Disturbance of the units also introduced sources of variation that were impossible to identify in analyses such as frequency of disturbance.

Kennicutt et al. (1996) listed eight criteria that effective monitoring parameters must meet (see Introduction). In this study the ASU method only met four.

- ASUs can be used within a hypothesis testing framework when deployed in appropriate experimental designs.
- The information provided by the ASUs is useful for management as it is directly related to the biota of the environment being studied and can provide information on diversity and relative abundance of small motile fauna which are an important component of marine environments.
- The fauna that recruit to ASUs are abundant and widespread in the environment and can sustain the sampling effort.
- The variables of the ASU are measurable and the samples are transportable.

The following monitoring criteria have not been adequately met:

- The samples must be collectable within logistic constraints;
- The variable must exhibit change in excess of detection limits;
- The change in the variable must be established above natural variation;
- The samples must amenable to quality assurance.

Conducting shore based research in Antarctic shallow marine environments is logistically demanding. Access to field sites is greatly limited by the presence of ice through much of the year. In addition to access to this remote location, ice also prevents the use of boats in local waters during periods of freeze or when drifting ice is blown into the nearshore waters. This greatly restricts the ability to retrieve samples throughout the year. The year long deployment required for the ASUs demands two consecutive field seasons to deploy and collect the samples. This increases the resources needed to complete the sampling and the time required for the research to be completed.

The ASU assemblage was highly variable both within and between sites and dependent on deployment positioning, duration and timing. The high natural variability of this assemblage imposes serious constraints on the utility of the assemblage for monitoring. Post impact studies of biological assemblages require comparison of an impacted site with several references sites to differentiate between sources of variation that are naturally occurring or that are related to the disturbance being investigated. High levels of natural variability between reference sites confound the ability of analyses to detect differences in the sites related to impacts. Quality assurance is also harder to maintain in a variable system as 'good' and 'bad' samples are harder to identify.

The sensitivity of the ASU assemblage to positioning and timing of deployment means that its use in a monitoring program must follow rigorous standardisation of deployment methods. Disturbance and loss of trays may be reduced by using divers to deploy and collect the ASUs as the trays would then not require long float lines which are vulnerable to entanglement in relatively small sections of floating ice.

From this study many questions about the processes that influence the fauna recruiting to the ASUs have arisen and not yet been answered. Sediment within the ASUs was identified as a potentially important variable. Experiments testing the effects of sediment loads would clarify the role sediment plays in shaping the ASU assemblage and identify sediment affiliated taxa from more generalist species.

Adjacent habitats are the source of many taxa recruiting to the ASUs, especially benthic species with no swimming ability and direct development. The role of surrounding habitats and the distance the fauna recruit from to the ASUs could be investigated by deploying ASUs at set distances from a range of habitats and comparing the assemblages to those of adjacent habitats.

Further investigation could also be made of the temporal changes in the ASUs. Results from this study showed that important recruitment and community development processes occurred during the winter. Surveying ASUs at monthly intervals throughout

the year would provide information about the abundance of fauna throughout the year and identify taxa that are recruiting to the ASUs and those that are breeding within it.

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Appendix 1. Taxa list for ASU assemblage.

Taxonomic Group	Family	Name/Code
Annelida		
Oligochaeta		Oligochatea
Polychaeta	Spirorbidae	Spirorbidae
	Polynoidae	Polynoidae
	Syllidae	Syllid Sp.1
	Syllidae	Syllid Sp.2
	Hesionidae	Hesionidae
	Terebellidae	Terebellidae
		Polychaete Sp.7
		Polychaete Sp.8
	Flabelligeridae	Flabelligerid Sp.1
		Polychaete Sp.10
		Polychaete Sp.11
		Polychaete Sp.12
	Capitellidae	Capitellidae
	Orbinidae	Orbinidae
	Dorvilleidae	Dorvelleid Sp.1
	Dorvilleidae	Dorvelleid Sp.2
	Serpulidae	Serpulidae
	Dorvilleidae	Dorvelleid Sp.3
	Maldanidae	Maldanidae
	Syllidae	Syllid Sp. 3

Taxa list continues on next page.

Taxonomic Group	Family	Name/Code
Arthropoda		
Chelicerata		
Acarina		Acarina
Pycnogonida		Pycnogonida
Crustacea		
Amphipoda	Aoridae	*Haplocheira plumosa*
	Eusiridae	*Antarctogenia macrodactyla*
	Sebidae	*Seba sp.*
	Lysianassidae	*Orchomene pinguides*
		Amphipod Sp.7
	Lysianassidae	*Orchomene franklini*
	Eusiridae	*Schraderia gracilis*
	Eusiridae	*Eusirid Sp.2*
		Amphipod Sp.12
		Amphipod Sp.14
		Amphipod Sp.15
		Amphipod Sp.16
		Amphipod Sp.17
		Amphipod Sp.18
		Amphipod Sp.19
		Amphipod Sp.20
	Exoedicerotidae	*Methalimedon nordenskjoldi*
	Phoxocephalidae	*Heterophoxus videns*
		Amphipod Sp.24
		Amphipod Sp.25
		Amphipod Sp.26
		Amphipod Sp.27
		Amphipod Sp.28
Copepoda		Copepoda

Taxa list continues on next page.

Taxonomic Group	Family	Name/Code
Arthropoda cont.		
Isopoda	Munnidae	*Munna c.f. maculata*
	Munnidae	*Munna c.f. antarctica*
	Sphaeromatidae	*Cymnodocella tubicauda*
	Paramunnidae	*Paramunna rostrata*
		Isopod Sp.4
		Isopod Sp.5
	Paramunnidae	*Austrosignum grande*
	Gnathiidae	*Gnathia polaris*
	Desmosomatidae	*Desmosoma sp.*
		Isopod Sp.9
		Isopod Sp.10
		Isopod Sp.11
		Isopod Sp.14
		Isopod Sp.15
		Isopod Sp.16
		Isopod Sp.16A
		Isopod Sp.17
	Arcturidae	*Arcturus sp.*
		Isopod Sp.19
Leptostraca		Leptostraca
Ostracoda		Ostracod Sp.1
	Cupridinidae	*Doloria sp.*
	Philomedidae	*Scleroconcha sp.*
		Ostracod Sp.4
Tanaidacea	Nototanidae	*Nototanais dimorphus*
	Nototanidae	*Nototanais antarcticus*

Taxa list continues on next page.

Taxonomic Group	Family	Name/Code
Echinodermata		
Asteroidea		Asteroid Sp.1
		Asteroid Sp.2
Echinoidea		Echinoidea
Holothuroidea		Holothuroidea
Ophiuroidea		Ophiura crassa
		Ophiuroid Sp.2
Mollusca		
Bivalvia		Bivalve Sp. 1
		Bivalve Sp. 2
		Bivalve Sp. 4
		Bivalve Sp. 5
Gastropoda	Cingulopsidae	*Skenella paludinoides*
	Littorinidae	*Laevilitorina antarctica*
	Rissoidae	*Onoba sp.*
	Rissoidae	*Onoba turquetti*
	Rissoidae	*Onoba gelida*
		Gastropod Sp.7
		Gastropod Sp.8
		Gastropod Sp.9
	Trochidae	*Submarginata sp.*
		Gastropod Sp.11
		Gastropod Sp.12
		Gastropod Sp.13
	Muricidae	*Trophon longstaffi*
		Gastropod Sp.15
Opisthobranchia		Opisthobranchia
Other Phyla		
Ascidians		Ascidacea
Nematoda		Nematoda
Nemertea		Nemertean Sp.1
		Nemertean Sp.2
Porifera		Porifera
Turbellaria		Tubellaria Sp.1
		Tubellaria Sp.2

Appendix 2. Key Taxonomic References.

Amphipods

With help from Dr Jim Lowry and Ms Helen Stoddart.

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Isopods

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Santa Barbara Museum of Natural History. 1997. Taxonomic atlas of the benthic fauna of the Santa Maria Basin and Western Santa Maria Barbara Channel. Volume 11. The Crustacea Part 2 – The Isopoda, Cumacea and Tanaidacea.

Polychaetes

With help from Dr Pat Hutchings.

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Molluscs

With help from Dr Peter Middelfart and Dr Winston Ponder.