BENTHIC PROTECTION ZONE OF THE GREAT AUSTRALIAN BIGHT MARINE PARK: 3. PILOT STUDY FOR PERFORMANCE ASSESSMENT (Volume 1)

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December 2003

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PO Box 120, Henley Beach,

South Australia 5022

Final Report to

National Parks and Wildlife South Australia and the

Commonwealth Department for Environment and Heritage

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Natural Heritage Trust
Helping Communities Helping Australia

Government of South Australia

Department for environment and heritage

ISBN 0 7308 5307 1

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Printed in Adelaide December 2003.

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Reviewers:	Dr Jason Tanner and Dr Simon Bryars
Approved by:	Professor Anthony Cheshire
Signed:	
Date:	December 2003
Distribution:	South Australia Department of Environment and Heritage, Commonwealth Department of Environment and Heritage, Consultative Committee of the GABMP, SARDI Aquatic Sciences Library
Circulation:	Public Domain
ISBN:	0 7308 5307 1

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ACKNOWLEDGEMENTS

The National Heritage Trust, National Parks and Wildlife South Australia and Commonwealth Department of Environment and Heritage provided funding to support this project. SARDI Aquatic Sciences provided significant additional funding and substantial in-kind support.

Special thanks go to the crew of the RV *Ngerin*, Mr Neil 'Chiko' Chigwidden, Mr David Kerr, Mr Chris Small and Mr Ralph Putz for their assistance in collecting samples. Mr Wetjens Dimmlich, Mr David Schmarr, Mr Nathan Strong and Mr Paul Van Ruth helped to deploy and retrieve the epibenthic sled and to sort the samples at sea.

Ms Suyin Deakin assisted with the sorting and identification of samples in the laboratory and entered sampling and taxonomic data into a database. Ms Annette Doonan, Mr Richard Saunders, Dr Scoresby Shepherd, Dr Karina Hall, Ms Magda Holt (SARDI Aquatic Sciences), Dr Jan Watson (Hydrozoan Research Laboratory), Dr Greg Rouse (SA Museum), Dr Mark O'Loughlin and Dr Phil Bock (Museum Victoria), and Dr Phil Alderslade (Museum of Art Gallery of the Northern Territory) helped to identify specimens belonging to various taxa.

Mr Peter Graham (Commonwealth Department of Environment and Heritage) and Mr Simon Clark (South Australian Department of Environment and Heritage) commented on drafts of the report. The review was formally reviewed by Dr Jason Tanner and Dr Simon Bryars (SARDI Aquatic Sciences) and approved for release by Professor Anthony Cheshire (Chief Scientist, SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

1. This report describes a survey of the epibenthic communities of the Great Australian Bight (GAB) that was conducted to: determine whether the benthic communities of the eastern and central GAB differ among sedimentary facies; provide a preliminary description of the GAB's benthic communities; compare them with other soft-bottom benthic communities; assess the suitability of the Benthic Protection Zone (BPZ) for protecting and representing the benthic communities of the GAB; and outline potential rationale and approaches for future performance assessment of the BPZ.

2. Samples of the epibenthic communities were collected from 65 sites during cruises conducted in April 2002 (25 sites) and November-December 2002 (40 sites). To provide a context for assessing the suitability of the BPZ for representing the benthic biodiversity of the eastern and central GAB, samples were collected from five sites in each of the eight sedimentary facies that occur on the shelf. To provide a basis for planning and conducting future assessments of the effectiveness of the BPZ in protecting benthic communities from anthropogenic impacts, five samples were collected from sites inside and adjacent to the BPZ and in each of the four sedimentary facies that comprise the BPZ

3. A total of 764 kg of living benthos belonging to 811 species was collected. Sessile poriferans, ascidians and bryozoans, collectively comprised over 96.5% of the biomass and 72.5% of the species collected. The most abundant free-living organisms were echinoderms and molluscs, which collectively comprised only 2% of the biomass and 11.6% of the species collected during the study.

4. Suspension-feeders comprised 86% of the species collected, whereas only 3.9 and 9.6% of species were deposit-feeders and scavengers/carnivores, respectively. The prevalence of suspension-feeders and paucity of deposit-feeders in the GAB compared to most other soft-bottom habitats may reflect the coarse sediments and conspicuous lack of fluvial inputs to the region. Relatively high plankton concentrations resulting from seasonal upwelling may also increase the regions capacity to support high densities of suspension-feeders.

5. The composition of benthic communities in the GAB was significantly different among sedimentary facies. Although poriferans, ascidians and/or bryozoans dominated the biomass in all facies, the number of species and relative abundance of individual species varied significantly among facies. The largest quantities of benthic organisms (15-20 kg/site) and

highest mean number of species (>35 species/site) were collected from the Intraclast Mollusc, Mollusc Intraclast and Bryozoan Intraclast facies of the inner and middle shelf.

6. The data collected in this study suggest that the GAB supports one of the worlds most diverse benthic ecosystems. Many species of the species found are also endemic to southern Australia, however, quantifying the proportion of species that are endemic to either southern Australia or the GAB is complicated by the lack of taxonomic information for most groups. At least two species of asteroids, four species of soft coral and several species of poriferans collected during this study have not been described.

7. The BPZ is relatively well placed to represent the biodiversity of the GAB. It includes four of the eight sedimentary facies that occur in shelf waters of the eastern and central GAB and 53% of the 811 species collected during this study were obtained from within the BPZ.

8. Benthic communities were significantly different inside and adjacent to the BPZ in three of the four sedimentary facies examined. Biomass was higher inside than outside the BPZ in three of these four facies. The mean number of species collected and mean diversity indices per site were higher inside than outside the BPZ in all four sedimentary facies. More species were collected from sites inside (432) the BPZ than those adjacent to the BPZ (300).

9. Future surveys to support performance assessment of the BPZ should include re-sampling with an epibenthic sled the 40 stations inside and adjacent to the BPZ that were sampled during the present study. This approach is recommended because it provides a cost-effective option for completing a preliminary performance assessment of the BPZ. Repeating this survey periodically (e.g. every 3-5 years) also represents the low cost option for ongoing performance assessment. Detailed data on fishing and mining activities in the region are needed to support future assessments and to provide a basis for identifying potential agents of future changes in the structure and composition of benthic communities. Future surveys of the GAB would, ideally, not be confined to simply resampling these 40 stations and monitoring anthropogenic activities in and near the GABMP more effectively. Extensive and intensive surveys of the entire GAB are required to assess the need for additional protected areas to represent and preserve the region's benthic communities and to provide a basis for future regional marine planning. Australia's Ocean's Policy and Marine Science and Technology Plan both identify the need for scientific information to underpin the management of key marine environments, such as the GAB, that are diverse, contain a high proportion of species that are endemic to Australia and are economically important.

1. INTRODUCTION

1.1. General Background

This is the third report in a three part series on the Great Australian Bight Marine Park (GABMP) by the South Australian Research and Development Institute (SARDI), Aquatic Sciences (Fig. 1.1). The report describes a survey of the epibenthic communities of the Great Australian Bight (GAB) that was conducted as a pilot study for the development a performance assessment system for the BPZ.

The Great Australian Bight (GAB) extends from Cape Pasley in Western Australia to Cape Catastrophe, Eyre Peninsula in South Australia (Figure 1). It is unique internationally, having the world's longest southern-facing coastline, being adjacent to the only circumpolar ocean and including a continental shelf that is up to 260 km wide (McLeay *et al.* 2003).

Near the Head of the Bight and along the eastern part of the GAB, the inner shelf is narrow, with the seafloor plunging to a depth of 50 m depth within a few kilometres of the coast, the middle shelf (out to ~150 m) is broad, and the outer shelf (to ~200 m) is also relatively narrow (James *et al*. 2001). Shelf sediments are largely devoid of terrigenous components, due to the absence of large rivers from the region, and are comprised mainly of relatively coarse biogenic fragments and minor amounts of quartz sand inshore. Inner shelf sediments are comprised mainly of bio-fragments and rhodolith gravel; middle shelf sediments by intraclasts, Holocene mollusc shells and bryozoan skeletons, and outer shelf sediments by bryozoan fragments (James *et al.* 2001).

The benthic communities of the GAB are diverse and include many species that are endemic to southern Australia (Edyvane 1998; Shepherd 1991). These high levels of biodiversity and endemism have been attributed to the unusual width of the continental shelf, the high degree of geographic isolation from similar habitats and the opportunities for incursions by tropical species afforded by the influence the Leeuwin Current (Andrew 1999). However, a recent literature review (McLeay *et al*. 2003) suggests that high biodiversity of the GAB may be reflect the presence of both eastern and western temperate Australian species, and taxa with tropical affiliations in the region.

1.2 Great Australian Bight Marine Park

The Benthic Protection Zone (BPZ), (Commonwealth waters) of the Great Australian Bight Marine Park (GABMP) was proclaimed in 1998 (McLeay *et al.* 2003). It is a 20 nautical-mile-wide strip that is orientated from north to south and extends from three nautical miles from the coast to the edge of Australia's Exclusive Economic Zone (EEZ), 200 nautical miles offshore (Fig. 1). Within this zone, the benthic communities are protected from demersal trawling and other potentially deleterious anthropogenic impacts. Before the BPZ was proclaimed, vessels of the Great Australian Bight Trawl Fishery (GABTF) conducted demersal trawls in depths of 120 to 160 m (Caton 2002).

The aim of the Benthic Protection Zone is "to preserve a representative sample of benthic flora and fauna and sediments" (Department of Environment Heritage and Aboriginal Affairs 1998a). This aim has two elements. The first is to "preserve" the ecological integrity of a sample of the GAB's benthic communities by providing protection from potentially destructive anthropogenic practices, such as demersal trawling. The second is "represent" within the park the unique and diverse animals and plants that occur within the GAB region.

The location of the BPZ was not determined on the basis of quantitative ecological data. In the absence of this information, the BPZ was located so as to preserve a cross-shelf transect near the widest part of the continental margin, including the Ceduna Terrace (Peter Graham, Commonwealth Department of Environment and Heritage, personal communication). Despite the GAB's international significance as a region of high diversity and endemism, few data are available on the benthic ecology of the GAB. No preliminary descriptions are available on the species composition of the benthic communities or environmental factors that affect their patterns of distribution and abundance. Hence, the suitability of the BPZ for preserving and representing the benthic biota of the GAB is unknown. The most informative data on the region's benthic ecology are the sedimentary data (James *et al.* 2001), which suggest that the sedimentary facies reflect the spatial distribution of benthic communities in the GAB. James *et al.* (2001) also provided qualitative descriptions of the benthic communities of the GAB based on seafloor images.

1.3 Rationale and Objectives

In April and December 2002, SARDI Aquatic Sciences conducted a survey of the benthic communities of the GAB from the RV *Ngerin*. The surveys were conducted as a pilot study for the development of a performance assessment system for the BPZ. The objectives of the study were: (1) to determine whether the benthic communities in the eastern and central GAB differ among sedimentary facies; (2) to provide a preliminary description of the benthic communities and compare them with soft-bottom benthic communities elsewhere; (3) to assess the suitability of the BPZ for protecting and representing the benthic communities of the GAB; and (4) to outline potential rationale and approaches for a future performance assessment of the BPZ.

2. METHODS

2.1. Sampling design

Samples of the epibenthic communities were collected from 65 sites in the GAB during cruises conducted in April 2002 (25 sites) and November-December 2002 (40 sites). To provide a basis for assessing the suitability of the BPZ for representing the benthic biodiversity of the eastern and central GAB, samples were collected from five sites in each of the eight sedimentary facies that comprise the region (Fig. 1). To assess the suitability of areas adjacent to the GAB for use as controls in future assessments of the performance of the BPZ, five samples were collected from each of the four sedimentary facies inside the BPZ (Fig. 1) for comparison with five samples collected from these four facies at sites located adjacent to the BPZ. Hence, twenty sites were used for both assessing the suitability of the BPZ for representing and protecting the benthic biodiversity of the GAB and for assessing the suitability of areas adjacent to the GAB for use as controls in future assessments of the performance of the BPZ. Two sets of five samples were collected from the Intraclast Bryozoan facies; one set and area in the eastern GAB and one set from an area adjacent to the GABMP.

2.2. Sample collection

Benthic invertebrates and macro-algae were collected at each site using a benthic sled. The sled had a mouth 1.81 m wide by 0.56 m high. The sides were 25 mm by 50 mm steel mesh and the internal and external cod-ends were 1.0 m in length and made of 50 and 80 mm nylon meshes, respectively (Fig. 2). At each site the sled was towed across the substrate for 5 minutes at a speed of 3.5 knots. Data recorded at each site included date, time, location (latitude and longitude) and depth.

2.3. Onboard sample processing

Samples collected during the sled tows at each site were bagged and frozen at -4°C aboard the research vessel. Large individual specimens were weighed, and sub-sampled before freezing.

2.4. Laboratory analysis

Samples were sorted and identified to species or putative taxon, and assigned a species identification number. Dead bryozoans, broken shells, and rocks were grouped together as rubble. A rapid assessment approach was taken and epi-bionts and specimens <1 cm long were not considered. All other specimens were weighed. Unitary animals, including molluscs, echinoderms and crustaceans were counted. Species were placed into three feeding guilds – suspension-feeders, deposit-feeders and scavengers/carnivores – based on their primary feeding mode after Barnes (1987) and Edgar (2000). Representative samples of each species were photographed. Molluscs, ascidians and polychaete worms were fixed in 10% seawater formalin (4% formaldehyde). Other samples were fixed in 75% ethanol. Voucher specimens and a database were lodged at the South Australian Museum, Adelaide.

2.5. Data analysis

2.5.1. Preparation and rationale

Most sites were dominated by modular rather than unitary organisms. Hence, the species composition of sites was described and compared using weights rather than counts of individuals.

The data analysis was conducted in two parts. Data from the sites (45) located in each of nine sedimentary facies that comprised the eastern and central GAB (but which were outside the BPZ) were used to provide a context for assessing the suitability of the BPZ for representing the benthic biodiversity of the region. For this analysis, the Intraclast Bryozoan sedimentary facies, which occurs in two areas, was separated as Intraclast Bryozoan (a) and Intraclast Bryozoan (b). Data from sites within the BPZ and adjacent sites were used to assess the suitability of these areas as control sites in future performance assessments of the BPZ.

2.5.2. Effects of sedimentary facies and depth on benthic community composition

For the purpose of this analysis, the specific depths recorded aboard the vessel were allocated to one of three depth classes: <60, 60-100 and >100m. The effects of sedimentary facies (fixed factor) and depth and on community composition were assessed using a two-way NPMANOVA with a cross-factorial design. Shannon's Diversity Index was calculated using the software package PC ORD.

2.5.3. Effect of the BPZ on benthic community composition

Differences in community composition inside and outside the BPZ were tested using a two-way NPMANOVA, with both factors (sediment and location) fixed and orthogonal, and with sediment type nested within location. Pair-wise comparisons were then used to identify where, if any, treatment differences occurred.

3. RESULTS

3.1 Total Sample

3.1.1 Biomass

A total of 764 kg of living benthos was collected from the 65 sites. Poriferans accounted for 69% (527 kg) of the biomass (Fig. 3a). Ascidians, bryozoans, echinoderms and cnidarians comprised 23 (173.5 kg), 5 (37.3 kg), 2 (12.8 kg) and 1% (7.4 kg) of the total biomass sampled, respectively. Other taxa collected, including molluscs, annelids, crustaceans, brachiopods, nemerteans and macroalgae, each comprised <0.5% of the total biomass sampled (Fig. 3a). Specimens collectively weighing 4.2 kg and comprising 0.5% of the total biomass sampled could not be identified to phyla. A total of 132 kg of rubble comprising mainly broken shells, bryozoans and rocks was also collected.

One species, 'Massive Hadromerid Sponge' (Appendix 1, Index No. 0027), accounted for 20% of the total weight of poriferans collected. More than 10 kg of five other species of sponges, 'Crunchy Sponge' (Index No. 0607), *Jaspis* sp (Index No. 0031), 'Orange Sandy Sponge 2' (Index No. 0763), 'Crunchy Brown Sponge' (Index No. 0039), 'Pale Orange Fan Sponge' (Index No. 0560) was also collected. Four ascidians, 'Sandy Liver Ascidian' (Index No. 0042), 'Sandy Colonial Ascidian' (Index No. 0230), 'Red/brown Sandy Ascidian' (Index No. 1052), 'Blue/green Encrusting Ascidian' (Index No. 0091), and one bryozoan *Adeona* sp 1 (Index No. 0004) were also collected in quantities of >10 kg.

3.1.2 Taxonomic composition and distribution

A total of 811 different species were identified from the 65 sites, of which 44% (362) were poriferans, 17% (138) ascidians, 11% (94) bryozoans, 7.5% (62) cnidarians, 6% (50) echinoderms, 5.5% (45) molluscs, and <5% were crustaceans (35), annelids (14), macroalgae (9), brachiopods (1) and nemertines (1) (Fig 3b).

The most widely distributed taxa were bryozoans, which occurred at 92% of sites, followed by poriferans and ascidians, which occurred at 88% and 82% of sites, respectively (Fig. 3c). Three species of bryozoans, *Adeona* sp 1 (Index No. 0004), 'Fenestrate Bryozoan 3' (Index No. 0241) and 'Green Membranipora' (Index No. 0082) occurred at more than 30% of sites, whereas only one species of poriferan, 'Massive Hadromerid Sponge' (Index No. 0027) was distributed as widely.

Suspension-feeders dominated samples, comprising 86% of the species collected (Table 1), whereas deposit-feeders and scavengers/carnivores comprised only 3.9 and 9.6% of the species collected, respectively.

3.2 Biomass and taxonomic composition in each sedimentary facies

3.2.1 Statistical analysis

Whilst there was considerable variability in the community composition of sites within sedimentary facies, community composition was significantly different among facies (NPMANOVA, $F_{8,44} = 1.5238$, $P = 0.0195 < 0.05$, Table 2). Assessment of the effects of depth on community composition was confounded by the effects of sediments, which also varied with depth. However, the analyses suggested that depth did not significantly affect community composition (NPMANOVA, $F_{2,23} = 0.7624$, $P = 0.6823$, >0.05, Table 2).

A non-parametric multidimensional scaling (nMDS) plot of community composition by weight of individual species is consistent with the outputs of the NPMANOVA (Fig. 4). Sites in some sedimentary facies (e.g. Intraclast Mollusc, Intraclast) consistently group together, whereas sites within other facies (e.g. Quartzose Skeletal) grouped less tightly (Fig. 4).

3.2.2 Biomass

Large quantities of benthic organisms (mean biomasses of between 15 and 20 kg per site) were collected from the Intraclast Mollusca, Mollusca Intraclast and Bryozoan Intraclast sedimentary facies, whereas moderate quantities (3-15 kg per site) were collected from the Intraclast Bryozoan (a and b), Quartzose Skeletal and Branching Bryozoan facies. Less than 1 kg of biomass per site was collected from Bryozoan and Intraclast facies (Fig. 5a).

Poriferans dominated the biomass of the benthic communities that occurred in six of the nine sedimentary facies in the eastern GAB (Fig. 6), with means of more than 10 kg per site collected from the Mollusc Intraclast, Intraclast Mollusc and Bryozoan Intraclast facies. Ascidians were slightly more abundant (by weight) in the Bryozoan, Intraclast and Intraclast Bryozoan (b) sediments and were the second most abundant taxa by weight in all other sedimentary facies. Bryozoans were the third most abundant taxa by weight in all sedimentary facies except the Mollusc Intraclast, where echinoderms comprised a greater proportion of the mean biomass.

The ‘Massive Hadromerid Sponge’ (Index No. 0027) was the most abundant species in three of the nine sedimentary facies - Intraclast Mollusc, Bryozoan Intraclast and Intraclast Bryozoan (b), where totals of 32, 14.5 and 17 kg of this species were collected, respectively. Another sponge *Jaspis* sp (Index No. 0031) dominated in the Branching Bryozoan and Intraclast Bryozoan (a) facies and the 'Crunchy Sponge' (Index No. 0607) was the most abundant species in the Quartzose Skeletal facies. Two ascidians, the 'Sandy colonial' (Index No. 0230, no photograph) and 'Cream/pink didemnid' (Index No. 1054) dominated in the Mollusc Intraclast and Bryozoan sedimentary facies, respectively.

3.2.3 Taxonomic composition

Means of more than 35 species per site were collected from the Intraclast Mollusc, Mollusc Intraclast and Bryozoan Intraclast facies, whereas only 10-30 species per site were collected from the Intraclast Bryozoan (a and b), Quartzose Skeletal, Branching Bryozoan and Intraclast facies. Less than 10 species per site were collected from the Quartzose Skeletal facies (Fig. 5b). The mean Shannon's Index for each site in each sedimentary facies was above 3.5 in the Intraclast Mollusca and Bryozoan Intraclast facies, and between 2.4 and 3.5 in all of the other facies (Fig. 5c).

More species of poriferans than any other major taxa were collected from sites located in six of the nine sedimentary facies - Mollusc Intraclast, Intraclast Mollusc, Bryozoan Intraclast, Intraclast Bryozoan (a), Branching Bryozoan and Bryozoan (Fig. 7). However, there were more species of bryozoans in the Quartzose Skeletal, Intraclast and Intraclast Bryozoan (b) sedimentary facies. Bryozoans were also the second most abundant species in three of the five sedimentary facies that were dominated by poriferan species. Ascidian taxa were the second most prolific in the Branching Bryozoan and Mollusc Intraclast facies.

3.3. Effect of the BPZ on benthic community composition

3.3.1 Statistical analysis

Both sedimentary facies and inside/outside BPZ significantly affected community composition by weight of individual species (Table 2). The interaction between sedimentary facies and inside/outside the BPZ was also significant (Table 2). Pair-wise *a posteriori* comparisons demonstrated that community composition was significantly different between sites located inside and outside the BPZ in three of four of the sedimentary facies: Branching Bryozoan, Intraclast and Quartzose Skeletal (Table 3).

The nMDS plot is consistent with the results of NPMANOVA and the pair-wise *a posteriori* comparisons, with sites located inside BPZ tending to group separately from those located outside the BPZ (Fig. 8).

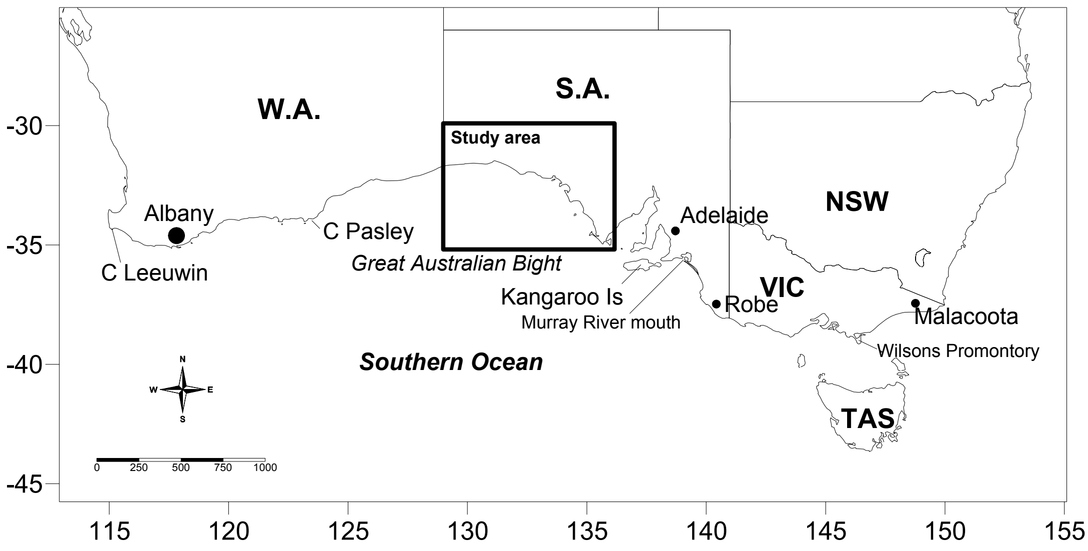
3.3.2 Biomass

The mean biomass was marginally higher inside the BPZ than outside the BPZ in three of the four sedimentary facies: Quartzose Skeletal, Intraclast and Intraclast Bryozoan (Fig. 9). Poriferans were the most abundant taxonomic group (by weight) in all four sedimentary facies located inside the BPZ and in the Quartzose Skeletal, Intraclast and Branching Bryozoan facies outside the BPZ (Fig. 10). Bryozoans were marginally more abundant than poriferans in the Intraclast Bryozoan facies outside the BPZ.

3.3.3 Taxonomic composition

A total of 432 species were collected from the 20 sites within the BPZ compared to 300 from the 20 sites outside the BPZ. Mean number of species collected from the sites within the BPZ was marginally higher than the number collected outside the BPZ in all four of the sedimentary facies. Similarly, the mean Shannon's Index was marginally higher at sites inside the BPZ in all four sedimentary facies (Fig. 9).

In general, more species belonging to each major taxonomic group were collected from sites located inside the BPZ than those outside the BPZ, especially in the Quartzose Skeletal and Intraclast facies. Poriferans and Bryozoans were common in all facies. Ascidians and Cnidarians were also important in the Intraclast Bryozoan and Branching Bryozoan facies (Fig. 11).



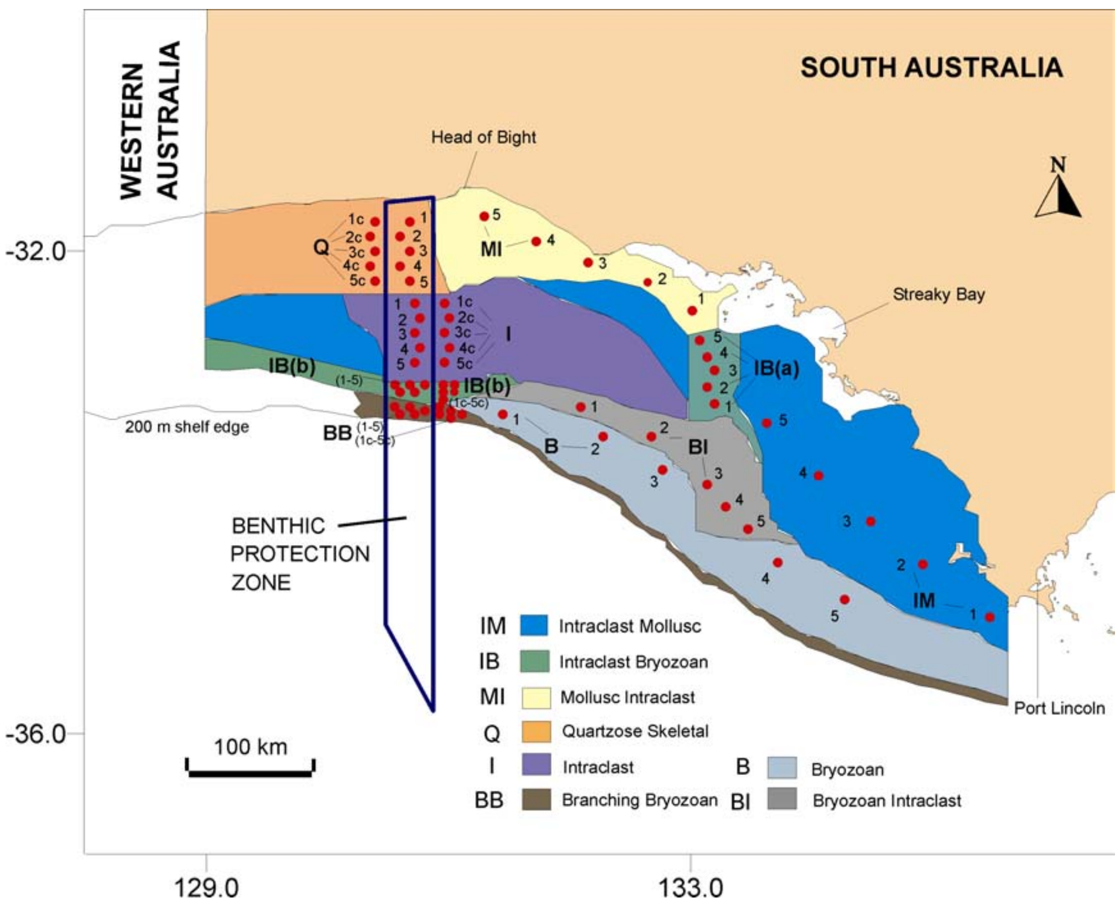


Figure 1. Location of study area, sedimentary facies (adapted from James *et al.* 2001) and Benthic Protection Zone of the Great Australian Bight Marine Park. Red dots indicate sites that were sampled with epibenthic sled. Sites located adjacent to the BPZ are labelled with "c" for "control".

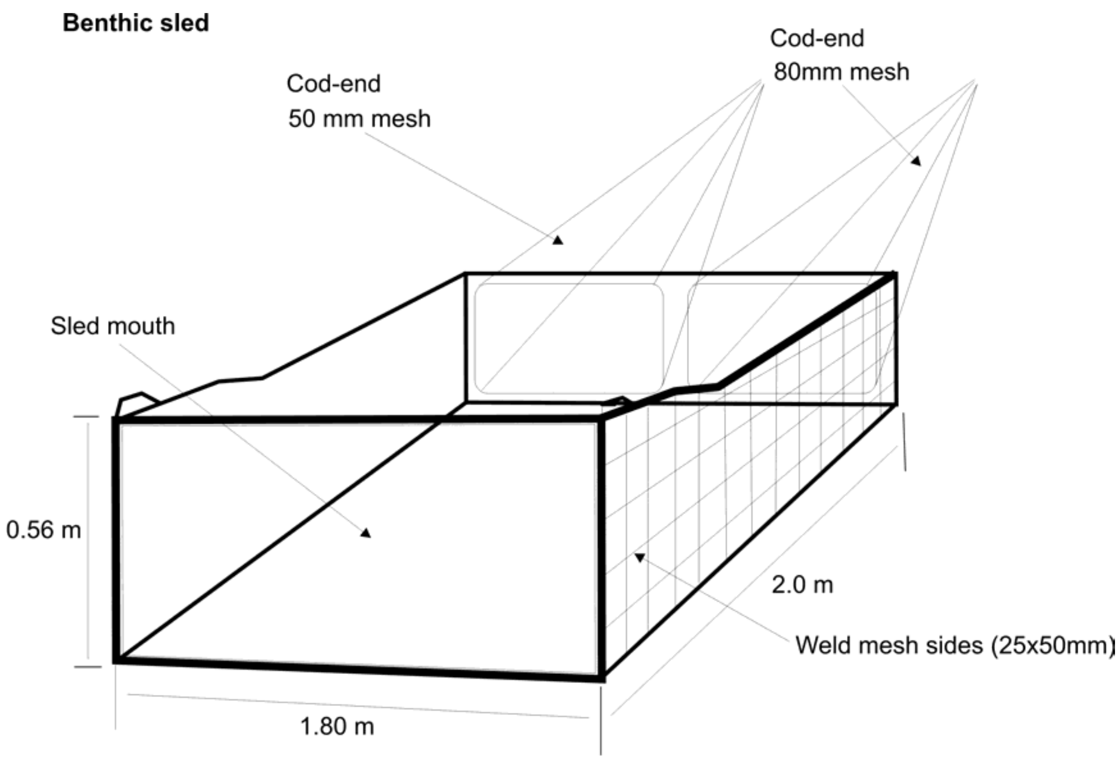


Figure 2. Diagram of the epibenthic sled used to collect samples at each site.

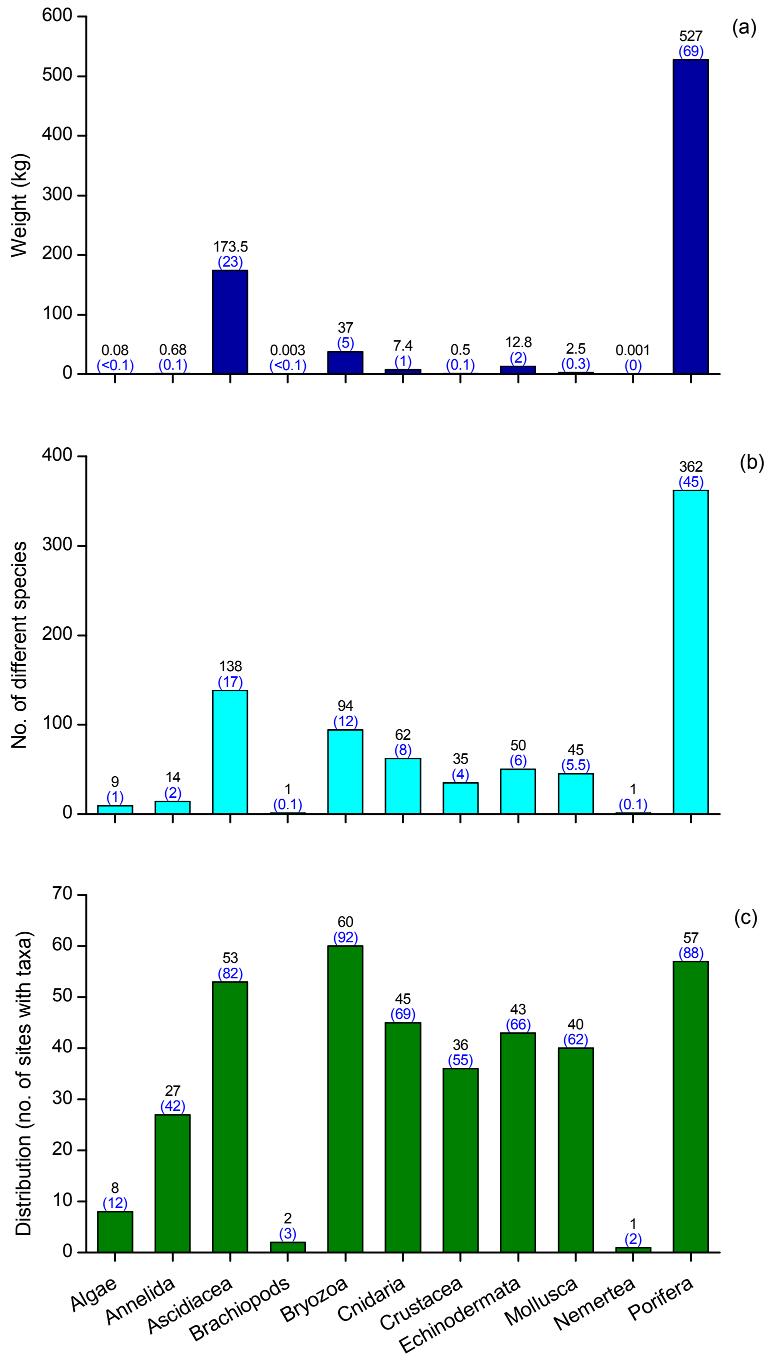


Figure 3. Total (a) weight and (b) number of species of each major taxonomic group collected during the survey, and (c) the total number of sites (out of 65) at which specimens belonging to each major group were collected. The numerical value and percent (in brackets) are shown above each bar.

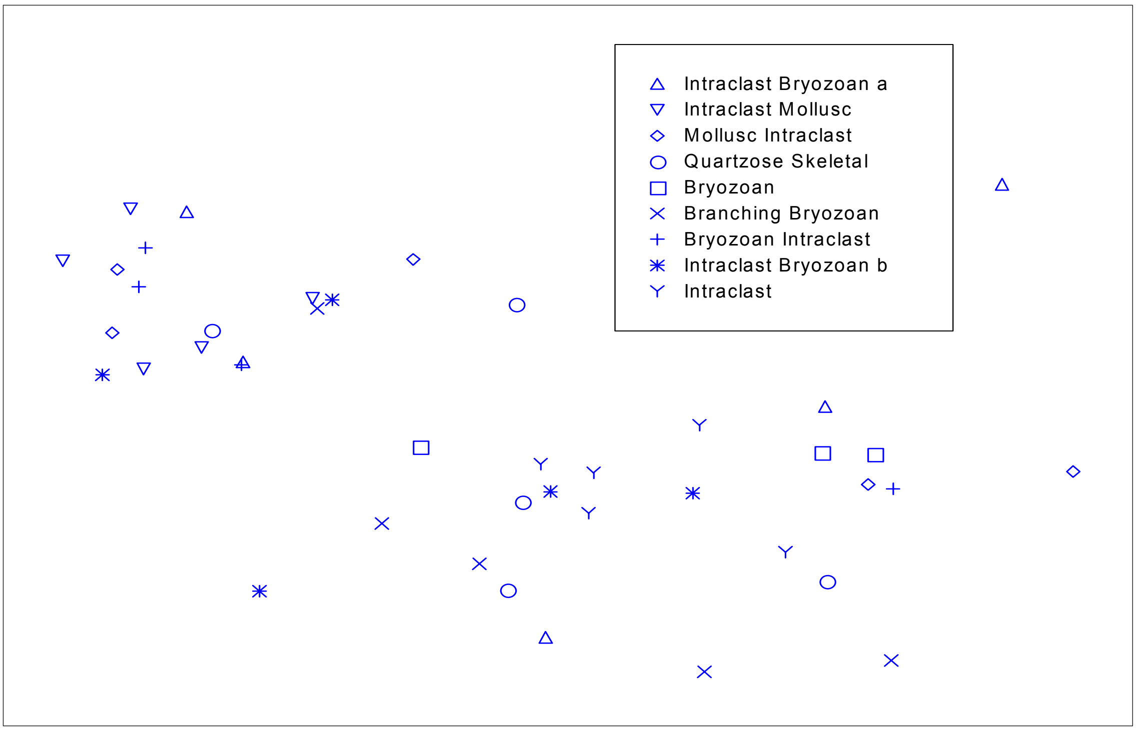


Figure 4. MDS plot of community composition based on weight of individual taxa in each sedimentary facies (stress = 0.16).

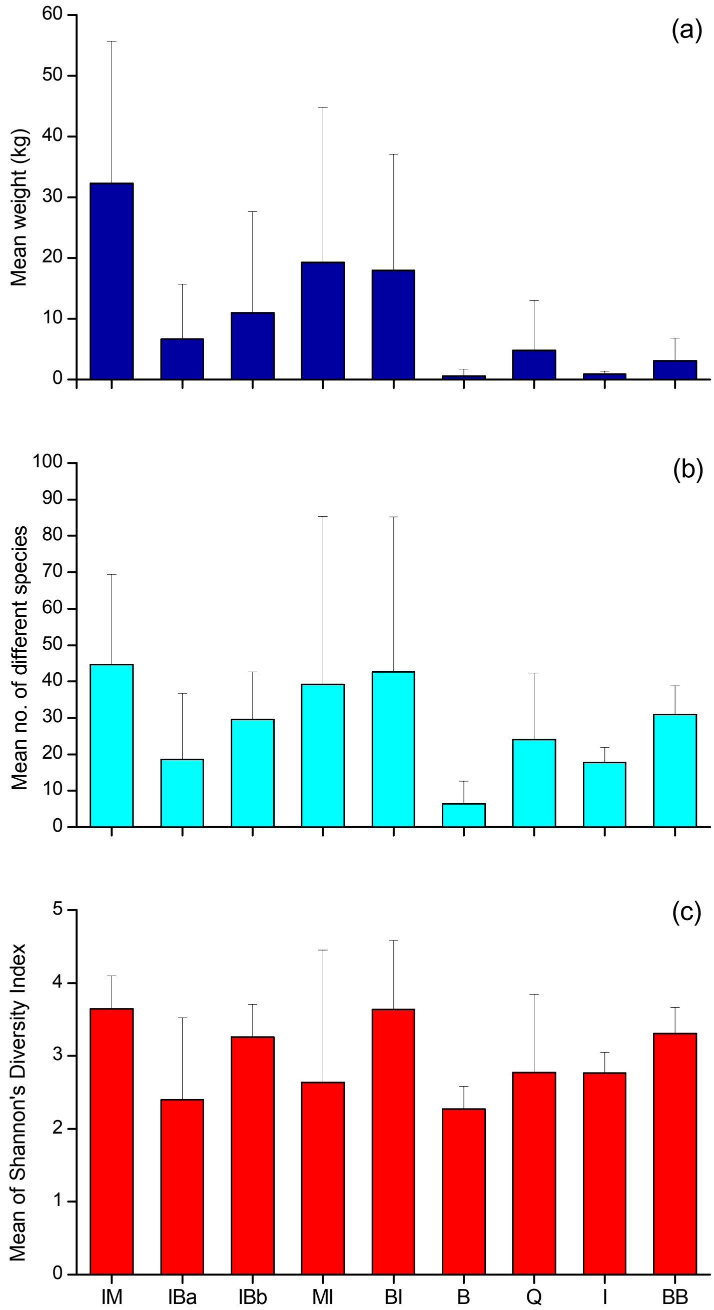


Figure 5. Mean (±SD) (a) weight, (b) number of species and (c) Shannon's Diversity Index for each site in each sedimentary facies sampled during the survey. (Sediment codes: IM = Intraclast Mollusc; IB = Intraclast Bryozoan (a and b); MI = Mollusc Intraclast; BI = Bryozoan Intraclast; B = Bryozoan; Q = Quartzose Skeletal; I = Intraclast; BB = Branching Bryozoan).

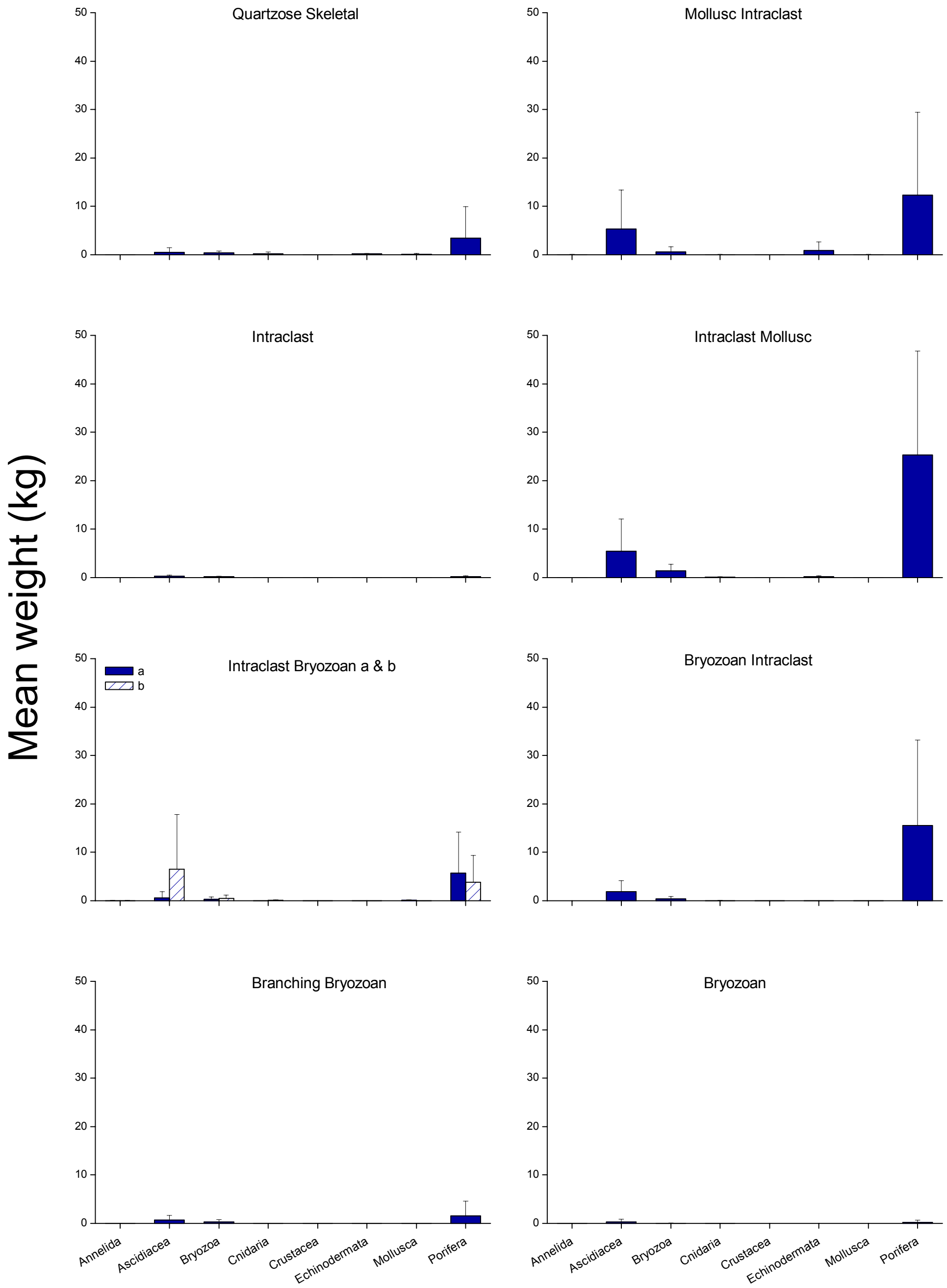


Figure 6. Mean weight (+SD) of each major taxonomic group within each sedimentary facies (for samples taken outside Benthic Protected Zone only).

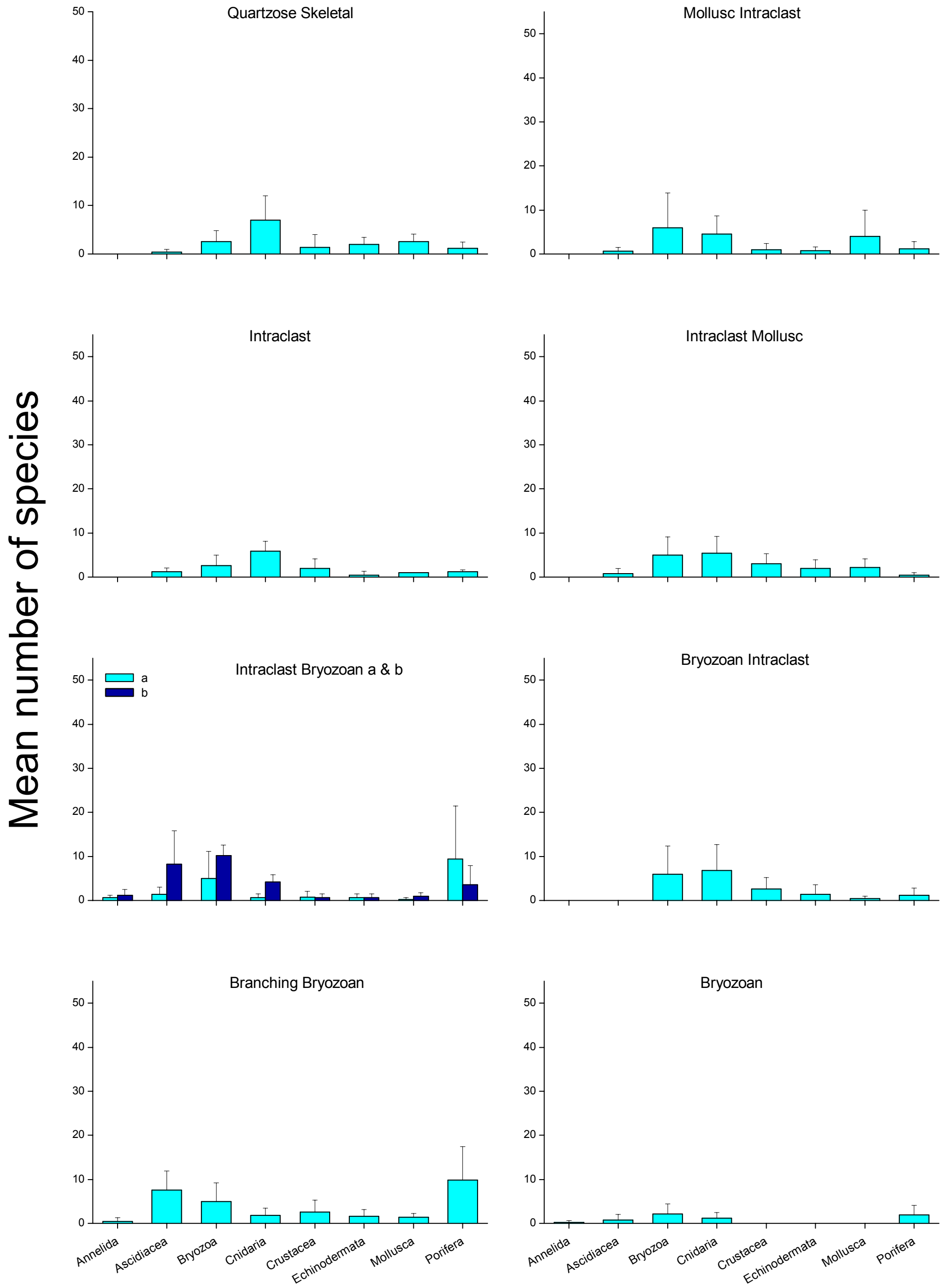


Figure 7. Mean number (±SD) of different species at each site in each sedimentary facies sampled in the GAB.

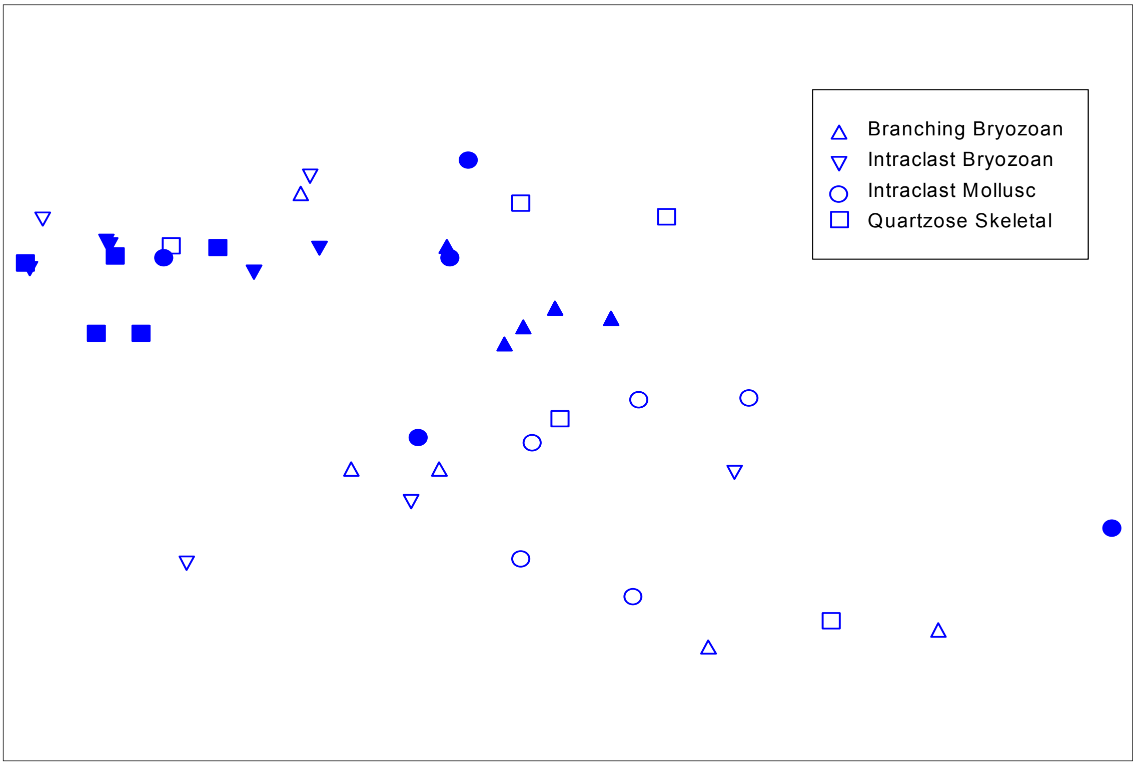


Figure 8. MDS plot of community composition based on weight of individual taxa in each sedimentary facies inside and outside the Benthic Protection Zone. Solid and open symbols are for sites inside and outside the Benthic Protection Zone respectively (stress = 0.18).

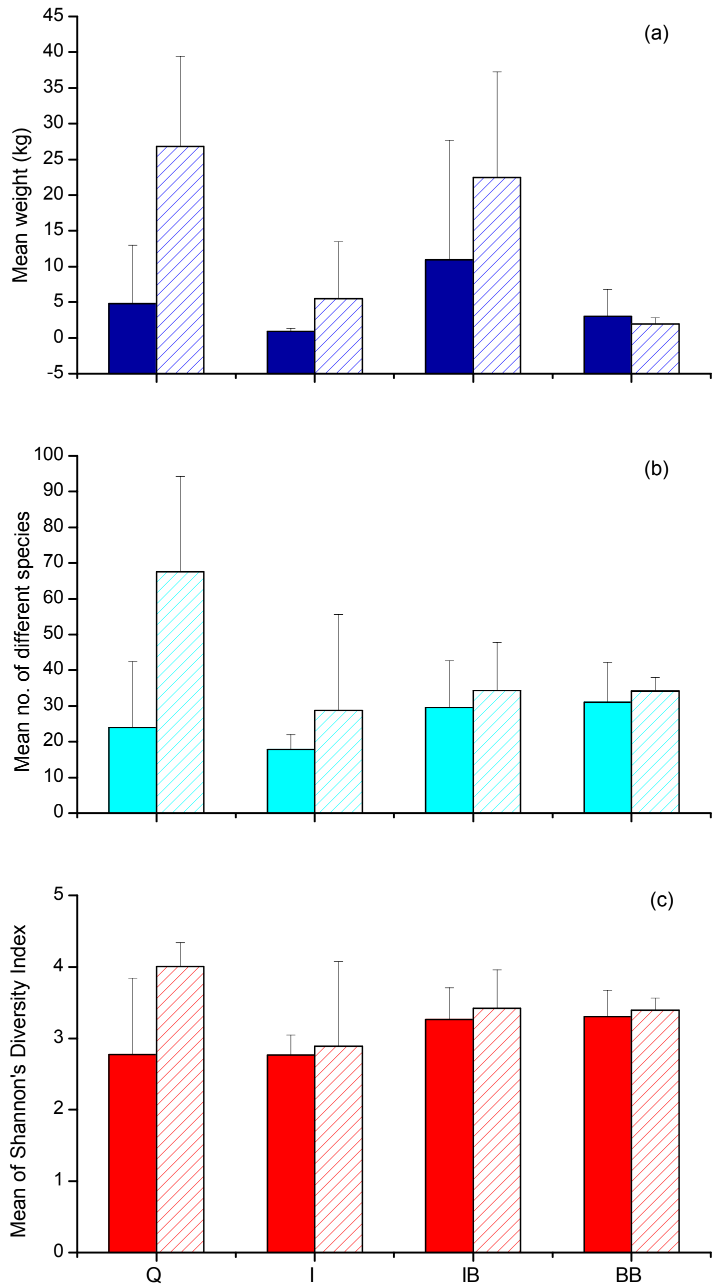


Figure 9. Mean (±SD) (a) weight, (b) mean number of species and (c) Shannon's Diversity Index per site for each sedimentary facies outside (solid bars) and inside the Benthic Protected Zone.

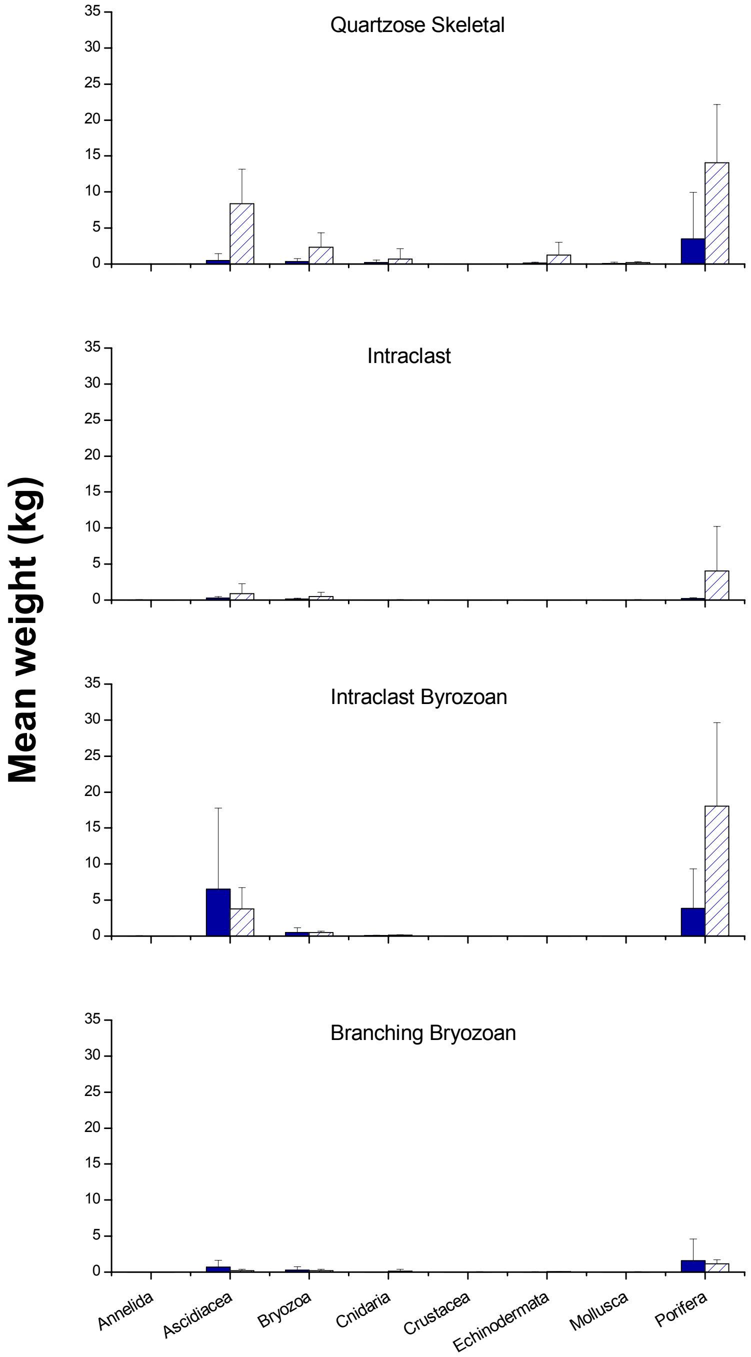


Figure 10. Mean weight (±SD) per sample for each major taxonomic group in each sedimentary facies outside (solid bar) and inside the Benthic Protected Zone.

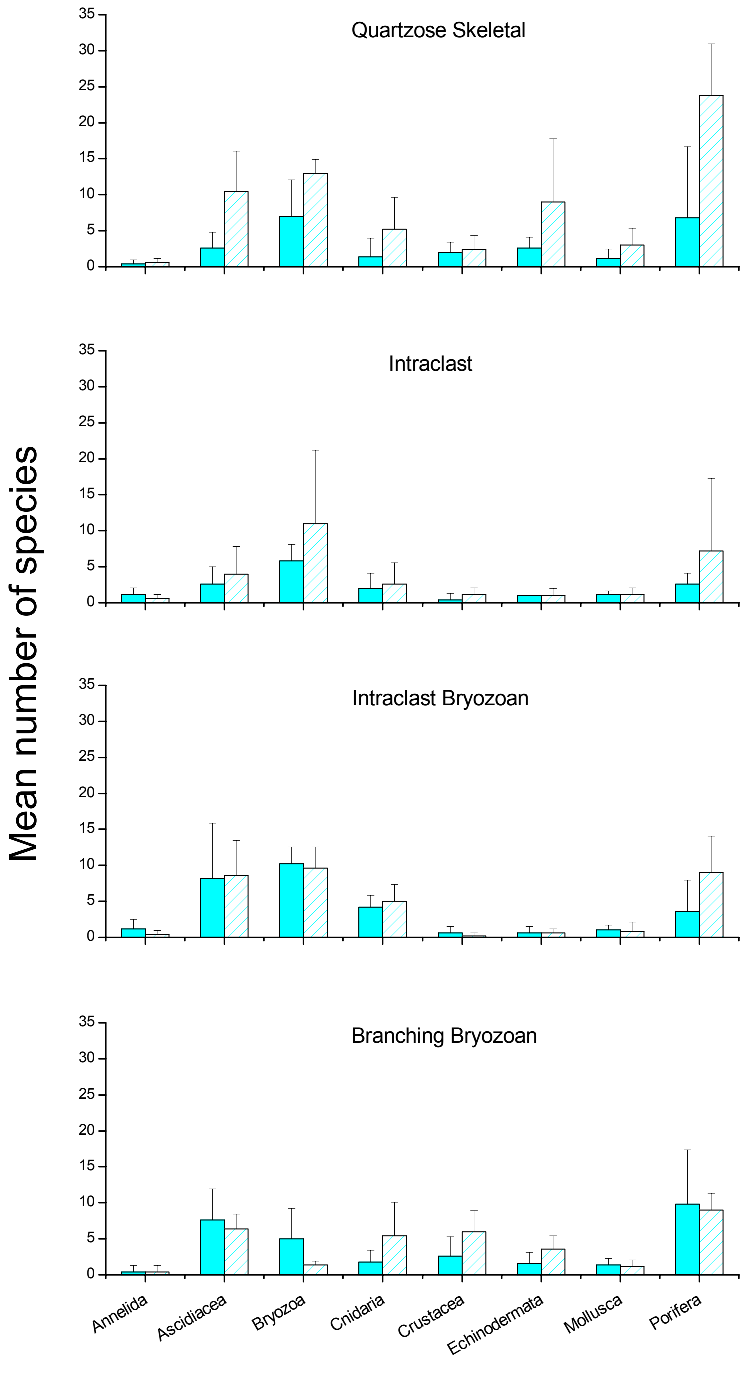


Figure 11. Mean number of species (+SD) per sample for each major taxonomic group in each sedimentary facies outside (solid bar) and inside the Benthic Protected Zone.

Table 1. Number of species from each feeding guild in each taxonomic group.

Taxonomic group	Number of species in feeding guild		
	Suspension feeder	Deposit feeder	Scavenger/ carnivore
Porifera	362	-	-
Cnidaria	62	-	-
Nemertea	-	-	1
Annelida	5	-	9
Crustacea	-	-	35
Mollusca	22	16	7
Brachiopoda	1	-	-
Bryozoa	94	-	-
Echinodermata	9	16	25
Ascidiacea	138	-	-
Total	693	32	77
(%)	(86%)	(3.9%)	(9.6%)

Table 2. Results of NPMANOVA on community composition by weight of individual species. Bold *P*-values indicate significant differences in community composition in relation to the factors shown ($P<0.05$).

Source	*df*	*SS*	*MS*	*F*	*P*
Effect of sedimentary facies					
Sedimentary facies	8	40680.53	5085.066	1.5238	***0.0195***
Residual	36	120137.9	3337.164		
Total	44	160818.4			
Effect of depth					
Depth	2	5306.137	2653.069	0.7624	*0.6823*
Residual	21	73074.79	3479.752		
Total	23	78380.93			
Effect of sedimentary facies and inside/outside the BPZ					
Sedimentary facies	3	18589.01	6196.338	2.6797	***0.0022***
Inside/Outside BPZ	1	10714.15	10714.15	4.6335	***0.0001***
Sediment*Inside/Outside	3	15129.3	5043.099	2.181	***0.0044***
Residual	32	73994.88	2312.34		
Total	39	118427.3			

Table 3. Pair-wise *a posteriori* tests for differences in community composition inside and outside the BPZ. Inside/outside BPZ was nested within sedimentary facies and found to be significant ($P<0.05$) in all cases except for the Intraclast Bryozoan facies. *P- values adjusted for multiple comparisons based on Legendre and Legendre (1998).

Sedimentary facies	*t*	*P*
Branching Bryozoan	1.5473	***0.0210***
Intraclast Bryozoan	1.3283	0.1411
Intraclast	1.7266	***0.0244***
Quartzose Skeletal	2.0271	***0.0478***

4. DISCUSSION

4.1 Benthic community differ among sedimentary facies

This study provides evidence that the spatial patterns of benthic community composition in the GAB, as measured by the weights of individual species, reflect the spatial distribution of the sedimentary facies. Similar associations between sediments and communities of benthic species have been reported in other benthic ecosystems (e.g. Weston 1988; Maurer *et al*. 1994). These relationships have generally been interpreted as resulting from the effects of sediment characteristics on the survival and reproduction of different groups of organisms (e.g. Weston 1988), whereas this relationship may exist in the GAB because the sedimentary facies are comprised largely of biogenic components derived from the local benthic communities (James *et al.* 2001). The difference reflects that lack of terrigenous sediments in the region.

As a result of their origin, information on the composition of the sedimentary facies presented by James *et al.* (2001) provides valuable insights into the composition of benthic communities that overlay these facies. However, not all taxa contribute equally to sediment development and taxa with large skeletal elements, such as bryozoans, molluscs and echinoderms, are over-represented in sediments compared to their abundance in the epibenthic communities. Hence, whilst James *et al.* (2001) showed that molluscan fragments dominate sediments of the inner and middle shelf and that bryozoan elements dominate outer shelf sediments, results of the present study indicate that poriferans and ascidians dominate most benthic communities in these parts of the GAB, comprising 69% and 23% of the benthic biomass, respectively. Images of the seafloor communities presented and described by James *et al.* (2001) support this assessment.

4.2 Benthic communities of the eastern GAB

The eastern GAB between Cape Catastrophe and Venus Bay is characterised by strong upwelling and enhanced productivity during summer and autumn (T.M. Ward, unpublished data). Large quantities of biomass (>30 kg/site) comprised of numerous species (>40 per site), (mainly poriferans, ascidians, echinoderms and bryozoans), were collected from sites in the Intraclast Mollusc facies that comprises the inner and middle shelf in this area. These findings are not consistent with the seafloor images described by James *et al.* (2001), which show “a rippled sand plain with little epibenthos”. This apparent anomaly may reflect the high level of spatial heterogeneity in community composition within this (and other) sedimentary facies in the GAB, where “islands” of profuse epibenthos are distributed haphazardly across extensive areas of relatively barren soft substrates.

Large quantities of biomass (>18 kg/site) comprising relatively high numbers of species (>40 per site) were also collected from the inner shelf Mollusc-Intraclast Sand and middle shelf Bryozoan-Intraclast Sand facies of the central GAB. The biomass collected from these facies was dominated by poriferans and ascidians. However, over 5 species of bryozoans and echinoderms were collected from each site in the Mollusc Intraclast facies and over 7 species of bryozoans were collected from each site in the Bryozoan-Intraclast Sand facies. The findings for the Bryozoan Intraclast facies are consistent with the observations of James *et al*. (2001), which suggest that this is an area with significant rocky outcrops and prolific epibenthic growth, including numerous sponges and diverse bryozoans, hydroids and ascidians. James *et al*. (2001) did not provide qualitative descriptions of the communities of the Mollusc-Intraclast Sand facies.

The Intraclast Bryozoan facies of the middle shelf of the eastern (IBa) and central (IBb) GAB also support relatively high quantities of biomass (>7 kg/site) and large numbers of species (>18/site). The significant quantities of poriferans, ascidians, bryozoans and cnidarians collected from these facies during this study are consistent with suggestions by James *et al*. (2001) that the hard substrates in this region support sponges, bryozoans, gorgonians and solitary corals. Apparent differences between the communities on the Intraclast Bryozoan facies in the eastern (IBa) and central (IBb) GAB may reflect the high levels of spatial heterogeneity within these facies, but these differences warrant further investigation.

In this study, the Quartzose Skeletal and Intraclast facies of the inner and middle shelf of the central GAB, respectively, were each found to support relatively low quantities of biomass (<6 kg/site) and moderate numbers of species (15-25/site), mainly poriferans, ascidians and bryozoans. James *et al*. (2001) also suggested that the Quartzose Skeletal facies was characterised by relatively few epifaunal organisms, with poriferans, ascidians and bryozoans covering only ~5% of the surface, and the remainder consisting of monotonously rippled sand and a few “islands” of profuse epibenthos. James *et al*. (2001) also suggested that epibenthic growth in the Intraclast facies was scattered and not clustered, and comprised mainly of long, thin sponges, hydroids and bryozoans.

The Bryozoan and Branching Bryozoan facies of the outer shelf and upper slope, respectively, each supports relatively low quantities of biomass (<5 kg/site) and moderate numbers of species (25-30/site). However, many of the species collected from the Branching Bryozoan facies were too small to be counted using the rapid assessment technique employed in the study and the diversity of this area may be higher than suggested by our results. In the Bryozoan facies, the rippled sand supports scattered colonies of bryozoans and hydroids, and rare islands of hard substrate that are covered by a dense growth of poriferans, bryozoans, hydroids and ascidians (James *et al*. 2001). In contrast, James *et al*. (2001) suggested that the Branching Bryozoan facies is covered by a uniform growth of tiny suspension-feeders, mainly poriferans. In the present study, numerous species of calcareous sponges were collected from the Branching Bryozoan facies.

4.3 Comparison with other benthic communities

Despite the large mesh size of the sled (50 mm) and limitations of the rapid assessment technique used in this study, the total number of species recorded was relatively high, with 811 species being collected from 65 10-minutes tows. In contrast, 334 and 456 species were collected from 63 and 270 5-minute tows respectively using a 2 m beam trawl (4 mm mesh) in the North Sea (Jennings *et al*. 1999; Callaway *et al*. 2002). A total of 846 species was collected from 107 15-minute tows using a 3 m beam trawl (30 mm mesh) in the Gulf of Carpentaria (Long *et al*. 1995). Given the limitations of the rapid assessment techniques used in this study, the 362 poriferans, 138 ascidians and 94 bryozoans collected suggest that the species richness of the GAB is at least comparable to the "extraordinarily high numbers of species" including 294 poriferans, 92 ascidians and 321 bryozoans that Dell (1972) reported from numerous surveys of the Antarctic shelf (Long *et al*. 1995). Hence, the GAB appears to support one of the world's most diverse soft-bottom communities.

The high species richness of the Antarctic communities has been attributed to the wide circumpolar distribution of many species (Arntz *et al*. 1994), whereas the biodiversity of the GAB has been attributed to the unusual width of the continental shelf, high degree of geographic isolation and opportunities for incursions by tropical species afforded by the Leeuwin Current (Andrew 1999). A recent review of the BPZ of the GABMP suggests that the high biodiversity of the GAB may reflect presence of temperate species with eastern and western Australian affinities, as well as "tropical stragglers" from northern regions. As the Antarctic and Australian landmasses were joined until the Late Cretaceous, the divergent explanations of the high diversity of the two regions may warrant further consideration. Formal assessments of the taxonomic similarities of the benthic fauna of the two regions may be informative in this regard. Certainly, the results of our study support the assertion by Long *et al.* (1995) that the simple link identified for the sub-tidal communities between species richness and latitudinal gradients (Longhurst and Pauly 1987; Alongi 1990) is not replicated in shelf communities and that the relationship between species richness, geographical location and environmental factors in these habitats is complex.

Comparing the species richness and composition of different benthic communities is also complicated by the effects of anthropogenic activities, such as demersal trawling, on these parameters. Trawling causes significant mortality of many benthic organisms, with sessile organisms being particularly vulnerable (Kaiser *et al* 2000). For example, pair trawling on the North West Shelf between 1959 and 1989 significantly reduced the abundance of poriferans, alcyonarians and gorgonians (Sainsbury *et al*. 1987). Similarly, beam trawling in the North Sea and Gulf of Alaska has significantly reduced the abundance of sessile organisms in these areas (Freese *et al*. 1999; Frid *et al.* 2000). The effects of trawling on the species richness and composition of benthic communities can often be difficult to distinguish from the effects of habitat characteristics and natural disturbance. This is because trawling effort can focus, depending on the target species, on communities and areas with significant vertical structure and high species richness and diversity, or those with relatively few sessile organisms and lower diversity. For example, the pair trawlers on the North West Shelf initially targeted the diverse sponge communities that supported significant quantities of the tropical snappers, *Lethrinus* and *Lutjanis* (Sainsbury *et al*. 1987), whereas prawn trawlers in the western Gulf of Carpentaria focus their activities on muddy substrates that support relatively few sessile organisms but high densities of several species of penaeid prawns (Pownall 1994). The effects of anthropogenic on the benthic communities of the GAB are unknown.

The dominance of colonial animals (i.e. poriferans, ascidians and bryozoans) in samples obtained during this study (collectively over 96.5% of the biomass and 72.5% of the species), reflects several aspects of the sampling program. Perhaps most importantly, most of the samples were collected from the middle and outer shelf, which provides ideal habitat for these groups, being both below the euphotic zone and unsuitable for fast-growing macroalgae which commonly out-compete these taxa in shallow water (Bergquist and Skinner 1982). In addition this habitat is sufficiently deep to provide some protection from most surge events, thus allowing these organisms to grow to relatively large sizes. In addition, the rapid assessment technique that was used in this study, which excluded epibionts and specimens less than 1 cm long, tends to favour large, colonial taxa over smaller, unitary species.

The dominance of poriferans and ascidians over bryozoans in terms of biomass can also be explained partially by the methodologies used in this study. Fragile organisms, like bryozoans, are more likely to be broken and lost through the meshes of the sled during retrieval than more robust taxa such as poriferans and ascidians. Furthermore, the use of wet weight to characterise species abundance favours taxa, such as poriferans and ascidians, that contain large quantities of water over taxa, such as bryozoans, that do not.

The overwhelming dominance of the benthic biomass of the GAB by sessile suspension-feeding organisms (Table 2) is, however, relatively unusual. Many epibenthic communities, e.g. in the Black and North Seas and on the Amazonian shelf, include more deposit-feeders and scavengers/carnivores than the GAB (e.g. Aller and Stupakoff 1996; Wijsman *et al.* 1999; Callaway *et al*. 2002). However, sessile suspension-feeders, including poriferans, ascidians and cnidarians, are important and/or dominant components of the coarse sediment communities of the eastern Gulf of Carpentaria (Long *et al.* 1995), outer Great Barrier Reef lagoon (Blaber *et al.* 1993), North West Shelf (Sainsbury 1987) and parts of the Ross and Wedell Seas of Antarctica (Bullivant 1967; Starmans *et al*. 1999). Several authors have noted that the abundance of suspension feeders is often low on muddy sediments and near river mouths, where the filtering apparatus may be clogged by high concentrations of suspended solids near the bottom (Long *et al.* 1995; Aller and Stupakoff 1996; Wijsman *et al.* 1999). Hence, the unusual prevalence of poriferans, ascidians and bryozoans in the GAB may reflect the very coarse sediments and conspicuous lack of fluvial inputs to the region (e.g. James *et al* 2001). Plankton blooms associated with upwelling in the GAB during summer and autumn that enhance primary and secondary productivity may also increase food availability and help to explain the dominance of sessile filter-feeder organisms in the GAB (Griffin *et al.* 1997; T. Ward, unpublished data).

Few free-living deposit-feeding organisms were collected during this study. For example, echinoderms and molluscs, comprised only 2% of the biomass and 11.6% of the species collected, whereas these taxa often dominate benthic communities located on inshore muddy sediments adjacent to large rivers, such as the Amazon and Danube (Aller and Stupakoff 1996, Wijsman *et al.* 1999). Many more free-living species would have been recorded in this study if a smaller mesh had been used on the sled (Kingsford and Battershill 1998) and epibionts and specimens less than 1 cm long had been identified and counted. However, these factors do not completely explain the unusually low numbers of deposit-feeding organisms collected. The most likely explanation for the paucity of these taxa is that the lack of terrigenous organic inputs into the sediment limits the food available to deposit-feeders (e.g. Wijsman *et al.* 1999).

Whilst most of the benthic species occurring in northern Australia are widely distributed in the Indo-West Pacific, the benthic communities of the GAB are renowned for their high levels of endemism. Results of this study support this view, but also emphasise the difficulties associated with quantifying the level of endemism for the region, or the links to the fauna of other regions, such as Antarctica. The putative species collected in this study (especially the poriferans) need to be assigned to existing taxa before the level of endemism for GAB species can be estimated with any degree of confidence. This process will be complicated by the need to describe many of the taxa collected during the study. At least two species of asteroids (families uncertain, Dr

Mark O'Loughlin, Museum Victoria, pers. comm.), two genera and four species of soft coral (families Plexauridae, Alcyoniidae, Isididae, Clavulariidae; Dr Phil Alderslade, Museum and Art Gallery of the Northern Territory, pers. comm.) and several of the poriferan species collected belong to undescribed taxa.

4.4. Suitability of BPZ for representing and protecting benthic communities of the GAB

The results of this study suggest that the BPZ is well placed to represent the benthic biodiversity of the eastern and central GAB. As well as including four of the eight sedimentary facies that occur on the shelf in the region, over half (i.e. 432 or 53%) of the 811 species obtained during this study were collected from the BPZ. Whether additional protected areas are needed to represent and preserve the benthic communities that occur in the Mollusc Intraclast, Intraclast Mollusc, Bryozoan Intraclast and Bryozoan sedimentary facies, and which are not included in the BPZ, remains unknown. This question will only be resolved by conducting extensive and intensive surveys of the benthic communities of the entire GAB.

Although benthic community composition was significantly different between sites located inside and outside the BPZ, the zone appears to be suitable for representing the communities of the four sedimentary facies that occur in the GABMP (i.e. the Quartzose, Intraclast, Intraclast Bryozoan and Branching Bryozoan facies). This is because in each facies the mean species richness and mean diversity indices were higher at sites located inside the BPZ than those located adjacent to the BPZ. In addition, the mean biomasses per site were higher inside than outside the BPZ in three of the four facies. Perhaps most importantly, a total of 432 species was collected from the 20 sites located inside the BPZ whereas only 300 species were collected from the 20 sites located adjacent to the BPZ. These results show that ongoing assessment of the performance of the BPZ is warranted because its benthic communities include a significant proportion of the species that occur in the GAB and appear to represent the communities of the Quartzose, Intraclast, Intraclast Bryozoan and Branching Bryozoan facies effectively.

The different levels of biomass and biodiversity recorded at sites located inside and adjacent to the BPZ have implications for future performance assessment and warrant further investigation. As the BPZ has only been established since 1998, and the prohibition of demersal trawling has been only partially successful (Ward *et al.* 2003), it seems unlikely that these differences reflect the (partial) protection of benthic communities resulting from the establishment of the BPZ. It seems more likely that this divergence reflects underlying ecological differences between the BPZ and adjacent areas. Such differences could limit, or at least affect, the use of areas outside the BPZ as spatial "controls" in future assessments of the effectiveness of the BPZ in protecting biodiversity. Hence, studies of the factors controlling these differences are needed.

4.5 Future performance assessment of the BPZ

Assessment of the effectiveness of marine protected areas in preserving benthic communities should ideally involve a "Before and After Controlled Impact" approach (Underwood 1994), where the "impact" is defined as the management action that limits anthropogenic activities within the experimental or managed site, in this case the BPZ. This approach cannot be taken for performance assessment of the BPZ, as no data are available on the structure of the benthic communities of the BPZ prior to the establishment of the GABMP. In the absence of this "before impact" data, performance assessment of the BPZ must necessarily involve (i) comparison of benthic communities inside the BPZ with those in adjacent areas; (ii) measurement of changes over time in the benthic communities within the BPZ; and (iii) most importantly, measurement of the difference in the changes in the benthic communities that occur over time at sites located inside and outside the BPZ (i.e. the time*location interaction effect).

By comparing the benthic communities of the BPZ and adjacent areas, the present study has effectively completed the first stage of a performance assessment of the type described above. To provide a basis for measuring both changes in the benthic communities within the BPZ over time and the difference between temporal changes that occur inside and outside the BPZ, any future survey that is conducted must (at least) include re-sampling the same 40 stations inside and outside the BPZ that were sampled during the present study using the same sampling method (i.e. the epibenthic sled). Data obtained by simply re-sampling these 40 stations with the epibenthic sled would provide the basis for completing a preliminary performance assessment of the BPZ. Repeating this survey periodically (e.g. 3-5 years) would represent the low cost option for ongoing assessment of the effectiveness of the BPZ in protecting the benthic communities of the Quartzose, Intraclast, Intraclast Bryozoan and Branching Bryozoan facies.

For an ongoing system for assessing the performance of the BPZ to be successful, it is essential that it includes the analysis of high quality data on all potentially deleterious anthropogenic activities, including fishing and mining, that occur in the region (see Ward *et al.* 2003). Data on these activities are essential because they provide a context for assessing the potential agents of any changes in benthic community composition that may occur in the future. The monitoring systems that are established must provide detailed information on both the nature of the activities undertaken and the locations where the activities occur, and at the very least must distinguish between activities undertaken inside and outside the GABMP (Ward *et al.* 2003). For future performance assessment of the BPZ to succeed, it will also be necessary to ensure that activities which are prohibited from the BPZ, such as demersal trawling, but which appear to have continued in the zone (Caton 2002; Ward *et al.* 2003) are both monitored and controlled effectively.

As well as re-sampling the 40 stations examined during the present study using the epibenthic sled, future surveys that are conducted to assist performance assessment of the BPZ should also include several other elements. For example, it would be useful to simply sample more sites located inside and outside the BPZ in order to develop a better understanding of spatial heterogeneity within each sedimentary facies. It would also be useful to sample (replicated) sites located along latitudinal transects that include BPZ and surrounding areas, in order to determine if differences observed in the present study among sites located inside and outside the BPZ reflects east-west environmental gradients that exist within the facies. It would also be useful to utilise additional sampling methods, especially video imagery, as this non-destructive sampling tool could potentially replace the epibenthic sled when the taxonomy of the benthic communities of the GAB becomes better known.

The overall lack of ecological information for the GAB noted by McLeay *et al.* (2003) suggests that future surveys of the region would, ideally, not be confined to the BPZ and adjacent areas, but would include the benthic communities of the entire GAB. This is because, as well as being highly diverse and containing an usually high proportion of species that are endemic to southern Australia (McLeay *et al.* 2003), the GAB supports one of Australia's most productive and valuable marine ecosystems (Ward *et al.* 2003). An extensive and intensive benthic survey of the GAB would not only provide a basis for assessing whether or not additional marine protected areas are required to effectively represent and protect the regions biodiversity, but would provide a scientific basis for future regional marine planning of this important area.

A comprehensive study of the benthic communities of the entire GAB would ideally utilise a wide range of sampling techniques, including swathe mapping, video imagery, benthic grabs (to sample sediments and infauna) and fish trawls (ideally comparable to the commercial gear used by GAB trawlers), as well as the epibenthic sled used in the present study. The application of this diverse range of techniques over the entire GAB, including the continental slope, would require the use of a large ocean-going research vessel, such as the MRV *Southern Surveyor*, which is now available for use as a national research facility. A large-scale study of the type described above would also need to involve a more rigorous approach to sorting and identifying species than the rapid assessment technique that was (necessarily) used in the present study. This approach would include the identification of epibionts and specimens <1 cm long and would require the allocation of significant resources to resolving the taxonomy of GAB species. Conducting an extensive and intensive survey of the entire GAB would be expensive, but would also provide significant benefits, including addressing the need for scientific information to support the management of key marine environments identified in Australia's Ocean's Policy and Australia's Marine Science and Technology Plan.

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