SPATIAL PATTERNS IN THE MACROBENTHIC FAUNA OF MANGROVE FORESTS IN THE BRISBANE WATER ESTUARY

PREPARED FOR

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December 2006

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INTRODUCTION

Estuaries are highly productive systems and their sediments are permanently or periodically inhabited by diverse assemblages of benthic organisms (Day et al., 1987). These organisms range in size from the minute bacteria and protozoans to larger colonial animals termed the macrobenthos. Macrobenthic organisms in estuarine waters are generally diverse (usually > 100 species) and most species are relatively sedentary (Day et al., 1987; Poore, 1992). They are represented by different types of feeding groups, i.e., epifaunal suspension-feeders, infaunal suspension feeders, surface deposit feeders, grazers, predators and scavengers, with suspension-feeders and deposit-feeders generally dominating the assemblages (Cummins et al., 2004).

Benthic invertebrates can have a profound effect on the sedimentary environment, through their feeding, burrowing, and ventilatory activities (Day et al., 1987; Bird et al., 1999). In particular, they play a vital role in the storage, transformation and release of nutrients (i.e. nutrient cycling) to the overlying water column (Coull, 1999; Cummins et al., 2004).

Australian estuaries have been under pressure from urbanisation since European colonisation and the aquatic communities that inhabit these estuaries have been subjected to a variety of stresses arising from contamination and nutrient enrichment. Physical disturbances associated with construction, recreational activities and dredging have also impacted negatively on a wide range of assemblages of estuarine organisms. The clearing and destruction of wetlands such as mangroves and saltmarshes has caused major impacts to the fauna that rely on them to provide habitat, shelter and as a source of food.

Anthropogenic disturbance has the potential to alter the structure and dynamics of marine communities (Warwick, 1993), which can manifest as increased variability in the diversity and abundance of marine organisms at different spatial and temporal scales (Warwick and Clark, 1993). Macrobenthic organisms are sensitive to anthropogenic disturbance, which can make them an ideal bio-indicator of potential environmental impact (Underwood et al., 2003).

In this study, the macrobenthic fauna inhabiting the mangrove forests within the Brisbane Water estuary were examined. For the purposes of this study, the macrobenthic fauna were considered to be those animals that were retained on a 0.5 mm sieve. The study focussed on quantifying patterns in the richness and abundance of macrobenthic fauna at a hierarchy of spatial scales. The collection of these data on spatial patterns was considered as a necessary first step in developing models about ecological processes within the estuary (Underwood et al., 2000).

METHODS

Fifteen locations were sampled in the Brisbane Water estuary to examine the variability in macrobenthic invertebrates within the mangrove forests at a number of spatial scales (see Table 1, Fig. 1). Two randomly nested sites were sampled at low tide at each location. Many of the mangrove locations were situated on the edge of the estuary and at some locations the fringing forest was quite narrow. Therefore, each site was generally chosen to cover an area of approximately 50 m of shoreline, extending back around 30 m into the forest.

Three replicate benthic sediment cores (10 cm diameter and 10 cm deep) were taken at each site to determine the diversity and abundance of macrobenthic fauna. These sediment samples were washed through a 0.5 mm mesh sieve and the contents retained on the sieve placed into pre-labelled plastic bags. The samples were fixed with 7% buffered formalin/seawater (v/v) containing Rose Bengal dye. In the laboratory, each sample was rinsed to remove the formalin before sorting.

All organisms were identified and counted to family level using an ISSCO M400 stereomicroscope. Ellis (1985) described taxonomic sufficiency as the level of identification necessary to meet a study's objectives. In terms of the amount of time and the costs involved, identifying organisms to levels that are finer than required is wasteful of resources that could be redirected into increasing the power of the scales of interest (Chapman, 1998). The family level is adequate for determining the effects of anthropogenic disturbances on macrobenthic assemblages (Chapman, 1998) and has been used successfully in numerous marine studies (Underwood et al., 2003; Cummins et al., 2004). Specimens were stored in 70% alcohol solution and a voucher collection was prepared for the study.

Univariate (ANOVA) and multivariate (PRIMER) statistical routines were used to analyse the data. Prior to ANOVA, the data sets were examined for homogeneity of variances using Cochran's test (Winer et al., 1991) and, if necessary, transformations were used to stabilise the variances (Underwood, 1981). Student-Newman-Keuls (SNK) tests were used to compare means (Underwood, 1981).

Multivariate statistical techniques were used to examine patterns in assemblages within saltmarshes using the PRIMER software package (Plymouth Marine Laboratories, UK). Multivariate methods such as PRIMER allow comparisons of two (or more) samples based on the degree to which these samples share particular species, at comparable levels of abundance (Clarke, 1993). Variation in the assemblage was measured for each site by calculating the average Bray-Curtis dissimilarities.

A non-metric multidimensional scaling (nMDS) ordination was used to graphically illustrate relationships between samples for each location. The significance of any apparent differences among locations was determined using ANOSIM (analysis of similarities) (Clark, 1993). A SIMPER (similarity of percentages) procedure was used to examine the contribution of taxa to the similarities (or dissimilarities) among locations (Clarke, 1993).

Table 1. Location of mangrove forests where macrobenthic fauna were sampled in the Brisbane Water estuary.

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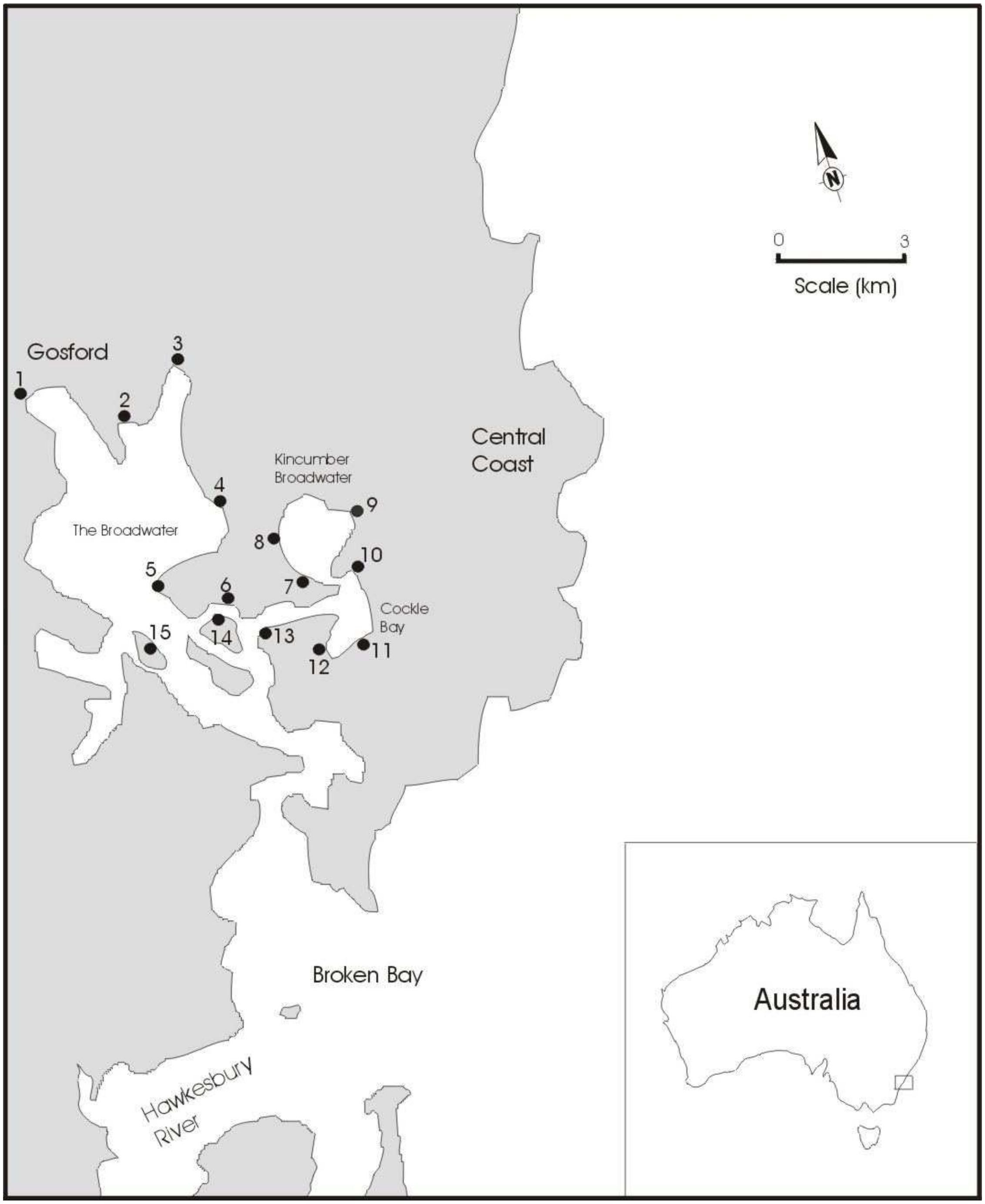

Figure 1. Mangrove invertebrate sampling locations in Brisbane Water.

RESULTS

The assemblages of macrobenthic invertebrates within the mangroves forests in Brisbane Water consisted of a total of 616 individuals from several groups of common estuarine fauna, which included worms, molluscs and crustaceans. The most abundant species was the bivalve mollusc *Glauconome plankta*. Other common taxa included the gastropod *Battilaria australis*, the crabs *Paragrapsus laevis* and *Heloecius cordiformis* and amphipods from the family Talitridae.

The analysis of variance detected significant difference in the richness and abundance of macrobenthic fauna between locations (Table 2). There were no differences detected among sites within a location (Table 2). In general, there were significantly greater numbers of taxa and/or individuals at some locations compared to others however there appeared to be no pattern associated with position within the estuary. Location 6 on Lintern Channel generally had the largest number of taxa and individual macrobenthic organisms (Fig. 2 & 3). Location 1 within Fagans Bay also had relatively greater richness and abundance of macrobenthic invertebrates (Fig. 2 & 3).

The non-metric multidimensional scaling (nMDS) ordination indicated that there were differences in the structure of the macrobenthic assemblages between the fifteen locations (Fig. 4). Some of the locations were consistently grouped together with little variation between samples, whilst others showed considerable variability among the samples. The stress value (0.12) associated with the ordination indicated that it was a useful 2-D picture (Clarke and Warwick, 1994). The ANOSIM test (Global R: 0.281) confirmed that there was a significant difference ($P < 0.01$) in the structure of the assemblages among locations (Clarke and Warwick, 1994).

The SIMPER procedure generally ranked the bivalve *Glauconome plankta* as the most important species that contributed to the structure of the assemblages at most locations (Table 3). The crab *Paragrapsus laevis* was also ranked highly at some locations (Table 3). The variability in other ranked taxa varied depending on which location was examined (Table 3).

Table 2. Summary of ANOVAs comparing the richness (number of taxa) and abundance (number of individuals) of macrobenthic fauna in sites within the mangrove forests in Brisbane Water (ns = not significant (P > 0.05); * significant (P < 0.05); ** significant (P < 0.01).

		Richness		**Abundance**	
Source of variation	**df**	**MS**	***F***	**MS**	***F***
Location	14	0.45	2.75*	1.94	2.8*
Site (Location)	15	0.16	0.9ns	0.69	1.3ns
Residual	60	0.18		0.53	
Total	89				
Cochran’s test			0.151ns		0.186ns
Transformation			ln (x+1)		ln (x+1)

Table 3. Macrobenthic taxa ranked in order of importance that contributed to the average similarity within a location as determined using SIMPER analysis.

	Location														
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Anthuridae		2													
Batillaria australis						3	2					1			
Bembicium auratum						4	3				2			3	
Capitellidae															4
Eunicidae												5			
Glauconome plankta	1	1	3	1	1	1	1	1	1	1	1	4	1	1	2
Heloecius cordiformis	2			4						4			4		1
Hymenosomatidae		4	2				5								
Littoraria luteola				2											
Onchidiidae		3													
Paragrapsus laevis			1			2			2			3		2	
Paragrapsus quadridentatus	5														
Nephtyidae												6			3
Neredidae							4								
Salinator solida	4							2		2					
Sesarma erythrodactyla				3	2								3		
Sphaeromatidae						5									
Talitridae	3					6				3					
Tellina deltoidalis												2			
Victoriopisa austrailiansis													2		

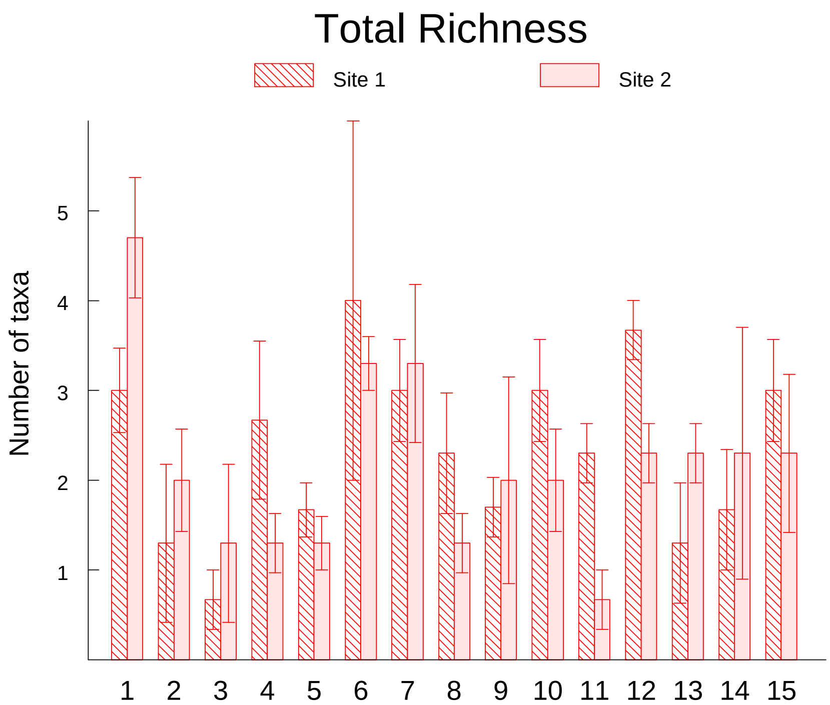

Figure 2. Mean (+SE) total richness (number of taxa) within each mangrove site and location.

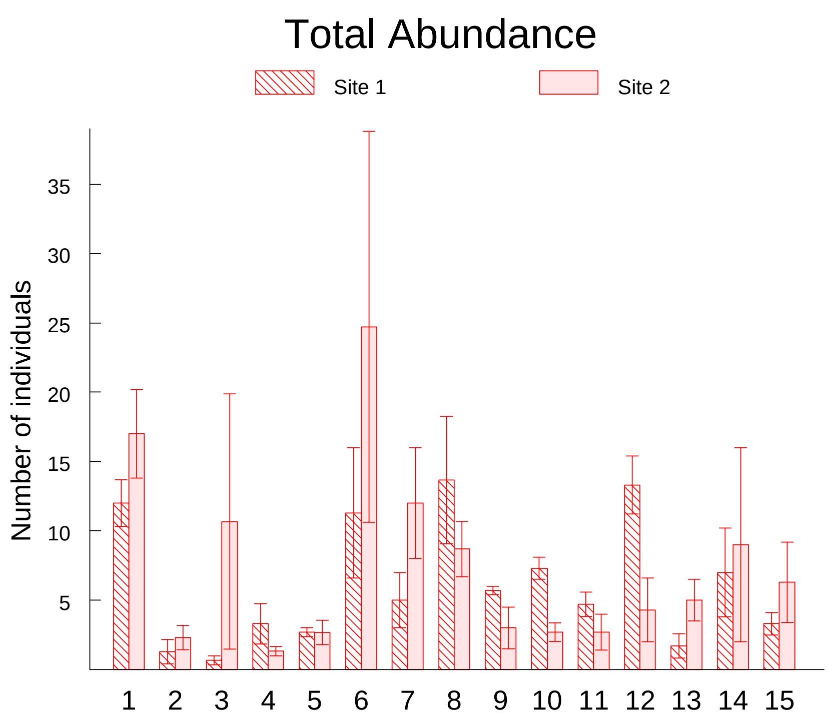

Figure 3. Mean (+SE) total abundance (number of individuals) within each mangrove site and location.

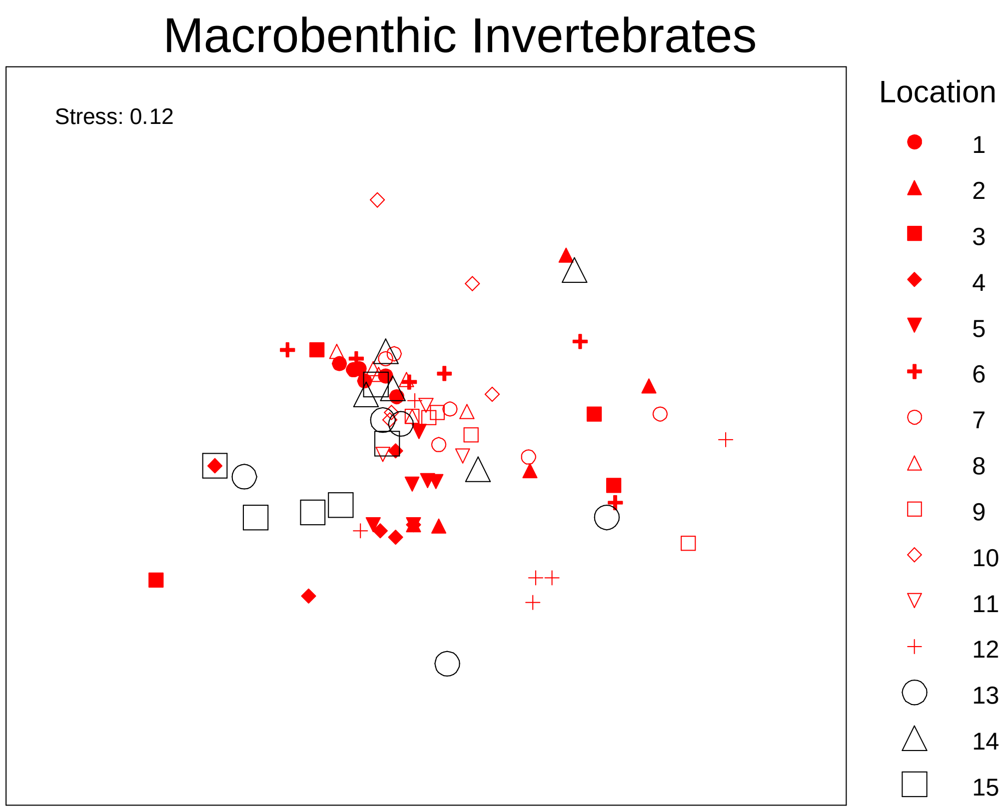

Figure 4. nMDS ordination plot for the abundance of macrobenthic invertebrates in each location within the mangrove forests in Brisbane Water estuary.

DISCUSSION

The mangrove forests in the Brisbane Water estuary supported a diverse assemblage of macrobenthic organisms. Most of the common families and species identified have been described from other estuaries in NSW (see Poore, 1982; Hutchings, 1999) and also within Brisbane Water (Gladstone and Schreider, 2003). These estuarine fauna include bivalve and gastropod molluscs, crustaceans such as crabs and amphipods, and numerous families of polychaete worms. It has been established that the structural complexity of a marine habitat is important for benthic organisms. Mangrove forests can support higher diversity of benthic organisms compared to less structurally complex habitats such as saltmarshes and non-vegetated areas (Clough, 1982). Furthermore, vegetated habitats such as mangroves can provide greater amounts of organic material as a food resource for benthic organisms.

The fifteen locations sampled around Brisbane Water were found to have differences in the number of taxa and number of individual macrobenthic invertebrates. Furthermore, some locations were also found to have different structures in the assemblages of macrobenthic fauna. These patterns are not surprising as there are many physical and biological differences in the mangrove forests within the estuary (Clark and Hannon, 1969). For example, there are hydrodynamic differences that can influence tidal regimes which can have a direct impact on supplying nutrients to the various fauna living in a forest and or the transport of larvae into and out of the forest.

The physical structure of the mangrove forest including the density of trees and their canopy cover can also influence the light available for algal growth on the forest floor or the amount of leaf litter available for macrobenthic organisms. The density and health of aerial peg roots (pneumatophores) of *Avicennia marina* can also add small-scale structure to the forest floor which in turn can influence the assemblages of macrobenthos. Finally, biological interactions between different components of the fauna may also have influence on the types of assemblages that can be found in these forests. For example, crabs can burrow and help to aerate the sediments which in turn can assist other species in colonising the sediments (Thrush, 1986; Inglis, 1997).

At smaller spatial scales (i.e. sites within locations) the observed patterns of diversity and abundance were less complex and relatively consistent within a location. The structure of the assemblage however was variable among the different taxonomic groups examined. Soft-sediment fauna are generally regarded as being patchy in their distribution and sampling designs investigating patterns of distribution and abundance need to incorporate several spatial scales so that this patchiness can be identified (Andrew and Mapstone, 1987; Morrisey et al., 1992). For the macrobenthic fauna in these mangrove forests, this patchiness was only apparent when the assemblage at a site was examined as well as at higher spatial scales such as location.

The importance of mangrove forests cannot be overstated, as they provide enormous ecological services to an estuary (Laegdsgaard and Johnston, 2001). The fauna that rely on these forests are also important to other ecological components within the estuary. Mangrove forests are required to provide habitat for macrobenthic organisms which are in turn important food for fish and birds within an estuary. In recent times, there has been evidence to support mangrove invasions or migrations into saltmarsh habitats within estuaries in NSW (Saintilan and Williams, 1999; Harty and Cheng, 2003). Some estuarine managers and the community have used this trend as a reason to provide less protection of mangroves than say saltmarshes. When considering these types of managerial decisions, it should be remembered that the mangroves of the estuary are much more productive than the saltmarshes.

ACKNOWLEDGMENTS

Doug Treloar and Louise Collier (Cardno Lawson Treloar Pty Ltd) are thanked for management support and editorial comments. Peter Freewater (Gosford City Council) and Neil Kelleher (Department of Infrastructure Planning and Natural Resources) are thanked for managerial support. Nick Roberts, William Roberts and Sharon Cummins are thanked for assistance in the field and laboratory. Dave Booth (UTS) is thanked for his comments on the draft report.

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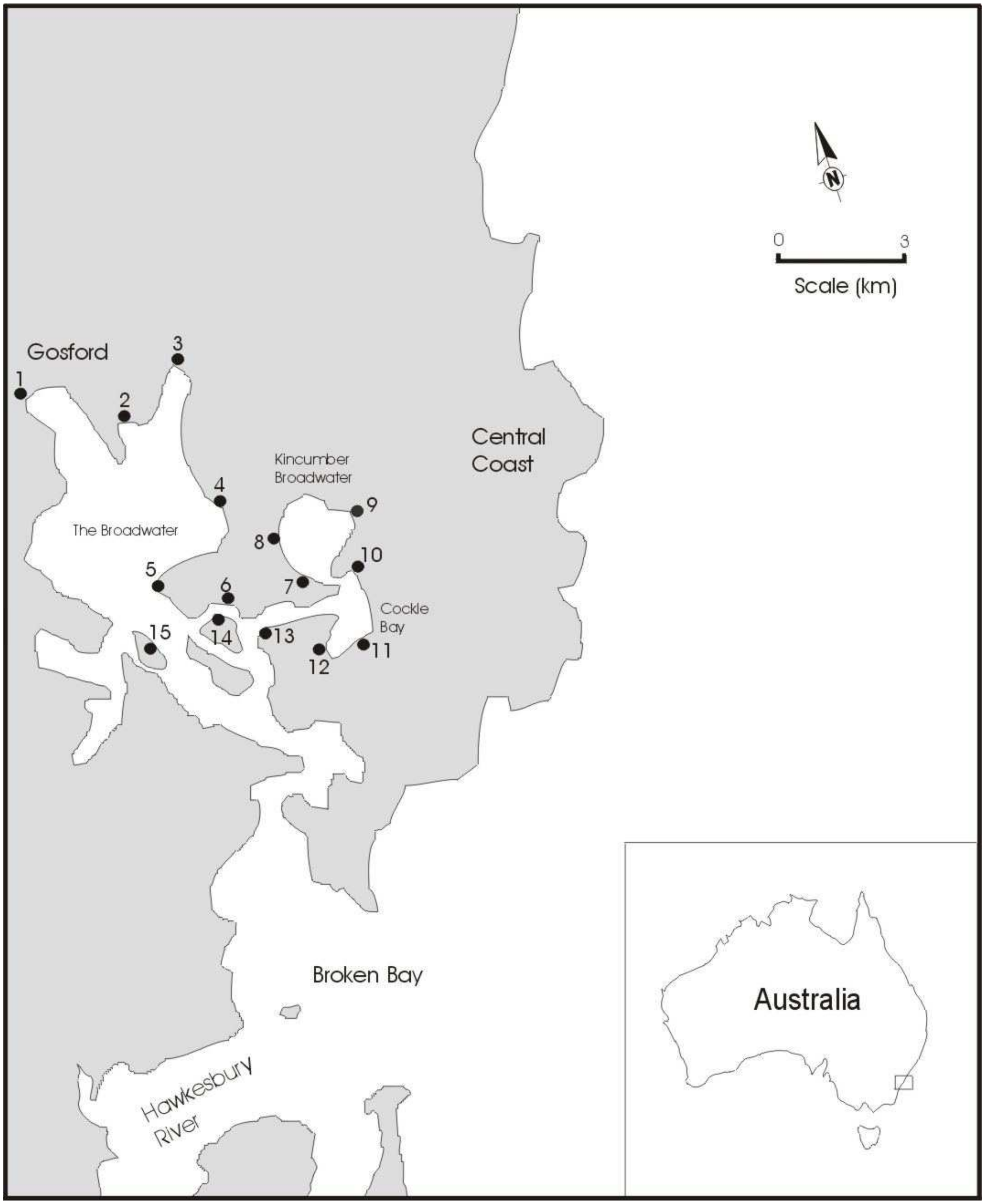

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Table 2. Summary of ANOVAs comparing the richness (number of taxa) and abundance (number of individuals) of macrobenthic fauna in sites within the mangrove forests in Brisbane Water (ns = not significant (*P* > 0.05); * significant (*P* < 0.05); ** significant (*P* < 0.01).

		Richness		Abundance	
Source of variation	**df**	**MS**	***F***	**MS**	***F***
Location	14	0.45	2.75*	1.94	2.8*
Site (Location)	15	0.16	0.9ns	0.69	1.3ns
Residual	60	0.18		0.53	
Total	89				
Cochran's test			0.151ns		0.186ns
Transformation			ln (*x*+1)		ln (*x*+1)

Table 3. Macrobenthic taxa ranked in order of importance that contributed to the average similarity within a location as determined using SIMPER analysis.

	Location														
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Anthuridae		2													
Batillaria australis						3	2					1			
Bembicium auratum						4	3				2			3	
Capitellidae															4
Eunicidae												5			
Glauconome plankta	1	1	3	1	1	1	1	1	1	1	1	4	1	1	2
Heloecius cordiformis	2			4						4			4		1
Hymenosomatidae		4	2				5								
Littoraria luteola				2											
Onchidiidae		3													
Paragrapsus laevis			1			2			2			3		2	
Paragrapsus quadridentatus	5														
Nephtyidae												6			3
Nerededae							4								
Salinator solida	4							2		2					
Sesarma erythrodactyla				3	2								3		
Sphaeromatidae						5									
Talitridae	3					6				3					
Tellina deltoidalis												2			
Victoriopisa austrailiansis													2		

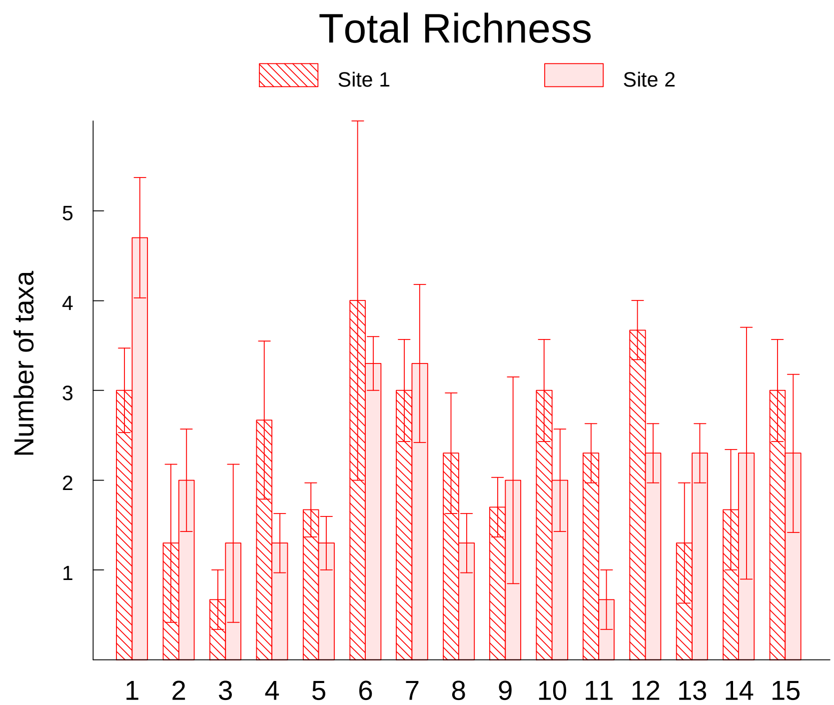

Figure 2. Mean (+SE) total richness (number of taxa) within each mangrove site and location.

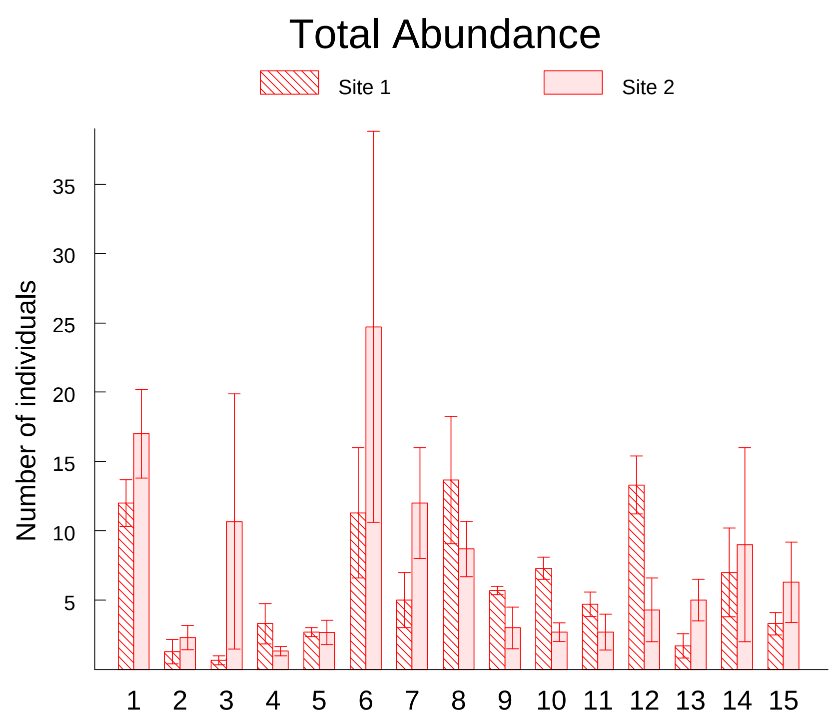

Figure 3. Mean (+SE) total abundance (number of individuals) within each mangrove site and location.

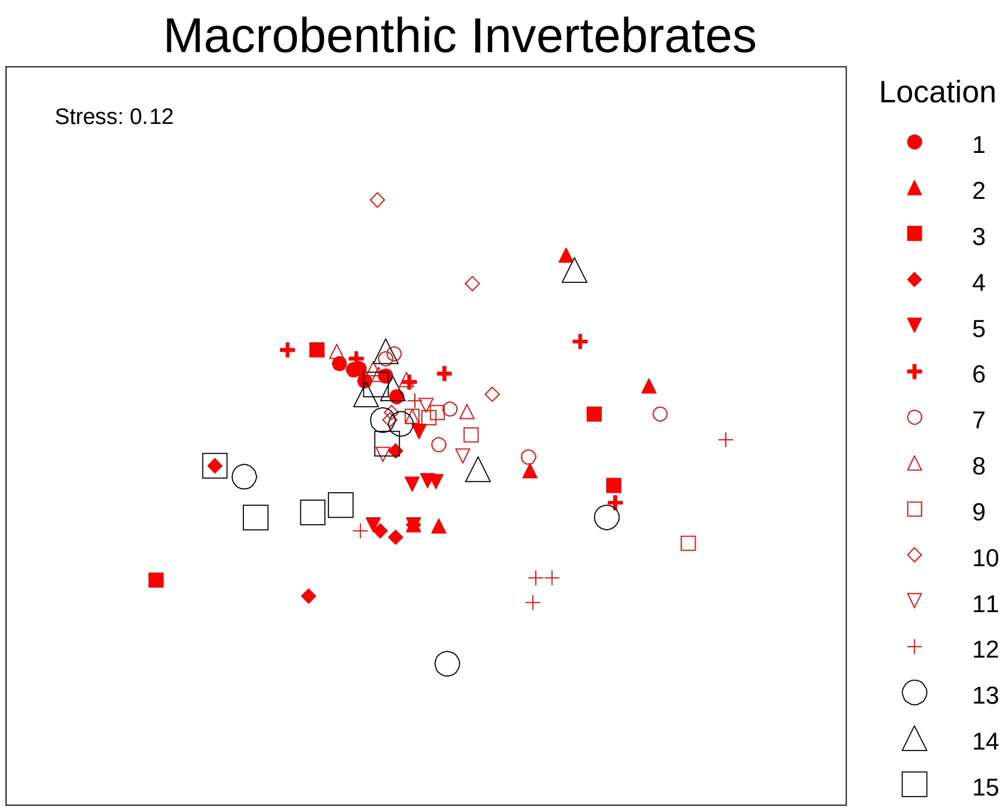

Figure 4. nMDS ordination plot for the abundance of macrobenthic invertebrates in each location within the mangrove forests in Brisbane Water estuary.

DISCUSSION

The mangrove forests in the Brisbane Water estuary supported a diverse assemblage of macrobenthic organisms. Most of the common families and species identified have been described from other estuaries in NSW (see Poore, 1982; Hutchings, 1999) and also within Brisbane Water (Gladstone and Schreider, 2003). These estuarine fauna include bivalve and gastropod molluscs, crustaceans such as crabs and amphipods, and numerous families of polychaete worms. It has been established that the structural complexity of a marine habitat is important for benthic organisms. Mangrove forests can support higher diversity of benthic organisms compared to less structurally complex habitats such as saltmarshes and non-vegetated areas (Clough, 1982). Furthermore, vegetated habitats such as mangroves can provide greater amounts of organic material as a food resource for benthic organisms.

The fifteen locations sampled around Brisbane Water were found to have differences in the number of taxa and number of individual macrobenthic invertebrates. Furthermore, some locations were also found to have different structures in the assemblages of macrobenthic fauna. These patterns are not surprising as there are many physical and biological differences in the mangrove forests within the estuary (Clark and Hannon, 1969). For example, there are hydrodynamic differences that can influence tidal regimes which can have a direct impact on supplying nutrients to the various fauna living in a forest and or the transport of larvae into and out of the forest.

The physical structure of the mangrove forest including the density of trees and their canopy cover can also influence the light available for algal growth on the forest floor or the amount of leaf litter available for macrobenthic organisms. The density and health of aerial peg roots (pneumatophores) of *Avicennia marina* can also add small-scale structure to the forest floor which in turn can influence the assemblages of macrobenthos. Finally, biological interactions between different components of the fauna may also have influence on the types of assemblages that can be found in these forests. For example, crabs can burrow and help to aerate the sediments which in turn can assist other species in colonising the sediments (Thrush, 1986; Inglis, 1997).

At smaller spatial scales (i.e. sites within locations) the observed patterns of diversity and abundance were less complex and relatively consistent within a location. The structure of the assemblage however was variable among the different taxonomic groups examined. Soft-sediment fauna are generally regarded as being patchy in their distribution and sampling designs investigating patterns of distribution and abundance need to incorporate several spatial scales so that this patchiness can be identified (Andrew and Mapstone, 1987; Morrisey et al., 1992). For the macrobenthic fauna in these mangrove forests, this patchiness was only apparent when the assemblage at a site was examined as well as at higher spatial scales such as location.

The importance of mangrove forests cannot be overstated, as they provide enormous ecological services to an estuary (Laegdsgaard and Johnston, 2001). The fauna that rely on these forests are also important to other ecological components within the estuary. Mangrove forests are required to provide habitat for macrobenthic organisms which are in turn important food for fish and birds within an estuary. In recent times, there has been evidence to support mangrove invasions or migrations into saltmarsh habitats within estuaries in NSW (Saintilan and Williams, 1999; Harty and Cheng, 2003). Some estuarine managers and the community have used this trend as a reason to provide less protection of mangroves than say saltmarshes. When considering these types of managerial decisions, it should be remembered that the mangroves of the estuary are much more productive than the saltmarshes.

ACKNOWLEDGMENTS

Doug Treloar and Louise Collier (Cardno Lawson Treloar Pty Ltd) are thanked for management support and editorial comments. Peter Freewater (Gosford City Council) and Neil Kelleher (Department of Infrastructure Planning and Natural Resources) are thanked for managerial support. Nick Roberts, William Roberts and Sharon Cummins are thanked for assistance in the field and laboratory. Dave Booth (UTS) is thanked for his comments on the draft report.

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