SPATIAL VARIABILITY IN SALTMARSHES AROUND THE BRISBANE WATER ESTUARY: PATTERNS ASSOCIATED WITH TIDAL REGIME AND ANTHROPOGENIC DISTURBANCE

PREPARED FOR

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INTRODUCTION

There have been large-scale declines of mangroves and saltmarshes in NSW estuaries and in some cases there have been permanent losses (Saintilan and Williams, 2000). Dredging, land filling, reclamation, and agricultural activities have all helped to reduce the distribution and abundance of these important estuarine assemblages (Butler and Jernakoff, 1999). In New South Wales, many saltmarshes have been cleared or damaged as a result of urban development (Adam, 1995) and in some places through colonisation by mangroves (Saintilan and Williams, 1999). In some estuaries there have been large-scale declines of up to 85% of the area of saltmarsh habitats (Chapman and Roberts, 2004).

Saltmarshes are dominated by salt-tolerant species of plants (Sainty and Jacobs, 2004) that are generally found high up on the shoreline of estuarine intertidal mudflats usually landward of fringing mangrove forests (Mitchell and Adam, 1989). Saltmarshes are important in the nutrient cycling process in estuaries and as feeding and nursery habitats for many birds, fish and invertebrates (Minello *et al.*, 2003). They are threatened in many parts of the world because in the past they were considered wastelands rather than valued wetlands. This was particularly true in urbanised parts of Australia (Stricker, 1995).

In the Brisbane Water estuary there are still significant areas of mangrove forest and saltmarsh meadows (Harty, 1994). The importance of these two habitat types to the estuary was highlighted by Harty (1994) and their subsequent conservation and management was given a high priority by Gosford City Council. Whilst there has been some mapping done for mangroves, saltmarsh and seagrasses within the estuary, these habitats have never been quantified at smaller spatial scales. Whilst it is generally thought that anthropogenic disturbance has impacted on the saltmarshes around the estuary, this aspect has never been quantified. The distribution and abundance of various saltmarshes were quantified at different spatial scales around the estuary and the effects of disturbance on both low- and high-level marsh habitats were examined.

METHODS

EXPERIMENTAL DESIGN

This study was designed to examine the spatial variability in saltmarsh assemblages around the Brisbane Water estuary. Specifically, we tested the hypothesis that there would be differences in the richness, abundance and structure of the assemblages of saltmarshes in areas having different tidal flushing characteristics. We also tested the hypothesis that saltmarshes in disturbed areas would have reduced richness and abundance, whilst the structure of disturbed saltmarshes would be quite different to those in relatively undisturbed locations. Furthermore, we tested the hypothesis that assemblages of saltmarshes in disturbed locations might be expected to be more variable than those in undisturbed locations because of physical disturbance and stress as proposed in the model by Warwick and Clarke (1993).

To determine the variability in saltmarsh meadows within the Brisbane Water estuary, sampling was done at a number of spatial scales (see Underwood, 1993). The experimental design involved sampling a total of fourteen large saltmarshes (Table 1; Figs 1 & 2) identified from mapping done by DPI Fisheries (unpublished data). Not all of these saltmarshes were used in the formal statistical analyses. Within each of four areas that represented different flushing regimes within the estuary, three saltmarsh locations were chosen (Fig. 1). Each location was stratified into low (Fig. 3) and high (Fig. 4) saltmarsh based on its elevation, tidal range and floristic characteristics. Low and high marsh were sampled and analysed independently as we had no logical hypothesis about the differences between these habitat types.

To test the hypothesis that disturbed saltmarshes would be reduced in their richness and abundance and experience greater spatial variability, four disturbed locations were randomly chosen from the six saltmarsh locations that were sampled throughout the estuary. The four disturbed locations were all highly accessible to the public or had significant development within their immediate catchments (Fig. 5).

Four undisturbed locations were also randomly chosen where they were considered to be relatively isolated from public access with no development within their catchments.

Within low and high marshes at each location, two randomly nested sites approximately 200 m in diameter and at least 400 m apart were chosen. Within each site, ten haphazardly placed 0.25 m^2 quadrats were sampled by estimating the percentage cover of each saltmarsh species in the quadrat (Fig. 6). The experimental design required that sampling be done at different spatial scales, which included 10s of meters, 100s of metres and kilometres (Fig. 1).

Furthermore, at each site, the number of species and relative abundance of saltmarshes and other plants were estimated at a broad scale by recording the number of species within the site and giving them a cover or abundance score. The cover classes were: (+) one plant or small patch, (++) not common, growing in a few places, and (+++) widespread. Each saltmarsh was also assessed in terms of the extent of anthropogenic disturbance.

Table 1. Saltmarshes sampled in Brisbane Water estuary.

Saltmarsh	Location	Comments
Erina Creek Wetland	1	Undisturbed
Egan Creek Saltmarsh	2	Disturbed
Saratoga Wetland	3	Disturbed
Rileys Island	4	Undisturbed (some *J. acutus*)
Lintern Saltmarsh	5	Disturbed
Empire Bay Wetland	6	Disturbed
Cockle Bay Nature Reserve	7	Undisturbed
Cockle Bay Wetland	8	Undisturbed
Bensville Saltmarsh	9	Relatively undisturbed, but disturbed in places
Davistown Wetland	10	Disturbed
Saratoga Saltmarsh	11	Disturbed
Kincumber Creek	12	Undisturbed
Pelican Island	13	Not used in formal analyses (Undisturbed however had very small area of low marsh)
Davistown Saltmarsh	14	Not used in formal analyses (directly connected to Lintern Saltmarsh, i.e. not independent)

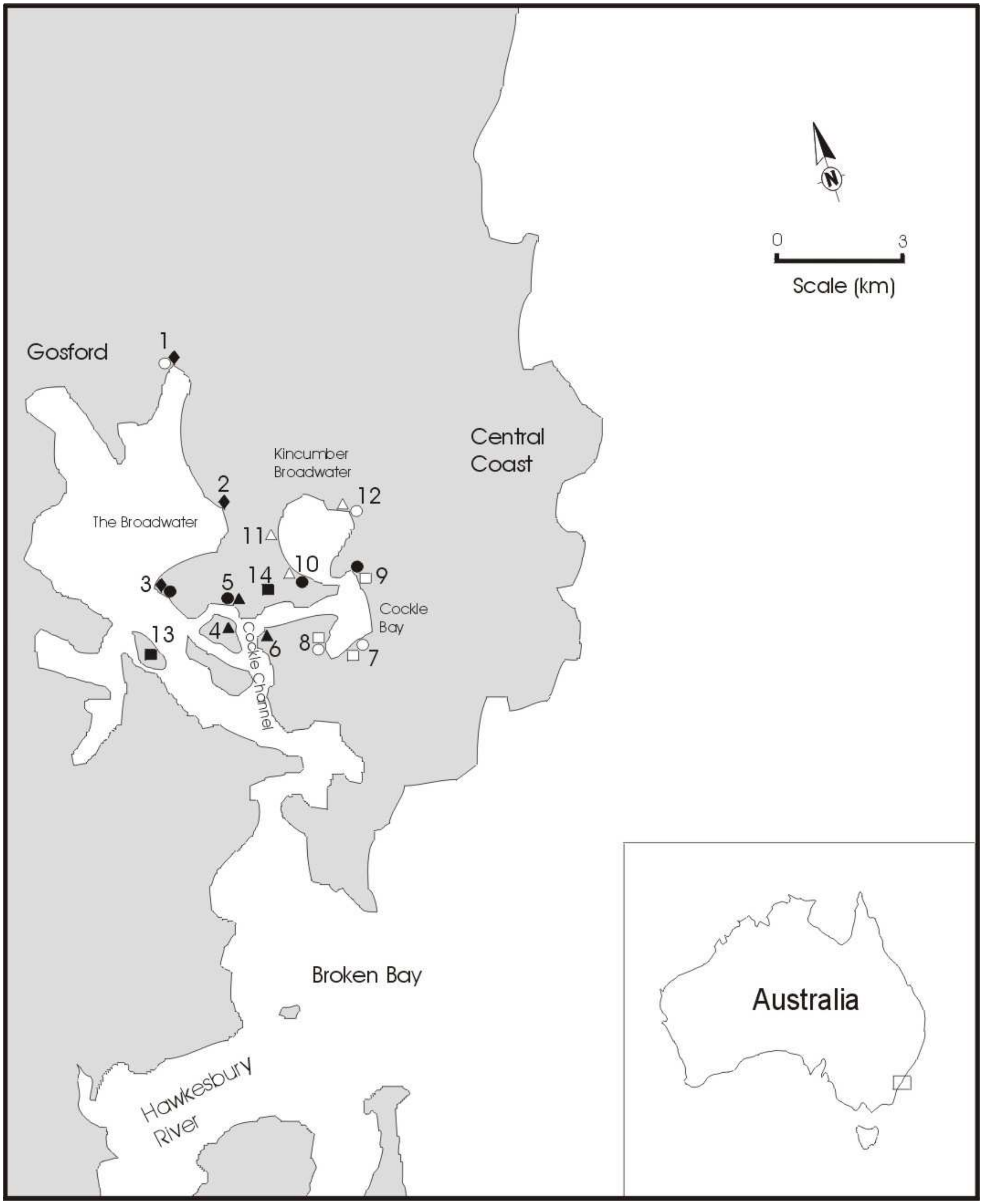


Figure 1. Saltmarshes locations sampled in the Brisbane Water estuary: The Broadwater (♦); Cockle Channel (▲); Cockle Bay (□); Kincumber Broadwater (Δ); disturbed (●) and undisturbed (○); not used in formal analyses (■).

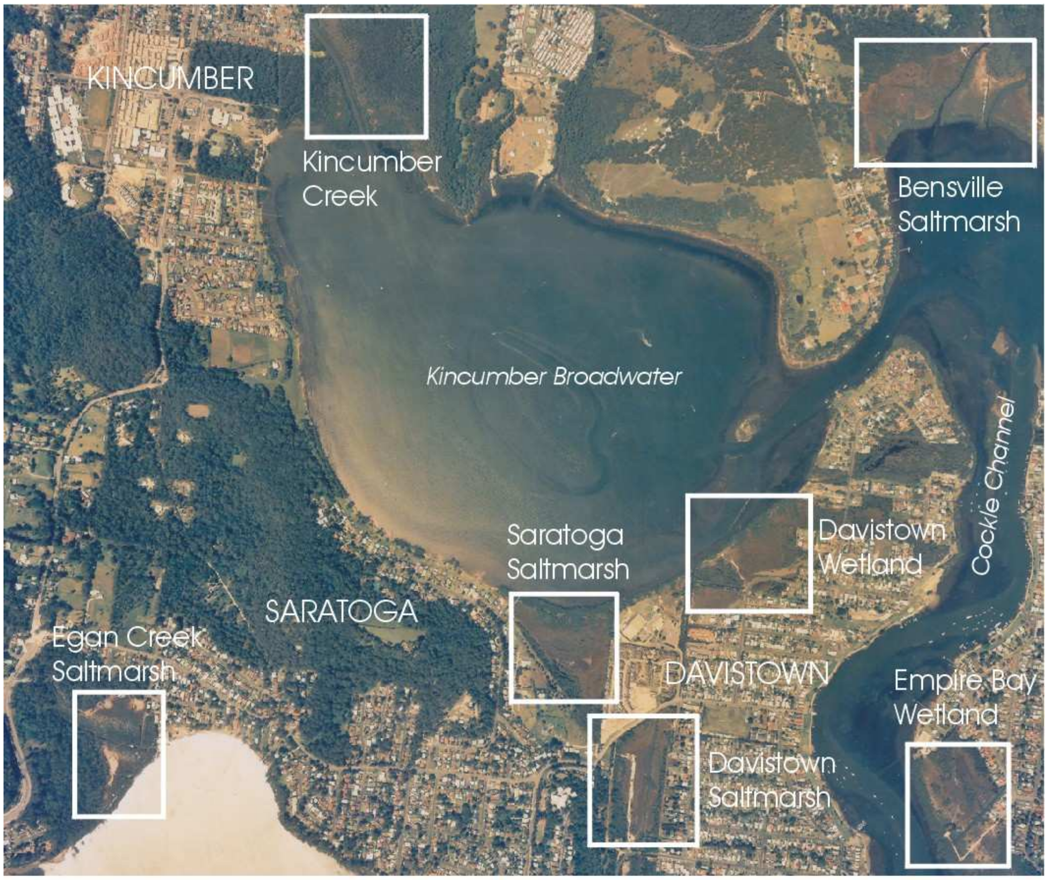


Figure 2a. Location of saltmarshes in Brisbane Water.

Figure 2b. Location of the saltmarshes in Brisbane Water.

Figure 3. Undisturbed low marsh.

Figure 4. Undisturbed high marsh.

Figure 5. Example of disturbance to a saltmarsh.

Figure 6. Quadrat ($0.25m^2$) used to estimate the number of species and percentage cover of saltmarshes at each site.

DATA ANALYSES

Both univariate (ANOVA – using GMAV) and multivariate (PRIMER) statistical routines were used to analyse the data. Prior to analysis of variance, the data sets were examined for homogeneity of variances using Cochran's test (Winer, 1971) and if necessary, transformations were done to stabilise the variances (Underwood, 1981).

Multivariate statistical techniques were used to examine patterns in the assemblages within the 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 and Warwick, 1994). A non-metric multidimensional scaling (nMDS) ordination was used to graphically illustrate relationships between samples. The significance of any apparent differences among locations and sites was determined using ANOSIM (analysis of similarities) (Clark and Warwick, 1994). A SIMPER (similarity of percentages) procedure was used to examine the contribution of taxa to the similarities (or dissimilarities) among locations (Clarke and Warwick, 1994).

RESULTS

HABITAT ASSESSMENT

The low marsh habitats were generally dominated by *Sarcocornia quinqueflora* and *Sporobolus virginicus*. Other species that were also recorded in the low marsh included *Samolus repens*, *Triglochin striatum, Cotula coronopifolia* and the grey mangrove *Avicennia marina* (Table 2).

The high marsh habitats were generally dominated by *Juncus kraussii* or *Juncus acutus* and *Sporobolus virginicus.* Other notable species that were recorded included *Selliera radicans*, *Suaeda australis*, *Samolus repens* and *Casuarina glauca* (Table 3).

Location 1. Erina Creek Wetland

This saltmarsh is located on the northern side of Erina Creek and included large areas of very good quality saltmarsh, with one site having some of the best saltmarsh in the Brisbane Water estuary (Fig. 2a). The extensive area of low saltmarsh, principally *Sporobolus virginicus* and *Sarcocornia quinqueflora*, was fringed by the river mangrove *Aegiceras corniculatum* and grey mangrove *Avicennia marina*. The high marsh included *Selliera radicans, Baumea juncea, Fimbrystylis ferruginea, Juncus kraussii* and *Sporobolus virginicus*.

Location 2. Egan Creek Saltmarsh

The low marsh was principally composed of *Sarcocornia quinqueflora* and *Sporobolus virginicus* with few other species present. The high marsh was affected by trail bikes. The main species in the high marsh were *Juncus kraussii and Baumea juncea* and fringing *Casuarina glauca.* This area has a good interface of saltmarsh and forest but is affected by weeds in the freshwater zone.

Location 3. Saratoga Wetland

The low marsh included abundant *Sarcocornia quinqueflora, Samolus repens* with lesser amounts of *Sporobolus virginicus* and *Triglochin striatum.* The high marsh included *Casuarina glauca*, *Juncus kraussii* and the noxious weed *Juncus acutus.* Other saltmarsh species included *Samolus repens* with smaller amounts of *Sporobolus virginicus* and *Triglochin striatum*.

Location 4. Rileys Island

Species in the low marsh were notably *Sarcocornia quinqueflora, Sporobolus virginicus* and *Triglochin striatum*. The high marsh included *Juncus kraussii, Casuarina glauca, Selliera radicans* and *Suaeda australis*. The weed *Juncus acutus* was also found in some areas on the island.

Location 5. Lintern Saltmarsh

The low marsh was predominately *Sarcocornia quinqueflora* and *Suaeda australis* interspersed with *Avicennia marina*. This area has extensive disturbance caused by trail bikes. Large bund walls were built at the back of the marsh to hold the spoil dredged when the sewerage pipeline was installed. These bund walls remain on the site.

Location 6. Empire Bay Wetland

The low marsh was in good condition despite the presence of bicycle tracks and included abundant *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Triglochin striatum*. The high marsh was fringed by *Casuarina glauca* and included abundant *Juncus kraussii* and *Suaeda australis*.

Location 7. Cockle Bay Nature Reserve

The low marsh included large areas of *Sarcocornia quinqueflora* and *Triglochin striatum* fringed by *Avicennia marina.* The high marsh included *Leptinella longipes, Sporobolus virginicus* and abundant *Baumea juncea*. *Melaleuca ericifolia* was invading some parts of this elevated marsh and in the medium term will out-compete the less competitive saltmarsh species.

Location 8. Cockle Bay Wetland

The low marsh was primarily *Sarcocornia quinqueflora* fringed by *Avicennia marina.* The high marsh, which may be considered intermediate marsh, includes large areas of *Schoenoplectus litoralis, Juncus kraussii, Samolus repens, Selliera radicans, Suaeda australis* and *Casuarina glauca.* Mosquitoes were abundant in this area.

Location 9. Bensville Saltmarsh

The low marsh is a mix of *Sarcocornia quinqueflora* with scattered *Avicennia marina* and patches of *Sporobolus virginicus*. The high marsh included extensive areas of *Juncus kraussii* and *Suaeda australis*. One holding in this area has grazing horses that have severely damaged the mangroves and saltmarsh.

Location 10. Davistown Wetland

The extensive low marsh was dominated by *Sarcocornia quinqueflora* and would be fully inundated by a 1.9 metre tide. The high marsh, restricted in size, included abundant *Juncus kraussii* and *Juncus acutus* with scattered patches of *Sporobolus virginicus*.

Location 11. Saratoga Wetland

The low marsh included large areas of *Sarcocornia quinqueflora* and *Samolus repens, w*ith smaller areas of *Triglochin striatum* and *Sporobolus virginicus.* The high marsh includes abundant *Juncus kraussii* and *Casuarina glauca* and the weed *Juncus acutus*. This saltmarsh is increasingly being made fresh by its catchment with the prediction that it will be overrun by semi-salt tolerant species including Buffalo Grass, Asparagus Fern and Kikuyu grass in decades to come.

Location 12. Kincumber Creek

The low marsh included extensive areas of *Sarcocornia quinqueflora, Sporobolus virginicus* and *Samolus repens.* The high marsh included abundant *Juncus kraussii, Sporobolus virginicus* and *Casuarina glauca.* These saltmarshes were considered to be relatively undisturbed.

Location 13. Pelican Island

The low marsh included extensive areas of *Suaeda australis*, scattered *Juncus kraussii* and *Juncus acutus*. The high marsh included areas of *Juncus kraussii*, *Suaeda australis*, *Selliera radi*cans mostly above the tidal 2.0 metre tidal zone. There were also large areas of saline land well above the tidal influence, probably placed there as a result of dredging. Remnant semi-salt and salt tolerant species were thriving in this elevated area.

Location 14. Davistown Saltmarsh

The low marsh was fringed by *Avicennia marina* and included *Sporobolus virginicus*, *Sarcocornia quinqueflora, Suaeda australis,* scattered *Juncus kraussii* and *Juncus acutus*. The high marsh included areas of *Juncus kraussii, Suaeda australis* and *Selliera radi*cans. This marsh is connected via a creek running through to Lintern Channel.

Table 2. List of species and their relative abundance in low marsh habitats (cover classes: + one plant or small patch; ++ not common, growing in a few places; +++ widespread); *denotes weed species.

	Saltmarsh Locations													
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Aegiceras corniculatum	+++			+		++			++	++		++	+	++
Apium prostratum							+				+			
Atriplex hastata													++	
Avicennia marina	+++		++	++	+++	++	+++	++	++	++	++	++		+++
Baumea juncea													+	
Cotula coronopifolia						+								
Cyperus polystachyos													+	
Isolepis cernua					+								+	
*Juncus acutus**			+	++						++	+		+++	
Juncus kraussii	+++	+		++	+	++	+	+++	+++	++	+	++	+++	+
Samolus repens	++		+++		+			++	+	++	+++	+++		++
Sarcocornia quinqueflora	++	+++	+++	+++		+++	+++	+++	+++	++	++	+++	+++	+++
Schoenoplectus litoralis								++						
Selliera radicans	++													
Sesuvium portulacastrum													+++	
Sporobolus virginicus	+++	+++	++	+++	++	++		+++	++	++	++	+++	+++	++
Suaeda australis				+++	++				++	++				++
Triglochin striatum	++	+	++		+	++	++	++		+	+++	+		+

Table 3. List of species and their relative abundance in high marsh habitats (cover classes: + one plant or small patch; ++ not common, growing in a few places; +++ widespread) *denotes weed species.

	Saltmarsh Locations													
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Apium prostratum							++						+	
*Asparagus asparagoides**			++											
*Asparagus densiflorus**		++	++											
*Aster subulatus**			+											
Atriplex hastata			+++								++		+	++
Baumea juncea	+++	+++					+++			+++		+++		+++
Bolboschoenous caldwelli			++								++			
Carex pumilio													++	
Carpobrotus glaucescens													+	
Casuarina glauca	+++	+++	+++	+++	+++	++	++	++		+++	+++	+++	+++	+++
*Chrysanthemoides monilifera**													+++	
Fimbristylis ferruginea	+++	++						+		++		++		
*Hydrocotyle bonariensis**													++	
Isolepis nodosa													++	
*Juncus acutus**			+++	+++					+++	+++	+++		+++	+++
Juncus kraussii	+++	+++	+++	+++		+++	+++	+++	+++	+++	+++	+++	+++	+++
Leptinella longipes							+						+	
Melaleuca ericifolia							+++							
Melaleuca styphelioides							++							
Myoporum boninese		+	+							++			+	
Phragmites australis													+	
Samolus repens	+++	+	+++					++			+++	++		
Sarcocornia quinqueflora			++	++		++	++	++	+++		+	++		++

	Saltmarsh Locations													
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Scaevola calendulacea													++	
Schoenoplectus litoralis														
Selliera radicans	++			++				++		+++			+++	++
Sesuvium portulacastrum														
Sporobolus virginicus	+++			+++		+++	++		++	++		++	+++	++
*Stenophratum secundatum**													+++	
Suaeda australis				++		+++		++		+++			++	++
Tetragonia tetragonoides			+											
Triglochin striatum	++	++	++				+							++

SPATIAL VARIABILITY

LOW MARSH

There were significant Site (Area x Location) interactions for all four variables tested within the low marsh (Table 4). These interactions represent small-scale variability within sites and may be due to the patchiness or mosaics of assemblages found within the saltmarsh. There were significant differences between the four areas for the total abundance (percentage cover) of saltmarshes and the cover of *Sarcocornia quinqueflora* (Table 4; Figs. 7 & 8). Generally, the cover was smaller in the Brisbane Water and Cockle Channel areas compared to those in Cockle Bay and Kincumber Broadwater (Figs. 7 & 8). Species richness had a significant Location (Area) interaction where Location 1 in Brisbane Water was greater than all other locations (Table 4; Figure 7). There were no patterns associated with the cover of *Sporobolus virginicus* between the four areas (Table 4; Fig. 8).

Table 4. Summary of ANOVAs comparing species richness and total abundance of saltmarsh and the abundance of *Sarcocornia quinqueflora* and *Sporobolus virginicus* within low marsh habitats in the Brisbane Water estuary (ns = not significant (*P* > 0.05); * significant (*P* < 0.05); ** significant (*P* < 0.01).

		Abundance		**Richness**	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	11560.7	7.32*	0.73	1.4ns
Location (Area)	8	1579.4	1.76ns	0.52	3.15*
Site (Area x Location)	12	896.1	3.44**	0.17	4.67**
Residual	216	260.7		0.04	
Total	239				
Cochran's test			0.15**		0.11ns
Transformation			None		Ln (x + 1)
		S. quinqueflora		***S. virginicus***	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	17172.6	5.84*	1430.9	0.74ns
Location (Area)	8	2940.9	2.22ns	1922.1	2.32ns
Site (Area x Location)	12	1327.4	3.15**	826.8	2.97**
Residual	216	421.7		277.9	
Total	239				
Cochran's test			0.13*		0.16**
Transformation			None		None

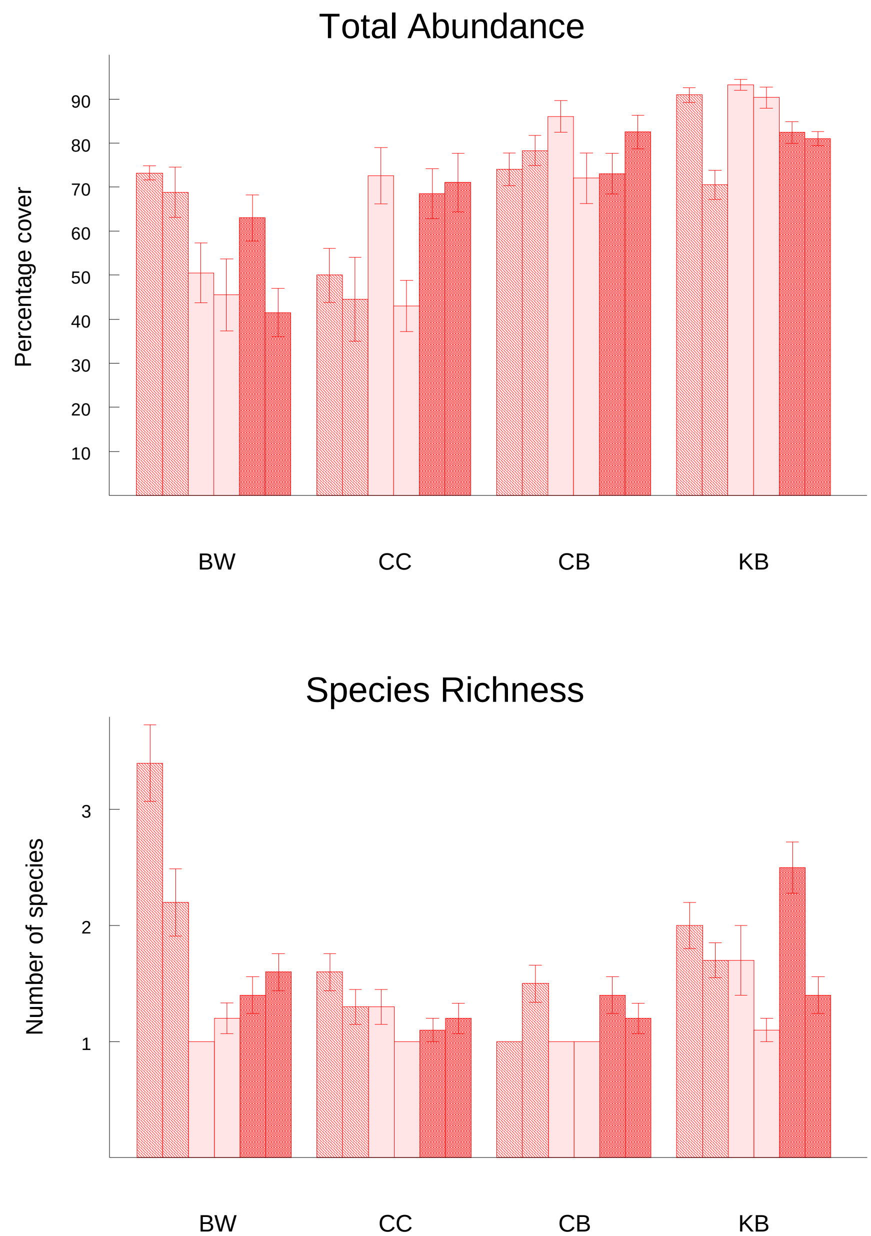
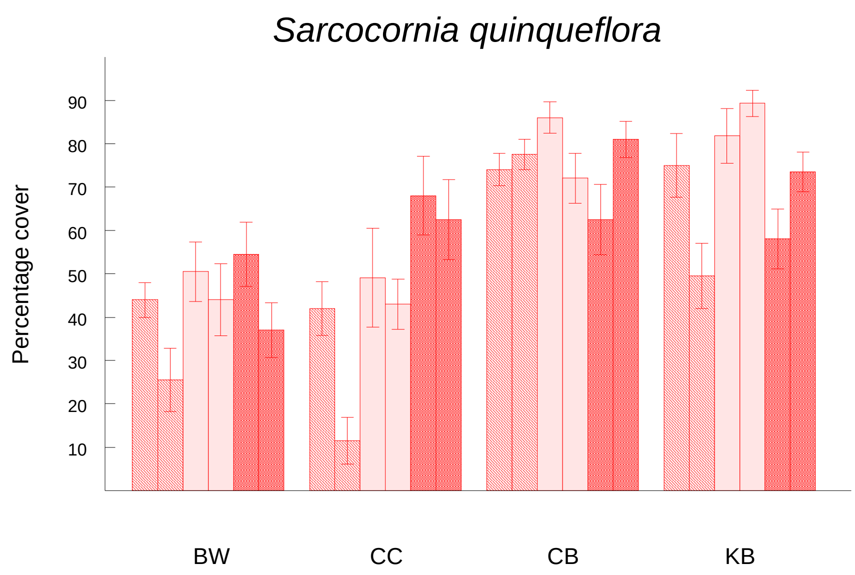


Figure 7. Mean (± SE) abundance and richness of saltmarsh at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in low marsh.



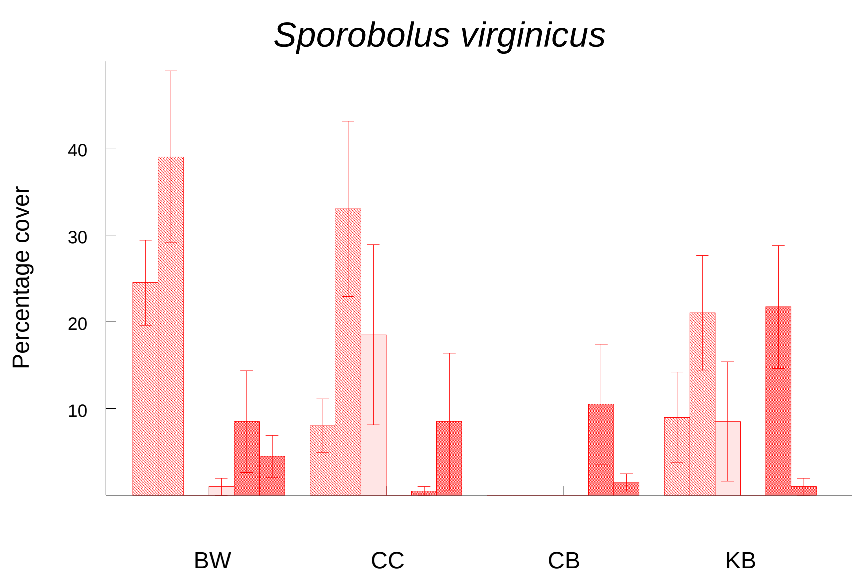


Figure 8. Mean (+ SE) abundance of *Sarcocornia quinqueflora* and *Sporobolus virginicus* at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in low marsh.

HIGH MARSH

There were significant Site (Area x Location) interactions for species richness, and the cover of *Juncus kraussii*, *Juncus acutus*, *Sporobolus virginicus*, *Suaeda australis* and *Selliera radicans* within the high marsh (Table 5). As with the low marsh these interactions represent small-scale variability among sites. There were no significant differences between the four areas for most of the variables analysed in the high marsh (Table 5; Figs 9 - 12). There were significant Location (Area) interactions for *Juncus acutus*, *Sporobolus virginicus* and *Selliera radicans* (Table 5).

STRUCTURE OF THE ASSEMBLAGE

The non-metric multidimensional scaling (nMDS) ordinations demonstrated considerable variation within the assemblages of saltmarshes in both low and high marsh habitats (Fig. 13). The stress value (see Fig. 13) associated with the ordination for the low marsh indicated that it was a good ordination with no real prospect of a misleading interpretation, whilst the high marsh was also considered to give a potentially useful 2-D picture (Clarke and Warwick, 1994). No patterns were observed within the ordinations that could be attributed to the different areas.

The ANOSIM tests confirmed that there were no significant differences in the structure of assemblages between areas in low marsh (R = 0.08ns) and high marsh (R = -0.04ns).

The SIMPER procedure generally ranked *Sarcocornia quinqueflora* and *Sporobolus virginicus* as important species that contributed to the structure of the assemblage in the low marsh in all four areas (Table 6). Within the high marsh, the most important species varied among areas and locations, but were generally either *Juncus kraussii*, S*porobolus virginicus*, *Baumea juncea*, *Juncus acutus* or *Selliera radicans* (Table 7)

Table 5. Summary of ANOVAs comparing species richness and total abundance of saltmarsh as well as common species of saltmarsh found within high marsh habitats in the Brisbane Water estuary (ns = not significant (*P* > 0.05); * significant (*P* < 0.05); ** significant (*P* < 0.01).

		Abundance		**Richness**	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	784.3	1.01ns	0.034	0.22ns
Location (Area)	8	774.1	1.73ns	0.154	0.61ns
Site (Area x Location)	12	446.5	1.57ns	0.254	4.1**
Residual	216	283.6		0.062	
Total	239				
Cochran's test			0.14**		0.11ns
Transformation			None		Ln (*x* + 1)
		J. kraussii		***J. acutus***	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	3454.9	0.62ns	4338.3	1.22ns
Location (Area)	8	5589.8	2.45ns	3567.4	4.18*
Site (Area x Location)	12	2284.02	5.38**	852.7	3.32**
Residual	216	424.5		256.9	
Total	239				
Cochran's test			0.10ns		0.22**
Transformation			None		None
		S. virginicus		***S. repens***	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	2159.2	0.36ns	53.6	1.37ns
Location (Area)	8	5927.5	3.1*	39.1	1.1ns
Site (Area x Location)	12	1913.8	4.83**	36.1	1.34ns
Residual	216	396.3		29.9	
Total	239				
Cochran's test			0.11ns		0.74**
Transformation			None		None
		S. australis		***S. radicans***	
Source	**df**	**MS**	***F***	**MS**	***F***
Area	3	1982.5	1.35ns	1174.4	0.67ns
Location (Area)	8	1468.8	2.79ns	1756.3	2.86*
Site (Area x Location)	12	527.4	3.11**	613.3	2.95**
Residual	216	169.4		207.8	
Total	239				
Cochran's test			0.38**		0.32**
Transformation			None		None

Table 6. Species ranked in order of importance that contributed to the average similarity within areas in low marsh as determined using the SIMPER analysis.

Area	BW			CC			CB			KB		
Location	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Species												
Juncus kraussii	3											
Samolus repens										3	2	3
Sarcocornia quinqueflora	1	1	1	1	1	1	1	1	1	1	1	1
Sporobolus virginicus	2		2	2	2	2			2	2	3	2
Triglochin striata							2					

Table 7. Species ranked in order of importance that contributed to the average similarity within areas in high marsh as determined using the SIMPER analysis.

Area	BW			CC			CB			KB		
Location	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Species												
Atriplex hastata									4			
Apium prostratum							5					
Baumea juncea	3				1		1					3
Fimbrystylis ferruginea	5											
Juncus acutus			4	1	3					1	5	
Juncus kraussii	1	1	2	4	5	1	2	1	1	2	3	1
Samolus repens	4	3						5	3			4
Sarcocornia quinqueflora			3	3		4	3	4	5	5	2	5
Selliera radicans		2			2			3				
Sporobolus virginicus	2	5	1	2	4	2	4	2	2	3	4	2
Suaeda australis						3				4	1	
Triglochin striata		4										

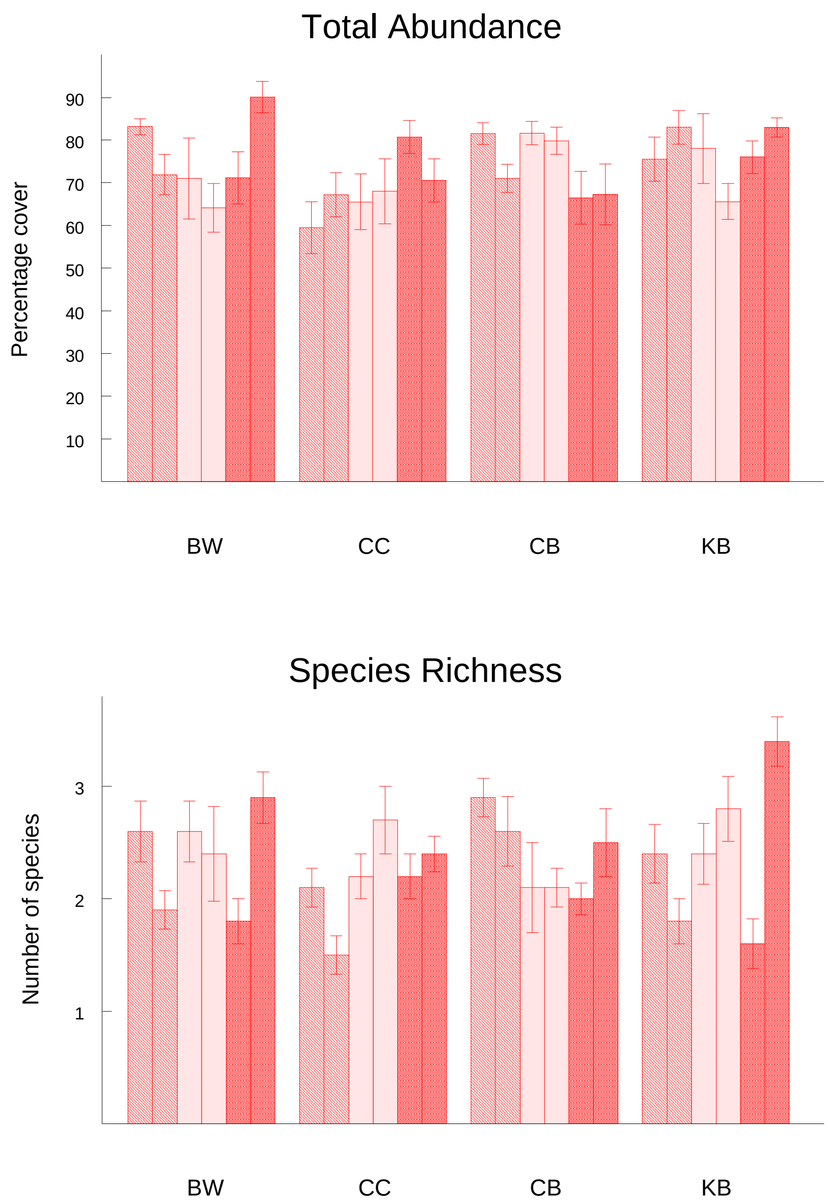
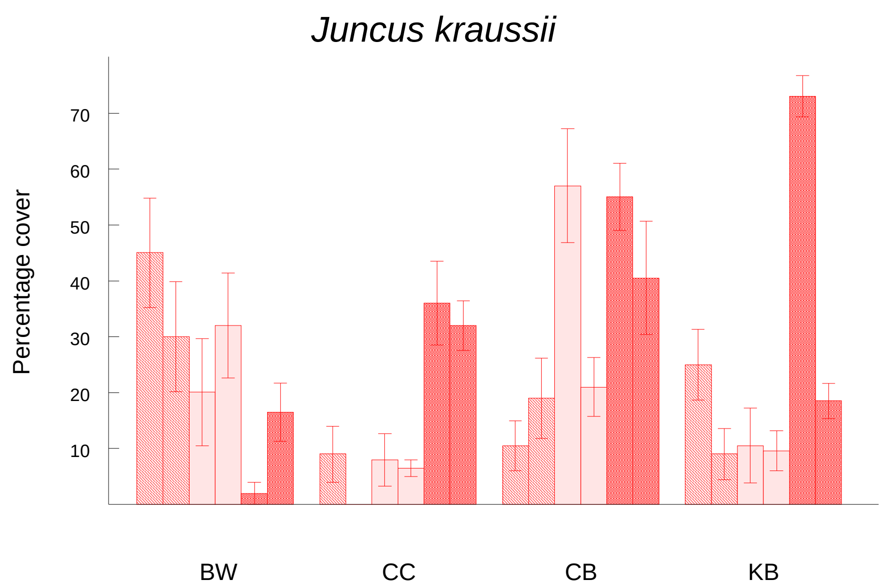


Figure 9. Mean (± SE) abundance and richness of saltmarsh at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in high marsh.



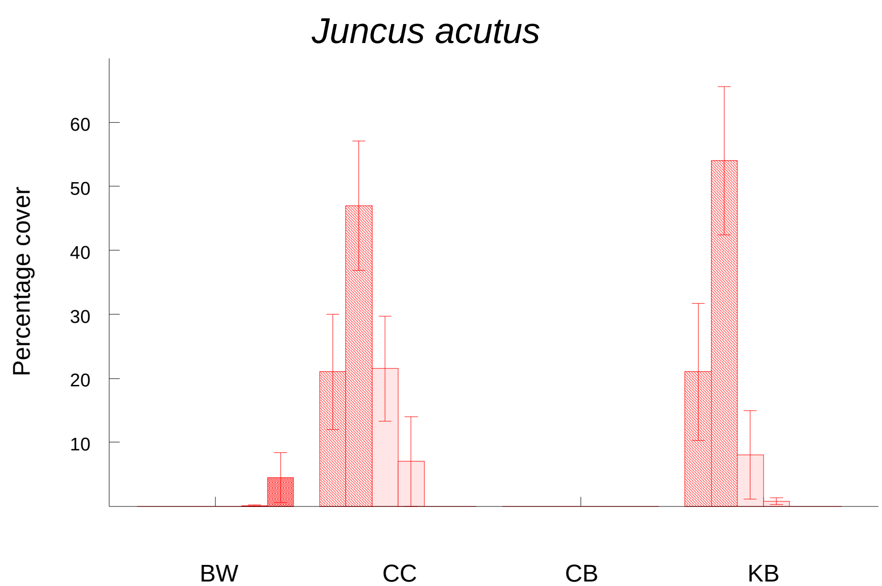
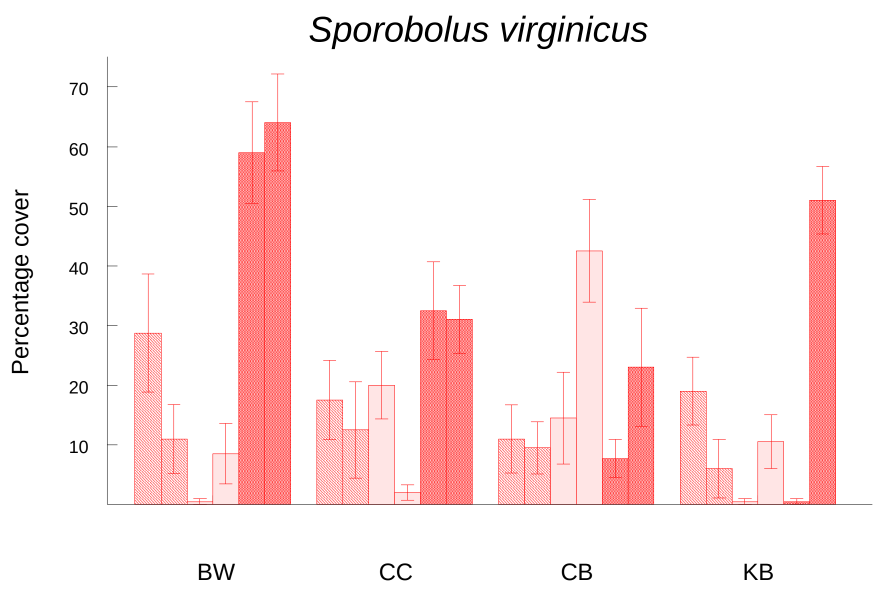


Figure 10. Mean (+ SE) abundance of *Juncus kraussii* and *Juncus acutus* at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in high marsh.



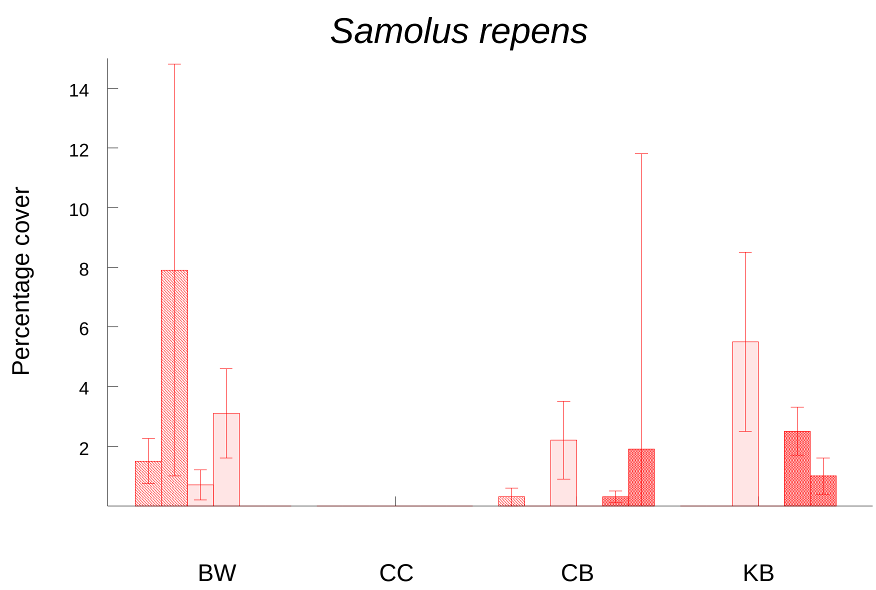


Figure 11. Mean (+ SE) abundance of *Sporobolus virginicus* and *Samolus repens* at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in high marsh.

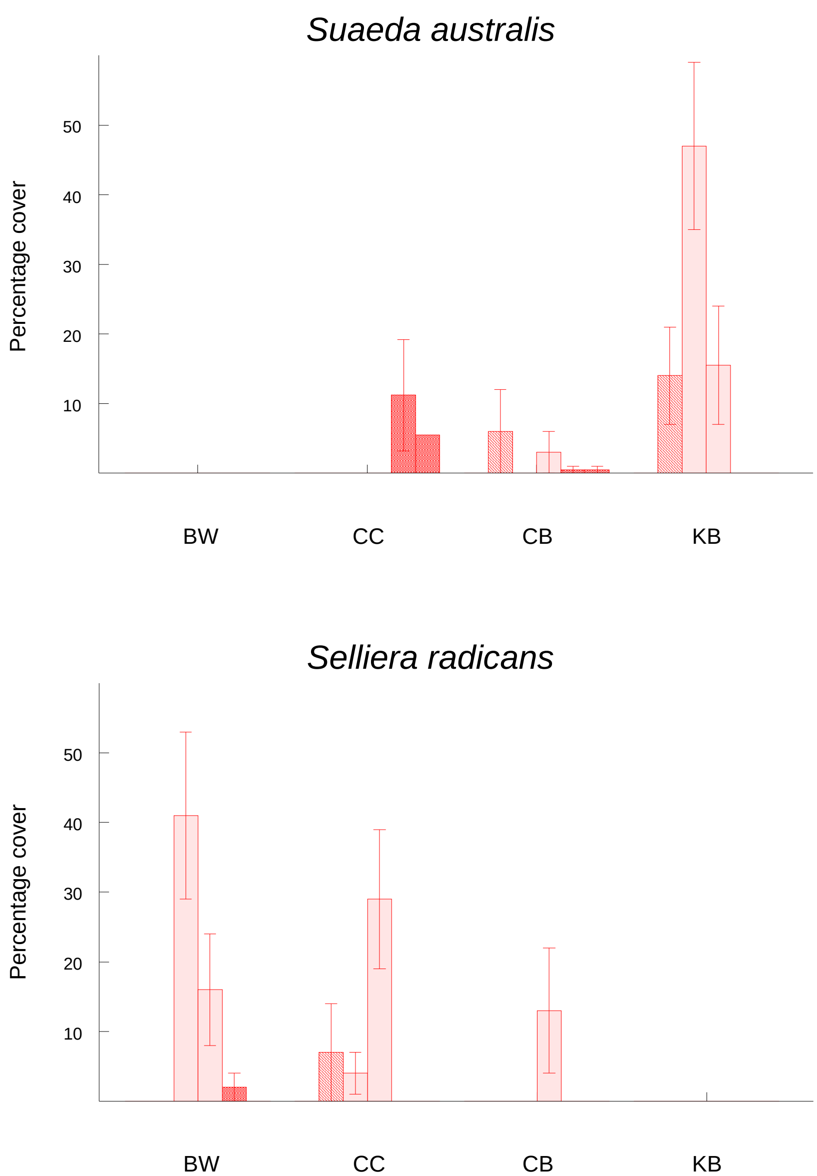
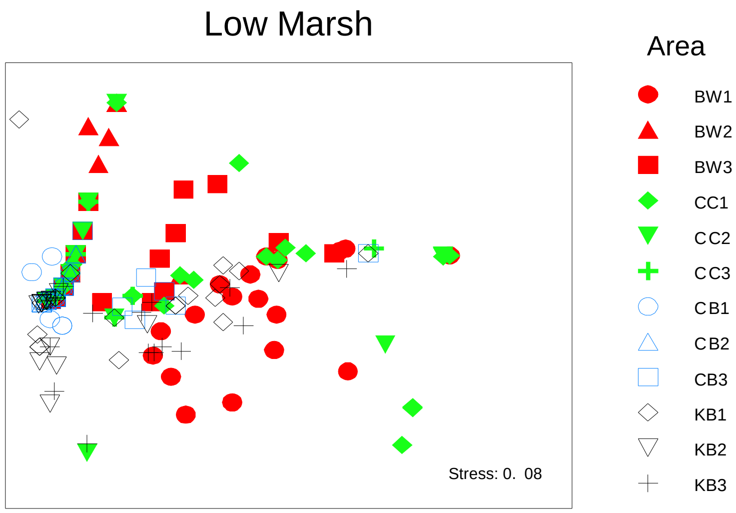


Figure 12. Mean (+ SE) abundance of *Suaeda australis* and *Selliera radicans* at two sites in three locations within four areas (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in high marsh.



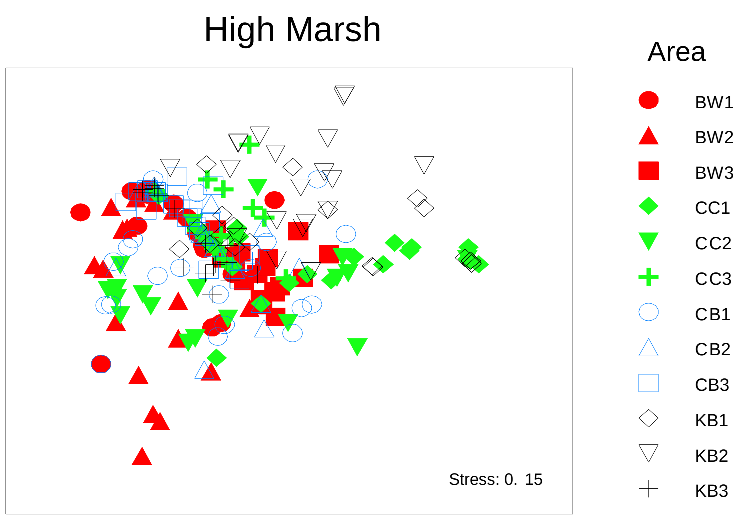


Figure 13. nMDS ordination for locations in each area (BW - Brisbane Water, CC – Cockle Channel, CB - Cockle Bay, KB – Kincumber Broadwater) in both low marsh and high marsh habitats.

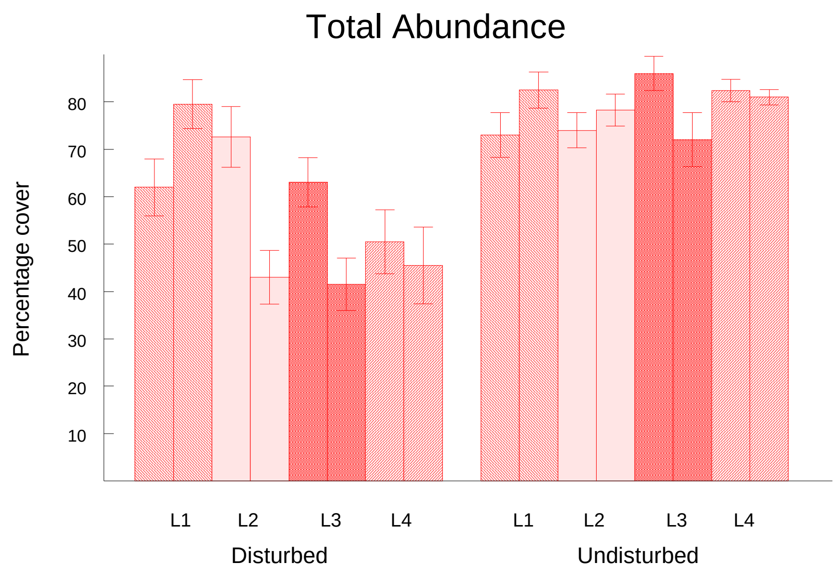
PATTERNS ASSOCIATED WITH DISTURBANCE

LOW MARSH

There were significant Site (Treatment x Location) interactions for all four variables tested within the low marsh (Table 8). These interactions represent small-scale variability within sites associated with patchiness within the saltmarsh. A significant treatment effect was detected for the total abundance of saltmarsh and the cover of *Sarcocornia quinqueflora* (Table 8; Figs 14 & 15). In general, disturbed saltmarshes had significantly smaller covers than undisturbed saltmarshes. There were no significant differences in the species richness between disturbed and undisturbed saltmarshes or for the cover of *Sporobolus virginicus* (Table 8; Figs 14 & 15).

Table 8. Summary of ANOVAs comparing species richness and total abundance of saltmarsh and the abundance of *Sarcocornia quinqueflora* and *Sporobolus virginicus* within disturbed and undisturbed low marsh in the Brisbane Water estuary (ns = not significant (*P* > 0.05); * significant (*P* < 0.05); ** significant (*P* < 0.01).

		Abundance		Richness	
Source	**df**	**MS**	***F***	**MS**	***F***
Treatment	1	18404.1	13.9*	0.4	0.13ns
Locations	3	742.1	0.6ns	0.82	0.78ns
Sites (Treatment x Location)	8	1235.2	4.62**	1.05	5.32**
Treatment x Location	3	1321.9	1.1ns	3.15	3.0ns
Residual	144	267.4		0.19	
Total	159				
Cochran’s test			0.16ns		0.16ns
Transformation			None		None
		S. quinqueflora		***S. virginicus***	
Source	**df**	**MS**	***F***	**MS**	***F***
Treatment	1	19669.2	19.4**	60.0	0.08ns
Locations	3	921.5	0.91ns	67.3	0.12ns
Sites (Treatment x Location)	8	875.9	2.1*	545.5	3.23**
Treatment x Location	3	1385.1	1.36ns	798.4	1.46ns
Residual	144	416.9		168.8	
Total	159				
Cochran’s test			0.19*		0.40**
Transformation			None		None



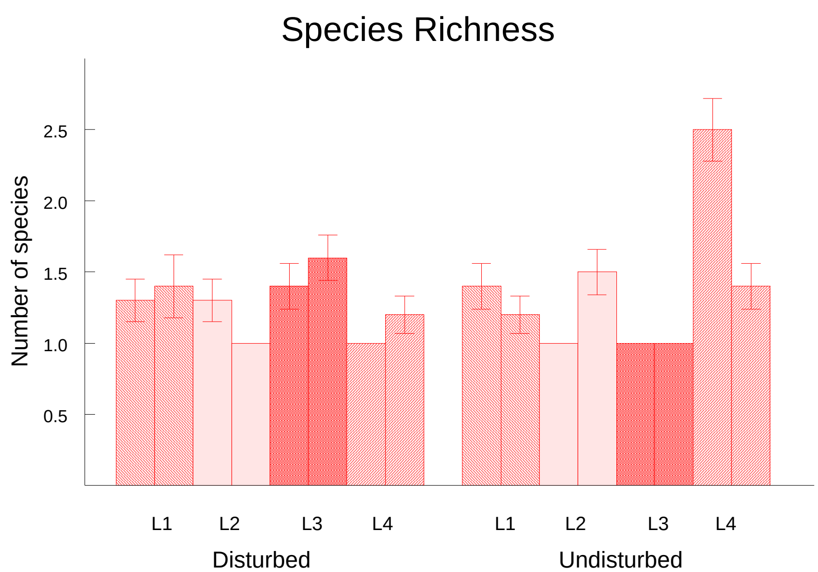
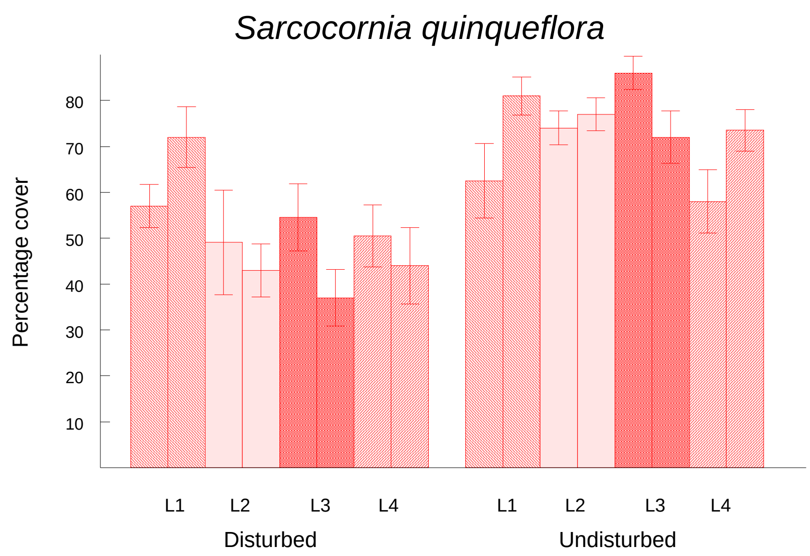


Figure 14. Mean (± SE) abundance and richness of saltmarsh at two sites in each of four disturbed and four undisturbed low marshes.



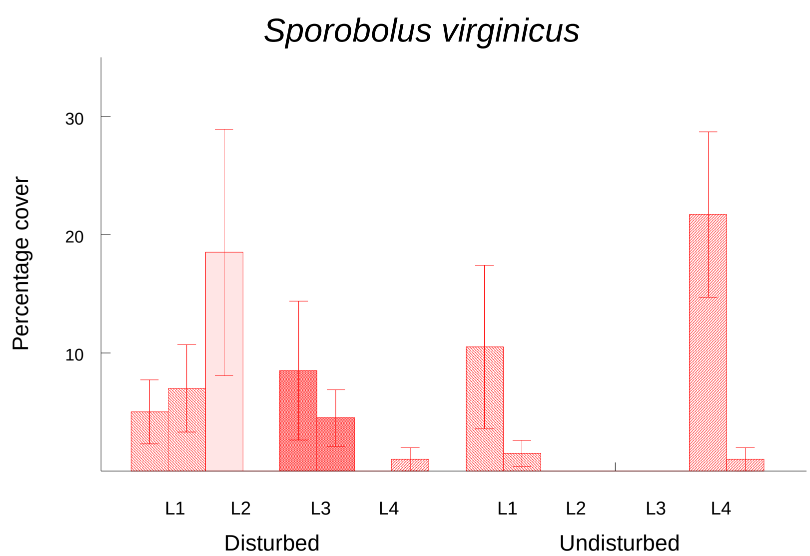


Figure 15. Mean (+ SE) abundance of *Sarcocornia quinqueflora* and *Sporobolus virginicus* at two sites in each of four disturbed and four undisturbed low marshes.

HIGH MARSH

There were significant Site (Treatment x Location) interactions for all but one of the variables tested within the high marsh (Table 9; Figs 16 - 18). A significant treatment x location interaction was detected for the total abundance of saltmarsh (Table 9; Fig. 16), where location 3 in the disturbed treatment was greater than the other locations.

There was a significant treatment effect detected for the cover of *Juncus kraussii* (Table 9). Generally the cover of *J. kraussii* was greater in undisturbed saltmarshes compared to disturbed saltmarshes (Fig. 17). Whilst not statistically significant, there was also a general pattern of greater cover of *Juncus acutus* within disturbed saltmarshes and a total absence of this species in undisturbed saltmarshes (see Fig 17). There were no significant differences in the covers of *Sporobolus virginicus* and *Samolus repens* (Table 9), however there was a pattern of greater cover in the undisturbed locations for *Samolus repens*, although this was not consistent for each treatment (Fig. 18).

STRUCTURE OF THE ASSEMBLAGE

The non-metric multidimensional scaling (nMDS) ordinations demonstrated considerable variation within the assemblages of saltmarshes in both low and high marsh habitats (Fig. 19). There appeared to be greater variability within the samples within the disturbed locations compared to the undisturbed locations. The stress value (see Fig. 19) associated with the ordination for the low marsh indicated that it was a good ordination with no real prospect of a misleading interpretation, whilst the high marsh was also considered to give a potentially useful 2-D picture (Clarke and Warwick, 1994). No patterns were observed within the ordinations that could be attributed to the different treatments however there were obvious differences between some locations. The ANOSIM tests confirmed that there were significant differences in the structure of assemblages between locations in both low marsh (R = 0.107*) and high marsh (R = 0.332*).

The SIMPER procedure generally ranked *Sarcocornia quinqueflora* and *Sporobolus virginicus* as important species that contributed to the structure of the assemblage in the low marsh in both treatments (Table 10). Within the high marsh, the most important species within undisturbed habitats was *Juncus kraussii* and S*porobolus virginicus* (Table 11). *Juncus acutus* was generally the most important species within disturbed locations and not represented at all in undisturbed locations (Table 11).

Table 9. Summary of ANOVAs comparing species richness and total abundance of saltmarsh as well as common species of saltmarsh found within disturbed and undisturbed high marsh habitats in the Brisbane Water estuary (ns = not significant (P > 0.05); * significant (P < 0.05); ** significant (P < 0.01).

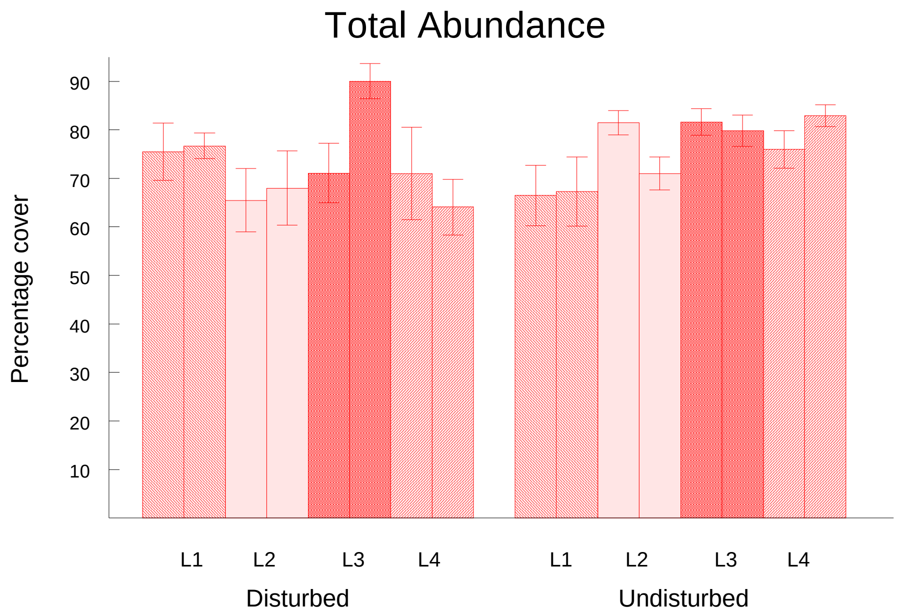
		Abundance		**Richness**	
Source	**df**	**MS**	***F***	**MS**	***F***
Treatment	1	381.3	0.41ns	0.31	0.33ns
Locations	3	750.9	2.56ns	1.01	0.3ns
Sites (Treatment x Location)	8	358.9	1.22ns	3.33	4.76**
Treatment x Location	3	927.9	3.16*	0.94	0.28ns
Residual	144	290.2		0.69	
Total	159				
Cochran's test			0.19*		0.16ns
Transformation			None		None
		J. kraussii		***J. acutus***	
Source	**df**	**MS**	***F***	**MS**	***F***
Treatment	1	23741.2	8.55**	3027.6	3.81ns
Locations	3	4283.8	1.54ns	795.5	1.37ns
Sites (Treatment x Location)	8	3071.9	7.81**	582.4	4.15**
Treatment x Location	3	1985.1	0.72ns	795.5	1.37ns
Residual	144	393.1		140.2	
Total	159				
Cochran's test			0.17ns		0.34**
Transformation			None		None
		S. virginicus		***S. repens***	
Source	**df**	**MS**	***F***	**MS**	***F***
Treatment	1	0.67	0.00ns	12.1	2.89ns
Locations	3	6564.9	3.22ns	22.5	2.33ns
Sites (Treatment x Location)	8	2039.1	8.88**	9.68	2.34*
Treatment x Location	3	3386.9	1.66ns	4.18	0.43ns
Residual	144	229.7		4.14	
Total	159				
Cochran's test			0.17ns		0.34**
Transformation			Arcsine		None

Table 10. Species ranked in order of importance that contributed to the average similarity within disturbed and undisturbed locations in low marsh as determined using the SIMPER analysis.

Treatment	**Disturbed**				**Undisturbed**			
Location	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Species								
Samolus repens								3
Sarcocornia quinqueflora	1	1	1	1	1	1	1	1
Sporobolus virginicus	2	2	2		2			2
Triglochin striata						2		

Table 11. Species ranked in order of importance that contributed to the average similarity within disturbed and undisturbed locations in high marsh as determined using the SIMPER analysis.

Treatment	**Disturbed**				**Undisturbed**			
Location	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Species								
Apium prostratum						5		
Atriplex hastata					4			
Baumea juncea	3	1				1		3
Juncus acutus	1	3	4					
Juncus kraussii	4	5	2	1	1	2	1	1
Samolus repens				3	3		5	4
Sarcocornia quinqueflora			3		5	3	4	5
Selliera radicans		2		2			3	
Sporobolus virginicus	5	4	1	5	2	4	2	2
Suaeda australis	2							
Triglochin striata				4				



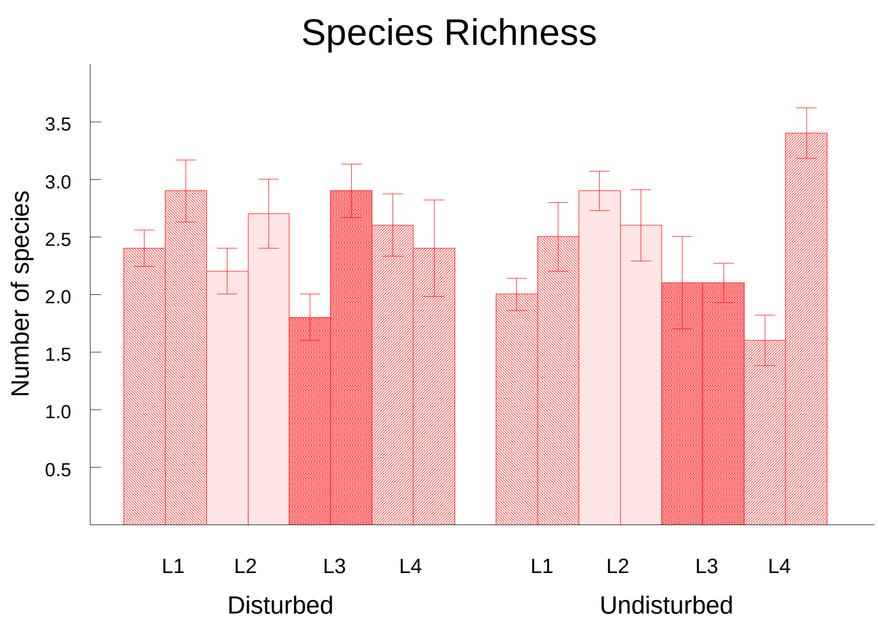
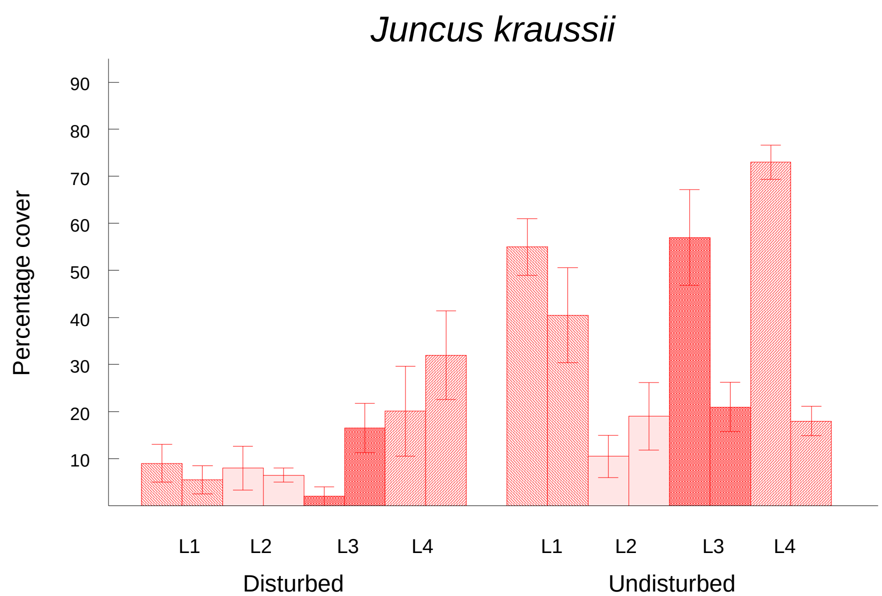


Figure 16. Mean (± SE) abundance and richness of saltmarsh at two sites in each of four disturbed and four undisturbed high marshes.



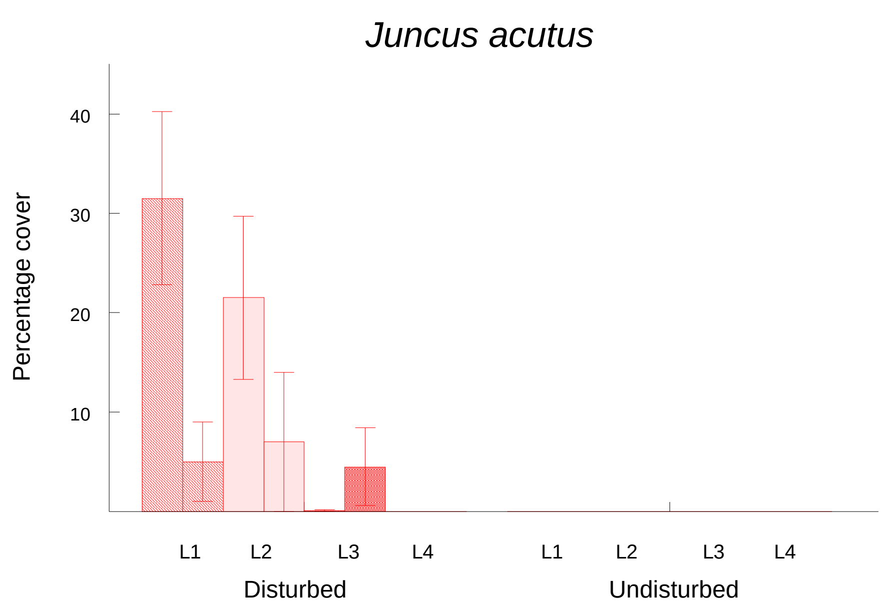
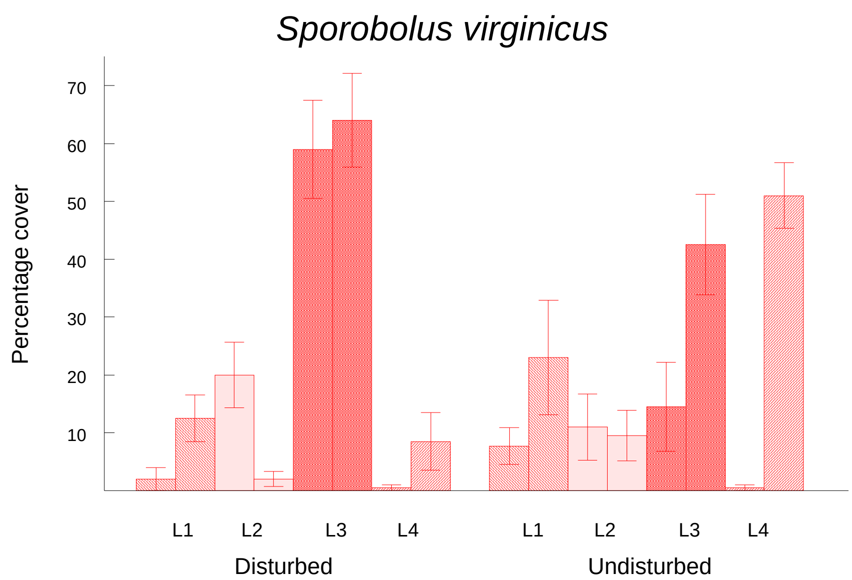


Figure 17. Mean (+ SE) abundance of *Juncus kraussii* and *Juncus acutus* at two sites in each of four disturbed and four undisturbed high marshes.



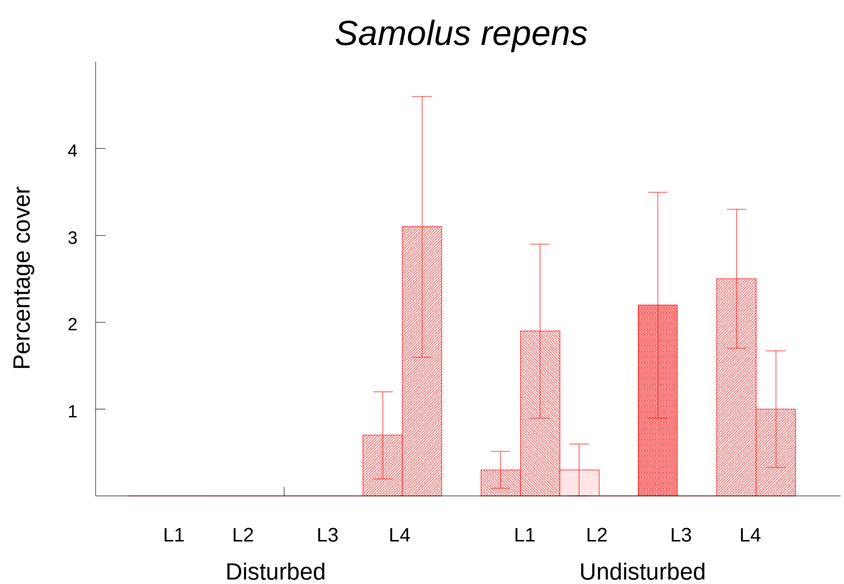
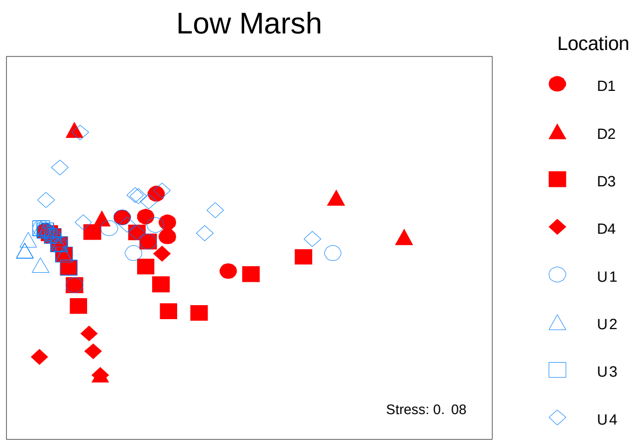


Figure 18. Mean (+ SE) abundance of *Sporobolus virginicus* and *Samolus repens* at two sites in each of four disturbed and four undisturbed high marshes.



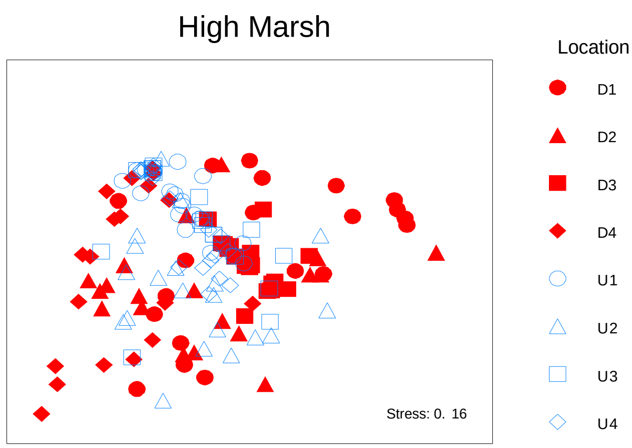


Figure 19. nMDS ordination for locations in disturbed and undisturbed low marsh and high marsh habitats.

DISCUSSION

The saltmarshes in the Brisbane Water estuary were diverse and abundant with over 30 species identified within the 14 saltmarshes examined. The low marshes were generally dominated by *Sarcocornia quinqueflora* and *Sporobolus virginicus* whilst the high marshes were dominated by *Juncus kraussii* and *Sporobolus virginicus* or *Juncus acutus*. These types of general patterns have been described for saltmarsh habitats along the coast of NSW (West *et al.*, 1985) and for Brisbane Water (Harty, 1994). We did not examine mid-marsh because it was not simply identifiable and/or was a mosaic of saltmarsh assemblages that had representatives of both low and high marsh (Zedler *et al.*, 1995). In general, and depending on elevations, the low marsh grades through a mosaic of assemblages until it reaches the high marsh on more elevated land. In our opinion the so-called mid marsh zone is non existent in most marshes that we examined in the Brisbane Water estuary.

Hydrodynamic modelling indicated that Cockle Bay and Kincumber Broadwater have essentially the same tidal characteristics whilst the tidal regimes in Brisbane Water were similar from a water level perspective. However Cockle Channel had significantly higher current velocities. Areas with restricted tidal exchange away from the main flow within the estuary i.e. Cockle Bay and Kincumber Broadwater generally had greater covers of saltmarsh within the low marsh habitat. The greater cover was primarily related to the dominance of *Sarcocornia quinqueflora*. This species is generally more abundant at the lowest elevation and generally situated behind mangrove forests (Harty and Cheng, 2003). These backwater saltmarshes may experience greater salinities and longer periods of inundation because they tend to fill and drain more slowly over any given tidal cycle compared to saltmarshes in the main tributary channels (Roy *et al.*, 2001). They also tend to experience fewer tidal inundations.

There were no patterns of saltmarsh distribution between the four different areas for high marsh habitat that could be associated with any tidal regimes. This was not surprising as these habitats are not frequently tidally inundated like the low marsh habitat and therefore a different set of processes would be causing the patterns in high marshes. High shore levels in saltmarshes are physically stressful because of infrequent inundation by tide, potentially large concentrations of salt in the soil and long periods of desiccation. These factors can limit growth and diversity of plants (Hacker and Bertness, 1999). High level saltmarshes are generally more diverse then low level marshes and this was supported by our data.

High marshes tend to have greater sources of temporal variability because their soils can become highly saline over time (St. Omer, 2004), they also tend to experience longer periods where they dry out and are more prone to freshwater influences. As they are more diverse, there is also the potential for greater biological interactions and competition between species in these habitats.

The productivity of saltmarsh increases with more water and nutrients and ideally this is supplied by tidal inundation and catchment runoff. Minello *et al.* (2003) studied the value of saltmarsh as nurseries for assemblages of nekton. They concluded that vegetated marsh had a higher nursery value then unvegetated marsh, but a lower nursery value than seagrass habitat. Tidal dynamics and the movement of nekton among components of the marsh complicated these comparisons and Minello *et al.* (2003) concluded that saltmarsh nursery value is highly dependent on geography, salinity regimes and tidal amplitude.

There were significant patterns associated with anthropogenic disturbance within the low marsh habitats. Generally, *Sarcocornia quinqueflora* had smaller percentage covers within disturbed locations compared with undisturbed locations. There is a wealth of literature that describes the loss of saltmarshes and associates this loss with anthropogenic disturbance at the scale of whole estuaries (Saintilan and Williams, 2000a). However we were unable to find any work that had quantified the effects of disturbance at smaller spatial scales in NSW. Whilst this pattern has been generalised in temperate estuaries, there has been no quantitative data that has shown this to be correct.

The cover of *Juncus kraussii* was greater in undisturbed locations whilst the introduced noxious species *Juncus acutus* was more abundance in disturbed locations. Increasingly, high marsh is being overrun by weeds and many of these weeds have moderate tolerance to salt. Examples of semi-salt tolerant exotic plants that were identified in the high marsh include *Juncus acutus* (Spiny Rush), Buffalo Grass, Lantana, Bitou Bush, *Ipomoea carioca*, Alligator Weed and species of Asparagus. The problems associated with weed invasions are many, and in some of the marshes examined, *Juncus acutus* is a significant problem. This species was also found on Pelican Island, where its proliferation has been encouraged.

Although much of the shoreline of Brisbane Water has been modified and large areas filled for housing, excellent areas of saltmarsh still remain. Some saltmarshes e.g. Erina Creek are in excellent condition and have good marsh/forest interface. Others e.g. Davistown have been affected by disturbances and have a poor interface with the urban area. The vigour of saltmarsh can be significantly reduced where small banks are constructed, eg. sewerage pipelines, and tidal inundation is restricted. A bank of only 10 cm height can be sufficient to prevent or reduce local tidal inundation.

Many saltmarsh species can easily be crushed by trampling and or wheels. There were many examples of disturbance to the marshes associated with vehicular use including cars, motorcycles and pushbikes. *Sarcocornia quinqueflora* is especially susceptible to the effects of physical disturbance such as trampling. Grazing cattle were observed within some marshes and this particular activity can cause significant damage to the marsh. In the marsh at Bensville, horses had been allowed access from the high marsh down to the edge of the water and they had caused damage to low marsh and had also eaten and destroyed the mangroves. The substratum of the marsh had also been significantly damage by their hard hooves.

Relatively large areas of non-fragmented marsh have the potential to be of a high ecological value and yet the community at large is generally unaware of the importance of saltmarsh to estuarine processes. The ideal interface on the edge of an estuary is a zonation of forest > high marsh > low marsh > mangroves > seagrass.

There are few areas left in Brisbane Water that fit this criterion, but where they exist eg Cockle Bay, disturbance of any type within the catchment should be resisted and appropriate management plans put in place to protect them into the future.

Educating the community about the importance of saltmarsh to the Brisbane Water estuary has been supported by council and environmental groups through rehabilitation programmes, eg. the Kincumber Creek Rehabilitation Project. Unfortunately, there is often direct conflict between this assemblage of plants and the community for living space. In general the community wins due to its position on the landscape and the indirect impacts of urbanising a catchment. The classic example of this has been the development of the Saratoga and Davistown area which was basically been built on a saltmarsh. The stormwater gutters in this area show a drainage network that is still dominated by saltmarsh species. The other social issues that sometimes impact on saltmarshes are the problems associated with certain disease carrying mosquitos which can proliferate in some of these wetlands. Often the cause of mosquito problems in these mashes can be associated with previous disturbance and changes to inundation patterns within the marsh.

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