Temporal and spatial variations in seagrass standing-stock at a meadow in Port Curtis, Queensland

David R. Currie[1, 2] *and Kirsty J. Small*[1]

[1] Centre for Environmental Management, Central Queensland University, P.O. Box 1319, Gladstone, Qld. 4680, Australia.
[2] *Present Address*: SARDI Aquatic Sciences, P.O. Box 120, Henley Beach, SA 5022, Australia.
Email: currie.david@saugov.sa.gov.au

Abstract. Studies to assess the health of seagrass beds in Port Curtis have been undertaken since 1994. Much of this work has been directed towards a relatively small bed at Wiggins Island near the mouth of the Calliope River, and has primarily involved intensive quantitative sampling of seagrass standing stock and assessments of its temporal relationships with sediment grain size, algal cover and macrobenthic community parameters. Two species of seagrass *Zostera capricorni* and *Halophila ovalis* occur throughout the intertidal zone at Wiggins Island. The former is most prolific, however both seagrass species are temporally subordinate to mat-forming, filamentous, green algae. Both algae and seagrass communities at Wiggins Island undergo annual cycles of growth and die-back that are broadly six months out of phase. The key period of growth for seagrass occurs between August and November and coincides with increasing seawater temperatures and daylight hours; it dies-back through February and June when seawater temperatures and daylight hours are declining. Algae, in contrast, flourish at the end of summer and die-back during spring. These seasonal cycles are almost certainly the result of natural cyclic phenomena, however a range of other environmental processes (including unpredictable climatic events and biological interactions) are understood to be contributing to large inter-annual differences in standing-stock at this location. In particular, flood events in the Calliope River are known to have an immediate impact on the benthic composition at Wiggins Island. Transportation and the reworking of fine sediments during major flow events (October 1998, February 1999 and October 2001) have resulted in significant declines in the biomass of seagrass, and the abundance and richness of infaunal organisms. Whether rapid algal growth at Wiggins Island following major flood events simply represents an opportunistic response to habitat availability, or possibly a response to elevated nutrient runoff derived from the Calliope River catchment, remains to be determined.

Introduction

Seagrass communities grow in most shallow and sheltered near-shore environments around Australia, and are widely regarded as important components of coastal ecosystems (Kirkman 1996; Coles *et al.* 2003; Walker, 2003). Seagrass is a major food source in detrital-based food chains, and a direct food source for grazing animals including dugong and green turtle (Preen 1995; Aragones, and Marsh 1999). The meadows they form can support a rich and diverse flora and fauna, and provide shelter and refuge for a variety of motile invertebrates and juvenile fish species. Additionally, seagrass meadows play important roles in stabilising sediments, reducing wave energy, and filtering nutrients and chemicals from the water column (English *et al.* 1994).

Topography, substrate type, tidal exposure, water clarity and salinity are all important factors in determining seagrass distribution and composition (Lanyon 1986; Carruthers *et al.* 2002). Under certain environmental conditions, some species may be lost or have reduced cover, allowing other species to become dominant. Seasonal variations in temperature and altered freshwater flows may also result in changes to seagrass composition and abundance.

Port Curtis, situated on the central coast of Queensland supports some of the regions most extensive seagrass meadows (Fig. 1). The estuarine waterway is also home to the fifth largest export port in Australia, and is presently a focus for rapid industrial expansion. As much of the land required for industrial growth is located on intertidal wetlands, site clearances have involved some reclamation of mangroves, salt-marshes and mud flats. The direct consequences of these land reclamation activities include loss of habitat and alterations to natural freshwater flows and tidal inundation patterns. These developments also have the capacity to modify sedimentary loads in the water column and thereby alter sediment deposition rates in adjacent intertidal seagrass beds.

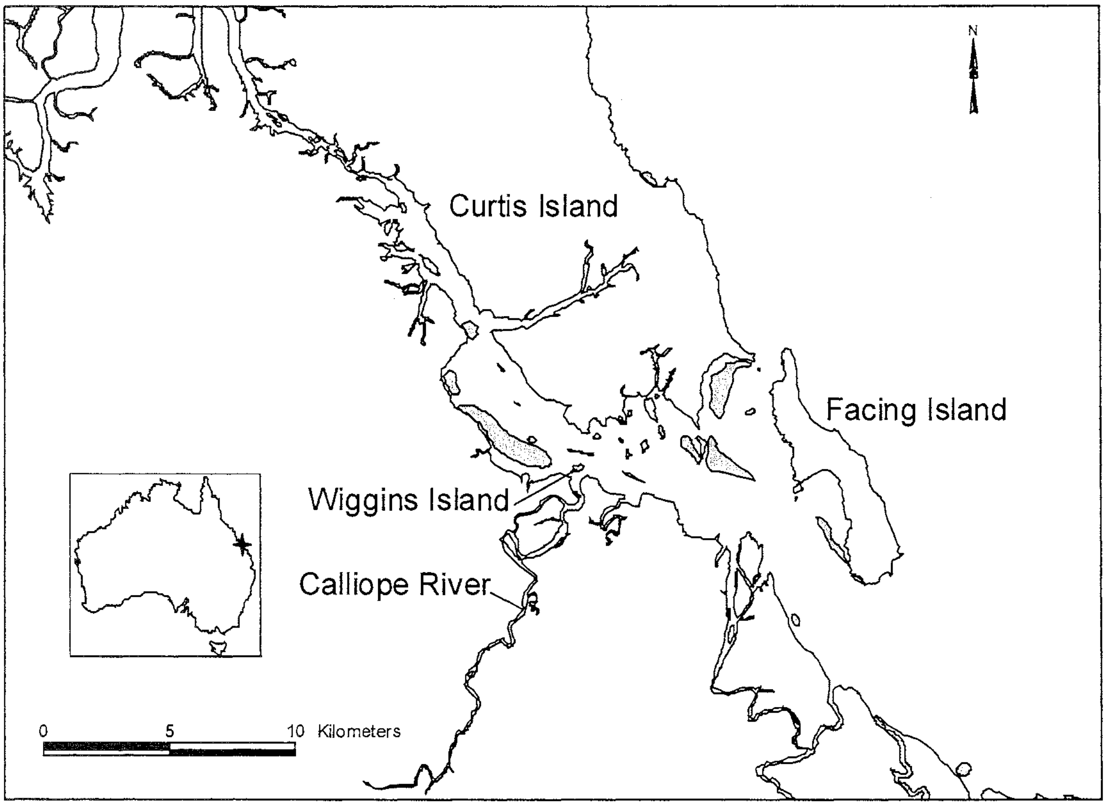


Fig. 1. Map of Port Curtis inner harbour showing the location and extent of seagrass beds (grey-fill polygons) as determined by Lee Long *et al.* (1992).

In an effort to quantify the possible deleterious effects of landfill developments on extensive seagrass beds near Wiggins Island, a research project was established in 1994. While this programme has undergone several changes in design and methodology (Houston 1995; Walker and Houston 1996; Lewis *et al.* 1999; Small *et al.* 2000), the current sampling design has remained unchanged since 1997. The design presently involves twice annual sampling of seagrass composition, standing-stock and macrobenthic diversity at a large intertidal mudflat to the west of Wiggins Island. This paper examines seasonal and geographical differences in these parameters between February 1997 and March 2001, and the relevance of observed changes in relation to coastal developments near Wiggins Island.

Methods

Twelve permanent marker buoys were established on the Wiggins Island mudflats during 1997 (Fig. 2). The buoys were used to identify the locations of seagrass sampling stations, and were placed a minimum of 80m apart near the outer margins of the Wiggins Island mudflat, in similar depths of water (ie 2-3m above the lowest astronomical tide). Spatial and temporal changes in seagrass cover and standing stock at these twelve sampling stations, were determined using a combination of diver observations and benthic grab sampling techniques between February 1997 and March 2001

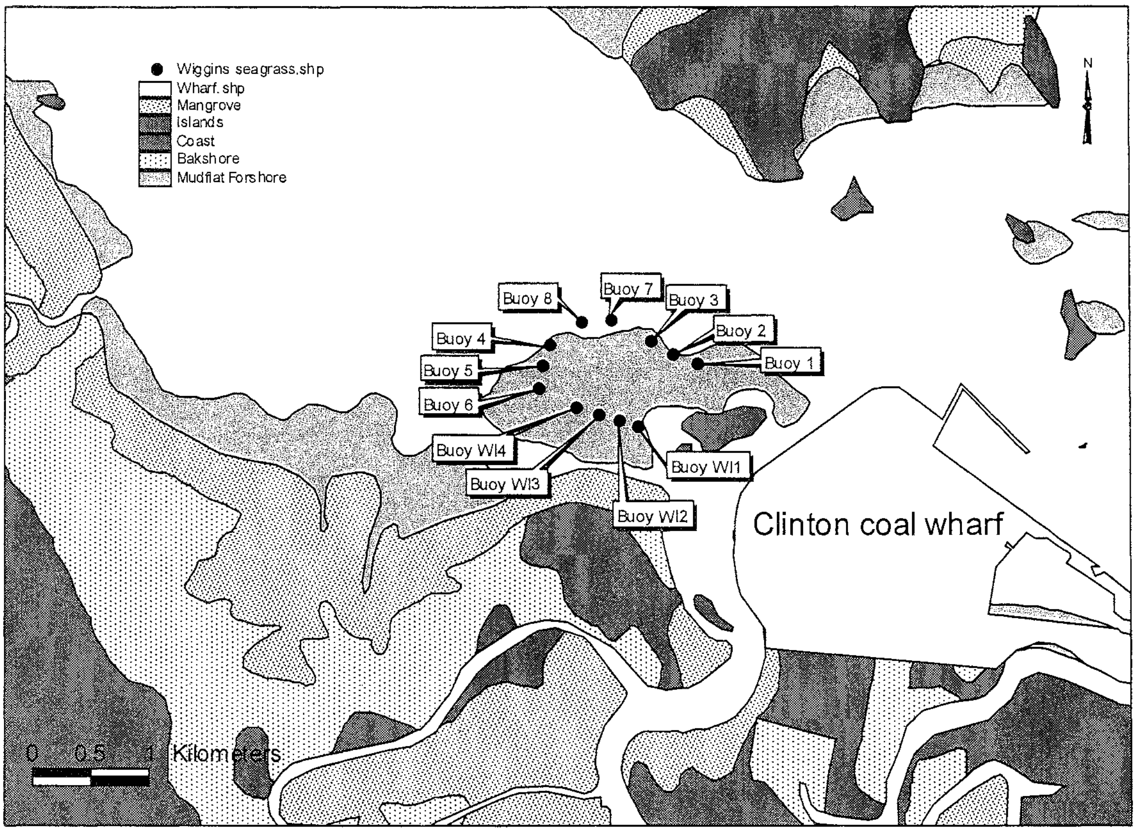


Fig. 2. Map of Wiggins Island mudflat showing the locations of stations sampled for seagrass and macrobenthos between February 1997 and March 2001.

Seagrass cover

Diver quadrats were used to estimate differences in species composition and percentage cover of seagrass and algae at the twelve sampling stations (1, 2, 3, 4, 5, 6, 7, 8, WI1, WI2, WI3, WI4) on eleven sampling dates (Feb97, Jun97, Sep97, Mar98, Jun98, Oct98, Sep99, Nov99, May00, Sep00, Mar01). A total of ten replicate quadrats ($0.5m^2$) were randomly placed by divers within a $100m^2$ sampling area around each buoy on each sampling date. These quadrats were visually assessed by divers, and the percent cover of each species of seagrass and algae recorded.

Two-way analysis of variance (ANOVA) was used to examine the effects of stations and sampling date on the mean percentage cover of both common seagrass species (*Zostera capricorni* and *Halophila ovalis*), and additionally a combined group of filamentous algae (including *Monostroma* and *Rhizoclonium* spp.). Prior to these analyses, homogeneity of variance was examined using Levene's test and heterogeneity removed where necessary by log10(n+1) and 1/(n+1) transformations.

Seagrass biomass

Measures of seagrass biomass were determined from live plant material collected from benthic grab samples. A total of ten replicate $0.1m^2$ van Veen grab samples were taken at random from each of four locations (WI1, WI4, 3 and 8) (Fig. 2) on nine separate sampling occasions (Jun97, Oct97, Mar98, Sep98, Feb99, Aug99, Mar00, Sep00, Mar01). The seagrass components were initially separated by wet sieving on a 1mm mesh screen. The seagrass was later separated into species (*Halophila ovalis* and *Zostera capricorni*) and further divided into above ground (leaves, shoots, flowers) and below ground (roots, rhizomes) components. All of these components were weighed before (wet weight) and after (dry weight) drying at 40° for a minimum of 24hrs, or until fully desiccated. Leaf-length and shoot density were also measured.

In an effort to better determine the most appropriate variables for assessing change in seagrass biomass, wet/dry weight relationships for various seagrass component parts were investigated. Correlation analysis confirmed that above-ground dry weights of seagrass were the most relevant measures for gauging seagrass biomass. All two-way ANOVA's assessing differences in seagrass biomass between sampling dates and stations were therefore conducted using above-ground, dry weight values only. Prior to these analyses, homogeneity of variance was examined using Levene's test and heterogeneity removed where necessary by log10(n+1) and 1/(n+1) transformations.

Macrobenthos

Part of the seagrass habitat is the fauna that live on or in the seagrasses, or in the sediments in which they grow. These benthic fauna are changed by disturbances to seagrass, and may offer an alternative/additional measure of seagrass health. The potential for using macrobenthic community structure as a surrogate for the well-being of seagrass at Wiggins Island was therefore examined. Temporal and spatial changes in macrofaunal composition at Wiggins Island were examined using the same suite of benthic grab samples employed to assess changes in seagrass biomass. Macrobenthic organisms were separated from the seagrass and fine sediment in each grab (10 replicate $0.1m^2$ van Veen grabs x 4 sampling stations) by sieving the sampled material on a 1mm mesh. The fauna retained was subsequently preserved in 10% formaldehyde solution and later sorted and identified to the highest taxonomic level (generally species). Type material from each new taxa encountered was lodged in the CQU reference collection in Gladstone.

Differences in the abundance and richness of macrofauna between stations and sampling dates were investigated using two-way analysis of variance (ANOVA). Again, prior to all analyses, homogeneity of variance was examined using Levene's test and heterogeneity removed where necessary by log10(n+1) and 1/(n+1) transformations. Relationships between macrofaunal abundance and richness, and the quantity of seagrass found at each station and sampling period, were additionally investigated using correlation analysis.

Sediment analysis

One supplementary grab sample was collected from the four benthic stations (WI1, WI4, 3 and 8) (Fig. 2) on each sampling date and used to determine the sediment grain size structure. Approximately 100 g of sediment from each grab was air dried and sieved through an agitated stack of sieves with apertures of 2mm, 1mm, 500μm, 250μm and 63μm. Each fractions mass was then calculated as a percentage of the total mass of the sample, after correction for moisture content. The strength of associations between the percentage fine muds (% < 63μm) and the composition of macrofauna and seagrass were later examined by correlation analysis.

Results

Seagrass cover

Analysis of variance shows that percent cover of all species groupings (*Zostera capricorni*, *Halophila ovalis* and algae) differed significantly ($p<0.05$) between sampling stations and sampling dates (Tables 1A, 2A, 3A). A series of post-hoc multiple comparison tests (SNK) were therefore conducted to identify which stations and dates contributed most to observed differences. Station differences in percentage cover of *Zostera capricorni*, *Halophila ovalis* and algae are summarized in Tables 1B, 2B and 3B respectively. Table 1B shows that *Zostera capricorni* cover was significantly greater on the western edge of the Wiggins Island mudflat (stations 4, 5 and 6) than at all other stations sampled. It dominated the benthic flora at these stations, and extended to cover nearly half of the available surface area. The same species was significantly less prolific on the northern and eastern edges of the mudflat (stations 1, 2, 3, 7, 8), where it generally covered less than 15% of the sediment surface. *Halophila ovalis* by comparison was subordinate. This seagrass species was normally found covering less than 2% of the available substrate. It is therefore noteworthy that significantly higher densities of this species were consistently observed by divers at a single station (7) on the northern edge of the mudflat (Table 2B). Filamentous algae were much more widespread and abundant at Wiggins Island. Algal densities varied markedly between stations, and were significantly lower at stations 4, 5, 6 and 7, and significantly higher at stations 1, 3, 8 and WI3 (Table 3B). This distribution tentatively suggests that *Zostera capricorni* and algal densities may be inversely related, and that one species group may be competitively excluding the other.

Temporal changes in percent cover of *Zostera capricorni*, *Halophila ovalis* and algae are summarized in Tables 1C, 2C and 3C respectively. These multiple comparison tables provide objective assessments of seasonal patterns in vegetative densities, but no consistent trends are readily apparent between taxa. *Zostera capricorni* cover displays some degree of seasonal periodicity, and was most abundant during a 3-month period immediately prior to the December/January wet-season (September 1999, November 1999, September 2000); and least abundant during a 5-month period following the wet-season (February 1997, June 1997, March 1998, June 1998, March 2001) (Table 1C). *Halophila ovalis*, by comparison, shows little temporal periodicity, and densities for this species remain relatively similar between seasons and years (Table 2C). Algal densities, in contrast, were typically highest during a 5-month period following the wet-season (June 1997, June 1998, May 2000, March 2001) (Table 3C).

Plots of changes in the mean percentage cover of *Zostera capricorni*, *Halophila ovalis* and algae between sampling stations and dates are presented in Figs. 3, 4 and 5 respectively. It is evident in all of these plots that change in percentage cover differs markedly over time at each sampling station. In effect, these plots are graphic representations of the significant date*station interactions determined for each key species during the analysis of variance. The plots confirm that the significant interaction term in *Zostera capricorni* is largely the result of unparalleled growth of this species at stations 4, 5 and 6 (western edge of mudflat) over the period following March 1998 (Fig. 3). Additionally, they verify that the significant interaction term for *Halophila ovalis* is most probably a result of unmatched fluctuations in percentage cover of this species at station 7 on the northern edge of the mudflat (Fig. 4). The principal causes for the significant date*station interaction in algal cover is less obvious. Mean percentage covers for algae intergrade at most stations and sampling dates (Fig. 5), however unusually high densities of algae at stations 1 and 3 during the middle part of 1998 and 2000 (Table 4) have probably contributed to the significance of this statistic.

Table 1A. Results of two-way ANOVA on differences in mean percent cover of *Zostera capricorni* at twelve stations over eleven sampling dates.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	785479.788	129	6088.991	16.369	.000	1.000
Intercept	627133.010	1	627133.010	1685.916	.000	1.000
DATE	208714.318	10	20871.432	56.108	.000	1.000
STATION	332083.117	11	30189.374	81.158	.000	1.000
DATE * STATION	248564.518	108	2301.523	6.187	.000	1.000
Error	435220.800	1170	371.984			
Total	1867356.000	1300				
Corrected Total	1220700.588	1299				

a Computed using alpha = .05
b R Squared = .643 (Adjusted R Squared = .604)

Table 1B. Results of post-hoc multiple comparisons test for differences in the mean percent cover of *Zostera capricorni* between the twelve stations.

	Station	N	Subset 1	2	3	4	5	6	7
Student-Newman-Keuls	1	110	.00						
	2	110	.16						
	7	100	5.54	5.54					
	3	110		9.40					
	8	100			14.78				
	WI 3	110			19.71	19.71			
	WI 1	110				23.57			
	WI 2	110					30.17		
	WI 4	110					31.60		
	6	110						41.10	
	5	110						42.48	
	4	110						46.91	
	Sig.		.088	.141	.060	.141	.586	.069	

Table 1C. Results of post-hoc multiple comparisons test for differences in the mean percent cover of *Zostera capricorni* between sampling dates.

	Date	N	Subset 1	2	3	4	5
Student-Newman-Keuls	MAR-1998	120	1.16				
	FEB-1997	120		9.72			
	JUN-1997	120		10.43			
	JUN-1998	120		14.53			
	MAR-2001	100		15.57			
	SEP-1997	120			22.89		
	OCT-1998	120			23.23		
	MAY-2000	120				31.67	
	SEP-2000	120					37.25
	SEP-1999	120					38.26
	NOV-1999	120					39.50
	Sig.		1.000	.093	.894	1.000	.643

Table 2A. Results of two-way ANOVA on differences in mean percent cover of *Halophila ovalis* at twelve stations over eleven sampling dates.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	56776.653	129	440.129	9.486	.000	1.000
Intercept	7057.313	1	7057.313	152.103	.000	1.000
DATE	1776.009	10	177.601	3.828	.000	.997
STATION	38015.474	11	3455.952	74.484	.000	1.000
DATE * STATION	16519.194	108	152.956	3.297	.000	1.000
Error	54286.100	1170	46.398			
Total	117483.000	1300				
Corrected Total	111062.753	1299				

a Computed using alpha = .05
b R Squared = .511 (Adjusted R Squared = .457)

Table 2B. Results of post-hoc multiple comparisons test for differences in the mean percent cover of *Halophila ovalis* between the twelve stations.

	Station	N	Subset 1	2
Student-Newman-Keuls	1	110	.00	
	2	110	.01	
	3	110	.07	
	WI 4	110	.29	
	WI 1	110	.52	
	6	110	.75	
	4	110	.76	
	WI 2	110	.84	
	8	100	1.16	
	WI 3	110	1.24	
	5	110	1.65	
	7	100		20.99
	Sig.		.794	1.000

Table 2C. Results of post-hoc multiple comparisons test for differences in the mean percent cover of *Halophila ovalis* between sampling dates.

	Date	N	Subset 1	2	3
Student-Newman-Keuls	MAR-2001	100	.08		
	MAR-1998	120	.74		
	SEP-1997	120	.97		
	MAY-2000	120	1.38	1.38	
	JUN-1998	120	1.93	1.93	1.93
	JUN-1997	120	2.19	2.19	2.19
	OCT-1998	120	2.25	2.25	2.25
	SEP-1999	120	2.35	2.35	2.35
	SEP-2000	120		3.82	3.82
	FEB-1997	120			4.09
	NOV-1999	120			4.28
	Sig.		.173	.068	.113

Table 3A. Results of two-way ANOVA on differences in mean percent cover of algae at twelve stations over eleven sampling dates.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	433708.699	129	3362.083	10.179	.000	1.000
Intercept	243274.972	1	243274.972	736.514	.000	1.000
DATE	152717.101	10	15271.710	46.235	.000	1.000
STATION	107332.773	11	9757.525	29.541	.000	1.000
DATE * STATION	173584.376	108	1607.263	4.866	.000	1.000
Error	386457.900	1170	330.306			
Total	1064191.000	1300				
Corrected Total	820166.599	1299				

a Computed using alpha = .05
b R Squared = .529 (Adjusted R Squared = .477)

Table 3B. Results of post-hoc multiple comparisons test for differences in the mean percent cover of algae between the twelve stations.

	STATION	N	Subset 1	2	3	4
Student-Newman-Keuls	7	100	1.90			
	6	110	3.04			
	4	110	3.82			
	5	110	5.15			
	WI 2	110		10.95		
	WI 4	110		12.80		
	WI 1	110		13.01		
	2	110		13.74		
	1	110			20.37	
	8	100			22.94	
	3	110			25.77	
	WI 3	110				30.69
	Sig.		.552	.671	.074	1.000

Table 3C. Results of post-hoc multiple comparisons test for differences in the mean percent cover of algae between sampling dates.

	Date	N	Subset 1	2	3	4	5
Student-Newman-Keuls	OCT-1998	120	.57				
	MAR-1998	120		6.85			
	SEP-1997	120		8.11			
	FEB-1997	120		8.96	8.96		
	SEP-1999	120		9.02	9.02		
	SEP-2000	120		10.53	10.53		
	NOV-1999	120		12.60	12.60		
	JUN-1998	120			15.31	15.31	
	MAR-2001	100			15.36	15.36	
	JUN-1997	120				19.52	
	MAY-2000	120					44.17

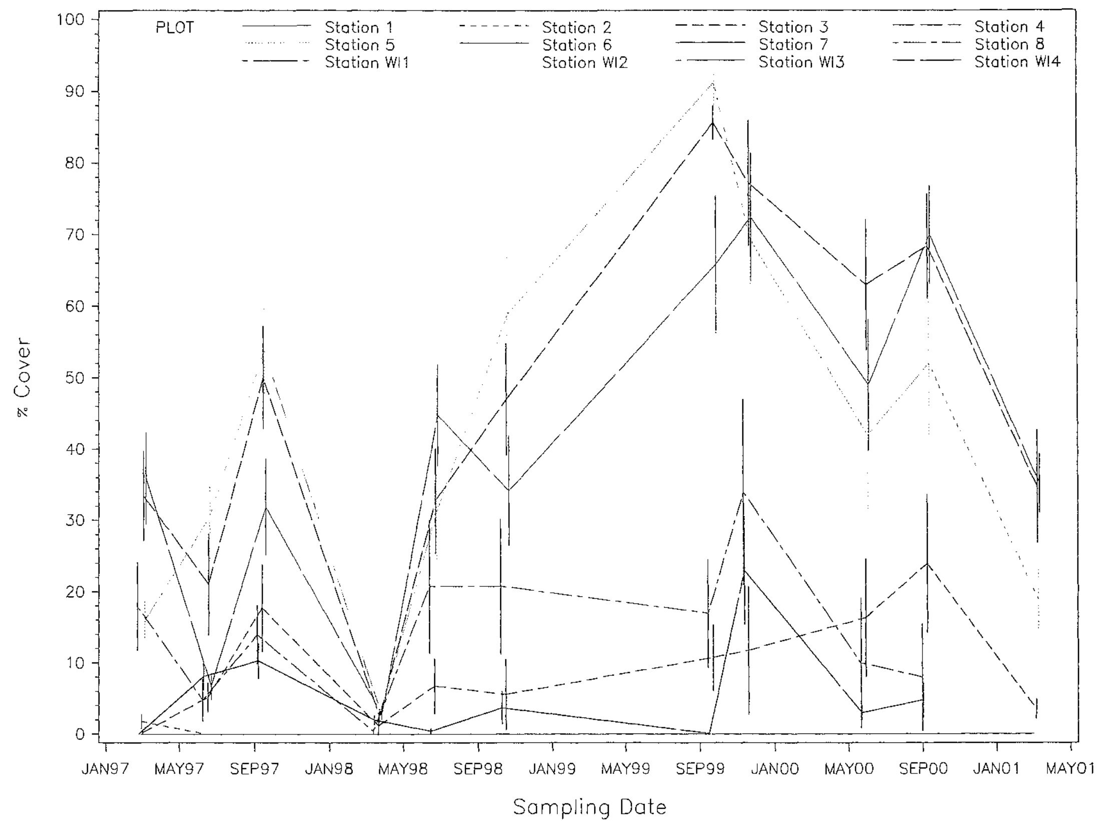


Fig. 3. Change in the mean percent cover of *Zostera capricorni* at 12 sampling stations surveyed between February 1997 and March 2001. Station means ± s.e. are determined from 10 x 0.5m^2 diver quadrats.

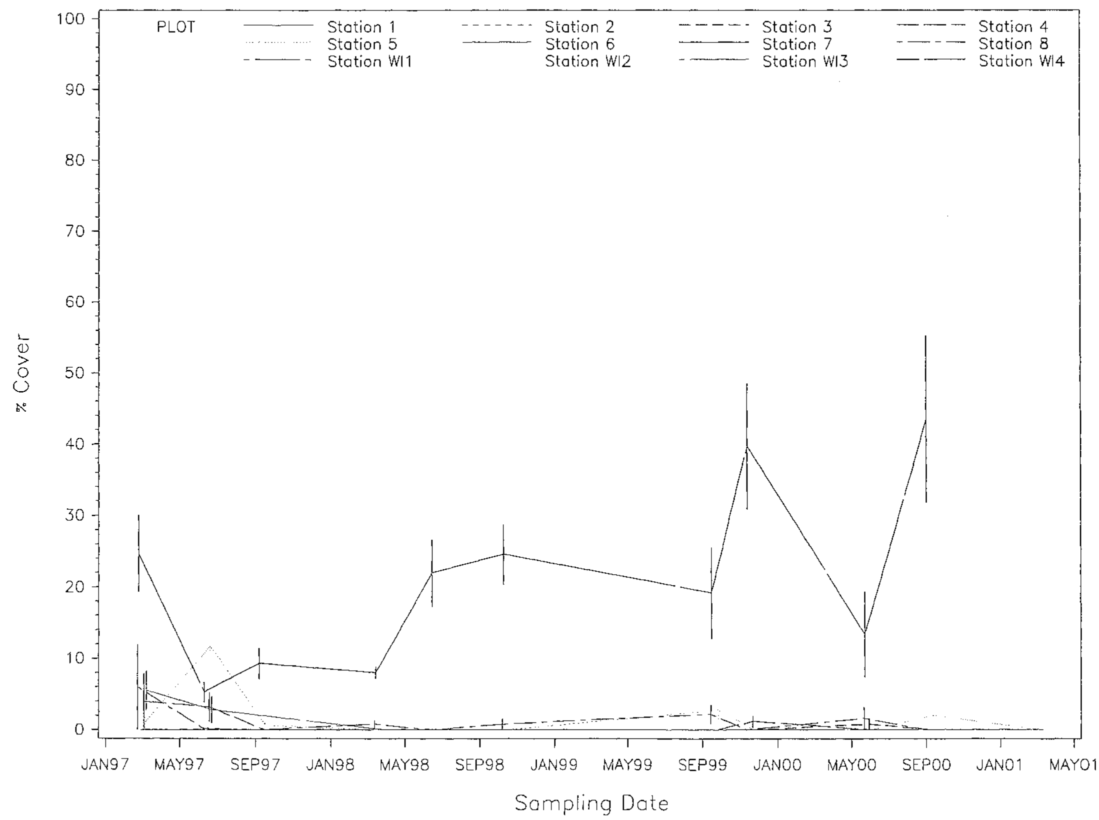


Fig. 4. Change in the mean percent cover of *Halophila ovalis* at 12 sampling stations surveyed between February 1997 and March 2001. Station means ± s.e. are determined from 10 x 0.5m^2 diver quadrats.

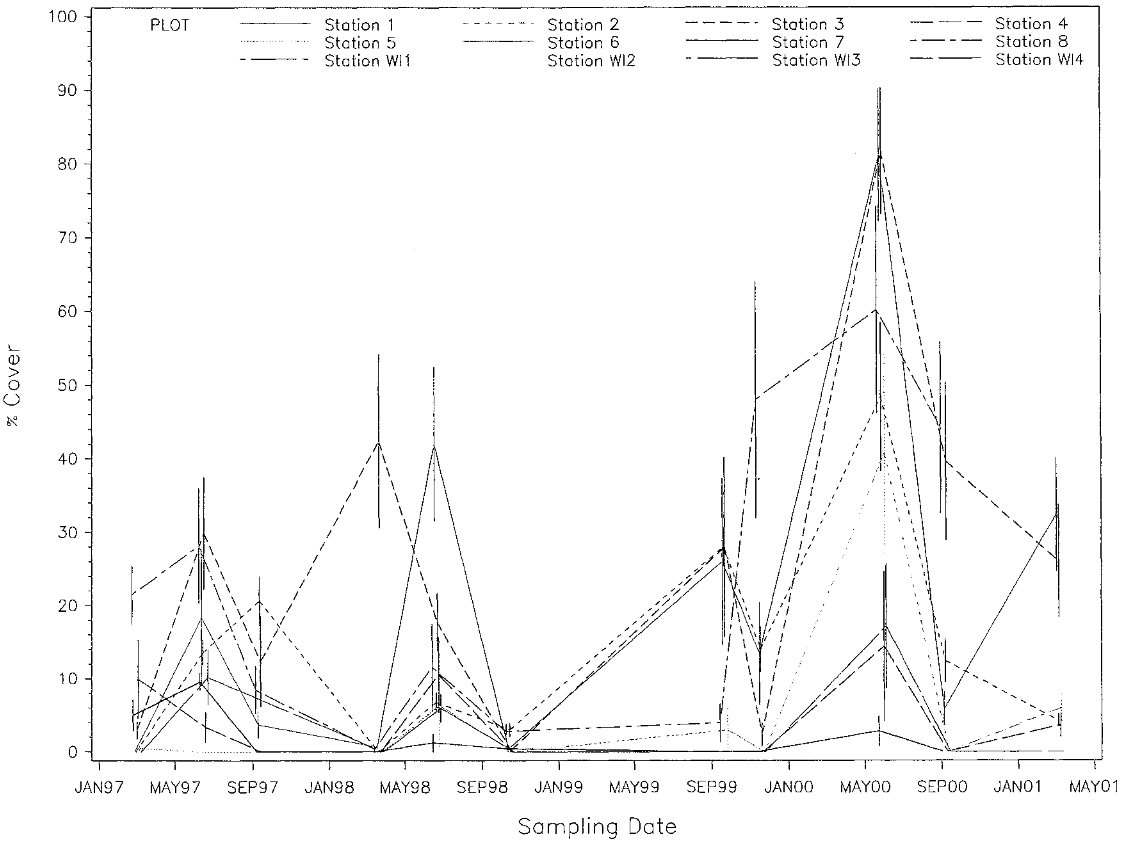


Fig. 5. Change in the mean percent cover of fillamentous algae at 12 sampling stations surveyed between February 1997 and March 2001. Station means ± s.e. are determined from 10 x 0.5m2 diver quadrats.

Seagrass biomass

Prior to examining differences in seagrass biomass between stations and sampling dates, two correlation tests were conducted to assist in determining the most appropriate measurement for this parameter in subsequent ANOVA's. The first of these examined strength of association between total wet and dry weights, and showed that these values were highly correlated ($p<0.01$, $r=0.93$). The second test examined relationships between seagrass component parts, and determined that above and below ground dry weight values were also highly correlated ($p<0.01$, $r=0.84$). Because of the high correlation value, and understanding that above-ground seagrass components often directly influence macrofaunal numbers (through habitat facilitation), above-ground dry weights were recognised as the most appropriate estimate of seagrass biomass for all further analysis.

Results of a two-way ANOVA to assess differences in seagrass biomass between sampling dates and stations are presented in Table 5A. This table shows that there were significant differences ($p<0.001$) in seagrass biomass between sampling dates and stations, and additionally, a significant ($p<0.001$) date*station interaction. Post-hoc Student-Newman-Keuls analysis (Table 5B) identifies which stations differed significantly. This indicates that the total seagrass biomass was significantly higher at station WI4 (southwestern edge of mudflat) than at all others. The test also indicates that seagrass biomass was similar at stations 8 and WI1, and significantly lower at station 3.

Table 4. Changes in percentage seagrass and algal cover at twelve sampling station off Wiggins Island. Means are derived from ten replicate $0.5m^2$ diver quadrats sampled on eleven occasions between February 1997 and March 2001.

Species	Station	Feb-97	Jun-97	Sep-97	Mar-98	Jun-98	Oct-98	Sep-99	Nov-99	May-00	Sep-00	Mar-01
Zostera capricorni	1	0	0	0	0	0	0	0	0	0		0
	2	1.8	0	0	0	0	0	0	0	0	0	0
	3	0.2	5.2	17.8	1.2	6.8	5.6	10.8	11.8	16.4	24	3.6
	4	33.5	21.1	50.1	2.5	32.8	47	85.6	77.2	63	68.4	34.8
	5	16	30.6	54	3.1	31.2	58.8	91.2	69.4	42	52	19
	6	36	6.8	35	2.8	44.8	34.2	65.8	72.4	49	70	35.3
	7	0	8.1	10.3	2	0.4		0.1	23	3	4.8	
	8	18	4.8	23.3	0.4		20.8	17	34	10	8	
	WI 1	0.2	0.4	24	0.1	4.4	9.2	43.8	44.8	48.8	75.4	8.2
	WI 2	0.7	1.8	10.8	0	2.4	12.8	48.8	71.4	73.6	77.6	32
	WI 3	1.8	12.7	20.7	0.4	13	73	27.2	18.6	16.2	23.2	10
	WI 4	8.5	33.7	38	1.4	17.8	13.6	68.8	51.4	58	43.6	12.8
Halophila ovalis	1	0	0	0	0	0	0	0	0	0		0
	2	0	0	0	0.1	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0.8	0	0
	4	4	3.2	0	0	0	0	0	1.2	0	0	0
	5	1	11.7	0.6	0	0	0	2.8	0	0	2	0
	6	5.5	2.8	0	0	0	0	0	0	0	0	0
	7	24.7	5.3	9.3	8	22		19.2	39.8	13.4	43.6	
	8	6	0.2	0	0.8		0.8	2.2	0	1.6	0	
	WI 1	2.3	0.7	1.3	0	0	0	0	0	0.8	0	0.6
	WI 2	0.4	2	0.4	0	0	1.6	4	0.4	0	0.2	0.2
	WI 3	2	0.4	0	0	1.2	0	0	10	0	0	0
	WI 4	3.2	0	0	0	0	0	0	0	0	0	0
Algae	1	0	18.4	3.7	0.7	42.1	0.4	26	13.4	81.2		32.4
	2	0	13.6	20.7	0	6.8	3	28	14	48.4	12.4	4.2
	3	3	29.9	12.4	42.4	17.8	0.2	28	2.4	81.8	39.6	26
	4	10	3.4	0	0	10.6	0	0	0	14.4	0	3.6
	5	0.5	0	0	0	6.4	0	3	0	40.8	0	6
	6	0	10.2	0	0	6	0	0	0	17.2	0	0
	7	5	9.6	0	0	1.2		0	0	2.8	0	
	8	21.5	28.2	12.1	0.4		2.8	4	48	60.2	44.2	
	WI 1	0	27.2	0.2	1.1	12.8	0	8.8	4.6	51.2	0	37.2
	WI 2	0	44	11.2	0	18.2	0	0	0	34.2	0	12.8
	WI 3	33	24.2	27.2	17.2	36.8	0	9.2	63.2	84.4	24.4	18
	WI 4	34.5	25.5	13.4	20.4	13.4	0	1.2	5.6	13.4	0	13.4

From observations of the mean densities in individual species, it is clear that much of elevated biomass at station WI4 is the result of high densities of *Zostera capricorni* (Table 6). A multiple comparison test to assess temporal differences (Table 5C) shows that seagrass biomass was significantly higher during October 1997, but did not differ significantly across all other sampling dates. This result is not consistent with temporal trends in percentage cover (both at stations and across transect), however it should be noted that grab and diver sampling dates were not directly matched. A plot of mean seagrass densities (Fig. 6) shows that the high values recorded during October 1997 are largely the result of exceptionally high densities at just one location (station WI4). Unparalleled temporal changes in density at this station also appear to have had a major contribution to the significant date*station interaction.

Table 5A. Results of two-way ANOVA on differences in above ground biomass at four stations over nine sampling events.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	1631.145	35	46.604	28.238	.000	1.000
Intercept	306.990	1	306.990	186.010	.000	1.000
DATE	555.151	8	69.394	42.047	.000	1.000
STATION	218.452	3	72.817	44.121	.000	1.000
DATE * STATION	857.543	24	35.731	21.650	.000	1.000
Error	534.728	324	1.650			
Total	2472.864	360				
Corrected Total	2165.874	359				

a Computed using alpha = .05
b R Squared = .753 (Adjusted R Squared = .726)

Table 5B. Results of post-hoc multiple comparisons test for differences in the total above ground biomass between the four stations.

		N	Subset		
	Station		1	2	3
Student-Newman-Keuls	3	90	.1246		
	8	90		.6523	
	WI1	90		.7024	
	WI4	90			2.2144
	Sig.		1.000	.794	1.000

Table 5C. Results of post-hoc multiple comparisons test for differences in the total above ground biomass between sampling dates.

		N	Subset	
	Date		1	2
Student-Newman-Keuls	MAR-2001	40	.0153	
	FEB-1999	40	.1987	
	AUG-1999	40	.2503	
	MAR-1998	40	.4698	
	MAR-2000	40	.6920	
	SEP-2000	40	.7242	
	SEP-1998	40	.7940	
	JUN-1997	40	.8158	
	OCT-1997	40		4.3510
	Sig.		.102	1.000

The effects of date and sampling station on algal density are summarised in Table 7A. This table shows that there were significant ($p<0.05$) differences in algal biomass between stations, between dates, and additionally between stations and dates. Post-hoc Student-Newman-Keuls tests (Table 7B) confirm that station differences are largely the result of elevated algal densities at station WI1 (near the mouth of the Calliope River). A similar multiple comparison test fails to discriminate differences in algal densities between sampling dates (Table 7C) (probably because the significance for this main effect is marginal, $p=0.04$). The same table shows that samples collected during March 1998, August 1999 and March 2000 generally have the highest algal densities, while those collected during February 1999, September 2000 and March 2001 have the lowest density. These rank orders of biomass do not appear to follow any continuing trend, and therefore provide little evidence for seasonal periodicity in this parameter. A plot of changes in mean algal density (Fig. 7) further confirms that most sampling stations follow quite different temporal trends. In view of the fact that the magnitude of change in algal biomass is most pronounced at station WI1, it is quite likely that changes at this station have largely contributed to the significant station*date interaction detailed in the ANOVA above (Table 7A).

Table 6. Changes in biomass (g) and leaf lengths (cm) of two seagrass species at four sampling stations off Wiggins Island. Means are derived from ten replicate 0.1m^2 van Veen grab samples collected at each station on nine occasions between June 1997 and March 2001.

			Sampling Period								
Station	Species	Component	Jun-97	Oct-97	Mar-98	Sep-98	Feb-99	Aug-99	Mar-00	Sep-00	Mar-01
WI1	*Halophila ovalis*	Above	0.04	0.08	0.01	0.02	0.02	<0.01	<0.01	0.01	<0.01
		Below	0.08	0.08	0.01	0.04	0.03	<0.01	<0.01	0.01	<0.01
		Leaf length	1.68	0.97		0.95	0.33			1.06	
	Zostera capricorni	Above	1.72	1.83	0.13	0.16	0.03	<0.01	0.91	1.33	0.05
		Below	2.30	1.34	0.28	0.14	0.11	<0.01	1.39	2.41	0.24
		Leaf length	7.43	8.34	4.72	7.95	2.23	5.15	8.19	7.70	2.67
8	*Halophila ovalis*	Above	0	1.81	0.24	0.76	0.01	0.04	0.44	0.00	0
		Below	0	2.86	0.36	0.69	0.01	0.08	0.42	0.00	0
		Leaf length		1.96	1.56	2.26	1.33	1.60	1.98	1.80	
	Zostera capricorni	Above	0.01	0.74	0.83	0.28	0.28	0.18	0.02	0.24	0
		Below	0.04	1.34	0.82	0.39	1.33	0.33	0.09	0.31	0
		Leaf length	5.40	7.46	6.22	8.78	6.50	3.58	4.85	7.29	
WI4	*Halophila ovalis*	Above	<0.01	0	0	0	0	0	<0.01	0	0
		Below	<0.01	0	0	0	0	0	<0.01	0	0
		Leaf length							1.12		
	Zostera capricorni	Above	1.46	12.91	0.68	1.72	0.34	0.77	1.01	1.03	0
		Below	1.50	7.70	0.82	1.78	1.26	1.45	1.28	1.44	0
		Leaf length	8.25	19.31	5.28	10.62	7.00	5.39	7.66	7.59	
3	*Halophila ovalis*	Above	0	0	0	0.01	0	0.01	0	0	0.01
		Below	0	0	0	0.03	0	<0.01	0	0	0.01
		Leaf length				1.50					0.12
	Zostera capricorni	Above	0.03	0.03	0	0.23	0.13	<0.01	0.38	0.29	<0.01
		Below	0.09	0.03	0	0.17	0.73	<0.01	0.94	0.32	<0.01
		Leaf length	6.75	4.57		5.45	4.60	4.75	8.61	4.78	0.64

Macrobenthos

A total of 3766 individuals representing 191 species were identified from the four seagrass stations sampled twice annually between June 1997 to March 2001. Molluscs (shellfish) were the most common taxonomic group encountered during the nine sampling events (63 species). Crustaceans (crabs, prawns etc) were the second most frequently collected taxa (60 species) followed by polychaetes (marine worms; 51 species) and echinoderms (sea stars, brittle stars, feather stars; 9 species). Other rarer taxa encountered included chordates (fish and sea squirts; 4 species), cnidarians (anemones; 2 species), sipunculans (peanut worms; 1 species) and branchiopods (lamp shells; 1 species).

Molluscs were the most abundant taxa recorded over the nine sampling events (Table 8). These shellfish accounted for more than 65% of the total abundance and were common during all sampling dates. Crustaceans and polychaetes also contributed largely to the total benthic abundance (19% and 13% respectively), while echinoderms and other rarer taxa accounted for the residual abundance (3%).

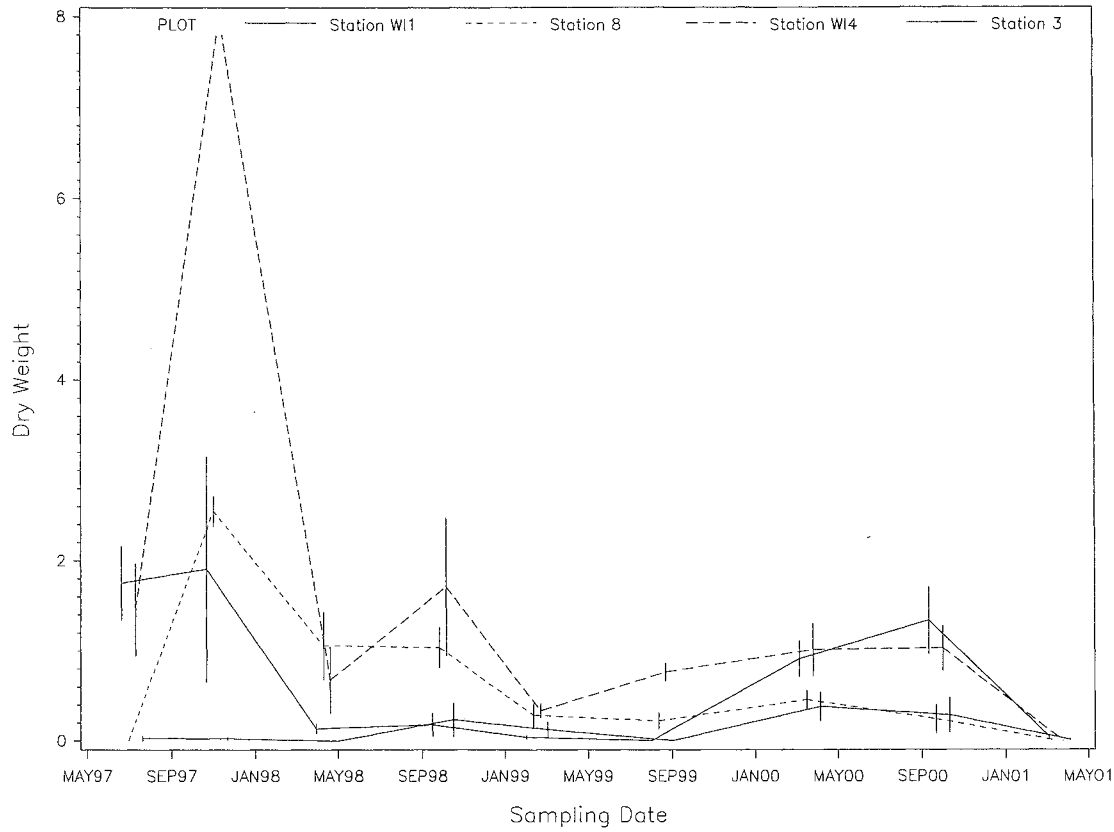


Figure 6. Change in total above ground seagrass biomass (*Zostera capricorni* + *Halophila ovalis*) at four stations sampled between June 1997 and March 2001. Means ± se are derived from 10 replicate 0.1m^2 van Veen grab samples.

Table 7A. Results of two-way ANOVA on differences in algae at four stations over nine sampling events.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	743.701	35	21.249	3.168	.000	1.000
Intercept	178.112	1	178.112	26.551	.000	.999
DATE	110.367	8	13.796	2.057	.040	.831
STATION	77.607	3	25.869	3.856	.010	.820
DATE* STATION	555.726	24	23.155	3.452	.000	1.000
Error	2173.473	324	6.708			
Total	3095.286	360				
Corrected Total	2917.173	359				

a Computed using alpha = .05 b R Squared = .255 (Adjusted R Squared = .174)

Table 7B. Results of post-hoc multiple comparisons test for differences in algae between the four stations.

	STATION	N	Subset 1	2
Student-Newman-Keuls	8	90	.2300	
	3	90	.5141	
	WI4	90	.5972	
	WI1	90		1.4722
	Sig.		.608	1.000

Table 7C. Results of post-hoc multiple comparisons test for differences in algae between sampling dates.

	DATE	N	Subset 1
Student-Newman-Keuls	FEB-1999	40	.0003
	SEP-2000	40	.2335
	MAR-2001	40	.2630
	OCT-1997	40	.3125
	SEP-1998	40	.5877
	JUN-1997	40	.6807
	MAR-1998	40	1.1807
	MAR-2000	40	1.3503
	AUG-1999	40	1.7218
	Sig.		.076

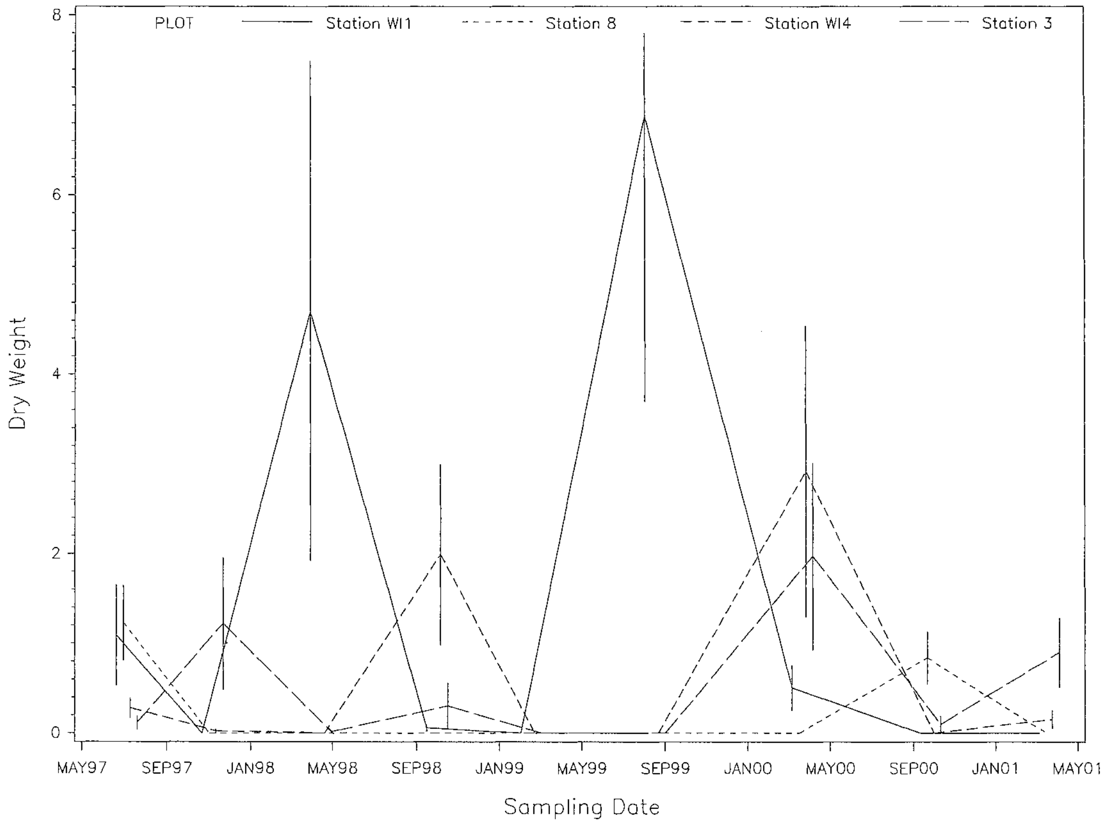


Fig. 7. Change in mean biomass of algae at Wiggins Island mudflat between June 1997 and March 2001. Means ± se are derived from 10 replicate $0.1m^2$ van Veen grab samples.

The effects of date and sampling station on benthic species richness are summarised in Table 9A. This table shows that there were significant differences (p<0.001) between dates and additionally between sampling stations. It also shows a significant (P<0.001) interaction between the number of species found at each station and sampling date. Post-hoc Student-Newman-Keuls tests (Table 9B) confirm that station differences in species richness are largely the result of significantly higher numbers of species at station WI1 (>6 species/grab), and significantly lower numbers at station 3 (<4 species/grab). Post-hoc tests also show that the significant date effect is principally due to reduced numbers of species in samples collected during the months of February and August 1999 (<5 species/grab; Table 9c). Most of these spatial and temporal differences can also be observed in a plot of mean species richness (Fig. 8A). The same plot shows that temporal trajectories at each station are quite different, and hence explain to some degree the underlying site*date interaction.

Table 8. Changes in the total abundance of eight macrobenthic taxa collected from four benthic sampling stations (3, 8, WI1, WI4) surveyed on nine occasions between June 1997 and March 2001.

Taxa	Jun97	Oct97	Mar98	Sep98	Feb99	Aug99	Mar00	Sep00	Mar01	Total
Mollusca	389	342	330	206	116	270	298	304	196	2451
Crustacea	53	133	65	158	48	78	69	54	69	727
Polychaete	63	29	57	40	37	45	37	74	122	504
Chordata	4	2	1	2	0	0	1	0	26	36
Echinodermata	0	7	1	2	1	4	2	5	12	34
Brachiopoda	0	4	1	1	1	3	0	0	0	10
Cnidaria	0	0	0	0	0	0	0	0	3	3
Sipuncula	0	0	0	0	1	0	0	0	0	1

Table 9A. Results of two-way ANOVA on differences in species richness at four stations over nine sampling events.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	1246.022	35	35.601	7.077	.000	1.000
Intercept	9282.178	1	9282.178	1845.273	.000	1.000
STATION	451.222	3	150.407	29.901	.000	1.000
DATE	181.372	8	22.672	4.507	.000	.997
STATION * DATE	613.428	24	25.559	5.081	.000	1.000
Error	1629.800	324	5.030			
Total	12158.000	360				
Corrected Total	2875.822	359				

a Computed using alpha = .05
b R Squared = .433 (Adjusted R Squared = .372)

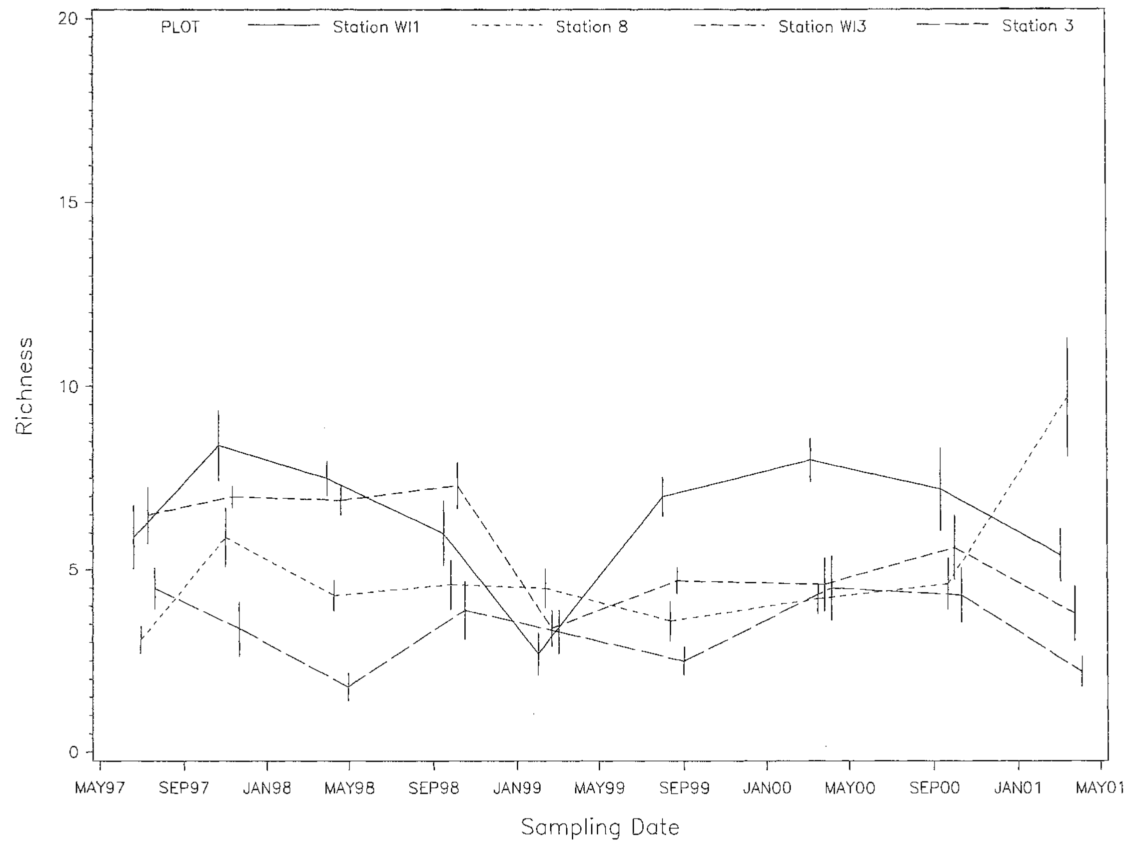
Table 9B. Results of post-hoc multiple comparisons test for differences in the mean species richness between the four stations.

	Station	N	Subset 1	2	3
Student-Newman-Keuls	3	90	3.38		
	8	90		4.94	
	WI4	90		5.53	
	WI1	90			6.46
	Sig.		1.000	.079	1.000

Table 9C. Results of post-hoc multiple comparisons test for differences in the mean species richness between sampling dates.

	Date	N	Subset 1	2	3
Student-Newman-Keuls	FEB-1999	40	3.48		
	AUG-1999	40	4.45	4.45	
	JUN-1997	40		5.00	5.00
	MAR-1998	40		5.13	5.13
	MAR-2001	40		5.28	5.28
	MAR-2000	40		5.32	5.32
	SEP-2000	40		5.43	5.43
	SEP-1998	40		5.45	5.45
	OCT-1997	40			6.17
	Sig.		.053	.420	.227

(A)



(B)

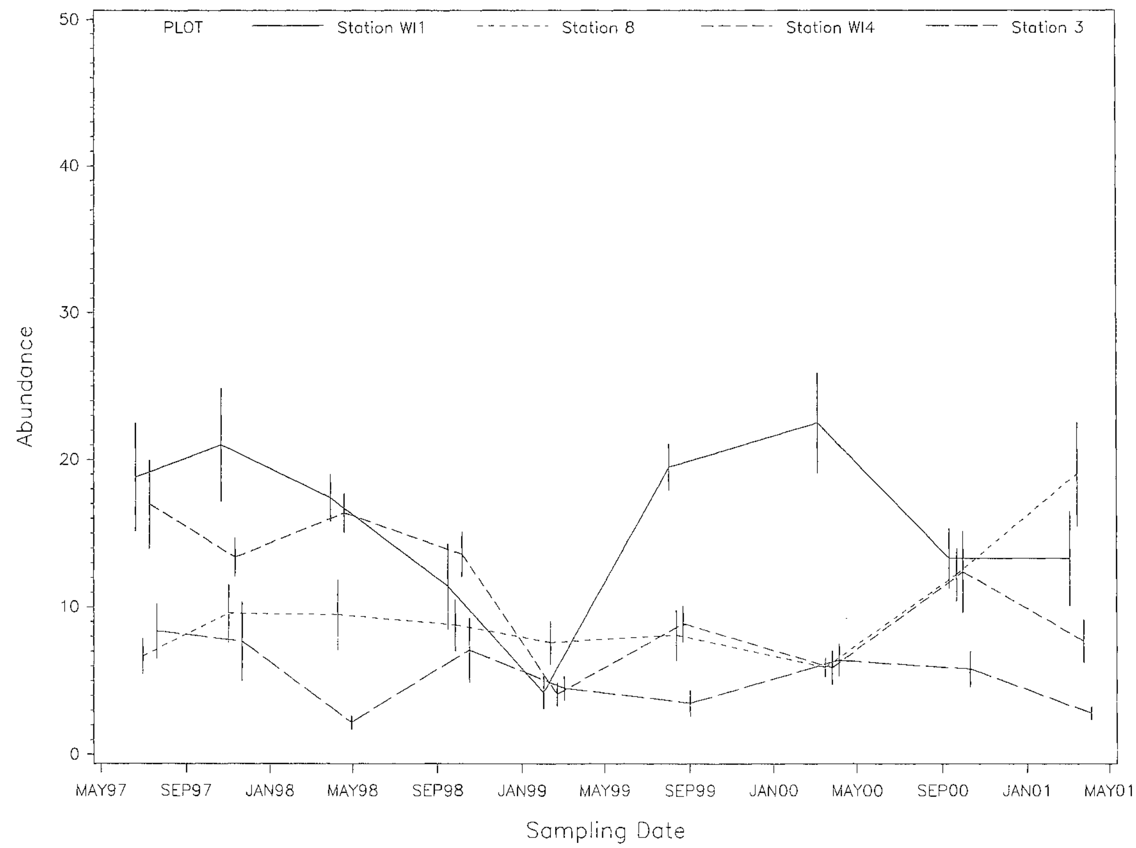


Fig. 8. Seasonal changes in (A) number of infaunal species and (B) total infaunal abundance at four Wiggins Island stations sampled between June 1997 and March 2001. Means ± se are derived from 10 replicate $0.1m^2$ van Veen grab samples.

Results of a two-way ANOVA to assess differences in the abundance of benthic organisms between sampling dates and stations are summarized in Table 10A. This table shows that there were significant differences ($p<0.001$) in numbers of organisms between sampling dates and stations, and additionally, a significant ($p<0.001$) date*station interaction. Post-hoc Student –Newman-Keuls analysis (Table 10B) identifies which stations differed significantly. Remarkably this test shows that, like species richness, species abundance was significantly higher at station WI1 and significantly lower at station 3. Multiple comparison tests for date-related differences in abundance (Table 10C) additionally mirror those for species richness, and confirm that species abundances were significantly lower during February 1999. The apparent strength of this relationship between species richness and abundance is further illustrated in a comparison of changes in station means over time (Figs. 8A & 8B). Because plots of species richness and abundance are virtually identical, it is evident that these parameters are linearly related. More importantly, however, this result suggests that individuals are evenly distributed among species at Wiggins Island. This is a rather unusual occurrence in unperturbed benthic communities, where the general observable pattern is one of numerical dominance by a small number of species (Gray 1981).

Table 10A. Results of two-way ANOVA on differences in species abundance at four stations over nine sampling events.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power
Corrected Model	10845.856	35	309.882	7.252	.000	1.000
Intercept	39396.544	1	39396.544	921.916	.000	1.000
DATE	1655.806	8	206.976	4.843	.000	.998
STATION	4887.500	3	1629.167	38.124	.000	1.000
DATE * STATION	4302.550	24	179.273	4.195	.000	1.000
Error	13845.600	324	42.733			
Total	64088.000	360				
Corrected Total	24691.456	359				

a Computed using alpha = .05
b R Squared = .439 (Adjusted R Squared = .379)

Table 10B. Results of post-hoc multiple comparisons test for differences in the mean species abundance between the four stations.

		N	Subset		
	Station		1	2	3
Student-Newman-Keuls	3	90	5.38		
	8	90		9.71	
	WI4	90		11.04	
	WI1	90			15.71
	Sig.		1.000	.172	1.000

Table 10C. Results of post-hoc multiple comparisons test for differences in the mean species abundance between sampling dates.

		N	Subset	
	Date		1	2
Student-Newman-Keuls	FEB-1999	40	5.10	
	AUG-1999	40		10.00
	MAR-2000	40		10.18
	SEP-1998	40		10.23
	MAR-2001	40		10.70
	SEP-2000	40		10.93
	MAR-1998	40		11.38
	JUN-1997	40		12.73
	OCT-1997	40		12.92
	Sig.		1.000	.483

Sediments

Sediments at the Wiggins Island sampling stations were principally composed of mud and sand (Table 11). Grain size structure varied considerably between sampling stations but was, on average, muddiest at stations WI1 and 8, and sandiest at stations WI4 and 3. Sediment grain size also varied markedly at each station between sampling dates. Sediments at Station 8, for example, were predominantly composed of mud in June 1997 and February 1999, but were chiefly composed of fine and medium sands in successive samplings during October 1997 and March 2000. It is unclear if such temporal changes are the result of physical modifications to sediments (possibly as a result of localised accretion and erosion), or small-scale heterogeneity in sediment grain size structure at the sampling stations. As the sample size is small (n=20), and because additionally there appears to be no consistent chronological pattern to the changes observed between stations, it is believed that the latter scenario is more likely.

Table 11. Percentage size distribution of sediments collected in supplementary grabs taken from four Wiggins Island sampling station (3, 8, WI1, WI4) on up to six occasions between June 1997 and March 2001.

Station	Sampling Date	Silt and Clay <63um	V. fine sand 63um	Fine sand 125um	Medium sand 250um	Coarse sand 500um	V. coarse sand 1mm	Granules 2mm
WI1	Jun-97	28.2	8.9	32.6	21.7	4.8	1.4	2.4
	Oct-97	30.1	10.7	24.7	24.8	7.0	1.5	1.3
	Mar-98	17.8	8.2	38.3	30.0	5.1	0.3	0.3
	Feb-99	51.0	14.6	17.2	11.1	5.4	0.4	0.4
	Mar-00	41.0	11.2	20.6	19.2	6.5	0.8	0.8
	Mar-01	27.4	15.9	28.1	22.3	5.3	0.1	0.8
	Mean	**32.6**	**11.6**	**26.9**	**21.5**	**5.7**	**0.7**	**1.0**
	s.d.	**11.7**	**3.1**	**7.8**	**6.3**	**0.9**	**0.6**	**0.8**
8	Jun-97	60.7	12.5	16.3	7.1	2.7	0.2	0.4
	Oct-97	0.0	0.6	22.1	47.7	8.0	8.1	13.5
	Feb-99	60.3	6.4	18.7	9.2	3.3	0.2	1.7
	Mar-00	6.3	3.6	40.8	26.7	5.5	5.1	11.9
	Mar-01	17.8	18.6	2.1	11.0	18.4	19.6	12.6
	Mean	**29.0**	**8.3**	**20.0**	**20.3**	**7.6**	**6.7**	**8.0**
	s.d.	**29.4**	**7.2**	**13.9**	**17.2**	**6.4**	**8.0**	**6.4**
WI4	Jun-97	36.5	6.4	23.9	24.3	6.9	1.2	0.7
	Feb-99	24.6	4.8	22.4	26.0	12.3	4.8	5.2
	Mar-00	19.0	9.2	33.3	27.5	6.9	1.3	2.8
	Mar-01	22.8	10.5	29.6	25.9	10.7	0.1	0.3
	Mean	**25.7**	**7.7**	**27.3**	**25.9**	**9.2**	**1.8**	**2.3**
	s.d.	**7.6**	**2.6**	**5.1**	**1.3**	**2.7**	**2.0**	**2.2**
3	Jun-97	15.0	10.2	45.7	19.4	6.6	2.2	0.8
	Mar-98	20.5	10.7	35.4	14.9	6.9	4.0	7.6
	Feb-99	0.6	15.1	39.4	35.9	8.6	0.1	0.3
	Mar-00	21.0	18.3	28.6	14.6	8.2	4.6	4.7
	Mar-01	15.2	10.6	36.7	23.7	10.0	2.8	1.0
	Mean	**14.5**	**13.0**	**37.2**	**21.7**	**8.1**	**2.7**	**2.9**
	s.d.	**8.24**	**3.59**	**6.22**	**8.77**	**1.37**	**1.77**	**3.18**

Seagrass, benthos and sediment relationships

Seagrass/benthos

The strength of the relationship between the amount of seagrass present in each grab sample and its associated macrobenthic diversity was examined by plotting seagrass biomass against species richness and calculating the correlation coefficient. The scatter plot (Fig. 9A) shows that species richness varied considerably over the range of seagrass biomasses sampled, and indicates that the two variables are poorly matched. This is formally evidenced by a non-significant correlation coefficient ($p>0.05$). The allied coefficient of determination ($r^2=0.036$) verifies that this relationship is extremely weak, and indicates that less than 4% of the variation in species richness is explained by differences in seagrass biomass.

The strength of the relationship between total seagrass biomass and total macrobenthic abundance was also investigated. The scatter plot for these variables (Fig. 9B) fails to show a definitive trend. Furthermore, no significant correlation could be detected between seagrass biomass and macrobenthic abundance.

Sediment /benthos

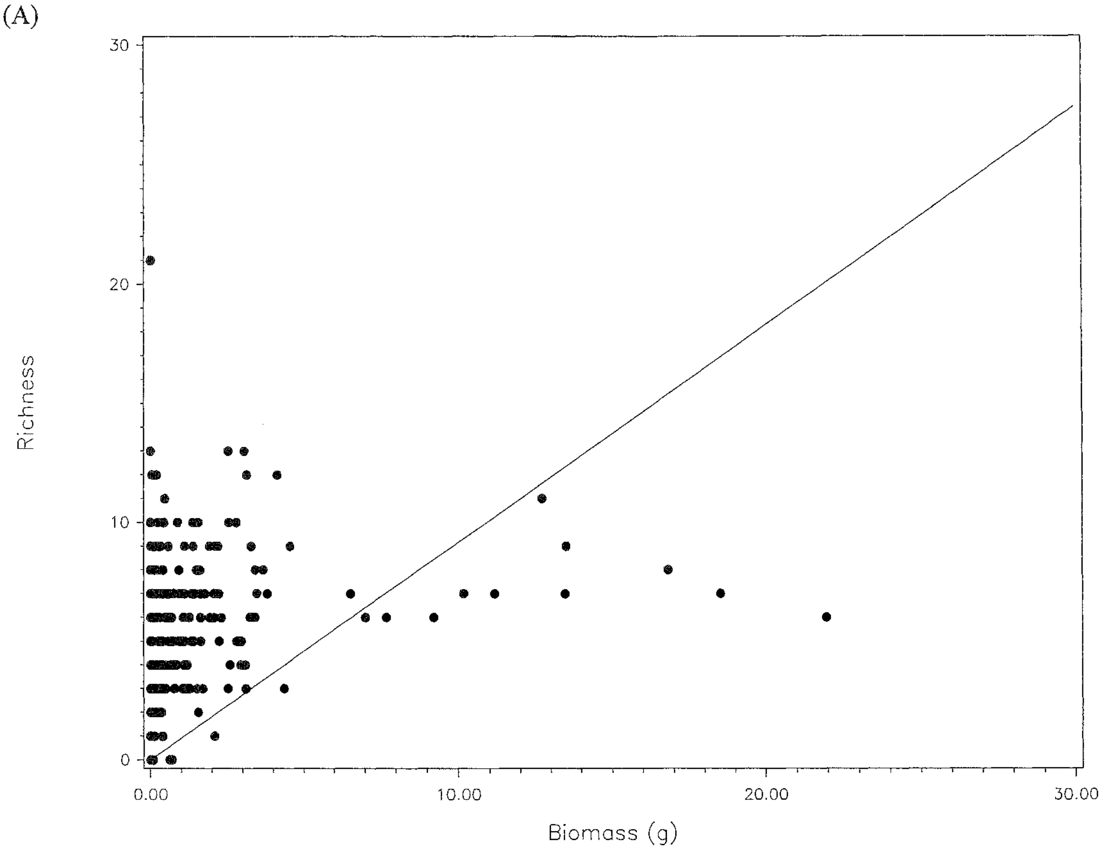
The effect of sediment composition on macrobenthic community composition was examined by constructing plots of percentage fine muds (<63 μm diameter) against macrobenthic species richness and abundance. The plot of species richness (Fig. 10A), shows a wide scatter of points with no apparent linear relationship between the number of species found and the quantity of fine muds. Pearson's correlation confirms that there is no significant relationship between these variables. It also indicates that less than 2% ($r^2=0.017$) of the variation in species richness can be explained by differences in sediment grain size structure.

Like species richness, the abundances of benthic organisms do not appear to be related to sediment grain size. Individual data points are widely distributed in the abundance scatter plot (Fig. 10B) and there is no indication of total organism counts trending either upwards or downwards along the length of the sediment axis. Correlation analysis confirms that there is no significant relationship between these variables, and further shows that less than 1% ($r^2=0.002$) of the variation in total species abundance can be explained by differences in sediment grain size.

Seagrass/sediment

The effects of sediment composition on the amount of seagrass present at each sampling station was examined by plotting percentage fine muds (<63μm) against seagrass biomass. This plot (Fig. 11) appears to indicate that sediment grain size has little influence on the total quantity of seagrass found at Wiggins Island. It shows that biomass measures vary considerably across a wide range of sediments and neither decline nor increase as sediments tend to either sand or mud. Correlation analysis confirms that there is no significant linear relationship between these variables, however it should be recognized that the coefficient may be substantially affected by the inclusion of a more comprehensive range of sediments. It is also quite possible, that the relationship between sediment grain size and seagrass biomass is in fact curvi-linear. Such a relationship may be expected from first principals, with seagrass flourishing in sediments that are neither too silty nor too course. However, once again, a fuller assessment of this association would require the inclusion of seagrass biomass data from a more comprehensive range of sediments.

(A)



(B)

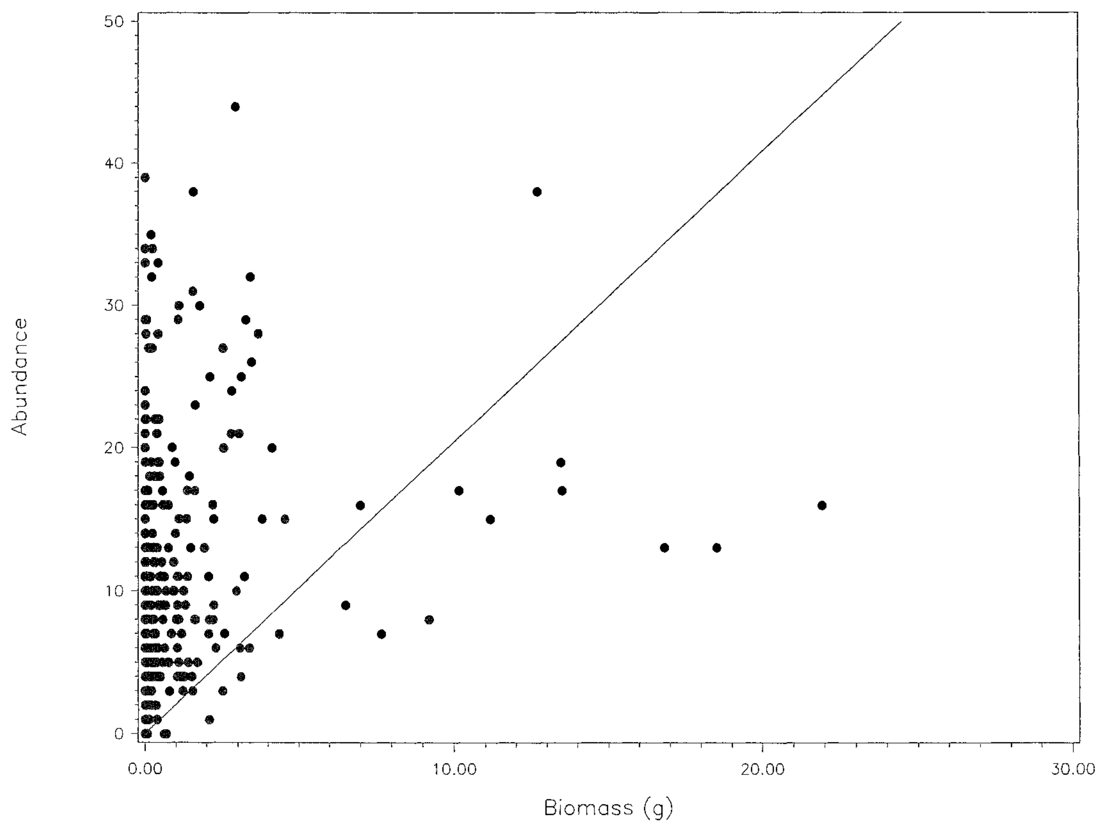
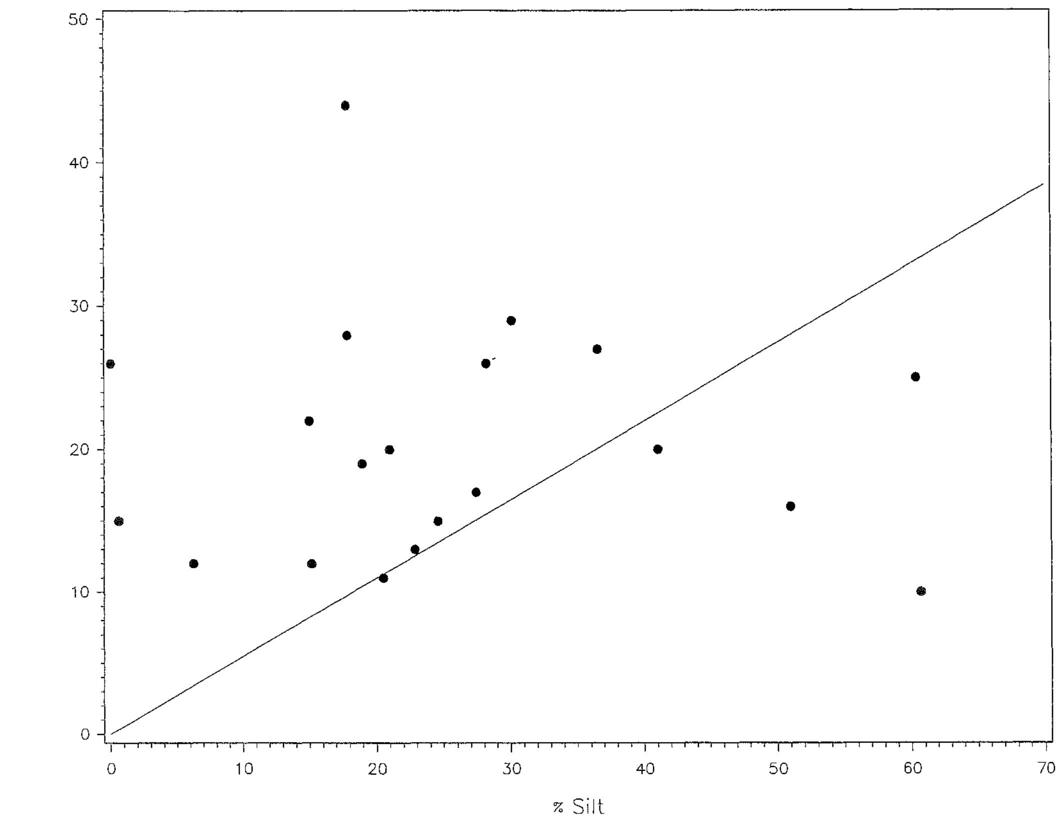


Fig. 9. Plot showing the relationship between the total above ground biomass of seagrass and: A) total number of species, B) total macrobenthic abundance. Note that data plotted are from 10 replicate grab samples taken at four benthic sampling stations (3, 8, WI1, WI4) on nine sampling dates (Jun 97, Oct97, Mar98, Sep98, Feb99, Aug99, Mar00, Sep00, Mar01).

(A)



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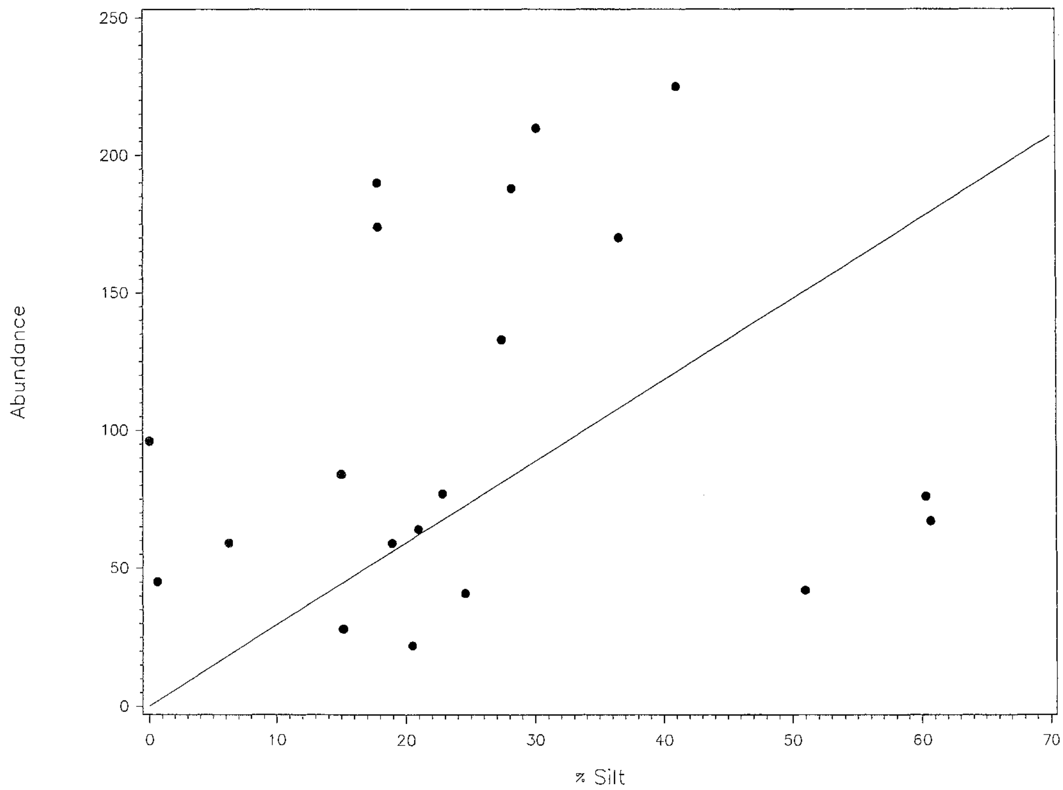

Fig. 10. Plot of relationship between the amount of silt present at each sampling station (% less than 63μm) and: A) total number of species, B) total macrobenthic abundance. Faunal counts are pooled totals from 10 replicate grabs collected at each of four benthic sampling stations (3, 8, WI1, WI4) on six sampling dates (Jun 97, Oct97, Mar98, Feb99, Mar00, Mar01). The amount of silt present was determined from a single supplementary grab sample collected from the same stations and sampling dates.

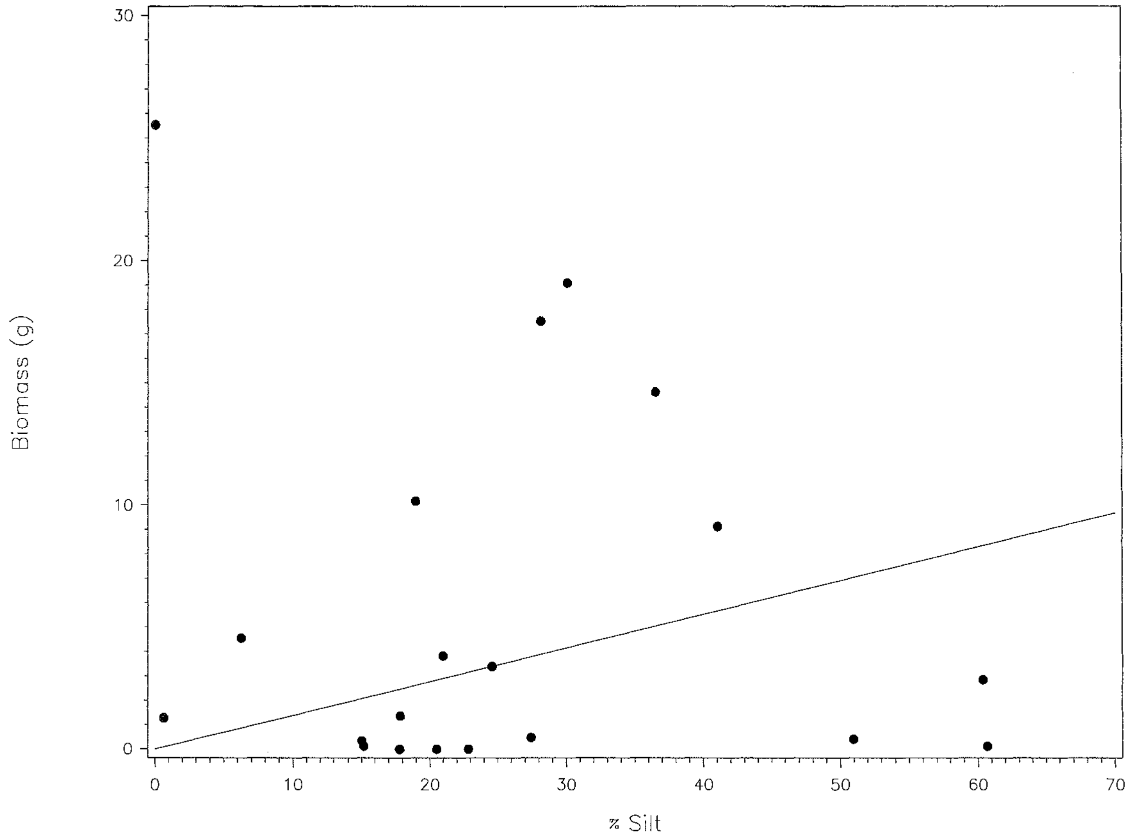

Fig. 11. Plot showing the relationship between total above ground seagrass biomass and the amount of silt (% less than 63 um) at each sampling station. The amount of silt present was determined from a single supplementary grab sample collected at each of the four benthic sampling stations (3, 8, WI1 and WI4) on six sampling dates (Jun 97, Oct 97, Mar 98, Feb 99, Mar 00, Mar 01).

Discussion

Seasonal changes in the quantity and composition of seagrass and algae at Wiggins Island mudflat were determined from a combination of diver estimates of percentage cover and grab estimates of biomass. Both of these techniques are commonly applied in seagrass research (Phillips and McRoy 1990), however both methods have inherent strengths and weaknesses. The large sampling unit applied in diver quadrats is much more suitable than smaller grabs for assessing the quantity of seagrass when the distribution is highly contagious (as it is at Wiggins Island). Diver quadrats, however, are much less quantitative than grabs because they rely on visual estimates that will vary between different observers. Because few other suitable sampling methods exist, a combination of these two techniques is generally regarded as rational strategy for gauging temporal and spatial trends in seagrass meadows. Unfortunately the relative performances of these two techniques could not be formally tested, as the date of sampling differed for each method.

Measures of seagrass cover and biomass were highest in most sampling years at stations situated near the western and southern borders of the Wiggins Island mudflat. Virtually all of the seagrass at these stations was composed of *Zostera capricorni*. This large-leafed intertidal species is common in sheltered coastal waters throughout Queensland (Coles *et al.* 1987; Lee Long *et al.* 1992), and appears to be well-adapted to the turbid water conditions of the inner harbour of Port Curtis. The reasons for why this species fails to flourish on the northern and eastern edges of the mudflat remain unclear. Water depths at all sampling stations were consistent (ie 2-3m above the lowest astronomical tide), so frequency and duration of tidal inundation is not thought to have contributed to these differences. It is also considered unlikely that these local differences in seagrass density are the result of variations in substrate type, particularly as no correlation could be found between seagrass biomass and sediment composition. The proximity of northern and eastern sampling stations to a deepwater channel offers one possible explanation; it is conceivable that observed reductions in seagrass densities here are due to inherent local differences in hydrology. Speed of water movement affects sediment transport and turbidity, and may also modify nutrient availability. Such factors have previously been implicated in the absence of seagrasses from the mouth of the nearby Fitzroy River (Lee Long *et al.* 1992), and similar processes might account for reduced densities of seagrass about the northern and eastern edges of the Wiggins Island mudflat (where tidal currents are likely to be elevated). Unfortunately, the relative contributions of different environmental factors to an optimum seagrass habitat are difficult to assess without supportive physico/chemical data. Moreover in the absence of any manipulative studies, it is difficult to determine if the drivers underpinning observed spatial differences in seagrass standing-stock are principally the result of natural or anthropogenic conditions.

Some of the largest and most devastating disturbances to seagrass meadows are caused by eutrophication of the waters in which they grow (Kirkman 1996; Abal and Dennison 1996). In this process high nutrient loads entering the water column (often from sewerage treatment discharges and agricultural run-off) stimulate rapid algal growth. In some cases, epiphytic forms of algae can develop and cover the surfaces of the seagrass. This growth restricts the plants ability to photosynthesise and, when the cover becomes extreme, the seagrass is unable to metabolise and eventually dies (Shepherd *et al.* 1989). Epiphytic algal species were commonly encountered at most stations surveyed at Wiggins Island in most years, but were particularly prevalent at those stations located closest to the mouth of the Calliope River (less than 2km downstream from a sewerage treatment plant). While it is tempting to advocate that reduced seagrass densities at these same stations are the result of competitive exclusions by algae, alternative explanations do exist. One of these is that reduced salinities, resulting from increased freshwater influences at these stations, favour algal growth at the expense of seagrass. Another is that high algal cover near the mouth of the Calliope reflects tolerance by algae to elevated water temperatures emanating from an industrial hot-water discharge less than 3km upstream. Once again, however, it is difficult to provide less ambiguous conclusions for these spatial differences without more comprehensively detailing water quality parameters across the sampling area.

Seasonal changes in seagrass and algal densities at Wiggins Island are no less difficult to explain in light of the many significant interactions that appear to have occurred between stations and sampling dates. There is, nonetheless, ample evidence to indicate that both seagrass and algae undergo annual cycles of growth and die-back that are broadly six months out of phase. The growth period for seagrass principally occurs between August and November, and coincides with increasing seawater temperatures and daylight hours; it dies back through February to June when seawater temperatures and daylight hours are declining. Algae, in contrast, flourish at the end of the summer and die back over three to four months following winter. These seasonal growth cycles are almost certainly linked to natural cyclic phenomena, including ambient temperature and light attenuation, however conspicuous variations in the magnitude of between-year differences indicate that additional ecosystem processes play important roles in the dynamics of seagrass and algae at Wiggins Island. Seagrass cropping rates from large vertebrate grazers such as dugong and green turtle are probably quite significant, given that these animals are frequently sighted in high concentrations at this location during spring. Invertebrate grazing intensities may also be considerable, but such impacts on vegetative standing-stock are difficult to quantify and are currently unknown. Other less predictable climatic events, including storms and floods are also likely to have considerable influences on inter-annual success of these benthic flora.

Freshwater inputs to the Calliope River catchment are principally derived from heavy summer rainstorms associated with monsoonal depressions. Cyclonic events occur intermittently within the region and large variations in flow are apparent. Water runoff at the mouth of the Calliope River as a result is highly pulsed. During severe floods, large volumes of sediment can be transported down river and may eventually settle-out and smother benthic flora and fauna at the Wiggins Island mudflat. Many seagrass and invertebrate species are intolerant of even light loads of fine particulate material, and often die when subject to sustained turbidity (Longstaff and Dennison 1999). By contrast, algal species are often the first taxa to flourish on virgin sediment surfaces when turbidity drops. Three significant freshwater flows in excess of 25000 megalitres have occurred in the Calliope River over the duration of the study (October 1998, February 1999 and October 2000). The timing of these flood events appears to elicit inconsistent temporal responses in populations of macrofauna, seagrass and algae. Seagrass biomass was significantly reduced over the sampling periods immediately following the February 1999 and October 2000 floods, but seagrass biomass increased slightly following the October 1998 flood. Algal biomass, in comparison, was generally reduced in the period immediately following each flood event. Infaunal diversity and abundance, in contrast, were markedly reduced in the periods following the October 1998 and February 1999 floods, but remained unchanged in the sampling period following the more significant October 2000 flood. Such differences in the responses of these taxa to flood events might be expected since tolerance levels for the quantity, composition and duration of the sediment burden will vary between species. Additionally, as recovery rates for these species will differ according to their recruitment success, variations in the timing to post-flood sampling will inevitably alter measures of population structure. Presently there is little empirical evidence to confirm whether observed unseasonal changes in seagrass, algae and macrofauna are the result of flood events, storm events, or perhaps land reclamation impacts. Such phenomena can, in practice, only be determined with a degree of certainty when appropriate spatial and temporal controls have been implemented.

The current survey design lacks suitable spatial controls, without which it is impossible to distinguish the relative importance of any man-made influences. All sample sites are currently located in close proximity to a range of putative impacts, and as such are likely to be subject, to varying degrees, by those impacts. In order to separate any anthropogenic influences from natural background variations, it is essential that one or more additional sites be established that are geographically separated from the influence of the impact under consideration. Ideally, these control sites should have been established prior to the commencement of the development under consideration, and sampled at the same time as those on Wiggins Island mudflat. This before, after, control, impact (BACI) design would have facilitated formal tests of all parameters for no significant change following the development. As the design currently stands, it cannot be said with any degree of confidence that apparent temporal changes in seagrass/algal cover and macrobenthic abundance are related to anything tangible. Indeed, all that can be said is that some key parameters changed over time, and that some site differences were apparent. The ambiguity of conclusions in this study on temporal and spatial changes in seagrass cover and biomass, emphasises the need for a more adequate monitoring design to better define the extent of change and identify their cause.

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