# Green Sea Turtle and Dugong Food Resource Assessment

Ashley Bunce and Peter Stratford

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Centre for Environmental Management
Faculty of Science, Engineering and Health
Central Queensland University
Gladstone Qld 4680

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# Green Sea Turtle and Dugong Food Resource Assessment

## Fitzroy Basin Association
## and
## Queensland Parks and Wildlife Services

## Shoalwater Bay Seagrass Surveys: 2002 – 2006

Centre for Environmental MANAGEMENT

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Gladstone Qld 4680

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# 1 EXECUTIVE SUMMARY

From February 2002 until January 2006 five seagrass meadows within Shoalwater Bay, a largely undisturbed natural embayment in central Queensland, were monitored for seagrass community structure and abundance. Shoalwater Bay is unique in that it is largely an intact natural system remote from human settlement and provides the most significant feeding grounds for dugong and green sea turtles in the southern Great Barrier Reef.

Seagrass community structure was found to be relatively stable throughout the study period, with meadows composed of mainly *Zostera capricorni*, *Halodule uninervis*, and *Halophila ovalis*. A fourth species, *Cymodocea serrulata*, was recorded occasionally but made up a very small proportion of the seagrass meadows.

The abundance of most species varied among sites, but was not consistent through time or space. *Zostera capricorni* was the dominant species at all but two sites, where it was co-dominant with *Halodule uninervis* at one site, the other being dominated by *Halodule uninervis*. Seagrass species formed a mosaic of irregular overlapping patches which appeared to be related to the local topography, drainage patterns and substrate of the sites. Patches ranged in size from one to 100 square metres or more and there was some indication of zonation with depth. Patches of *Zostera capricorni* were generally more abundant and larger on the inner half (i.e. landward) or mid portions of the flats while patches of *Halodule uninervis* and *Halophila ovalis* became more abundant further from the shore.

There did not appear to be any differences among sites in terms of species present and their abundance. Each appeared as a local variation on a theme of a mixed meadow of *Zostera capricorni, Halodule uninervis* and *Halophila ovalis*. There was no evidence of a gradient along the coast between McDonald Point and Raspberry Creek.

Species composition of the five sites appeared to be mostly consistent with the seagrass distribution maps presented in previous studies of the Shoalwater Bay seagrass communities. Seagrass throughout the area was patchy with moderate cover, but the perennial nature of the meadows ensures food and habitat resources are available year round. Other areas have been observed to have much higher seagrass cover and biomass but are often seasonal in nature, suggesting the seagrass is only available at certain times of year.

The biomass of seagrass within the area appears to be relatively consistent throughout the year, providing significant habitat and a continual supply of food resources for the dugong and green sea turtle that reside or visit the area. However, minor natural fluctuations in seagrass cover were recorded throughout the study period, which followed a seasonal pattern with seagrass being less abundant in autumn and more abundant in spring and summer. Furthermore, each seagrass species exhibits a slightly different phenology resulting in a relatively constant seagrass biomass throughout the year. It does not appear that changes in seagrass biomass or cover are contributing to the observed decline in dugong and turtle numbers with the southern Great Barrier Reef. However, algal and epiphytic concentrations were not accurately assessed, and may provide a confounding variable in terms of food supply for such animals.

Sabina Point seagrass meadow showed a sudden and rapid decline in seagrass between February 2004 and June 2004. Seagrass within the meadow declined from approximately 20% mean cover to less than 5% cover over this short period. A drastic change in sediment composition is implicated as the sediment characteristics changed from muddy sand to almost exclusively sand over the same time period. The cause for the change in sediments is unknown, however, increased wind activity was recorded during March 2004, including 5 consecutive days where wind speeds from the south east exceeded 50 km $hr^{-1}$ and were within the top 1% of maximum wind speeds recorded throughout the entire study period. The Sabina Point site is located on a protruding headland and as such is exposed to increased wave activity generated by strong south easterly winds. There was also some evidence for an increase in the sand fraction in sediments at nearby Duck Hole Creek and to a lesser extent Whelans Hut, but the protected sites at Windmill Creek and Ross Creek remained unchanged. In addition, February 2004 appears to have had the highest mean daily temperatures (31.5°C) recorded throughout the entire study period, while a significant rainfall event also occurred at this time. Although such environmental conditions are generally unlikely to cause such a localised decline in seagrass cover it should be noted that the seagrass at Sabina Point unlike other sites was dominated by *Halodule uninervis* and it is possible that this species may have a different tolerance to these conditions. Despite the decline, the seagrass at Sabina Point was showing signs of recovery during the last survey. This represents an 18 month to 2 year recovery period, which is similar to that observed in Hervey Bay after a flood event wiped out most seagrass in the area.

Habitat degradation within intertidal areas, among other factors, has been identified as a major issue for the continued survival of both dugongs and green sea turtles. The seagrass meadows within Shoalwater Bay appear to be relatively healthy. Although there may be some seasonality in the cover of different seagrass species, the overall biomass appears to be stable through time. Hence, the seagrass meadows provide a reliable source of food for the main grazing species in the area, dugong and green turtle, supporting large populations of both species within Shoalwater Bay.

# 2 INTRODUCTION

Shoalwater Bay is a large, semi-enclosed bay located in the Mackay/Capricorn section of the Great Barrier Reef Marine Park (GBRMP). The Shoalwater Bay region covers approximately 520,000 ha, of which approximately half is marine (Lee Long *et al.*, 1997a). It has a complex shoreline comprised of broad shallow bays, channels and islands and lies within the Shoalwater Bay Military Training Area operated by the Australian Government Department of Defence. The area has been reserved for defence force training since 1965. Access to the area is restricted and as a consequence coastal development is non-existent, providing a relatively undisturbed environment. Significant rivers are also absent from the area and consequently it is reasonably free of nutrients and other anthropogenic pollutants (Lee Long *et al.*, 1997a).

The tidal range is up to 6.3 m, creating strong currents and turbid waters (Lee Long *et al.*, 1997b; Chilvers *et al.*, 2004). The large tidal range and broad shallow bays result in extensive intertidal sand and mud banks (Lee Long *et al.*, 1997b; Chilvers *et al.*, 2004), a prime habitat for seagrass communities.

Seagrass meadows in Shoalwater Bay were first mapped during a survey in March and April 1987 (Coles *et al.*, 1987; Lee Long *et al.*, 1993). Limited subtidal seagrass occurs within the bay due to large tidal fluctuations and high turbidity so much of the available seagrass resource is on large intertidal banks (Lee Long *et al.*, 1997a; Coles *et al.*, 2002). The last mapping of seagrass extent in Shoalwater bay was undertaken in 1996 (Lee Long *et al.*, 1997a). Approximately 62% of the known seagrass resources in the Mackay/Capricorn section of the GBRMP are located within Shoalwater Bay.

Seagrasses in coastal regions are also thought to play an important role in maintaining sediment stability and water clarity. For example, seagrasses can act as nutrient and sediment sinks (Duarte and Chiscano, 1999; Rasheed, 1999), as well as affect sediment and water dynamics by reducing the energy in the water thereby, effectively creating a baffle (van Keulen and Borowitzka, 2003; Mellors *et al.*, 2005). Coastal seagrass meadows are, therefore, an important resource both from an economic and ecological perspective.

## *2.1 Seagrass Species Distribution*

Within Shoalwater Bay, *Zostera capricorni*, *Halodule* and *Halophila* species dominate intertidal meadows. Lee Long *et al.* (1997a) found that *Zostera capricorni* dominant meadows were more numerous, more extensive and generally had a higher above ground-biomass than other meadows.

During pilot surveys conducted by Queensland Parks and Wildlife Service in October and November 2001, seagrass meadows at nine locations between Macdonald Point and Raspberry Creek were inspected on foot at low tide. Most sites were dominated by *Zostera capricorni* to varying degrees with *Halodule uninervis* and *Halophila ovalis* occurring to a lesser extent. *Cymodocea serrulata* was observed occasionally. Seagrass species appeared to form a mosaic of irregular overlapping patches related to the local topography, drainage patterns and substrate of the sites. Patches ranged in size from one to 100 square metres or more. There was some indication of zonation with depth – patches of *Zostera capricorni* were generally more abundant and larger on the inner half (i.e. landward) or mid portions of the flats while patches of *Halodule uninervis* and *Halophila ovalis* became more abundant further from the shore. *Halophila ovalis* was often seen in depressions caused by local disturbances (e.g. dugong feeding, ray wallows, mud crab excavations). Biomass and shoot count samples collected at 30m intervals from 600m transects running parallel and perpendicular to the beach at the Sabina Point site during pilot surveys support these anecdotal observations.

Tropical seagrass meadows are generally subject to natural temporal fluctuations and, vary seasonally and between years (Mellors *et al.*, 1993; McKenzie, 1994; Lee Long *et al.*, 1997a). The potential for widespread seagrass loss has been well documented with the causes of loss being natural such as cyclones and floods (Poiner *et al.*, 1989), or due to human influences such as agricultural runoff (Preen *et al.*, 1995) industrial runoff (Shepherd *et al.*, 1989), oil spills (Jackson *et al.*, 1989) and dredging (Pringle, 1989).

## 2.2 Icon Species

The seagrasses in the Shoalwater Bay are considered regionally important as feeding habitats for icon species such as dugongs, *Dugong dugong* (Müller 1776), and green sea turtles, *Chelonia mydas* (Linnaeus 1758) (Lanyon *et al.*, 1989; Marsh *et al.*, 1996; Chilvers *et al.*, 2004; Limpus *et al.*, 2005). Seagrasses and mangroves are also considered important as nursery habitat for species of commercial and recreational fishing value (Lee Long *et al.*, 1997a).

The Shoalwater Bay area is considered the most important dugong habitat in the Great Barrier Reef region south of Cape York, supporting the largest dugong population between Cooktown and Hervey Bay (Marsh *et al.*, 1996). Due to a decline in dugong numbers and a high accidental catch of dugong in gill nets in the late 80s and early 90s the Bay has been designated a Zone 'A' dugong protection area and the Shoalwater Bay (dugong) Plan of Management was developed (GBRMPA, 1997). River set nets as well as foreshore and offshore set and drift nets are prohibited in the area.

Dugongs are listed as Vulnerable under the (Queensland) *Nature Conservation Act* 1992 and are protected under the *Environmental Protection and Biodiversity Conservation Act 1999*, which lists dugong as marine and migratory species (Coles *et al.*, 2002). Dugong are listed as Vulnerable to extinction at a global scale by the World Conservation Union (IUCN) and are listed on Appendix I of the Convention on International Trade in Endangered Species (CITES), and on Appendix II of the Convention on Migratory Species (CMS). The dugong is the only herbivorous mammal that is strictly marine, and is the only extant species in the Family Dugongidae (Lanyon *et al.*, 1989; Chilvers *et al.*, 2004). Dugong will generally eat most seagrass species, but have been shown to prefer seagrass species of the genera *Halophila* and *Halodule* (Lanyon *et al.*, 1989; Chilvers *et al.*, 2004).

Dugong populations are subject to a variety of human threats throughout their range (Coles *et al.*, 2002). Factors identified as risks include boat traffic, dredging, coastal development, traditional hunting, commercial gill netting, illegal fishing, defence activities, land clearing, agricultural activities and sediment run-off (Coles *et al.*, 2002, Limpus *et al.*, 2005). For dugong populations to exist in a healthy state these impacts must be effectively managed or the effects understood and where possible, prevented altogether. Furthermore, natural impacts including tropical cyclones, floods, storms and predators may also affect dugong numbers. Underpinning all these factors is the requirement for dugong to have available a healthy and abundant food source in the form of seagrass meadows (Coles *et al.*, 2002).

Long-term trends in dugong abundance along the urban coast of Queensland (i.e. Cooktown to the border of Queensland and New South Wales) are complicated by increasing evidence of large-scale movements of dugong. Overall, the available evidence suggests a long-term decline at a regional scale with short-term fluctuations at more local scales (Marsh *et al.*, 2002). Marsh *et al.* (2005) used anecdotal information and records of dugong by-catch from a government shark control program on the east coast of Queensland for evidence of a decline from a suggested 72,000 dugong supported in the region in the early 1960s compared with an estimated 4,220 dugongs in the mid-1990s. A series of standardised aerial surveys between 1986/87 and 1994 also suggest a decline in dugong numbers in the Great Barrier Reef World Heritage Area between Hinchinbrook

Island and the southern boundary of the region. The number of dugongs in the region declined from an estimated 3,479 (± s.e. 459) in 1986/87 to 1,682 in 1994 (± s.e. 236) (Marsh *et al.*, 1996). Another standardised aerial survey conducted in 1999 indicates that numbers of dugong in the southern Great Barrier Reef region had increased to levels similar to that obtained in 1986/87 (Marsh *et al.*, 2002). Similar trends were also observed for dugong in Harvey Bay and are considered to be too great to be attributed to natural increase in the absence of migration (Marsh *et. al.*, 2002).

Shoalwater Bay also supports the largest known feeding concentration of the southern Great Barrier Reef genetic stock of green turtles in one of the least disturbed major embayments in eastern Australia, and is one of the least impacted foraging populations (Limpus *et al.*, 2005). Tens of thousands of individuals feed on the seagrass meadows and fringing reefs of the area. The principal food items include seagrass, especially *Halophila* spp. and *Halodule* spp., and to a lesser extent algae and mangrove fruit (Limpus, 1996). Some of the world's last remaining large green turtle stocks breed in Australia, particularly within Queensland. The populations are not however, considered sustainable under the existing management regimes (Limpus *et al.*, 2005). The largest threats to Queensland's population of green sea turtles are indigenous hunting, boat strike, entanglement in fishing gear and habitat degradation (Limpus *et al.*, 2005).

Green turtle are listed as Vulnerable under the (Queensland) *Nature Conservation Act 1992* and are protected under the *Environment Protection and Biodiversity Conservation Act 1999*, which lists green turtle as Vulnerable and as marine and migratory species. Green turtle are listed as Endangered at a global scale by the World Conservation Union (IUCN) and are listed under Appendix I of the Convention on International Trade in Endangered Species (CITES) and Appendix I of the Convention on Migratory Species (CMS).

Globally, green turtle populations appear to be recovering from overexploitation following conservation measures introduced in the 1970s, however, continued declines may still be occurring in some areas due to incidental capture in pelagic fisheries and habitat loss (Hays, 2004; Broderick *et al.*, 2006). Locally, the southern Great Barrier Reef stock of green turtle are exposed to a low mortality risk due to incidental capture in Australian coastal fisheries or from traditional harvesting in northern Australian and nearby South East Asian waters (Chaloupka and Limpus, 2001). Just how serious these threats are to the long-term viability of the southern Great Barrier Reef green turtle stock is not known at this stage (Chaloupka and Limpus, 2001). A significant increase in the abundance of the southern Great Barrier Reef green turtle population was recorded between 1985 and

1992, where the population was reported to be increasing at a rate of *ca.* 10.6% pa (Chaloupka and Limpus, 2001). An increase (3% pa) in annual beach census of nesting green female turtles was also recorded over the last 25 years consistent with a global recovery from overexploitation reported for sea turtles generally (Chaloupka and Limpus, 2001;Hays, 2004; Broderick *et al.*, 2006).

In addition to dugong and turtles, juvenile fish and prawns and a variety of seabirds, migratory waders and shorebirds depend on the seagrass habitat within Shoalwater Bay for food and/or shelter (Lee Long *et al.*, 1997a).

## 2.3 Objectives

The last surveys of the seagrass meadows in Shoalwater Bay were conducted in 1996 (Lee Long *et al.*, 1997a). Since that time casual and anecdotal observations made by the turtle research team working in Shoalwater Bay have suggested that fluctuations in seagrass quality and quantity may be correlated with the growth and reproductive condition of turtles, and the breeding success of species such as ospreys and pelicans (Limpus *pers. comm.*). Unfortunately, no quantitative seagrass data are available to refute or support this impression.

In Moreton and Hervey bays, where regular seagrass monitoring is undertaken, evidence is accumulating which suggests fluctuations in the abundance and nutrient status of seagrass correlates with the population demographics of turtle and dugong (Limpus *pers. comm.*). There is however, insufficient long-term information on the abundance, productivity and seasonal change of seagrass within the Great Barrier Reef Marine Park to make any firm connection between habitat status and dugong numbers (Coles *et al.*, 2002). In addition, seagrass information that is available for many of the existing dugong protection areas is broad-scale and over 10 years old (Coles *et al.*, 2002).

The Queensland Parks and Wildlife Service initiated a program in 2001 to describe natural fluctuations in species composition and abundance of intertidal seagrass meadows in Shoalwater Bay. Following initial pilot surveys conducted in October and November 2001, regular (4 times per year) seagrass monitoring was undertaken over a four year period from February 2002 until January 2006. From February 2005 the program was subsequently undertaken and completed by the Centre for Environmental Management at Central Queensland University in collaboration with Queensland Parks and Wildlife Service.

Specifically, the aims of the program were to:

- undertake regular (4 times per year) survey of sites (areas which represent major intertidal seagrass habitats in the Bay) over a four year period;
- determine any seasonal and natural fluctuations in the extent of intertidal seagrass within the Shoalwater Bay area;
- provide baseline information on an undisturbed seagrass environment which could be used as a benchmark for other studies; and
- add to the understanding of the effect natural changes in seagrass communities may have on other species, e.g. dugong and green sea turtles.

# 3 MATERIALS AND METHODS

## 3.1 *Site Description*

About 37% of Shoalwater Bay is shallow open water (<10m deep) and supports a little over 13,000ha of seagrass meadows (Lee Long *et al.*, 1997a). Most of these meadows are located on large intertidal banks and are considered the most important seagrass resource in the southern region of the GBR Marine Park (GBRMPA, 1997).

Lee Long *et al.* (1997a) identified twelve meadow types (seagrass communities) within Shoalwater Bay. Those meadow types (4) dominated by *Zostera capricorni* made up approximately half of the area covered by seagrass within Shoalwater Bay and were more numerous, more extensive and generally had much higher above-ground biomass than most other meadows. The other eight meadow types were dominated by pioneering seagrass species belonging to the genera *Halophila* and *Halodule* and made up the remaining seagrass habitat. Shoalwater Bay is known to support very large populations of dugong and green turtle, which feed on the extensive seagrass meadows with *Zostera capricorni, Halophila* and *Halodule* species comprising a major proportion of the diet of both species (Lanyon *et al.*, 1989; Lee Long *et al.*, 1993; Aragones and Marsh, 2000; Masini *et al.*, 2001; Limpus *et al.*, 2005).

### *3.1.1 Sampling Sites Selection*

Due to limited resources and entry restrictions during defence exercises it was not possible to regularly access seagrass habitats in all parts of Shoalwater Bay. Only a limited number of intertidal meadows between McDonald Point and Raspberry Creek (Figure 1) on the western side of the bay could be visited on a regular basis

Fortunately, the mostly continuous intertidal banks between McDonald Point and Raspberry Creek support the most common seagrass communities in Shoalwater Bay (Lee Long *et al.*, 1997; McKenzie *pers. comm.*) and are a common feeding ground for turtles and dugong (Limpus *pers. comm.*; Mulville *pers. comm.*). Thus, it can be reasonably argued that survey sites situated in this area would sample meadows that are 'typical' or 'representative' of the seagrass resource used by these two species and of most seagrass communities in the Bay.

During pilot surveys conducted by Queensland Parks and Wildlife Service in October and November 2001, seagrass meadows at nine locations between McDonald Point and

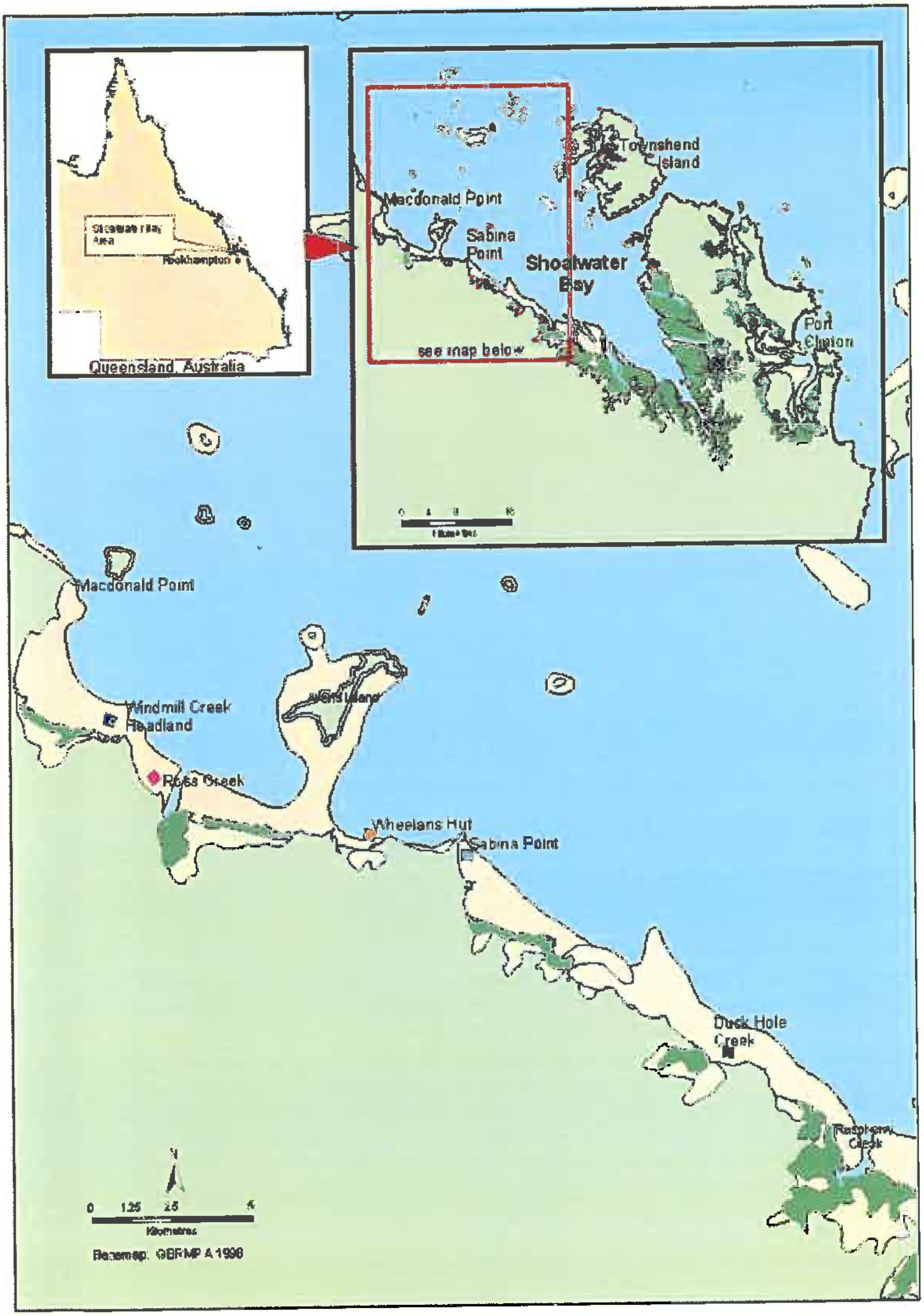


Figure 1: Location map of the five seagrass sampling sites within Shoalwater Bay, Queensland, Australia.


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PO Box 1319, Gladstone Q4680

Raspberry Creek were inspected on foot at low tide (Figure 2). All sites visited were dominated by *Zostera capricorni* to various degrees with *Halodule uninervis* and *Halophila ovalis* comprising a common but less abundant component of the seagrass. *Cymodocea serrulata* was observed occasionally.

Of the nine coastal locations visited during the pilot study, five – those adjacent to Windmill Creek Headland, Ross Creek, Whelan's Hut Point, Sabina Point and Duck Hole Creek (Figure 1) – were nominated as monitoring sites for this project. The exact location of each site is listed in Appendix I. These five sites include the full range of variation in species composition, with 3 sites (Ross Creek, Whelans Hut, and Duck Hole Creek) being dominated by *Zostera capricorni,* 1 site (Windmill Creek) where *Zostera capricorni and Halodule uninervis* were co-dominant and a final site (Sabina Point) dominated by *Halodule uninervis.* All sites were also likely to be accessible under all weather conditions. A maximum of five sites could be surveyed on any visit given operational constraints.

Figure 2: Sample collection at Duck Hole Creek, near Raspberry Creek in Shoalwater Bay.

## 3.2 Timing of surveys

Surveys were timed such that extremes in seasonal fluctuations during the year were recorded. In a study of tropical intertidal seagrasses in the Townsville region over 2 years abundance of total seagrass and individual seagrass species fluctuated seasonally, with minimum abundance in the dry season (August to September) and subsequent recovery of seagrass during the wet season months (November to March). However, some variation among sites and years was noted (Lanyon and Marsh, 1995). Given that operational considerations limited surveys to four per year it was decided that surveys would be conducted quarterly in February/March, May/June, August/September and November/December or as near to this as access restrictions and suitable spring tide periods allowed (appendix II).

## 3.3 Sampling Design

Since spatial patterning of seagrass across the tidal flat is patchy or largely random, a systematic sampling layout was designed as it gives a more 'uniform' or 'representative' coverage of the sampling site (Brown, 2001).

Each sampling site was set up with four 300m long transects running perpendicular to the shore and each 100m apart and covered an area of 300m x 300m (90,000m$^2$) at each site. This layout permits a reasonably representative sampling of within site patchiness. Adequately sampling the heterogeneity within each site ensures that between and within site differences in species composition are not confounded. In an attempt to avoid taking samples from the same place on successive visits, each transect was allocated to one of 20 randomly arranged positions within a 10m wide belt on each sampling date.

Each transect was aligned to begin at about 2m above datum (100m – 200m from the beach depending on slope of flats) and extended seaward 300m to a level between 0.5m and 1.5m above datum depending on the slope of the flats. The GPS coordinates for the start of each transect were recorded (Appendix 1). Seagrass cover was estimated using 50cm x 50 cm quadrats placed at 10m intervals (starting at 10m) along each transect (i.e. 30 quadrats per transect and 120 quadrats per site).

## 3.4 Choice of variables

A variety of methods have been developed for the measurement of seagrass composition and abundance. These include visual estimates of seagrass cover (McKenzie *et al.*, 2003), indirect measures of above ground biomass/standing crop using calibrated ranking systems (Mellors, 1991; Mumby *et al.*, 1997), photography and image analysis techniques (Lee, 1997; Fong *et al.*, 2000), point intercept grids (Lanyon and Marsh, 1995), counts of shoot density (Lin and Shao, 1998), direct measures of biomass using cores (Duarte *et al.*, 1998; Duarte and Chiscano, 1999), grabs (Long *et al.*, 1993) or harvested quadrats (Lanyon and Marsh, 1995).

Non-destructive rapid visual estimates such as those used by Seagrass-Watch and pioneered by Mellors (1991) produce large data sets for minimal effort, but may incorporate varying degrees of irresolvable error due to inconsistent use of ranks and standards over time in different situations or by different individuals. In particular, when seagrass abundance is high the ability of these techniques to resolve real differences decreases (Mumby *et al.*, 1997).

Direct measures of shoot counts and biomass are more accurate and less prone to subjective bias but are more time consuming to gather. When samples are harvested destructive impacts may become an issue, for example if the seagrass is rare or endangered.

The following variables were assessed, with all methods tested in the field during the pilot study in October and November 2001:

- Total percentage cover (estimated)
- Shoot biomass per species (dry weight in 0. 01g $m^{-2}$)
- Total below ground biomass (dry weight in 0.01g $m^{-2}$)

Sampling was initially undertaken by staff from Queensland Parks and Wildlife Service (i.e. February 2002 to December 2004), however, when the project was transferred, staff from within the Centre for Environmental Management at Central Queensland University and Queensland Parks and Wildlife Service completed the remaining sampling. To ensure consistency with sampling staff from Queensland Parks and Wildlife Service provided training in survey methods and undertook field sampling in conjunction with staff from the Centre for Environmental Management. In addition to the change in personnel, there was also a change in methodology that occurred at this time. The collection of seagrass biomass data (from February 2002 to December 2003) from cores was replaced with estimates species cover (from February 2004 to January 2006) using a modification to the Seagrass Watch methods (see below) due to logistical constraints. Appendix II provides details of the dates for each sampling period and the parameters measured.

### *3.5 Precision Issues and Individual Sample Size*

Although using 50cm x 50cm quadrats (Figure 3) is the popular "standard" for intertidal ecologists worldwide (Andrew and Mapstone, 1987), logistical considerations required the use of smaller sampling units for biomass determination. The use of 10cm diameter cores was investigated even though intuition suggested that they would yield data sets that had extremely high variance and lacked sufficient precision (SE/mean) to allow detection of statistically significant effects.

Figure 3: Comparing seagrass sampling methods in Shoalwater Bay during pilot studies in November 2001. Note the size of the 10cm circle compared with the 50cm x 50cm quadrat.

Trial surveys using 20 cores yielded precision values mostly less than 0.15 for biomass data. This is comfortably within the 0.1 – 0.2 level of precision aimed for in field programs (Thresher and Gunn, 1986).

It is also noteworthy that the precision of percentage cover estimates using 50cm x 50cm quadrats is very similar to that using 10cm diameter circles. Trials on a typical seagrass flat at Sabina Point in November 2001 yielded precision values of 0.1, 0.08, & 0.13 for three sets of 20 quadrats (50cm x 50cm) and 0.11, 0.09 and 0.17 for three sets of 20 circles (10cm diameter) sampled along the same transects. Despite the fact that quadrats were about 32 times the area of circles, their larger size resulted in a minor reduction in data variability. This was most likely due to the fact that variations in seagrass density occur on a scale between 1m$^2$ and 100 m$^2$ (Turner *et al.*, 1999), whereas below this shoots tend to be fairly evenly distributed (pilot study data, October and November 2001). As both quadrats and circles were smaller than a square metre they mostly sampled the same "within patch" level of cover.

## *3.6 Sample Collection and Processing*

### *3.6.1 Percent Cover and Species Composition*

Total percentage cover was visually estimated in 50cm x 50cm quadrats on a quarterly (three monthly) basis using the Seagrass Watch method (McKenzie *et al.*, 2003).

Trials in the field indicated that visual estimates of seagrass cover could be made without compromising the collection of core samples. Attempts were made to estimate individual species cover, but these could not be made reliably. Fine-bladed *Zostera capricorni* and *Halodule uninervis* in particular were very difficult to distinguish in the field. However, from February 2004 until the end of the sampling period in January 2006, species cover was estimated using a slight modification of the Seagrass Watch methods (McKenzie *et al.*, 2003). A total percent cover estimate was recorded (all species combined), followed by an estimate of the proportion of cover per species. Species estimates were allocated a number from 0 to 10 (i.e. in 10% increments), and then multiplied by the total percent cover, giving an estimated percent cover per species. It was deemed that trying to estimate species cover to a finer scale would introduce too much error between observers.

### *3.6.2 Biomass Sampling*

Biomass and shoot samples were collected using a 10cm diameter, 25cm deep corer from February 2002 until December 2003. Core samples were taken at 30m intervals along each transect. Samples were sieved and washed to remove sand and mud; shoots were then separated from roots and rhizomes. Shoots were sorted into species, counted and bagged separately. Above and below ground components were dried at 50°C for 10 hours then weighed to the nearest 0.001g. Attempts were made to separate roots and rhizomes into species but this proved too difficult in mixed samples. Additionally, some samples were so tangled it could not be done accurately.

### *3.6.3 Nutritional analysis*

Seagrass samples for nutritional analysis were collected by randomly taking roots and shoots of species present at each site when collecting cores for biomass analysis during sampling trips conducted in 2005. Samples were then placed in sealed polyethylene bags. Samples were sieved and washed to remove sand and mud; shoots were then separated from roots and rhizomes. Shoots were sorted into species, counted and bagged separately. Above and below ground components were dried at 50°C for 10 hours then weighed to the nearest 0.001g.

The nutritional quality of samples was then determined using Near Infrared Spectroscopy (NIRS). NIRS can provide quick, non-destructive and quantitative analyses for measuring organic composition via calibrating the spectral features or reflected NIR spectrum of a sample with laboratory reference values (Foley *et al.*, 1998). NIRS was used to determine the dietary fibre fraction expressed as Neutral Detergent Fibre (NDF), which describes those component polysaccharides and lignin that cannot be digested by monogastric organisms. Crude protein was assessed using total nitrogen content (ANL).

## *3.7 Physical parameters*

### *3.7.1 Temperature*

Temperature loggers (i-buttons™), courtesy of Department of Primary Industries and Fisheries, Northern Fisheries Centre, were deployed at two sampling sites – Sabina Point and Windmill Creek for the duration of the study (Figure 4). The temperature loggers were installed near the centre of the survey sites to record fluctuations in temperature on the seagrass flats. At each site one set of loggers was placed within a pool, while another was placed just above the water level. Loggers were replaced as needed during the study so that a continuous record of temperature could be generated. However, in some instances data loggers were not recovered so the temperature record was not always continuous over the study period.

Figure 4: Temperature loggers deployed on the Sabina Point seagrass meadow, March 2005.

### 3.7.2 Rainfall

Rainfall records at Sabina Point and Pine Mountain were collected on a monthly basis by John Stocks, Range Manager, Pine Mountain Ranger Station using a rain gauge.

### 3.7.3 Wind speed

Wind speed data from February 2002 until January 2006 for Rundle Island (23°31′45″S; 151°16′35″E) were obtained from the Bureau of Meteorology (Brisbane). Data for wind speed (km $hr^{-1}$) and direction (decimal degrees) were provided as 3-hourly observations. Mean monthly wind speed throughout the study period was calculated from daily averages.

### 3.7.4 Sediment Composition

Sediment composition was assessed in each of the 50cm x 50cm quadrats from June 2002 until January 2006 using the Seagrass Watch methods (McKenzie *et al.*, 2003). Surface sediment texture was assessed by rubbing a small quantity between the fingers and noting grain size in order of dominance (mud, sand, grit and rubble). Overall sediment composition for the site was estimated by weighting the grain size records in each quadrat as follows:

- 1 if only one component was present (e.g. mud)
- ½ each if two components were present (e.g. mud and sand), and
- ⅓ each if three components were present.

Weighted scores for each component were then summed and expressed as a proportion of the sum of all weighted components. The proportions were then graphed to elucidate any seasonal patterns or general changes in sediment composition. However, these data are qualitative and any interpretation of results should be treated with caution.

#### 3.7.5 *Lyngbya majuscula*

The presence of *Lyngbya majuscula* (hereafter referred to as *Lyngbya*) was recorded as absent, low, medium or high for each quadrat during the sampling program. The number of quadrats *Lyngbya* was recorded in was summed for each site and divided by the total number of quadrats per site to give an estimate of the proportion of *Lyngbya*. This proportion was then graphed to elucidate any seasonal patterns or general changes in *Lyngbya* presence. These data are also qualitative and any interpretation of results should be treated with caution.

Anecdotal observations of *Lyngbya* presence within the sampling areas were also obtained from John Stocks, the Range Manager stationed at Pine Mountain at the time.

### 3.8 Statistical Analysis

#### 3.8.1 Analysis of Variance

Due to the changing of methods part way through this study (Appendix II), not all parameters sampled can be compared with each other (e.g. biomass data cannot be compared to species composition data as they were collected over different time periods).

Species cover and composition data are expressed as a proportion (or percentage) and are therefore bounded by set limits; i.e. 0 and 1 (or 0 and 100%). An arcsine transformation was used to provide a more realistic distribution of values (Quinn and Keough, 2002). This transformation moves very low or very high values towards the centre, giving them more theoretical freedom to vary, thereby meeting the assumptions of analysis of variance (ANOVA) (Quinn and Keough, 2002).

Analysis of variance was used to determine whether there were any spatial and temporal differences in seagrass cover (from February 2002 until January 2006) and whether there were any interaction effects between the factors. Data were tested for homogeneity of variance and normality and the significance levels were reduced ($p < 0.01$) where the data did not meet the assumptions of ANOVA.

Changes in species composition were analysed using ANOVA with year, season and site as the factors. These analyses were conducted on data collected from February 2004 until January 2006. Tukey's post hoc tests were used to determine where any differences occurred, if any.

Given difficulties in separating species composition for below ground biomass and that it has previously been determined that above-ground dry weights of seagrass were the most robust and relevant measures of seagrass biomass, statistical analyses were performed using above-ground dry weight values only (Kirkman, 1996; Currie *et al.*, 2003). Changes in species biomass between years, seasons and sites were analysed using ANOVA. These analyses were conducted on the biomass data collected from February 2002 until December 2003. Tukey's post hoc tests were used to determine where any differences occurred, if any.

Changes in major sediment components between years, seasons and sites were analysed using ANOVA. These analyses were conducted on the sediment data collected from June 2002 until January 2006. Data were arcsine transformed and Tukey's post hoc tests were used to determine where any differences occurred, if any.

### *3.8.2 Multivariate Analysis*

Spatial and temporal differences between species composition in Shoalwater Bay were examined using Bray-Curtis (B-C) similarity measures (Bray and Curtis, 1957). This similarity measure was chosen because it is not affected by joint absences, it gives more weighting to abundant than rare species, and it has consistently performed well in preserving "ecological distance" in a variety of simulations on different types of data (Field *et al.*, 1982).

Differences in species composition (based on percent cover and biomass) between years, seasons and sites were plotted using non metric multidimensional scaling (*n*MDS) using the statistical package PRIMER (Clarke and Gorley, 2001). A two way crossed analysis of similarity (ANOSIM) was then used to determine the relationships in community structure between years, sites and seasons (Clarke and Warwick, 1994). Data were fourth root transformed to decrease the influence of the large number of zero values (Quinn and Keough, 2002). Note that percent cover and species biomass data were collected over different time periods so could not be compared in the same analysis (Appendix II).

Changes in sediment composition throughout the study period at sites within Shoalwater Bay were also examined using Bray-Curtis (B-C) similarity measures (Bray and Curtis, 1957). Differences in sediment composition were plotted using non metric multidimensional scaling (*n*MDS) using the statistical package PRIMER (Clarke and Gorley, 2001). A two way crossed analysis of similarity (ANOSIM) was then used to determine the relationships in sediment composition between sites, seasons and years (Clarke and Warwick, 1994). Data were fourth root transformed to decrease the influence of the large number of zero values (Quinn and Keough, 2002).

# 4 RESULTS

## 4.1 Seagrass Cover

In total 9,600 quadrats were assessed at the five sites (1,920 per site) for seagrass cover from February 2002 until January 2006. Mean seagrass cover for all sites over the entire study period was reasonably similar among years, with a range of ~16% to ~21%, although a consistent decline through time was observed (Figure 5 – "All Sites"). However, at the individual sites the mean seagrass cover was relatively consistent over the study period with differences between years generally ranging from 5 – 10% (Figure 5). The exception was Sabina Point where a consistent decline in seagrass cover was observed throughout the study period, decreasing from ~28% to less than 5% in the course of the four years. This site is likely to have unduly influenced the overall seagrass cover estimates, so some caution is required when interpreting the overall trends.

Seasonal seagrass cover was relatively consistent, with only slight changes from one season to another at most sites (Figure 6). Again, Sabina Point showed the most variation with a marked increase in seagrass cover during the summer months (January – March). At all other sites the seagrass cover was within 5% of each season (Figure 6). Windmill Creek was particularly consistent, with only ~1% variation throughout the seasons.

Mean seagrass cover ranged between 2% and 39% at any one site on any sampling date, with the majority having a mean cover of between 12% and 32% (Figure 7). Interestingly, both the maximum and minimum cover was recorded at Sabina Point, with the maximum occurring in the first sampling period (February 2002) and the minimum occurring in September 2004 and September 2005 (Figure 7). The Sabina Point site showed a very marked change in seagrass cover between the February and June samplings in 2004, with a decrease from approximately 22% to 4% over this time. Similar trends were not observed at any of the other sites, although seagrass cover at these sites did vary to some extent (Figure 7). From June 2004 until September 2005, seagrass cover at Sabina Point remained below 5%. However, there was some sign of a recovery with mean seagrass cover estimates increasing to 10% by January 2006 (Figure 7).

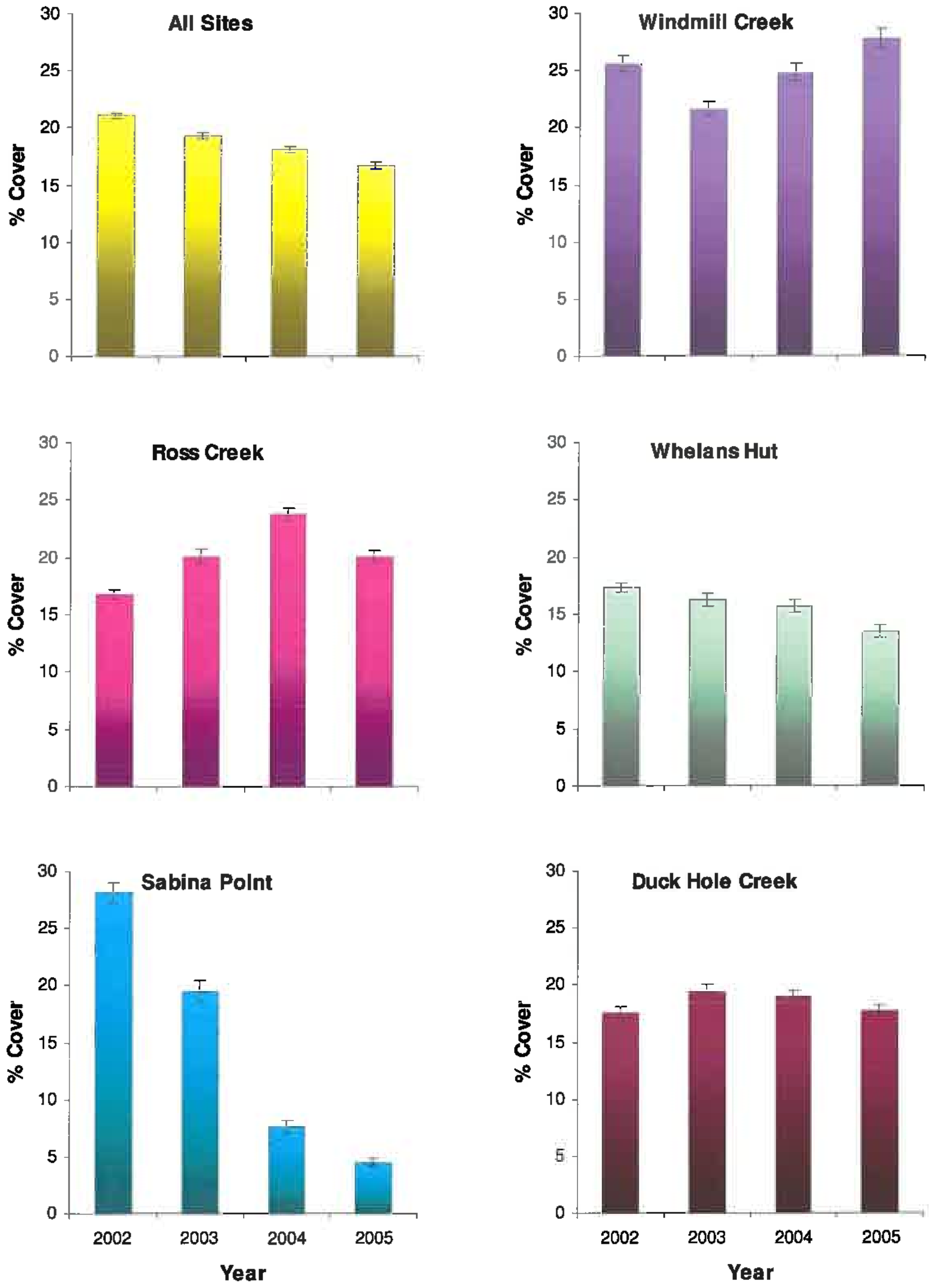


Figure 5: Mean seagrass cover (±SE) for each year of sampling at the five sites within Shoalwater Bay. Data are also shown as means for all sites combined. n = 480 quadrats x 5 sites x 4 years = 9,600.

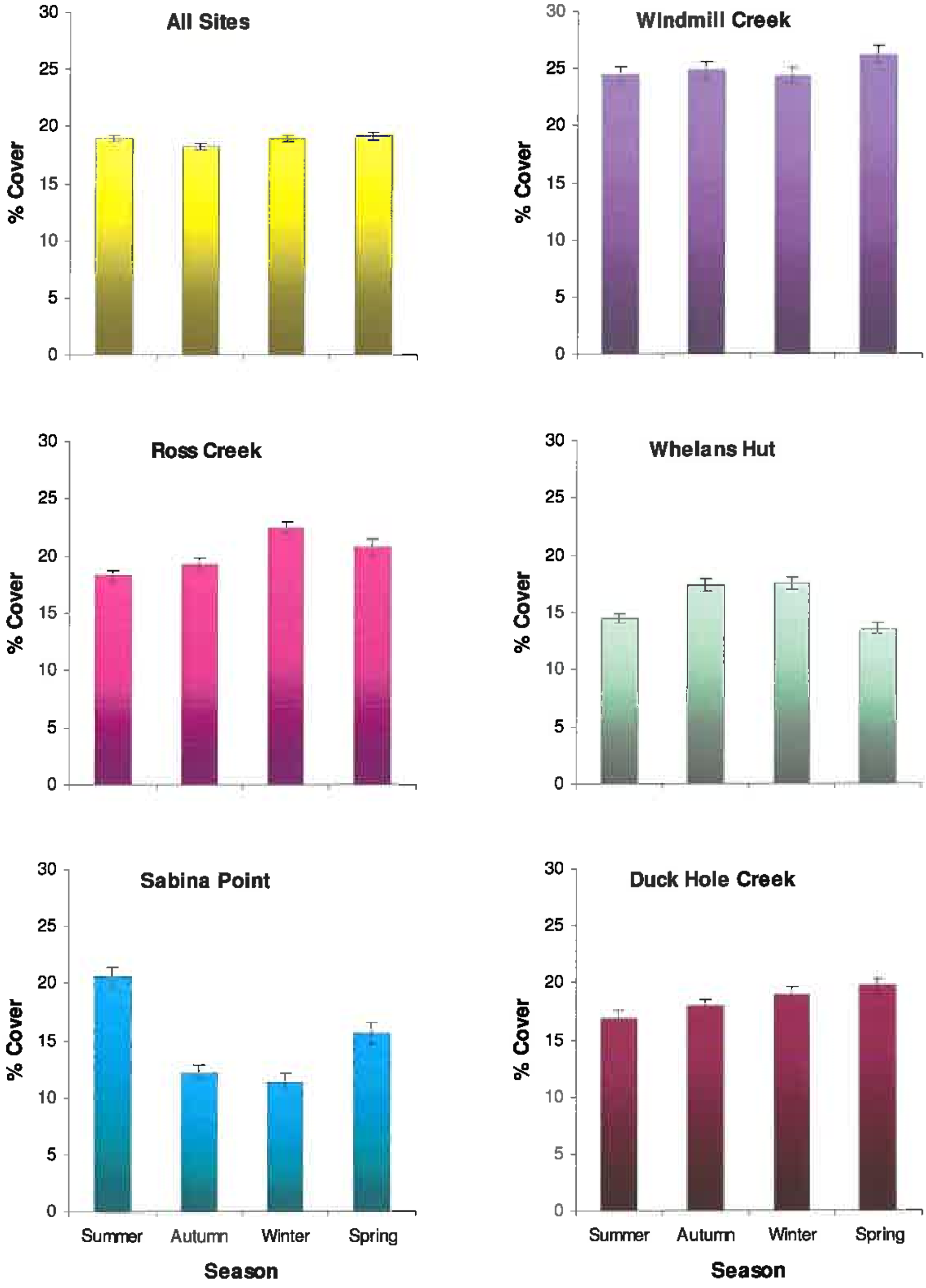


Figure 6: Mean seagrass cover (±SE) for each season of sampling at the five sites within Shoalwater Bay. Data are also shown as means for all sites combined. n = 480 per season per site

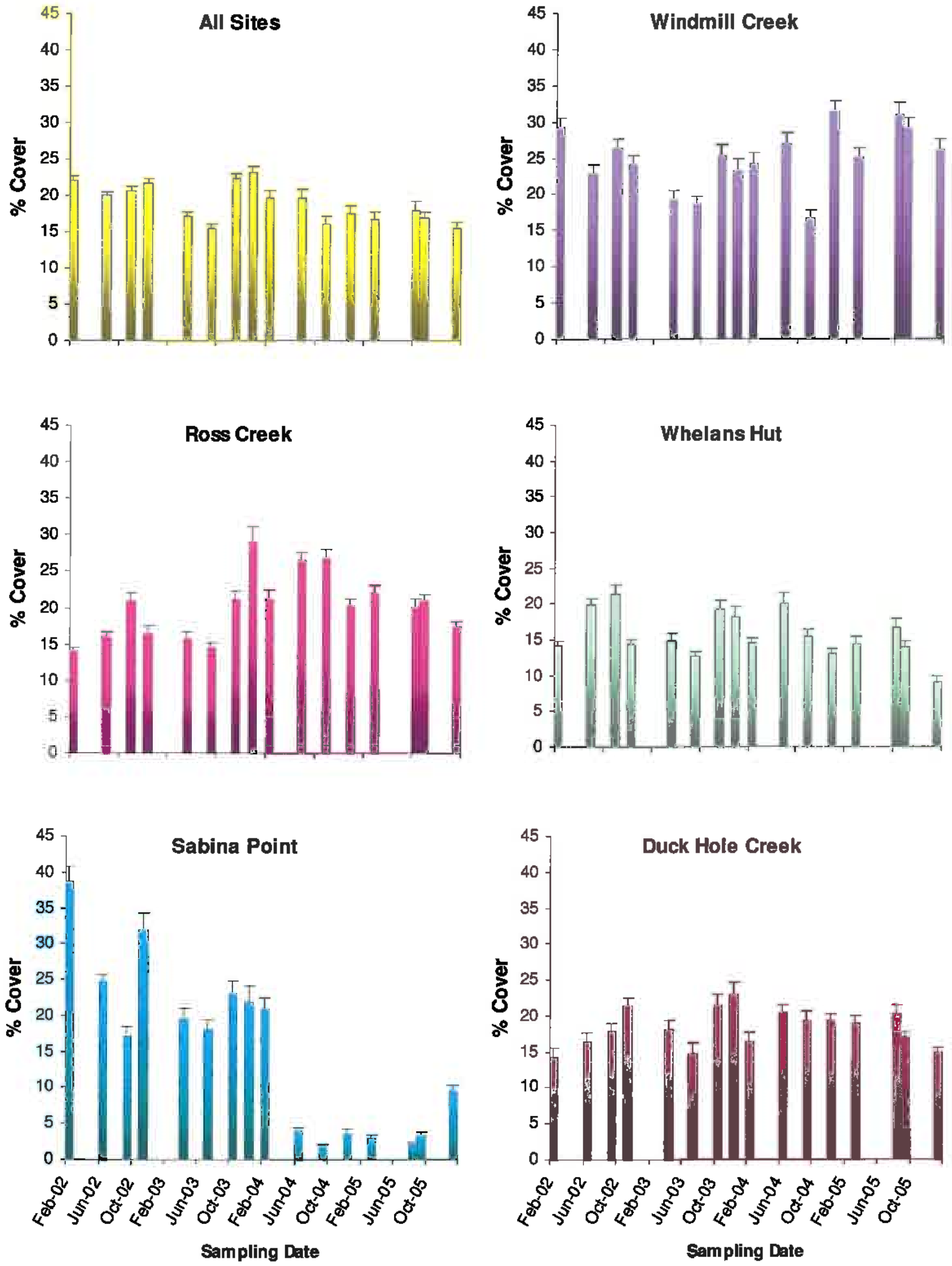


Figure 7: Mean seagrass cover (±SE) for each sampling date between February 2002 and January 2006 at the five sites within Shoalwater Bay. Data are also shown as a mean for all sites combined. n = 120 per sampling date per site.

### 4.1.1 Temporal and Spatial Changes in Seagrass Cover

Mean seagrass cover varied considerably throughout the study period (Figure 7). For instance, seagrass cover decreased with time at Sabina Point, while it generally increased at Windmill Creek and Ross Creek (Figure 5). At other sites seagrass cover remained relatively stable.

Seagrass cover across all sites varied across years ($F_{3,9599}$ = 78.389, p <0.001, Table 1a). Tukey's post hoc comparison tests reveal that all four sampling years had a different mean seagrass cover to one another, with mean cover decreasing chronologically from 2002 until 2005 (Table 1b, Figure 5 – "All Data"). Seagrass cover did not show a significant difference between seasons when all sites were compared ($F_{3,9599}$ = 1.741, p = 0.156, Table 1a). However, seagrass cover at individual sites did vary to some extent throughout the year (Figure 6).

Seagrass cover was significantly different among sites ($F_{4,9599}$ = 240.020, p < 0.001, Table 1a, Figure 8), indicating a spatial difference throughout the sampling area. Post hoc tests for differences between sites within Shoalwater Bay indicate that all five sites are significantly different from each other (Table 1c, Figure 8). Sabina Point and Whelans Hut have the lowest mean seagrass cover while Windmill Creek has the highest (Table 1c, Figure 8).

A three way analysis of variance indicates that there were significant interaction effects between years, seasons and sites ($F_{36,9599}$ = 13.641, p < 0.001, Table 1a). That is, seagrass cover varied between years, seasons and sites, but not in the same manner throughout. Consequently, seagrass cover at the five sampling sites within Shoalwater Bay was variable through space and time.

When Sabina Point was removed from the analyses (given the very large reduction in seagrass cover compared to other sites) there was a significant difference in seagrass cover between seasons ($F_{3,7679}$ = 10.670, p <0.001, Table 2a), and also between sites ($F_{3,7679}$ = 158.415, p <0.001, Table 2a) and years ($F_{3,7679}$ = 3.021, p <0.001, Table 2a). Post hoc tests for differences between seasons indicate that mean seagrass cover in autumn is significantly lower than other seasons, while there is no significant difference in seagrass cover between winter and summer or summer and spring (Table 2c).

Table 1a: Analysis of Variance table for the proportion of seagrass cover at five sites within Shoalwater Bay. Each site was sampled on 16 occasions between February 2002 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2 = 0.253$

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 8.083 | 3 | 2.694 | 78.389 | <0.001 |
| Season | 0.180 | 3 | 0.060 | 1.741 | 0.156 |
| Site | 33.000 | 4 | 8.250 | 240.020 | <0.001 |
| Year * Season | 4.552 | 9 | 0.506 | 14.716 | <0.001 |
| Year * Site | 40.987 | 12 | 3.416 | 99.371 | <0.001 |
| Season * Site | 7.393 | 12 | 0.616 | 17.924 | <0.001 |
| Year * Season * Site | 16.880 | 36 | 0.469 | 13.641 | <0.001 |
| Error | 327.225 | 9520 | 0.034 | | |
| Total | 2054.691 | 9599 | | | |

Table 1b: Tukey's post hoc multiple comparison test for observed differences in seagrass cover between years at five sites within Shoalwater Bay. Each site was sampled on 16 occasions between February 2002 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | | |
|---|---|---|---|---|---|
| Year | N | 1 | 2 | 3 | 4 |
| 2005 | 2400 | 0.3763 | | | |
| 2004 | 2400 | | 0.3930 | | |
| 2003 | 2400 | | | 0.4189 | |
| 2002 | 2400 | | | | 0.4532 |
| Signif. | | 1.000 | 1.000 | 1.000 | 1.000 |

Table 1c: Tukey's post hoc multiple comparison test for observed differences in seagrass cover between sites within Shoalwater Bay. Each site was sampled on 16 occasions between February 2002 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| Site | N | 1 | 2 | 3 | 4 | 5 |
| Sabina Point | 1920 | 0.3253 | | | | |
| Whelans Hut | 1920 | | 0.3753 | | | |
| Duck Hole Creek | 1920 | | | 0.4078 | | |
| Ross Creek | 1920 | | | | 0.4471 | |
| Windmill Creek | 1920 | | | | | 0.4962 |
| Signif. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Table 2a: Analysis of Variance table for the proportion of seagrass cover at four sites within Shoalwater Bay (excluding Sabina Point). Each site was sampled on 16 occasions between February 2002 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2 = 0.253$

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 0.298 | 3 | 0.099 | 3.021 | 0.029 |
| Season | 1.053 | 3 | 0.351 | 10.670 | <0.001 |
| Site | 15.634 | 3 | 5.211 | 158.451 | <0.001 |
| Year * Season | 5.031 | 9 | 0.559 | 16.992 | <0.001 |
| Year * Site | 4.730 | 9 | 0.526 | 15.977 | <0.001 |
| Season * Site | 1.802 | 9 | 0.200 | 6.088 | <0.001 |
| Year * Season * Site | 4.727 | 27 | 0.175 | 5.322 | <0.001 |
| Error | 250.536 | 7616 | 0.033 | | |
| Total | 17414.433 | 7680 | | | |

Table 2b: Tukey's post hoc multiple comparison test for observed differences in seagrass cover between years at four sites within Shoalwater Bay (excluding Sabina Point). Each site was sampled on 16 occasions between February 2002 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| Year | N | Subset 1 | Subset 2 |
|---|---|---|---|
| 2003 | 1920 | 0.4235 | |
| 2005 | 1920 | 0.4297 | 0.4297 |
| 2002 | 1920 | 0.4325 | 0.4325 |
| 2004 | 1920 | | 0.4408 |
| Signif. | | 0.4140 | 0.2290 |

Table 2c: Tukey's post hoc multiple comparison test for observed differences in seagrass cover between seasons at four sites within Shoalwater Bay (excluding Sabina Point). Each site was sampled on 16 occasions between February 2002 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| Year | N | Subset 1 | Subset 2 | Subset 3 |
|---|---|---|---|---|
| Autumn | 1920 | 0.4138 | | |
| Winter | 1920 | | 0.4303 | |
| Summer | 1920 | | 0.4361 | 0.4361 |
| Spring | 1920 | | | 0.4461 |
| Signif. | | 1.000 | 0.7550 | 0.3180 |

Table 2d: Tukey's post hoc multiple comparison test for observed differences in seagrass cover between sites within Shoalwater Bay (excluding Sabina Point). Each site was sampled on 16 occasions between February 2002 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | | |
|---|---|---|---|---|---|
| **Site** | **N** | **1** | **2** | **3** | **4** |
| Whelans Hut | 1920 | 0.3753 | | | |
| Duck Hole Creek | 1920 | | 0.4078 | | |
| Ross Creek | 1920 | | | 0.4471 | |
| Windmill Creek | 1920 | | | | 0.4962 |
| Signif. | | 1.000 | 1.000 | 1.000 | 1.000 |



Centre for Environmental Management, Central Queensland University
PO Box 1319, Gladstone Q4680

## 4.2 Species Composition

From 2004 to 2006, all quadrats were also assessed for species composition. Four seagrass species were found during the course of the study: *Zostera capricorni, Halophila ovalis, Halodule uninervis* and *Cymodocea serrulata*. *Zostera capricorni* was the dominant species at Ross Creek, Whelans Hut and Duck Hole Creek with other species occurring to a lesser extent, while *Zostera capricorni* and *Halodule uninervis* were co-dominant at Windmill Creek (Figure 9). *Halodule uninervis* was dominant at Sabina Point. However, the species composition data only includes 2004 and 2005, a period when Sabina Point had very low seagrass cover (Figure 7).

*Halophila ovalis* was present at all sites in low levels while *Cymodocea serrulata* was present at all sites except Ross Creek, but was in such low levels at most sites that it does not show when compared to other species (Figure 9).

Temporal distributions of seagrass community structure based on species composition showed no significant differences between years (Analysis of Similarity (ANOSIM): R-statistic = 0.004, p = 0.225). Ordination plots based on the non-metric multidimensional scaling (*n*MDS) of similarities in community type (i.e. how similar each transect is to one another based on species composition) are shown in Figure 10a, with both 2004 and 2005 showing similar distribution patterns. An even spread of samples is also observed when the same ordination is divided by season (Figure 10b). The corresponding ANOSIM shows no significant differences in community composition between seasons (R-statistic = 0.01, p = 0.104). However, an ANOSIM based on site shows a significant difference between community composition (R-statistic = 0.36, $p < 0.001$). The *n*MDS ordination plot shows that both Sabina Point and Windmill Creek sites appear to be separate from the other sites (Figure 10c).

When the ordination plots are divided by species (Figure 11) it becomes apparent that the different species separate out in different ways. *Zostera capricorni* appears to dominate in the left of the plot, while *Halodule uninervis* dominates towards the centre top of the plots, generally where *Zostera capricorni* is less abundant. *Cymodocea serrulata* appears to occur in similar areas to *Halodule uninervis*, and less so where *Zostera capricorni* occurs. Similarly, *Halophila ovalis* appears more dominant where *Zostera capricorni* is less abundant, but is still often present with *Zostera capricorni*.

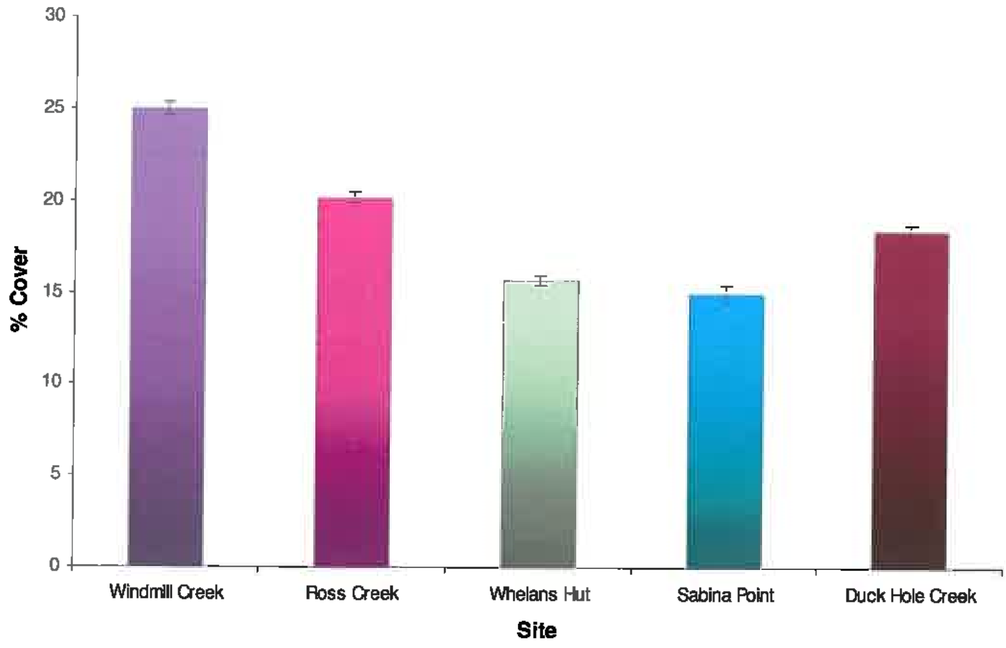


Figure 8: Mean seagrass cover (±SE) between February 2002 and January 2006 at each of five sites within Shoalwater Bay.

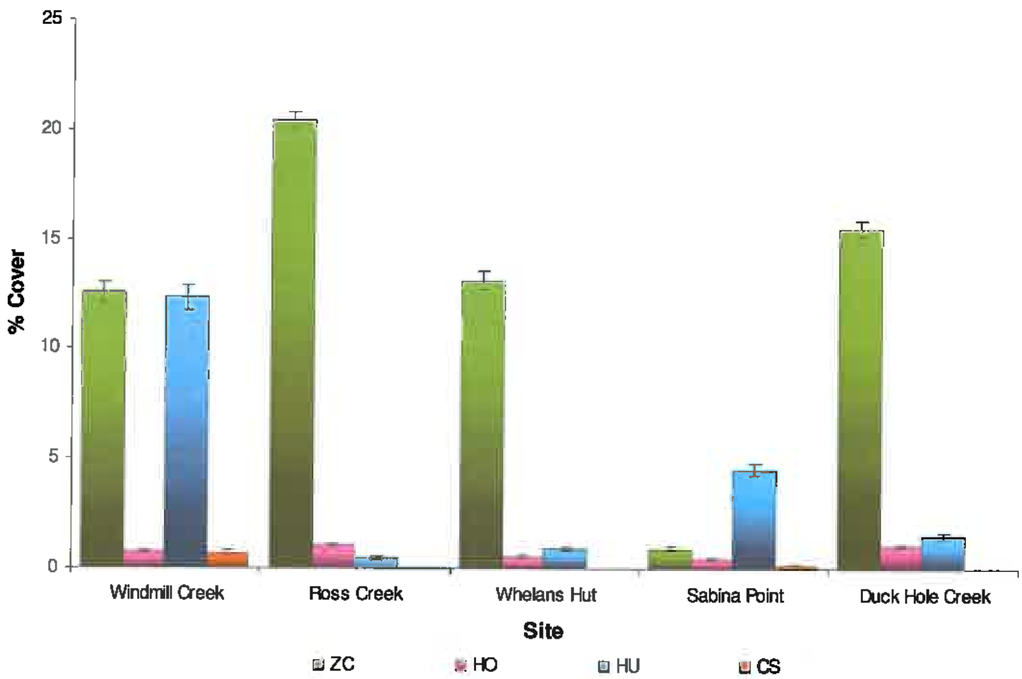


Figure 9: Mean seagrass species composition (±SE) at the five sampling sites within Shoalwater Bay between February 2004 and January 2006. ZC = *Zostera capricorni*; HO = *Halophila ovalis*; HU = *Halodule uninervis*; CS = *Cymodocea serrulata*.

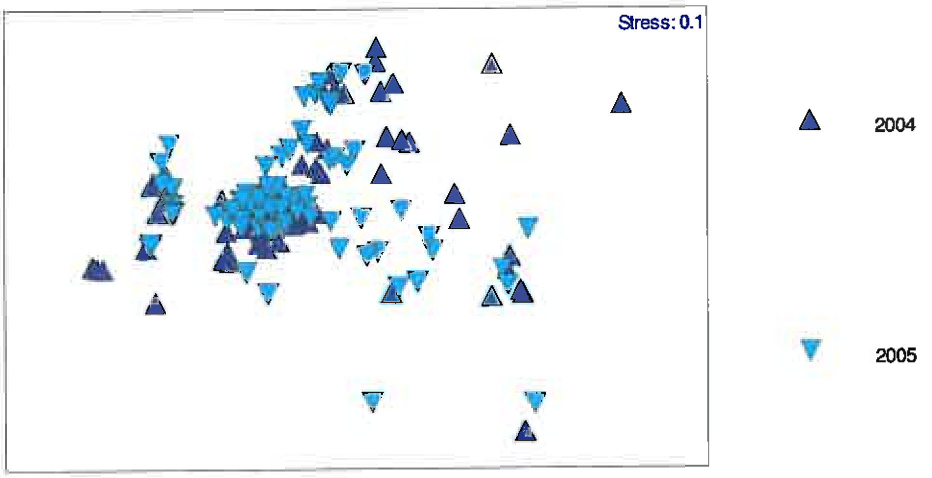


Figure 10a: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities for seagrass composition by year. Analysis of Similarities sample statistic (R) = 0.004, p = 0.225.

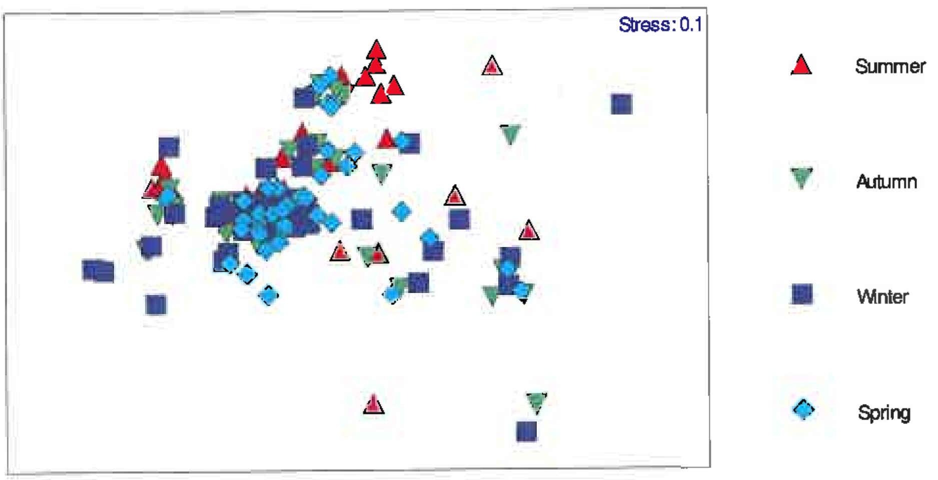


Figure 10b: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities for seagrass composition by season. Analysis of Similarities sample statistic (R) = 0.01, p = 0.104.

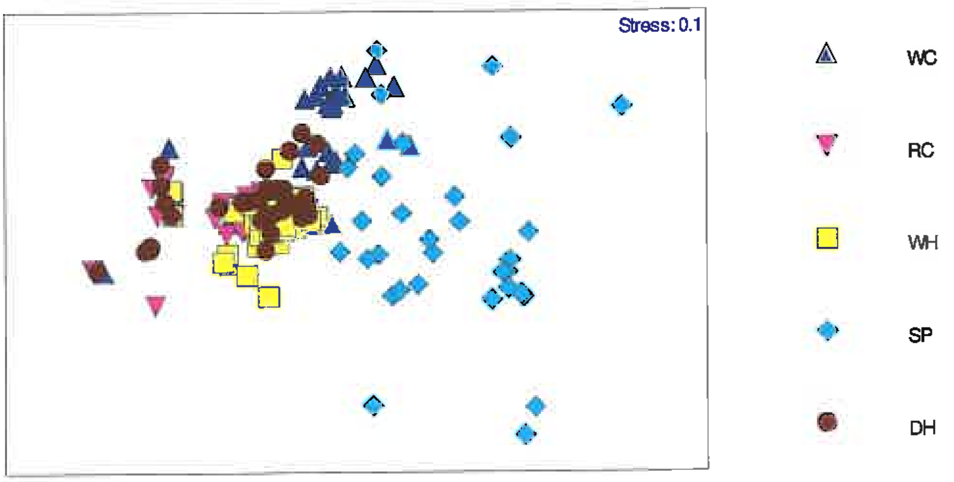


Figure 10c: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities for seagrass composition by site. Analysis of Similarities sample statistic (R) = 0.36, $p < 0.01$. WC = Windmill Creek; RC = Ross Creek; WH = Whelans Hut; SP = Sabina Point; and DH = Duck Hole Creek.

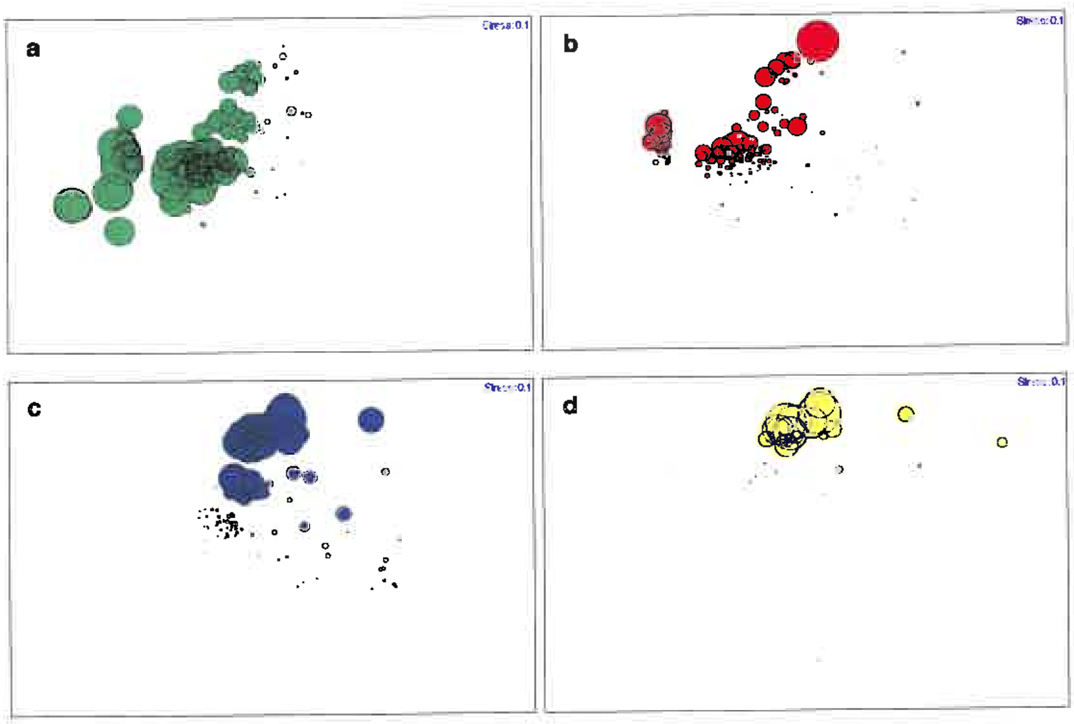


Figure 11: Plot of species abundance superimposed on a non-metric Multi Dimensional Scaling (*n*MDS) ordination of Bray-Curtis similarity measures for seagrass at five sites within Shoalwater Bay from February 2004 until January 2006. a) *Zostera capricorni*; b) *Halophila ovalis*; c) *Halodule uninervis*; and d) *Cymodocea serrulata*.

## *Zostera capricorni*

*Zostera capricorni* cover varied over years, seasons and sites as indicated by a significant interaction effect in a three way analysis of variance ($F_{12,4799} = 4.589$, $p < 0.001$, Table 3a). Figure 12 shows seagrass cover divided by year and Figure 13 shows cover divided by season. *Zostera capricorni* had significantly higher mean cover in 2004 as opposed to 2005, except at Windmill Creek ($F_{1,4799} = 11.199$, $p < 0.001$, Table 3a). Seasonal trends indicate that *Zostera capricorni* has slightly more cover during autumn and winter sampling periods, with a decrease again in spring.

In addition to the significant interaction effect, ANOVA shows significant differences for season ($F_{3,4799} = 23.082$, $p < 0.001$, Table 2a) and site ($F_{4,4799} = 395.412$, $p < 0.001$, Table 3a). Tukey's post hoc tests reveal that spring and summer are similar and that winter and autumn are similar in terms of mean seagrass cover (Table 3b, Figure 13). In terms of sites, Sabina Point has a significantly lower mean seagrass cover than all other sites (Table 3c, Figure 9). Windmill Creek and Whelans Hut had similar mean cover, whilst Duck Hole and Ross Creek's were different again (Table 3c, Figure 9). Ross Creek had the highest mean cover of *Zostera. capricorni* (Table 3c).

### 4.2.1 *Halophila ovalis*

*Halophila ovalis* varies differently over years, seasons and sites as indicated by a significant interaction effect in a three way analysis of variance ($F_{12,4799} = 6.755$, $p < 0.001$, Table 4a). *Halophila ovalis* had higher mean cover in 2004 as opposed to 2005 (Figure 12), although this was not significant ($F_{1,4799} = 0.276$, $p = 0.599$, Table 4a). Seasonal trends (Figure 8) suggest that *Halophila ovalis* has slightly less cover during autumn and winter sampling periods, with an increase in spring/summer seasons. Tukey's post hoc tests reveal that spring and summer are similar and that winter, autumn and spring are also similar in terms of mean *Halophila ovalis* cover (Table 4b, Figure 13). Tukey's post hoc tests also reveal that Sabina Point, Whelans Hut and Windmill Creek have similar *Halophila ovalis* cover (Table 4c, Figure 9). Duck Hole Creek is similar to Windmill Creek and Ross Creek, but not to Sabina Point or Whelans Hut. Ross Creek is similar to Duck Hole Creek but not any of the other sites (Table 4c, Figure 9). Ross Creek had the highest mean cover of *Halophila ovalis* (Table 4c).

### 4.2.2 *Halodule uninervis*

As for the other species, *Halodule uninervis* also varies differently over years, seasons and sites as indicated by a significant interaction effect in a three way analysis of variance

Table 3a: Analysis of Variance table for the proportion of *Zostera capricorni* cover (%) at five sites within Shoalwater Bay. Each site was sampled on 8 occasions over 2 years between February 2004 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2$ = 0.279.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | .144 | 1 | 0.144 | 11.199 | 0.001 |
| Season | .892 | 3 | 0.297 | 23.082 | <0.001 |
| Site | 20.382 | 4 | 5.096 | 395.412 | <0.001 |
| Year * Season | .181 | 3 | 0.060 | 4.669 | 0.003 |
| Year * Site | .401 | 4 | 0.100 | 7.780 | <0.001 |
| Season * Site | 1.079 | 12 | 0.090 | 6.976 | <0.001 |
| Year * Season * Site | .710 | 12 | 0.059 | 4.589 | <0.001 |
| Error | 61.340 | 4760 | 0.013 | | |
| Total | 162.195 | 4799 | | | |

Table 3b: Tukey's post hoc multiple comparison test for observed differences in *Zostera capricorni* cover (%) between seasons at five sites within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Season | N | 1 | 2 |
| Spring | 1200 | 0.1120 | |
| Summer | 1200 | 0.1143 | |
| Winter | 1200 | | 0.1388 |
| Autumn | 1200 | | 0.1418 |
| Signif. | | 0.9580 | 0.9140 |

Table 3c: Tukey's post hoc multiple comparison test for observed differences in *Zostera capricorni* cover (%) between sites over 2 years within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | | |
|---|---|---|---|---|---|
| Site | N | 1 | 2 | 3 | 4 |
| Sabina Point | 960 | 0.0091 | | | |
| Windmill Creek | 960 | | 0.1279 | | |
| Whelans Hut | 960 | | 0.1330 | | |
| Duck Hole Creek | 960 | | | 0.1565 | |
| Ross Creek | 960 | | | | 0.2071 |
| Signif. | | 1.000 | 0.863 | 1.000 | 1.000 |

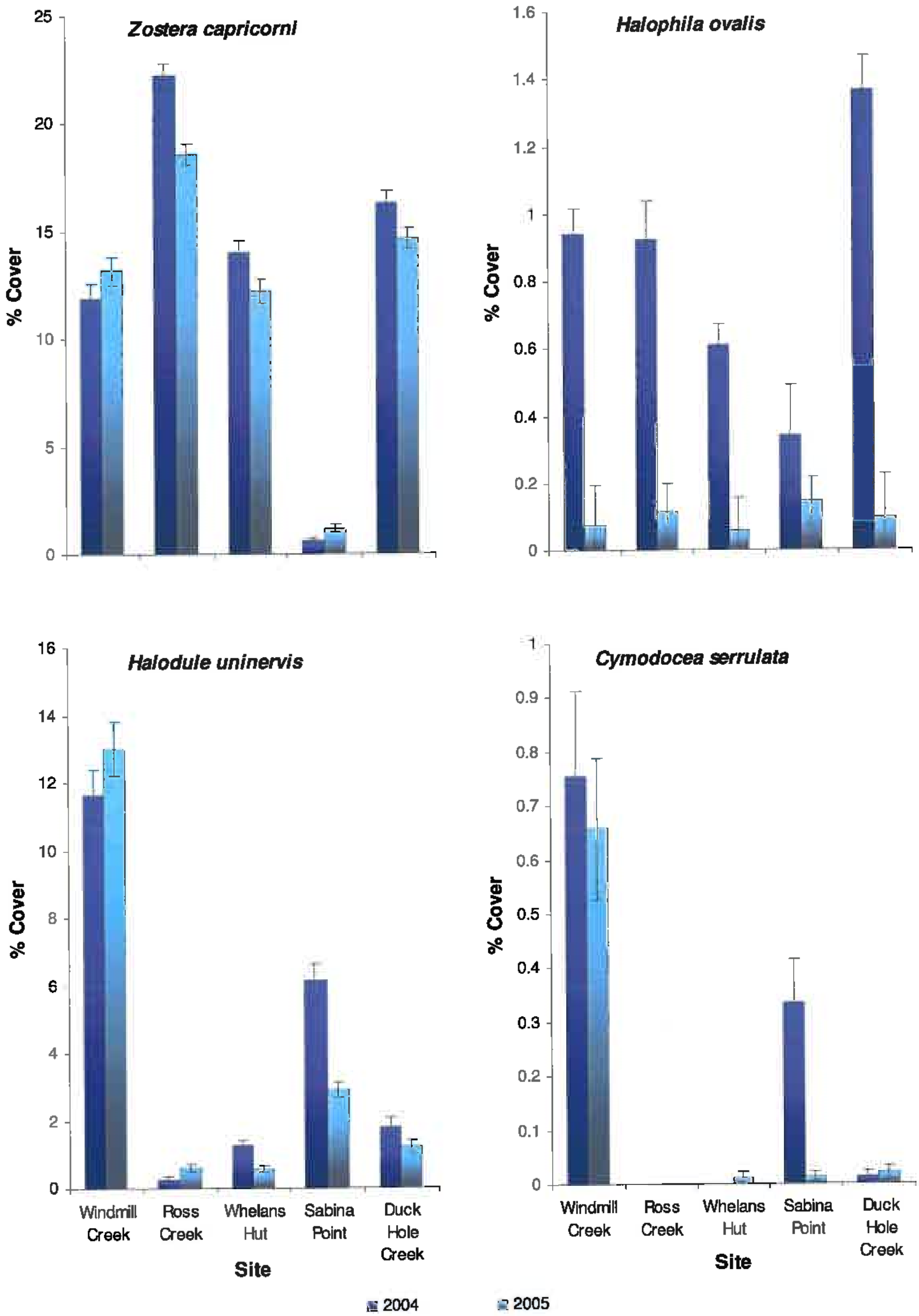


Figure 12: Mean seagrass cover (±SE) for the four species of seagrass in 2004 and 2005 at each of the five sampling sites within Shoalwater Bay. Note the different y-axis scales on each graph. n = 480 per site per year.

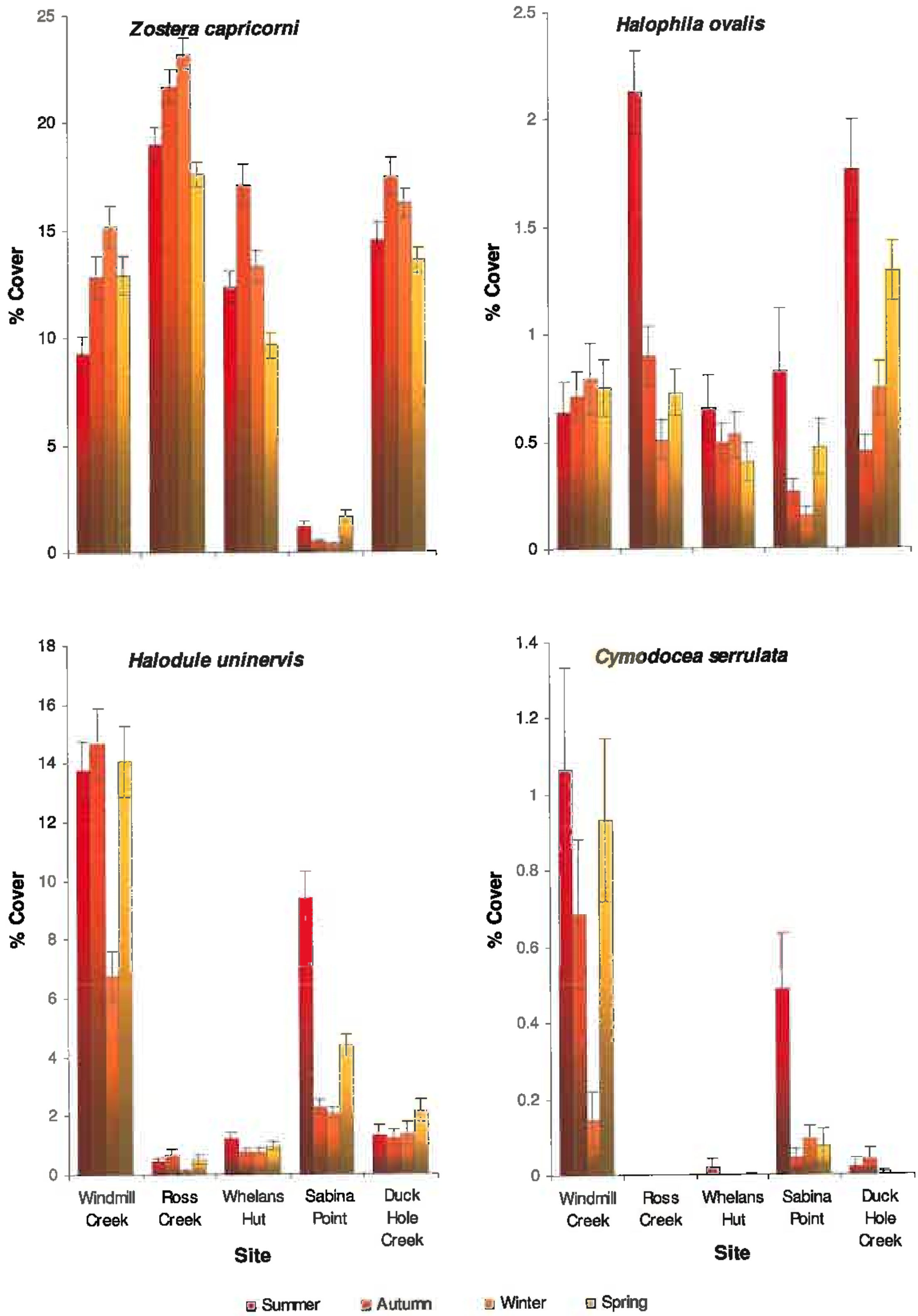


Figure 13: Mean seagrass cover (±SE) of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. Data is only available from 2004 and 2005. Note the different y-axis scales on each graph. n = 240 per site per season.

Table 4a: Analysis of Variance table for the proportion of *Halophila ovalis* cover at five sites within Shoalwater Bay. Each site was sampled on 8 occasions over 2 years between February 2004 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2 = 0.065$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | <0.001 | 1 | <0.001 | 0.276 | 0.599 |
| Season | 0.013 | 3 | 0.004 | 10.332 | <0.001 |
| Site | 0.028 | 4 | 0.007 | 16.572 | <0.001 |
| Year * Season | 0.015 | 3 | 0.005 | 12.071 | <0.001 |
| Year * Site | 0.008 | 4 | 0.002 | 4.763 | 0.001 |
| Season * Site | 0.040 | 12 | 0.003 | 7.900 | <0.001 |
| Year * Season * Site | 0.034 | 12 | 0.003 | 6.755 | <0.001 |
| Error | 2.024 | 4760 | <0.001 | | |
| Total | 2.164 | 4799 | | | |

Table 4b: Tukey's post hoc multiple comparison test for observed differences in *Halophila ovalis* cover between seasons at five sites within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Season | N | 1 | 2 |
| Winter | 1200 | 0.0055 | |
| Autumn | 1200 | 0.0056 | |
| Spring | 1200 | 0.0073 | 0.0073 |
| Summer | 1200 | | 0.0096 |
| Signif. | | 0.1380 | 0.0320 |

Table 4c: Tukey's post hoc multiple comparison test for observed differences in *Halophila ovalis* cover between sites over 2 years within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | |
|---|---|---|---|---|
| Site | N | 1 | 2 | 3 |
| Sabina Point | 960 | 0.0042 | | |
| Whelans Hut | 960 | 0.0045 | | |
| Windmill Creek | 960 | 0.0073 | 0.0073 | |
| Duck Hole Creek | 960 | | 0.0084 | 0.0084 |
| Ross Creek | 960 | | | 0.0107 |
| Signif. | | 0.011 | 0.7670 | 0.1030 |

($F_{12,4799}$ = 13.554, $p < 0.001$, Table 5a). *Halodule uninervis* composition was similar between years at most sites, but varied considerably between sites (Figure 12). Seasonal trends suggest that *Halodule uninervis* has slightly less cover during autumn and winter sampling periods, with an increase in spring/summer seasons (Figure 13). However, levels were too low at many sites for any real trends to become evident (Figure 13), although there were significant differences for season ($F_{3,4799}$ = 22.113, $p < 0.001$, Table 5a) and site ($F_{4,4799}$ = 319.315, $p < 0.001$, Table 5a). Tukey's post hoc tests reveal that autumn, spring and summer are similar in cover, while winter is significantly lower (Table 5b, Figure 13). Tukey's post hoc tests also reveal that Ross Creek, Whelans Hut and Duck Hole Creek have similar *Halodule uninervis* cover (Table 5c, Figure 9). Sabina Point has more cover than all sites except Windmill Creek, which has considerably more *Halodule uninervis* than all other sites (Table 5c, Figure 9).

### *4.2.3 Cymodocea serrulata*

*Cymodocea serrulata* shows no significant year, season or site interaction ($F_{12,4799}$ = 1.694, $p = 0.062$, Table 6a), but a significant interaction is found between season ($F_{3,4799}$ = 6.262, $p < 0.001$, Table 6a) and site (($F_{4,4799}$ = 39.085, $p < 0.001$, Table 6a) suggesting that cover of *Cymodocea serrulata* varied over different seasons and sites, but less so over years. Cover was similar over years at each site (Figure 12) except Sabina Point. However, it should be noted that occurrences of *Cymodocea serrulata* were very low so any interpretation of results needs to be treated with caution. Again a significant difference was found between seasons with autumn, spring and summer showing the highest levels of *Cymodocea serrulata* cover (Table 6b, Figure 13). Autumn and spring were also similar to the winter levels (Table 6b). Windmill Creek had the highest level of *Cymodocea serrulata* cover (Table 6c, Figure 9) but generally the levels were so low that further comparable statistics are not appropriate.

## *4.3 Seagrass Biomass*

Biomass data were obtained from 1600 core samples collected between February 2002 and December 2003. The mean biomass varied considerably among sites (Figure 14), with Windmill Creek and Sabina Point having the highest levels. Whelans Hut had the lowest biomass of all the sites sampled (Figure 14). *Zostera capricorni* is the largest contributor at most sites, but *Halodule uninervis* contributes the most at Windmill Creek and Sabina Point (Figure 15). This corresponds to the species composition data reported above.



Centre for Environmental Management, Central Queensland University
PO Box 1319, Gladstone Q4680

Table 5a: Analysis of Variance table for the proportion of *Halodule uninervis* cover at five sites within Shoalwater Bay. Each site was sampled on 8 occasions over 2 years between February 2004 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2$ = 0.273.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 0.060 | 1 | 0.060 | 7.508 | 0.006 |
| Season | 0.530 | 3 | 0.177 | 22.113 | <0.001 |
| Site | 10.196 | 4 | 2.549 | 319.315 | <0.001 |
| Year * Season | 0.496 | 3 | 0.165 | 20.694 | <0.001 |
| Year * Site | 0.357 | 4 | 0.089 | 11.196 | <0.001 |
| Season * Site | 1.324 | 12 | 0.110 | 13.826 | <0.001 |
| Year * Season * Site | 1.298 | 12 | 0.108 | 13.554 | <0.001 |
| Error | 37.997 | 4760 | 0.008 | | |
| Total | 52.258 | 4799 | | | |

Table 5b: Tukey's post hoc multiple comparison test for observed differences in *Halodule uninervis* cover between seasons at five sites within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| Season | N | Subset 1 | Subset 2 |
|---|---|---|---|
| Winter | 1200 | 0.0220 | |
| Autumn | 1200 | | 0.0403 |
| Spring | 1200 | | 0.0453 |
| Summer | 1200 | | 0.0496 |
| Signif. | | 1.000 | 0.0540 |

Table 5c: Tukey's post hoc multiple comparison test for observed differences in *Halodule uninervis* cover between sites over 2 years within Shoalwater Bay. Each site was sampled on 16 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| Site | N | Subset 1 | Subset 2 | Subset 3 |
|---|---|---|---|---|
| Ross Creek | 960 | 0.0044 | | |
| Whelans Hut | 960 | 0.0083 | | |
| Duck Hole Creek | 960 | 0.0126 | | |
| Sabina Point | 960 | | 0.0442 | |
| Windmill Creek | 960 | | | 0.1270 |
| Signif. | | 0.2560 | 1.0000 | 1.0000 |

Table 6a: Analysis of Variance table for the proportion of *Cymodocea serrulata* cover at five sites within Shoalwater Bay. Each site was sampled on 8 occasions over 2 years between February 2004 and January 2006. Analysis is conducted on arcsine transformed data using α = 0.01. $R^2$ = 0.051.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 0.001 | 1 | 0.001 | 3.676 | 0.055 |
| Season | 0.004 | 3 | 0.001 | 6.262 | <0.001 |
| Site | 0.036 | 4 | 0.009 | 39.085 | <0.001 |
| Year * Season | 0.001 | 3 | <0.001 | 0.869 | 0.456 |
| Year * Site | 0.002 | 4 | <0.001 | 2.071 | 0.082 |
| Season * Site | 0.011 | 12 | 0.001 | 3.950 | <0.001 |
| Year * Season * Site | 0.005 | 12 | <0.001 | 1.694 | 0.062 |
| Error | 1.088 | 4760 | <0.001 | | |
| Total | 1.147 | 4799 | | | |

Table 6b: Tukey's post hoc multiple comparison test for observed differences in *Cymodocea serrulata* cover between seasons at five sites within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Season | N | 1 | 2 |
| Winter | 1200 | 0.0005 | |
| Autumn | 1200 | 0.0015 | 0.0015 |
| Spring | 1200 | 0.0020 | 0.0020 |
| Summer | 1200 | | 0.0031 |
| Signif. | | 0.0680 | 0.0500 |

Table 6c: Tukey's post hoc multiple comparison test for observed differences in *Cymodocea serrulata* cover between sites over 2 years within Shoalwater Bay. Each site was sampled on 8 occasions between February 2004 and January 2006. α = 0.01. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Site | N | 1 | 2 |
| Ross Creek | 960 | <0.0001 | |
| Whelans Hut | 960 | <0.0001 | |
| Duck Hole Creek | 960 | 0.0001 | |
| Sabina Point | 960 | 0.0017 | |
| Windmill Creek | 960 | | 0.0071 |
| Signif. | | 0.0850 | 1.0000 |

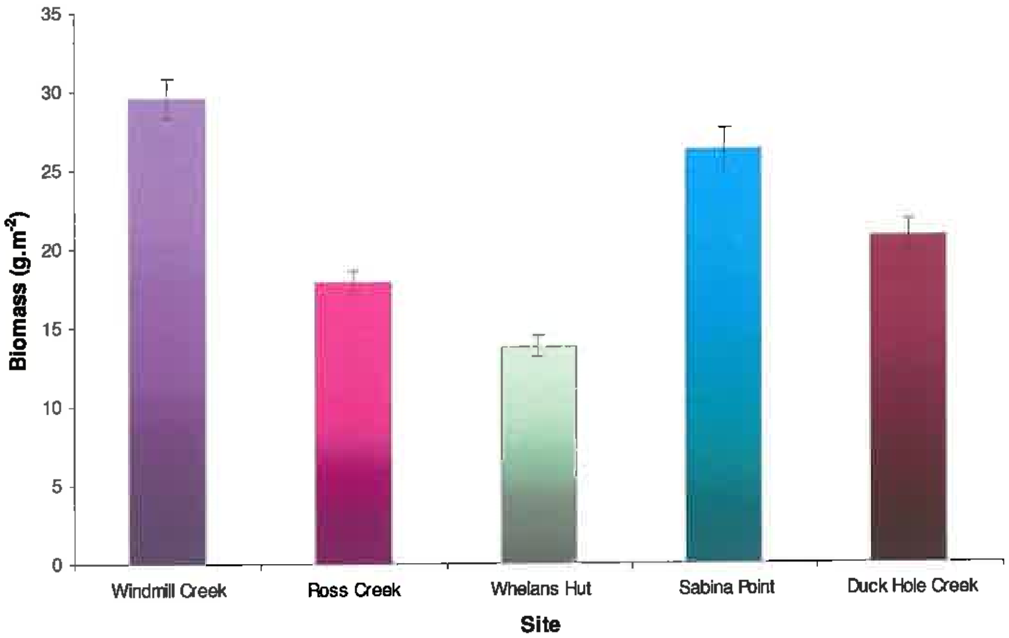


Figure 14: Mean seagrass biomass (±SE) between February 2002 and December 2003 at each of five sites within Shoalwater Bay. n = 320 per site.

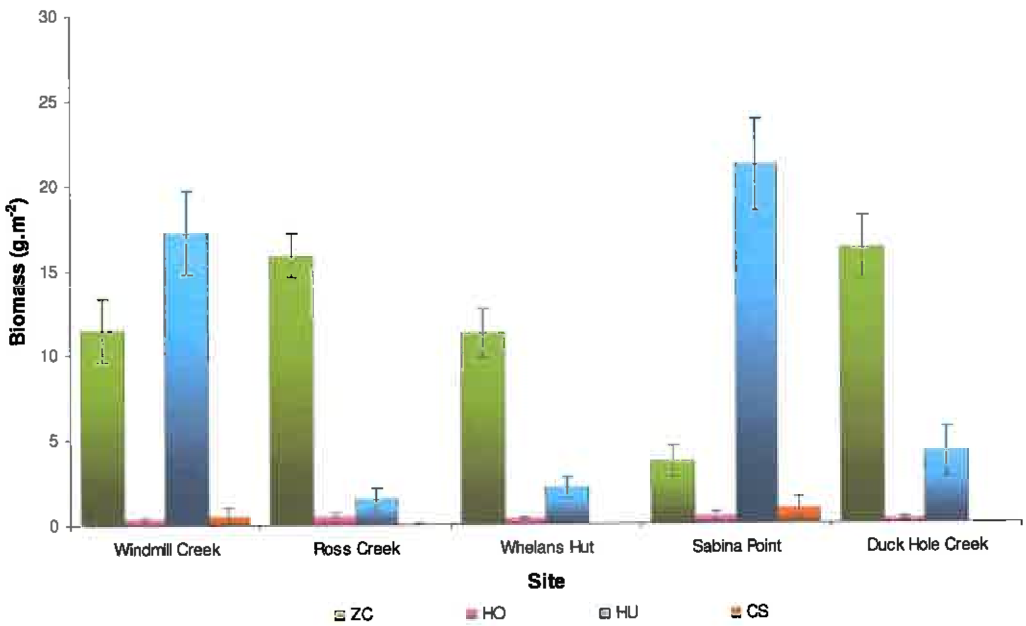


Figure 15: Mean seagrass biomass (±SE) at the five sampling sites within Shoalwater Bay between February 2002 and December 2003. ZC = Zostera capricorni; HO = Halophila ovalis; HU = Halodule uninervis; CS = Cymodocea serrulata. n = 320 per site.

Analysis of variance for the overall biomass indicates that seagrass biomass varied significantly over years ($F_{1,1599} = 8.093$, $p = 0.005$, Table 7a), seasons ($F_{3,1599} = 9.219$, $p < 0.001$, Table 7a) and sites ($F_{4,1599} = 40.175$, $p < 0.001$, Table 7a) with a significant interaction also between these factors ($F_{12,1599} = 4.078$, $p < 0.001$, Table 7a). Within each site the biomass is reasonably consistent (Figure 16), although in some cases the error bars are large indicating a high degree of variation. Post hoc tests for season indicate that overall biomass is greatest in winter and spring, with autumn having the lowest biomass (Table 7b, Figure 17). Sabina Point and Windmill Creek had the highest overall biomass, while Whelans Hut and Ross Creek had the lowest (Table 7c, Figure 14).

Temporal distributions of seagrass community structure based on biomass showed a significant difference between years (Analysis of Similarity (ANOSIM): R-statistic = 0.055, p = 0.003). Ordination plots based on the non-metric multidimensional scaling (*n*MDS) of similarities in community type (i.e. how similar each transect is to one another based on biomass) show similar distribution patterns for both 2002 and 2003 (Figure 18a). An even spread of samples is also observed when the same ordination is divided by season (Figure 18b). The corresponding ANOSIM shows no significant differences in community composition between seasons (R-statistic = 0.012, p = 0.094). However, an ANOSIM based on site shows a significant difference between community composition (R-statistic = 0.199, p < 0.001). The *n*MDS ordination plot for site (Figure 18c) shows that both Sabina Point and Windmill Creek sites separate out from the other sites. Pairwise tests show no significant differences between Windmill Creek and Sabina Point (R-statistic = -0.007, p = 0.545) indicating that the two sites are very similar in community structure based on biomass. No significant differences were found between Whelans Hut and Duck Hole Creek (R-statistic = 0.071, p = 0.017) or Ross Creek and Duck Hole Creek (R-statistic = 0.011, p = 0.202) suggesting that the three sites are very similar in community composition.

When the ordination plots are divided by species (Figure 19) it is evident that Sabina Point and Windmill Creek are characterised by greater biomass of *Halodule uninervis* and *Cymodocea serrulata*. The remaining three sites are dominated by *Zostera capricorni*, while *Halophila ovalis* is more cosmopolitan and appears at most sites, at least to some extent.

Table 7a: Analysis of Variance table for the above ground biomass of seagrass collected at five sites within Shoalwater Bay. Each site was sampled on 8 occasions over 2 years between February 2002 and December 2003. Analysis is conducted using fourth root transformed data and $\alpha = 0.01$. $R^2 = 0.170$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 0.159 | 1 | 0.159 | 8.093 | 0.005 |
| Season | 0.545 | 3 | 0.182 | 9.219 | <0.001 |
| Site | 3.165 | 4 | 0.791 | 40.175 | <0.001 |
| Year * Season | 0.337 | 3 | 0.112 | 5.710 | 0.001 |
| Year * Site | 0.403 | 4 | 0.101 | 5.118 | <0.001 |
| Season * Site | 0.718 | 12 | 0.060 | 3.037 | <0.001 |
| Year * Season * Site | 0.964 | 12 | 0.080 | 4.078 | <0.001 |
| Error | 30.727 | 1560 | 0.020 | | |
| Total | 37.019 | 1599 | | | |

Table 7b: Tukey's post hoc multiple comparison test for observed differences in above ground biomass between seasons at five sites within Shoalwater Bay. Each site was sampled on 8 occasions between February 2002 and December 2003. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Season | N | 1 | 2 |
| Autumn | 400 | 0.1409 | |
| Summer | 400 | 0.1681 | 0.1681 |
| Spring | 400 | | 0.1826 |
| Winter | 400 | | 0.1888 |
| Signif. | | 0.032 | 0.156 |

Table 7c: Tukey's post hoc multiple comparison test for observed differences in above ground biomass between sites over two years within Shoalwater Bay. Each site was sampled on 8 occasions between February 2002 and December 2003. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | |
|---|---|---|---|---|
| Site | N | 1 | 2 | 3 |
| Whelans Hut | 320 | 0.1083 | | |
| Ross Creek | 320 | 0.1410 | 0.1410 | |
| Duck Hole Creek | 320 | | 0.1627 | |
| Sabina Point | 320 | | | 0.2064 |
| Windmill Creek | 320 | | | 0.2321 |
| Signif. | | 0.026 | 0.291 | 0.139 |

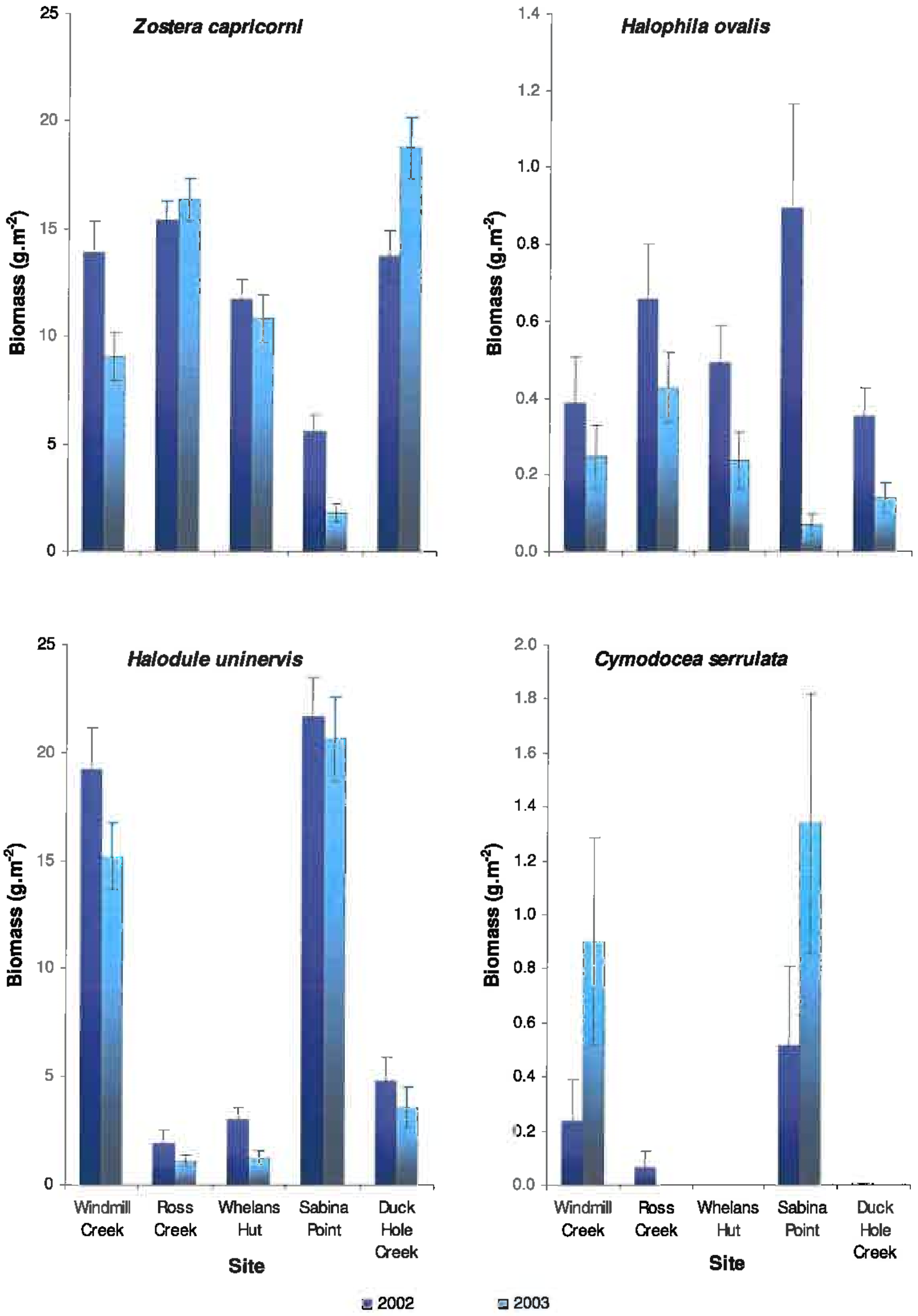


Figure 16: Mean biomass (±SE) of the four seagrass species for 2002 and 2003 at each of five sites within Shoalwater Bay. Data is only available for 2002 and 2003. n = 160 per site per year. Note the difference in y-axis scales.

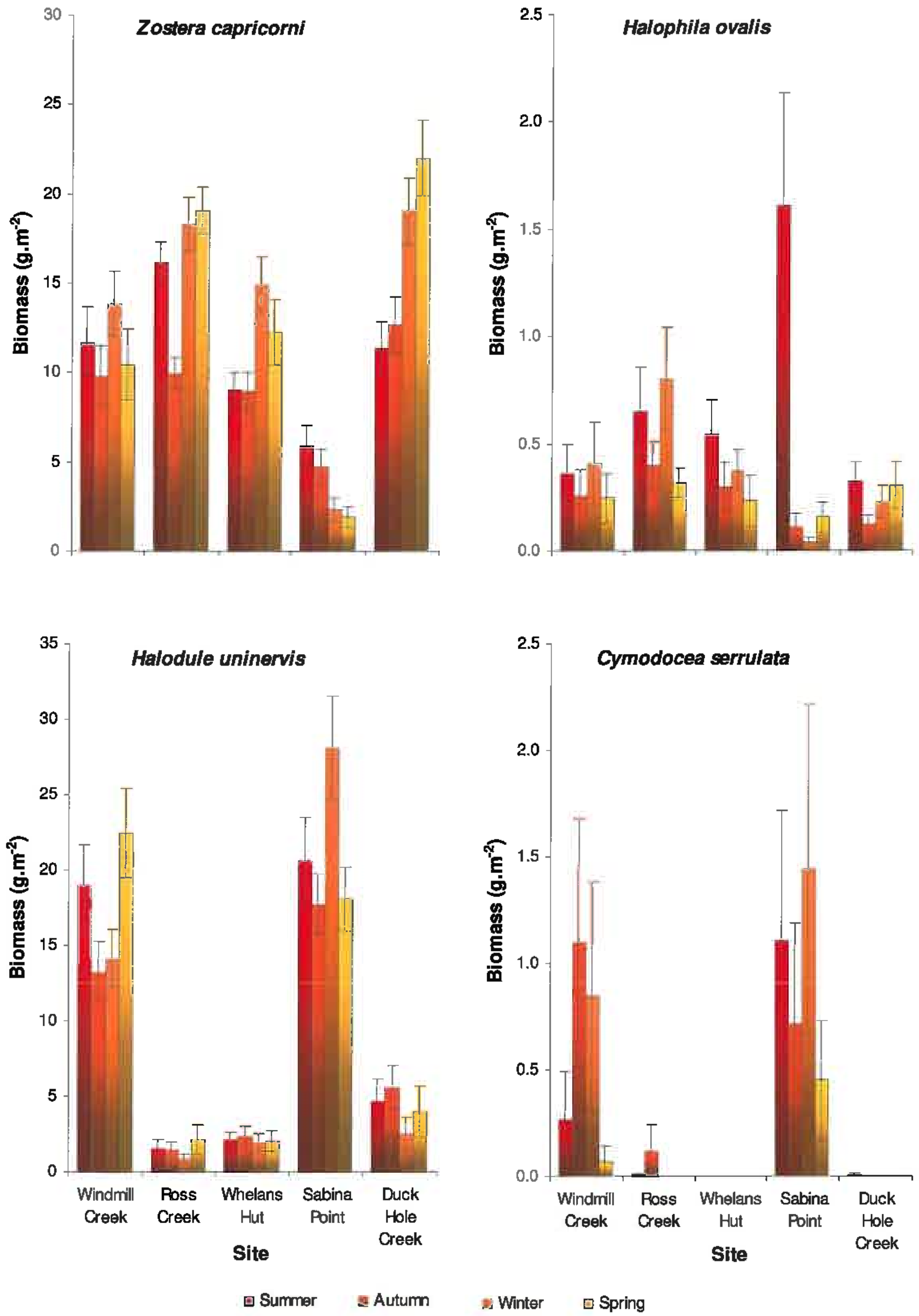


Figure 17: Mean seagrass biomass (±SE) of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. Data is only available from 2002 and 2003. Note the different y-axis scales on each graph. n = 80 per site per season.

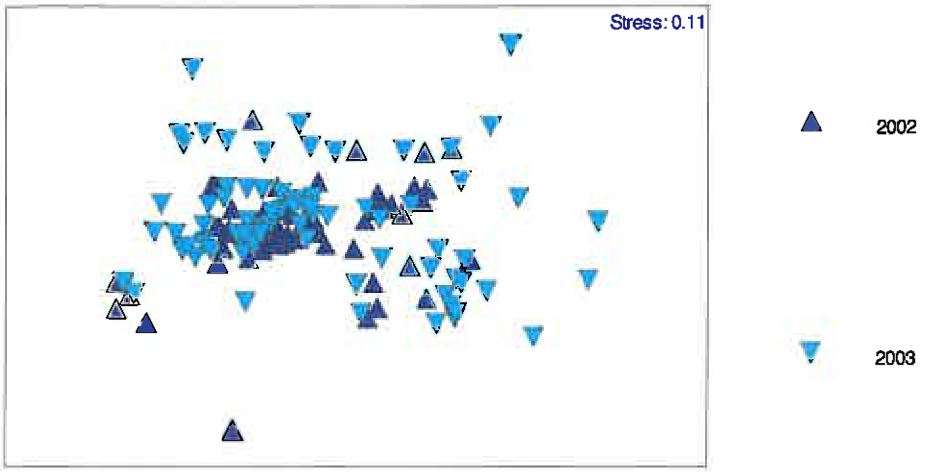


Figure 18a: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of above ground biomass by year. Analysis of Similarities sample statistic (R) = 0.055, p = 0.003.

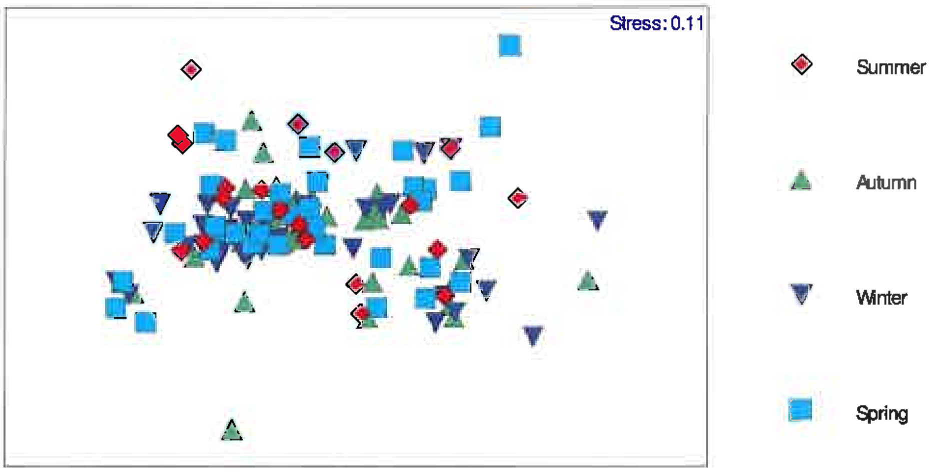


Figure 18b: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of above ground biomass by season. Analysis of Similarities sample statistic (R) = 0.012, p = 0.094.

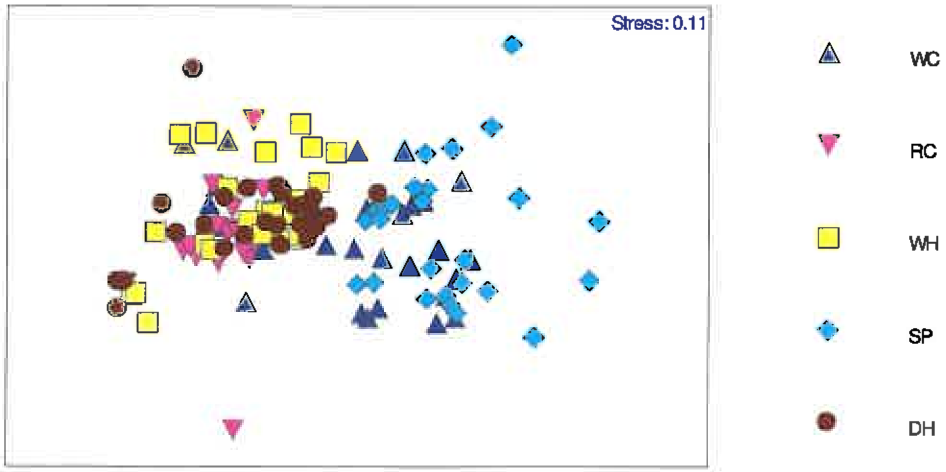


Figure 18c: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of above ground biomass by site. Analysis of Similarities sample statistic (R) = 0.199, p = 0.001. WC = Windmill Creek; RC = Ross Creek; WH = Whelans Hut; SP = Sabina Point; and DH = Duck Hole Creek.

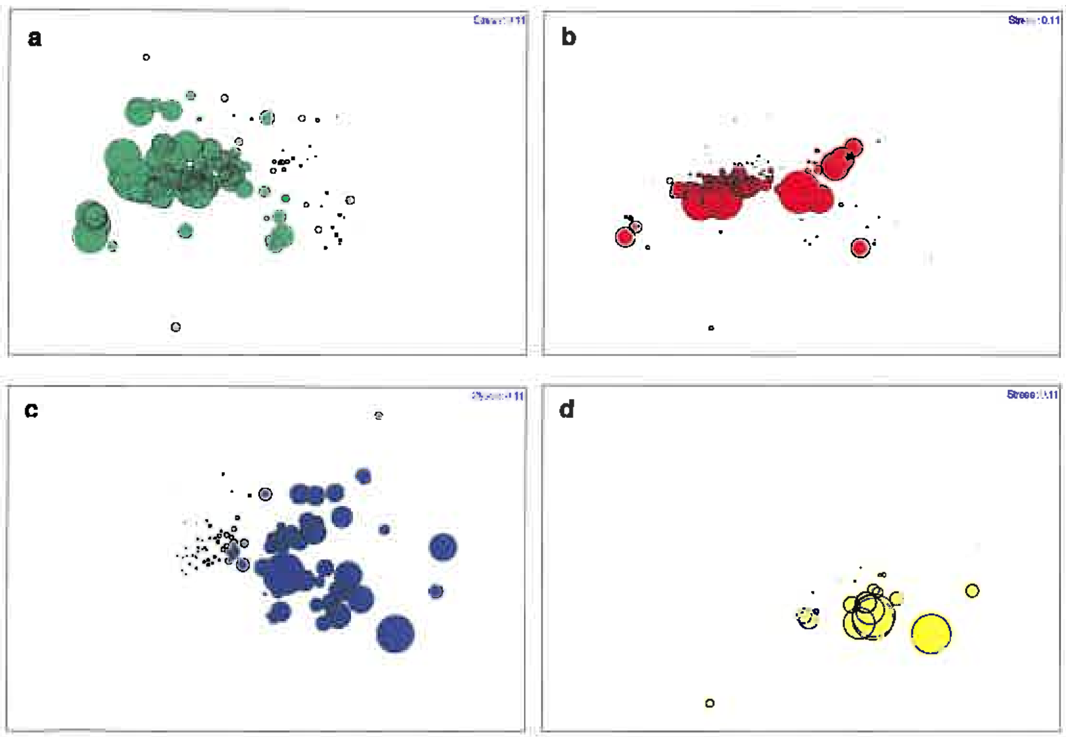


Figure 19: Plots of seagrass biomass superimposed on a non-metric Multi Dimensional Scaling (*n*MDS) ordination of Bray-Curtis similarity measures for seagrass at five sites within Shoalwater Bay from February 2002 until December 2003. a) *Zostera capricorni*; b) *Halophila ovalis*; c) *Halodule uninervis*; and d) *Cymodocea serrulata*.

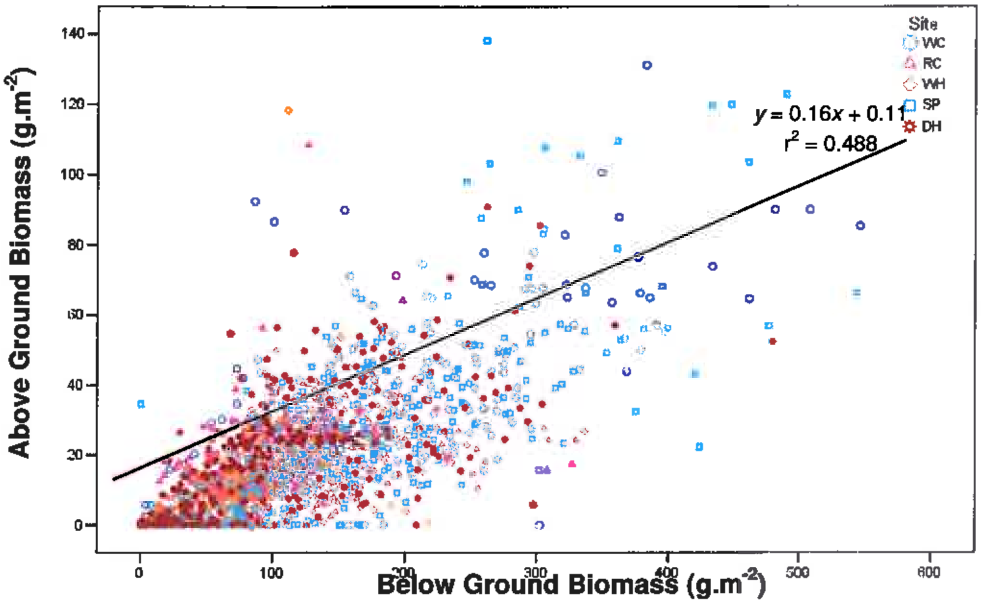


Figure 20: Relationship between above and below ground biomass at all sites within Shoalwater Bay. Samples were collected using a 10cm diameter core sampling device from February 2002 until December 2003. WC = Windmill Creek; RC = Ross Creek; WH = Whelans Hut; SP = Sabina Point; and DH = Duck Hole Creek.

### 4.3.1 Above versus Below Ground Biomass

Although only the above ground biomass was used in analyses due to the difficulty of separating below ground biomass into species, both were found to be significantly correlated ($r^2$ = 0.487, p <0.001, Figure 20). Thus indicating that as below ground biomass increases the above ground biomass also increases. However, it should also be noted that below ground biomass may be present without any above ground biomass, as indicated in Figure 20.

### 4.3.2 Nutritional quality of seagrass

Nutritional data were obtained from 114 samples, which were subsequently separated into above and below ground biomass components and analysed. The above ground biomass nitrogen content (ANL) of seagrass samples (Figure 21) varied significantly among seagrass species ($F_{3,114}$ = 5.864, p = 0.002, Table 8a), with the above ground biomass nitrogen content of *Halophila ovalis* being greater than compared with *Halodule uninervis* and *Zostera capricorni*, with *Cymodocea serrulata* recording the lowest above ground biomass nitrogen content of all species examined (Table 8b). However, there were no significant differences in above ground biomass nitrogen content with respect to season ($F_{3,114}$ = 0.952, p = 0.423, Table 8a) or site ($F_{4,114}$ = 1.718, p = 0.162, Table 8a), although the sample sizes available for the analyses were very small. Similarly, the below ground biomass nitrogen content (ANL) of seagrass samples (Figure 22) also varied significantly among seagrass species ($F_{3,114}$ = 3.373, p = 0.025, Table 9a), with the below ground biomass nitrogen content of *Halophila ovalis* being greatest and lowest in *Halodule uninervis* (Table 9b). However, there were no significant differences in below ground biomass nitrogen content with respect to season ($F_{3,114}$ = 0.835, p = 0.481, Table 9a) or site ($F_{4,114}$ = 0.824, p = 0.516, Table 9a), although again the sample sizes used in the analyses were very small and some caution should therefore be used when interpreting these results.

There were no significant differences in the fibre content (NDF) of above ground biomass samples (Figure 23) with respect to season ($F_{3,114}$ = 0.444, p = 0.723, Table 10), species ($F_{3,114}$ = 0.604, p = 0.615, Table 10), or site ($F_{4,114}$ = 0.393, p = 0.813, Table 10). Similarly, the NDF of below ground biomass samples (Figure 24) did not vary significantly with respect to season ($F_{3,114}$ = 2.464, p = 0.072, Table 11), species ($F_{3,114}$ = 2.560, p = 0.065, Table 11), or site ($F_{4,114}$ = 0.116, p = 0.976, Table 11). However, the sample sizes used in these analyses were very small and some caution should be used when interpreting these results.

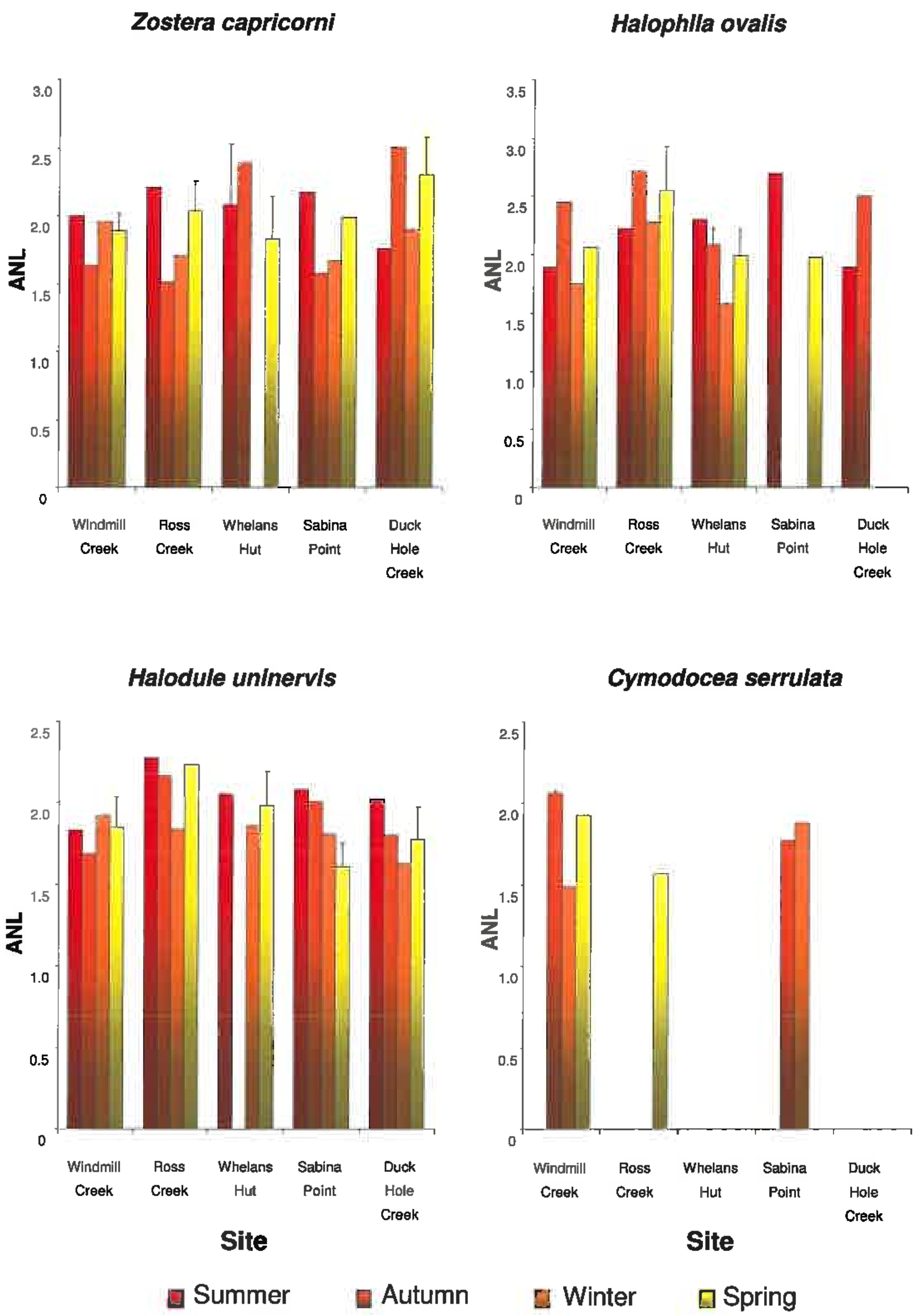


Figure 21: Mean total nitrogen content (±SE) of above ground biomass of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. Note the different y-axis scales on each graph.

Table 8a: Analysis of Variance table for the total nitrogen content (ANL) of above ground biomass of seagrass collected at five sites within Shoalwater Bay. $\alpha = 0.01$. $R^2 = 0.170$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Season | 0.246 | 3 | 0.082 | 0.952 | 0.423 |
| Species | 1.513 | 3 | 0.504 | 5.864 | 0.002 |
| Site | 0.593 | 4 | 0.148 | 1.718 | 0.162 |
| Season * Species | 0.604 | 8 | 0.076 | 0.876 | 0.543 |
| Season * Site | 0.686 | 12 | 0.057 | 0.662 | 0.778 |
| Species * Site | 0.917 | 10 | 0.092 | 1.063 | 0.408 |
| Season * Species * Site | 2.096 | 19 | 0.110 | 1.279 | 0.241 |
| Error | 4.141 | 48 | 0.086 | | |
| Total | 413.562 | 114 | | | |

Table 8b: Tukey's post hoc multiple comparison test for observed differences in the total nitrogen content of above ground biomass between species at five sites within Shoalwater Bay. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | |
|---|---|---|---|---|
| Species | N | 1 | 2 | 3 |
| *Cymodocea serrulata* | 7 | 1.556 | | |
| *Halodule uninervis* | 32 | | 1.865 | |
| *Zostera capricorni* | 47 | | 1.870 | |
| *Halophila ovalis* | 22 | | | 2.252 |
| Signif. | | 1.000 | 1.000 | 1.000 |

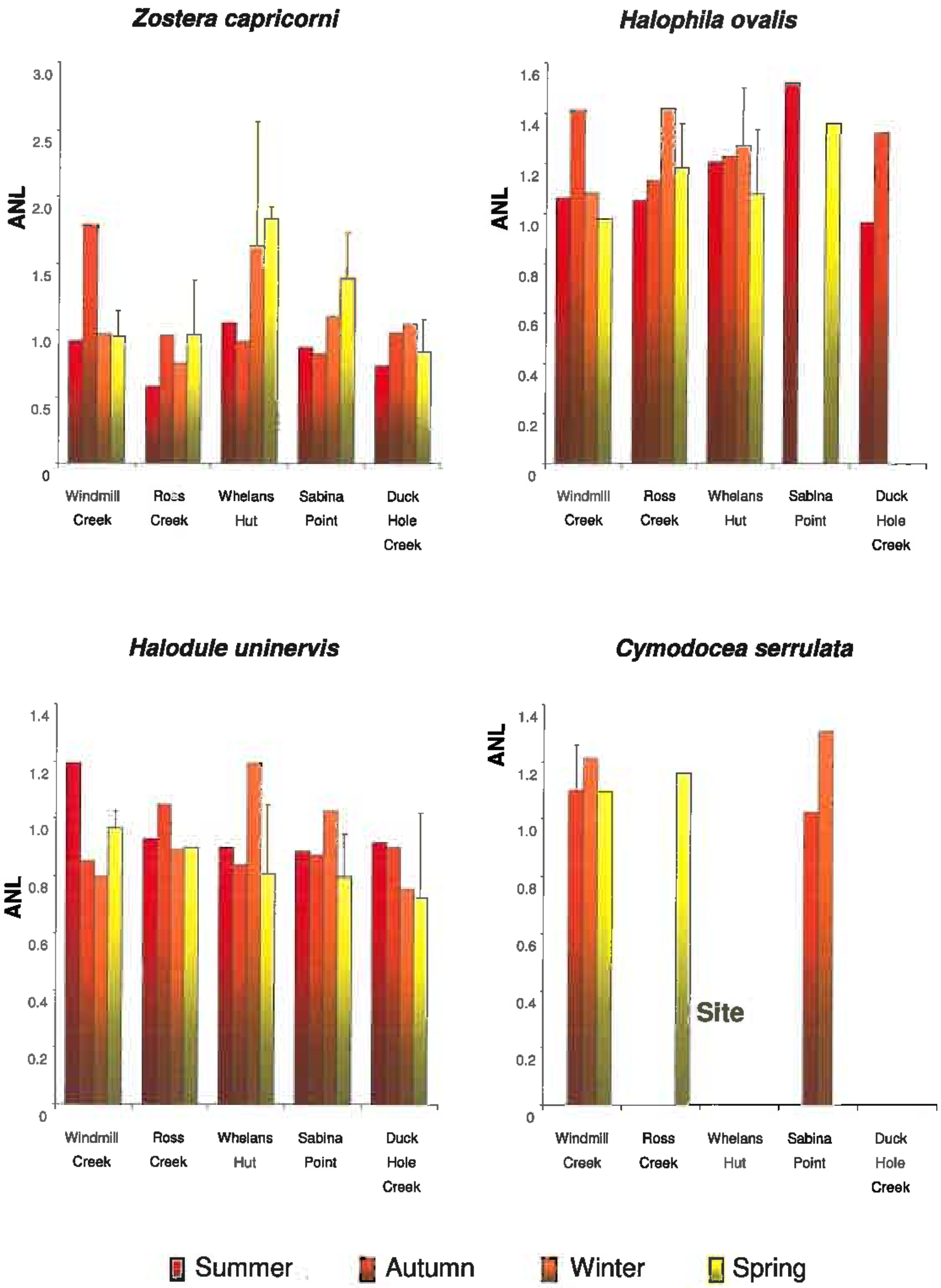


Figure 22: Mean total nitrogen content (±SE) of below ground biomass of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. Note the different y-axis scales on each graph.

Table 9a: Analysis of Variance table for the total nitrogen content (ANL) of below ground biomass of seagrass collected at five sites within Shoalwater Bay. $\alpha = 0.01$. $R^2 = 0.170$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Season | 0.209 | 3 | 0.070 | 0.835 | 0.481 |
| Species | 0.844 | 3 | 0.281 | 3.373 | 0.025 |
| Site | 0.275 | 4 | 0.069 | 0.824 | 0.516 |
| Season * Species | 0.383 | 8 | 0.048 | 0.574 | 0.795 |
| Season * Site | 0.751 | 12 | 0.063 | 0.750 | 0.697 |
| Species * Site | 0.429 | 10 | 0.043 | 0.514 | 0.873 |
| Season * Species * Site | 1.006 | 21 | 0.048 | 0.574 | 0.918 |
| Error | 4.340 | 52 | 0.083 | | |
| Total | 128.408 | 114 | | | |

Table 9b: Tukey's post hoc multiple comparison test for observed differences in the total nitrogen content of below ground biomass between species at five sites within Shoalwater Bay. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| **Species** | **N** | **1** | **2** |
| *Halodule uninervis* | 32 | 0.887 | |
| *Zostera capricorni* | 53 | 1.021 | 1.021 |
| *Cymodocea serrulata* | 7 | 1.143 | 1.143 |
| *Halophila ovalis* | 22 | | 1.183 |
| Signif. | | 0.062 | 0.371 |

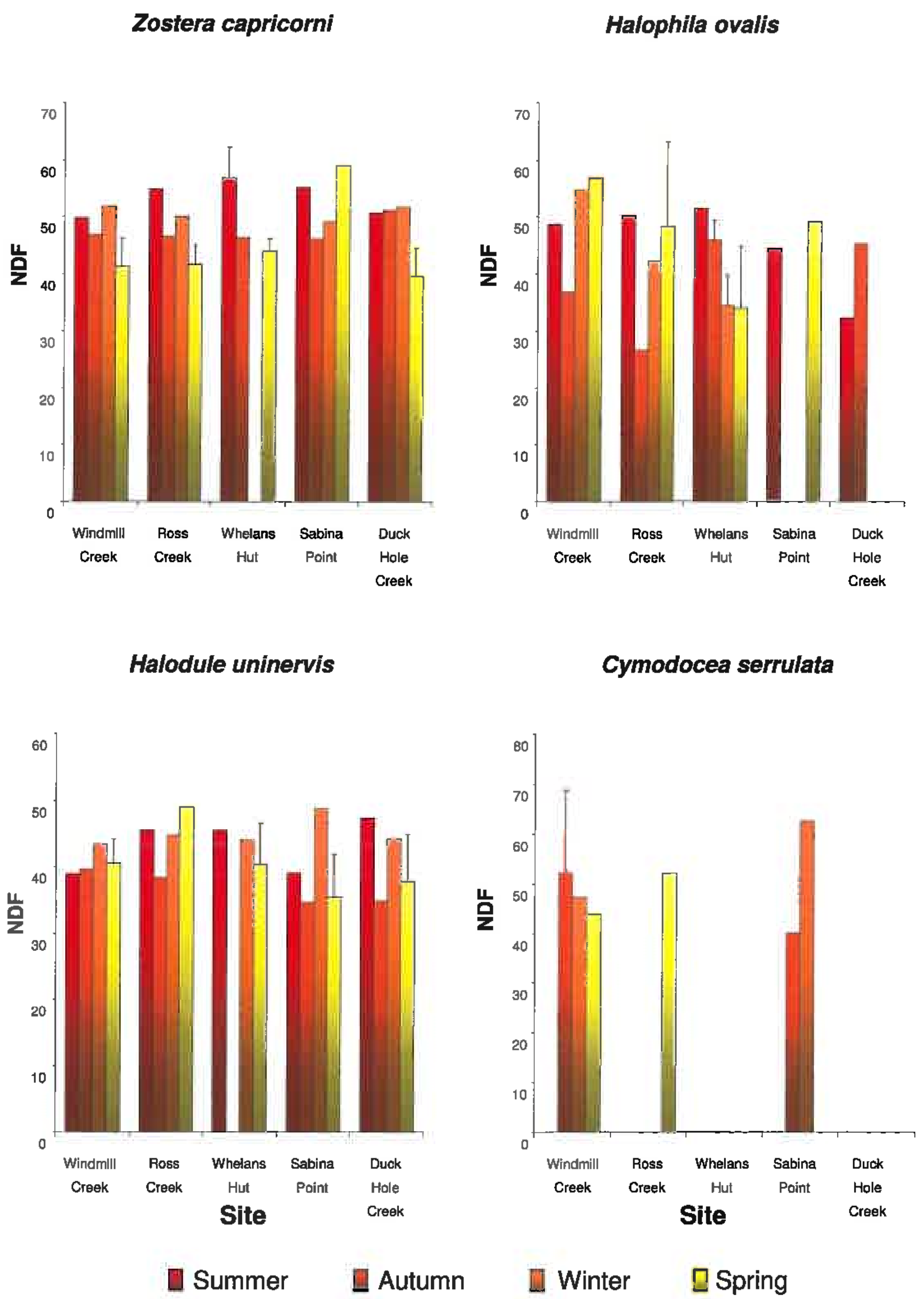


Figure 23: Mean Neutral Dietary Fibre (±SE) of above ground biomass of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. Note the different y-axis scales on each graph.

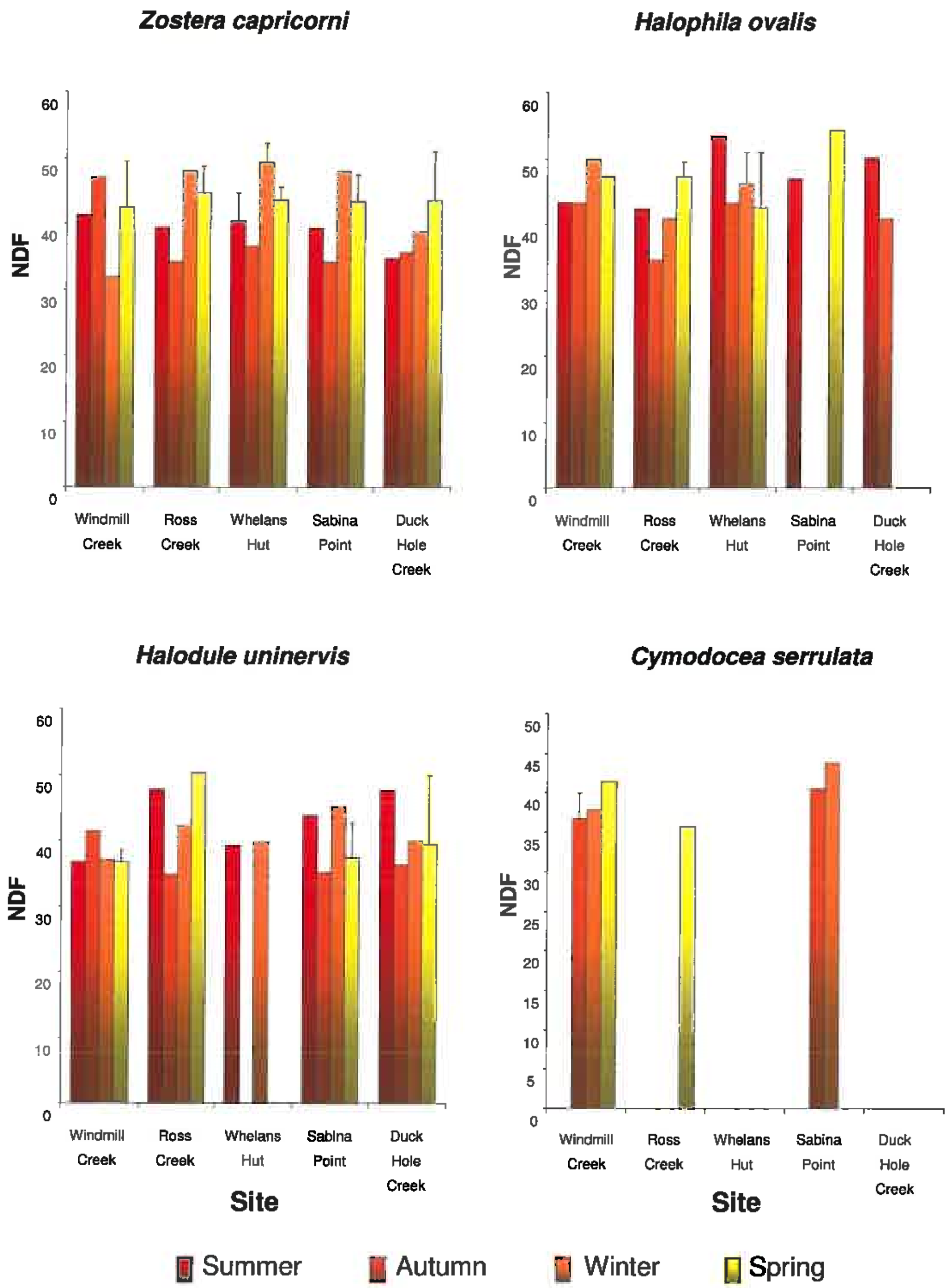


Figure 24: Mean Neutral Dietary Fibre (±SE) of below ground biomass of the four seagrass species for seasons at each of the five sampling sites within Shoalwater Bay. . Note the different y-axis scales on each graph.

Table 10: Analysis of Variance table for the Neutral Dietary Fibre (NDF) of above ground biomass of seagrass collected at five sites within Shoalwater Bay. α = 0.01. $R^2 = 0.170$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Season | 218.111 | 3 | 72.704 | 0.444 | 0.723 |
| Species | 297.055 | 3 | 99.018 | 0.604 | 0.615 |
| Site | 257.316 | 4 | 64.329 | 0.393 | 0.813 |
| Season * Species | 292.233 | 8 | 36.529 | 0.223 | 0.985 |
| Season * Site | 964.315 | 12 | 80.360 | 0.491 | 0.911 |
| Species * Site | 1191.720 | 10 | 119.172 | 0.728 | 0.695 |
| Season * Species * Site | 1263.215 | 19 | 66.485 | 0.406 | 0.983 |
| Error | 8845.319 | 54 | 163.802 | | |
| Total | 211317.422 | 114 | | | |

Table 11: Analysis of Variance table for the Neutral Dietary Fibre (NDF) of below ground biomass of seagrass collected at five sites within Shoalwater Bay. α = 0.01. $R^2 = 0.170$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Season | 364.809 | 3 | 121.603 | 2.464 | 0.072 |
| Species | 379.037 | 3 | 126.346 | 2.560 | 0.065 |
| Site | 22.813 | 4 | 5.703 | 0.116 | 0.976 |
| Season * Species | 195.072 | 8 | 24.384 | 0.494 | 0.855 |
| Season * Site | 342.187 | 12 | 28.516 | 0.578 | 0.850 |
| Species * Site | 312.097 | 10 | 31.210 | 0.632 | 0.780 |
| Season * Species * Site | 758.159 | 20 | 37.908 | 0.768 | 0.737 |
| Error | 2615.917 | 1560 | 49.357 | | |
| Total | 203893.041 | 1599 | | | |

## 4.4 Temperature

The mean daily temperatures recorded at Windmill Creek and Sabina Point are shown in Figure 25. Unfortunately, some loggers were lost, damaged or failed so a complete record of temperature for the area for the duration of the study is not available (Figure 25).

Throughout the year the mean daily temperature at the two sites ranged between 15℃ and 32℃ (Figure 25), with the maximums occurring between December and March and minimums occurring in June/July. However, the range of temperatures is considerably larger, ranging between 8℃ and 47℃. Higher temperatures were recorded in February 2002 (up to 66℃) but were likely to be anomalies as they only occurred on two days.

The temperature differential between the surface and pool loggers was minimal, with all loggers following a similar pattern. The mean daily temperatures fluctuated with the tides, providing somewhat of a buffer in temperatures (Figure 25).

During the course of the seagrass surveys, February 2004 appears to have had the highest mean daily temperatures (31.5℃). However, data recording was only available from mid February, so a continuous record over the summer months is not available.

## 4.5 Rainfall

Rainfall records were collected on a monthly basis by John Stocks at Sabina Point and the Pine Mountain Ranger station (Figure 26). Rainfall fluctuated throughout the sampling period, with the maximum rainfall occurring in February 2003 with between 400 and 500 mm over the month. December 2003, January and February 2004 also had almost 400mm fall between them. January 2005 also had high rainfall levels, with approximately 200mm falling. Both Sabina Point and Pine Mountain follow similar trends in rainfall, suggesting that rainfall is reasonably consistent across the study area.

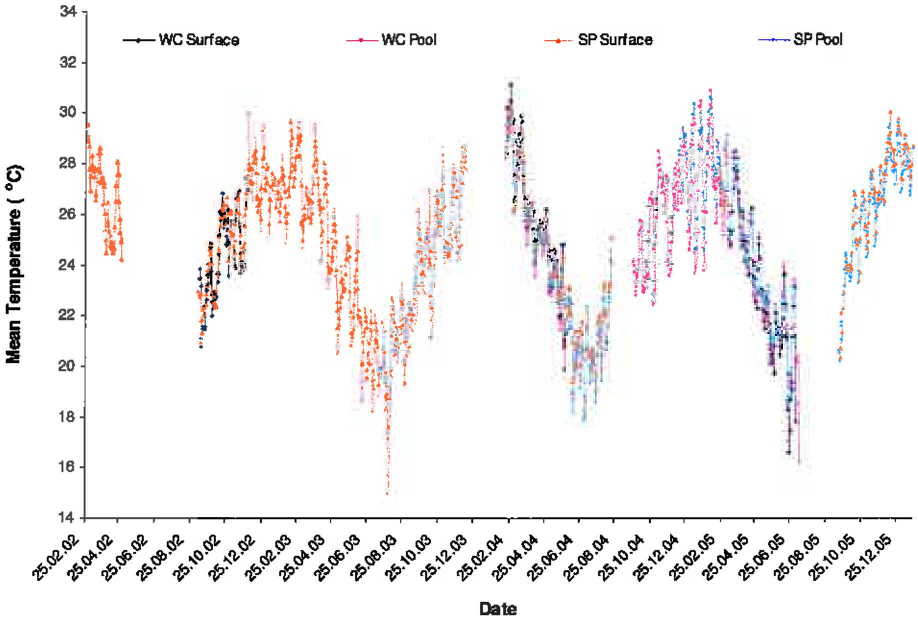


Figure 25: Mean daily temperatures on seagrass meadows at Windmill Creek (WC) and Sabina Point (SP). Temperatures for all locations are displayed on the one chart to provide a more continuous record over time. Temperatures are recorded using i-button® temperature loggers on the surface of the meadow in an area that fully drains at low tide (surface) and within a shallow intertidal pool in a similar location.

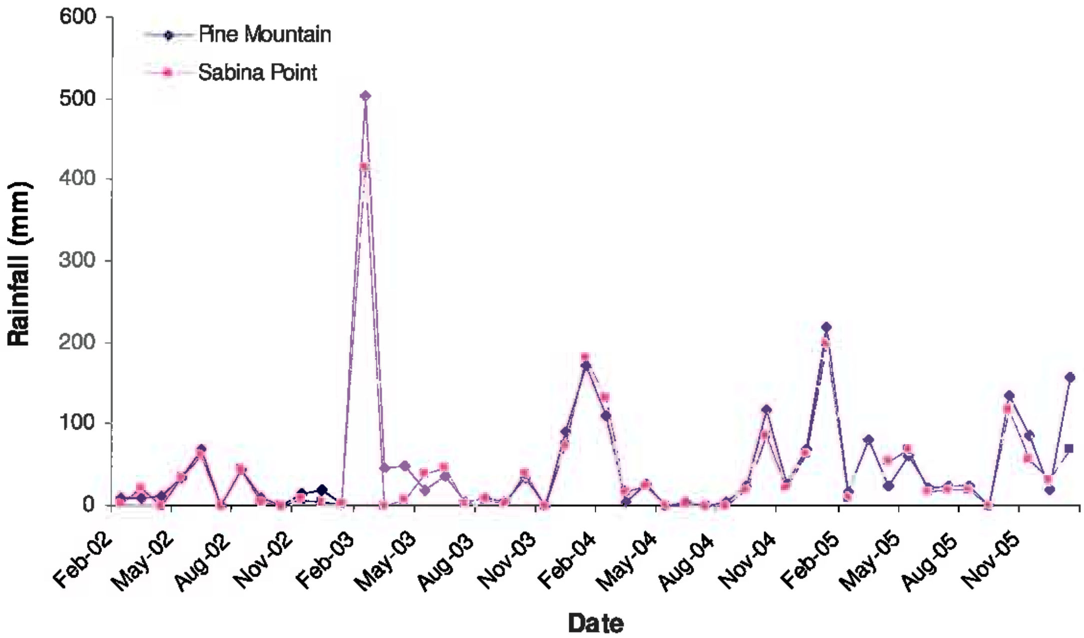


Figure 26: Monthly rainfall (mm) at Pine Mountain and Sabina Point during the seagrass sampling period.

## 4.6 Wind Speed

Wind data for Rundle Island (23°31´45″S; 151°16´35″E) for the period of February 2002 to January 2006 was obtained from the Bureau of Meteorology (Brisbane). Wind was predominantly from the south east throughout the sampling period. Wind speed fluctuated throughout the period but average daily winds speeds were generally between 20 km $hr^{-1}$ and 35 km $hr^{-1}$ (Figure 27). There was some indication of a seasonal pattern in wind speed with stronger winds recorded during Summer and Autumn (i.e. November to April). No cyclone activity was recorded in the area during the study period. The highest monthly wind speeds recorded throughout the sampling period occurred during March 2005. However, during March 2004 increased wind activity was also recorded, including 5 consecutive days where wind speeds from the south east exceeded 50 km $hr^{-1}$ and were within the top 1% of maximum wind speeds recorded throughout the entire study period (Figure 27).

## 4.7 Sediment Composition

Sites within Shoalwater Bay generally consist of mud and sand based sediments (Figure 28a). Mud comprised between 30 and 50% of all sediment types over the whole study area, but was as high as 80% at some sites (i.e. Whelans Hut and Duck Hole Creek, Figure 28d & 28f). Although sediment fractions varied between sampling periods to some extent, most sites retained a relatively consistent mix of sediments (Figure 28). However, Sabina Point showed a very marked difference in sediment type between September 2003 and February 2004 (Figure 28e), with the mud fraction almost disappearing being replaced by sand. Duck Hole Creek, and to a lesser extent Whelans Hut, showed some decline in the mud component (Figure 28f), with a corresponding increase in the sand fraction, although not to the same extent as Sabina Point. The proportion of sand within sediments varied significantly with respect to site ($F_{4,74}$ = 29.441, p <0.001, Table 12a) and year ($F_{3,74}$ = 16.734, p <0.001, Table 8a) and there was also a significant interaction between these factors ($F_{4,74}$ = 4.536, p <0.001, Table 12a). The proportion of sand across all sites increased significantly throughout the study period (Table 12b). Post hoc tests indicate that Sabina Point was significantly different to all other sites (Table 12c). However, the measures of sediment type are qualitative, and need to be treated with some degree of caution.

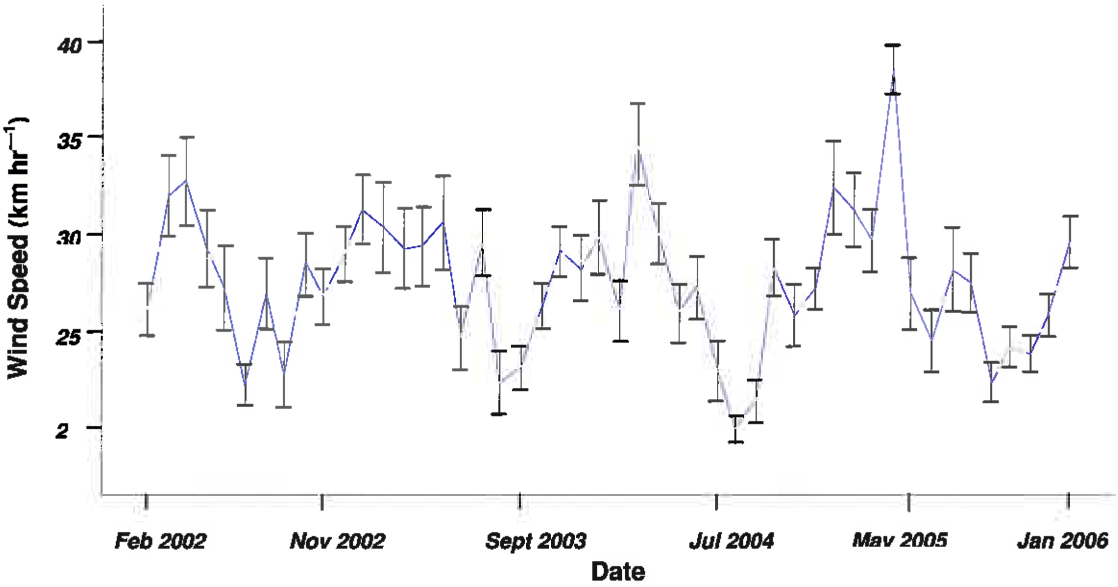


Figure 27: Daily average wind speed (km $hr^{-1}$) from February 2004 until January 2006 for Rundle Island (23°31′45″S; 151°16′35″E). Data were obtained from the Bureau of Meteorology (Brisbane). Error bars indicate ± s.e.

Table 12a: Analysis of Variance table for the proportion of sand within sediments at five sites within Shoalwater Bay. Each site was sampled on 15 occasions between June 2002 and January 2006. Analysis is conducted using arcsine transformed data and $\alpha = 0.01$. $R^2 = 0.253$.

| Source | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Year | 0.599 | 3 | 0.200 | 16.734 | <0.001 |
| Season | 0.004 | 3 | 0.001 | 0.029 | 0.993 |
| Site | 1.406 | 4 | 0.352 | 29.441 | <0.001 |
| Year * Season | 0.176 | 3 | 0.022 | 0.505 | 0.848 |
| Year * Site | 0.650 | 4 | 0.054 | 4.536 | <0.001 |
| Season * Site | 0.133 | 12 | 0.011 | 0.344 | 0.977 |
| Year * Season * Site | 0.281 | 12 | 0.009 | 0.471 | 0.952 |
| Error | 12.171 | 75 | 0.020 | | |
| Total | 16.389 | 74 | | | |

Table 12b: Tukey's post hoc multiple comparison test for observed differences in the proportion of sand within sediments between years at five sites within Shoalwater Bay. Each site was sampled on 15 occasions between June 2002 and January 2006. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | | |
|---|---|---|---|---|
| Year | N | 1 | 2 | 3 |
| 2002 | 15 | 0.2787 | | |
| 2003 | 20 | 0.3702 | 0.3702 | |
| 2004 | 20 | | 0.4521 | 0.4521 |
| 2005 | 20 | | | 0.5275 |
| Signif. | | 0.064 | 0.115 | 0.168 |

Table 12c: Tukey's post hoc multiple comparison test for observed differences in differences in the proportion of sand within sediments between sites over four years within Shoalwater Bay. Each site was sampled on 15 occasions between June 2002 and January 2006. $\alpha = 0.01$. Means for groups in homogeneous subsets are displayed based on Type III Sum of Squares.

| | | Subset | |
|---|---|---|---|
| Site | N | 1 | 2 |
| Duck Hole Creek | 15 | 0.3164 | |
| Ross Creek | 15 | 0.3273 | |
| Whelans Hut | 15 | 0.3665 | |
| Windmill Creek | 15 | 0.3707 | |
| Sabina Point | 15 | | 0.6975 |
| Signif. | | 0.655 | 1.000 |

Temporal distributions of sediment structure were dissimilar between years (Analysis of Similarity (ANOSIM): R-statistic = 0.226, $p < 0.001$). Ordination plots based on the non-metric multidimensional scaling (*n*MDS) of similarities in sediment composition show similar distribution patterns for both 2002 and 2003, however, 2004 and 2005 were significantly dissimilar to other years (Figure 29a). An even spread of samples is observed when the same ordination is divided by season (Figure 29b). The corresponding ANOSIM shows no significant differences in community composition between seasons (R-statistic = -0.047, p = 0.835). However, an ANOSIM based on site shows a significant dissimilarity in sediment composition between sites (R-statistic = 0.382, $p < 0.001$). The *n*MDS ordination plot for site (Figure 29c) shows that Sabina Point separates out from the other sites.

### *4.8 Lyngbya majuscula*

John Stocks, Range Manager stationed at Pine Mountain, recorded *Lyngbya majuscula* blooms wherever possible during the course of this study. John's observations suggest that *Lyngbya* appears after hot, dry weather and disappears after rain. *Lyngbya* is regularly seen from early July to the end of November, disappearing after the storms arrive. Whilst present, *Lyngbya* can become very extensive and cover everything. Blooms were also noted to vary in magnitude from year to year.

Data collected during the course of the seagrass surveys corroborate the observations provided by John. Apart from December 2002, *Lyngbya* was mostly absent during the summer months (Figure 30), a period when rain storms are frequent. During the winter months *Lyngbya* was more common, particularly from July to September (Figure 30). At some sites almost 90% of surveyed quadrats had *Lyngbya* present (e.g. Ross Creek, Whelans Hut, Figure 30) and this generally occurred in winter. However, due to the subjective nature of the data collection during the seagrass surveys it is difficult to determine the level of blooms and overall cover.

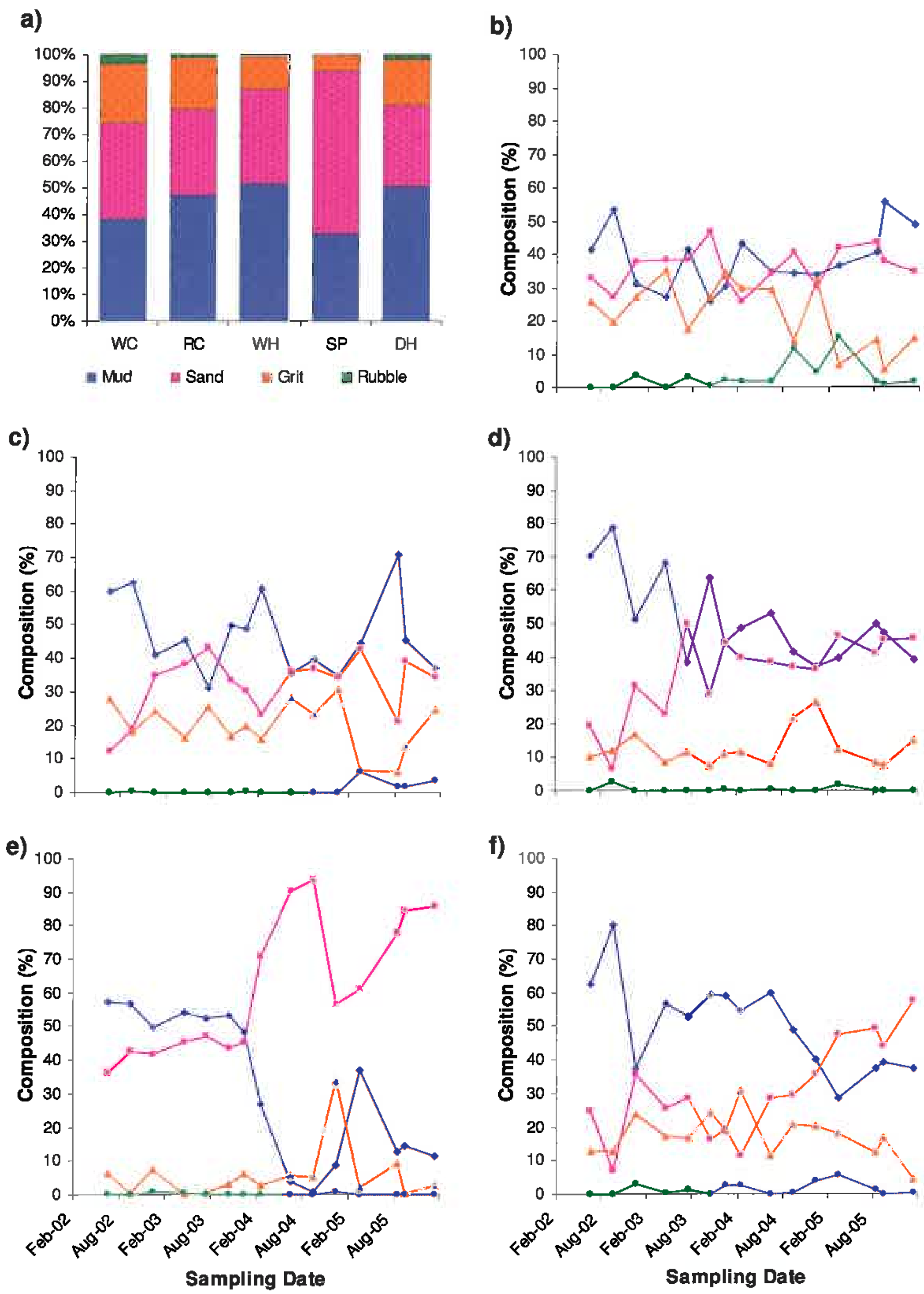


Figure 28: Sediment composition (%) for each site. Data presented in these figures are based on subjective (qualitative) assessment of sediment size only. Data is not continuous but lines are provided to illustrate trends and patterns. a) Mean sediment composition over all sampling periods for each site, b) Windmill Creek, c) Ross Creek, d) Whelans Hut, e) Sabina Point, and f) Duck Hole Creek.

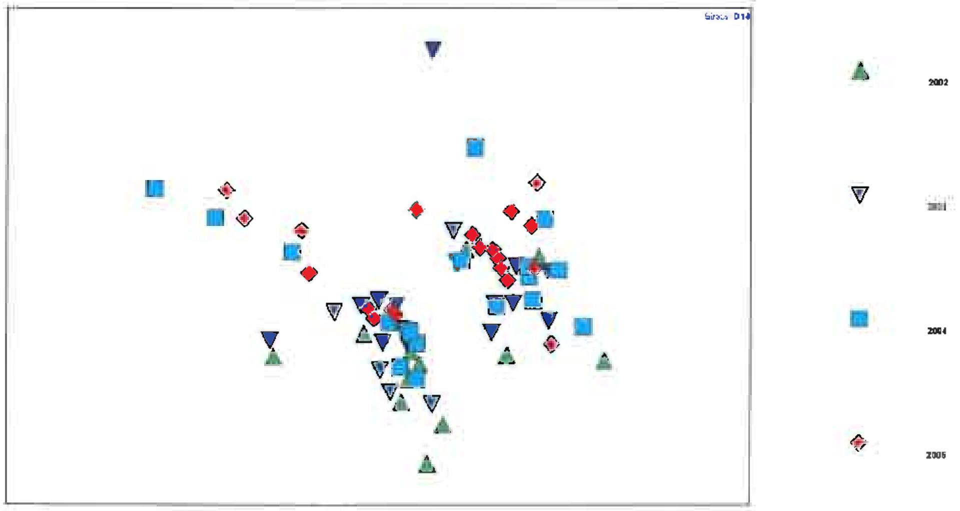


Figure 29a: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of sediment composition by year. Analysis of Similarities sample statistic (R) = 0.226, $p < 0.001$.

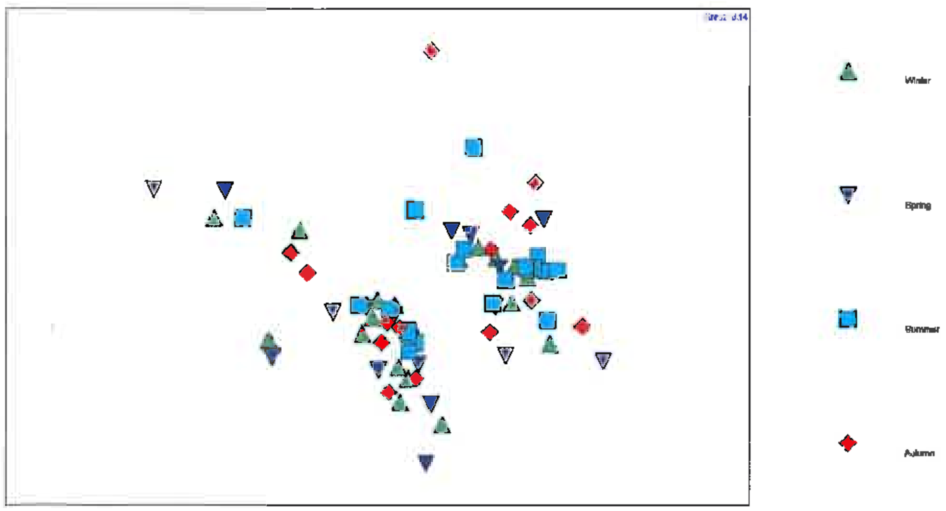

Figure 29b: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of sediment composition by season. Analysis of Similarities sample statistic (R) = -0.047, p = 0.835.

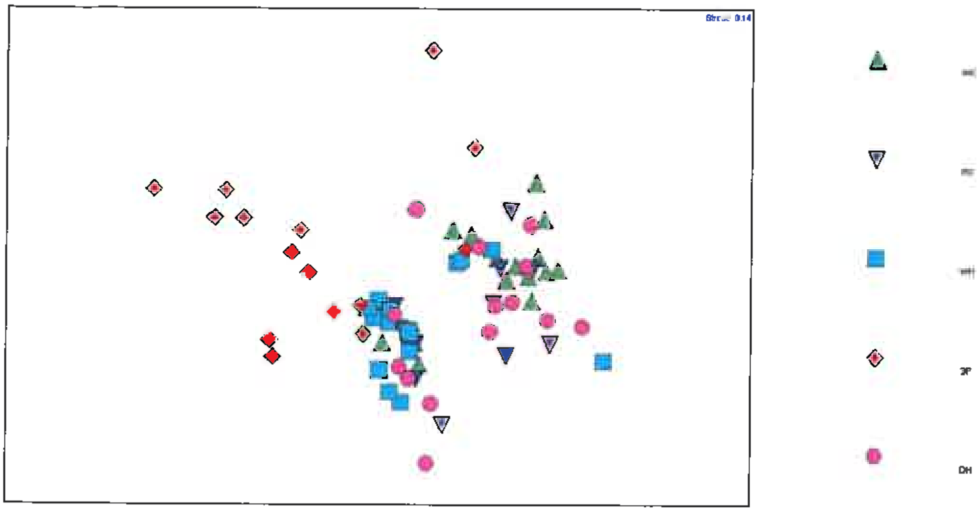


Figure 29c: Non-metric Multi Dimensional Scaling (*n*MDS) ordination based on Bray-Curtis similarities of sediment composition by site. Analysis of Similarities sample statistic (R) = 0.382, $p < 0.001$. WC = Windmill Creek; RC = Ross Creek; WH = Whelans Hut; SP = Sabina Point; and DH = Duck Hole Creek.

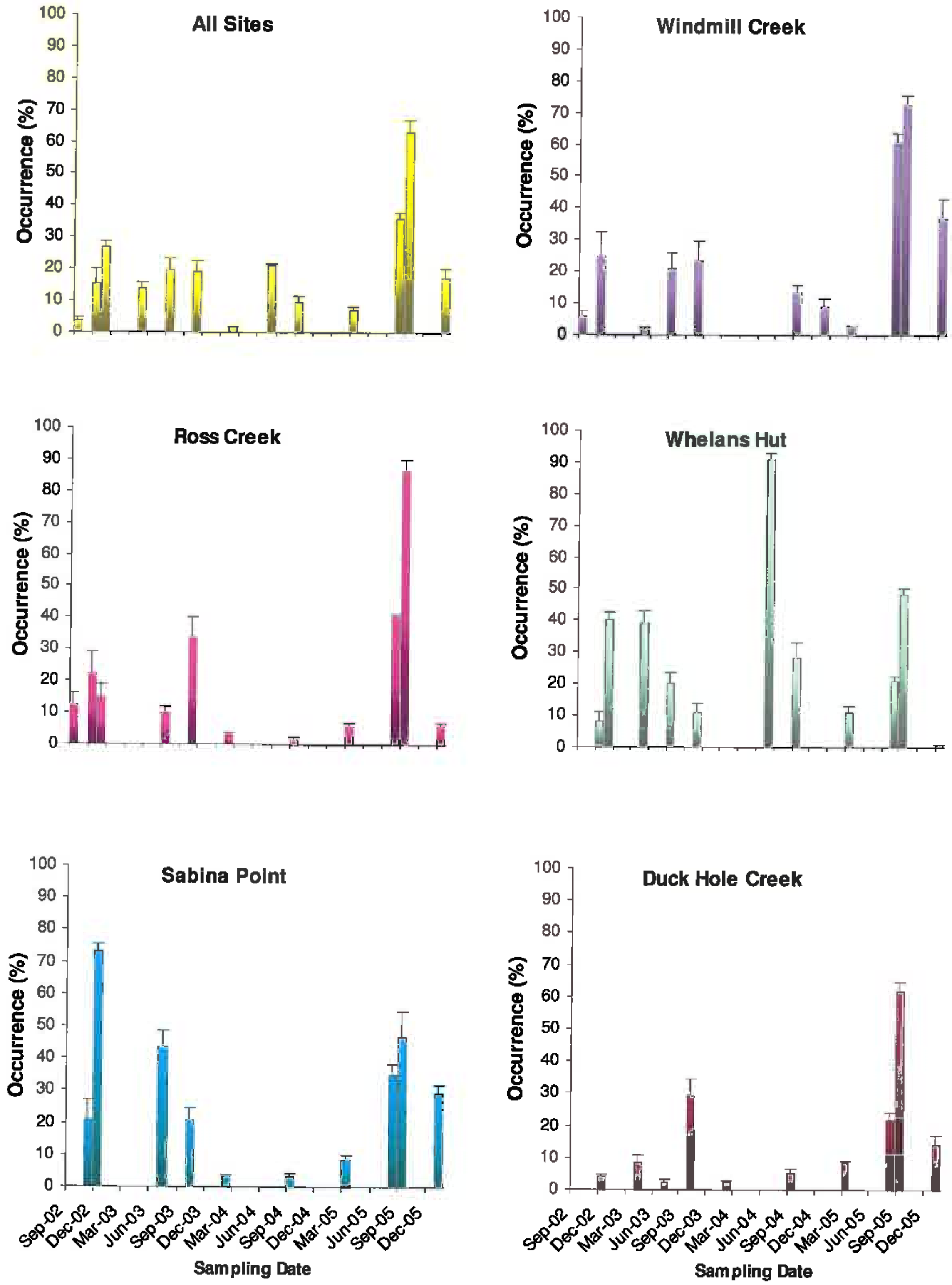


Figure 30: *Lyngbya majuscula* presence within the Shoalwater Bay sampling sites. Estimates of occurrence are based on the number of times *Lyngbya* was observed within quadrats at each site on each sampling period.

# 5 DISCUSSION

The results of this study indicate that the seagrass meadows within Shoalwater Bay are in relatively good health at present. Seagrass cover and biomass within the five meadows sampled over the course of this study were generally within the range found in previous studies (Lee Long *et al.*, 1993; Lanyon and Marsh, 1995; Lee, 1997; Campbell and McKenzie, 2001; McKenzie and Campbell, 2003; Campbell and McKenzie, 2004). However, intertidal meadows in western Shoalwater Bay now appear to be dominated by *Zostera* species, as opposed to mixtures of *Halodule* and *Halophila* as reported by Lee Long *et al.* (1997a).

The seagrass condition in Shoalwater Bay can be considered "fair", as per the Seagrass Watch methods (Campbell and McKenzie, 2001). Although the rating is "fair" in terms of seagrass condition, the overall extent of the seagrass biomass remains high, with a "fair" rating occurring throughout the year. In comparison, other locations that are assigned a "good" rating are often seasonal in character, suggesting that the overall availability of seagrass to consumers and inhabitants is limited.

Seagrass species appeared to form a mosaic of irregular overlapping patches related to the local topography, drainage patterns and substrate of the sites. Patches ranged in size from one to 100 square metres or more. There was some indication of zonation with depth – patches of *Zostera capricorni* were generally more abundant and larger on the inner half (i.e. landward) or mid portions of the flats while patches of *Halodule uninervis* and *Halophila ovalis* became more abundant further from the shore. *Halophila ovalis* was often seen in depressions caused by local disturbances (e.g. dugong feeding, ray wallows, mud crab excavations). Biomass and shoot count samples collected at 30m intervals from 600m transects running parallel and perpendicular to the beach at the Sabina Point site during pilot surveys support these anecdotal observations. There did not appear to be any large and striking differences between sites in terms of species present and their abundance. Each appeared as a local variation on a theme of a mixed meadow of *Zostera capricorni, Halodule uninervis* and *Halophila ovalis*. There was no evidence of a gradient along the coast between McDonald Point and Raspberry Creek.

Species composition of the five sites appears mostly consistent with the seagrass distribution maps presented by Lee Long *et al.* (1997a) in their study of Shoalwater Bay seagrass communities. *Zostera capricorni* dominated the Duck Hole Creek and Whelans Hut sites which are situated within the *Zostera capricorni* meadow type of Lee long *et al.* (1997a). Similarly, *Halodule uninervis* was abundant at the Windmill Creek Headland and

Sabina Point sites which are situated within the boundaries of the *Halodule/Halophila* meadow type.

The only discrepancy is Ross Creek which is dominated by *Zostera capricorni* but is in an area designated as *Halodule/Halophila* meadow by Lee Long *et al.* (1997a). The most likely explanation is that meadow boundaries have changed to some extent since the Lee Long *et al.* (1997) study. Changes in the local topography and depth of the seagrass flats at the Ross Creek site may now favour a different mix of species. Indeed, Lee Long *et al.* (1997) noted that local topography played a major role in defining the species mix on intertidal seagrass meadows. In addition, *Halodule uninervis* and *Halophila ovalis* could be considered as pioneer species capable of rapid colonisation in disturbed regions (Masini *et al.*, 2001; Rasheed *et al.*, 2002), so a change in meadow type may be the result of succession processes or a response to short/medium term changes in sediment composition.

## 5.1 Seasonal Distribution

It is well documented that Shoalwater Bay is the largest seagrass habitat in the southern Great Barrier Reef (Marsh *et al.*, 1996; GBRMPA, 1997; Waycott *et al.*, 2005). Whilst a number of broad-scale surveys from the 1980's until today have provided a series of distributional maps of seagrass in the Great Barrier Reef Marine Park (Coles *et al.*, 1987; Lanyon *et al.*, 1989; Poiner *et al.*, 1989; Lee Long *et al.*, 1993; Lee Long *et al.*, 1997a; Campbell *et al.*, 2002; Coles *et al.*, 2002; Rasheed *et al.*, 2002; McKenzie and Campbell, 2003), few studies have concentrated on the temporal changes in seagrasses within Shoalwater Bay.

Seagrasses are generally considered to show seasonal differences in distribution and abundance (McKenzie, 1994; Lanyon and Marsh, 1995; Lee Long *et al.*, 1997a; Lee, 1997; Lin and Shao, 1998). In this study, natural fluctuations in seagrass cover were recorded, with mean seagrass cover generally varying between 15% and 30%. These fluctuations followed a significant seasonal pattern, with seagrass being less abundant during autumn and highest during spring and summer. Lee Long *et al.* (1997a) recorded a similar seasonal pattern reporting that seagrass in the region was less abundant at the end of summer than during spring.

In addition to seasonal fluctuations in the overall seagrass cover in Shoalwater Bay each seagrass species may be exhibiting different seasonal trends. Seagrass communities within the Shoalwater Bay region of this study are dominated by *Zostera capricorni* and to a lesser extent *Halodule uninervis*. When individual species were analysed separately different seasonal variations became evident. *Zostera capricorni* was more abundant in autumn and winter. *Halodule uninervis* was less abundant in winter. *Halophila ovalis* and *Cymodocea serrulata* were both less abundant in autumn, winter and spring than in summer. Consequently, although each species exhibits a slightly different phenology it results in a relatively constant seagrass biomass throughout the year.

Nutritional quality of seagrass species differed significantly with respect to total nitrogen content (ANL), although there were no significant differences among species with respect to Neutral Detergent Fibre NDF. While no significant seasonal differences in nutritional quality were found the small sample sizes available require some caution when interpreting these results. Furthermore, given the limited data available it was not possible to examine possible seasonal shifts in the nutritional quality of above and below ground biomass of seagrass, particularly with respect to protein or total nitrogen content. However, such changes would have important dietary consequences and implications for the population dynamics of dugong and green turtles in Shoalwater Bay and therefore warrants further investigation.

## *5.2 Seagrass Decline*

Waycott *et al.* (2005) noted that seagrass meadows in the Great Barrier Reef appeared to be prone to short term changes in standing biomass and that changes were often part of the ongoing process of recruitment and disturbance. However, the dramatic reduction in seagrass cover at Sabina Point between February and June 2004, whereby seagrass declined from approximately 20% cover to less than 5% cover is unlikely to be part of these natural fluctuations.

It is evident that the decline in seagrass at Sabina Point is related to an equally dramatic change in sediment composition. Prior to February 2004, the dominant sediment at Sabina Point was mud (approx. 55%), with the remainder being mostly sand. However, between February and June 2004 the relative proportions of sand and mud altered very sharply, with sand replacing mud and comprising almost 100% of the substrate. The nearby sites of Duck Hole Creek, and to a lesser extent Whelans Hut, showed some decline in the mud component, with a corresponding increase in the sand fraction, although not to the same extent as Sabina Point.

The cause of the change in sediments is not known, however, increased wind activity was recorded in March 2004, including 5 consecutive days where wind speeds from the south east exceeded 50 km $hr^{-1}$ and were within the top 1% of maximum wind speeds recorded throughout the entire study period. The Sabina Point site is located on a protruding headland and is potentially exposed to increased wave activity generated by strong south easterly winds (Figure 1). Given the Sabina Point site is dominated by *Halodule uninervis*, a pioneering seagrass, it suggests that this area may be a disturbed high energy environment. No apparent cyclone activity was recorded during the study, however, previous events, such as cyclone Joy in early 1990, caused widespread damage to seagrass beds in western Shoalwater Bay (Limpus *pers. comm.*).

A boat ramp is located at Sabina Point and the area is used periodically for landing during military exercises. Disturbance at this site may also lead to a localised change in sediment composition and subsequent decline in seagrass cover, but at present there is no evidence available to suggest this has occurred. It is also noted that defence forces have conducted large scale exercises within the Shoalwater Bay Training Area with no apparent detrimental effects to the seagrass.

Unfortunately, available environmental data for the area is limited. However, the highest mean daily temperatures (31.5°C) recorded throughout the entire study period occurred in February 2004, while a significant rainfall event also occurred at this time. Studies indicate that seagrasses are likely to be stressed or die when water temperatures exceed 35°C (Marsh *et al.*, 1986; Seddon and Cheshire, 2001; Limpus *et al.*, 2005; Campbell *et al.*, 2006). No significant blooms *Lyngbya* were recorded during the study period, however, very large blooms are known to occur within Shoalwater Bay, including a bloom in 2002 that was observed overgrowing seagrass beds along 18km of coast and covering a surface area of more than 11$km^2$ (Arthurs *et al.*, 2006). It is possible that blooms may have occurred between sampling periods in the present study and were therefore not observed. Wide-scale environmental conditions are generally unlikely to cause such a localised decline in seagrass cover. Nevertheless, it should be noted that the seagrass community at Sabina Point, unlike other sites, was dominated by *Halodule uninervis* and it is possible this species may have a different tolerance to such conditions. There is little data available on the physiological responses of different seagrass species to environmental conditions, however, Campbell *et al.* (2006) found *Halodule uninervis* was more tolerant to thermal stress than *Zostera capricorni* when examining the photosynthetic responses of tropical seagrass to ecologically relevant elevated seawater temperatures.

The seagrass at Sabina Point may be recovering, with a slight increase in cover observed during the last sampling period. This is approximately 18 months to 2 years after the initial loss and is comparable to studies in Hervey Bay where a period of 2 years was required for seagrass to recover after a flood related loss (Preen *et al.*, 1995; Campbell and McKenzie, 2004). Unfortunately the research program in Shoalwater Bay ceased before the recovery of the seagrass could be further ascertained. Other studies, such as the Reef Water Quality Protection Plan monitoring of seagrasses at Ross Creek and Whelans Hut, may be able to make note of the recovery at regular intervals (Haynes *et al.*, 2005).

### *5.3 Dugongs and Green Sea Turtles*

The Shoalwater Bay area is regionally important as a feeding area for dugong and green turtles (Limpus, 1996; Limpus *et al.*, 2005) as well a prawn and fish nursery habitat (Lee Long *et al.*, 1997a). Shoalwater Bay is unique in that it is largely an intact natural system and is remote from human settlement (GBRMPA, 1997; Lee Long *et al.*, 1997a).

In the past, declines in dugong numbers have been reported from the southern Great Barrier Reef, including the Shoalwater Bay region (Marsh *et al.*, 1996; GBRMPA, 1997). Shoalwater Bay supports the most important dugong feeding habitat in the southern region of the Great Barrier Reef Marine Park as well as the largest dugong population in the park south of Cooktown (Marsh *et al.*, 1996; GBRMPA, 1997). Based on diving depth profiles, dugongs appear to be highly dependent on the seagrasses growing in intertidal and shallow subtidal areas (Chilvers *et al.*, 2004).

Shoalwater Bay also supports a large foraging population of green turtles in one of the least disturbed major embayments in eastern Australia, and is one of the least impacted foraging populations (Limpus *et al.*, 2005). Some of the world's last remaining large green turtle stocks breed in Australia, particularly within Queensland. The populations are not however, considered sustainable under the existing management regimes (Limpus *et al.*, 2005). The largest threats to Queensland's population of green sea turtles are indigenous hunting, boat strike, entanglement in fishing gear and habitat degradation (Limpus *et al.*, 2005).

Habitat degradation within intertidal areas is therefore of major concern for the continued survival of both of these iconic species (Lanyon *et al.*, 1989). With the ever increasing urbanisation of Queensland's coastlines, more and more pressure is being put on coastal marine resources, including seagrass meadows. Despite these state-wide pressures, the seagrass meadows within Shoalwater Bay appear to be relatively healthy and the biomass appears to be consistent through time. Shoalwater Bay is a large, undisturbed natural embayment and is therefore likely to have increasing importance in supporting populations of both species and providing a refuge from threats, such as entanglement in nets, boat strike and indigenous hunting.

The results of this suggest that the seagrass meadows within Shoalwater Bay appear to be relatively healthy. Although there may be some seasonality in the cover of different seagrass species, the overall biomass appears to be stable through time. Hence, the seagrass meadows provide a reliable source of food for the main grazing species in the area, dugong and green turtle, supporting large populations of both species within Shoalwater Bay.

# 6 CONCLUSION

Seagrass cover within western Shoalwater Bay was generally stable over the four years of this study (February 2002 to January 2006) apart from a large decline in seagrass that was observed at Sabina Point. Seasonal fluctuations in seagrass cover were observed, with each species exhibiting slightly different phenologies resulting in a relatively constant seagrass biomass throughout the year

The Sabina Point seagrass meadow experienced a rapid decline in seagrass cover for a six month period in conjunction with a corresponding change in sediment structure. The cause of the change in sediments is not known but may be linked to changes in environmental conditions, including increased wind activity and resultant wave action, high temperatures and large rainfall events. Seagrass cover at Sabina Point appeared to be recovering approximately 18 months to 2 years after the initial decline, with a slight increase in cover observed during the last sampling period.

Seagrass cover and biomass within Shoalwater Bay was typically lower than has been reported in other seasonal seagrass meadows, but the biomass was consistent throughout the year and sites. The seagrass meadows provide a reliable source of food for the two main grazing species in the area, dugong and green sea turtle, supporting the presence of large populations of both species within the Shoalwater Bay area. Shoalwater Bay is a largely intact and natural system with limited or no urban development within the bay or adjacent to it and is therefore likely to have increasing importance in supporting populations of both species and providing a refuge from threats, such as entanglement in nets, boat strike and indigenous hunting.

This study has shown that seagrass cover at Shoalwater Bay fluctuates naturally, following a seasonal pattern while providing a reliable food resource for dugong and green turtles. However, it is evident from Sabina Point that changes in seagrass cover within Shoalwater Bay may be occurring on more localised scales. The reason for the rapid decline in seagrass cover is still unclear and further investigation into the effect of changes in environmental conditions, such as temperature, salinity, turbidity and eutrophification is warranted.

This study examined changes in seagrass cover and biomass over time and seagrass condition or health was inferred from this data. It is recommended that future studies also record algal and epiphytic concentrations as well as photosynthetic rates using pulse amplitude modulated (PAM) fluorometry to provide a more robust assessment of seagrass health and the condition of the Shoalwater Bay seagrass meadows (e.g. McKenzie *et al.*, 2003; Campbell *et al.*, 2005). The resilience of seagrass meadows and their capacity to recover following disturbances can be measured by determining the size of seed reserves (McKenzie *et al.*, 2005). It is also recommended that changes in the distribution and extent of seagrass communities are mapped. Future studies should also investigate the influence of seasonal fluctuations in seagrass biomass and nutritional quality on the population dynamics of dugong and green turtle.

# 7 ACKNOWLEDGEMENTS

A large number of people have made significant contributions to this project. In particular, we are grateful to Queensland Parks and Wildlife Service for initiating this project and providing ongoing support. Alice Kay was responsible for initiating the project and Susan Crocetti was instrumental in providing ongoing support during the transition of the project from QPWS to CEM and through to completion. We are also indebted to the skilled and dedicated band of QPWS staff, CEM staff and volunteers who have contributed enormously in the field. The nutritional analyses were performed by James Sheppard at James Cook University. Financial support for the completion of this project was provided by the Fitzroy Basin Association and initial funding was provided by QPWS. Thanks also to Susan Crocetti, John Olds, Paul O'Neill, Alistair Melzer and Shane Westley who provided valuable feedback on earlier versions of this report.

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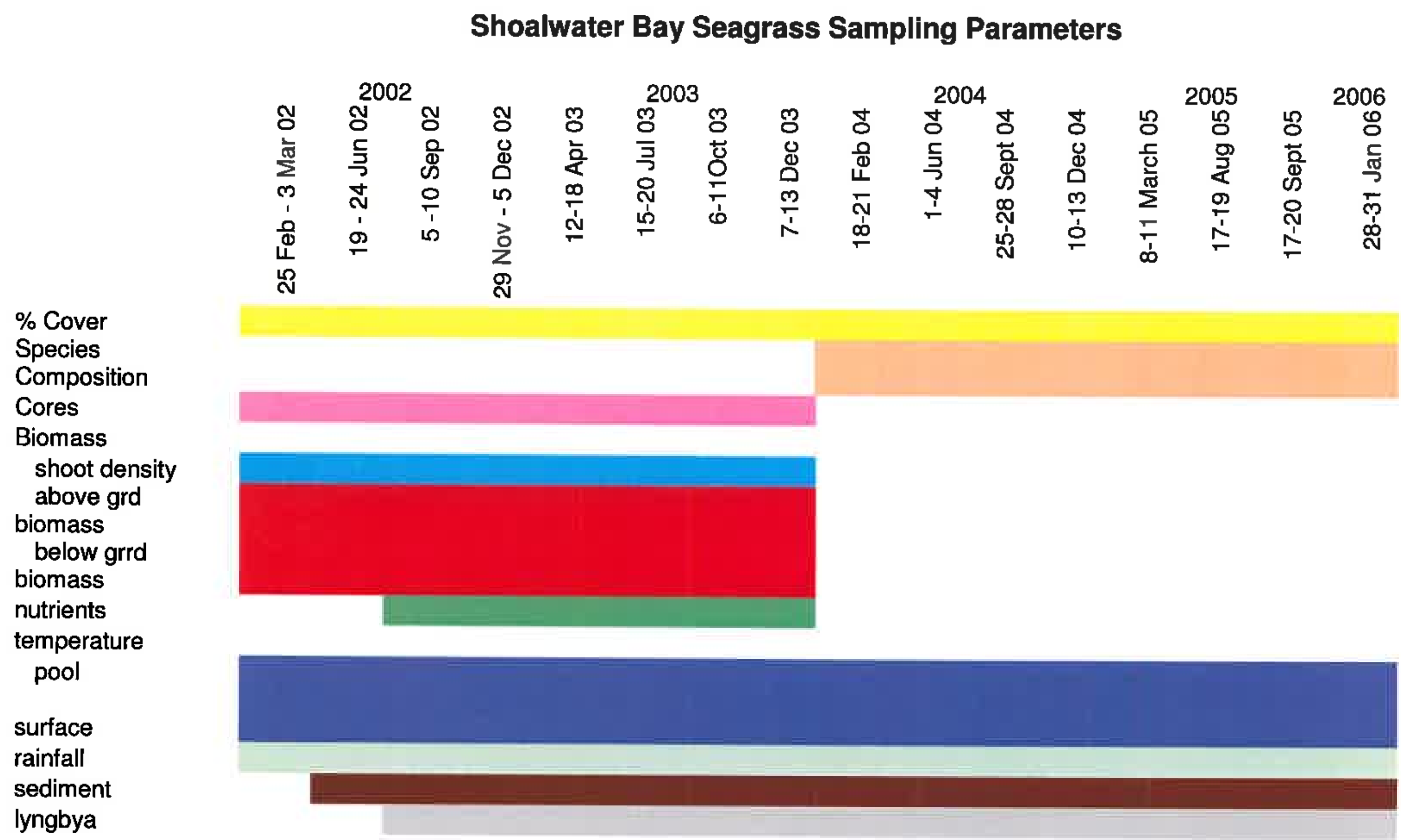
## APPENDIX I

Transect locations for each of the sampling sites within Shoalwater Bay. Latitude and longitude are provided in decimal degrees, chart datum WGS84.

| Site | Transect | Latitude | Longitude |
|---|---|---|---|
| Windmill Creek | 1 | S22.36602 | E150.20047 |
| | 2 | S22.36632 | E150.20145 |
| | 3 | S22.36658 | E150.20228 |
| | 4 | S22.36720 | E150.20395 |
| Ross Creek | 1 | S22.38096 | E150.21253 |
| | 2 | S22.38169 | E150.21303 |
| | 3 | S22.38242 | E150.21363 |
| | 4 | S22.38318 | E150.21424 |
| Sabina Point | 1 | S22.40218 | E150.29988 |
| | 2 | S22.40313 | E150.29982 |
| | 3 | S22.40407 | E150.29982 |
| | 4 | S22.40497 | E150.29980 |
| Whelans Hut | 1 | S22.39720 | E150.27380 |
| | 2 | S22.39735 | E150.27478 |
| | 3 | S22.39748 | E150.27577 |
| | 4 | S22.39762 | E150.27677 |
| Duck Hole Creek | 1 | S22.46151 | E150.37221 |
| | 2 | S22.46168 | E150.37321 |
| | 3 | S22.46171 | E150.37417 |
| | 4 | S22.46173 | E150.37513 |

## APPENDIX II


Shoalwater Bay Seagrass Sampling Parameters
2002
2003
2004
2005
2006
25 Feb - 3 Mar 02
19 - 24 Jun 02
5 -10 Sep 02
29 Nov - 5 Dec 02
12-18 Apr 03
15-20 Jul 03
6-11Oct 03
7-13 Dec 03
18-21 Feb 04
1-4 Jun 04
25-28 Sept 04
10-13 Dec 04
8-11 March 05
17-19 Aug 05
17-20 Sept 05
28-31 Jan 06
% Cover
Species
Composition
Cores
Biomass
shoot density
above grd
biomass
below grrd
biomass
nutrients
temperature
pool
surface
rainfall
sediment
lyngbya