Port Curtis Seagrass Monitoring Programme

Southern Pacific Petroleum (Management)
Surveys: 2000 – 2002

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2003

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1.0 Executive summary

The development of the Stuart Oil Shale project in the Targinnie region of Port Curtis has the capacity to impact extensive adjacent seagrass beds through increased sedimentation and changes to freshwater flows. Since 1998, Southern Pacific Petroleum (Management) has funded an annual seagrass research programme to assess the magnitude and persistence of any biological changes resulting from these developments. The programme is specifically directed towards establishing and monitoring seagrass health parameters at seven sampling stations (17, 18, 21, 23, 25, 27 and 29) in four intertidal seagrass beds in Port Curtis (Friend Point, Flying Fox Creek, Worthington Island and Black Swan Creek). Key parameters examined include seagrass composition, cover, biomass and macrobenthic diversity. This report presents results and principal findings from spatial and temporal analysis of data collected during annual surveys of the seagrass beds in November 2000, September 2001 and November 2002.

Estimates of seagrass cover and biomass were determined from diver quadrat and grab sampling techniques. Both of these methods provided similar results and showed that seagrass standing stock differed significantly between both stations and years. Of the seven sampling stations, Station 26 (Worthington Island) contributed significantly greater cover and biomass than other sites. The differences in biomass and cover between years were primarily due to a progressive temporal decline in the standing stock of seagrass each consecutive survey from the onset of sampling. No patterns in collected data (water depth, sediment structure) were detected that could account for differences between either stations or years. In examining other physical data for the region, significant relationships were found between Calliope River rainfall and discharge data, and between Calliope discharge volume and turbidity within the harbour. Furthermore, the importance of flow events as a nutrient source was highlighted by the significant relationship between turbidity pulses and associated phosphate loads. Annual mean rainfall, discharge volume, turbidity and phosphate all increased slightly in 2002 compared to 2001. It is suggested that reduced nutrient loads due to decreased rainfall since 1996 may be limiting seagrass growth in Port Curtis.

The macrobenthic fauna found in the SPP seagrass sites during 2000, 2001 and 2002 primarily consisted of polychaete worms, bivalve molluscs, crustacea and gastropods. Species richness was greatest among polychaete worms (58 species) followed by bivalve molluscs (45 species), crustaceans (41) and gastropod molluscs (18 species). Less common taxa listed under miscellaneous included echinoderms, osteicthyes, sipunculids, branchiopods and ascidians. Bivalves and polychaetes accounted for the greatest abundance during 2002 (37% and 28% of total consecutively) followed by gastropods (17%) and crustaceans (15%). There were significant differences ($p<0.001$) in the abundance and richness of these organisms between sampling stations and years. Station 25 at Worthington Island had significantly greater abundance to all other stations and Station 21 (Friend Point) was significantly lower in species richness. Benthic abundance was significantly lower in 2001 compared to 2000 and 2002 whereas species richness was lower in 2001 and 2002 compared to the first years sampling.

Our interpretation of the temporal and spatial changes evident in this survey is at this stage limited. Combining SPP(M) seagrass biomass with results from a port –wide survey sampled at a similar time revealed that *Zostera capricorni* attains greatest growth in the high intertidal reaches of the harbour and highlighted some inadequacies in SPP(M) sampling design. In general, the apparently widespread nature of seagrass decline (from the lower harbour at Flying Fox to the upper reaches at Black Swan) appears to indicate that changes are due to one or more pervasive environmental influences.

2.0 Introduction

Seagrass communities grow in most shallow and sheltered near shore regions around Australia, and are widely regarded as important components of coastal ecosystems (Kirkman, 1996). Seagrass is a major food source in detrital based food chains, and a direct food source for grazing animals including dugong and green turtle (Lanyon, 1986). The meadows they form can support a rich and diverse flora and fauna, and provide shelter and refuge for a variety of motile invertebrates and juvenile fish species. Additionally, seagrass meadows play important roles in stabilising sediments, reducing wave energy, and filtering nutrients and chemicals from the water column (English *et al.*, 1994).

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

One potential consequence of the Stuart Oil Shale development is an alteration of natural drainage channels and freshwater flows adjacent to seagrass beds in Port Curtis. In an effort to mitigate the possible deleterious effects of changed freshwater flows on seagrass, Southern Pacific Petroleum (Management) commissioned the Centre for Environmental Management to initiate a monitoring programme at two seagrass beds (Friend Point and Flying Fox Creek) adjacent to the site of the Stuart Oil Shale project in 1998 (Lewis *et al.*, 2000). The objectives of this programme were to: 1) develop a baseline dataset for seagrass communities adjacent to the Stuart Oil Shale project, and 2) investigate and characterise any spatial and temporal changes in seagrass community structure that may be associated with the development.

Following a scientific review that identified a lack of spatial control sites in the initial survey design, a revised sampling programme was established in November 2000 (Lewis *et al.*, 2000). The revised programme design included two additional seagrass beds (Worthington Island and Black Swan Creek), and has resulted in an annual spring assessment of seagrass composition, standing-stock and macrobenthic diversity at seven discrete sampling stations in Port Curtis (Currie *et al* 2003[a]). This report examines spatial and temporal variations in these parameters between November 2000 and November 2002, and the relevance of observed changes in relation to Stuart Oil Shale developments.

3.0 Methodology

Four intertidal seagrass beds on the southern shore of Port Curtis were monitored for seagrass health parameters during this study (Figure 1). The beds located at Black Swan, Worthington Island, Friend Point and Flying Fox Creek, occurred at approximately four kilometre intervals, and collectively embraced many of the principal seagrass beds growing on mud-banks in the inner harbour. Two stations, situated between 400m and 1000m apart, were generally sampled at each seagrass bed (Worthington Island – 25 and 26, Friend Point – 17 and 18, Flying Fox Creek – 21 and 23), however the small bed size at Black Swan limited sampling at this site to just one station (29). Spatial and temporal variations in seagrass at all seven stations was examined using a combination of diver observation and benthic grab sampling techniques on three spring sampling periods (November 2000, September 2001 and November 2002).

3.1 Seagrass cover

Changes in the species composition and percentage cover of seagrasses and algae between each station and sampling period were determined from diver quadrats. A total of ten replicate quadrats ($0.5m^2$) were randomly placed by divers within a $25m^2$ sampling area at each station. These quadrats were visually assessed by divers, and the percent cover of each species of seagrass and algae recorded.

Two-way analysis of variance (ANOVA) was used to examine the effects of location (stations 17, 18, 21, 23, 25, 27 and 29) and sampling period (November 2000, September 2001 and November 2002) on total seagrass cover. Similar analyses were also used to test for station and date differences in individual species cover. Unfortunately, because of the rarity and contagious distributions of most seagrass species encountered, this analysis could only be applied to examine differences in the distribution of the more cosmopolitan species ie *Zostera capricorni*. ANOVA's were also omitted for testing differences in algal cover between stations and sampling periods, as no algal species were recorded in any of the replicate quadrats sampled during the course of the study. Prior to all analysis, homogeneity of variance was examined using Levene's test and heterogeneity removed where necessary by $\log_{10}(n+1)$ and $1/(n+1)$ transformations (Zar 1984, SPSS 1999).

3.2 Seagrass biomass

Measures of seagrass biomass were determined from live plant material collected from benthic grab samples. A total of ten replicate $0.1m^2$ van Veen grab samples were taken at random from each station, and the seagrass components separated by wet sieving on a 1mm mesh screen. The seagrass was later separated into species (*Halophila ovalis, Halophila spinulosa, Halophila decipiens and Zostera capricorni*) and further divided into above ground (leaves, shoots, flowers) and below ground (roots, rhizomes) components. All of these components were weighed before (wet weight) and after (dry weight) drying at 40° for 24hrs. Leaf-length and shoot density was also measured.

It was previously determined that above-ground dry weights of seagrass were the most robust and relevant measures of seagrass biomass (Currie *et al* 2003[a], Kirkman 1996). Consequently, all two-way ANOVA's used for assessing differences in seagrass biomass between sampling dates and stations, were conducted using above-ground dry weight values only. Separate ANOVA's were conducted on the total seagrass biomass and additionally on the biomass of individual species to examine their relative contributions to observed differences. Again, because of the paucity of most seagrass species, it was only possible to examine differences in the biomass of one very common species, *Zostera capricorni*.

3.3 Macrobenthos

Temporal and spatial changes in macrofaunal composition at the four seagrass beds surveyed were examined using the same suit of benthic grab samples employed to assess changes in seagrass biomass. Macrobenthic organisms were separated from the seagrass and fine sediment in each grab (10 replicate $0.1m^2$ van Veen grabs x 7 sampling stations) by sieving the sampled material on a 1mm mesh. The fauna retained was subsequently preserved in 10% formaldehyde solution and later sorted and identified to the highest taxonomic level (generally species). Type material from each new taxa encountered was lodged in the CQU reference collection in Gladstone.

Differences in the abundance and richness of macrofauna between stations and sampling dates were investigated using two-way analysis of variance (ANOVA). Prior to these analysis, homogeneity of variance was examined using Levene's test and heterogeneity removed where necessary by $\log_{10}(n+1)$ and $1/(n+1)$ transformations. Relationships between macrofaunal abundance and richness, and the quantity of seagrass found at each station and sampling period, were additionally investigated using correlation analysis. Spatial and inter annual differences between macroinvertebrate communities at the seven stations were further examined using Bray-Curtis (B-C) dissimilarity measures (Bray and Curtis 1957). B-C dissimilarity measures calculated (for all 21 dates*sites) resulted in a triangular matrix, which was used to map the site inter-relationship in two dimensions using multidimensional scaling (MDS). MDS plots a measure of similarity between objects in two or more dimensions so the distances between objects correspond closely to their similarities and ecologically meaningful patterns become more apparent (Gamito and Raffaelli 1992). The computer package PRIMER (Clarke and Gorley 2001) was employed for ordinations in this study. The final configuration presented here was the best solution (i.e. exhibited the lowest 'stress' value or least distortion) from a minimum of 50 starts.

3.4 Sediment analysis

Approximately 100 g of air-dried sediment from each grab was ground with a mortar and pestle to retain discrete particles. The sample was then weighed and sieved through an agitated stack of Endecott test sieves with apertures of 2mm, 1mm, 500µm, 250µm and 63µm. After dry sieving, the sediment fractions remaining on the sieves were wet with sodium hexametaphosphate dispersing solution. The resultant slurry was washed through the sieve stack until the wash water was clear, and the residual material air-dried at 40°C until a constant mass was reached. Each fraction mass was calculated as a percentage of the total mass of the sample, after correction for moisture content. The fraction less than 63µm was calculated as the difference between the sum of the fractions greater than 63µm and the total mass of the sample less moisture (AS 1289.C6.1, 1977). The strength of associations between sediment structure and the composition of seagrass were later examined by correlation analysis.

3.5 Quality assurance and quality control procedures

An extensive quality control procedure was implemented for the SPP(M) seagrass monitoring programme. The procedure which covered protocols for sampling collection, transportation, laboratory processing, data analysis and reporting is outlined in Appendix 1. In most instances field and laboratory procedures followed appropriate Australian Standards (Australian Standard AS/NSZ 5667.12, 1999; AS 1289.BI.1, 1977; AS 1289.C6.1, 1977), however, in cases where no Australian Standards were documented the relevant authority for the methodology is cited.

4.0 Results

4.1 Seagrass cover

The effects of sampling date and location on the density of seagrass (as determined from diver quadrats) is summarised in Table 1a. This table shows that seagrass cover differs significantly ($p<0.001$) between sampling stations. A post-hoc multiple comparison test (Student-Newman-Keuls; Table 1b) highlights relative contributions to stations differences, and indicates that seagrass cover is significantly higher at station 26 than at all other sampling locations. It also shows that seagrass cover is significantly lower at stations 17 and 29, than the rest of the stations sampled. By examining changes in mean percentage cover of the four seagrass species observed by divers (Table 2), it is further apparent that the elevated densities recorded at station 26 are principally due to a high density of *Zostera capricorni* in 2000 and 2001.

The analysis of variance table (Table 1a) also shows that seagrass cover differs significantly ($p<0.001$) between sampling dates. A post hoc multiple comparison test (Student-Newman-Keuls, Table 1c) for this parameter indicates that seagrass cover is significantly higher in November 2000 compared to the other two sampling dates. The same table shows an annual decline in seagrass cover to November 2002.

The interaction term (date*station) in the analysis of variance table (Table 1a) is also significant. To assist in the interpretation of this result, a plot of marginal means was constructed (Figure 2). This figure indicates that the significant interaction is most probably the result of an unparalleled increase in seagrass cover at station 29. An examination of mean species densities (Table 2) confirms that the interaction is principally due to a five-fold increase in *Zostera capricorni* cover at station 29 between 2000 and 2001 and the appearance of *Halophila decipiens* for the first time at this station in 2002.

4.2 Seagrass biomass

Results of a two-way ANOVA to assess differences in seagrass biomass between sampling dates and stations are presented in Table 3a. This table shows that there were significant differences ($p<0.001$) in seagrass biomass between sampling dates and stations, and additionally, a significant ($p<0.001$) date*station interaction. Post-hoc Student-Newman-Keuls analysis (Table 3b) identifies which stations differed significantly. This indicates that the total seagrass biomass was significantly higher at stations 23, 21 (Flying Fox) and 26 (Worthington) than at all others. The test also indicates that seagrass biomass was significantly higher at station 26 that at station 21 and higher at 21 than 23. From observations of the mean densities in individual species, it is clear that much of elevated biomass at stations 21, 23 and 26 is the result of high densities of *Zostera capricorni* (Table 4) and to a lesser degree *Halophila ovalis*.

Post-hoc Student-Newman-Keuls analysis shows that estimates of seagrass biomass for each sampling date differ significantly (Table 3c). Further, its shows that there has been a progressive annual decline in seagrass biomass since November 2000. A collective assessment of the mean densities of individual species (Table 4) confirms that there was a significant decline in the standing stock of seagrass between 2000 and 2001 and then again between 2001 and 2002. In addition, the same table (Table 4) shows that seagrass biomass declined at each station between the three sampling dates Nov 2000, Sep 2001 and Nov 2002, although there were marginal increases between 2000 and 2001 at station 29 (Black Swan, 0.16g) and between 2001 and 2002 at station 25 (Worthington Island, 0.05g). The significant date*station interaction term detailed in the ANOVA table (Table 3a) is most likely due to the consistently low biomass at stations 17, 18 and 29 (graphically represented in Figure 3).

Analysis of variance was also used to formally test for differences in the densities of different seagrass species between sampling dates (Table 5a). This analysis showed significant ($p<0.001$) species, date, and species*date interaction terms. A post-hoc Student-Newman-Keuls test (Table 5b) confirms that the significant species result is due to elevated densities of *Zostera capricorni*. Furthermore, the same test shows that the mean dry weights of all three other species recorded (*Halophila spinulosa, Halophila ovalis* and *Halophila decipiens*) are more than an order of magnitude less than that of *Zostera capricorni* (Table 5b). A post-hoc Student-Newman-Keuls test (Table 5c) explains the significant difference in seagrass densities observed between sampling dates (Table 5a). This test indicates that there was a significant decline in the collective dry weights of the four seagrass species each year from the onset of sampling in Nov 2000. It is clear from Table 5d that the negative change between 2001 and 2002 was primarily a result of declines in *Zostera capricorni*, as densities of other species either increased marginally (*H. ovalis*) or remained at zero (*H. decipiens* and *H. spinulosa*). The table also suggests that the significant species*date interaction term is the result of unparalleled declines in the density of *Zostera capricorni* in comparison with all other seagrass species (also depicted graphically in Figure 4).

The contributions of individual species to observed differences in seagrass density between stations and sampling dates was further investigated using two-way analysis of variance. Unfortunately, the low densities of *Halophila spinulosa, Halophila ovalis* and *Halophila decipiens* precluded their use in such analysis, and consequently only *Zostera capricorni* was examined (Table 6a). This analysis showed significant ($p<0.001$) station, date, and station*date interaction terms. A post-hoc Student-Newman-Keuls test (Table 6b) shows that *Zostera capricorni* was significantly more prolific at station 26 that at station 21, and that the densities of this species at both of these stations was significantly more than all other stations sampled. Differences in the mean biomass of *Zostera capricorni* between the three sampling dates are examined using a post-hoc Student-Newman-Keuls test (Table 6c). This test confirms that there was a significant decline in the standing stock of *Zostera capricorni* between 2000 and 2001 and then again between 2001 and 2002. As the biomass values for each year in this multiple comparison test are only marginally smaller than those obtained with data for all species combined (Table 3c), it is clear that most differences in biomass between stations and sampling dates are directly due to variations in *Zostera capricorni* density.

4.3 Macrobenthos

There were 1926 individuals from 175 species found at the seven stations sampled in Port Curtis during November 2000, September 2001 and November 2002 (Table 7). Polychaete worms were the most common taxonomic group encountered during the three sampling events (58 species). Bivalve molluscs (shellfish) were the second most frequently collected taxa (45 species) followed by crustaceans (crabs/prawns; 41 species) and gastropod molluscs (marine snails; 18 species). Other rarer taxa encountered (collectively referred to in Table 7 as 'miscellaneous') included echinoderms (starfish and sea cucumbers; 5 species) osteicthyes (fish; 3 species), sipunculids (peanut worms; 2 species), nemertean worms (proboscis worms; 1 species), brachiopods (lamp shells; 1 species) and ascidians (sea squirts; 1 species).

Bivalve molluscs were the most frequently encountered taxa at all sampling stations during each annual survey (Table 7) and account for 38% of the overall abundance of benthic organisms. This is particularly noteworthy given the large decline in the number of species represented in this taxonomic group for each sampling period since 2000 (2000: 38 species, 2001: 17 species, 2002: 11 species present). The abundance for bivalve molluscs was the highest ever recorded in November 2002 when species richness was at its lowest recorded level (11 species present). Polychaetes also contributed largely to the total benthic abundance (28%) followed by gastropods and crustaceans (17% and 15% respectively). Abundance of gastropods increased vastly in 2002 compared to previous years (97% increase in numbers from 2001). The miscellaneous taxonomic grouping collectively accounted for the residual abundance (3%).

The effects of date and sampling station on the abundance of benthic organisms are summarised in Table 9a. This table shows that there were significant ($p<0.001$) differences between stations, sampling dates and, additionally, a significant date*station interaction. Post-hoc Student-Newman-Keuls tests (Table 9b) confirm that significant station differences in infaunal abundance are largely the result of lower mean abundance at station 21 than stations 17, 18 and 26 and significantly higher abundance at station 25 than all other stations. It is clear from Table 8 and confirmed by a post-hoc Student-Newman-Keuls test (Table 9c) that benthic infaunal abundance was significantly lower in September 2001 compared to the two other sampling dates (November 2002 and November 2000). Furthermore, a decrease at stations 21, 23 and 26 between 2001 and 2002, (Table 8 and Figure 6) in contrast with an increase at all other stations, largely explains the significant date*station interaction term (Table 9a, $p<0.01$).

The statistical significance of date and sampling location on benthic species richness is summarised in Table 10a. This table shows significant ($p<0.01$) date, station, and interaction terms (date*station). A post-hoc Student-Newman-Keuls test for differences in richness between stations (Table 10b) revealed that richness at station 21 is significantly lower than 17, 18, 23 and 25 but not stations 23 and 29. The strong relationship between species abundance and richness noted in the previous years report was tested using Pearson's correlation analysis. Although the significant association between these parameters was clearly maintained in the current survey ($n=210$ $p<0.01$ $r^2=0.56$), with 56% of differences in infaunal richness being explained by changes in abundance, it was stronger in 2001 ($n=140$ $p<0.001$ $r^2=0.74$) (Currie *et al* 2003[a]). A post-hoc Student-Newman-Keuls test for differences in richness between dates (Table 10c) shows that species richness was significantly greater in November 2000 compared to the other two sampling years (September 2000 and November 2001). Pictorially, the results for benthic richness closely mirror those for benthic abundance and provide evidence for the significant date*station interaction term (Table 10a, Figure 7) seen in a decrease at stations 21, 23 and 26 between 2001 and 2002, in contrast to an increase at all other stations (Table 7 and Figure 7).

4.4 Macrobenthic community analysis

To assess the level of inter-annual variation in benthic community structure, an ordination of Bray-Curtis dissimilarity measures was calculated from a matrix of species abundance data collected from each sampling station (seven) and sampling period (2000, 2001, 2002) (Figure 8). In this ordination it is apparent that there is a pronounced temporal gradient illustrated by a downward progression across the three years. Although sites sampled in 2000, 2001 and 2002 form three station groupings, the lack of departure between year groups indicates the presence of similar species in successive surveys.

Bubble plots of species richness (Figure 9) and abundance (Figure 10) superimposed on the MDS ordination presented in Figure 8 facilitate interpretation of the differences in community structure between the three sampling periods. Patterns apparent in these bubble plots provide additional and compelling visual confirmation for important spatial and temporal trends for benthos formally identified in two-way ANOVA's in the previous section. Numerals in the plot represent total species richness or abundance, while the diameter of circles around them illustrates the number on a monotonic scale. It is evident from Figure 9 that on average species richness was greatest in 2000, poorest in 2001 (centrally located in the plot) and slightly higher in the 2002 survey. Abundance of benthic organisms was higher in 2000 than 2001 and greatest in 2002 (Figure 10).

While the ordination plot presented in Figure 8 shows variation in benthos at all stations over the duration of the study, it does not readily demonstrate the level of change in community structure evident at each sampling station with time. To better illustrate temporal shifts in species composition at each of the seven stations, locations of individual stations and sampling periods have been sequentially highlighted on a series of individual plots (Figure 11). In these plots the lengths of the lines connecting the larger circles (individual stations) indicate the magnitude and direction of change in infaunal community structure between successive samplings (i.e. short lines indicate little temporal change while longer lines reflect large temporal change). Lengths of the interconnecting lines vary between stations, indicating that inter-annual changes are not consistent across all stations. However, temporal shifts in community structure at almost all stations over the three-year period move in the same general direction. One exception to this is station 29, which, apart from displaying the greatest inter-annual change, shows movement in a direction perpendicular to the other sites. On closer examination this difference is due to unusually low species richness and abundance at this site in 2001.

4.4 Sediment

Particle size distribution remained relatively consistent in the 2002 survey compared to previous years, with most stations generally exhibiting sediments principally composed of silt and clay fractions (Table 11). There was, however, a substantial shift at station 21 (Flying Fox) from a composition primarily of silt and clay to chiefly sand and granules.

4.5 Seagrass and sediment relationships

Seagrass/sediment

The effect of sediment composition on amount of seagrass present was examined by plotting the percentage silt (<63μm diameter) against seagrass biomass (Figure 12). This scatter plot fails to show a definitive trend. Furthermore, no significant correlation could be detected between seagrass biomass and sediment.

5.0 Discussion

The general decline in seagrass cover at most seagrass stations since 2000 was paralleled by a significant decline in seagrass biomass at all stations. No longshore pattern was present to account for these observed and collective differences. The rank order of seagrass cover and biomass at stations within this decline was generally maintained from 2001 to 2002. *Zostera capricorni* was the most common and prolific species encountered and accounted for most of the observed changes. The significant annual decline apparent in this survey is, however, difficult to explain. Many variables play a large part in determining the prevalence and extent of seagrass communities. A primary influence is light availability, highly affected by sediment quantity and deposition, which is in turn determined by local hydrographic conditions. Besides affecting critical light availability, the smothering effects of sedimentation on seagrass communities are well documented and recognised as a crucial threat to their preservation. Within recent years and months there have been activities within Port Curtis, which may well have contributed to an increased load of fine particulate matter in the water column. These activities include dredging of shipping channels, dredging of specific areas to accommodate future wharf pylons and clearing and removal of riparian ground cover. As the SPP sediment sampling regime is not geared to detect the effects of any such activities, their influence on seagrass communities are presently unknown.

Despite the paucity of supportive physico/chemical data for the seagrass sampling stations surveyed in this study, recently established data loggers are providing insights into the physical dynamics of the Port and their potential impacts on seagrass standing stock. An aqualab situated at Clinton Coal Wharf provides time-series physico/chemical data (electrical conductivity, dissolved oxygen, available phosphate levels, temperature and pH) and a nephelometer station close to Wiggins Island provides 10 minute turbidity measurements (both owned and maintained by the Gladstone Port Authority). This data spans a five (aqualab) and six (nephelometer) year period inclusive of SPP seagrass sampling dates. Additionally a Natural Resources and Mines sampling station situated in the Calliope River at Castlehope, Gladstone provides daily and monthly totals for stream volume discharge and rainfall from 1996. Several significant relationships were found to exist between these physical variables. Volume of discharge (ML) from the mouth of the Calliope River was significantly ($p<0.01$ $r^2=0.42$ $n=85$) correlated with local rainfall (mm). Furthermore, rainfall (mm) and discharge volume (ML) from the Calliope River both displayed significant relationships with turbidity within the harbour ($p<0.01$ $r^2=0.16$ $n=49$ and $p<0.05$ $r^2=0.13$ $n=49$ respectively), which varied significantly ($p<0.01$ $r^2=0.23$ $n=49$) with phosphate. Electrical conductivity (µS) at Clinton coal wharf was found to correlate significantly with rainfall ($p<0.05$ $r^2=-0.083$ $n=56$) as well as volume of discharge ($p<0.05$ $r^2=-0.21$); this negative relationship signifying the extent to which freshwater flows impact upon the salinity of the harbour.

Total monthly rainfall and discharge plots show that over the duration of this survey there has been a decrease in flow from the mouth of the Calliope River due to decreased rainfall since November 2000 (Appendix 1 Figures 1a and 1b). Annual plots show there was slightly more rain and hence discharge in 2002 than 2001 (Appendix 1, Figures 2a and 2b). It is further apparent that the rainfall and discharge volumes detected over the last seven years are greatly diminished compared to the discharge volume and rainfall peak present in January 1996, highlighting recent drought conditions. The first sampling survey (November 2000) took place within a discharge event and there has been limited discharge and rainfall since this time (October/November 2000). Generally, reduced freshwater flows favour seagrass growth by allowing reduction of turbidity in receiving waters and therefore, increased light penetration (Thomas and Rasheed 2002). However, within the six year span of turbidity measurements (1997 to 2002), the mean annual turbidity at Wiggins Island peaked in 2000 and 2002 compared to other years and generally turbidity was higher in the three years spanning the survey compared to the previous three years (Appendix 1 Figure 3). This periodicity in turbidity may well have affected light availability to the extent of a general decline in seagrass standing stock over the course of the SPP(M) seagrass study. Experimental studies have shown that *Halophila ovalis* has a very limited tolerance to light deprivation compared to larger species of seagrass, with complete plant death after 30 days in the dark (Longstaff *et al* 1999). This may contribute to explaining the limited distribution of this species within the generally turbid waters of Port Curtis. Conversely, there is the possibility that high river discharges are providing a desirable and necessary influx of nutrient (highly significant relationships have been determined between freshwater flows, mean turbidity and mean phosphate concentration at Clinton coal wharf), which proves favourable to seagrass growth once flow associated turbidity settles out. Annual mean rainfall, freshwater discharge, turbidity and phosphate values all increased from 2001 to 2002 (Appendix 2 Figure2a and 2b, Figures 4a and 4b). There has been a mean annual decline in temperature spanning the three-year duration of the SPP seagrass survey that appears to follow the plots of seagrass biomass in this study (Figure 4c). However, on closer examination the differences in mean temperatures are less than one degree and are considered too small to have a deleterious effect on seagrass growth. The mean annual increase in electrical conductivity since 1999 (Figure 4d) is most likely due to a reduction in freshwater draining into the harbour over the last few years.

In August 2002 a quantitative port-wide assessment of seagrass composition and standing stock was undertaken by Central Queensland University. Employing similar techniques used in the SPP(M) survey, the study sampled approximately 180 stations on a grid array that covered the entire port. This sampling provided comparable estimates of seagrass species compositions and biomass over the full range of depths and sediment represented in the port. From the tabulated results it was clear that *Zostera capricorni* formed the major component of seagrass meadows throughout the port (Appendix 1 Table 1). It is speculated that *Zostera capricorni* may have a competitive advantage over other species in estuarine areas due to a greater tolerance to varying salinity (Long *et al* 1993). The mapped results of this study clearly show that, although seagrass biomass across the whole port was patchy, there was a higher incidence of *Zostera capricorni* in the upper reaches of the harbour where salinity fluctuates most (Appendix 2 Figure 5) (CQU Portwide survey unpublished data). Results of the SPP 2002 seagrass survey were mapped on an identical scale to enable direct comparison with CQU port wide findings; from which it is further confirmed that *Zostera capricorni* attains its greatest biomass in these upper regions of the port (Appendix 2 Figure 5). Additionally, this figure revealed a disparity in biomass over a relatively short distance at Black Swan 2002 (0.028g (St 29 SPP(M)) vs. 1.160g (St 30 port-wide)). This identifies major shortcomings within SPP(M) sampling design, further highlighting the importance of adequate spatial replication within a seagrass monitoring programme. The distance between these two stations is 130 meters and although this relatively large distance provides some explanation for the very different biomass values at these sites in 2002, it also indicates that the SPP(M) station 29 is most likely peripheral to the main seagrass meadow in this area. The results of the port-wide survey also suggest that seagrass reaches its greatest biomass at sites distant to the industrialised inner harbour (including SPP(M) seagrass sites), however, lack of historical data makes this information difficult to assess.

Relationships between macrofaunal assemblages and associated seagrass were undetermined. However, the general movement of benthic station assemblages in year groups (seen in MDS analysis) implies that all stations were responding to similar influences during successive years and may be following pervasive environmental changes also expressed as declines in seagrass biomass. Interestingly, in 2002 the stations with the lowest abundance and richness (21 and 23), which are set apart from others within this year group, are also the most southerly and geographically proximal to the mouth of the Calliope River. The significance of this result, particularly in relation to freshwater flow and turbidity regimes, is currently being investigated.

Other seagrass studies within Port Curtis (GPA sampling surveys) also documented substantial loss in seagrass over the same period as the SPP(M) sampling survey (Currie *et al*[b] 2003). Elsewhere in Queensland this was not the case. Seagrass studies at Port Mourilyan, Karumba and Weipa documented substantial increases in seagrass since 2000 (Roelofs *et al* 2002, Roelofs *et al* 2001, Thomas and Rasheed 2002, Rasheed and Thomas 2002). Thomas and Rasheed (2002) found that the total area of seagrass meadows in Port Mourilyan increased by 327% between 2000 and 2001. Unfortunately the validity of these comparisons is questionable as different methodologies were employed (area versus biomass).

The difficulty in understanding the spatial and temporal differences in seagrass biomass and cover may be partly attributed to the location of seagrass sampling sites within beds as well as the inadequate longshore replication previously recognised (Station 29 has only one site). The majority of sites are peripheral to major and recognised seagrass meadows, no doubt due to their original selection as macrobenthic stations rather than seagrass monitoring sites, and consequently trends depicted by these sites are possibly not representative of the meadow as a whole (as indicated by results of other surveys). Just as the surveys are conducted annually at times when seagrass biomass is greatest (spring), sites should also be situated in representative seagrass habitat. It is documented that long term seagrass monitoring should be planned after background data has been collected for a minimum of three years and analysed (Kirkman 1995). In view of this it is suggested that the SPP(M) seagrass monitoring programme undergo review to form a more scientifically valid sampling design while optimising use of existing sites and data.

6.0 Acknowledgements

We would like to thank the CEM Marine Ecology Group for undertaking the field and laboratory work associated with this project, including Jill Campbell, Shona Marks and Damon Shearer for collection of seagrass and macrobenthos and for sediment analysis. Thanks also to Andrew Davis for skippering the research vessel. We gratefully acknowledge the use of water quality data collected by The Department of Mines and Resources at Calliope River, Castlehope and by Gladstone Port Authority at Wiggins Island and Clinton Coal Wharf, Port Curtis.

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Figure 1. Map of Port Curtis showing the locations of seven stations sampled for seagrass during November 2000, September 2001 and November 2002.

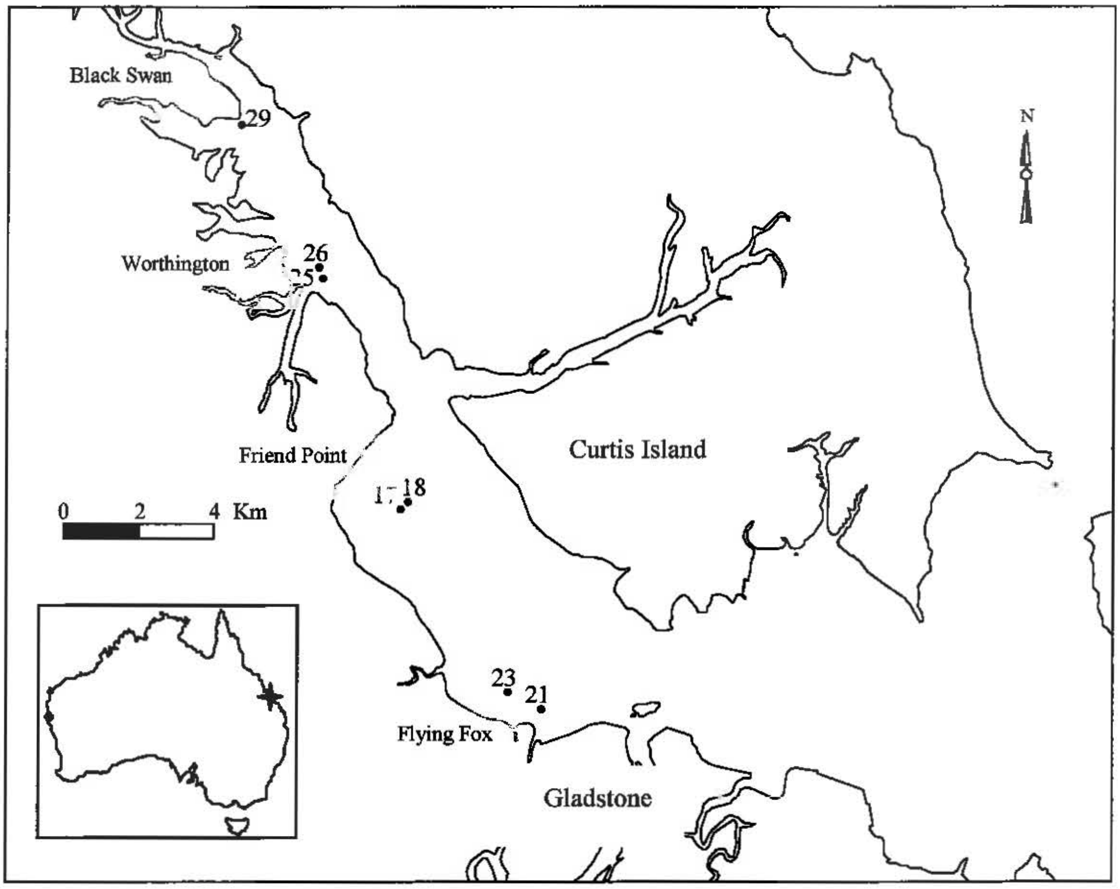


Figure 2: Changes in mean percent cover of seagrass at seven sampling stations in Port Curtis surveyed during November 2000, September 2001 and November 2002. Means are derived from 10 x $0.5m^2$ diver quadrats.

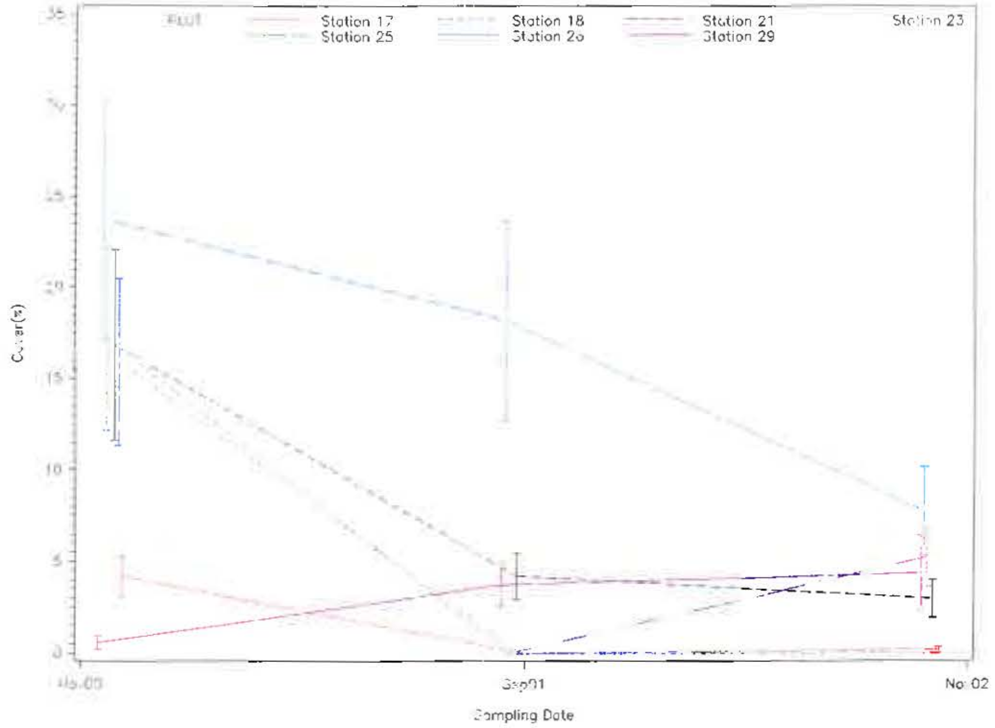


Figure 3: Changes in mean seagrass biomass at seven sampling stations in Port Curtis surveyed during November 2000, September 2001 and November 2002. Means are above ground dry weights collected in 10 x $0.1m^2$ van Veen samples.

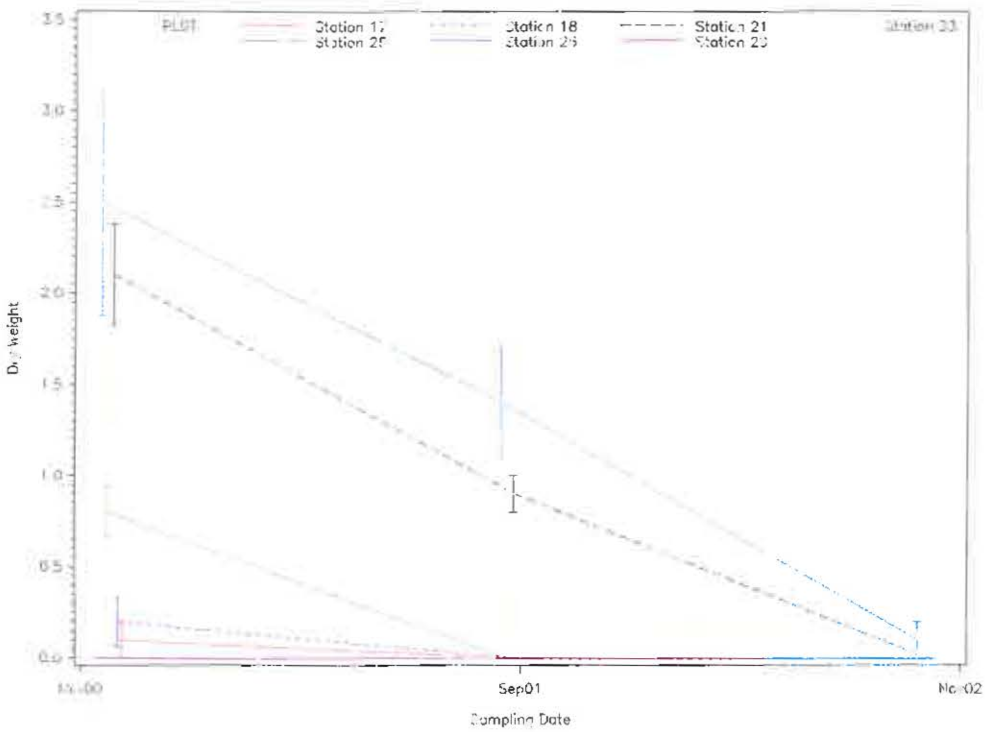


Figure 4. Changes in mean seagrass biomass of four seagrass species in Port Curtis surveyed during November 2000, September 2001 and November 2002. Means are above ground dry weights collected in 10 x 0.1m^2 van Veen samples.

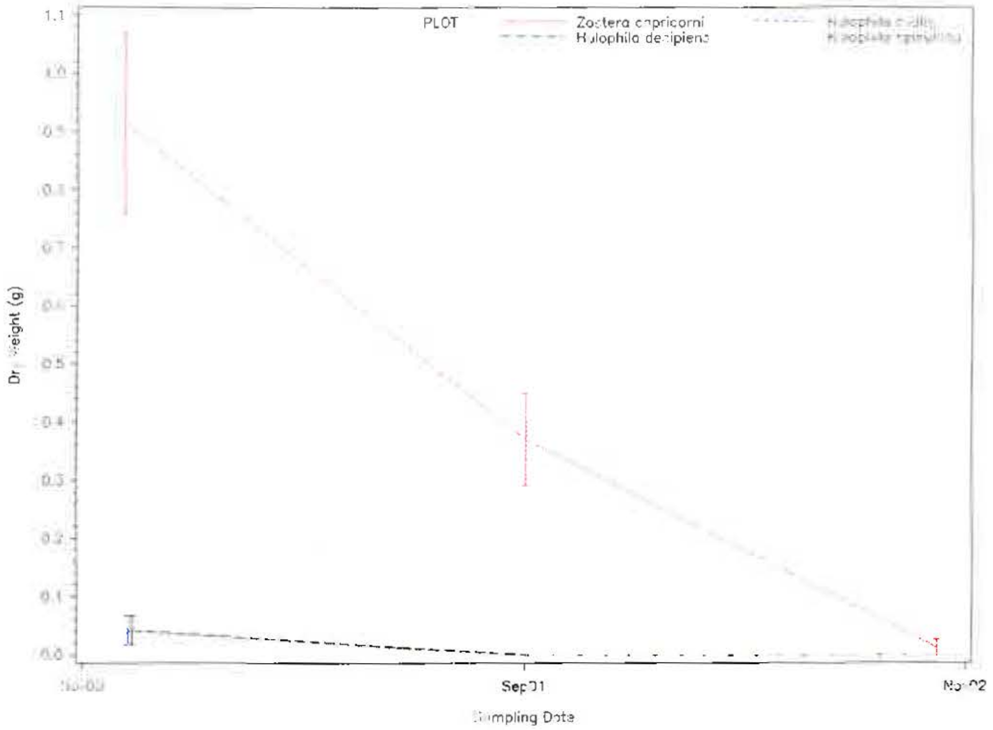


Figure 5. Changes in mean biomass of *Zostera capricornia* at seven sampling stations in Port Curtis over three surveys (November 2000, September 2001 and November 2002). Means are above ground dry weights collected in 10 x 0.1m^2 van Veen samples.

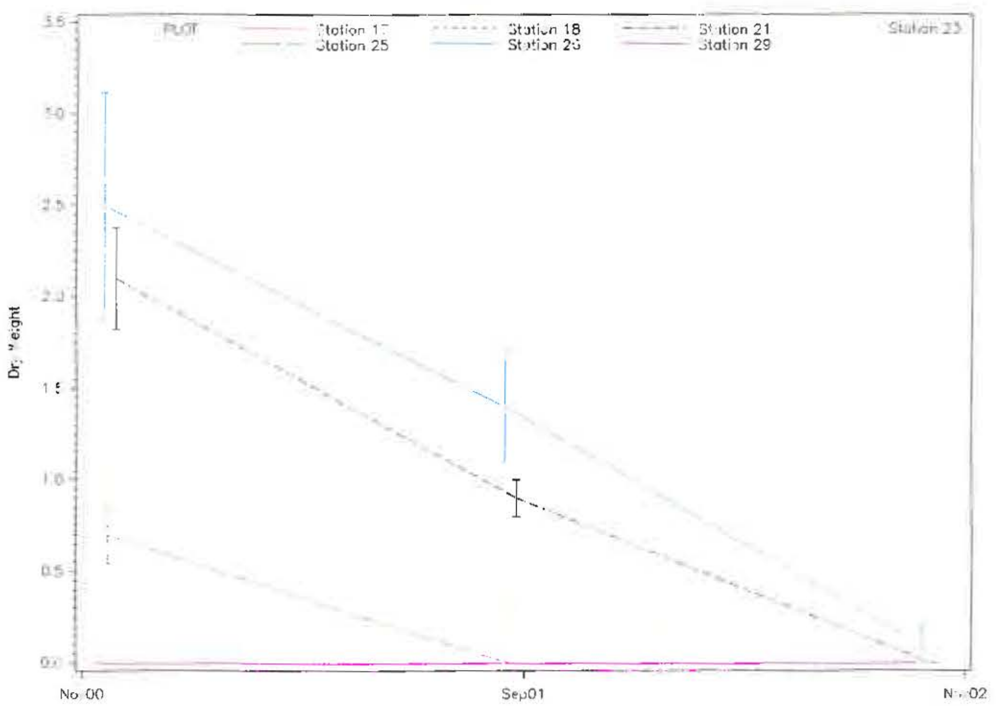


Figure 6: Changes in mean abundance of infauna at seven sampling stations in Port Curtis surveyed during November 2000, September 2001 and November 2002). Means are derived from 10 replicate $0.1m^2$ van Veen grab samples.

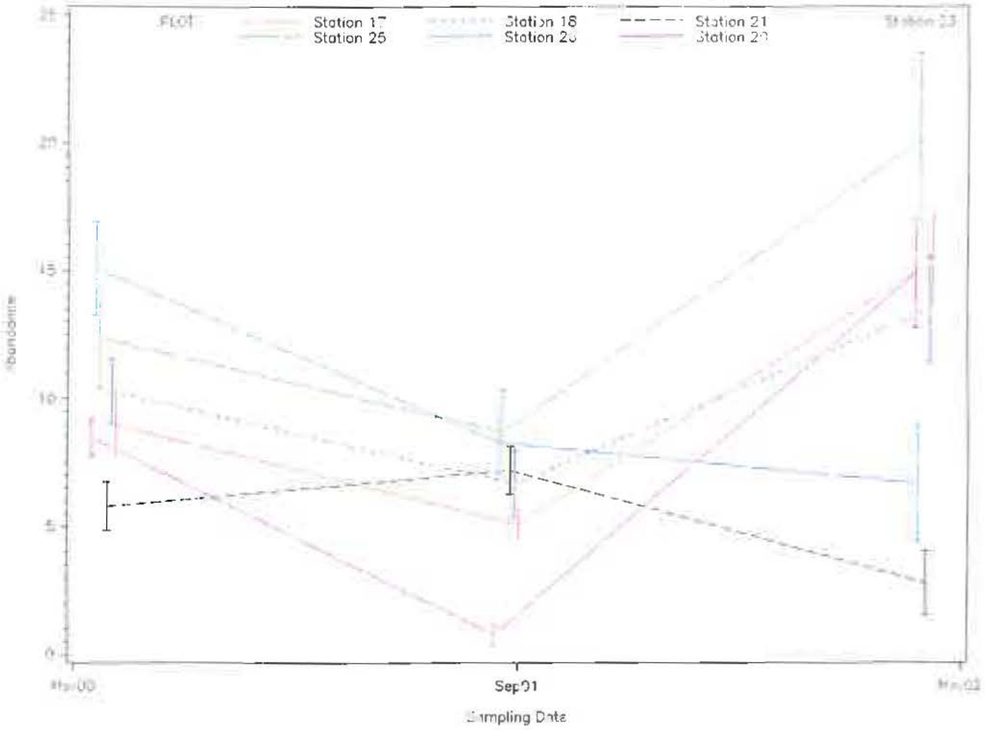


Figure 7: Changes in mean species richness at seven sampling stations in Port Curtis surveyed during November 2000, September 2001 and November 2002). Means are derived from 10 replicate $0.1m^2$ van Veen grab samples.

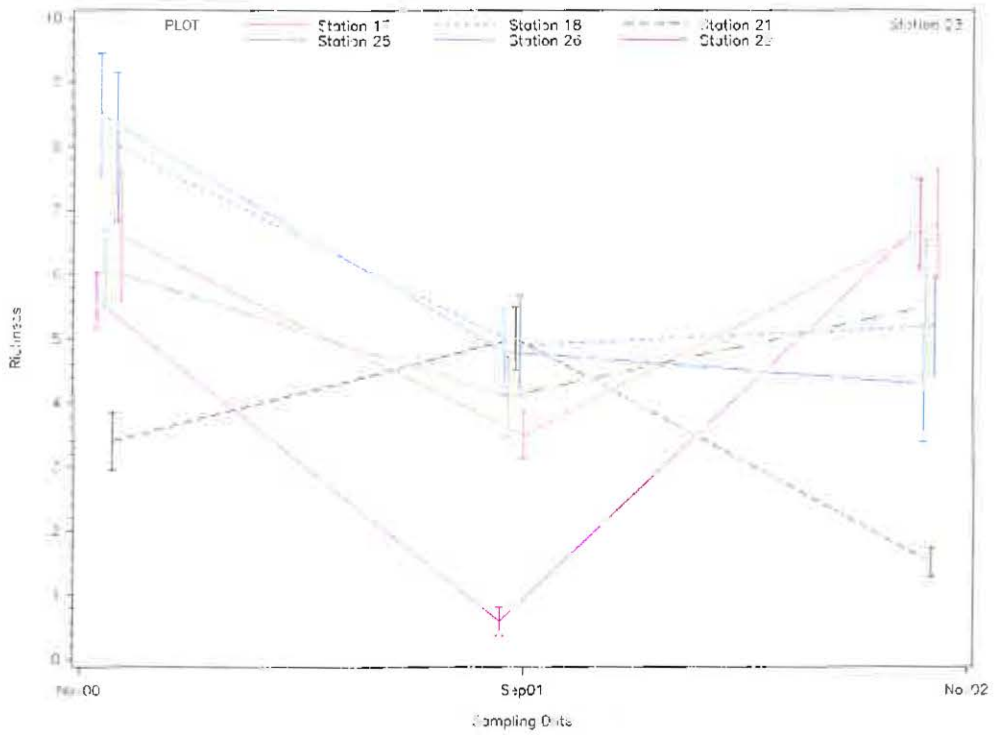


Figure 8. MDS ordination of macrobenthic community data collected from seven seagrass sampling stations during November 2000, September 2001 and November 2002.

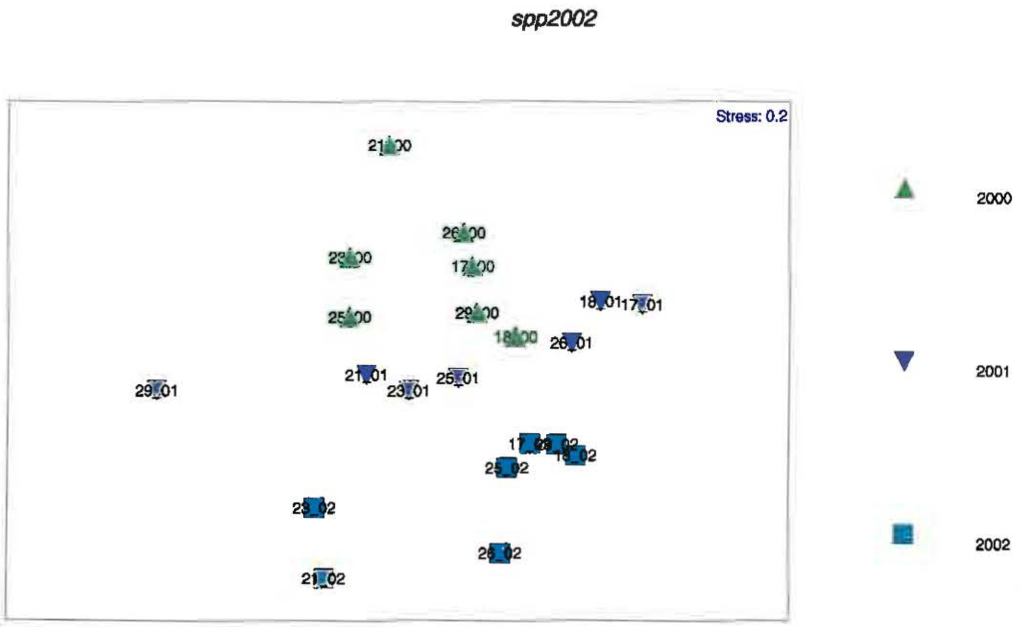


Figure 9. Plot of species richness superimposed on MDS ordination of seven seagrass stations sampled during November 2000, September 2001 and November 2002.

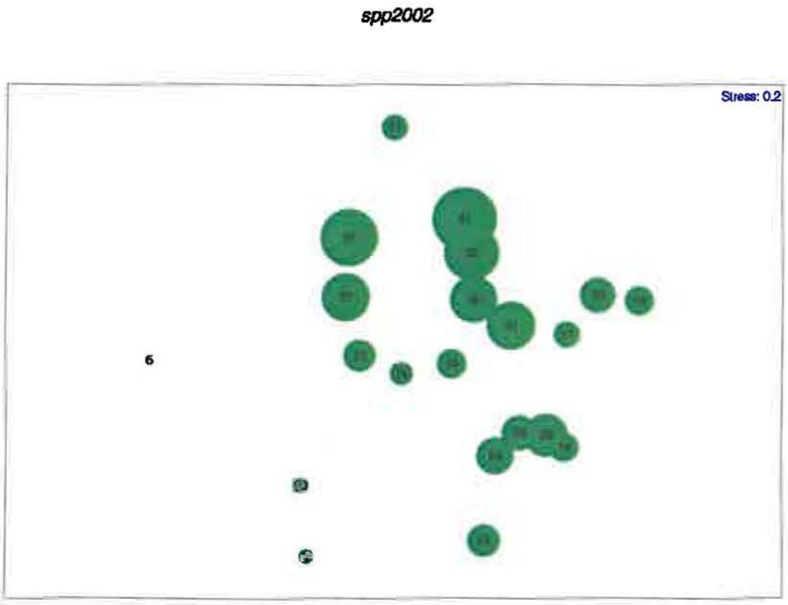


Figure 10. Plot of species abundance superimposed on MDS ordination of seven seagrass stations sampled during November 2000, September 2001 and November 2002.

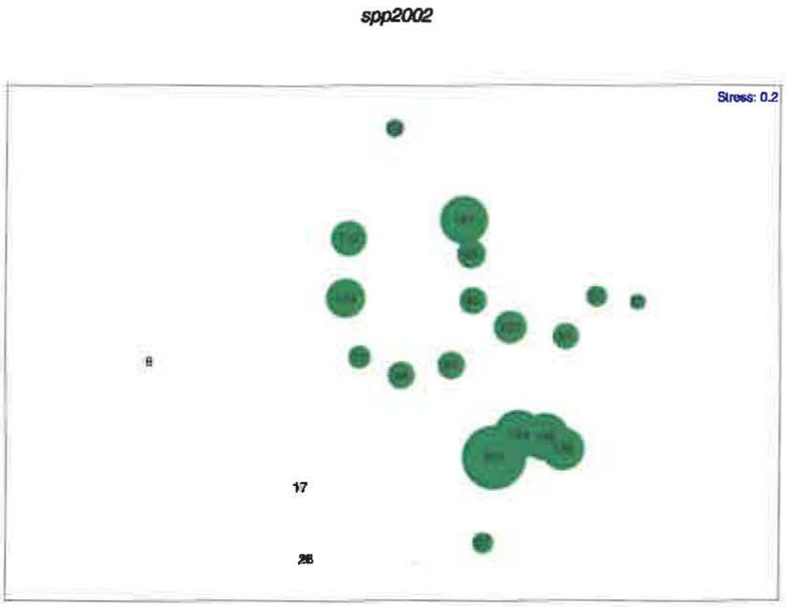


Figure 11. MDS plots of annual changes in community structure at each sampling station (large circles) superimposed on an ordination of all sampling stations and sampling periods (small circles).

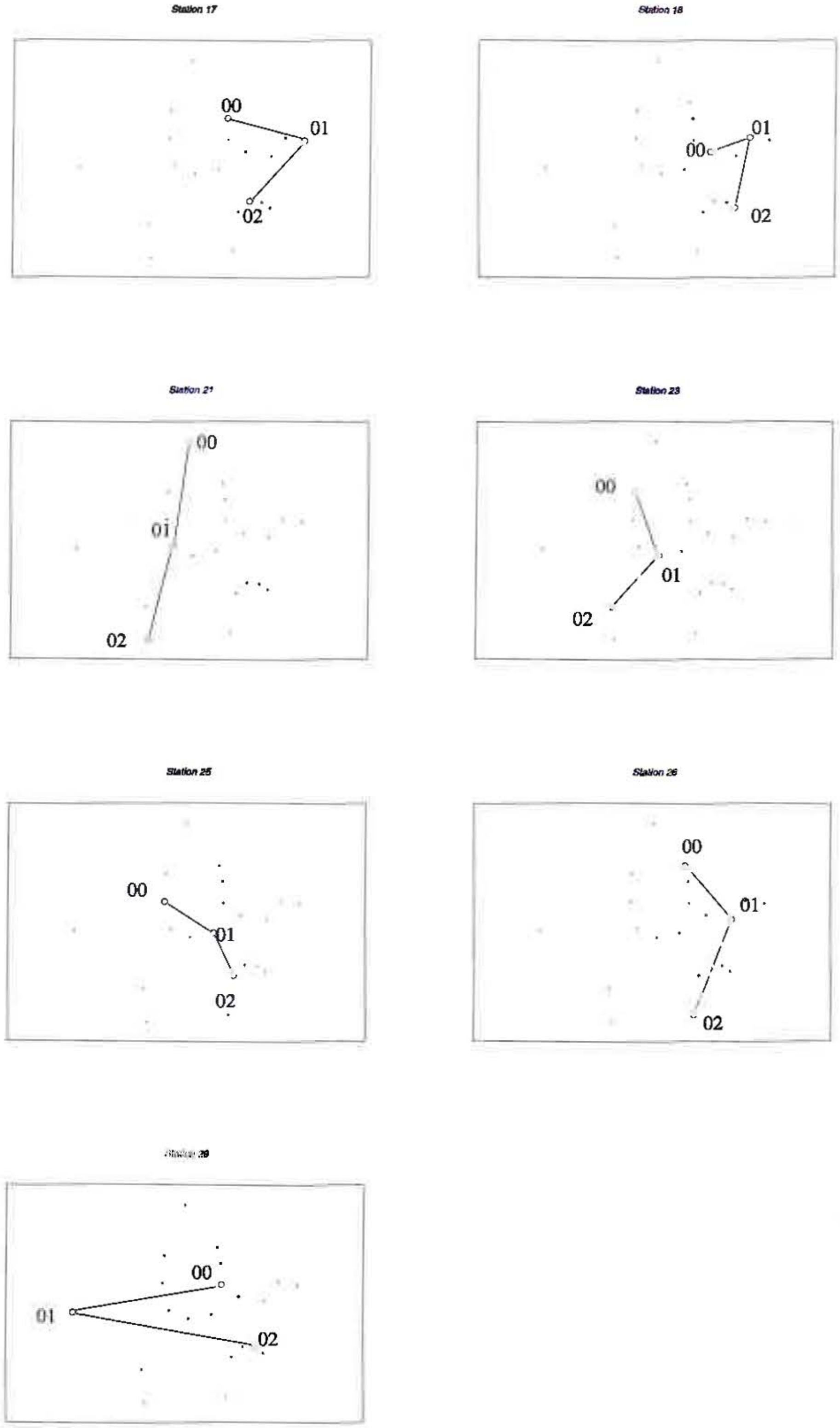


Figure 12: Plot showing the relationship between the total biomass of seagrass and the amount of silt (<63μm) at each sampling station. Estimates of the amount of silt present are means derived from 10 replicate grab samples.

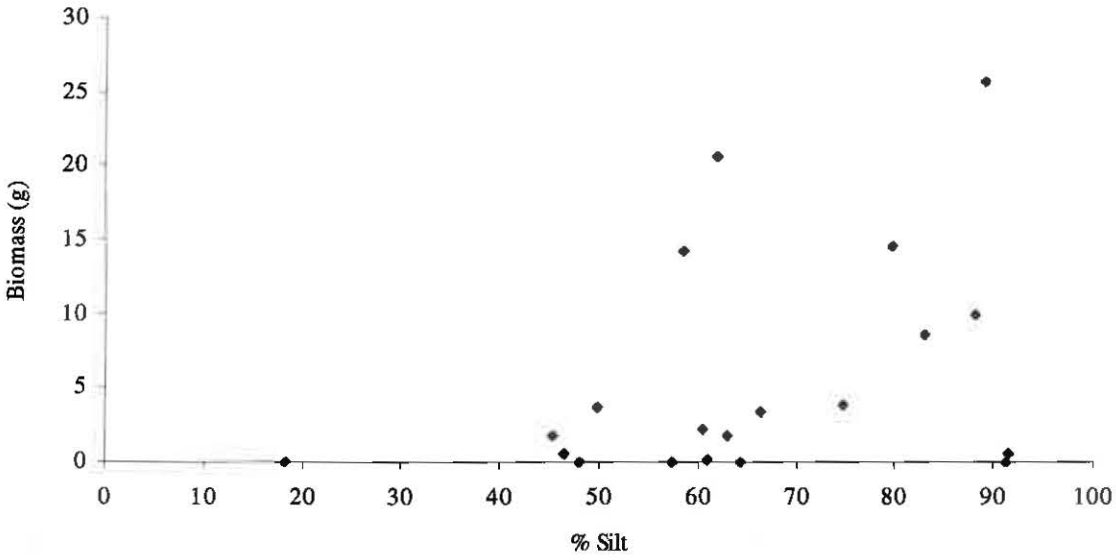


Table 1a. Results of two-way ANOVA on differences in total seagrass cover at seven stations (17,18,21,23,25,26,29) sampled on three dates (November 2000, September 2001 and November 2002).

Source	*Type III Sum of*	*df*	*Mean Square*	*F*	*Sig.*	*Observed*[a]
Corrected Model	10301.744[b]	20	515.087	38.672	0.000	1.000
Intercept	9520.260	1	9520.260	714.762	0.000	1.000
DATE	2989.999	2	1494.999	112.241	0.000	1.000
LOCATION	4361.333	6	726.889	54.573	0.000	1.000
DATE * LOCATION	2950.412	12	245.868	18.459	0.000	1.000
Error	2517.384	189	13.319			
Total	22339.388	210				
Corrected Total	12819.127	209				

[a] Computed using alpha = 0.05
[b] R Squared = .804 (Adjusted R Squared = 0.783)

Table 1b. Results of the Student-Newman-Keuls post-hoc multiple comparison test for differences in the mean percentage cover of seagrass between the seven Port Curtis sampling stations (17,18,21,23,25,26,29).

	Location	*N*	*Subset*			
			1	2	3	4
Student-Newman-Keuls	17	30	1.4917			
	29	30	2.9250			
	23	30		5.2633		
	18	30		5.3350		
	25	30			7.5167	
	21	30			8.0167	
	26	30				16.5833
	Sig.		0.130	0.939	0.596	1.000

Table 1c. Results of the Student-Newman-Keuls post-hoc multiple comparison test for differences in the mean percentage cover of seagrass between three sampling dates (2000, 2001 and 2002).

	Date	*N*		*Subset*
			1	2
Student-Newman-Keuls	NOV-02	70	3.7171	
	SEP-01	70	4.4286	
	NOV-00	70		12.0536
	Sig.		0.250	1.000

Table 2. Change in percentage seagrass and algal cover at seven sampling stations in Port Curtis. Means and associated standard deviations are derived from ten replicate 0.5m² diver quadrats sampled in November 2000, September 2001 and November 2002.

Site	Station	% Cover														
		Halophila ovalis			*Halophila decipiens*			*Halophila spinulosa*			*Zostera capricorni*			Algae		
		2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002
Friends Point	17	0	0	0.40 (1.26)	11.60 (8.73)	0	0.60 (1.35)	4.40 (6.92)	0	0.00	0.90 (1.66)	0	0.00	0	0	0
"	18	0	0	0.00	62.20 (20.54)	0	0.20 (0.42)	1.60 (5.06)	0	0.00	0	0	0.00	0	0	0
Flying Fox Ck	21	0	0	0.00	0	0	0.00	0	0	0.00	67.40 (30.73)	16.80 (5.27)	12.00 (7.94)	0	0	0
"	23	0	0	12.00 (7.77)	0	0	0.00	0	0.40 (1.26)	0.00	23.00 (15.00)	19.00 (14.70)	7.60 (6.65)	0	0	0
Worthington Isl	25	0.20 (0.63)	0		0	0	18.70 (13.18)	2.80 (6.55)	0	2.10 (4.93)	66.00 (28.24)	0	0.40 (0.52)	0	0	0
"	26	0	0	2.10 (6.30)	0	0		0	0	29.10 (17.57)	95.00 (8.50)	72.80 (26.45)	0	0	0	0
Black Swan	29	0	0	17.40 (22.15)	0	0		0	2.40 (3.37)		2.40 (4.30)	12.60 (11.32)	0.30 (0.67)	0	0	0

Table 3a. Results of two-way ANOVA on differences in total seagrass biomass at seven stations (17,18,21,23,25,26,29) sampled on three dates (November 2000, September 2001 and November 2002).

Source	*Type III Sum of Squares* [b]	*df*	*Mean Square*	*F*	*Sig.*	*Observed Power* [a]
Corrected Model	112.711	20	5.636	17.764	0.000	1.000
Intercept	59.456	1	59.456	187.417	0.000	1.000
DATE	36.329	2	18.164	57.257	0.000	1.000
LOCATION	50.820	6	8.470	26.699	0.000	1.000
DATE * LOCATION	25.562	12	2.130	6.715	0.000	1.000
Error	59.959	189	0.317			
Total	232.125	210				
Corrected Total	172.669	209				

[a] Computed using alpha = 0.05
[b] R Squared = 0.653 (Adjusted R Squared =0.616)

Table 3b. Results of Student-Newman-Keuls post-hoc multiple comparison test for differences in the mean biomass of seagrass between the seven Port Curtis sampling stations (17,18,21,23,25,26,29).

	Station	*N*	*Subset*			
			1	2	3	4
Student-Newman-Keuls	17	30	0.0723			
	29	30	0.0870			
	18	30	0.1237			
	25	30	0.3527			
	23	30		0.6473		
	21	30			0.9723	
	26	30				1.4693
	Sig.		0.220	1.000	1.000	1.000

Table 3c. Results of the Student-Keuls post-hoc multiple comparison test for differences in the mean biomass of seagrass between the three sampling dates (November 2000, September 2001 and November 2002) in Port Curtis.

	Date	*N*	*Subset*		
			1	2	3
Student-Newman-Keuls	NOV-02	70	0.0986		
	SEP-01	70		0.4046	
	NOV-00	70			1.0931
	Sig.		1.000	1.000	1.000

Table 4. Change in mean above ground biomass, shoot number and leaf length of four seagrass species at seven sampling stations in Port Curtis. Means and associated standard deviations are derived from ten replicate 0.1m² van-Veen grab samples collected during November 2000, September 2001 and November 2002.

Site	Station	Species	Dry weight (g/0.01m³)						No. Shoots			Leaf Length (cm)		
			2000 Above	2001 Above	2002 Above	2000 Below	2001 Below	2002 Below	2000	2001	2002	2000	2001	2002
Friends Point	17	*H. decipiens*	0.2 (0.13)	0	0	0.21 (0.14)	0	0	165 (131)	0	0	1.39 (0.10)	0	0
"	17	*H. spinulosa*	0.02 (0.07)	0	0	0.01 (0.02)	0	0	0	0	0	1.85 (0.00)	0	0
"	18	*H. decipiens*	0.37 (0.12)	0	0	0.34 (0.08)	0	0	290 (132)	0	0	1.25 (0.14)	0	0
Flying Fox Ck	21	*Z. capricorni*	1.88 (0.78)	0.84 (0.25)	0	3.11 (1.11)	1.67 (0.83)	0	275 (82)	217 (84)	0	9.54 (1.18)	6.87 (0.82)	0
"	21	*H.ovalis*	0.04 (0.11)	0.02 (0.05)	0	0.03 (0.09)	0.05 (0.16)	0	11 (28)	0	0	1.48 (0.00)	0.97 (0.20)	0
"	23	*Z. capricorni*	0.97 (0.74)	0.33 (0.17)	0.05 (0.05)	1.46 (0.95)	1.18 (0.06)	0.21 (0.19)	125 (84)	188 (115)	16 (17)	9.15 (0.83)	3.74 (0.50)	5.32 (1.49)
"	23	*H.ovalis*	0.36 (0.16)	0	0.14 (0.08)	0.41 (0.24)	0	0.20 (0.13)	115 (87)	4 (9)	43 (26)	1.83 (0.19)	1.39 (0.21)	1.75 (0.60)
Worthington Is	25	*Z. capricorni*	0.82 (0.62)	0.01 (0.01)	0	1.19 (0.63)	0.01 (0.01)	0	66 (49)	10 (12)	0	12.50 (2.32)	0.90 (0.22)	
"	25	*H.ovalis*	0.03 (0.04)	0	0.03 (0.05)	0.03 (0.04)	0	0.03 (0.04)	13 (13)	0	13 (27)	2.13 (0.25)	0	1.00 (0.00)
	25	*H. decipiens*	0	0	0.01 (0.03)	0	0	0.01 (0.02)	0	0	13 (27)	0	0	1.45 (0.46)
"	25	*H. spinulosa*	0.15 (0.29)	0	0.02 (0.03)	0.15 (0.30)	0	0.01 (0.01)	8 (17)	0	2 (4)	1.48 (0.06)	0	1.62 (0.28)
"	26	*Z. capricorni*	2.44 (2.09)	1.46 (0.84)	0.38 (0.14)	4.04 (1.71)	3.28 (1.48)	1.92 (0.73)	276 (71)	238 (95)	106 (66)	12.60 (3.21)	8.42 (1.93)	6.49 (2.82)
	26	*H. ovalis*	0	0	0.01 (0.02)	0	0	0.02 (0.03)	0	0	15 (24)	0	0	1.26 (0.61)
"	26	*H. spinulosa*	0.02 (0.08)	0	0	0.02 (0.05)	0	0	1 (2)	0	0	1.34 (0.00)	0	
Black Swan	29	*Z. capricorni*	0.02 (0.05)	0.03 (0.04)	0.03 (0.05)	0.03 (0.06)	0.08 (0.01)	0.05 (0.09)	1 (3)	9 (13)	6 (10)	4.93 (0.00)	7.63 (0.62)	7.12 (2.47)
"	29	*H.ovalis*	0	0.15 (0.09)	0.04 (0.07)	0	0.24 (0.16)	0.02 (0.04)	0	55 (32)	10 (16)	0	1.88 (0.11)	1.70 (0.57)

Table 5a. Results of two-way ANOVA on differences in the biomass of four seagrass species (*Z. capricorni, H. ovalis, H. spinulosa and H. decipiens*) on three sampling dates (November 2000, September 2001 and November 2002).

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Observed Power*
Corrected Model	55.816	11	5.074	29.466	0.000	1.000
Intercept	14.864	1	14.864	86.316	0.000	1.000
DATE	9.082	2	4.541	26.370	0.000	1.000
SPECIES	29.123	3	9.708	56.372	0.000	1.000
DATE * SPECIES	17.612	6	2.935	17.045	0.000	1.000
Error	142.586	828	0.172			
Total	213.266	840				
Corrected Total	198.402	839				

[a] Computed using alpha = 0.05
[b] R Squared = 0.281 (Adjusted R Squared = 0.272)

Table 5b. Results of Student-Newman-Keuls post-hoc multiple comparisons test for differences in the mean biomass of four species of seagrass (*Z. capricorni, H. ovalis, H. decipiens* and *H. spinulosa)* sampled during November 2000, September 2001 and November 2002 in Port Curtis.

	Species	*N*	*Subset*	
			1	2
Student-Newman-Keuls	*H. spinosa*	210	0.0037	
	H. decipiens	210	0.0349	
	H. ovalis	210	0.0389	
	Z. capricorni	210		0.4547
	Sig.		0.661	1.000

Table 5c. Results of Student-Newman-Keuls post –hoc multiple comparison test for differences in the mean biomass of seagrass between three sampling dates (November 2000, September 2001 and November 2002) in Port Curtis.

	Date	*N*	*Subset*		
			1	2	3
Student-Newman-Keuls	NOV-02	280	0.0246		
	SEP-01	280		0.1011	
	NOV-00	280			0.2733
	Sig.		1.000	1.000	1.000

Table 5d. Mean above ground dry weights of four seagrass species (*Z. capricorni, H. ovalis, H. decipiens* and *H. spinulosa)* collected in grab samples at seven stations (17,18,21,23,25,26,29) during November 2000, September 2001 and November 2002.

Species	*Mean (s.e.)*		
	2000	2001	2002
Z. capricorni	0.92 (0.15)	0.38 (0.07)	0.06 (0.02)
H. ovalis	0.06 (0.02)	0.02 (0.01)	0.03 (0.01)
H. decipiens	0.10 (0.02)	0.00 (0.00)	0.00 (0.00)
H. spinulosa	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)

Table 6a. Results of two-way ANOVA on differences in the biomass of *Zostera capricorni* at seven stations (17,18,21,23,25,26,29) sampled on three dates (November 2000, September 2001 and November 2002).

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Observed Power*[a]
Corrected Model	109.710[b]	20	5.485	19.029	0.000	1.000
Intercept	43.412	1	43.412	150.593	0.000	1.000
DATE	26.156	2	13.078	45.368	0.000	1.000
LOCATION	56.235	6	9.372	32.513	0.000	1.000
DATE * LOCATION	27.318	12	2.277	7.897	0.000	1.000
Error	54.483	189	.288			
Total	207.605	210				
Corrected Total	164.193	209				

[a] Computed using alpha = 0.05
[b] R Squared = 0.631 (Adjusted R Squared = 0.633)

Table 6b. Results of Student-Newman-Keuls post-hoc multiple comparisons test for differences in the mean biomass of *Zostera capricorni* between the seven Port Curtis sampling stations (17,18,21,23,25,26,29).

	Station	*N*	*Subset*			
			1	2	3	4
Student-Newman-Keuls	17	30	0.0000			
	18	30	0.0000			
	29	30	0.0247			
	25	30	0.2750	0.2750		
	23	30		0.4777		
	21	30			0.9533	
	26	30				1.4520
	Sig.		0.198	0.145	1.000	1.000

Table 6c. Results of the Student-Newman-Keuls post- hoc multiple comparison test for the differences in the mean biomass of *Zostera capricorni* between three sampling dates (November 2000, September 2001 and November 2002) in Port Curtis.

	Date	*N*	*Subset*		
			1	2	3
Student-Newman-Keuls	NOV-02	70	0.0647		
	SEP-01	70		0.3799	
	NOV-00	70			0.9194
	Sig.		1.000	1.000	1.000

Table 7. Annual change in the total abundance and richness of five macrobenthic taxa collected from seven seagrass sampling stations (17,18,21,23,25,26,29) during November 2000, September 2001 and November 2002.

Taxa	Abundance				Richness			
	2000	2001	2002	Total	2000	2001	2002	Total
Polychaete	237	154	154	545	37	27	32	58
Crustacea	129	79	78	286	24	12	19	41
Bivalvia	256	203	276	735	38	17	11	45
Gastropoda	86	3	228	317	15	3	4	18
Miscellaneous	15	13	15	43	4	5	7	13
TOTAL	723	435	751	1926	118	64	73	175

Table 8. Change in macrofaunal richness, abundance and diversity (Shannon Weiner) at seven seagrass sampling stations (17,18,21,23,25,26,29) surveyed during November 2000, September 2001 and November 2002. Note that species richness and abundance values given are totals obtained from 10 x $0.1 m^2$ van Veen grab samples.

Site	Station	Richness			Abundance			Diversity		
		2000	2001	2002	2000	2001	2002	2000	2001	2002
Friends Point	17	35	19	23	90	51	154	3.09	2.27	2.19
"	18	31	23	19	103	67	135	3.2	2.65	1.76
Flying Fox Ck	21	17	21	9	58	72	28	1.94	2.68	1.77
"	23	37	15	10	112	84	17	3.17	2.35	2.03
Worthington Is	25	31	19	24	124	87	201	2.44	2.08	1.64
"	26	41	17	21	151	83	67	3.03	2.18	2.59
Black Swan	29	30	5	28	85	8	149	2.83	1.49	2.29
Mean (s.d.)		31.70 (7.59)	17.00 (5.89)	20.00 (8.00)	103.29 (29.84)	64.57 (27.89)	107.29 (70.16)	2.81 (0.47)	2.24 (0.40)	2.04 (0.34)

Table 9a. Results of two-way ANOVA on differences in the abundance of benthic organisms at seven seagrass sampling stations (17,18,21,23,25,26,29) surveyed on three dates (November 2000, September 2001 and November 2002).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power [a]
Corrected Model	4733.429 [b]	20	236.671	8.320	0.000	1.000
Intercept	17664.171	1	17664.171	620.960	0.000	1.000
DATE	779.171	2	389.586	13.695	0.000	0.998
STATION	1312.229	6	218.705	7.688	0.000	1.000
DATE * STATION	2642.029	12	220.169	7.740	0.000	1.000
Error	5376.400	189	28.447			
Total	27774.000	210				
Corrected Total	10109.829	209				

[a] Computed using alpha = 0.05

[b] R Squared = 0468 (Adjusted R Squared =0.412)

Table 9b. Results of Student-Newman-Keuls post-hoc multiple comparisons test for differences in mean macrofaunal abundance between seven seagrass sampling stations (17,18,21,23,25,26,29) in Port Curtis.

	Station	*N*	*Subset*		
			1	2	3
Student-Newman-Keuls	21	30	5.27		
	23	30	7.10	7.10	
	29	30	8.07	8.07	
	17	30		9.83	
	26	30		10.03	
	18	30		10.17	
	25	30			13.73
	Sig.		0.107	0.174	1.000

Table 9c. Results of the Student-Newman-Keuls post- hoc multiple comparison test for the differences in the mean abundance of benthic organisms between three sampling dates (November 2000, September 2001 and November 2002) in Port Curtis.

	Date	*N*	*Subset*	
			1	2
Student-Newman-Keuls	SEP-2001	70	6.46	
	NOV-2000	70		10.33
	NOV-2002	70		10.73
	Sig.		1.000	0.658

Table 10a. Results of two-way ANOVA on differences in the richness of benthic organisms at seven seagrass sampling stations (17,18,21,23,25,26,29) surveyed on three dates (November 2000, September 2001 and November 2002).

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Observed Power*[a]
Corrected Model	861.229[b]	20	43.061	7.616	0.000	1.000
Intercept	5190.171	1	5190.171	917.970	0.000	1.000
DATE	249.457	2	124.729	22.060	0.000	1.000
STATION	178.895	6	29.816	5.273	0.000	0.995
DATE * STATION	432.876	12	36.073	6.380	0.000	1.000
Error	1068.600	189	5.654			
Total	7120.000	210				
Corrected Total	1929.829	209				

[a] Computed using alpha = 0.05
[b] R Squared = .446 (Adjusted R Squared =0.388)

Table 10b. Results of Student-Newman-Keuls post-hoc multiple comparisons test for differences in mean species richness between seven seagrass sampling stations (17,18,21,23,25,26,29) in Port Curtis.

	Station	*N*	*Subset* 1	2
Student-Newman-Keuls	21	30	3.30	
	29	30	4.33	4.33
	23	30	4.40	4.40
	25	30		5.23
	17	30		5.63
	26	30		5.87
	18	30		6.03
	Sig.		0.175	0.067

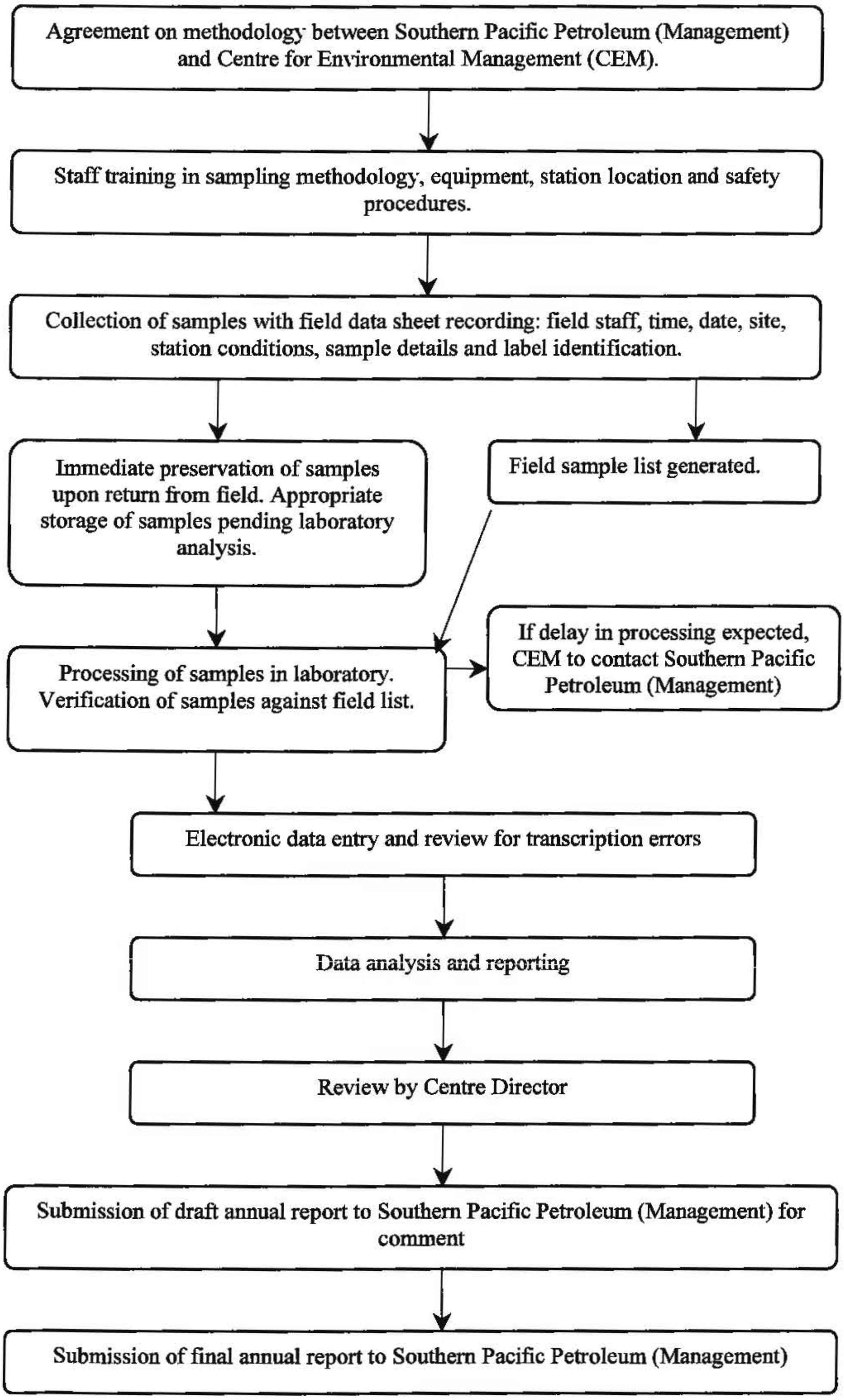
Table 10c. Results of the Student-Newman-Keuls post- hoc multiple comparison test for differences in the mean richness of benthic organisms between three sampling dates (November 2000, September 2001 and November 2002) in Port Curtis.

	Date	*N*	*Subset* 1	2
Student-Newman-Keuls	SEP-2001	70	3.91	
	NOV-2002	70	4.53	
	NOV-2000	70		6.47
	Sig.		0.128	1.000

Table 11. Percentage size distribution of sediment collected from benthic grab samples (n=10) at seven seagrass sampling stations (17,18,21,23,25,26,29) surveyed during November 2000, September 2001 and November 2002.

Site	Station	<63um (silt and clay)			63um - 1mm (sands)			>1mm (granules)		
		2000	2001	2002	2000	2001	2002	2000	2001	2002
Friends Point	17	60.41	57.33		33.65	42.67		5.94	0.00	
"	18	49.82	48.02	64.37	45.80	51.98	32.48	4.38	0.00	3.16
Flying Fox Ck	21	61.81	82.98	18.30	34.79	17.02	49.91	3.40	0.00	31.79
"	23	58.38	66.22	63.01	32.68	33.78	33.27	8.94	0.00	3.71
Worthington	25	88.18	91.32	91.61	10.99	8.68	7.36	0.83	0.00	1.03
"	26	89.04	79.60	74.87	10.91	20.40	21.61	0.06	0.00	3.52
Black Swan	29	60.89	45.34	46.51	32.37	54.66	35.91	6.75	0.00	17.58

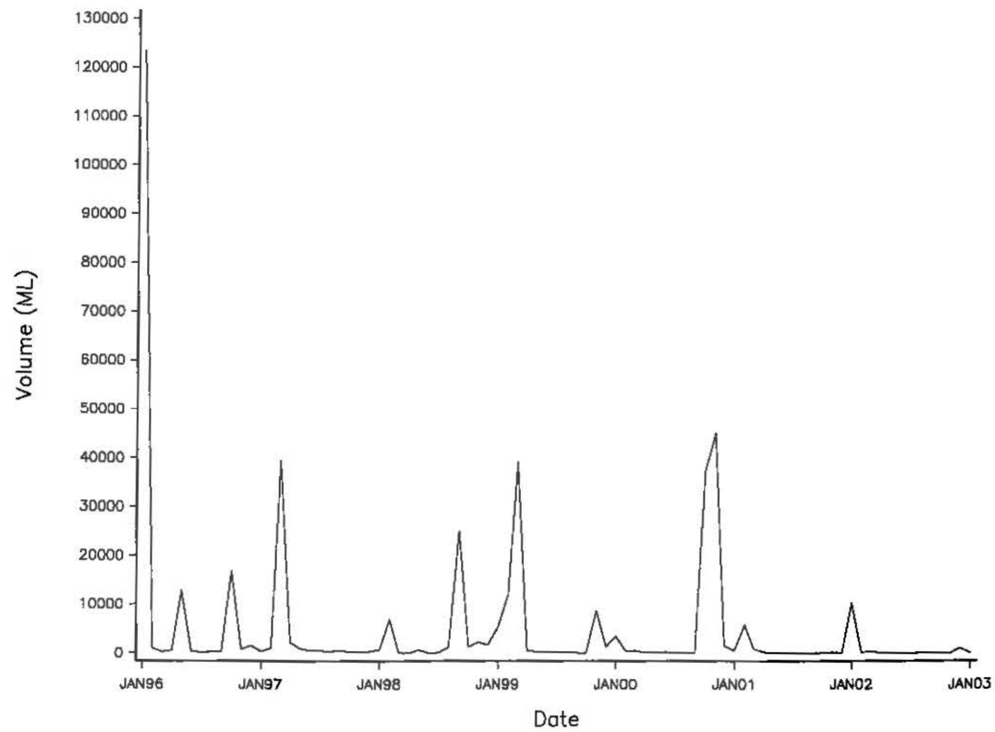
Appendix 1. Quality Control Procedures



Appendix 2. Physical data/ Port wide seagrass data

Figure 1: Total monthly (a) discharge volume (ML) and (b) rainfall (mm) measured at Calliope River, Castlehope from January 1996 to January 2002.

(a)



(b)

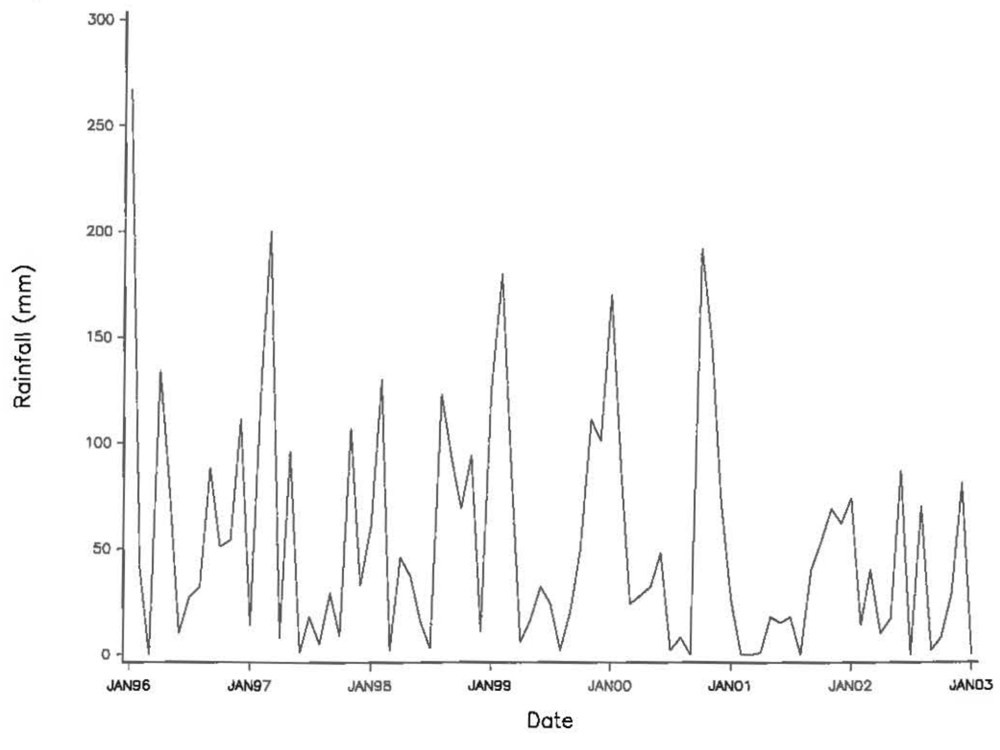
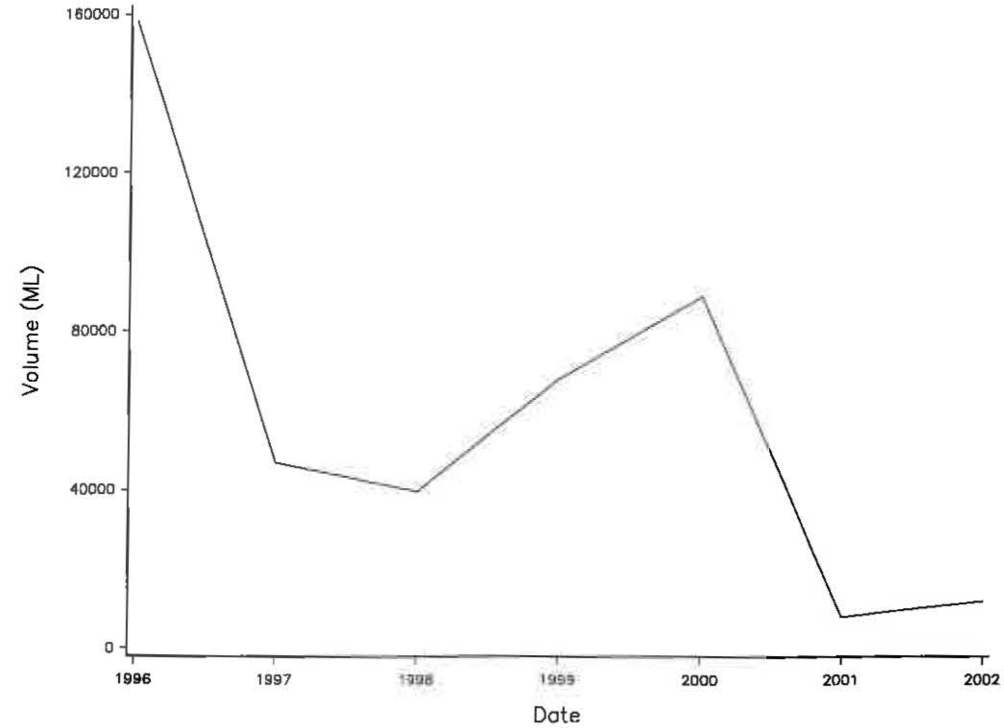


Figure 2: Total annual (a) discharge volume (ML) and (b) rainfall (mm) measured at Calliope River, Castlehope from January 1996 to January 2002.

(a)



(b)

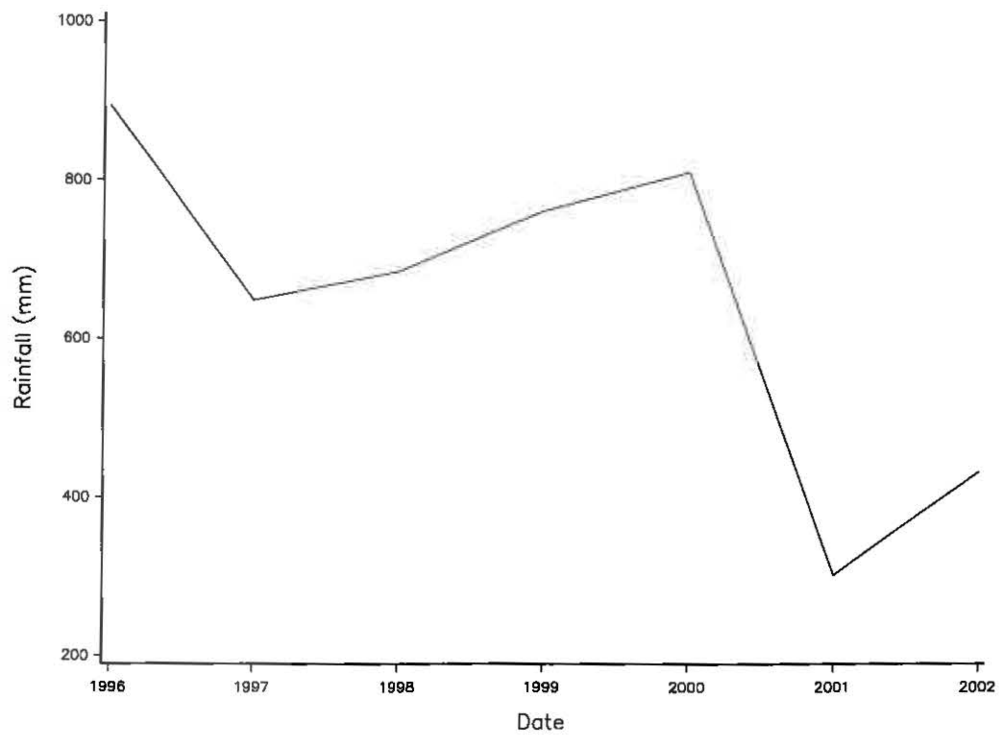


Figure 3: Mean annual turbidity (NTU) and associated standard errors taken at Wiggins Island, Port Curtis Harbour from July 1996 to April 2003. Yearly means are calculated from hourly (or 10 minute interval) turbidity measurement values.

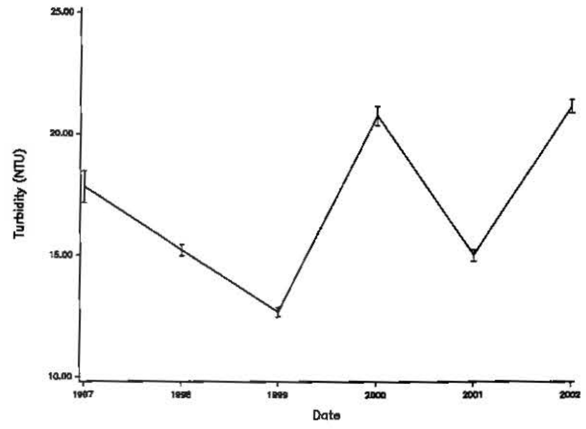


Figure 4: Mean annual (a) turbidity (NTU), (b) phosphate (ppb), (c) electrical conductivity (µS) and (d) temperature (°C) and associated standard errors taken at Clinton coal wharf (Port Curtis Harbour) from January 1998 to December 2002 (Phosphate is missing 2000). Yearly means are calculated from daily (4 readings in 24 hours) measurement values.

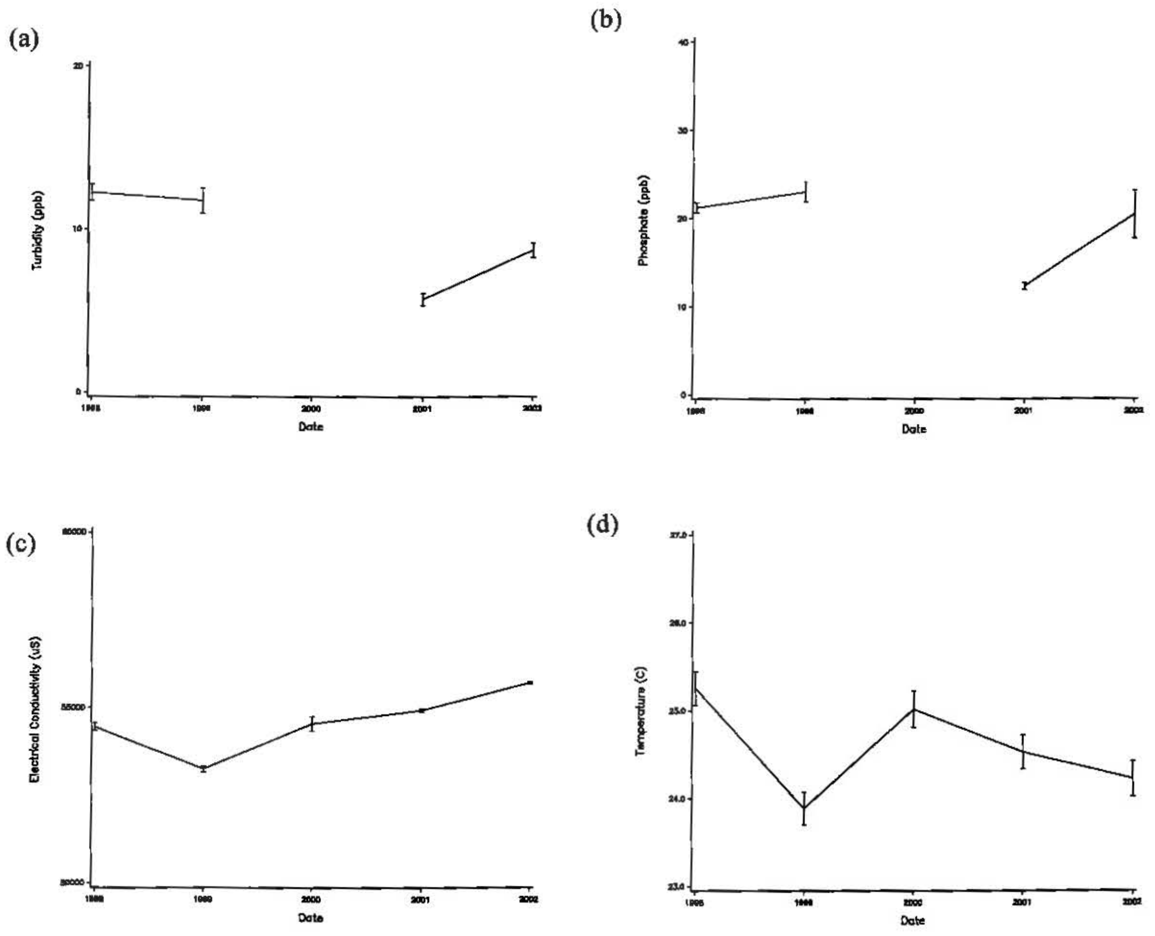


Figure 5: Map of *Zostera capricorni* biomass collected at SPP(M) and Port Wide seagrass sampling sites in August/September 2002 and November 2002 consecutively.

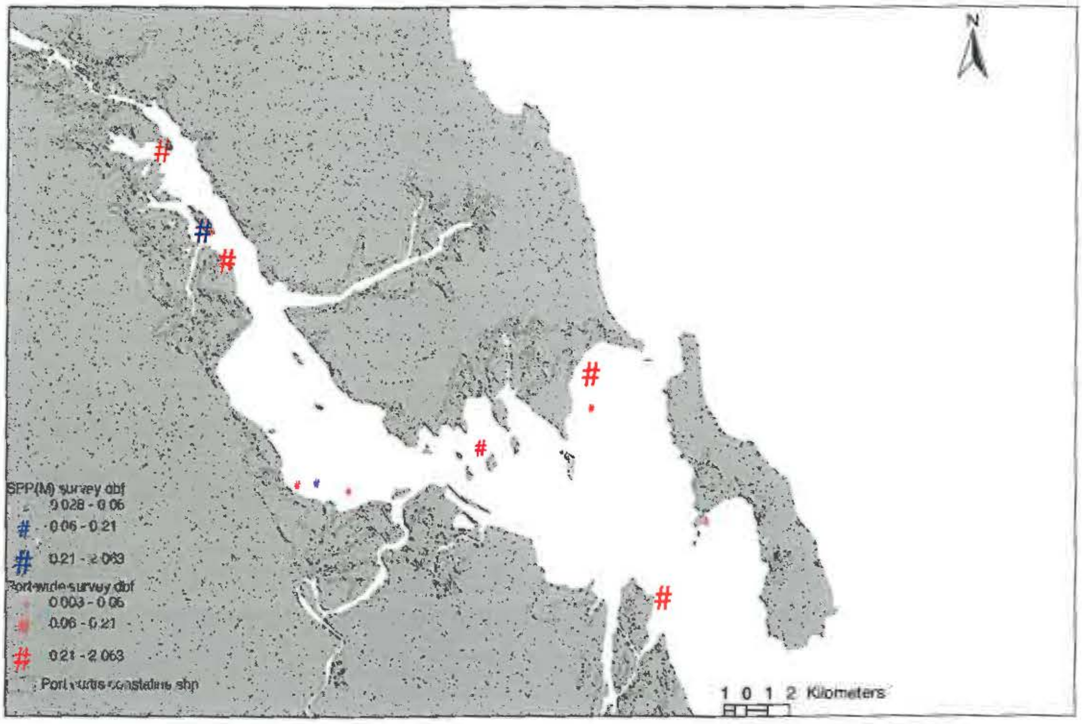


Table 1: Seagrass biomass values for six species collected from 28 port-wide seagrass and macrobenthic survey sampling sites in August/September 2002.

Rank Species	Stations	Grabs	Depth range	Biomass
1 *Zostera capricorni*	11	25	+1.6 to –0.4	6.89 (73.5%)
2 *Halodule pinifolia*	6	15	+1.7 to –1.1	0.77 (8.2%)
3 *Halophila ovalis*	4	7	+1.3 to –0.1	0.25 (2.7%)
4 *Halodule uninervis*	3	7	+0.9 to +0.3	0.22 (2.3%)
5 *Halophila ovata*	2	3	+0.7 to +0.4	0.01 (0.1%)
6 *Halophila spinulosa*	2	3	-0.32 to –16.0	1.24 (13.2%)