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Monitoring Oyster Point Seagrasses - 1995 to 1999

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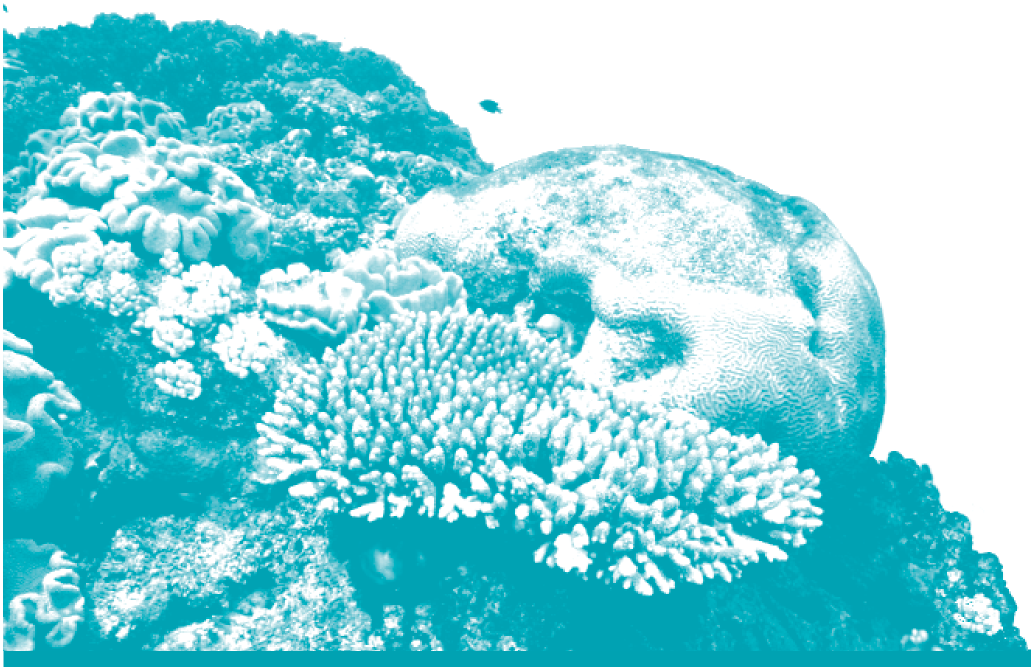
Robert G Coles and Len J McKenzie



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SUMMARY

The Queensland Department of Primary Industries, Northern Fisheries Centre, was contracted by the Great Barrier Reef Marine Park Authority to test for persistence of a silt layer identified in a November 1998 seagrass survey of the Oyster Point Region and which covered seagrasses in the northern part of the survey area. Seagrass surveys of this area prior to the present survey were contracted by the Department of State Development to provide maps of seagrasses at Oyster Point, Cardwell, prior to, during and after capital and maintenance dredging of the boat channel and marina at the Port Hinchinbrook development. The aim of these surveys was to assess possible impacts of dredging on adjacent seagrass habitats. This included measuring any changes in seagrass biomass, species composition and distribution that may result from changes in hydrology, sediment transport and depth profiles. These original surveys also reported on the type and abundance of animals of fisheries value found in the seagrass meadows.

In the present report, an assessment of changes in seagrass distribution and abundance since the baseline (November 1995) and previous monitoring surveys of December 1997 and November 1998 is included. We provide a quantification of changes between years and comment on the possible impacts of the dredging program.

Seagrass survey methodology was based on standard techniques developed for monitoring seagrasses in tropical Queensland ports (see Coles et al. 1996b; Lee Long et al. 1996). Information collected from transect sites and from randomly located sites were used to map the seagrass meadow boundaries and to estimate biomass (by species) in the monitoring area. Sampling was conducted in late spring (November/December) each year to allow comparison between years without a seasonal component. Estimates of aboveground seagrass biomass, percent seagrass species composition of biomass, percent cover of algae and sediment characteristics were recorded at each site. Differential GPS fixes (±1.5m) and the depths to the nearest decimetre at each survey site were also recorded. All survey data were entered onto the Geographic Information System (GIS) (MapInfo®) for presentation of seagrass species distribution and abundance. Meadow boundaries drawn on GIS maps are based on above-ground seagrass presence/absence information and location of sample sites.

Major Findings include:

1. There were initial losses of low-density seagrasses (up to 0.3 ha) where capital dredging of the access channel cut through existing meadows. There has been no seagrass regrowth in the dredged channel and regrowth is not expected because of tidal flows and low light intensities under the turbid silt layer. The seagrass community on the edges immediately adjacent to the dredged access channel was similar each year before and after dredging.
2. The silty layer identified in November 1998 north of the access channel did not persist through to December 1999. The source of the silty layer could not be linked to sediments found in the dredged channel. Seagrasses that were showing signs of recent silt burial in November 1998 had mostly recovered by December 1999.

3. Six species of seagrasses occurred at Oyster Point during the study (1995-1999). The three dominant species (*Halophila ovalis, Halophila decipiens* and *Halodule uninervis/pinifolia*) are fast-growing and naturally highly variable in abundance. *Halophila spinulosa* and *Halophila tricostata* occurred in small amounts in baseline surveys, and were uncommon, or not found, in later surveys.
4. Above-ground biomass, area and depth ranges for each of the major seagrass species at Oyster Point decreased between 1995 and 1998, then recovered (back to near 1995 levels) in 1999. Apart from the initial loss of seagrass in the dredged channel, these changes are within the ranges of natural variation for these seagrass species measured at other tropical locations in Queensland, and are natural biological processes. Increased wind and cloud and reduction in light reaching the seagrass from 1995 to 1998 are the likely causes of the declines in seagrass biomass.
5. Total area of seagrass habitat mapped in the survey area varied little ranging from 252 ±16 ha in November 1998 to 312 ±14 ha in December 1999.
6. The distribution and biomass of *Halophila decipiens* varied widely between years. Reductions occurred between November 1995 and November 1998, followed by increases in 1999. These changes were in areas well away from Oyster Point, and included the "reference" areas, indicating that changes were widespread.
7. Maximum depth ranges of the major species shallowed in 1997, 1998 and 1999. There were, however, no changes in the distribution and location of the seagrass meadows or in the sea floor topography that could explain these differences in seagrass depth. Decreases in maximum depth ranges observed in 1997 and 1998 are likely a result of lower light availability caused by increased wind driven turbidity in the two month period leading up be these surveys.
8. *Halophila decipiens* had the deepest mean depth of occurrence in each survey. Mean depth below Mean Sea Level (MSL) for *Halophila decipiens* at Oyster Point was significantly shallower in December 1997 and November 1999 than in November 1995 (0.28m and 0.24m respectively). *Halophila ovalis* and *Halodule pinifolia/uninervis* average depths did not change significantly.
9. There were declines in seagrass biomass (all species pooled) in the study area from 1995 to 1998, followed by a return to near pre-dredging (1995) biomass in 1999. The changes were within the ranges of natural variability measured in the region and were uneven across the study area.
10. Long-term monitoring (15 to 20 years) is required for a complete assessment of changes in seagrasses adjacent to Oyster Point. This 4-year study provides a useful starting point and a baseline for further monitoring.

INTRODUCTION

Seagrasses are recognised as a major component of the marine ecology at Oyster Point. They play important roles in supporting marine food webs and species of fisheries value, buffering sediment and nutrient impacts, and as food to local dugong and turtle populations. The Oyster Point seagrasses are part of an almost continuous seagrass habitat, which extends from Mangrove Point in Hinchinbrook Channel to Meunga Creek, north of Cardwell (Lee Long et al. 1998a) - possibly an important feeding corridor for dugong. A review of tropical seagrasses ecology and the impacts of natural and anthropogenic factors (see Coles et al. 1997) demonstrated the need to map and monitor seagrass resources at Oyster Point and to identify areas requiring special conservation measures.

Reconnaissance and baseline surveys by Coles et al. (1996a; 1997) documented the distribution and abundance of seagrass meadows in the vicinity of Oyster Point in September 1994, November 1995 and August 1996. These surveys provided measures of natural seasonal variability in seagrasses at Oyster Point prior to capital dredging of the main boat access channel in Spring 1997.

Maintenance dredging of the main boat channel at Oyster Point began in August 1998 and continued beyond the November 1998 monitoring survey into early 1999. The marina was also deepened during 1998. The opening and widening of the marina entrance began on 20th November - 4 days prior to the 1998 monitoring survey.

Seagrass monitoring surveys were conducted in December 1997 (Lee Long et al. 1998b) (immediately following capital dredging) and November 1998 (Lee Long et al. 1999) (immediately after opening and widening of the marina entrance, and while dredging of the marina and maintenance dredging of the main boat channel continued). A silt layer was identified in the November 1998 survey, covering seagrasses in the northern survey region, and plants displayed symptoms of burial and light deprivation. The present monitoring survey (December 1999) was conducted for the Great Barrier Reef Marine Park Authority to test for persistence of the silt layer and possible impacts on seagrasses.

An assessment of changes in seagrass distribution and abundance in late Spring/early Summer since the baseline (November 1995) and with the previous monitoring surveys of December 1997 (Lee Long et al. 1998b) and November 1998 (Lee Long et al. 1999) is included. A quantification of changes between years and comment on possible impacts of the dredging program is provided.

METHODS

Site Description

Oyster Point is on the mainland coast at the northern end of the Hinchinbrook Channel (Figure 1). Two mainland catchments flow into this region. At the northern end, waters flow off the Cardwell Range that includes rainforests, plantation pine forests and agricultural land. At the southern end lies the Herbert River catchment that comprises mostly agricultural land (sugar cane and pasture).

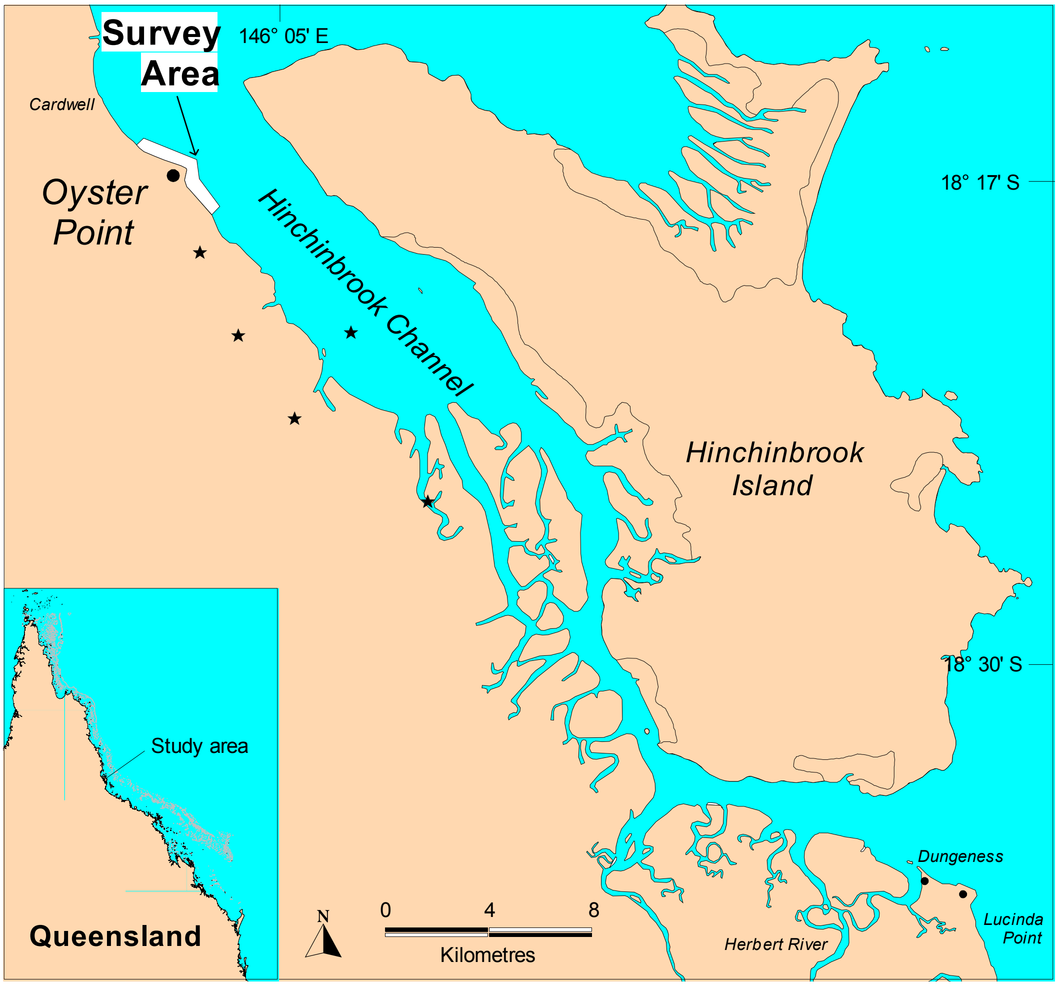

Figure 1. Location of Oyster Point survey area.
(★ denotes existing aquaculture facilities.)

Hinchinbrook Channel is approximately 4 km wide and up to 20 m deep near Oyster Point. Mangrove and *Melaleuca* wetlands and dry sclerophyll woodlands form a major part of the vegetation of the landward (western) margin of the channel. Average annual rainfall for the Cardwell area is 2129 mm, of which 1450 mm falls from January to March (Director of Survey, Department of Defence, Canberra). The only urban coastal developments adjacent to the channel are Cardwell immediately north and the small township of Dungeness in the south. There are two prawn farms and two barramundi farms operating south of Oyster Point, and a small pearl-raft aquaculture operation in the Hinchinbrook Channel. The Port Hinchinbrook development at Oyster Point is a residential and tourist complex including a marina and access channel.

Sampling Design

Seagrass survey methodology was based on standard techniques developed for monitoring seagrasses in tropical Queensland ports (see Coles et al. 1996b; Lee Long et al. 1996). Transects, fixed point sample sites and randomly located sites were used to map the seagrass meadow boundaries and estimate biomass (by species) in the monitoring region which extended 2 km north and 2 km south of Oyster Point (Map 1). Impacts were assumed to be most likely in the north survey region because of the net northward current flow and possible entrainment of sediments (Wolanski 1994; Sinclair Knight Merz (SKM) 1998).

QDPI were asked to include control sites in the Oyster Point sample design from 1997 in a BACI-type design to test for further impacts on above ground biomass from dredging. Given the high spatial variability of the seagrass meadows, sediment types and water quality around Oyster Point, the establishment of 'true' control sites was not feasible. Instead, 'reference' regions were included to provide data on seagrass from areas close to the survey area. These were located 1 km north and 0.5 km south of the core monitoring area. Subsequent sampling of the reference regions from 1997 to 1999 indicated they were too different in seagrass biomass and water quality to be considered suitable for use in a comparative experimental design. The data from these regions were used to provide information as extensions of the north-south distance-from-Oyster Point and are treated this way in the final analysis.

Seagrass

Sampling was conducted in late spring (November/December) each year to allow comparison between years without a seasonal component:

13 – 15th November, 1995 (baseline)

18 – 20th December, 1997 (monitoring)

24 –27th November, 1998 (monitoring)

13 –15th December, 1999 (monitoring)

To measure changes in impact away from the source, 24 sampling transects in total were set perpendicular to the shoreline at measured intervals away from the dredged access channel,. Intervals between transects were approximately 100m in the first 1 km, then every 500m until the 2 km limit of the survey area.

Transects originated from permanent markers established in baseline surveys. Sampling sites on transects were a minimum 20 m apart and continued to at least the seaward edges of seagrass meadows. Additional random sites were sampled to measure continuity of bottom habitat between transects. Seabed habitat parameters were recorded at each site by a diver, within a 10 m radius of a point located by differential GPS.

At each site, the diver recorded estimates of aboveground seagrass biomass, percent seagrass species composition of biomass, percent cover of algae, sediment characteristics and other special notes. A differential global positioning system was used to accurately locate each survey site (±1.5m) and record time. Depths of survey sites were recorded with a depth sounder (nearest decimetre) and standardised to depth below mean sea level (MSL), corrected to tidal datum from recorded water levels for the Cardwell Storm Tide gauge (courtesy Queensland Transport, Maritime Division, 2001).

Above-ground seagrass biomass was determined in 3 replicate quadrats (each 0.25m^2) at each site, using a "visual estimates of biomass" technique described by Mellors (1991). This technique involved each observer ranking seagrass biomass in the field. Ranks were calibrated for each observer against quadrats that were harvested and measured. The regression equation that best explained the diver's rank estimate of biomass was used to convert that diver's field estimates to aboveground biomass (g DW m^{-2}).

Seagrasses were identified according to Kuo and McComb (1989). Sediment characteristics were described using visual estimates of grain size: shell grit, rock gravel, coarse sand, sand, fine sand and mud.

Geographic Information System

All survey data were entered onto a Geographic Information System (GIS) (MapInfo®), for presentation of seagrass species distribution and abundance. A GIS basemap using aerial photographic images (courtesy Beach Protection Authority, 01/08/1991, altitude 1830m) was rectified to AMG Zone 55 coordinates.

Boundaries of seagrass meadows were determined based on the GPS fix at each survey site. Meadow boundaries drawn on GIS maps are our estimates based on above-ground seagrass presence/absence information and location of sample sites.

Location and size of meadows mapped are affected by errors associated with digitising and rectifying aerial photographs onto basemaps and GPS fixes for survey sites. The error in determining the area of seagrass was estimated to be ±10 m either side of the meadow edge based on the distance between survey sites. Other errors associated with mapping, such as differences between the GPS and the diver's sampling position, were assumed to be embedded within this range. Estimates of error (in hectares) were calculated using the polygon buffer function in MapInfo®.

Analysis

Overall changes in seagrass biomass (all species and meadows pooled) between years were analysed using ANOVA. Biomass data were ln(x+1) transformed when data were non-normal.

"Reference" regions were different (seagrass biomass and water quality conditions) from the survey regions near Oyster Point. Because of this they could not be considered as "controls" for analysis of impacts in the survey regions. Instead, changes in seagrass biomass were assessed at each 100m interval away from Oyster Point and the access channel. The 'reference' regions only provide information as extensions of the north-south sample design.

The north and south survey regions at Oyster Point appeared to be affected differently by wind-driven waves and turbidity, and were treated separately. Subtidal seagrasses were analysed separately from intertidal seagrasses. Intertidal seagrasses receive a different light regime than sub-tidal plants because they are exposed at low tide. Mean lowest tide (0.45m above Lowest Astronomical Tide (LAT)) for the 2 month period (the period of shoot turnover for these species) prior to sampling was chosen as the level to separate intertidal sites from sub-tidal sites.

Year-to-year changes in aboveground seagrass biomass were analysed for all species pooled. Intertidal and sub-tidal zones were analysed separately in the northern and southern regions. Year-to-year changes in seagrass biomass were examined at each 100m increment away from Oyster Point using transect data only (Appendix - Table 2). Changes in the mean biomass value between 1995 to 1998 and 1998 to 1999 for each 100m increment within each depth zone (± the standard error of the difference between the two means) were plotted to assess trends (Figure 4).

Standard parametric tests were used for analysis of data (Sokal and Rohlf 1987). Non-parametric tests (Kruskal-Wallis) were used when data were unbalanced or non-normal. All divers had significant linear regressions when calibrating aboveground biomass estimates against a set of harvested quadrats (Appendix – Table 3). Depth analyses were performed on transect data only.

RESULTS

Seagrass Species

Six species of seagrasses (from two families) were identified in the survey area.

Seagrass taxa	**Nov 1995**	**Dec 1997**	**Nov 1998**	**Dec 1999**
Family *Hydrocharitaceae Jussieu*				
Halophila ovalis (Br.) D.J. Hook	✓	✓	✓	✓
Halophila decipiens Ostenfeld	✓	✓	✓	✓
Halophila spinulosa (R.Br.) Aschers. In Neumayer	✓	✓	✓	✓
Halophila tricostata Greenway	✓			
Family Cymodoceaceae Taylor				
Halodule uninervis (wide & narrow leaf)(Forsk.) Aschers*	✓	✓	✓	✓
Halodule pinifolia (Miki) den Hartog*	✓	✓	✓	✓

* *Halodule uninervis* (narrow leaf) and *Halodule pinifolia* are very similar in morphology and are difficult to distinguish underwater. Recent studies from the Queensland east coast suggest there are no genetic distinctions between the two currently recognised species (M. Waycott. Pers. Comm.). In this study (1995-1999) they have been combined and the data pooled for analyses.

Seagrass Distribution

The total area of seagrass habitat mapped in the monitoring region in December 1999 (312 ±14 ha) was greater than in all previous surveys (Table 1, Map 2).

Halophila ovalis was the most common species at Oyster Point and present in approximately 85% of the total area of seagrass mapped in December 1999 – similar to November 1998 (89%) and slightly greater than in December 1997 (75%) and November 1995 (70%) (Table 1, Map 5). There were two distinct zones of seagrass which persisted between years: a near-shore intertidal band dominated by *Halodule pinifolia/uninervis* (narrow) and a sub-tidal band dominated by *Halophila ovalis*, with some *Halophila decipiens* (Maps 3 to 5). *Halophila spinulosa, Halophila tricostata* and *Halodule uninervis* (wide) were uncommon and very patchily distributed within the survey region. Small areas of *Halophila tricostata* were found in baseline surveys (November 1995 and August 1996) seaward of *Halophila ovalis. Halophila tricostata* was absent in the last three annual monitoring surveys.

An estimated 0.3 ha of low-density seagrass was initially lost as a direct result of capital dredging. There has been no seagrass regrowth in the dredged channel. Regrowth is not expected because of tidal flows and low light intensities under the turbid silt layer. Small patches of seagrass (usually *Halophila ovalis)* were found immediately adjacent to the dredged channel each year.

Halophila decipiens did not occur close (within 300m) to Oyster Point during the study. Its distribution/location and area varied widely between years, with an overall increase in area from 73.8 ±8.8ha (November 1995) to 87.7 ±9.3ha (December 1999) (Table 1, Map 4). *Halophila ovalis* and *Halodule pinifolia/ uninervis* (narrow) area did not vary significantly between years (Table 1, Map 3 & Map 5).

Table 1. Frequency of occurrence (sites), mean above-ground biomass and area for each seagrass species at Oyster Point in November 1995, December 1997 November 1998, and December 1999.

Species	November 1995			December 1997			November 1998			December 1999		
	sites	Biomass (±SE) (g DW m^{-2})	Area (ha)	sites	Biomass (±SE) (g DW m^{-2})	Area (ha)	# sites	Biomass (±SE) (g DW m^{-2})	Area (ha)	# sites	Biomass (±SE) (g DW m^{-2})	Area (ha)
Halodule pinifolia/uninervis (narrow)	78	4.16 ± 0.43	28.3 ± 8.3	117	4.86 ± 0.37	40.7 ± 8.7	125	2.89 ± 0.14	44.7 ± 9.2	73	3.93 ± 0.28	35.9 ± 8.0
Halodule uninervis (wide)	4	0.79 ± 0.19	1.0 ± 0.6	2	11.37 ± 5.55	0.1 ± 0.3	4	0.82 ± 0.32	1.6 ± 0.9	1	13.18 ±	3.5 ± 2.5
Halophila decipiens	79	3.95 ± 0.28	73.8 ± 8.8	49	2.23 ± 0.39	91.7 ± 13.0	11	0.28 ± 0.12	12.2 ± 3.1	67	2.16 ± 0.25	87.7 ± 9.3
Halophila ovalis	267	4.73 ± 0.14	199.3 ± 14.4	298	3.91 ± 0.17	213.8 ± 14.8	287	1.87 ± 0.11	224.8 ± 15.7	327	3.91 ± 0.14	263.9 ± 13.3
Halophila spinulosa	1	0.32 ± 0.16	0.20 ± 0.02	1	0.95	0.1 ± 0.2	-	-	-			-
Halophila tricostata	11	2.76 ± 0.71	3.2 ± 1.4	-	-	-	-	-	-			-
All species pooled	349	5.46 ± 0.13	285.4 ± 16.0	377	5.05 ± 0.27	285.3 ± 16.8	364	2.50 ± 0.10	252.3 ± 16.3	383	4.50 ± 0.13	312.2 ± 13.8

The seaward edge of the seagrass meadows north and south of Oyster Point varied only slightly between years. It retracted slightly in 1998 and returned to earlier (1995) limits again in 1999 (Map 2). The changes in distribution of *Halophila decipiens* (Map 4) contributed most of this variability.

Seagrasses ranged in depth from approximately 0.4 to 4.4m below MSL in 1995, 0.5 to 4.0m below MSL in 1997, 0.5 to 3.6m below MSL in 1998 and 0.5 to 3.8m below MSL in 1999. Species depth ranges were affected by the presence of only a few plants at the deeper extent of distribution. *Halodule pinifolia/uninervis* (narrow) dominated the shallowest depth zone (0.5-1m below MSL) and the *Halophila* species dominated the zone immediately seaward (mean depths 2-3m below MSL; Figure 2, Maps 3 to 5). *Halophila decipiens* extended the deepest in all four surveys (Figure 2, Map 4).

Mean depth of occurrence for *Halophila decipiens* at Oyster Point was significantly shallower in December 1997 and November 1999 than in November 1995 (0.28 and 0.24m respectively) (ANOVA F=4.23, 134 d.f., p<0.01) (Figure 2). *Halophila ovalis* and *Halodule pinifolia/uninervis* average depths did not change significantly between sampling events (ANOVA F=1.51, 728 d.f., p=0.21; F=1.71, 232 d.f., p=0.16 respectively) (Figure 2).

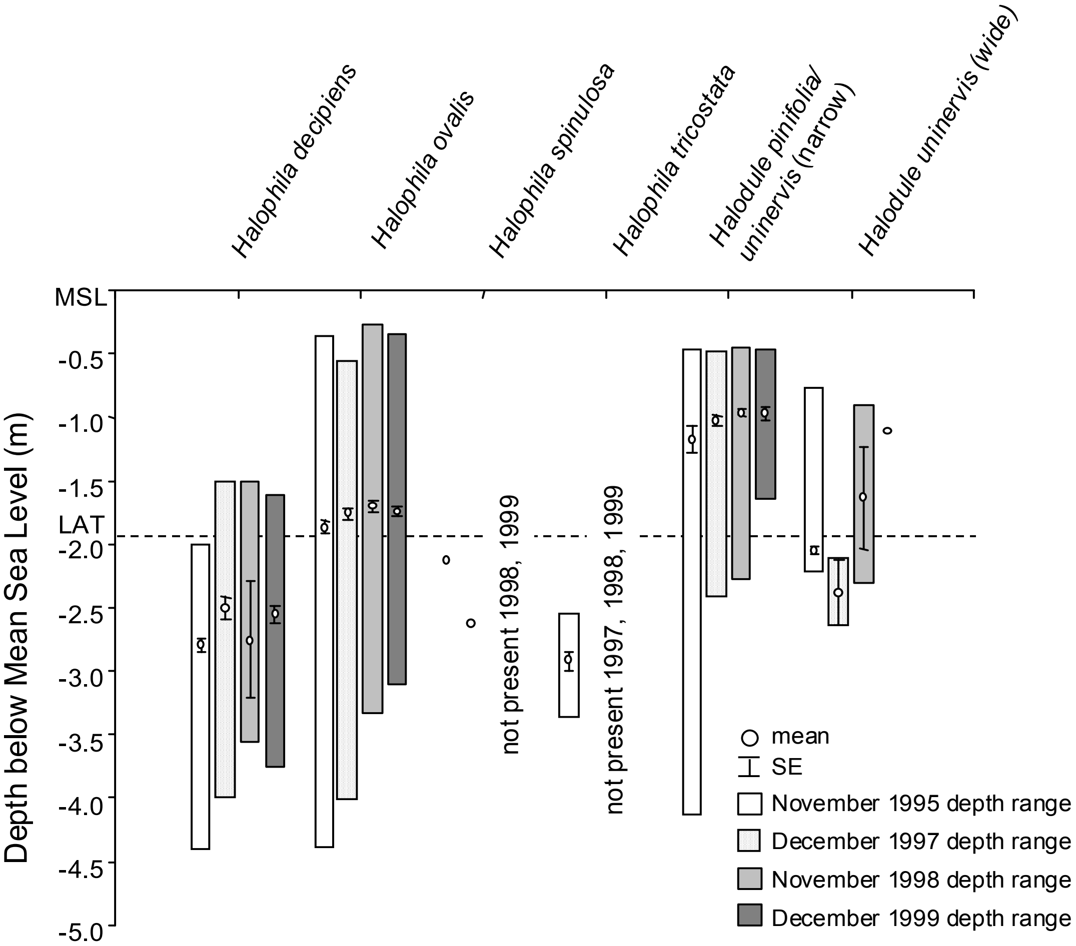

Figure 2. Mean, standard error and range of depth of occurrence for each seagrass species in the survey region at Oyster Point in November 1995, December 1997, November 1998 and December 1999; transect data only (*MSL = Mean Sea Level; LAT = Lowest Astronomical Tide*).

Seagrass Biomass

Mean aboveground biomass of seagrass at Oyster Point (all species and meadows pooled) varied little from 5.46 ±0.13 g DW m^{-2} in November 1995 to 5.05 ±0.27 g DW m^{-2} in December 1997 but declined significantly to 2.50 ±0.10 g DW m^{-2} in November 1998 (ANOVA F=51.48, 1472 d.f., p<0.001)(Table 1). The overall 45% decline in aboveground seagrass biomass from 1995 to 1998 was followed by an 80% increase in 1999 to near the 1995 value (Figure 3, Table 1).

Changes in seagrass biomass were uneven over the survey region. At southern transects within 300m of Oyster Point, aboveground seagrass biomass did not change significantly throughout the study (Figure 4). There were gains in aboveground seagrass biomass at some transects more than 500m south of Oyster Point between 1995 and 1997 (Lee Long et al. 1999), but the overall trend for most transects was a decline (between 4 and 10g DW m^{-2}) from 1995 to 1998 followed by an increase in 1999 (Figure 4).

Declines in seagrass biomass from 1995 to 1998 occurred in the northern intertidal region (between 5 and 10 g DW m^{-2} in the 100 to 400m transects;), northern sub-tidal region (100-2000m transects; about 4 g DW m^{-2}) and in both southern regions (500m to 2000m transects) (Figure 4). Most of these declines were reversed in 1999, when decreases were minor and almost all transects increased (between 2 and 7g DW m^{-2}) in biomass. From 1995 to 1997 declines occurred in the northern intertidal region close to Oyster Point and the northern sub-tidal region >800m from Oyster Point (Lee Long et al. 1999). From 1997 to 1998 declines occurred inter-tidally and sub-tidally, but mostly 200 to 700m north of Oyster Point. An 18 g DW m^{-2} decline in biomass at 100m north of Oyster Point in 1997 was from one unusually high-biomass site in a small patch of seagrass recorded in 1995.

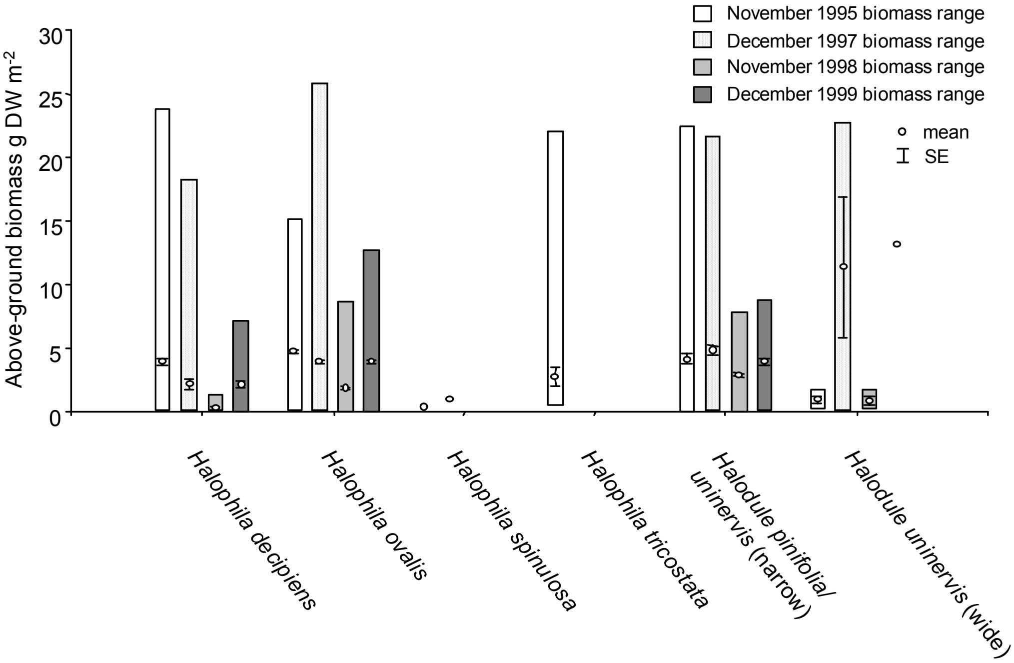

Figure 3. Mean, standard error and range of above-ground biomass for each seagrass species in the survey region at Oyster Point (sites with seagrass present) in November 1995, December 1997, November 1998 and December 1999.

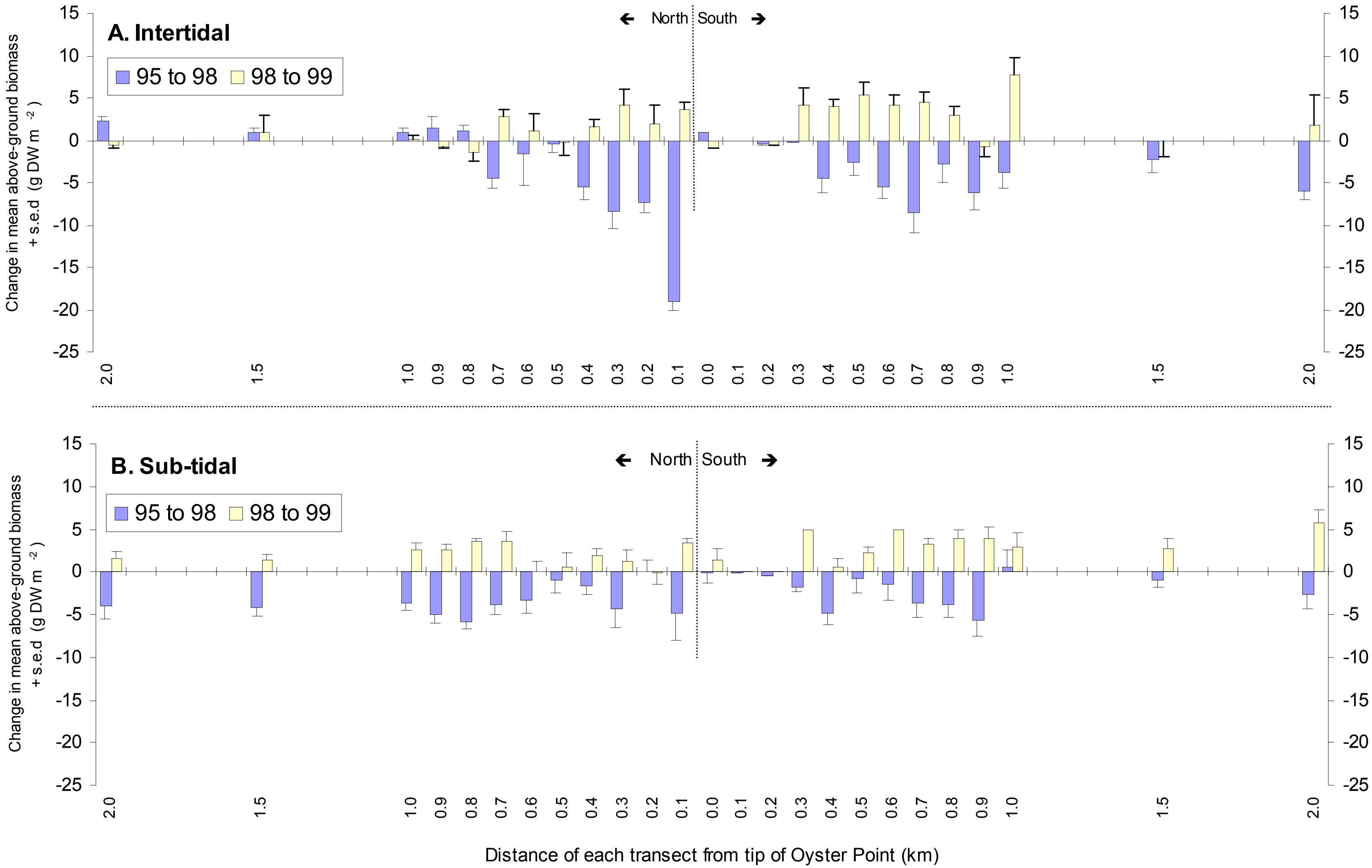

Figure 4. Changes in mean aboveground seagrass biomass (all species pooled, g DW m^{-2}) between November 1995 to November 1998 and November 1998 to December 1999 for each permanent transect at Oyster Point. A = intertidal seagrasses. B = sub-tidal seagrasses. Error bars represent the standard error of difference between the two means (s.e.d).

Sediment

A layer (2-10cm thick) of fine, silty mud was identified in 1998 at several sites north of the access channel, seaward of the 1.5m depth contour, but was not present south of the access channel (Lee Long et al. 2000). *Halophila ovalis* and *Halodule pinifolia/uninervis* plants had lost their green (chlorophyll) coloration on parts that were buried by the silt layer and a few loose plants also occurred in the silt layer. This fine silty mud was similar in texture to the fine silt layer that was present each year in the intertidal zone of the northern and southern regions. The original source of the sediment could not be determined.

In 1999 the silty mud in the northern sub-tidal region was only thin (1-3 cm) and very patchy. No silt layer was observed in the southern sub-tidal region. A powdery mud covered the consolidated mud/sand/shell substrate in some areas, but not thickly enough to smother seagrasses. Low densities of *Halophila ovalis* and *Halophila decipiens* plants were growing over the powdery mud substrate and still had green (i.e. photosynthetically active) leaves.

A thick layer of silt was also found at several sites in the dredged access channel, but not found immediately seaward of the channel. Conditions were extremely turbid and no seagrass was found in this silty flocculant layer. In December 1997 (immediately following capital dredging) it was less than 0.1m thick. It was most widespread and thickest (approx. 0.5m thick) in the channel in November 1998, but in December 1999 was only a 0.1m thick layer at several sites in the inner part of the channel - not in the seaward half of the channel. This material appears to have drifted from elsewhere and collected (or "trapped") in the access channel and may change according to tide and flow conditions.

Climate Data

Climate data for the 2 months prior to each sampling event indicated increases from 1995 to 1998 in the number of strong wind (eastern sector, >10 knots) days (Figure 5) and cloudy (8/8 cloud-cover) days (Figure 6). The total number of cloudy days for 2 months prior to the November 1998 survey was 22 days – very high compared with the 120-year average (9.3 days) for September and October.

Winds also affected water turbidity unevenly over the survey region. Observations during this study and by SKM suggest that the northern survey region close to Oyster Point and the southern intertidal region were the most exposed to wind-driven sediment re-suspension and hence to year-to-year increases in turbidity.

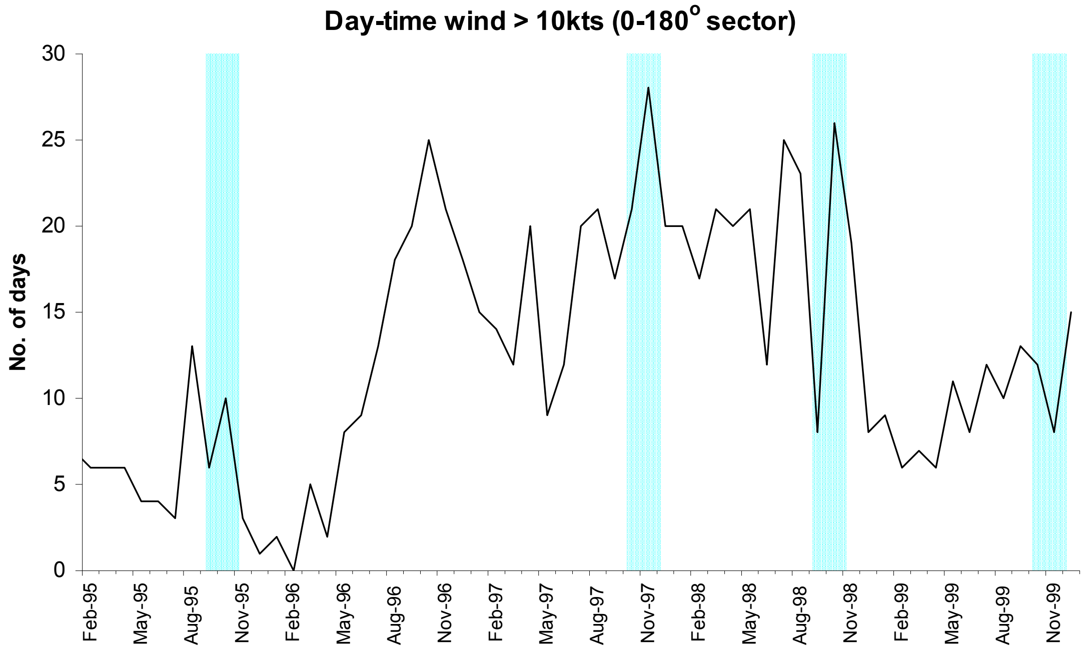

Figure 5. Number of eastern sector windy days (>10 knots at 0900 or 1500 hrs) per month at Cardwell, from February 1995 to December 1999. Data courtesy of Bureau of Meteorology, Queensland. Shaded areas indicate 2 month period prior to each sampling event.

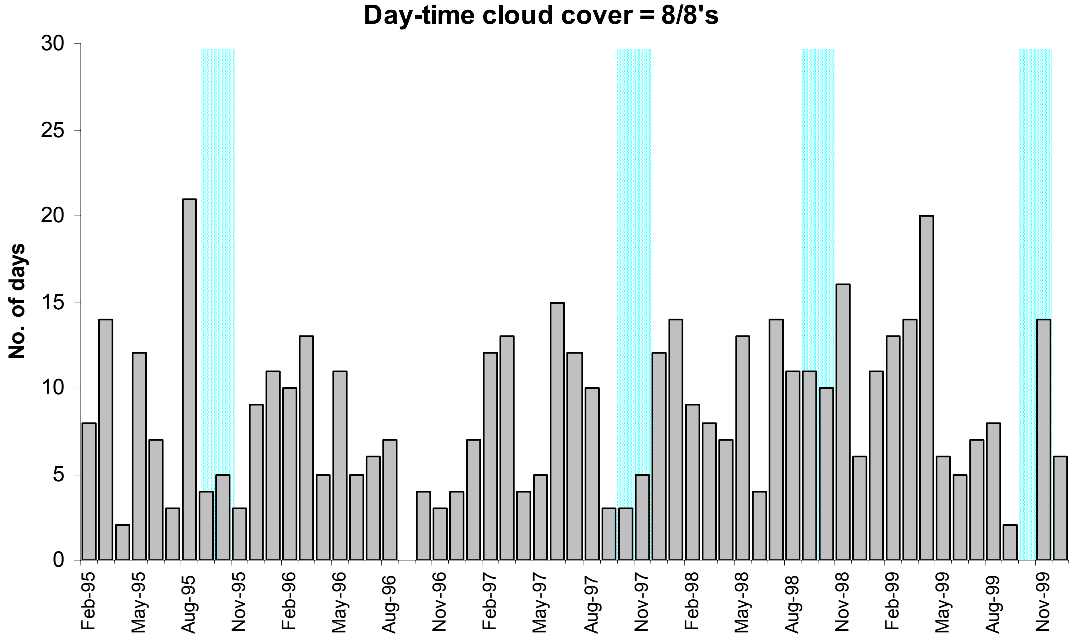

Figure 6. Number of cloudy (8/8 cloud cover at 0900 or 1500 hrs) days per month at Cardwell, from February 1995 to December 1999. Data courtesy of Bureau of Meteorology, Queensland. Shaded areas indicate 2 month period prior to each sampling event.

Map 1. Oyster Point survey region and sampling sites - November 1995 to December 1999.

Map 2. Distribution of seagrass (all species pooled) at Oyster Point - November 1995 to December 1999.

Map 3. Distribution of *Halodule uninervis* (narrow) at Oyster Point - November 1995 to December 1999.

Map 4. Distribution of *Halophila decipiens* at Oyster Point - November 1995 to December 1999.

Map 5. Distribution of *Halophila ovalis* at Oyster Point - November 1995 to December 1999.

DISCUSSION

Seagrass Area and Distribution Patterns

The silty layer found at sites north of the dredged access channel in November 1998 was found at only a few sites in December 1999, and seagrass distribution and biomass had returned to near pre-dredging levels. Although the source of the silt cannot be accurately determined, the layer may have resulted from changes in hydrology when the dredged channel was created – collecting and directing silts from the mangrove fringe, through the channel and depositing them offshore north of the channel. This model of hydro- and sediment-dynamics was originally suggested by Wolanski (Australian Institute of Marine Science (AIMS), Pers. Comm.) but has not been tested. Silt deposition patterns probably change according to tide and flow conditions. Results of this survey indicate that silt deposition patterns one year after the capital dredge and excavation works at Oyster Point has not caused detectable changes in seagrass distribution and abundance.

The dredged channel may still cause re-distribution of inshore silts to the offshore northern area, possibly over the long-term (greater than 5 years). It would be most appropriate to test for persistence of this silt layer (and survival of local seagrasses) by conducting additional monitoring at a frequency of every 3-5 years).

There has been little change in seagrass distribution and area (all species and meadows pooled) at Oyster Point over the 4 year study period (Map 2). Distribution patterns of the major species changed little, with a persistent nearshore band of *Halodule uninervis* dominating the intertidal extent of seagrass meadows and a broad *Halophila ovalis* band subtidally. The only major species that did vary greatly between years was *Halophila decipiens*, which increased, declined 80% and increased again to its original (1995) area, between monitoring events. *Halophila decipiens* is an ephemeral species with large natural fluctuations in abundance and distribution seasonally and between years (Birch and Birch 1984; McKenzie et al. 1996; McKenzie et al. 1998). Large changes in *Halophila decipiens* distribution were mostly in areas distant from Oyster Point and were likely due to natural changes.

While the maximum depth ranges of the major species in 1997, 1998 and 1999 were shallower than in 1995, there was no corresponding difference in the distribution and GPS derived location of the meadows. There were also no large changes in bottom topography that could explain these differences in seagrass depth. The shallower maximum depth ranges of the major species in December 1997 and November 1998 may be a result of lower light availability caused by increased wind driven turbidity in the two month period leading up be these surveys. Maximum depths for the major species remained shallow in December 1999. The depth range of *Halophila decipiens* did deepen in December 1999, however it is unclear as to why *Halophila ovalis* and *Halodule uninervis* maximum depths continued to be shallow. Depth ranges were affected by the presence of only a few plants at the deeper extent of distribution and the 1999 survey may have missed these isolated *Halophila ovalis* and *Halodule uninervis* plants.

Seagrass Biomass

The chosen "reference" regions were so different from the survey regions in prevailing wind, water quality and seagrass biomass that they were not considered reliable "controls" for BACI-type analyses of impacts on Oyster Point seagrasses. For species that are naturally highly variable, reference or control sites are very difficult to use for analysis of impacts. Instead, we analysed for changes in seagrass with distance from the source of impact and considered the 'reference' regions as north-south extensions of the core monitoring area.

Seagrass biomass at Oyster Point declined overall (approximately 45% for all species pooled) from 1995 to 1998, then increased (approx 80%) to near the 1995 levels in December 1999. These variations are within the known range of natural change for these seagrass species. For colonising tropical Australian seagrasses, a 50% to 70% decline in the biomass and distribution is thought necessary to trigger management intervention (Coles et al. 1996b; Lee long et al. 1996). Low-biomass meadows of *Halophila ovalis, Halophila decipiens* and *Halodule uninervis* (narrow-leaf) probably vary naturally by up to 70% (eg. at Mourilyan Harbour, McKenzie et al. 1998; and Karumba, Qld Dept Primary Industries 1999).

Annual changes in seagrass biomass were uneven over the survey regions. Most losses (between 1995 and 1998) were in parts of the northern sub-tidal region distant from Oyster Point; the northern intertidal region close to Oyster Point; and the southern intertidal region distant from Oyster Point. Overall, declines in the northern and southern survey regions between 1995 and 1998 were reversed in 1999.

Seagrass biomass in the silt-affected area in 1998 (Lee Long et al. 1999) was not significantly different to biomass immediately near-by, but plants showed signs of recent burial and were beginning to lose chlorophyll coloration on their buried parts. Prolonged direct burial by silt has potential to kill seagrasses, but in December 1999 there was far less silt present and seagrass distribution and biomass had recovered.

The year-to-year changes in biomass at Oyster Point between November 1995 and December 1999 are mostly within the expected background ranges of variability for these seagrass species.

Light is one of the most important factors influencing growth and survival of seagrasses and year-to-year changes in meteorological conditions alone could explain much of the changes in seagrass biomass. The Sinclair Knight Merz turbidity monitoring program spanning one hundred days in 1997 established that wind-driven turbidity patterns masked any dredging-related turbidity plumes except on two days of calm clear water (Sinclair Knight Merz, 1998). Wind alone is probably the dominant influencing factor on water turbidity at Oyster Point and year-to-year changes in cloud and wind would mask possible impacts of the dredging program.

An increase in seagrass biomass in December 1999, corresponded with a decrease in the number of strong-wind days and cloudy days, and could be explained by an increase in the total light budget available for seagrass growth in the 1999 sampling season.

The increase in eastern sector winds from the 1995 sampling season to the 1997 sampling season was coincident with a decline in seagrass biomass in these parts of the survey region. Additional increases in cloud cover in 1998 could also explain further declines in seagrass abundance over most regions. Subsequent decreases in wind and cloud in the 1999 sampling season are coincident with increases in seagrass biomass and distribution.

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APPENDIX

Table 2. Number of intertidal and sub-tidal sites used to calculate mean above-ground biomass at each survey transect, north and south, of Oyster Point in November 1995, December 1997 and November 1998.

Transect distance (km)	Number of sites															
	North								South							
	Intertidal				Sub-tidal				Intertidal				Sub-tidal			
	1995	1997	1998	1999	1995	1997	1998	1999	1995	1997	1998	1999	1995	1997	1998	1999
0.0	0	1	1	0	1	3	2	2								
0.1	1	3	3	2	4	2	4	1	0	0	0	0	1	0	0	0
0.2	6	4	5	3	7	3	4	3	3	0	1	0	3	0	0	0
0.3	3	5	3	5	6	4	4	5	1	0	2	5	2	1	3	1
0.4	3	6	6	2	7	8	4	8	7	10	8	6	2	1	3	3
0.5	3	4	4	3	10	8	3	7	8	10	6	3	3	3	4	2
0.6	2	4	4	3	10	7	5	8	9	7	14	4	3	1	1	1
0.7	2	2	9	2	10	6	6	8	6	5	6	4	7	3	3	6
0.8	2	4	4	3	19	7	7	10	3	3	3	4	6	4	2	7
0.9	4	4	5	3	18	7	4	9	2	2	5	2	8	8	2	10
1.0	4	3	4	3	15	11	8	11	3	4	5	3	7	5	7	5
1.5	3	5	5	3	18	11	9	13	6	3	2	2	13	7	7	7
2.0	3	6	3	2	14	17	11	14	3	4	3	3	5	9	6	8

Table 3. Results of regressions of each diver's seagrass biomass estimation with harvested above-ground biomass (g DW m^{-2}).

Diver	**November 1995**			**December 1997**			**November 1998**			**December 1999**		
	r^2	F	P	r^2	F	p	r^2	F	p	r^2	F	p
G. Chisholm	0.97	117.54	0.001									
R.G. Coles	0.92	48.56	0.002	0.79	37.81	<0.001						
L. Makey	0.88	29.32	0.006									
P.A. Daniel				0.77	33.14	<0.001	0.86	30.80	0.003			
W.L. Lee Long	0.99	411.43	<0.001	0.98	207.25	<0.001	0.88	35.84	0.002	0.98	157.71	<0.001
L.J. McKenzie	0.97	191.02	<0.001									
C.A. Roder				0.96	249.70	<0.001						
A.J. Roelofs	0.97	156.84	<0.001	0.99	244.43	<0.001	0.90	47.26	0.001	0.86	25.00	0.008
R. Thomas										0.82	18.72	0.012
T. Curruthers*										0.95	80.15	<0.001

* Analysis performed on Ln (x+1) data.