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Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2007

Michael Rasheed
Skye McKenna
Helen Taylor
Tonia Sankey

Department of Primary Industries and Fisheries
Marine Ecology Group
Northern Fisheries Centre

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Department of Primary Industries and Fisheries

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Rasheed, M.A., McKenna, S.A., Taylor, H.A., and Sankey, T.L.

Marine Ecology Group
Northern Fisheries Centre

Department of Primary Industries and Fisheries
PO Box 5396 Cairns Qld 4870

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Enquiries should be directed to:
Marine Ecology Group
Northern Fisheries Centre
PO Box 5396
Cairns, QLD, 4870, Australia

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EXECUTIVE SUMMARY

This report details findings of the 2007 annual seagrass monitoring survey for Port Curtis and Rodds Bay. The program was developed from a baseline survey conducted in 2002 and from recommendations of the Port Curtis Integrated Monitoring Program (PCIMP) review.

In 2007 seagrasses in Port Curtis were in the healthiest condition recorded since the inception of the monitoring program. Most of the monitoring meadows were at or near their highest recorded density and area. This was particularly true for intertidal seagrass meadows which in several cases had more than doubled in biomass from 2006. However the three subtidal monitoring meadows did not exhibit the same trends. While they remained relatively healthy they had either declined in biomass or area from the previous year.

The changes to seagrasses observed in the monitoring program appear to be largely linked to a combination of climate factors and tidal exposure and the natural resilience and capacity for recovery in individual seagrass meadows. Changes observed were consistent between seagrasses within the port infrastructure area and at reference sites in nearby Rodds Bay as well as other Queensland locations where seagrasses are monitored.

The presence of seagrass meadows and dugong activity in intertidal areas adjacent to port facilities and infrastructure has implications for port management. Some of the most utilized seagrass meadows also appear to be those in closest proximity to major port infrastructure and proposed areas of expansion. Future port infrastructure developments would require careful management to ensure minimal impacts on these communities. The fact that "healthy" seagrass meadows and dugong activity have continued to exist within the port indicates that these important habitats can co-exist with well managed port activities and development.

Increases in density of the highly productive *Zostera capricorni* meadows over the past two years had positive implications for local fisheries production as these meadows are especially valuable as nursery habitat for juvenile tiger prawns and other commercial and recreational fish species.

Post the October 2007 seagrass survey the Gladstone area experienced substantial rainfall and related turbid plumes within the port area which were likely to have a negative effect on seagrasses. The very healthy condition of seagrasses recorded prior to these events may have provided the meadows with a high resilience and potentially greater capacity to recover from flood related impacts.

This was the fourth survey in the established annual monitoring program and we have already identified some of the likely climate related drivers of seagrass change. A recent expansion of the seagrass monitoring program within PCIMP has led to a series of turbidity, light and temperature loggers and monitoring stations being established in the seagrass meadows late in 2007 by the Centre for Environmental Management at CQU. With the aid of this new data we will be in a far stronger position to determine the major drivers of seagrass change and will be better able to assess any anthropogenic (human induced) impacts to seagrass meadows that may arise in the future.

INTRODUCTION

Seagrass meadows in Queensland are known to provide valuable nursery habitats for juvenile commercial and recreational fisheries species, as well as important food resources for endangered and threatened species such as dugong and turtles. The value of seagrasses in the Port of Gladstone area (Port Curtis) to dugong has been recognised by the declaration of the Rodds Bay Dugong Protection Area (DPA). Seagrasses also show measurable responses to changes in water quality making them ideal candidates for monitoring the "health" of port environments. Results from long term monitoring programs throughout other Queensland port locations have provided valuable information on the relationships between climatic changes, anthropogenic disturbance and seagrass abundance. They have also indicated that healthy and productive seagrass habitats can co-exist with appropriately managed port facilities. Long term seagrass monitoring programs have enabled port managers to make informed decisions regarding planning and development of port infrastructure that will have minimal impact on fisheries and the marine environment.

Central Queensland Ports Authority (CQPA) recognised that seagrass meadows comprised an important and sensitive component of the marine habitats within the port and as part of their commitment to maintaining the health of the marine environment within the port CQPA commissioned the DPI&F Marine Ecology Group (MEG) to conduct a baseline, fine scale survey of seagrass resources within the port limits and nearby Rodds Bay in 2002 (Rasheed *et al.* 2003). The baseline survey identified large areas of seagrass within the port limits, with seagrass communities often occurring adjacent to port facilities and infrastructure. The baseline survey mapped 13,578 ha of seagrass habitat within Port Curtis and Rodds Bay finding that these habitats appeared to be healthy, however, detailed historical comparisons were not possible as the baseline survey was the first fine scale survey of the complete area.

An annual long term seagrass monitoring program was considered valuable given the proximity of meadows to port and industrial infrastructure and possible impacts associated with future port and coastal developments. The ability of seagrasses to show measurable growth responses to changes in water quality, and their extensive distribution through the port made them an ideal candidate for monitoring marine environmental health in the Port. At the request of CQPA and from recommendations from the Port Curtis Integrated Monitoring Program (PCIMP) review of monitoring in the Port Curtis region (SKM 2004) a long term seagrass monitoring strategy for the port was developed.

From the results of the 2002 baseline survey and consultation with port users, thirteen seagrass meadows were selected to monitor. These monitoring meadows represented the range of seagrass communities within the port, and a good coverage of meadows that would most likely be impacted by port facilities and developments. Monitoring meadows included both intertidal and subtidal seagrasses as well as meadows preferred as food by dugong and those likely to support high fisheries productivity. Three meadows in Rodds Bay (outside of the port limits) were also selected to monitor to provide information on seagrasses unlikely to be impacted by port activity and to assist in separating out port related versus regional causes of seagrass change detected in the monitoring program.

The annual monitoring program has been in place since 2004 (see Rasheed *et al.* 2005; 2006; Taylor *et al.* 2007). Some significant changes to seagrass monitoring meadows had occurred between the 2002 baseline and subsequent monitoring surveys from 2004 to 2006. Generally regional and local climatic factors were the most likely causes of the seagrass changes rather than port related activities during this time. The first 3 years of monitoring has helped to better establish the range of natural changes for Port Curtis seagrasses and has placed us in a strong position to discern natural changes from human induced or port related change

Recognising the importance of seagrass meadows to a number of port users and the potential to value add to the program it was decided to shift the seagrass monitoring program to PCIMP from 2007. The continued monitoring program will provide information required to aid in planning of port development and maintenance programs that will have minimal effects on the marine environment as well as a tool to assess the health of Port Curtis' marine environment.

The objectives of the survey were to:

1. Conduct annual long term seagrass monitoring within the Gladstone port limits (Port Curtis) and Rodds Bay area based on information collected in the 2002 baseline survey
2. Monitor distribution, abundance and species composition of selected seagrass meadows within the port limits and Rodds Bay
3. Analyse changes in seagrass meadows measured since the baseline and subsequent annual monitoring surveys
4. Place observed changes within a regional and state-wide context

METHODOLOGY

Seagrass surveys of the Gladstone port limits (Port Curtis) and Rodds Bay were conducted between the 25th and 28th of October 2007. The survey was conducted in late October as seagrasses in the region were likely to be at their maximum density and distribution in late spring, and also to allow direct comparisons with previous surveys in the monitoring program which were all conducted in October/November. Thirteen meadows from the baseline survey (Rasheed *et al*. 2003) were selected for long term monitoring. These meadows were representative of the range of seagrass communities identified in the baseline survey and were also located in areas likely to be vulnerable to impacts from port operations and developments.

Seagrass habitat observations included species composition, above ground biomass, percent algal cover, depth below mean sea level (MSL) (for subtidal sites), sediment type, time and position (differential Global Positioning System (dGPS). Two sampling methods were used to survey the seagrass meadows; helicopter and divers. Methodology depended on the depth and size of area to be surveyed, as well as dive safety constraints. A detailed description of the methods used to characterise the monitoring meadows is provided in Rasheed *et al*. (2003).

Seagrass above ground biomass was determined using a modified “visual estimates of biomass” technique described by Mellors (1991). This technique involves an observer ranking seagrass biomass in the field in three random placements of a $0.25m^2$ quadrat at each site. Ranks were made in reference to a series of quadrat photographs of similar seagrass habitat for which the above ground biomass had previously been measured. Two separate biomass ranges were used: low biomass and high biomass. The relative proportion of the above ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above ground biomass estimates in grams dry weight per square metre (g DW m^{-2}). At the completion of sampling each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats was harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to determine above ground biomass estimates.

Habitat Mapping and Geographic Information System

Spatial data from the field surveys were incorporated into the CQPA/DPI&F Geographic Information System (GIS) database. Three GIS layers were created:

Site information – site data containing above ground biomass (for each species), depth below mean sea level (MSL) (for subtidal sites), sediment type, time, differential Global Positioning System (dGPS) fixes (±1.5m) and sampling technique.

Seagrass meadow biomass and community types – area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of the Queensland region (Table 1). Abundance categories (light, moderate, dense) were assigned to community types according to above ground biomass of the dominant species (Table 2).

Seagrass landscape category - area data showing the seagrass landscape category determined for each meadow:

Isolated seagrass patches
The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries

Continuous seagrass cover
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of unvegetated sediment.

Table 1 Nomenclature for community types in Port Curtis and Rodds Bay, October 2007

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2 Density categories and mean above ground biomass ranges for each species used in determining seagrass community density in Port Curtis and Rodds Bay, October 2007

Density	**Mean above ground biomass (g DW m^{-2})**				
	***H. uninervis* (narrow)**	***H. ovalis H. decipiens***	***H. uninervis* (wide)**	***H. spinulosa***	***Z. capricorni***
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

Meadows were also assigned a mapping precision estimate (in metres) based on mapping methodology utilised for that meadow (Table 3). Mapping precision for coastal seagrass meadows ranged from ±5m to ±20m for the monitoring meadows (Table 3). The mapping precision estimate was used to calculate a range of meadow area for each meadow and was expressed as a meadow reliability estimate (R) in hectares. Additional sources of mapping error associated with digitising and rectifying aerial photographs onto base maps and with dGPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 3 Mapping precision and methodology for seagrass meadows in Port Curtis and Rodds Bay, October 2007

Mapping precision	**Mapping methodology**
≤5m	Meadow boundaries mapped in detail by dGPS from helicopter Intertidal meadows completely exposed or visible at low tide Relatively high density of mapping and survey sites Recent aerial photography aided in mapping
10m	Meadow boundaries determined from helicopter and diver surveys Inshore boundaries mapped from helicopter Offshore boundaries interpreted from survey sites and aerial photography Relatively high density of mapping and survey sites
20m	Meadow boundaries determined from helicopter and diver surveys Some boundaries mapped from helicopter Offshore boundaries interpreted from diver survey sites Lower density of survey sites for some sections of boundary

RESULTS

Seagrass species, distribution and abundance for monitoring meadows in 2007

Five seagrass species (from three families) were identified in the thirteen seagrass monitoring meadows (Plate 1). For a complete list of species found within the port limits see Rasheed *et al.* (2003):

Family CYMODOCEACEAE Taylor:
Halodule uninervis (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier

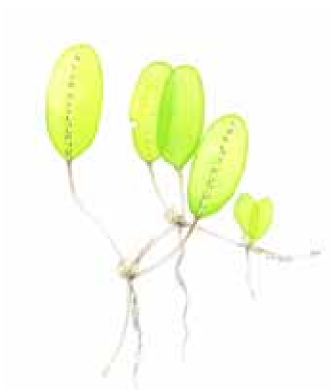
Family HYDROCHARITACEAE Jussieu:
Halophila decipiens Ostenfeld
Halophila ovalis (R. Br.) Hook. F.
Halophila spinulosa (R. Br) Hook. F.

Family ZOSTERACEAE Drummortier:
Zostera capricorni Aschers.

Zostera capricorni

Halodule uninervis

Halophila spinulosa



Halophila ovalis

Halophila decipiens

A total of 2498.7 ± 93.9 ha of seagrass habitat was mapped in the thirteen seagrass monitoring meadows in October 2007 (Table 4). Meadow area ranged from 3.2 ha to 662.0 ha with the smallest meadow situated at Rodds Bay and largest meadow located at Pelican Banks (Table 5; Map 3). A total of 405 monitoring sites (excluding meadow boundary mapping sites) were surveyed, 80% (322 sites) of which had seagrass present (Map 1). Of these monitoring sites 320 intertidal sites were surveyed from helicopter and 85 subtidal sites were surveyed using boat based methods (diver).

The thirteen monitoring meadows that were surveyed included eight different community types depending on species presence and dominance (Maps 2, 3 and 4; Table 4). Communities that were dominated by *Zostera capricorni* were the most common followed by communities dominated by *Halophila decipiens* and *Halophila ovalis*. In the north of the survey area, *Zostera capricorni* and *Halophila ovalis* communities dominated the intertidal sand and mud banks between Mud Island and Fishermans Landing wharves with *Halophila decipiens* dominating in subtidal areas. Further south, *Zostera capricorni* communities occurred between South Trees Inlet and Barney Point.

Mean above ground biomass for the monitoring meadows ranged from 1.20 ± 0.67 g DW m^{-2} in the light *Zostera capricorni* with *Halophila ovalis* meadow near Wiggins Island (meadow 4) to 28.11 ± 7.67 g DW m^{-2} for the smallest *Zostera capricorni* meadow in Rodds Bay (meadow 94) (Table 6).

Seagrass cover for intertidal meadows located on the mainland coast between South Trees and North Fishermans Landing was patchy with the majority of meadows consisting of aggregated patches of seagrass (Table 4; Maps 2 & 3). Cover of seagrasses in other areas including Pelican Banks, Quoin Island and Rodds Bay was more consistent with meadows having a continuous cover of seagrass (Table 4; Maps 3 & 4). The majority of the monitoring meadows were located on sediments dominated by mud often combined with a smaller component of sand and/or shell. The exceptions were Pelican Banks (meadow 43), Quoin Island (meadow 48) and South Trees (meadow 58) which occurred on sediments dominated by sand.

An unidentified species of filamentous green algae was common on the banks adjacent to Wiggins Island (Map 5).

Dugong feeding activity was observed on the majority of intertidal seagrass meadows surveyed. The highest density of dugong feeding trails was observed at the *Zostera capricorni* with *Halophila ovalis* meadow at Wiggins Island west (meadow 5; Map 2) with dugong feeding trails recorded at 58% of sampling sites. Dugong feeding trails were also observed at Quoin Island (meadow 48), Wiggins Island (meadow 4), Pelican Banks (meadow 43), South Trees (meadow 58) and the intertidal meadows to the north and south of Fishermans Landing (meadows 6 & 8).

Map 1. Location of 2007 seagrass monitoring sites and seagrass meadows from the 2002 baseline survey in Ports Curtis and Rodds Bay

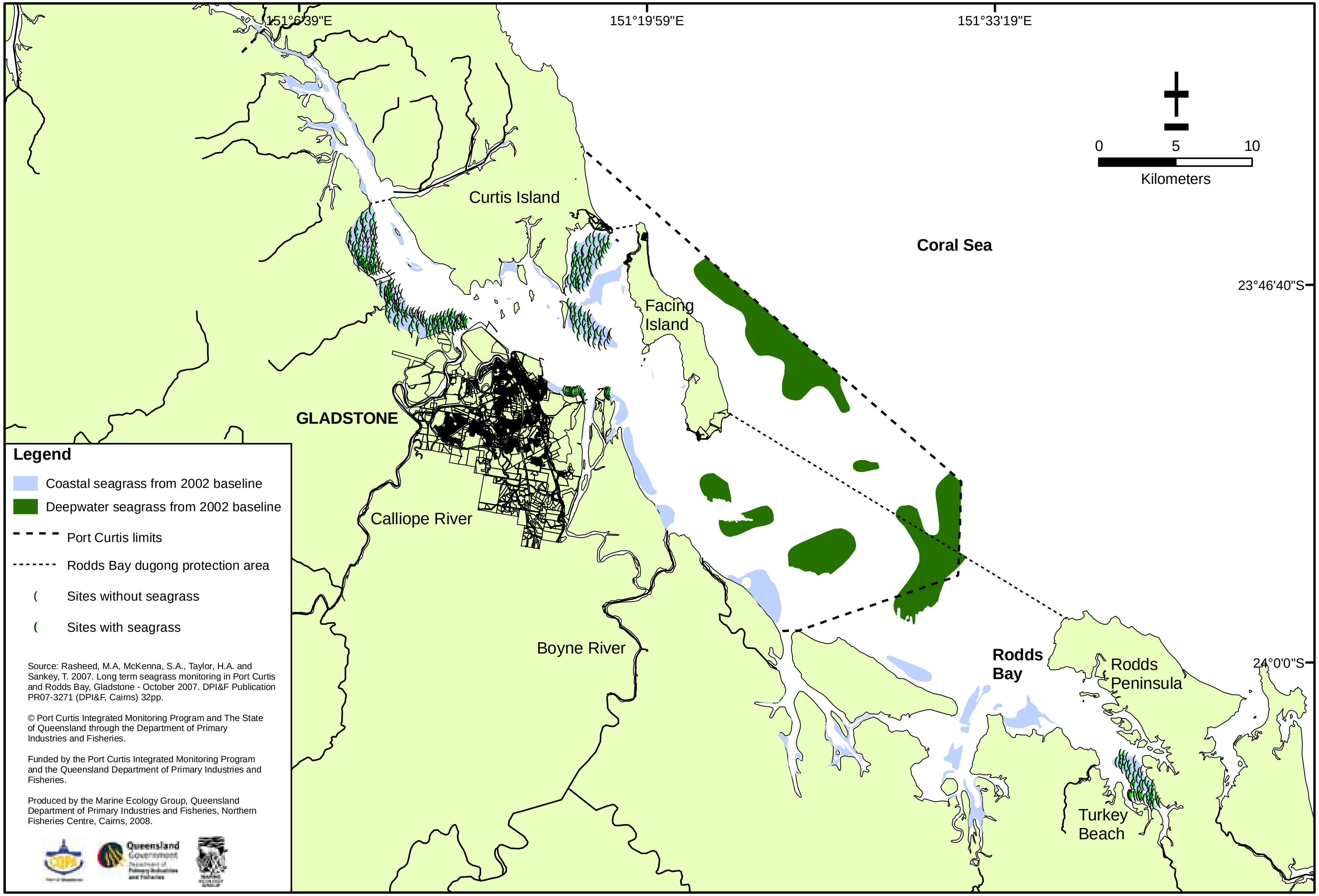
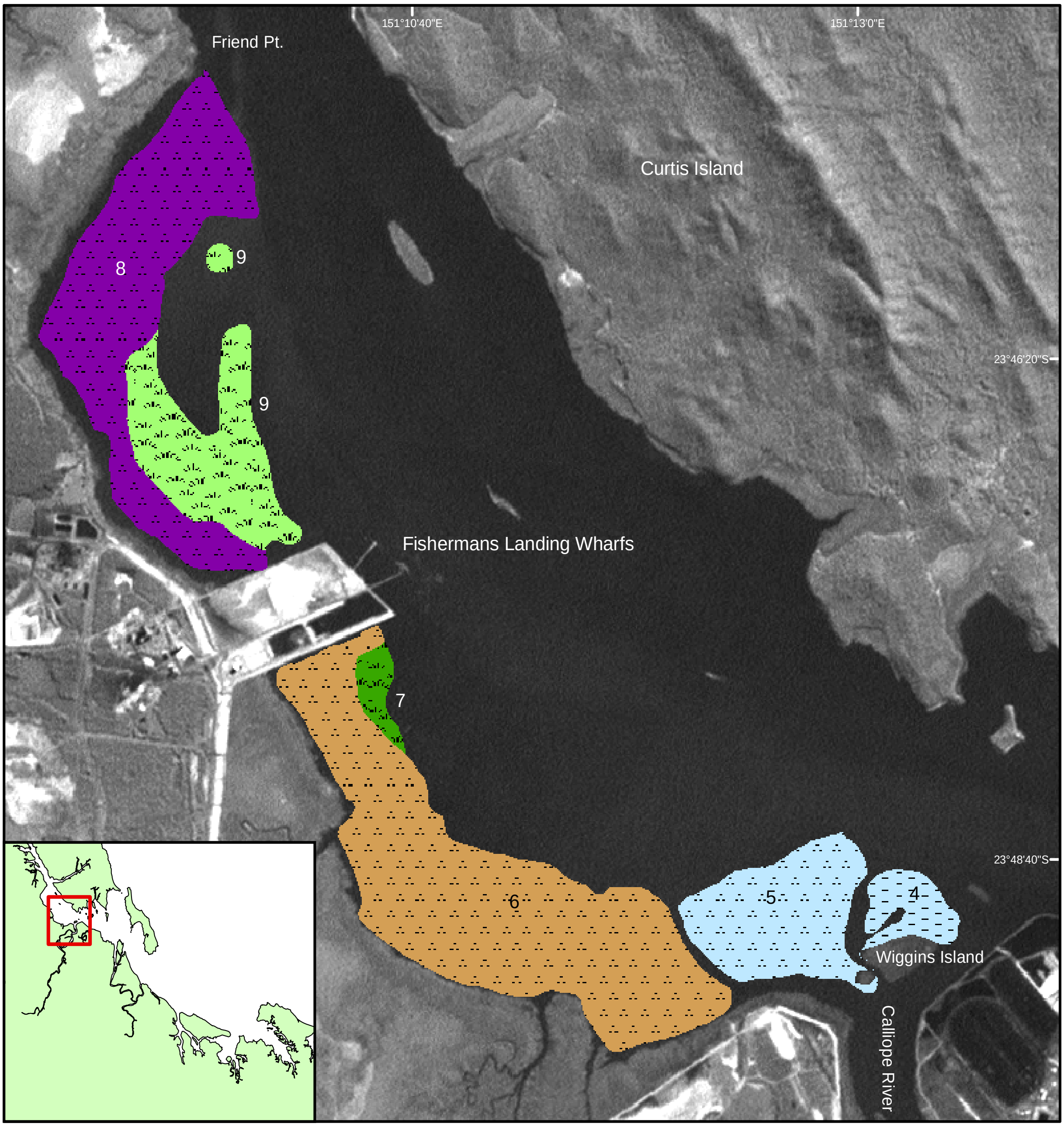


Table 4 Community type, seagrass cover and species present in the thirteen Gladstone monitoring meadows, October 2007

Monitoring Meadow	Location	No. of sites	Community Type	Cover	Species Present
4	Wiggins Island	20	Light *Z. capricorni* with *H. ovalis*	Isolated patches	*Z. capricorni, H. ovalis*
5	Wiggins Island	31	Light *Z. capricorni* with *H. ovalis*	Aggregated patches	*Z. capricorni, H. ovalis*
6	South Fishermans	46	Moderate *H. ovalis* / *Z. capricorni*	Aggregated patches	*H. ovalis, Z. capricorni, H. decipiens*
7	South Fishermans	5	Moderate *H. decipiens* with mixed species	Continuous over	*H. decipiens, H. ovalis, Z. capricorni*
8	North Fishermans	37	Light *Z. capricorni* with mixed *Halophila* species	Aggregated patches	*Z. capricorni, H. ovalis, H. decipiens, H. spinulosa*
9	North Fishermans	23	Moderate *H. decipiens*	Continuous cover	*H. decipiens, H. ovalis, Z. capricorni, H. spinulosa,*
43	Pelican Banks	61	Light *Z. capricorni*	Continuous cover	*Z. capricorni, H. ovalis*
48	Quoin Island	29	Light *H. uninervis* (wide) with mixed species	Continuous cover	*H. uninervis* (wide), *H. uninervis* (thin), *H. ovalis*
58	South Trees	24	Light *Z. capricorni* with *H. ovalis*	Aggregated patches	*Z. capricorni, H. ovalis,*
60	South Trees	11	Light *Z. capricorni*	Aggregated patches	*Z. capricorni, H. ovalis*
94	Rodds Bay	10	Moderate *Z. capricorni*	Continuous cover	*Z. capricorni*
96	Rodds Bay	34	Moderate *Z. capricorni*	Continuous cover	*Z. capricorni, H. ovalis, H. decipiens*
104	Rodds Bay	15	Moderate *Z. capricorni*	Continuous cover	*Z. capricorni*

Map 2. Monitoring meadows in the Fishermans Landing region, 2007



Legend

Community type

- Light *Z. capricorni* with *H. ovalis*
- Light *Z. capricorni* with mixed *Halophila* species
- Moderate *H. ovalis* / *Z. capricorni*
- Moderate *H. decipiens*
- Moderate *H. decipiens* with mixed species

* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Meadow Cover

- Aggregated Patches
- Continuous Cover
- Isolated Patches

0 1 2

Kilometers

Background: Landsat ETM + Panchromatic 24 July 1994

Source: Rasheed, M.A., McKenna, S.A., Taylor, H.A and Sankey, T. 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. DPI&F Publication PR07-3271 (DPI&F, Cairns) 32p.

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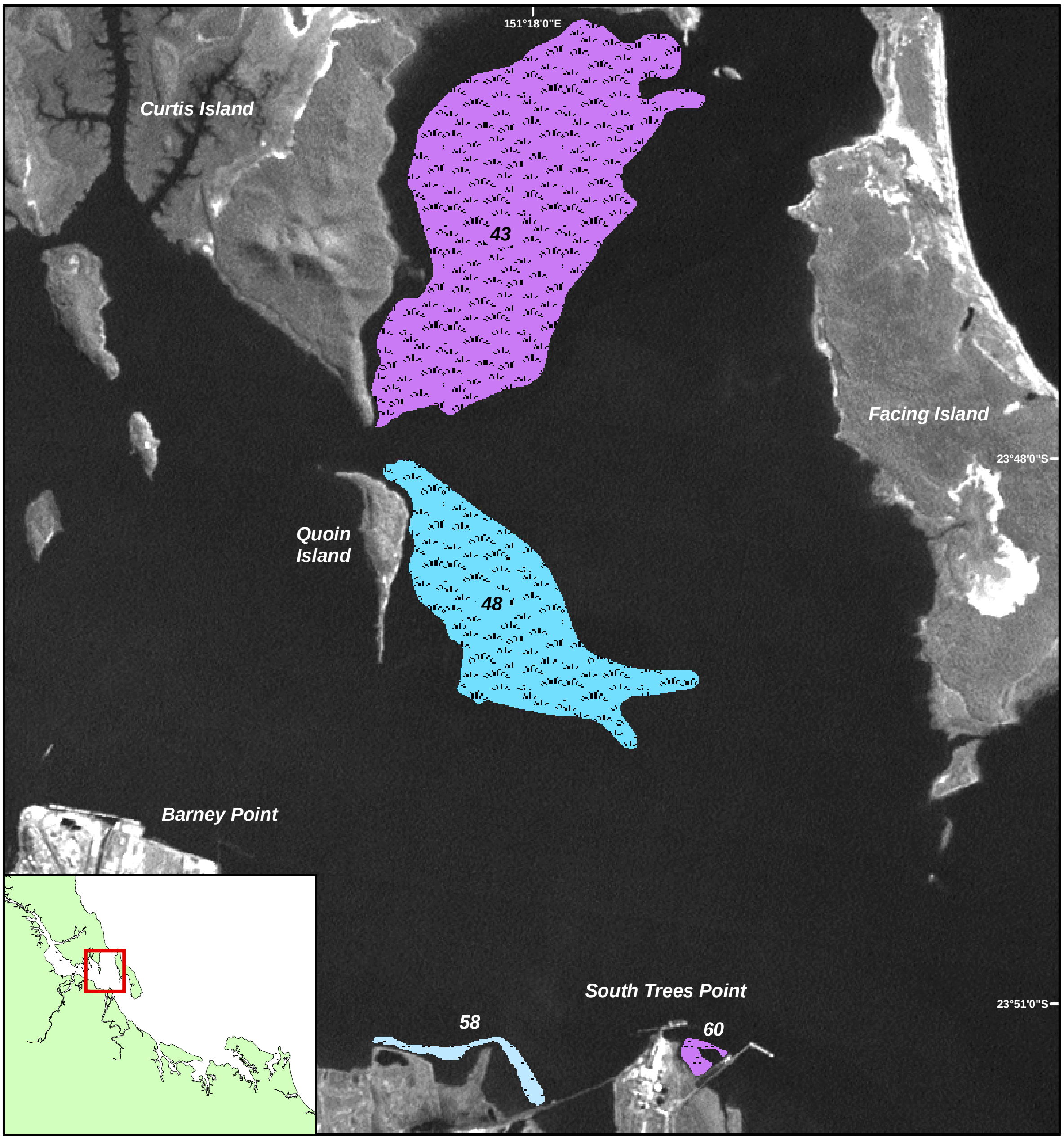
Produced by the Marine Ecology Group, Queensland Department of Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2008.

Map 3. Monitoring meadows in the Quoin Island and South Trees region, 2007



Legend

Community type

- Light *H. uninervis* (wide) with mixed species
- Light *Z. capricorni*
- Light *Z. capricorni* with *H. ovalis*

Meadow cover

- Aggregated Patches
- Continuous Cover
- Isolated Patches

0 1 2
Kilometres

Source: Rasheed, M.A., McKenna, S.A., Taylor, H.A. and Sankey, T 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. DPI&F Publication PR07- 3271 (DPI&F, Cairns) 32p.

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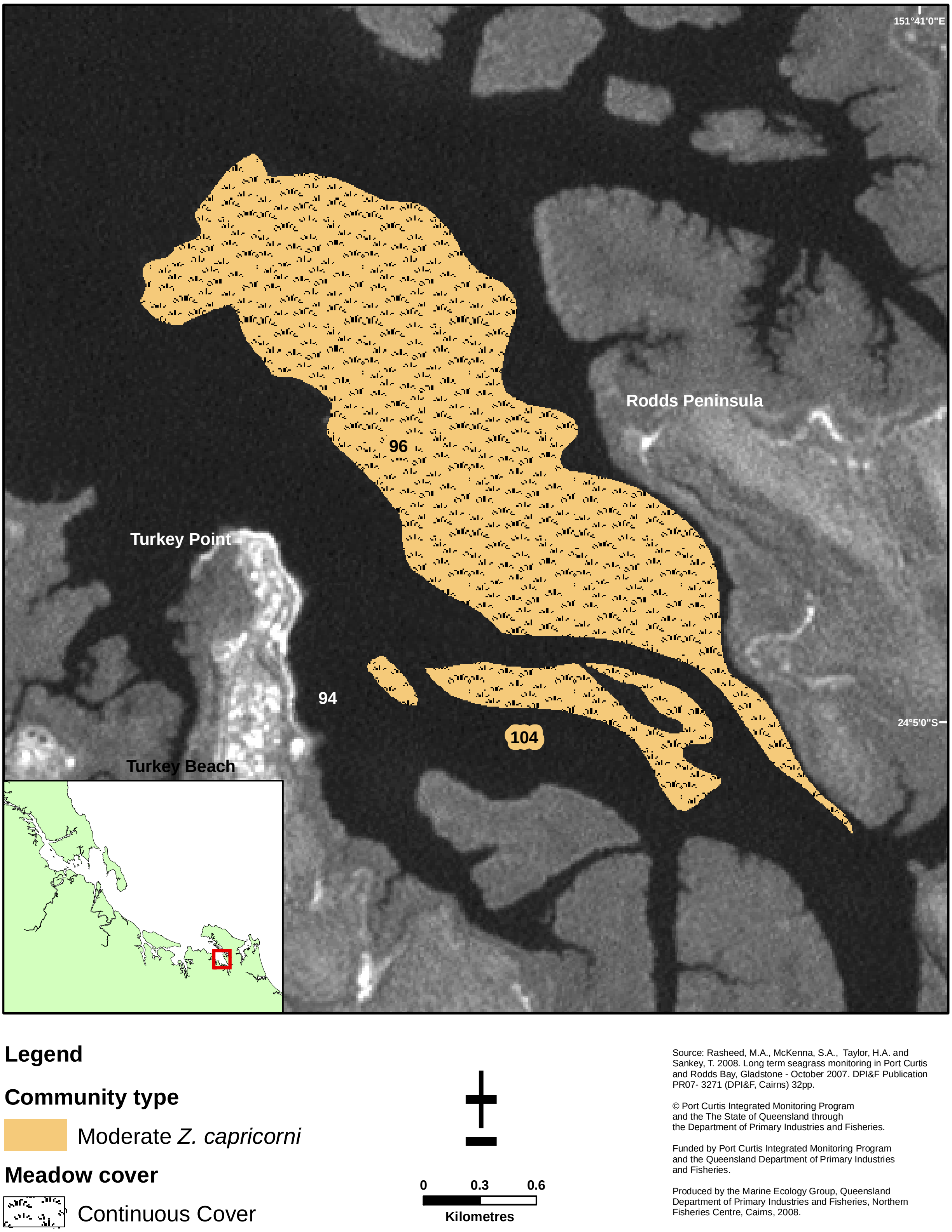
** This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed*

Background: Landsat ETM + Panchromatic 24 July 1994

Map 4. Monitoring meadows in the Rodds Bay region, 2007



Source: Rasheed, M.A., McKenna, S.A., Taylor, H.A. and Sankey, T. 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. DPI&F Publication PR07- 3271 (DPI&F, Cairns) 32pp.

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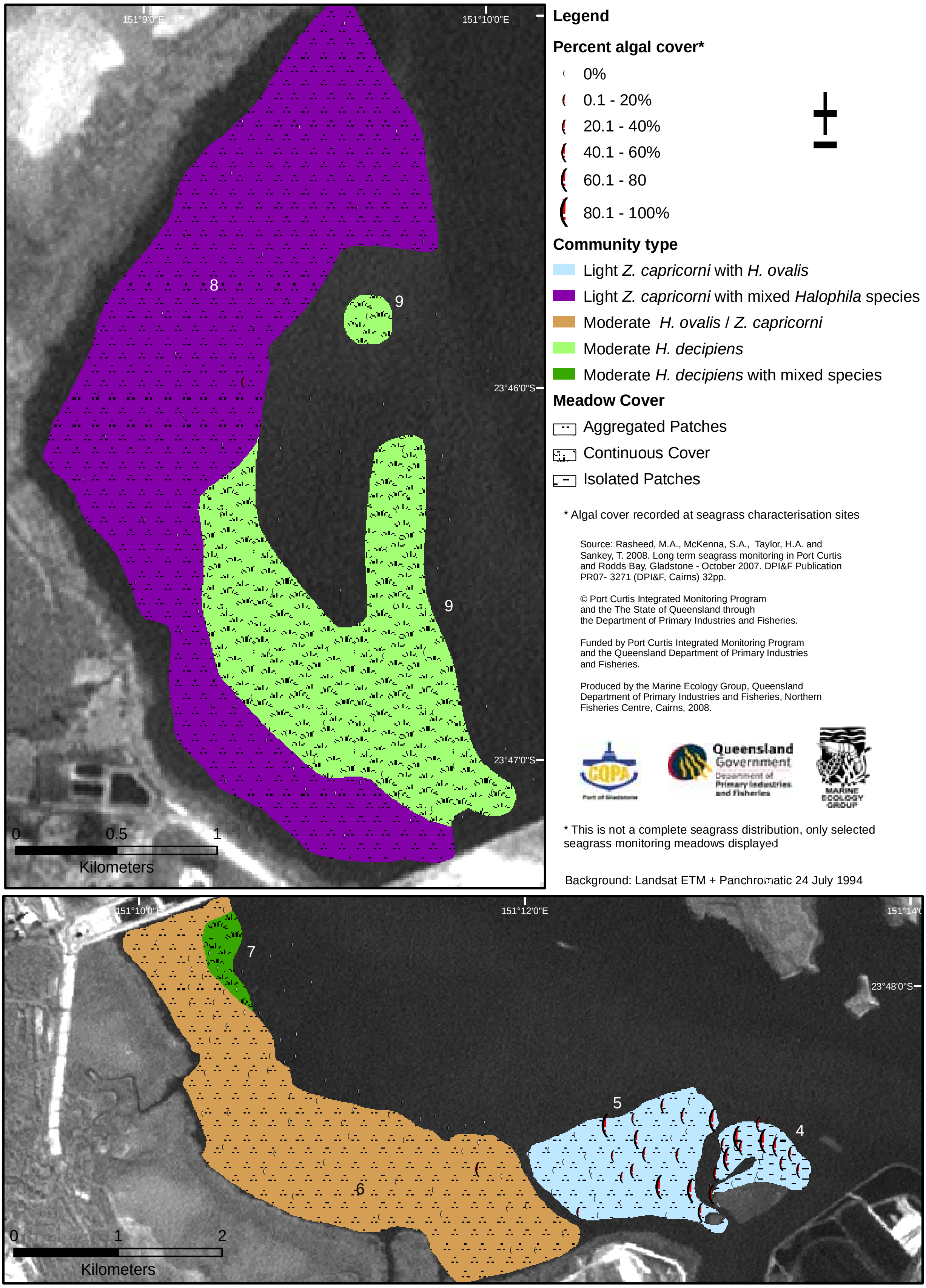
* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Background: Landsat ETM + Panchromatic 24 July 1994

Map 5. Algal cover in the Fishermans Landing region, 2007



COMPARISON WITH PREVIOUS MONITORING SURVEYS

In 2007 seagrass density and area for the majority of monitoring meadows were amongst the highest recorded in the monitoring program to date. Seagrass biomass had increased for 10 of the 13 meadows and was similar to the previous year for two of the remainder (Table 6; Maps 6-9; Appendix 1). The only meadow to show a significant decline in biomass from 2006 was the Quoin Island *Halodule* meadow (meadow 48), however this meadow still had a biomass that was significantly higher than all years prior to 2006 (Appendix 1).

Intertidal seagrass monitoring meadows in the Wiggins Island and Fishermans Landing area (meadows 4,5,6 & 8) had continued to increase in biomass in 2007 from the extremely low levels recorded in 2005 (Figure 1). Mean biomass for each of these meadows was the highest recorded in the program to date (Table 6; Figure 1) with meadows 5 & 6 being significantly higher than any previous survey (Appendix 1). There was generally an increase in the proportion of *Zostera capricorni* that accompanied this increase in biomass (Figure 1). Area of most of these meadows was also larger than in previous surveys. However, these increasing trends did not occur for the two subtidal *Halophila decipiens* meadows in the vicinity (Meadows 7 & 9). Biomass of these meadows was unchanged from 2006 and the area of the southern meadow (meadow 7) had declined substantially to its smallest size in the monitoring program (Map 6; Figure 1). Both of these meadows have been shown to be highly dynamic from year to year with large fluctuations in both biomass and area occurring in the past.

Seagrass meadows adjacent to South Trees Point (meadows 58 & 60) had also increased significantly in biomass in 2007 from previous years (Figure 1; Table 6; Appendix 1). The area and species composition of the meadows remained similar to the last 3 years (Figure 1; Table 5). These low biomass meadows have shown many changes since the 2002 baseline but in 2007 were in the healthiest condition recorded in the program.

The three intertidal *Zostera capricorni* monitoring meadows in Rodds Bay had also increased significantly in biomass to be at least double that of 2006 (Figure 1; Table 6; Appendix 1). These meadows were at their highest recorded biomass but remained similar in size and species composition to previous years.

The largely subtidal *Halodule uninervis* monitoring meadow at Quoin Island (meadow 48) remained at a relatively high biomass in 2007 although it had declined from the highest recorded level of 2006 (Table 6; Figure 1; Appendix 1). In the baseline survey in 2002, this meadow was dominated by the narrow leaf form of *Halodule uninervis*, however in each subsequent survey there had been a shift in species composition with the heavier wide leaf form of the species becoming dominant (Figure 1). In 2007 there was a reversal of this trend with an increase in the proportion of the lighter narrow leaf form explaining the corresponding reduction in biomass (Figure 1).

The Pelican Banks *Zostera capricorni* dominated meadow has been the most stable in the monitoring program with both biomass and area remaining relatively consistent between surveys (Tables 5 & 6; Figure 1; Appendix 1). Biomass for this meadow had not changed significantly between years apart from a peak reached in 2005 (Appendix 1).

Table 5 Area (ha) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006 and October 2007.

Meadow ID	See map	Location	Meadow depth	Area ± R (ha)				
				2002	2004	2005	2006	2007
4	**6**	Wiggins Island	intertidal	35.8 ± 1.7	35.6 ± 1.7	32.5 ± 1.9	35.9 ± 2.1	40.2 ± 2.0
5	**6**	Wiggins Island	intertidal	149.8 ± 2.5	143.6 ± 2.5	140.11 ± 2.5	147.4 ± 2.5	147.5 ± 2.9
6	**6**	South Fishermans	intertidal	464.0 ± 12.9	373.5 ± 11.9	406.4 ± 12.7	428.8 ± 13.0	470.1 ± 12.9
7	**6**	South Fishermans	subtidal	72.6 ± 11.4	185.6 ± 8.7	112.1 ± 12.3	203.1 ± 8.2	20.6 ± 2.4
8	**6**	North Fishermans	intertidal	269.1 ± 11.3	268.3 ± 12.5	231.1 ± 12.3	275.2 ± 12.0	309.9 ± 12.0
9	**6**	North Fishermans	subtidal	268.3 ± 14.9	284.4 ± 7.1	7.0 ± 1.1	143.9 ± 8.0	153.0 ± 8.3
43	**7**	Pelican Banks	intertidal	624.8 ± 12.3	592.8 ± 12.4	614.6 ± 11.9	606.8 ± 14.5	662.0 ± 13.2
48	**7**	Quoin Island	intertidal/subtidal	421.4 ± 10.2	285.8 ± 21.8	316.6 ± 18.7	285.1 ± 19.9	301.7 ± 19.8
58	**7**	South Trees	intertidal	71.9 ± 3.9	11.2 ± 2.3	23.7 ± 2.4	24.0 ± 2.4	18.9 ± 2.1
60	**7**	South Trees	intertidal	11.1 ± 0.7	0.8 ± 0.4	7.7 ± 0.6	7.5 ± 0.8	7.9 ± 0.8
94	**8**	Rodds Bay	intertidal	3.1 ± 0.4	2.7 ± 0.8	3.1 ± 0.8	2.9 ± 0.8	3.2 ± 0.8
96	**8**	Rodds Bay	intertidal	321.9 ± 10.6	303.5 ± 10.3	314.8 ± 10.6	324.4 ± 11.9	327.0 ± 11.5
104	**8**	Rodds Bay	intertidal	47.7 ± 4.3	38.9 ± 3.8	41.94 ± 3.8	35.6 ± 4.5	36.7 ± 5.2
Total				**2755.3 ± 96.6**	**2526.7 ± 96.1**	**2251.6 ± 91.6**	**2520.6 ± 100.8**	**2498.7 ± 93.9**

Table 6 Mean above ground biomass (g DW m^{-2}) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006 and October 2007.

Meadow ID	See map	Location	Meadow depth	Mean biomass (g dw m^{-2})				
				2002	2004	2005	2006	2007
4	**6**	Wiggins Island	intertidal	0.8 ± 0.4	0.74 ± 0.36	0.33 ± 0.15	0.74 ± 0.26	1.20 ± 0.67
5	**6**	Wiggins Island	intertidal	1.4 ± 0.3	0.57 ± 0.19	0.86 ± 0.5	3.73 ± 0.77	8.78 ± 1.17
6	**6**	South Fishermans	intertidal	1.1 ± 0.1	0.24 ± 0.09	0.94 ± 0.61	2.65 ± 0.66	6.32 ± 0.86
7	**6**	South Fishermans	subtidal	0.9 ± 0.2	1.91 ± 0.36	0.03 ± 0.02	3.7 ± 0.95	4.16 ± 1.36
8	**6**	North Fishermans	intertidal	2.1 ± 0.3	0.14 ± 0.08	0.06 ± 0.04	1.28 ± 0.49	3.89 ± 0.77
9	**6**	North Fishermans	subtidal	0.9 ± 0.3	1.93 ± 0.27	0.001 ± 0.001	4.98 ± 0.72	4.64 ± 0.63
43	**7**	Pelican Banks	intertidal	20.8 ± 3.1	18.71 ± 2.13	28.3 ± 3.3	14.17 ± 1.07	13.87 ± 2.24
48	**7**	Quoin Island	intertidal/subtidal	1.8 ± 0.2	1.11 ± 0.2	2.12 ± 1.01	9.52 ± 1.85	6.21 ± 0.80
58	**7**	South Trees	intertidal	1.8 ± 0.5	0.47 ± 0.12	1.19 ± 0.35	0.44 ± 0.34	5.60 ± 1.24
60	**7**	South Trees	intertidal	9.4 ± 3.3	0.08 ± 0.01	0.09 ± 0.03	4.23 ± 0.58	9.04 ± 2.40
94	**8**	Rodds Bay	intertidal	15.1 ± 11.8	2.3 ± 0.51	17.11 ± 3.02	10.54 ± 1.38	28.11 ± 7.67
96	**8**	Rodds Bay	intertidal	6.4 ± 3.1	0.9 ± 0.5	3.62 ± 1.41	7.7 ± 1.58	21.56 ± 4.88
104	**8**	Rodds Bay	intertidal	8.4 ± 3.7	1.26 ± 0.43	10.73 ± 2.62	10.76 ± 1.81	25.20 ± 7.09

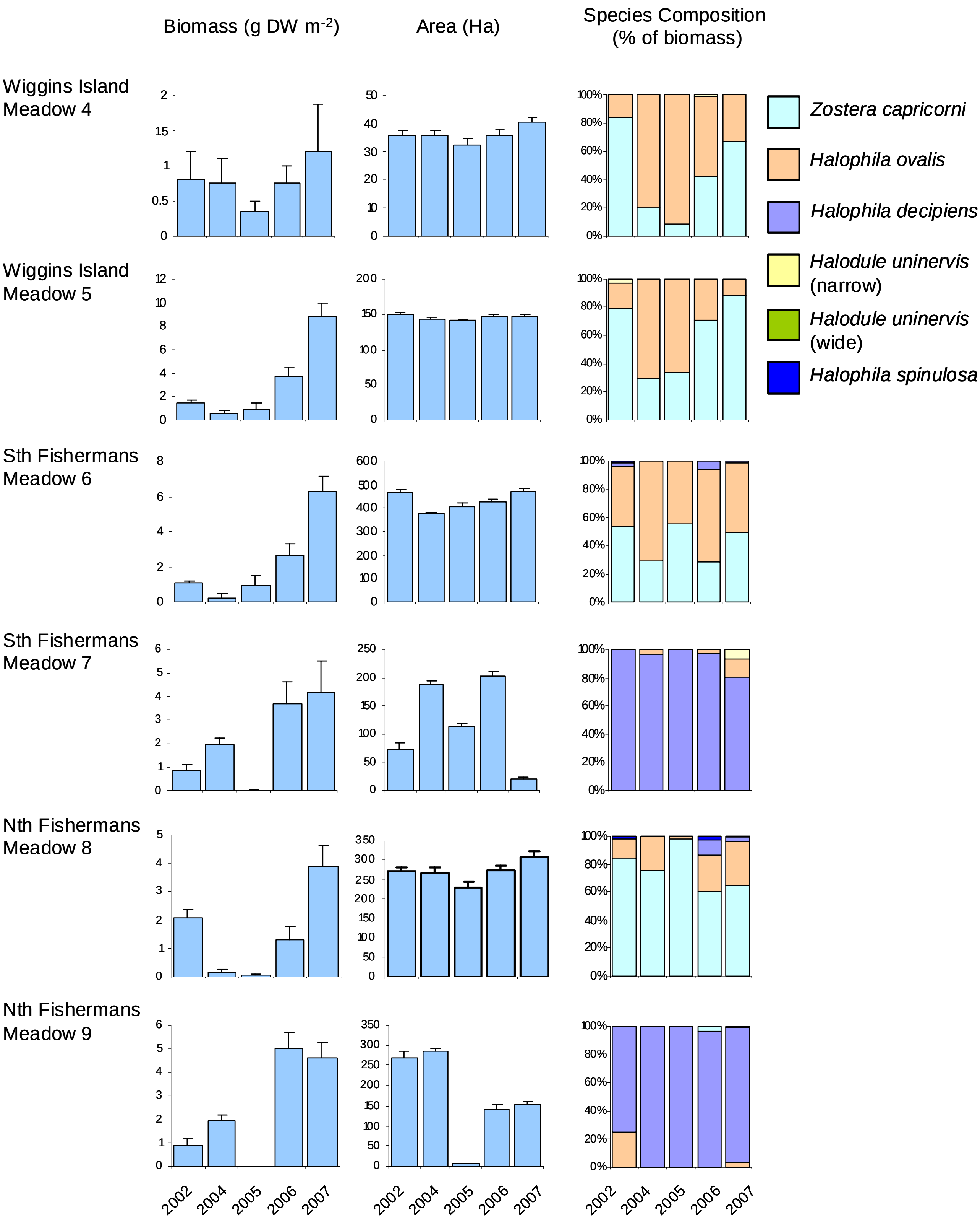


Figure 1(a) Changes in biomass, area and species composition for monitoring meadows in 2002, 2004, 2005, 2006 & 2007 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

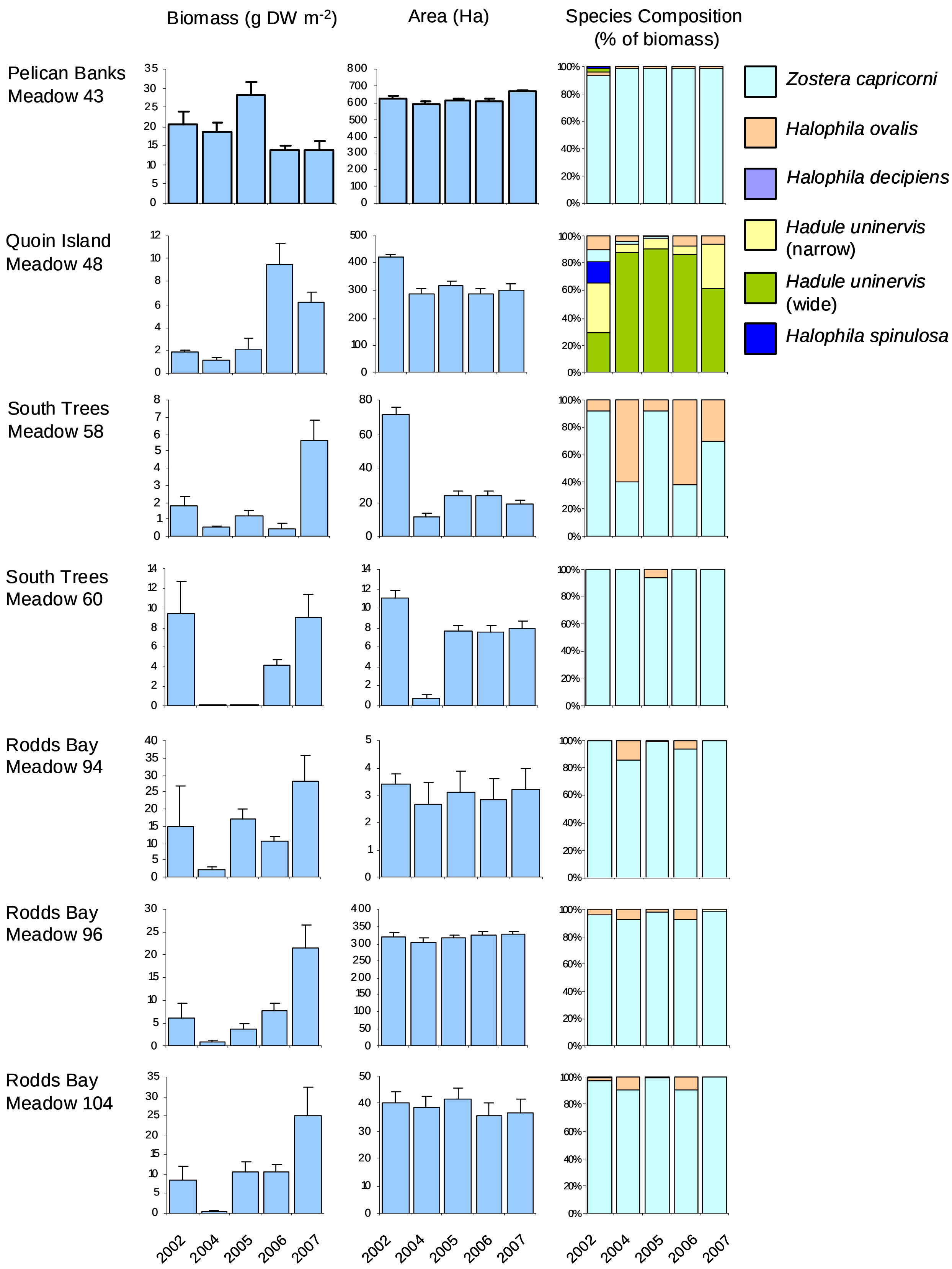
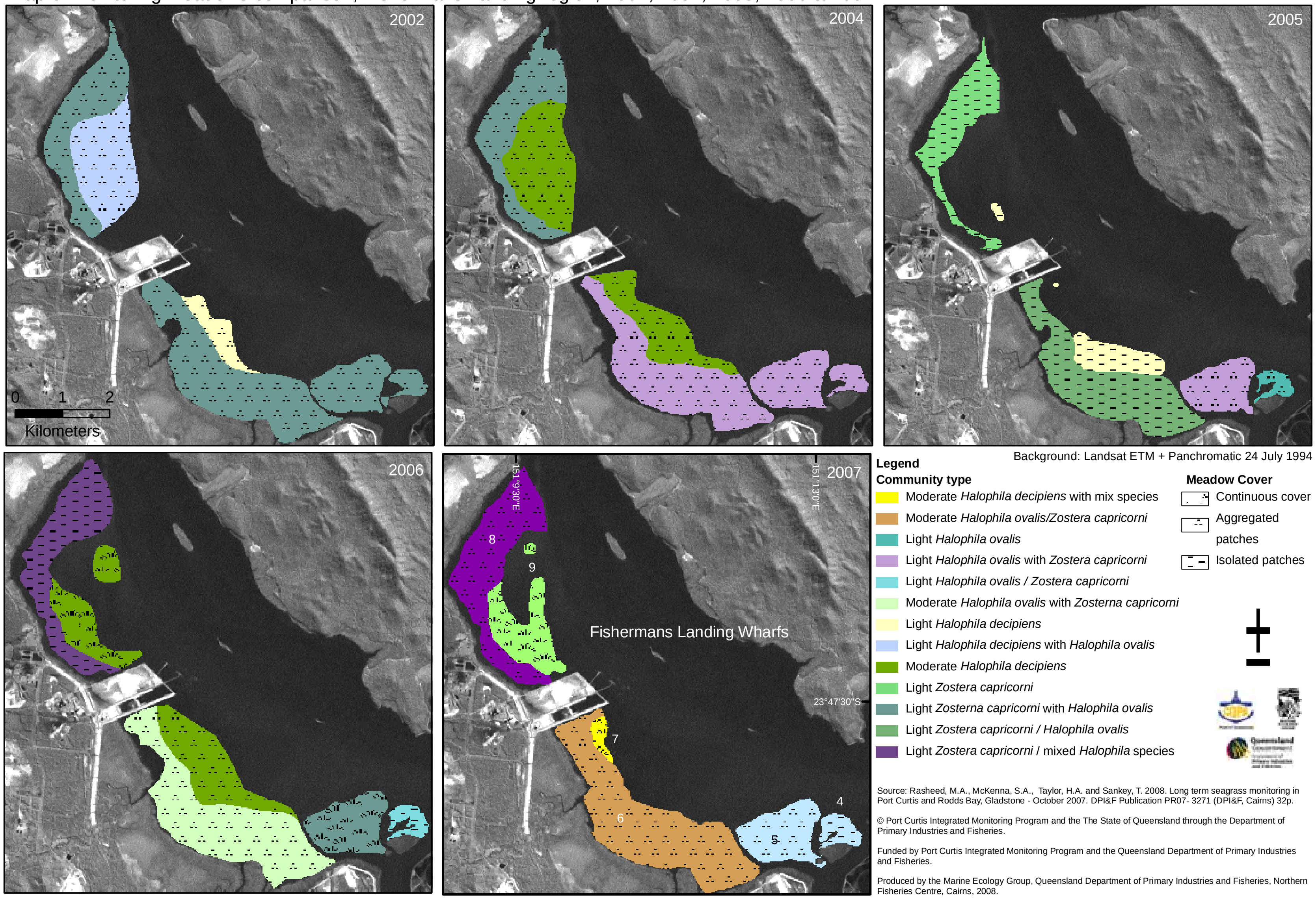


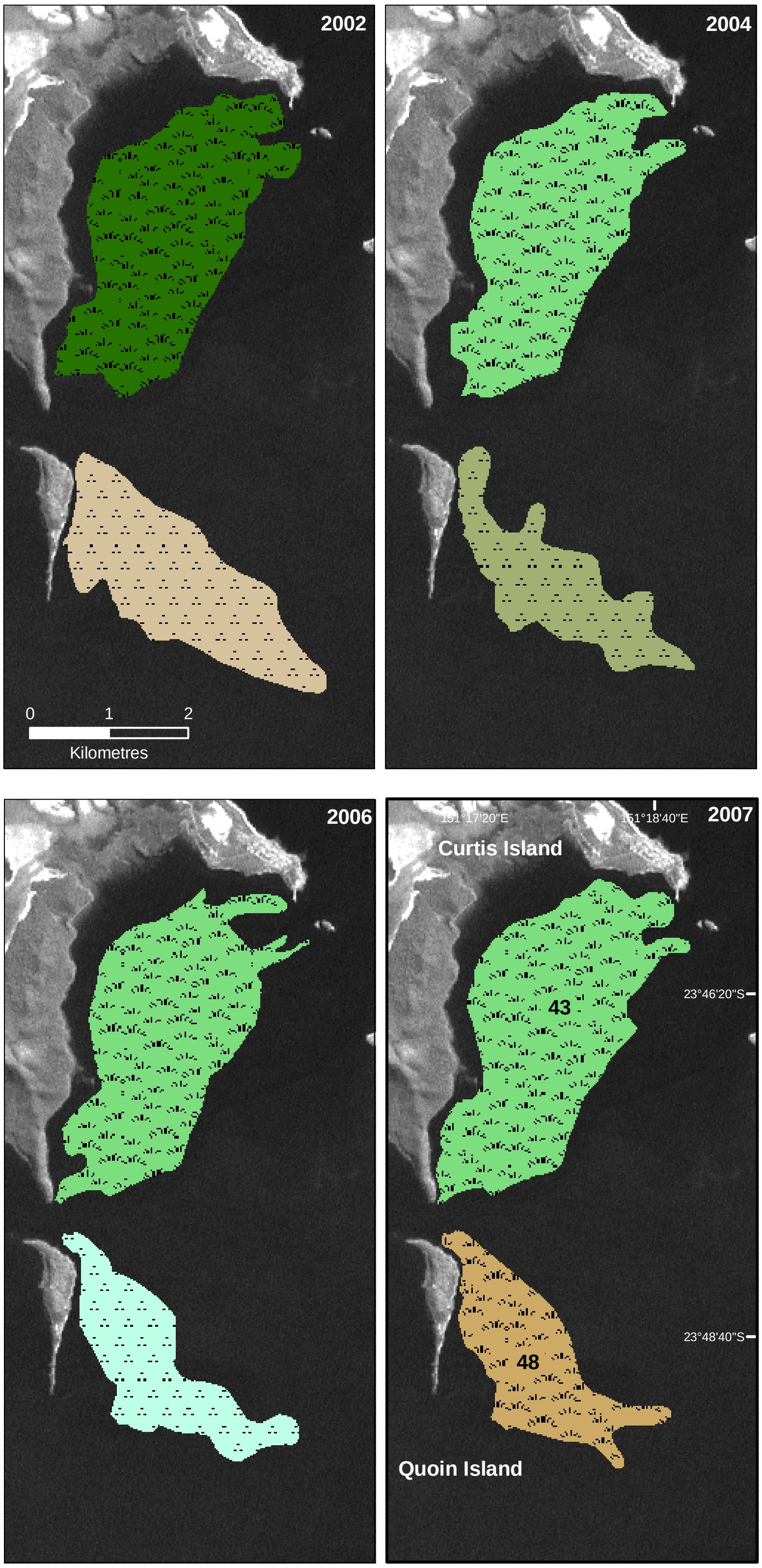
Figure 1(b) Changes in biomass, area and species composition for monitoring meadows in 2002, 2004, 2005, 2006 & 2007 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

Map 6. Monitoring meadows comparison, Fishermans Landing region, 2002, 2004, 2005, 2006 & 2007



* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Map 7. Monitoring meadows comparison in the Quoin Island region, 2002, 2004, 2005, 2006 & 2007



Legend

Community type

- Light *Halodule uninervis* (wide) with mixed species
- Light *Zostera capricorni*
- Moderate *Zostera capricorni*
- Light *Halodule uninervis* (wide)
- Moderate *Halodule uninervis* (wide) with *Halophila ovalis / Halodule uninervis* (thin)
- Moderate *Halodule uninervis* (thin) with *Halodule uninervis* (wide)

Meadow cover

- Continuous cover
- Aggregated patches

Source: Rasheed, M.A., McKenna, S.A., Taylor, H.A. and Sankey, T. 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. DPI&F Publication PR07- 3271 (DPI&F, Cairns) 32pp.

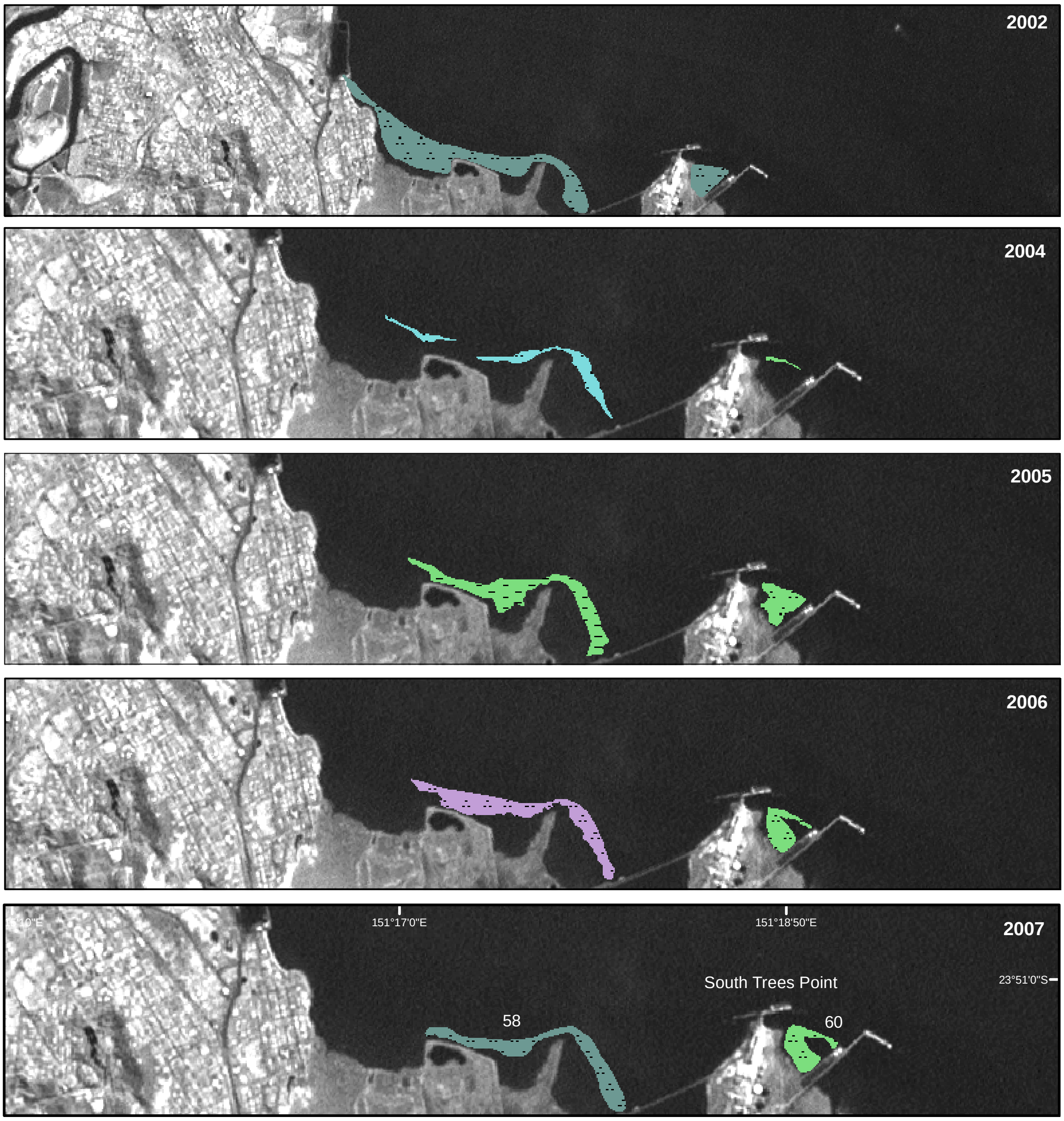
Funded by Port Curtis Integrated Monitoring Program and the Queensland Department of Primay Industries and Fisheries

Produced by the Marine Ecology Group, Queensland Department of Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2008.

* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Background: Landsat ETM + Panchromatic 24 July 1994

Map 8. Monitoring meadows comparison in the South Trees region, 2002, 2004, 2005, 2006 & 2007



Background: Landsat ETM + Panchromatic 24 July 1994

Legend

Community type

- Light *Halophila ovalis* with *Zostera capricorni*
- Light *Halophila ovalis/Zostera capricorni,*
- Light *Zostera capricorni*
- Light *Zostera capricorni* with *Halophila ovalis*

Meadow cover

- Aggregated Patches
- Continuous Cover
- Isolated Patches

0 1 2
Kilometers

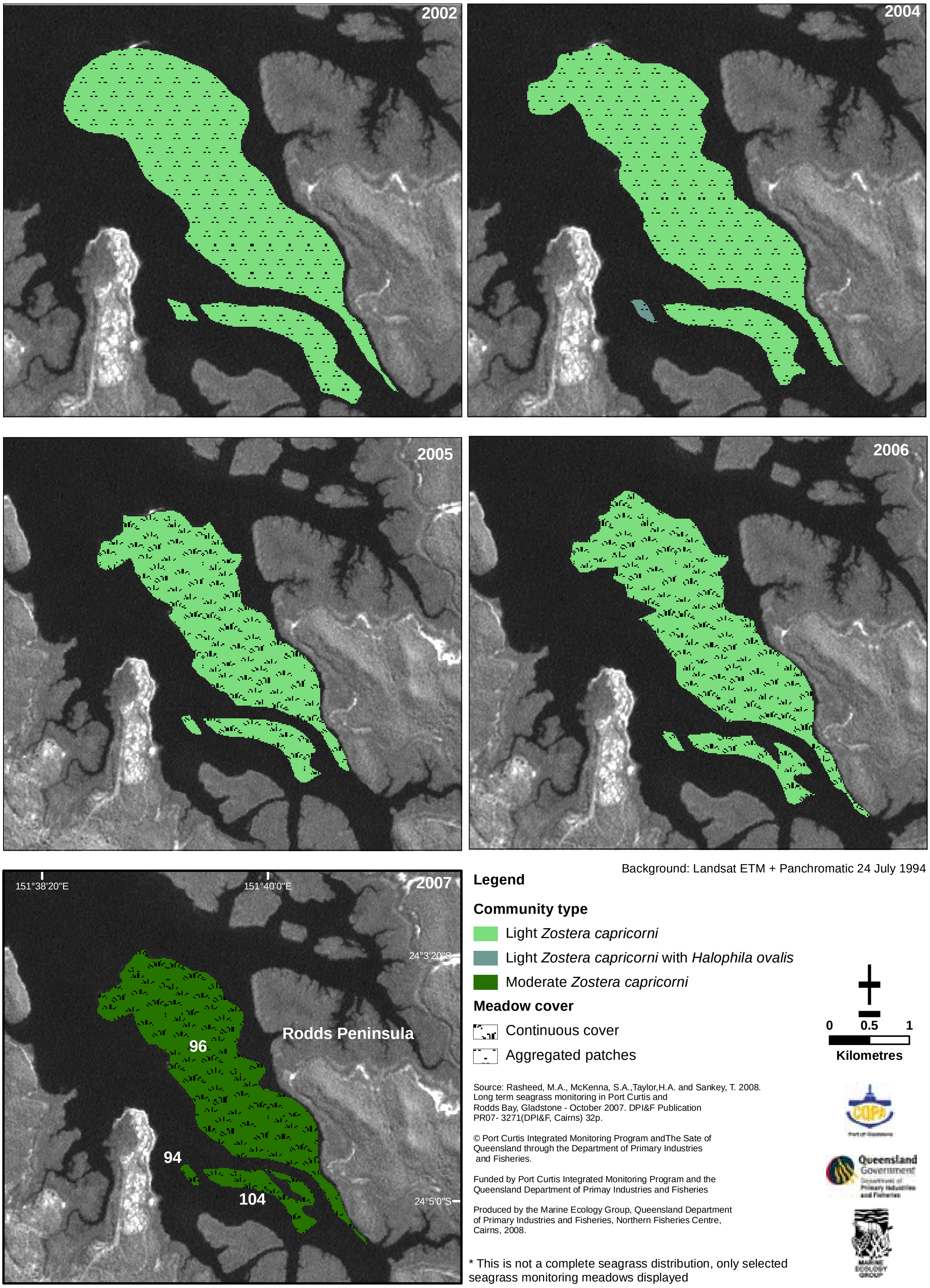
Source: Rasheed, M.A., McKenna, S.A., Taylor, H.T and Sankey, T. 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. DPI&F Publication PR07- (DPI&F, Cairns) 32p.

Funded by Port Curtis Integrated Monitoring Program and the Queensland Department of Primay Industries and Fisheries

Produced by the Marine Ecology Group, Queensland Department of Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2008.

* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Map 9. Comparison of monitoring meadows in the Rodds Bay region, 2002, 2004, 2005, 2006 & 2007



DISCUSSION

In 2007 seagrasses in Port Curtis were in the healthiest condition recorded since the inception of the monitoring program in 2002. Most of the monitoring meadows were at or near their highest recorded biomass and area. This was particularly true for intertidal seagrass meadows which in several cases had more than doubled in biomass from 2006. However the three subtidal monitoring meadows did not exhibit the same trends. While they remained relatively healthy they had either declined in biomass or area from the previous year.

The drivers of seagrass change in Port Curtis appear to be associated with local and regional climate conditions. Factors such as tidal exposure, rainfall, river flows, solar irradiance and temperature have been linked to previous seagrass changes recorded in the program. (Rasheed *et al.* 2005; 2006; Taylor *et al.* 2007). The most recent changes to seagrasses (2006 to 2007) also appear to be largely consistent with climatic factors. During 2007 there had been an increase in rainfall and lower mean monthly air temperatures compared to the previous year (Figures 2a & b). In addition, solar irradiance and hours of daytime exposure of intertidal banks had remained relatively low and there was no significant freshwater flow event of the Calliope River into the port (Figure 2c & d). These factors were conducive to the increases in intertidal seagrasses that were observed. Under these conditions intertidal seagrasses would have been far less susceptible to thermal stress and desiccation that can occur when meadows are exposed at low tide (Erftemeijer & Herman 1994; Rasheed *et al.* 2005). The increases occurred for meadows adjacent to the mainland coast in the inner area of Port Curtis (Fishermans Landing, Wiggins Island, South Trees) as well as the reference meadows in Rodds Bay adding further support to a natural rather than anthropogenic (human activity) driver for seagrass change.

The same climatic conditions, however, were likely to have had the opposite effect on subtidal seagrasses. These deeper meadows are not subjected to exposure related stress and the lower solar irradiance would likely result in reduced light available for seagrass growth. The meadows most affected were dominated by *Halophila decipiens* a known colonising species that has large natural variations in density and distribution. *Halophila decipiens* is capable of producing relatively long lived seeds that can lay dormant in the sediment for at least two years and can rapidly colonise when conditions are favourable (Hammerstrom *et al*. 2005; McMillan 1991). Conversely *Halophila decipiens* quickly declines when conditions are less favourable such as a reduction in available light. The patterns of change for these meadows in Port Curtis were typical for this type of seagrass community in Queensland.

Similar trends for intertidal and subtidal seagrasses have been found in other Queensland locations where seagrasses are monitored, with changes strongly linked to exposure and climate conditions. Recent surveys in Cairns have seen intertidal *Zostera capricorni* meadows increase substantially in abundance with a corresponding decrease in subtidal *Halophila* meadows (Rasheed *et al.* 2008). Intertidal seagrasses in the Gulf of Carpentaria have also reached record densities in the last two years with a return to more normal climate conditions following several years of drought (Rasheed and Taylor 2008).

The complete recovery of intertidal seagrass meadows in the Wiggins Island and Fishermans Landing region in 2007 was also a positive sign for seagrass health within the port. These meadows had declined dramatically in 2004 and 2005 and have taken substantially longer to recover than other intertidal meadows in the region. It was thought that additional factors other than climate and exposure were affecting these meadows including the influence of the nearby Calliope River, increased abundance of algae and low resilience of the seagrass communities (see Rasheed *et al*. 2006; Taylor *et al.* 2007). The Calliope River has had a minimal flow since the major flushing event that occurred in February 2003 (Figure 2). This has meant that the seagrass meadows near the mouth of the river were unlikely to have been exposed to significant inputs of nutrients, sediments, herbicides, low salinity water or other inputs associated with flooding that can have negative impacts on seagrass growth. The fact that these meadows have taken longer to recover from the 2004 declines may reflect that they have a lower resilience and capacity to recover than other seagrass meadows in the survey area. These meadows were low biomass and highly patchy in nature prior to the decline with no evidence of a substantial seed bank from which recovery could occur (Rasheed *et al.* 2006). The observed recovery therefore relied on the vegetative expansion of the remaining isolated patches of seagrass and recruitment from outside of the meadow resulting in a much longer recovery period than other meadows where a consistent cover of seagrass plants remained from which recovery could occur (Rasheed 1999; 2004).

The only intertidal meadow that didn't experience an increase in density was the large *Zostera capricorni* meadow on Pelican Banks. This meadow has remained at a consistent density between surveys (with the exception of 2005). The Pelican Banks meadow has far less exposure to estuarine influences than the other intertidal meadows in the study due to its location at the entrance between Curtis and Facing Islands. The regular tidal flushing of clean oceanic water over these banks is likely to have a buffering effect that would dilute the effects of runoff related turbidity possibly explaining its relative stability throughout the monitoring program.

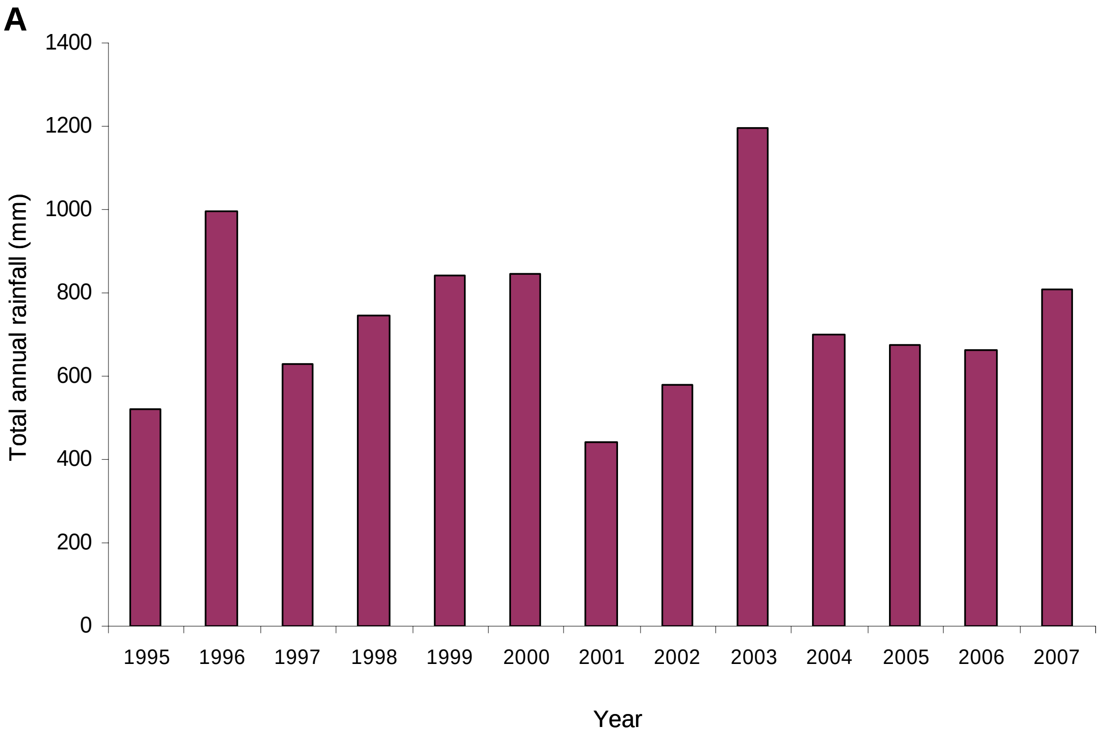
The healthy *Zostera capricorni* communities identified in the 2007 monitoring are likely to provide an important refuge for fish and crustacean species and are recognized as key nursery areas for many commercial species (Rasheed and Thomas 2002; McKenzie *et al.* 1996; Watson *et al.* 1993). Healthy *Zostera capricorni* meadows in Cairns Harbour have been demonstrated to be important habitat for juvenile tiger prawns and were estimated to be worth over AUD $3,687 per hectare per year in total landed value (1992 value) (Watson *et al.* 1993).

Evidence of dugong activity in the Port Curtis seagrass meadows has been consistently observed throughout the monitoring program. The seagrass meadows around Wiggins Island in particular appear to be heavily utilised by dugong, as feeding trails were found at a majority of sites sampled in 2007, and have been recorded in all previous surveys. Further evidence of feeding activity was observed in South Trees, Quoin Island and Fishermans Landing. Green sea turtles were regularly observed within the seagrass meadows particularly on Pelican Banks where they were often 'stranded' at low tide.

The presence of seagrass meadows and dugong activity in intertidal areas adjacent to port facilities and infrastructure has implications for port management. Some of the most utilized seagrass meadows also appear to be those in closest proximity to major port infrastructure and proposed areas of expansion. Future port infrastructure developments such as wharves, breakwaters and reclamations would require careful management to ensure minimal impacts on these communities. The fact that "healthy" seagrass meadows and dugong activity have continued to exist within the port indicates that these important habitats can co-exist with well managed port activities and development.

Post the November 2007 seagrass survey the Gladstone area has received substantial rain, flooding and related turbid plumes within the port area. These factors were likely to have a negative effect on seagrasses at least in the short term. Results from the survey however show that seagrasses in the Port Curtis area were in a very healthy condition which should have provided the meadows with a high resilience and potentially greater capacity to recover from flood related impacts.

This was the fourth survey in the established annual monitoring program and we have already identified some of the likely climate related drivers of seagrass change. A recent expansion of the seagrass monitoring program within PCIMP has led to a series of turbidity, light and temperature loggers and monitoring stations being established in the seagrass meadows in late 2007 by the Centre for Environmental Management at CQU. With the aid of this new data we will be in a far stronger position to determine the major drivers of seagrass change and will be better able to assess any anthropogenic (human induced) impacts to seagrass meadows that may arise in the future.



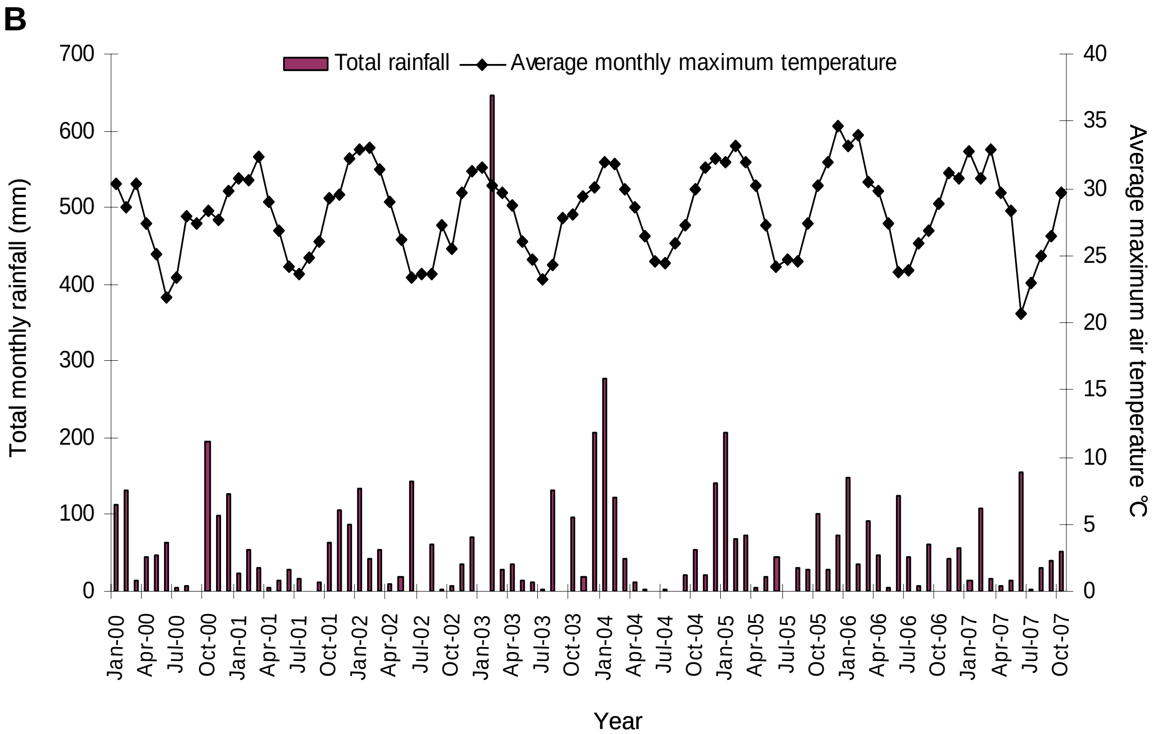
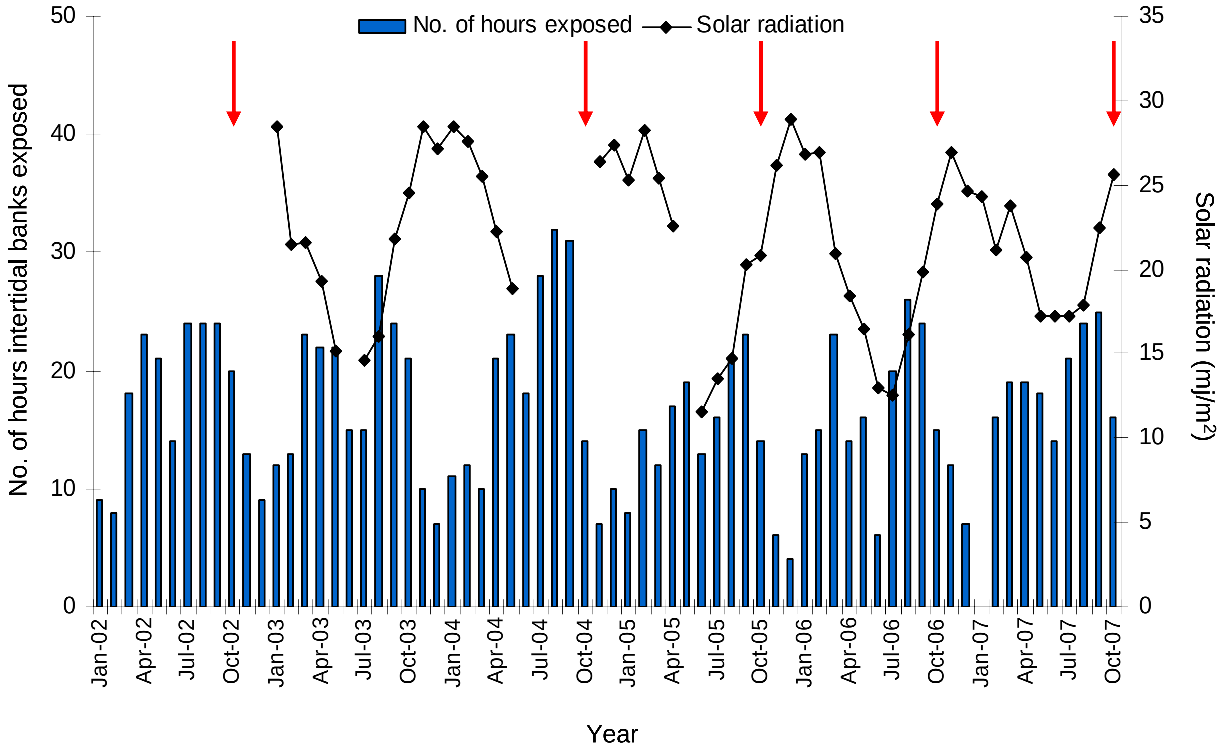


Figure 2a (A) Total annual rainfall recorded at Gladstone from 1995 to 2007 (Bureau of Meteorology); (B) Gladstone mean monthly maximum temperature and total monthly rainfall (Bureau of Meteorology).

C



D

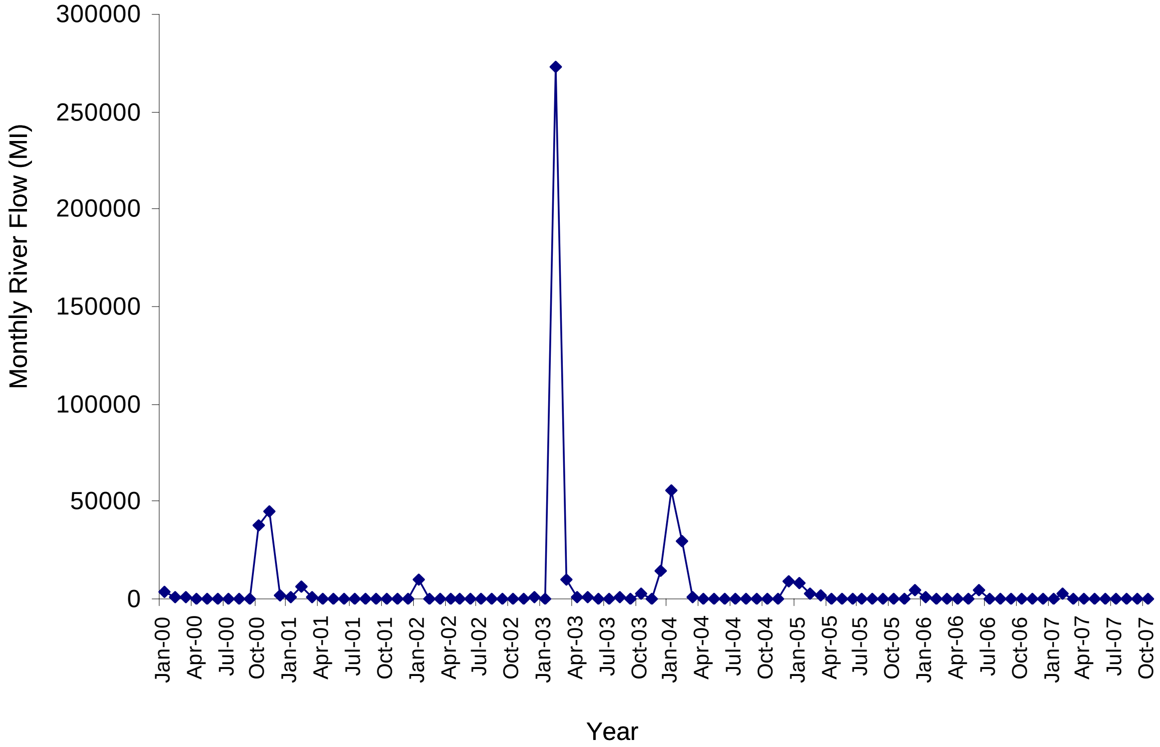


Figure 2b (C) The monthly total number of daylight hours that intertidal banks are exposed and solar radiation (megajoules/metre^2) recorded from 2002 to 2007 (red arrows indicate times of seagrass monitoring surveys)(Bureau of Meteorology and Maritime Safety Queensland) and (C) Total monthly river flow for the Calliope River between 2000 and 2007 (Queensland Department of Natural Resources and Mines).

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APPENDIX 1

Results of one-way ANOVA for mean above ground biomass versus year for the thirteen seagrass monitoring meadows in Port Curtis and Rodds Bay (2002, 2004, 2005, 2006 and 2007) (* significant difference in biomass between years)

Meadow 4^	**DF**	**SS**	**MS**	**F**	**P**
Between Years	4	2554.73	638.681	1.22	**0.3068**
Within Years	90	47044.8	522.72		
Total	94	49599.5			
Meadow 5[#]					
Between Years	4	92.9286	23.2321	25.92	**<0.0001***
Within Years	151	135.365	0.89646		
Total	155	228.294			
Meadow 6[#]					
Between Years	4	84.8714	21.2179	27.02	**<0.0001***
Within Years	201	157.838	0.78526		
Total	205	242.709			
Meadow 7^					
Between Years	4	22075	5518.74	14.62	**<0.0001***
Within Years	82	30963	377.598		
Total	86	53038			
Meadow 8^					
Between Years	4	140077	35019.4	17.45	**<0.0001***
Within Years	180	361289	2007.16		
Total	184	501367			
Meadow 9					
Between Years	4	516.237	129.059	15.69	**<0.0001***
Within Years	104	855.31	8.22413		
Total	108	1371.55			
Meadow 43					
Between Years	4	7960.68	1990.17	5.53	**0.0003***
Within Years	292	105082	359.871		
Total	296	113043			
Meadow 48[~]					
Between Years	4	11.3584	2.8396	27.01	**<0.0001***
Within Years	195	20.5001	0.10513		
Total	199	31.8586			
Meadow 58[~]					
Between Years	4	3.59624	0.89906	9.75	**<0.0001***
Within Years	131	12.0786	0.0922		
Total	135	15.6748			
Meadow 60[#]					
Between Years	4	55.3645	13.8411	12.03	**<0.0001***
Within Years	44	50.635	1.1508		
Total	48	106			
Meadow 94[~]					
Between Years	3	3.8486	1.28287	7.19	**0.0006***
Within Years	38	6.77911	0.1784		
Total	41	10.6277			
Meadow 96^					
Between Years	4	60626.6	15156.7	10.34	**<0.0001***
Within Years	145	212496	1465.49		
Total	149	273123			
Meadow 104[#]					
Between Years	4	121.761	30.4404	8.43	**<0.0001***
Within Years	79	285.213	3.61029		
Total	83	406.974			

^ Kruskal-Wallis ANOVA; [#] One-way ANOVA using square root transformed data; [~]One-way ANOVA using log+1 transformed data; Meadow 94 data from 2002 discarded due to a small number of sites.

Results of Least Significant Difference (LSD) pair-wise comparisons of mean above ground biomass (g DW m-2) for the Gladstone monitoring meadows. Means that share a common letter for each meadow are not significantly different (p>0.05).

Meadow 4[#]	
Year	**Mean Biomass**
2002	0.8 a
2004	0.74 a
2005	0.33 a
2006	0.79 a
2007	1.2 a

Meadow 5	
Year	**Mean Biomass**
2002	1.4 b
2004	0.57 c
2005	0.86 bc
2006	3.73 a
2007	8.78 d

Meadow 6	
Year	**Mean Biomass**
2002	1.1 b
2004	0.24 c
2005	0.94 c
2006	2.65 a
2007	6.32 d

Meadow 7[#]	
Year	**Mean Biomass**
2002	0.9 ab
2004	1.91 a
2005	0.03 b
2006	1.9 a
2007	4.16 a

Meadow 8[#]	
Year	**Mean Biomass**
2002	2.1 a
2004	0.14 b
2005	0.06 b
2006	1.28 a
2007	3.89 a

Meadow 9	
Year	**Mean Biomass**
2002	0.9 bc
2004	1.93 b
2005	0.0008 c
2006	4.98 a
2007	4.64 a

Meadow 43	
Year	**Mean Biomass**
2002	20.8 b
2004	18.71 bc
2005	28.3 a
2006	14.17 bc
2007	13.87 c

Meadow 48	
Year	**Mean Biomass**
2002	1.8 b
2004	1.11 b
2005	2.12 b
2006	9.52 a
2007	6.21 a

Meadow 58	
Year	**Mean Biomass**
2002	1.8 b
2004	0.47 c
2005	1.19 bc
2006	0.44 c
2007	5.60 a

Meadow 60	
Year	**Mean Biomass**
2002	9.4 a
2004	0.08 b
2005	0.09 b
2006	4.23 a
2007	9.04a

Meadow 94	
Year	**Mean Biomass**
2002	15.1 n/a
2004	2.3 c
2005	17.11 ab
2006	10.54 b
2007	28.11 a

Meadow 96[#]	
Year	**Mean Biomass**
2002	6.4 ab
2004	0.9 bc
2005	3.62 ab
2006	7.7 a
2007	21.56 a

Meadow 104	
Year	**Mean Biomass**
2002	8.4 bc
2004	1.26 c
2005	10.73 b
2006	10.75 ab
2007	25.20 a

[#] Kruskal-Wallis pair-wise comparisons