Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008

Gladstone Ports Corporation

PCIMP

Queensland Government

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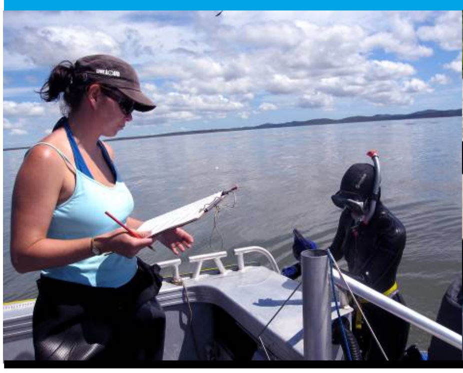

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On 26 March 2009, the Department of Primary Industries and Fisheries was amalgamated with other government departments to form the Department of Employment, Economic Development and Innovation.

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EXECUTIVE SUMMARY

This report details findings of the 2008 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 2008 seagrasses in Port Curtis were in a relatively healthy condition compared with previous monitoring surveys. Most of the monitoring meadows had only slight changes in density and area from the previous year's survey. However both the intertidal and subtidal meadows in the Fisherman's Landing area and the Quoin Island meadow had some significant declines in biomass.

The drivers of seagrass change in Port Curtis appear to be largely associated with local climate conditions, fine scale variability in the physical meadow environment and the natural resilience and capacity for recovery in individual seagrass meadows. Substantial rainfall and related turbid plumes that occurred in early 2008 within the port area appeared to have a negative effect on the seagrass meadows near the mouth of the Calliope River. The very healthy condition of seagrasses recorded in 2007 may have provided the meadows with a high resilience and potentially greater capacity to recover from flood related impacts in the longer term.

The 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. Data loggers provided the first glimpse of *in situ* conditions to evaluate changes occurring at the meadow scale. The loggers, while valuable, have been in place under a year making comparative analyses difficult. Relationships between meadow dynamics and physical parameters will be better resolved as a larger dataset develops.

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 utilised 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.

This was the fifth survey in the established annual monitoring program and some of the likely climate related drivers of seagrass change have been identified. Additional information on light and temperature being collected in the program will strengthen our ability to separate the natural and human induced causes of change 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.

Gladstone Ports Corporation Limited (GPCL) recognises that seagrass meadows comprise 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. GPCL commissioned the Queensland Primary Industries & Fisheries (QPIF; Department of Employment, Economic Development and Innovation (DEEDI)) 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 region.

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. At the request of GPCL 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 represent the range of seagrass communities within the port and include meadows that would most likely be impacted by port facilities and developments. Monitoring meadows include both intertidal and subtidal seagrasses as well as meadows preferred 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 in order 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 (i.e. as a control).

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 have occurred between the 2002 baseline and subsequent monitoring surveys from 2004 to 2007. Generally, regional and local climatic factors were the most likely causes of seagrass change rather than port related activities during this time. The last four 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 add value to the program, it was decided to shift the seagrass monitoring program to PCIMP from 2007. Under PCIMP, the monitoring program provides information required to aid in planning of port development and maintenance programs that will have minimal effects on the marine environment in addition to ensuring the health of Port Curtis' marine environment. The collaborative monitoring program between PCIMP and QPIF was further expanded in late 2007 to include *in situ* measurements of three key variables that are known to impact seagrass health: light, turbidity and temperature. The physicochemical data will be incorporated into monitoring assessments in order to resolve what impact they have on seagrass dynamics at the meadow scale.

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 during subsequent annual monitoring surveys
4. Document temporal physicochemical water quality parameters at selected seagrass meadows within port limits (Central Queensland University separate report).
5. Interpret the affects of changes in temporal physicochemical water quality parameters on distribution, abundance and species composition of selected seagrass meadows within the port limits.
6. Place observed changes within a regional and state-wide context

METHODS

Seagrass surveys of the Gladstone port limits (Port Curtis) and Rodds Bay were conducted between the 12th and 16th of November 2008. The survey was conducted in mid November 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 previously 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 (Global Positioning System; GPS). 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. 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 (i.e. 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 observed during the survey. After ranking these quadrats, the seagrass 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.

In December 2007, PCIMP began collecting light, turbidity and temperature data in all ten of the seagrass monitoring meadows within Port Curtis (no data collected in Rodds Bay). A complete summary of the methods and data collected is provided in Wilson et al. (2008). Temperature data was collected at all ten meadows whilst light and turbidity were collected at Pelican Banks (meadow 43), North Fisherman's (meadow 8), and Wiggins Island (meadow 4; see Map 2 & 3).

Habitat Mapping and Geographic Information System

Spatial data from the field surveys were incorporated into the GPCL/QPI&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 (GPS) 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, November 2008

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with mixed species	Species A is 50-90% 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, November 2008

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 GPS 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, November 2008

Mapping precision	**Mapping methodology**
≤5m	Meadow boundaries mapped in detail by GPS 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 2008

Five seagrass species (from three families) were identified in the thirteen seagrass monitoring meadows (Figure 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.

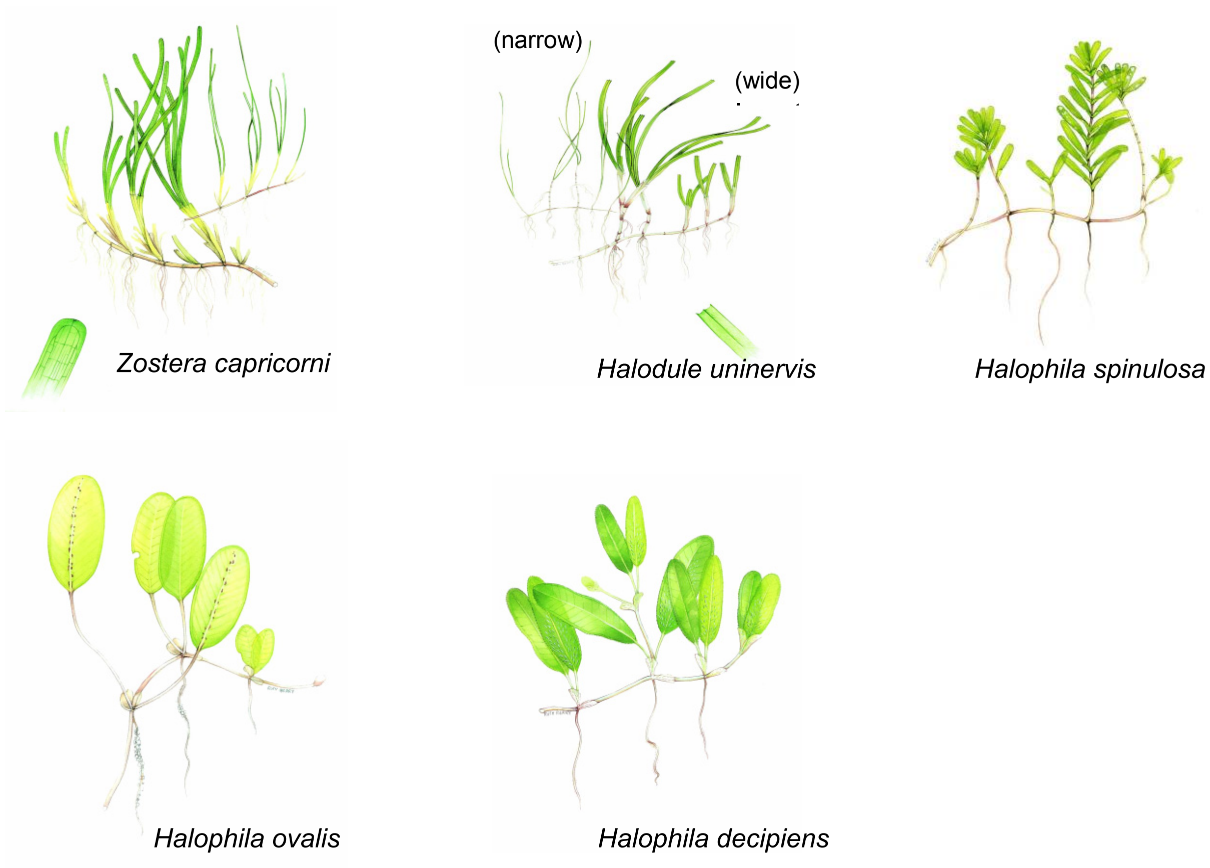


Figure 1. Seagrass species present during 2008 Port of Gladstone monitoring surveys.

A total of 2703.6 ± 96.3 ha of seagrass habitat was mapped in the thirteen seagrass monitoring meadows in November 2008 (Table 4). Meadow area ranged from 3.2 ha to 681.4 ha with the smallest meadow situated at Rodds Bay and largest meadow located at Pelican Banks (Table 5; Map 3). A total of 419 monitoring sites (excluding meadow boundary mapping sites) were surveyed, 83% (347 sites) of which had seagrass present (Map 1). Of these monitoring sites 306 intertidal sites were surveyed from helicopter and 113 subtidal sites were surveyed using boat based methods (diver).

The thirteen monitoring meadows that were surveyed included seven 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.

A new seagrass meadow (meadow 49) was mapped in 2008 between the Quoin Island monitoring meadow (48) and the southern section of Quoin Island (Map 3). This relatively small and patchy intertidal meadow was dominated by *Halophila ovalis*.

Mean above ground biomass for the monitoring meadows ranged from 0.30 ± 0.09 g DW m^{-2} in the light *Halophila decipiens* subtidal meadow north of Fisherman's Landing (meadow 9) to 25.96 ± 3.03 g DW m^{-2} for the moderate *Zostera capricorni* meadow at Pelican Banks (meadow 43) (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 isolated or 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 aggregated patches and some 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) and Quoin Island meadows (meadow 48 & 49) which occurred on sediments dominated by sand.

Dugong feeding activity was observed on the majority of intertidal seagrass meadows surveyed. The highest density of dugong feeding trails was observed at the light *Zostera capricorni* meadow at Wiggins Island west (meadow 5; Map 2) with dugong feeding trails recorded at 69% of sampling sites. Dugong feeding trails were also observed at Quoin Island meadows (meadow 48 & 49), Wiggins Island (meadow 4), Pelican Banks (meadow 43), South Trees (meadow 58) and across the intertidal meadows to the north and south of Fishermans Landing (meadows 6 & 8).

Map 1. Location of 2008 seagrass monitoring sites and seagrass meadows from the 2002 baseline survey in Ports Curtis and Rodds Bay

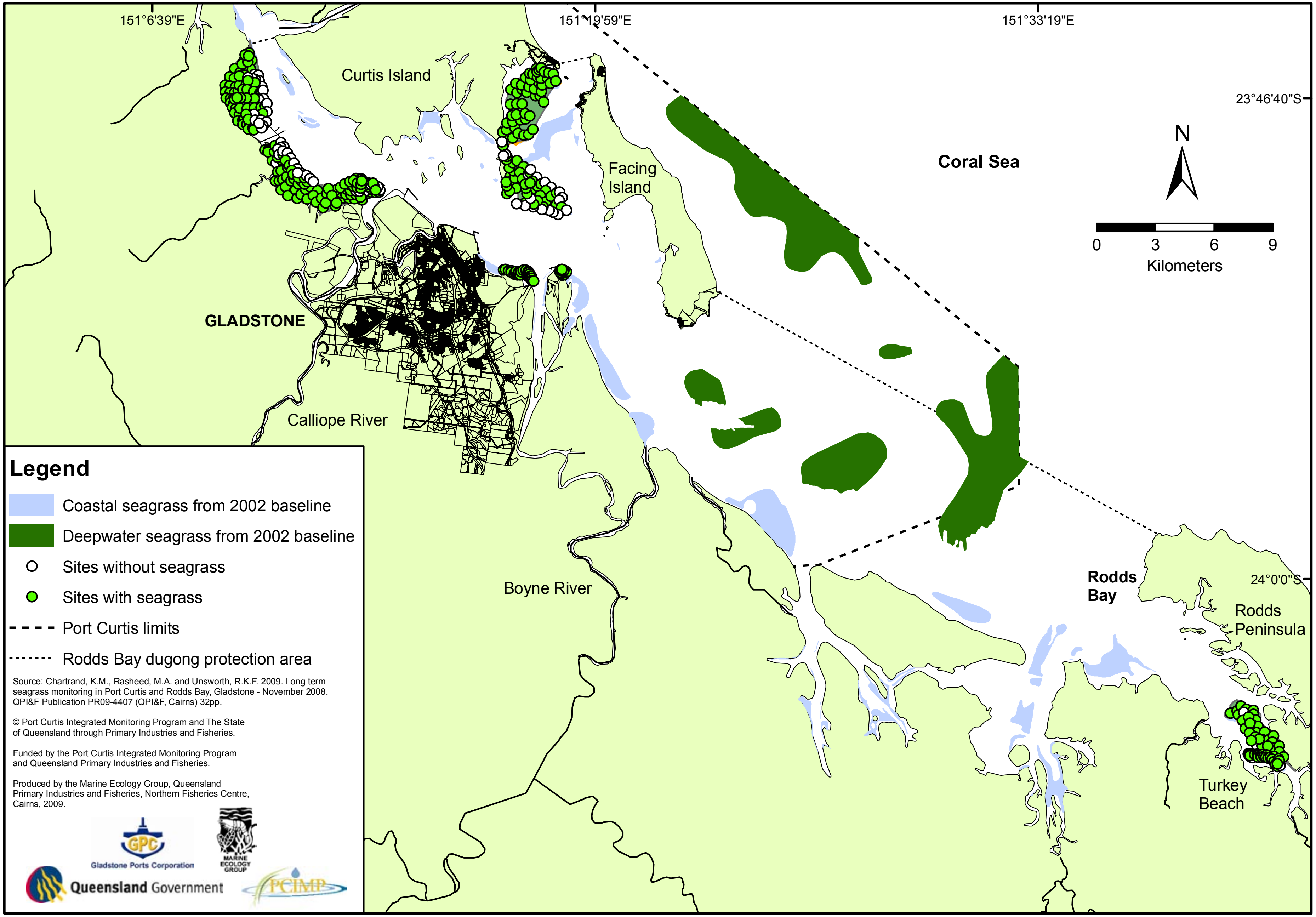
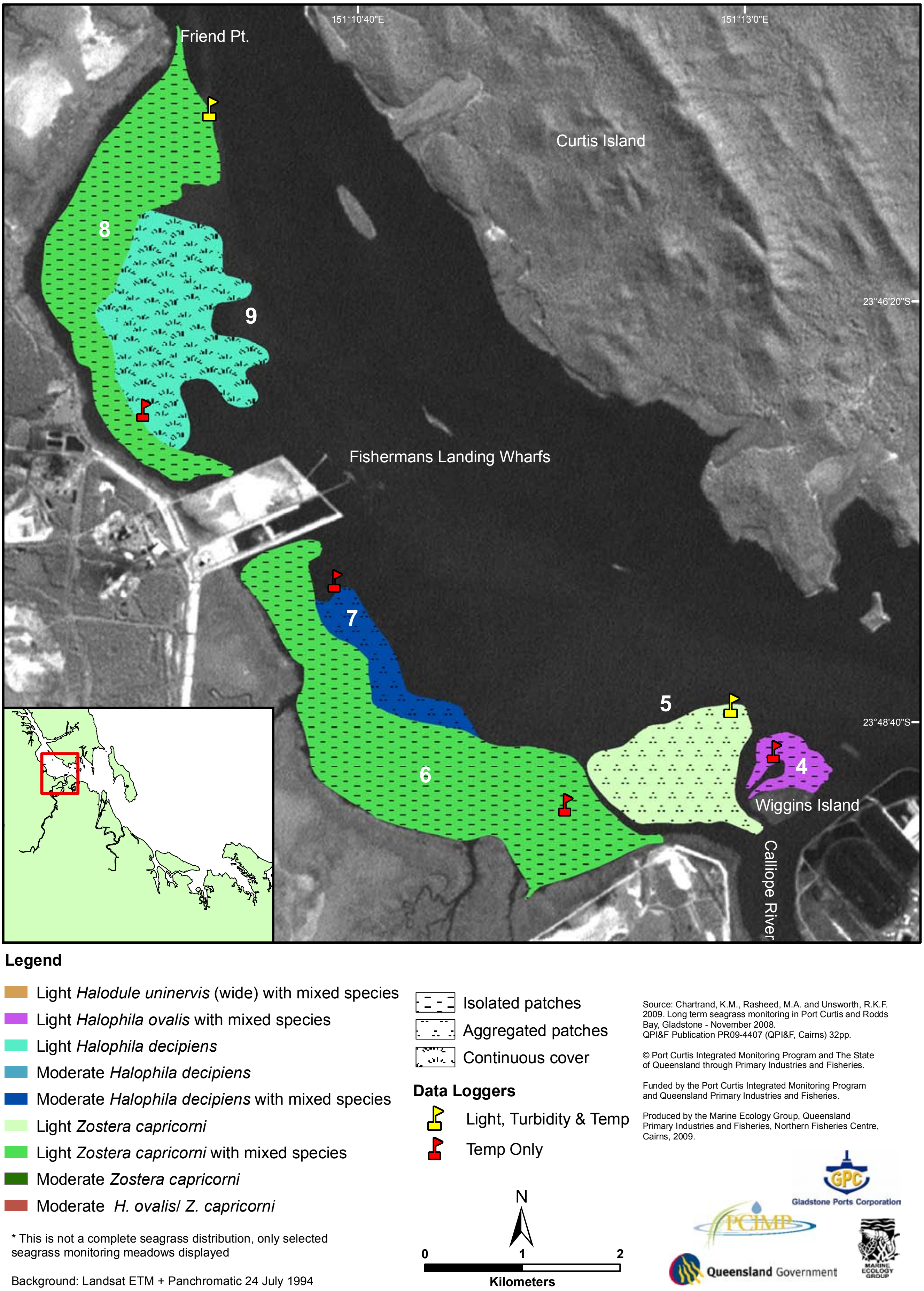


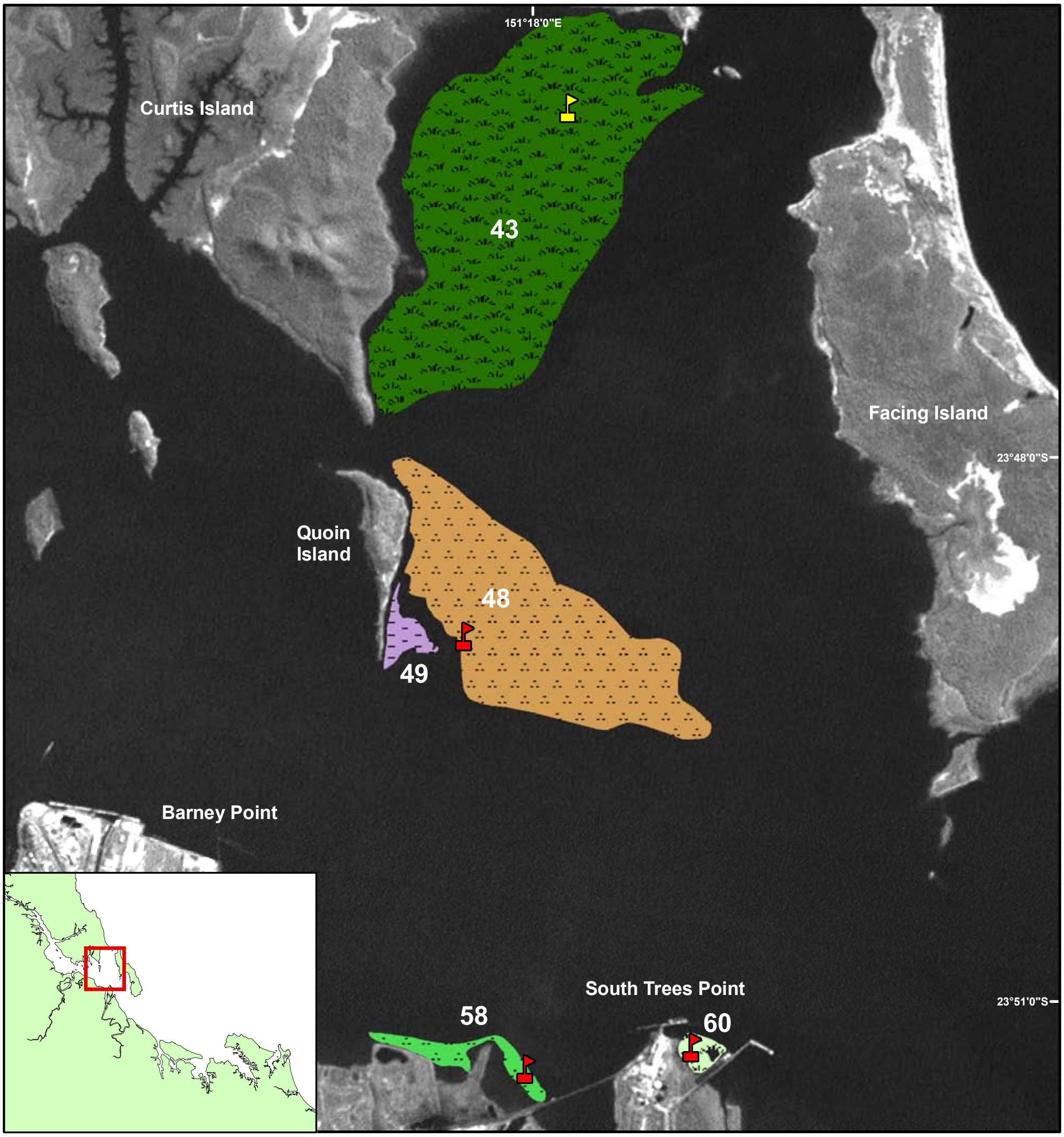
Table 4 Community type, seagrass cover and species present in the thirteen Gladstone monitoring meadows, November 2008.

Monitoring Meadow	Location	No. of sites	Community Type	Cover	Species Present
4	Wiggins Island	18	Light *H. ovalis* with mixed species	Isolated patches	*H. ovalis, Z. capricorni*
5	Wiggins Island	32	Light *Z. capricorni*	Aggregated patches	*Z. capricorni, H. ovalis*
6	South Fishermans	42	Light *Z. capricorni* with mixed species	Isolated patches	*Z. capricorni, H. ovalis, H. decipiens*
7	South Fishermans	11	Moderate *H. decipiens* with mixed species	Aggregated patches	*H. decipiens, H. ovalis*
8	North Fishermans	38	Light *Z. capricorni* with mixed species	Isolated patches	*Z. capricorni, H. spinulosa, H. ovalis, H. decipiens*
9	North Fishermans	29	Light *H. decipiens*	Continuous cover	*H. decipiens, Z. capricorni*
43	Pelican Banks	52	Moderate *Z. capricorni*	Continuous cover	*Z. capricorni, H. ovalis*
48	Quoin Island	35	Light *H. uninervis* (wide) with mixed species	Aggregated patches	*H. uninervis* (wide), *H. uninervis* (thin), *H. spinulosa, H. decipiens, H. ovalis*
58	South Trees	28	Light *Z. capricorni* with mixed species	Aggregated patches	*Z. capricorni, H. ovalis,*
60	South Trees	11	Light *Z. capricorni*	Continuous cover	*Z. capricorni, H. ovalis*
94	Rodds Bay	11	Light *Z. capricorni*	Continuous cover	*Z. capricorni*
96	Rodds Bay	32	Moderate *Z. capricorni*	Aggregated patches	*Z. capricorni*
104	Rodds Bay	21	Light *Z. capricorni*	Aggregated patches	*Z. capricorni*

Map 2. Monitoring meadows in the Fishermans Landing region, 2008



Map 3. Monitoring meadows in the Quoin Island and South Trees region, 2008



Legend

- Light *Halodule uninervis* (wide) with mixed species
- Light *Halophila ovalis* with mixed species
- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate *Zostera capricorni*
- Isolated patches
- Aggregated patches
- Continuous cover

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

Data Loggers

- Light, Turbidity & Temp
- Temp Only

N

0 1 2

Kilometres

Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&F, Cairns) 32pp.

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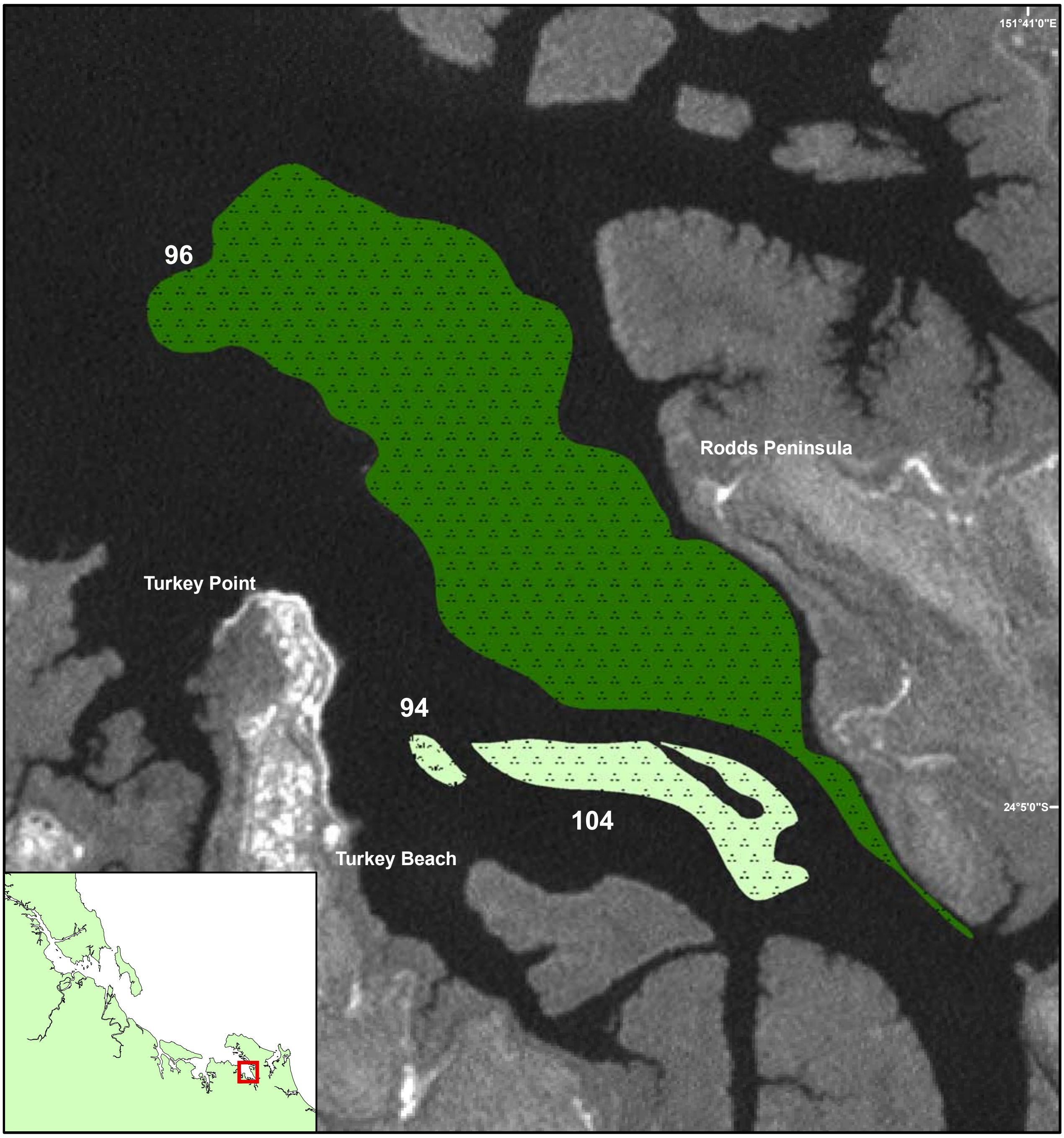
Background: Landsat ETM + Panchromatic 24 July 1994

Map 4. Monitoring meadows in the Rodds Bay region, 2008



Legend

- Light *Zostera capricorni*
- Moderate *Zostera capricorni*
- Aggregated patches
- Continuous cover

N

0 0.5 1

Kilometres

Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&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

Comparison with Previous Monitoring Surveys

In 2008, seagrass density and meadow area were similar to levels measured in past monitoring surveys in the Port of Gladstone. However, there were some significant declines from the previous year with 10 of the 13 meadows declining in biomass and only one meadow, the Pelican Banks *Zostera* meadow (meadow 43), showing a significant increase in biomass from 2007 (Table 6; Maps 6-9; see Appendix),.

Both intertidal and subtidal seagrass monitoring meadows in the Fishermans Landing area (meadows 6, 7, 8 & 9) had significantly declined in biomass from the peak levels recorded in 2007 to near the lowest densities recorded in 2004 & 2005 (Figure 2). Species composition in these meadows shifted slightly with an increase in the proportion of biomass made up by the meadows' dominant species (Figure 2). The meadow area of the two subtidal meadows (7 & 9) increased significantly from 2007 while the intertidal meadows (6 & 8) remained essentially unchanged in size. These results follow previous findings whereby the subtidal meadows appear highly dynamic compared to the neighbouring intertidal meadows.

Seagrass biomass, area and cover on the two intertidal meadows closest to the mouth of the Calliope River (meadow 4 & 5) were not significantly different from 2007 values. Species composition only shifted slightly in meadow 5 to a monospecific stand of *Zostera capricorni* (Map 5). Filamentous green algae was again common on the banks adjacent to Wiggins Island (meadow 4) which has been observed during surveys since 2004 (Rasheed *et al.* 2005, 2007).

Seagrass meadows adjacent to South Trees Point (meadows 58 & 60) had similar biomass to 2007 levels and was significantly higher than the previous three survey years (Figure 1; Table 6; see Appendix). The area of both meadows increased slightly from 2007 with no considerable changes to species composition (Figure 1; Table 5). These low biomass meadows appeared to be quite healthy overall in both 2007 and 2008 compared to previous years.

The largely subtidal *Halodule uninervis* monitoring meadow at Quoin Island (meadow 48) declined further in biomass in 2008 following an initial decrease recode in the 2007 survey (Table 6; Figure 2; see Appendix). 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 2). 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 for this year (Figure 2). However, this relationship does not hold for the 2008 survey where a further reduction in biomass occurred in conjunction with a return to the larger wide leaf form of *Halodule universis* dominating the species composition (Figure 2).

The Pelican Banks *Zostera capricorni* dominated meadow has been the most stable in the monitoring program in both biomass and area between years despite a significant rise in meadow biomass in 2008 to near its 2005 peak (Tables 5 & 6; Figure 2; see Appendix).

The three intertidal *Zostera capricorni* monitoring meadows in Rodds Bay were at their highest recorded biomass in 2007. In 2008, there was some fluctuation in biomass however not at a significant level (Figure 2; see Appendix). Meadow size and species composition was unchanged from the previous year.

Table 5 Area (ha) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006, October 2007 and November 2008.

Meadow ID	See map	Location	Meadow depth	Area ± R (ha)					
				2002	2004	2005	2006	2007	2008
4	**5**	Wiggins Island	intertidal	35.8 ± 1.7	35.6 ± 1.7	32.5 ± 1.9	35.9 ± 2.1	40.2 ± 2.0	34.6 ± 1.8
5	**5**	Wiggins Island	intertidal	149.8 ± 2.5	143.6 ± 2.5	140.11 ± 2.5	147.4 ± 2.5	147.5 ± 2.9	151.2 ± 2.7
6	**5**	South Fishermans	intertidal	464.0 ± 12.9	373.5 ± 11.9	406.4 ± 12.7	428.8 ± 13.0	470.1 ± 12.9	453.1 ± 13.2
7	**5**	South Fishermans	subtidal	72.6 ± 11.4	185.6 ± 8.7	112.1 ± 12.3	203.1 ± 8.2	20.6 ± 2.4	65.9 ± 5.1
8	**5**	North Fishermans	intertidal	269.1 ± 11.3	268.3 ± 12.5	231.1 ± 12.3	275.2 ± 12.0	309.9 ± 12.0	294.9 ± 12.6
9	**5**	North Fishermans	subtidal	268.3 ± 14.9	284.4 ± 7.1	7.0 ± 1.1	143.9 ± 8.0	153.0 ± 8.3	242.5 ± 8.2
43	**6**	Pelican Banks	intertidal	624.8 ± 12.3	592.8 ± 12.4	614.6 ± 11.9	606.8 ± 14.5	662.0 ± 13.2	681.4 ± 12.8
48	**6**	Quoin Island	intertidal/subtidal	421.4 ± 10.2	285.8 ± 21.8	316.6 ± 18.7	285.1 ± 19.9	301.7 ± 19.8	370.9 ± 19.4
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	27.4 ± 2.2
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	10.7 ± 0.9
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	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	329.9 ± 11.6
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	37.7 ± 5.0
Total				**2755.3 ± 96.6**	**2526.7 ± 96.1**	**2251.6 ± 91.6**	**2520.6 ± 100.8**	**2498.7 ± 93.9**	**2703.4 ± 96.3**

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, October 2007 and November 2008.

Meadow ID	See map	Location	Meadow depth	Mean biomass (g DW m^{-2})					
				2002	2004	2005	2006	2007	2008
4	**5**	Wiggins Island	intertidal	0.8 ± 0.4	0.74 ± 0.36	0.33 ± 0.15	0.74 ± 0.26	1.20 ± 0.67	0.78 ± 0.47
5	**5**	Wiggins Island	intertidal	1.4 ± 0.3	0.57 ± 0.19	0.86 ± 0.5	3.73 ± 0.77	8.78 ± 1.17	6.92 ± 1.03
6	**5**	South Fishermans	intertidal	1.1 ± 0.1	0.24 ± 0.09	0.94 ± 0.61	2.65 ± 0.66	6.32 ± 0.86	1.42 ± 0.32
7	**5**	South Fishermans	subtidal	0.9 ± 0.2	1.91 ± 0.36	0.03 ± 0.02	3.7 ± 0.95	4.16 ± 1.36	1.20 ± 0.53
8	**5**	North Fishermans	intertidal	2.1 ± 0.3	0.14 ± 0.08	0.06 ± 0.04	1.28 ± 0.49	3.89 ± 0.77	0.69 ± 0.25
9	**5**	North Fishermans	subtidal	0.9 ± 0.3	1.93 ± 0.27	0.001 ± 0.001	4.98 ± 0.72	4.64 ± 0.63	0.30 ± 0.09
43	**6**	Pelican Banks	intertidal	20.8 ± 3.1	18.71 ± 2.13	28.3 ± 3.3	14.17 ± 1.07	13.87 ± 2.24	25.96 ± 3.03
48	**6**	Quoin Island	intertidal/subtidal	1.8 ± 0.2	1.11 ± 0.2	2.12 ± 1.01	9.52 ± 1.85	6.21 ± 0.80	2.81 ± 0.60
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	4.89 ± 1.26
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	11.29 ± 3.65
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	17.33 ± 8.70
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	24.84 ± 5.01
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	18.89 ± 4.84

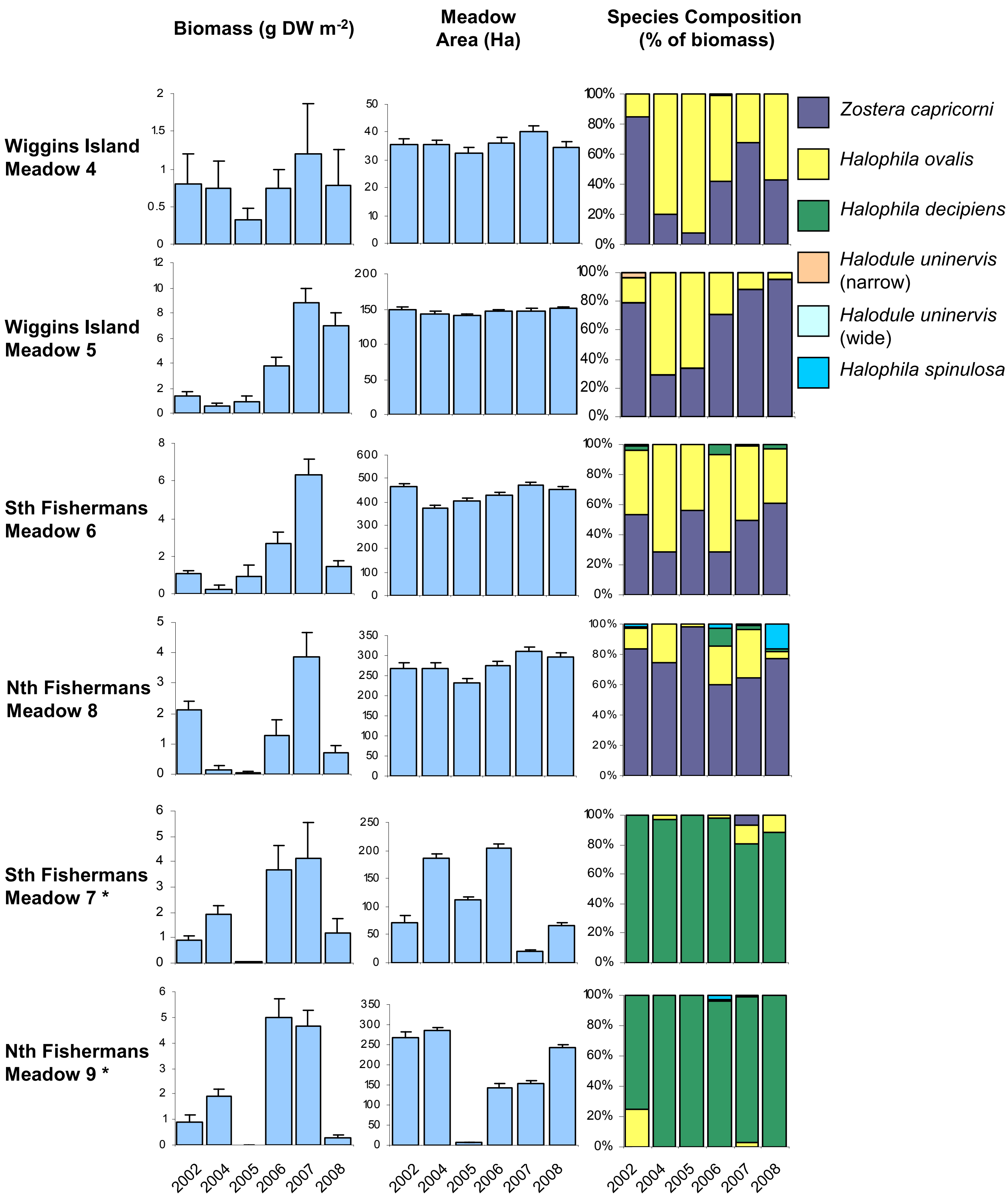


Figure 2(A) Changes in biomass, area and species composition for monitoring meadows in 2002 & 2004 - 2008 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

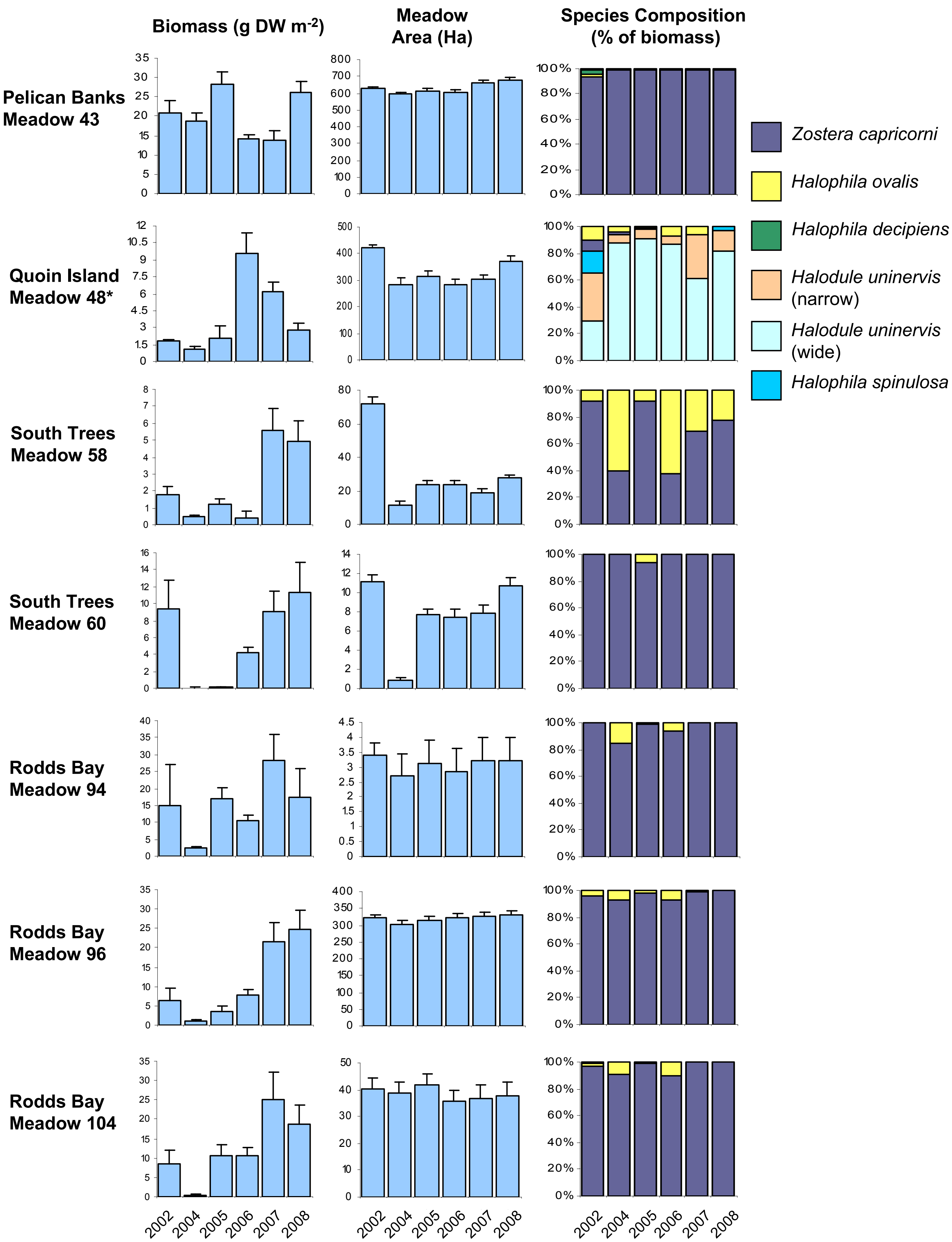
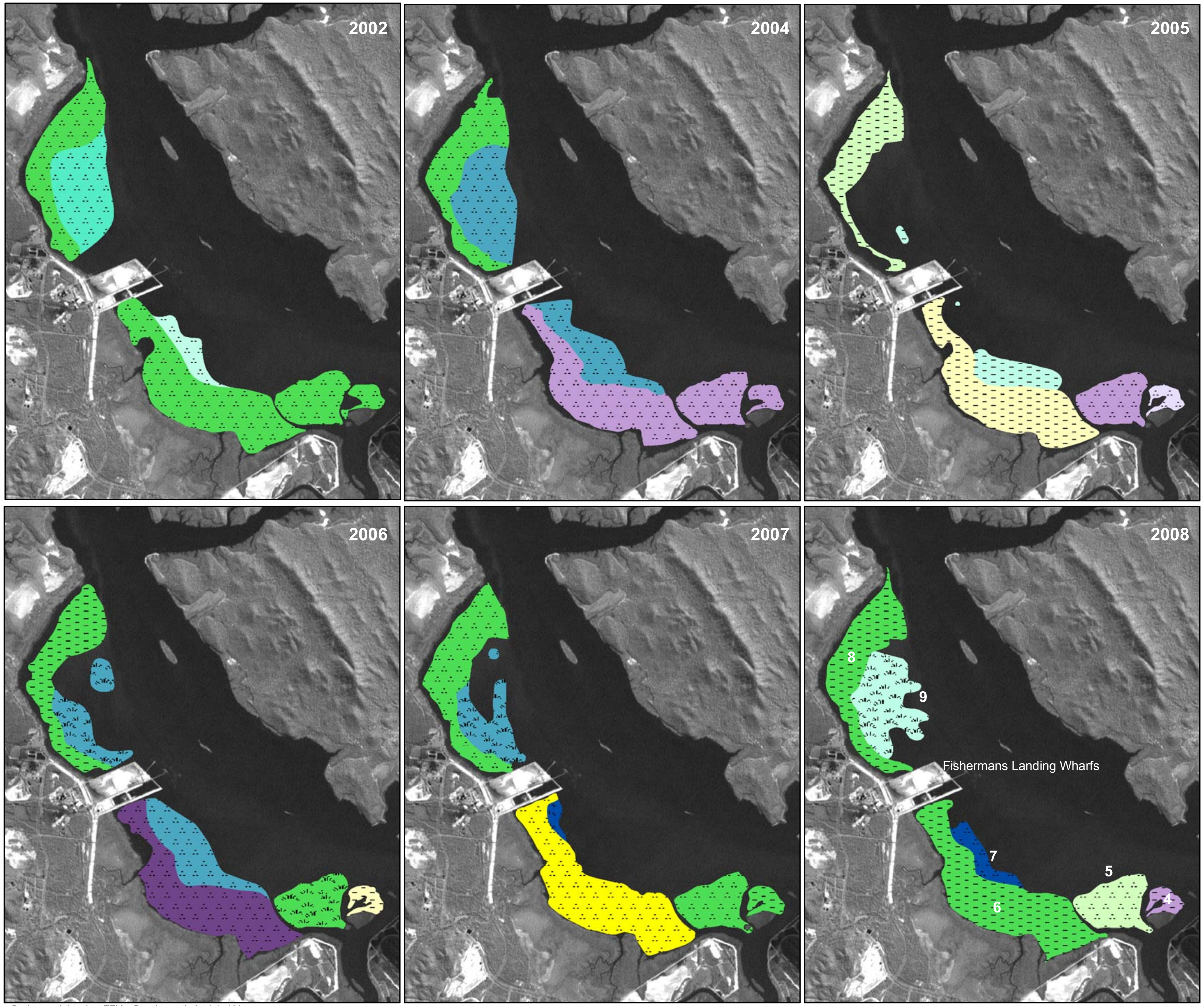


Figure 2(B) Changes in biomass, area and species composition for monitoring meadows in 2002 & 2004 - 2008(Biomass error bars = SE; Area error bars = “R” reliability estimate)

Map 5. Monitoring meadows comparison, Fishermans Landing region, 2002, 2004, 2005, 2006, 2007 & 2008



Legend

- Light *Halodule uninervis* (wide) with mixed species
- Moderate *Halodule uninervis* (wide) with mixed species
- Light *Halophila ovalis* with mixed species
- Moderate *Halophila ovalis* with mixed species
- Light *Halophila decipiens*
- Light *Halophila decipiens* with mixed species
- Moderate *Halophila decipiens*
- Moderate *Halophila decipiens* with mixed species
- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate *Zostera capricorni*
- Light *Halophila ovalis* / *Zostera capricorni*
- Moderate *Halophila ovalis* / *Zostera capricorni*
- Isolated patches
- Aggregated patches
- Continuous cover

0 2 4
Kilometers

N

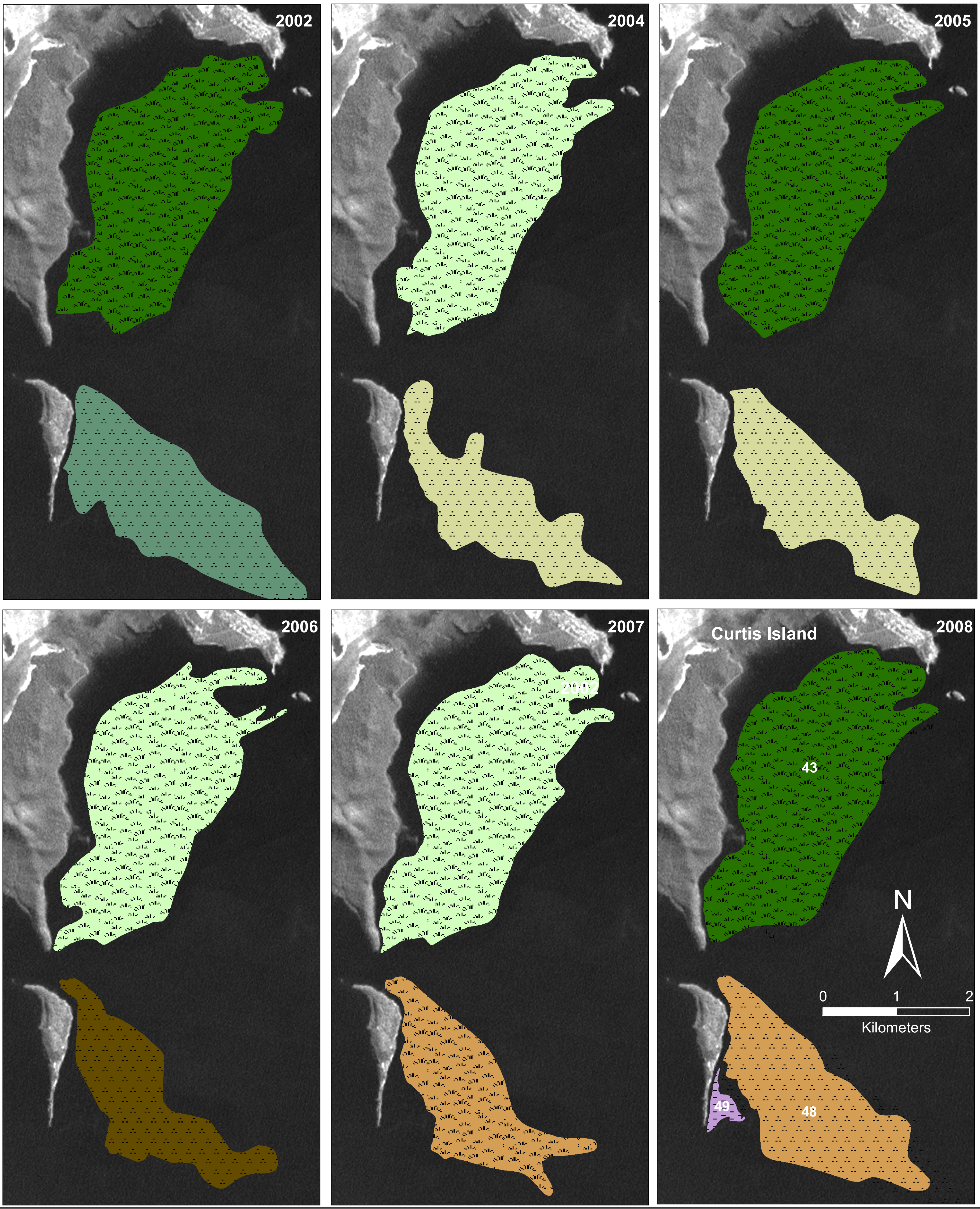
Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&F, Cairns) 32pp.

Funded by the Port Curtis Integrated Monitoring Program and Queensland Primary Industries and Fisheries.

Produced by the Marine Ecology Group, Queensland Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2009.

Background: Landsat ETM + Panchromatic 24 July 1994
* This is not a complete seagrass distribution, only selected seagrass monitoring meadows displayed

Map 6. Monitoring meadows comparison in the Quoin Island region, 2002, 2004, 2005, 2006, 2007 & 2008



Legend

Aggregated patches — Continuous cover — Isolated patches

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

Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&F, Cairns) 32pp.

Funded by the Port Curtis Integrated Monitoring Program and Queensland Primary Industries and Fisheries.

Produced by the Marine Ecology Group, Queensland Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2009.

Gladstone Ports Corporation

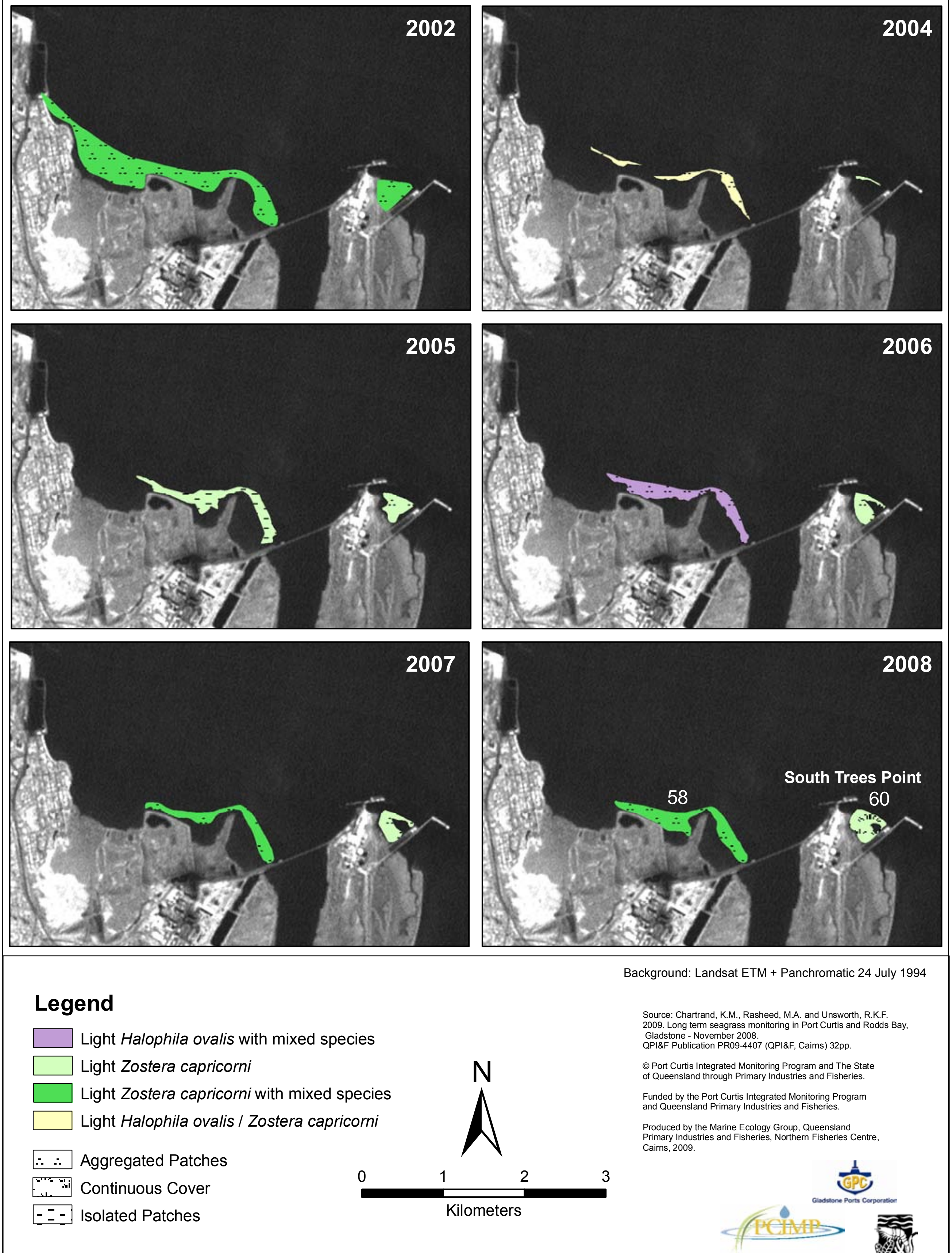
PCIMP

Queensland Government

Marine Ecology Group

Background: Landsat ETM + Panchromatic 24 July 1994

Map 7. Monitoring meadows comparison in the South Trees region, 2002, 2004, 2005, 2006, 2007 & 2008



Background: Landsat ETM + Panchromatic 24 July 1994

Legend

- Light *Halophila ovalis* with mixed species
- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Light *Halophila ovalis* / *Zostera capricorni*
- Aggregated Patches
- Continuous Cover
- Isolated Patches

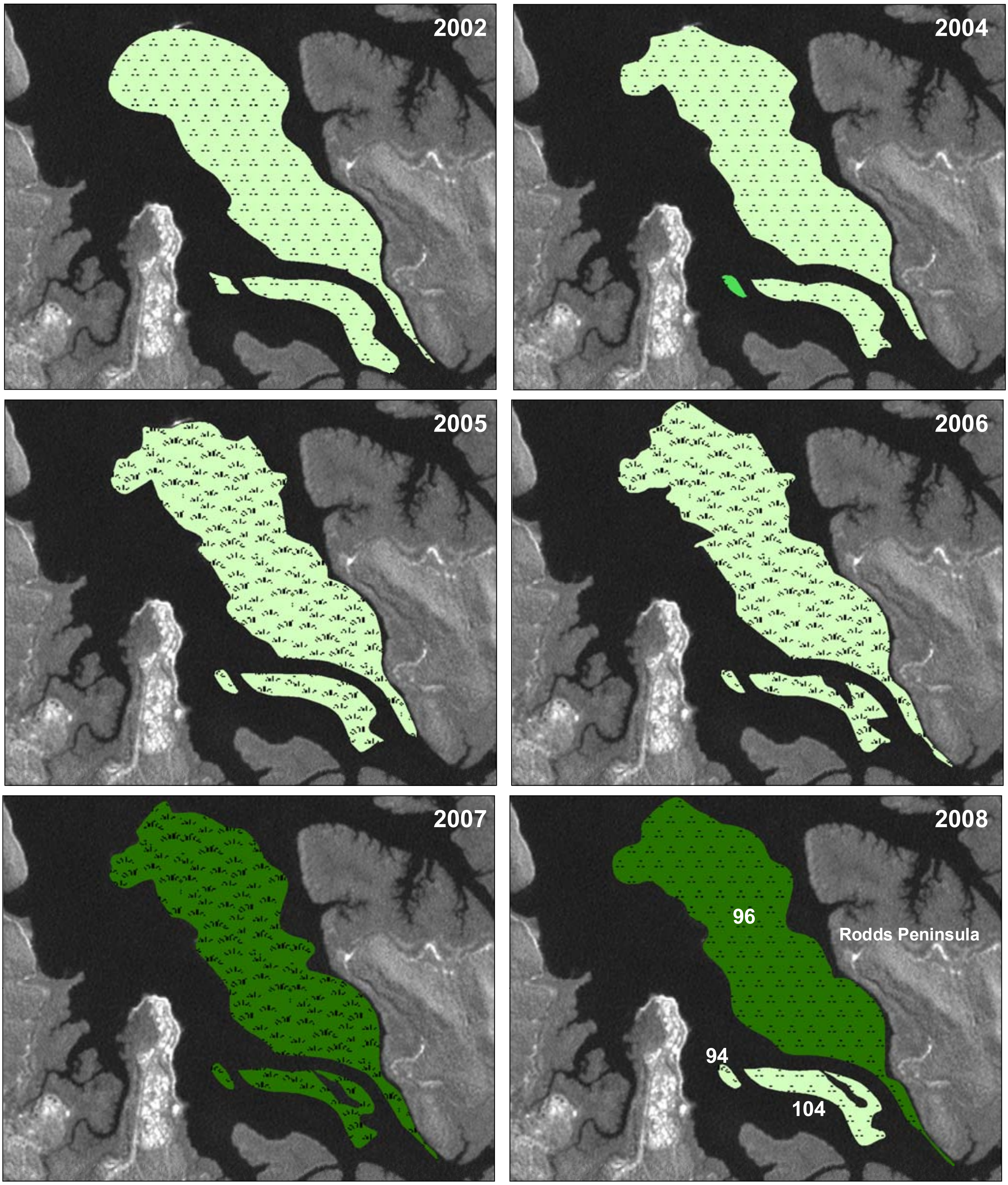
Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&F, Cairns) 32pp.

Funded by the Port Curtis Integrated Monitoring Program and Queensland Primary Industries and Fisheries.

Produced by the Marine Ecology Group, Queensland Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2009.

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

Map 8. Comparison of monitoring meadows in the Rodds Bay region, 2002, 2004, 2005, 2006, 2007 & 2008



Legend

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate *Zostera capricorni*
- Isolated patches
- Aggregated patches
- Continuous cover

N

0 1 2
Kilometers

Background: Landsat ETM + Panchromatic 24 July 1994

Source: Chartrand, K.M., Rasheed, M.A. and Unsworth, R.K.F. 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. QPI&F Publication PR09-4407 (QPI&F, Cairns) 32pp.

Funded by the Port Curtis Integrated Monitoring Program and Queensland Primary Industries and Fisheries.

Produced by the Marine Ecology Group, Queensland Primary Industries and Fisheries, Northern Fisheries Centre, Cairns, 2009.

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

Gladstone Ports Corporation

PCIMP

Queensland Government

MARINE ECOLOGY GROUP

Climate and Water Quality Data

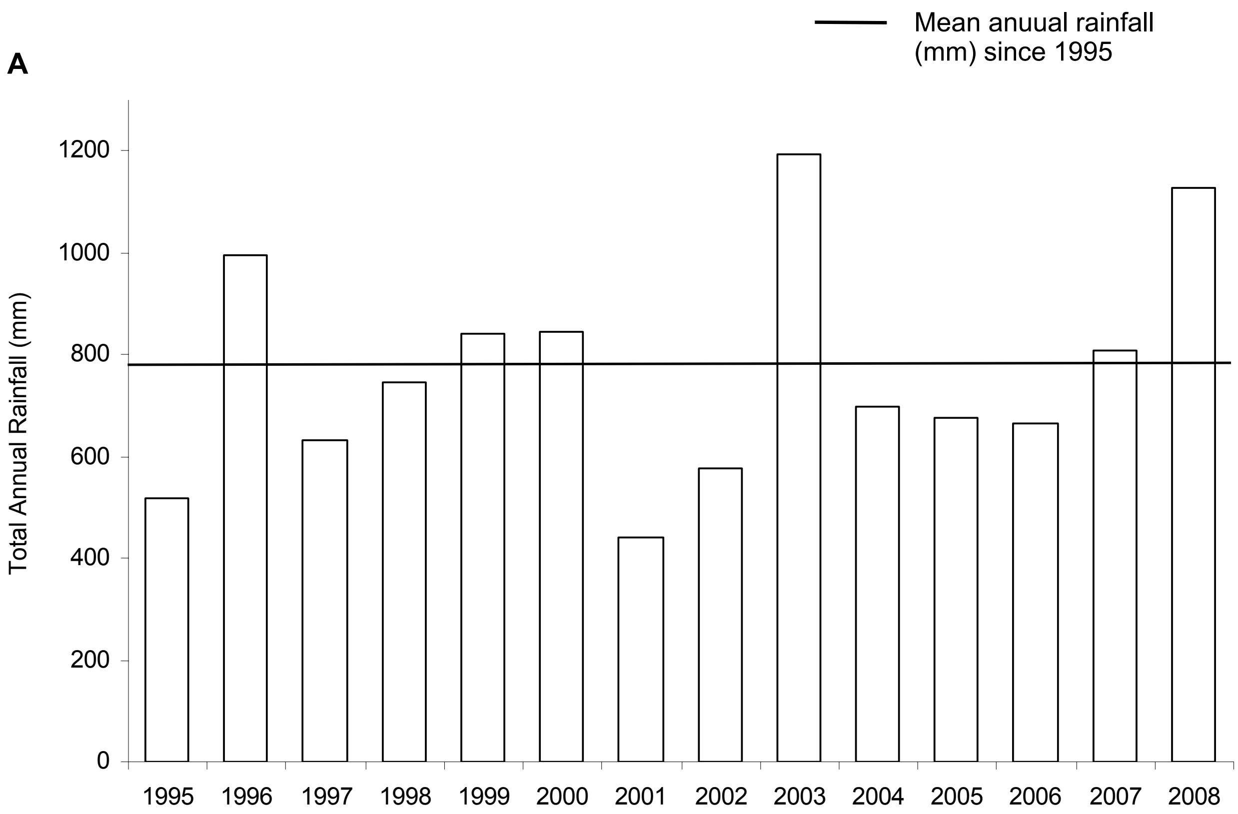
Total annual rainfall for the Gladstone region was above average in 2008 (since 1995; Figure 3A) which coincided with high flows of the major catchment for the Gladstone area, the Calliope River (Figure 3B). The Calliope River catchment empties into Port Curtis directly adjacent to the Wiggins Island and Fisherman's Landing meadows (meadows 4-9; Map 2).

Total daytime tidal exposure in 2008 was down from the previous year yet similar to most previous years of the monitoring program (Figure 3C). Most notably, daytime tidal exposure was found to be positively correlated with above-ground biomass in all intertidal monitoring meadows over the last six years of surveys (see Appendix). The mean monthly maximum air temperature was below average for most months during 2008 prior to the November monitoring survey and did not rise above 30ºC with the exception of October (Figure 3C).

Data loggers recorded variable physical conditions across Port Curtis monitoring meadows during the first ten months of their deployment. The monthly running mean temperature for Port Curtis meadows differed at times by up to 2 ºC for some meadows (Figure 4A). The deepest meadows had the lowest mean annual temperature (subtidal South Fisherman's meadow (7) and mostly subtidal Quoin Island (48)) (Figure 4A). Mean annual temperature for the Pelican Banks (43) meadow was also lower than other meadows most likely due to its proximity to open ocean and greater flushing. There was a strong negative relationship between temperature and above-ground biomass for all intertidal meadows with data loggers (Map 2-3; see Appendix). This correlation controlled 56% of the variability in biomass among meadows.

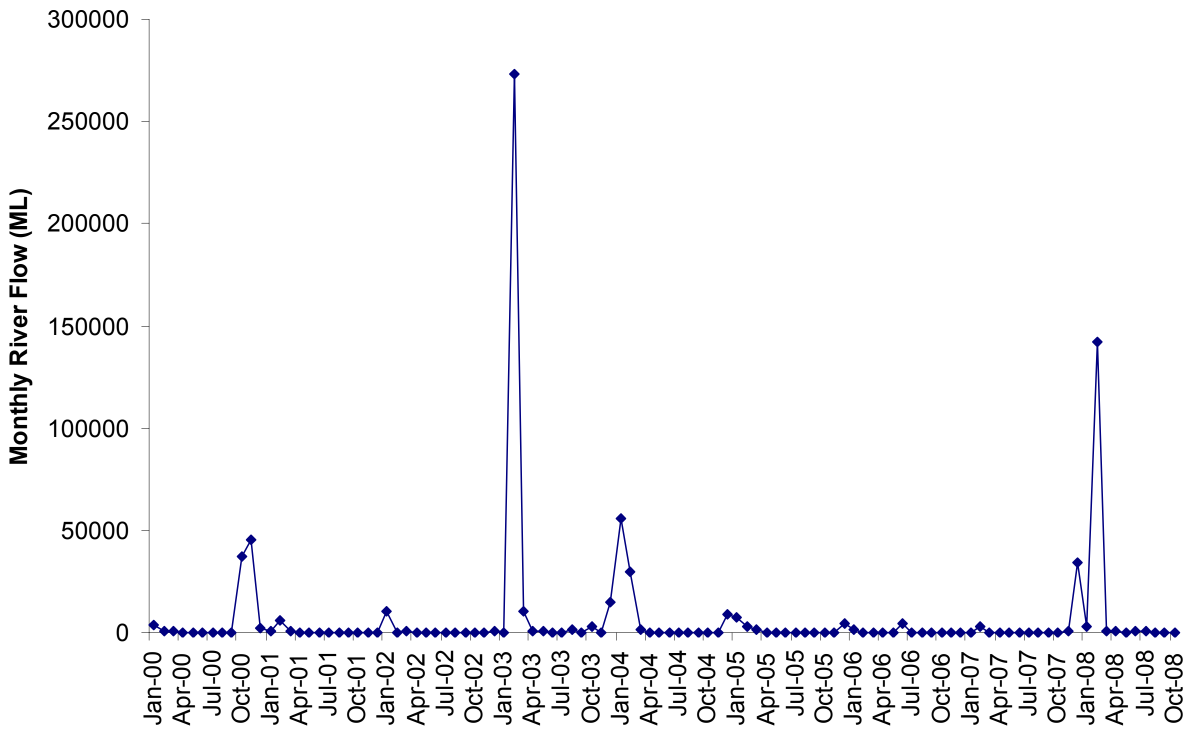
Overall, Pelican Banks and Wiggins Island (meadow 4 and 43) had a higher light environment than at North Fisherman's (meadow 8; Figure 4B). The trend is consistent with expected higher turbidity in the Fisherman's Landing area following high rainfall and flushing of the Calliope River in late 2007 and early 2008 (see above; Figure 3). Pelican Banks (43) is open to more oceanic flushing from tidal movement which maintains better light conditions. The Wiggins Island (4) meadow, despite being at the mouth of the Calliope River, is also more open to flushing than the Fisherman's Landing meadows and likely returns to more favorable light conditions sooner than the Fisherman's Landing meadows.

A



Mean anuual rainfall (mm) since 1995
Total Annual Rainfall (mm)
0
200
400
600
800
1000
1200
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008

B



Monthly River Flow (ML)
0
50000
100000
150000
200000
250000
300000
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Jul-08
Oct-08

C

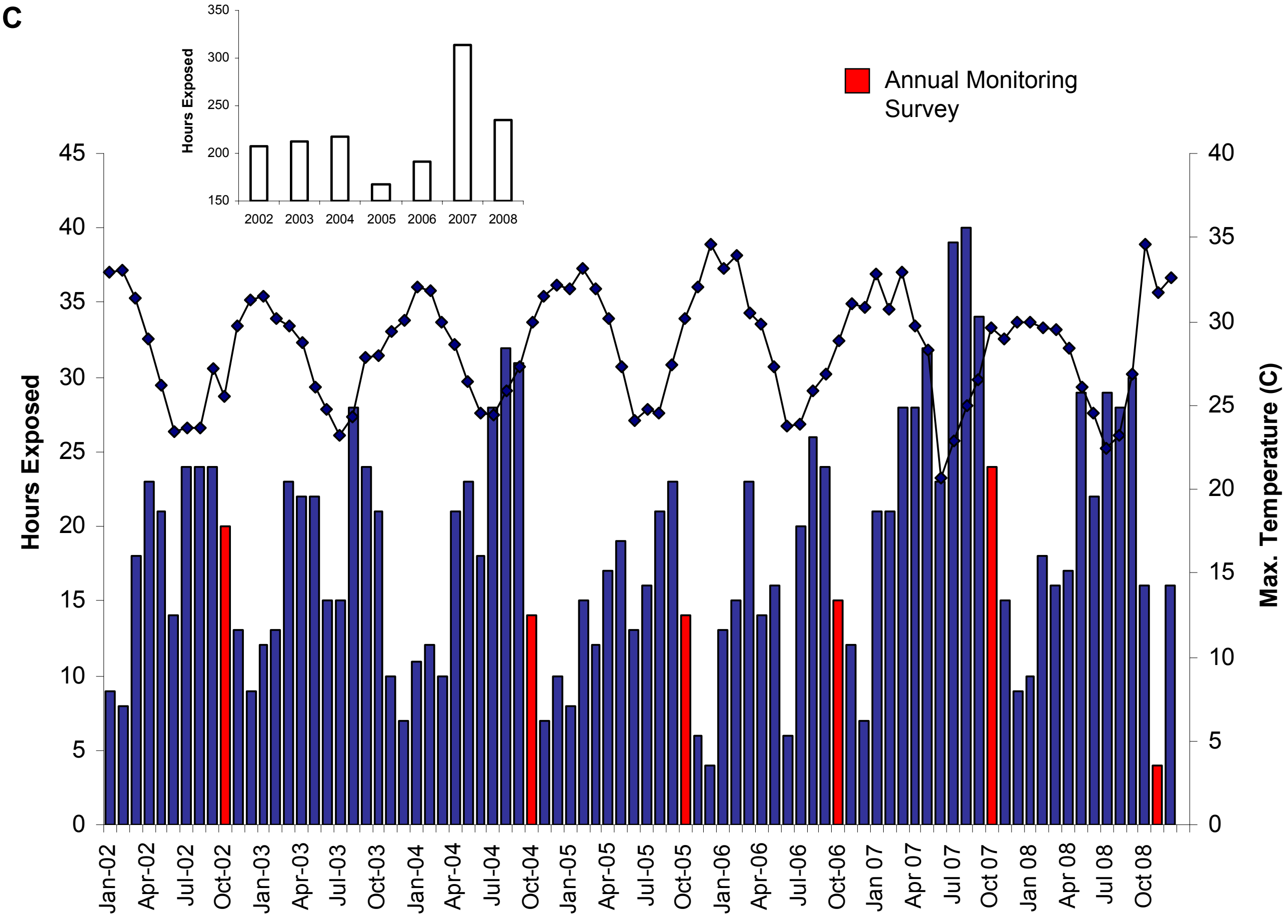


Figure 3 (A) Total annual rainfall for the Gladstone area from 2000 to 2008 (Bureau of Meteorology); (B) Total monthly river flow for the Calliope River between 2000 and 2008* (Queensland Department of Natural Resources and Mines); (C) The monthly total number of daylight hours that intertidal banks were exposed and mean monthly solar radiation (megajoules/metre^2) recorded from 2002 to 2008 (red months indicate times of seagrass monitoring surveys) and inset is total annual hours of daytime exposure (Bureau of Meteorology and Maritime Safety Queensland).

** November & December 2008 data unavailable*

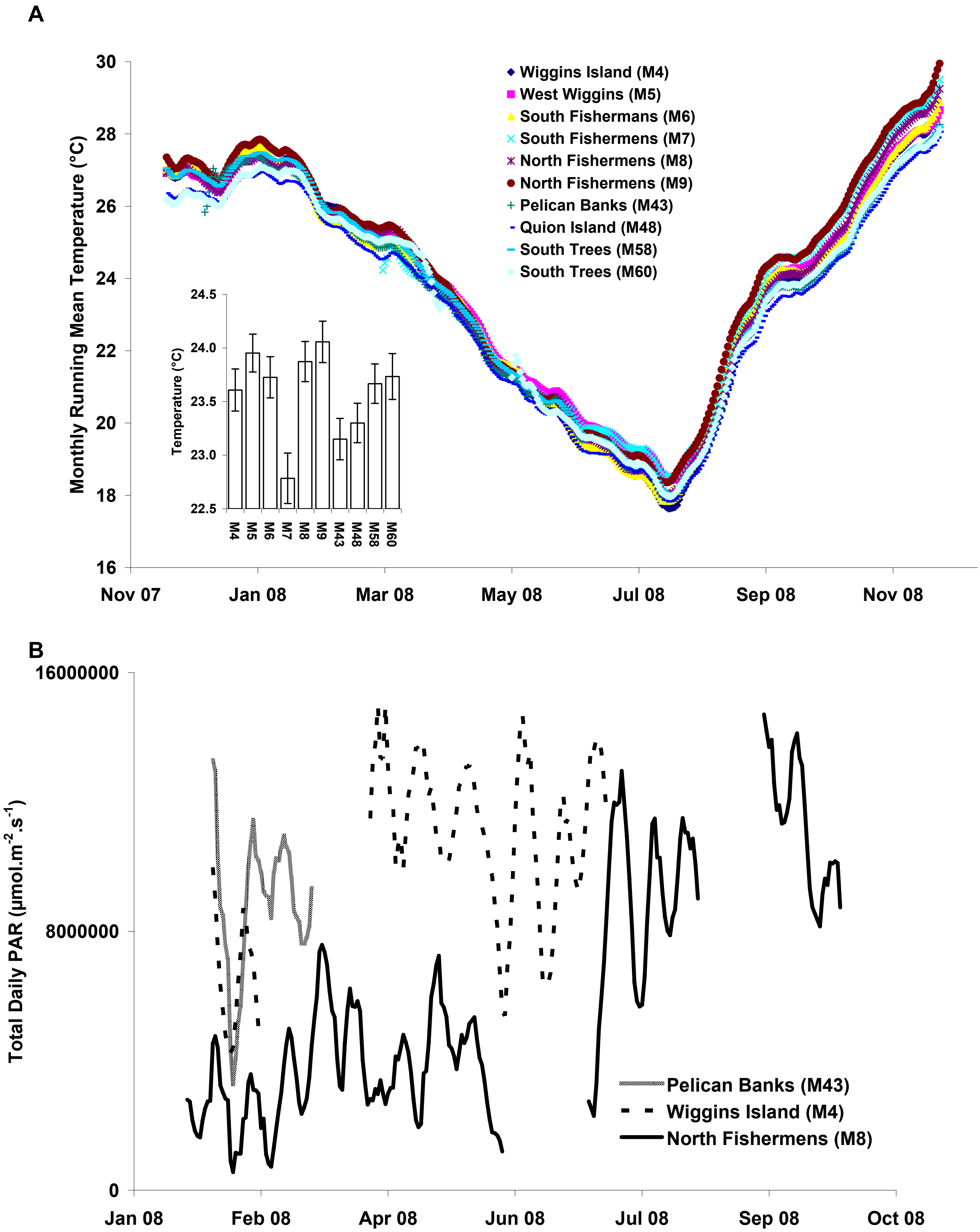


Figure 4 (A) The monthly mean running temperature (ºC) recorded from December 2007 to November 2008 within 10 of the 13 monitoring meadows. Inset is the mean annual temperature of each meadow;. (B)Total daily photosynthetic active radiation (PAR) recorded from January to October 2008 within 3 of the13 monitoring meadows. Breaks in the data are due to technical difficulties with the loggers.

DISCUSSION

The 2008 monitoring survey of Port Curtis and Rodds Bay found that seagrass in the region was reasonably healthy. Most of the monitoring meadows were only slightly down from their previously recorded peak abundance and area but were still at relatively high levels compared to earlier surveys. However, the four Fisherman's Landing monitoring meadows (meadow 6-9) and the subtidal Quoin Island meadow (48) exhibited more substantial biomass declines.

The drivers of seagrass change in Port Curtis appear to be largely associated with local climate conditions and fine scale variability in the physical meadow environments. The high rainfall for the Gladstone region and concurrent high flows of the Calliope River (Figure 3) were the likely significant drivers of seagrass decline in the Fisherman's Landing meadows during 2008. High catchment rainfall can result in the inputs of sediment, nutrients, herbicides, and low salinity water and periods of high turbidity, strong currents and sediment burial that coincide with flood events. Such events typically have an initial negative impact on seagrasses (Campbell and McKenzie 2004, Waycott et al. 2007). In the longer term these effects may be reversed with associated nutrient inputs to the system enhancing seagrass growth as the sediments become enriched and light conditions improve post flooding (Waycott et al. 2007).

The positive correlation between daytime tidal exposure and above-ground biomass in all intertidal meadows was somewhat unexpected since tidal exposure and biomass is often negatively correlated. Tidal exposure in tropical seagrass meadows typically leads to desiccation and extreme temperature conditions at the seagrass blade surface, which can both result in the condition known as burning and ultimately declines in above-ground biomass (Erftemeijer & Herman 1994, Chartrand et al 2008, Unsworth et al. 2008). The positive influence exhibited in Gladstone meadows suggests that a low light environment may be limiting seagrass growth. During periods of lower daytime low tides (and increased tidal exposure) more light would be available to seagrasses. Providing light and temperature do not reach threshold levels known to cause thermal stress (Campbell et al. 2006), this increase would provide a benefit to seagrasses growing in light limited environments. Fewer hours of daytime tidal exposure during 2008 (Figure 3C) may have therefore added to poor light conditions in some areas such as Fisherman's Landing where low light was the likely cause of declines in seagrass biomass.

Although regional-scale factors including rainfall, tidal exposure and river flow influence meadow dynamics, finer scale physical processes can lead to high inter-meadow variability. Data loggers introduced in December 2007 provided the first glimpse of *in situ* conditions to evaluate changes occurring at the meadow scale. The loggers, while valuable, have been in place under a year making comparative analyses difficult. Relationships between meadow dynamics and physical parameters will be better resolved as a larger dataset develops. However, preliminary analysis did demonstrate the value of the loggers and some of the general trends that were emerging. For example, there was a strong negative relationship between temperature and above-ground biomass for all intertidal meadows with data loggers, which controlled the majority of the variability in biomass among meadows (Map 2-3; see Appendix). Previous use of mean monthly maximum air temperature for the Gladstone region was indiscriminate and as such limited the interpretation of changing meadow dynamics whereas the resolution from the loggers now provides a clearer picture. The light and turbidity dataset does not comprise a complete record of conditions due to technical difficulties over the first year thus making interpretation of these parameters more difficult. In general, the light patterns that did emerge (Figure 4) correspond with the trends in high rainfall, flushing of the Calliope River and meadow location. While these initial patterns indicate strong correlations between the physical environment and seagrass meadow dynamics, a more detailed understanding of these relationships will emerge as the logger datasets expand alongside annual monitoring surveys.

Despite the decline in biomass in the Fisherman's Landing subtidal meadows (meadow 7 & 9; Figure 2), meadow area increased in from 2007. There are two likely explanations for this trend. First, there may have been a dramatic improvement in light conditions mid-year allowing these meadows to expand quickly. Meadow area and biomass may have later declined when conditions deteriorated around the time of the annual monitoring survey. A second explanation for the observed trends may be that the light environment in the Fisherman's Landing area over 2008 only reached levels promoting growth and expansion around the time of the annual survey. In this situation, the subtidal meadows may have first expanded in area via rhizome extension or seed germination prior to an increase in overall above-ground biomass (to have occurred in the ensuing post-survey months). The dominant species in these meadows is *Halophila decipiens,* a fast growing species that has large natural variations in density and distribution. *Halophila decipiens* is also capable of producing relatively long lived seeds that can lay dormant in the sediment for at least 2 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. Thus, in either scenario, the dynamic nature of *Halophila* meadows is likely responsible for the disparate trends in biomass and meadow area for these subtidal meadows.

In addition to the Fisherman's Landing meadows, the Quoin Island meadow (48) also declined in biomass in 2008. The majority of this meadow was also subtidal and was likely impacted by reduced light from higher rainfall and flood runoff in the region during 2008. In previous surveys declines in biomass for this meadow tended to be accompanied by a shift from the larger, wide leaf growth form of the dominant species (*Halodule uninervis*) to the narrow leaf form of the species. In 2008 the seagrass became less dense but the wide leaf form remained dominant. An increase in leaf size is a common response of seagrass species to a reduction in available light (Abal et al. 1996; Gordon et al. 1994; Rasheed 2000) and may explain the trends observed for Quoin Island.

The only intertidal meadow that exhibited a significant increase in density was the large *Zostera capricorni* meadow on Pelican Banks (43). This meadow has remained at a relatively consistent density between surveys with the exception of the two peak years of 2005 and 2008. 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 and extreme temperatures (Figure 4) possibly explaining its relative stability throughout the monitoring program. The healthy *Zostera capricorni* communities identified throughout Port Curtis and Rodds Bay during the 2008 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 2008 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 utilised 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.

This was the fifth survey in the established annual monitoring program and some of the likely climate related drivers of seagrass change have been identified. The expansion of the seagrass monitoring program within PCIMP and the Centre for Environmental Management at CQU to establish the turbidity, light and temperature loggers in the seagrass meadows in late 2007 will place us in a far stronger position to determine the major drivers of seagrass change in the years to come. The expanded program will also lead to a better ability to separate the natural and human induced causes of change to seagrass meadows that may arise in the future.

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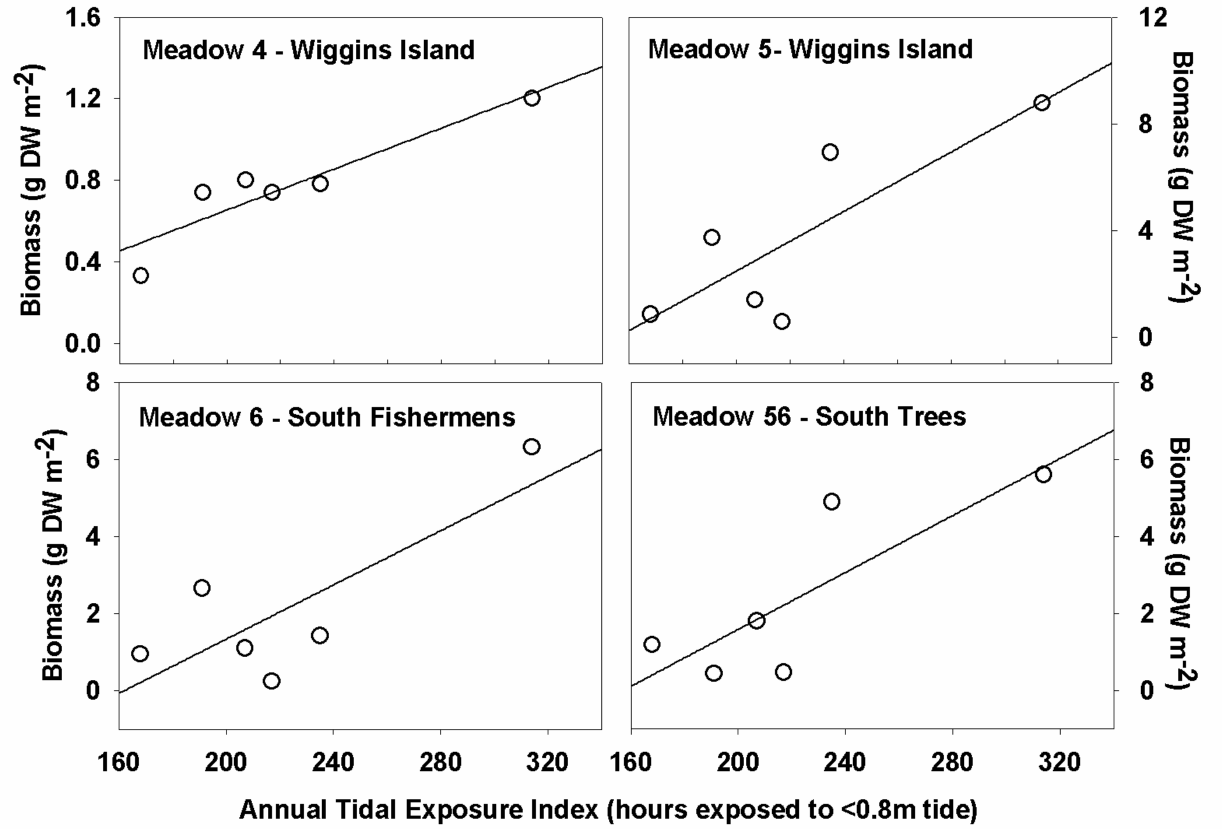
APPENDIX

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, 2007 & 2008) (* significant difference in biomass between years)

Meadow 4^	DF	SS	MS	F	P
Between Years	5	4155.76	831.152	1.2	0.3136
Within Years	106	73372.2	692.191		
Total	111	77528			
Meadow 5#					
Between Years	5	118.584	23.7168	22.42	**<0.0001***
Within Years	182	192.5	1.05769		
Total	187	311.003			
Meadow 6#					
Between Years	5	88.5723	17.7145	22.84	**<0.0001***
Within Years	242	187.684	0.77555		
Total	247	276.256			
Meadow 7^					
Between Years	5	29372	5874.4	11.92	**<0.0001***
Within Years	91	44845	492.802		
Total	96	74217			
Meadow 8^					
Between Years	5	220063	44012.5	14.48	**<0.0001***
Within Years	217	659700	3040.13		
Total	222	879771			
Meadow 9^					
Between Years	5	140380	28076.1	50.87	**<0.0001***
Within Years	132	72851.5	551.905		
Total	137	213232			
Meadow 43#					
Between Years	5	134.494	26.8989	4.4	**0.0007***
Within Years	343	2095.96	6.11068		
Total	348	2230.46			
Meadow 48#					
Between Years	5	104.572	20.9144	21.43	**<0.0001***
Within Years	231	225.416	0.97583		
Total	236	329.988			
Meadow 58#					
Between Years	5	42.6977	8.53954	7.64	**<0.0001***
Within Years	158	176.612	1.1178		
Total	163	219.31			
Meadow 60#					
Between Years	5	71.9655	14.3931	8.62	**<0.0001***
Within Years	54	90.201	1.67039		
Total	59	162.166			
Meadow 94#(no 2002)					
Between Years	5	65.6728	16.4182	3.48	**0.0142**
Within Years	50	226.644	4.72175		
Total	55	292.317			
Meadow 96^					
Between Years	5	97095.3	19419.1	8.72	**<0.0001***
Within Years	176	392145	2228		
Total	181	489240			
Meadow 104#					
Between Years	5	136.713	27.3427	6.05	**<0.0001***
Within Years	99	447.503	4.52023		
Total	104	504.217			

^ Kruskal-Wallis ANOVA
# square- root transformed

Multiple linear regression modeling between seagrass above-ground biomass and daytime annual tidal exposure (<0.8m tide) in four intertidal meadows. Biomass data was gathered over the dry season (September-November) for 13 seagrass meadows within the Port Curtis and Rodds Bay region (Gladstone) from 2002 to 2008 (no data available in 2003)



Multiple regression model parameters and their significance.

Meadow Location	Meadow Number	F	P	R^2
Wiggins Island	4	21.7	0.01	84.4
Wiggins Island	5	8.1	0.05	66.9
South Fishermans	6	7.4	0.05	64.9
South Trees	58	8.3	0.04	67.5

Observed significant relationships ($p<0.05$, $R^2=0.61$) between mean dry season (November) seagrass meadow biomass and mean annual water temperature across 7 intertidal seagrass meadows within the Port Curtis in 2008 (no temperature data for Rodds Bay, subtidal meadows excluded from analysis).