Long term seagrass monitoring in the Port of Mourilyan - December 2008

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EXECUTIVE SUMMARY

This report details results from the December 2008 seagrass monitoring survey for the Port of Mourilyan, conducted as part of the annual long term monitoring. The monitoring program was developed following a baseline survey in December 1993 and examines selected representative seagrass meadows in Mourilyan Harbour. Total area of each monitoring meadow, species composition and seagrass density (above-ground biomass) were measured for comparison with previous surveys.

The 2008 monitoring survey of Mourilyan Harbour recorded reductions in seagrass biomass and area for most meadows, adding to previous long-term trends of decline. Repeated declines and recovery of seagrass meadows combined with the impacts of Tropical Cyclone Larry have left seagrasses in a vulnerable state with a low resilience to further impacts. Only one of the meadows remained in a relatively robust condition, the intertidal *Zostera capricorni* meadow near Bradshaw Island.

The recent changes to seagrass meadows at Mourilyan Harbour are most likely a result of a combination of regional climate, severe storms and localised catchment issues rather than port-related activities. However, the reduced resilience of these meadows makes them more vulnerable to any future natural stressors or anthropogenic impacts such as port expansions and coastal developments. Given the fragile state of many of the meadows, continued monitoring of seagrasses will be important to ensure their longer term recovery and to effectively manage these important marine habitats. Further investigation into water quality within the Port of Mourilyan would also assist in determining whether land-based run-off is influencing the decline of seagrasses within the port.

INTRODUCTION

Background

Seagrass forms an ecologically valuable component of Mourilyan Harbour's marine environment (Thomas *et. al.* 2006). Seagrasses also provide a good indicator of overall marine environmental health. This is because they show measurable growth responses to a broad range of water quality parameters and are therefore a good "integrator" of water quality conditions (Dennison *et al*. 1993). In recognition of this importance, the Ports Corporation of Queensland Limited (PCQ) (the port authority for the Port of Mourilyan) in conjunction with the Queensland Primary Industries and Fisheries (QPIF) has developed a long term seagrass monitoring program for the Port of Mourilyan. This program aims to monitor the health of Mourilyan Harbour's marine environment and fisheries habitats while providing for the ecologically sustainable use and development of the associated port and shipping facilities.

Seagrass baseline surveys and a three year monitoring program for the Port of Mourilyan seagrasses from December 1993 through to July 1997 established a range of seasonal and inter-annual variation in seagrass distribution and abundance (McKenzie *et al*. 1998). The current annual monitoring program commenced with surveys in 2000 which identified widespread declines in subtidal seagrass since 1997 that were likely due to flooding of the Moresby River (Thomas and Rasheed 2001). Since 2000 surveys have been carried out annually with changes to seagrass meadows generally linked to local and regional climate conditions or non-point source inputs in the broader Moresby River catchment (Thomas and Rasheed 2003; 2004; McKenna *et al*. 2005).

This report details the results of the eighth annual long term seagrass monitoring survey conducted in October and December 2008.

Objectives

The specific objectives of this seagrass monitoring survey were to:

1. Map the distribution and abundance of seagrass monitoring meadows in the Port of Mourilyan.
2. Assess changes in these monitoring meadows since November 2007, and compare results with previous seagrass monitoring surveys.
3. Incorporate the results into the PCQ Geographic Information System (GIS) database for the Port of Mourilyan.

METHODS

Five seagrass meadows have been the subject of periodic monitoring at Mourilyan Harbour since baseline surveys of the entire port limits in 1993 (see McKenzie *et al*. 1998). The five meadows were selected on the basis that they represent the range of seagrass species and habitats within the port limits. These five meadows were again targeted for the 2008 survey.

Seagrass surveys were conducted using two field techniques: intertidal aerial and sub-tidal boat surveys. Intertidal seagrasses were surveyed using a helicopter at low tide on October 16th 2008 when these habitats were exposed. Helicopter surveys are an effective and efficient means to survey large areas of intertidal seagrass habitat. Four of the five monitoring meadows were intertidal and surveyed using this technique. These included: Bradshaw (1), Lily (2), Seaforth Edge (4) and Seaforth Bank (3). Subtidal seagrasses in the Channel (5) meadow and some deeper sites of Seaforth Bank (3) and Seaforth Edge (4) were surveyed from a boat on December 5th using a real-time underwater video camera and a Van Veen sediment grab on December 5th 2008. This camera technique provides an image of the sea floor from which visual estimates of above-ground biomass were made. A detailed description of methodology and survey techniques can be found in McKenzie *et al*. (1998) and Thomas and Rasheed (2001). The Van Veen grab was utilised to confirm seagrass species and to determine sediment composition.

Some seagrasses encountered outside of the monitoring meadows in this survey were documented, but this survey only intended to target the five monitoring meadows rather than the entire port limits. The last survey of seagrasses in the entire port limits was conducted in 2000 (Thomas and Rasheed 2001).

Geographic Information System

Spatial data from the field surveys were incorporated into the Geographic Information System (GIS) established for Mourilyan Harbour. This database includes data from all previous baseline and monitoring surveys. Two GIS layers were created for this survey:

- **Site data** - contains above-ground biomass (for each species present), depth below mean sea level (dbMSL) (for subtidal meadows), sediment type, time, differential Global Positioning System (dGPS) fixes (± 5 m) 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 (Thomas and Rasheed 2003) (Table 1). Abundance categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 2).

Table 1 Nomenclature for community types in Mourilyan Harbour, December 2008

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 Mourilyan Harbour, December 2008

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

Each meadow was assigned a mapping precision estimate (in metres) based on mapping methodology utilised for that meadow (Table 3). Mapping precision ranged from ± 5 m for the intertidal meadows to ± 30 m for the subtidal Channel meadow (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 Mourilyan Harbour, December 2008

Mapping precision	Mapping methodology
± 5 m	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.
± 10 m	Some intertidal meadow boundaries mapped in detail by dGPS from helicopter. Most meadow boundaries determined by camera survey sites. Reliability based on distance between survey sites.
± 30 m	Meadow boundary interpreted from camera surveys. Meadow (in the channel) entirely subtidal. Relatively high density of survey sites. Recent aerial photography aided in mapping.

RESULTS

Seagrass Species, Distribution and Abundance for Monitoring Meadows in 2008

Four seagrass species (from three families) were present in the monitoring meadows in the current survey (Figure 1) (for a full description of species and distribution refer to baseline survey McKenzie *et al.* 1996):

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.

Family ZOSTERACEAE Drummortier:
Zostera capricorni Aschers.

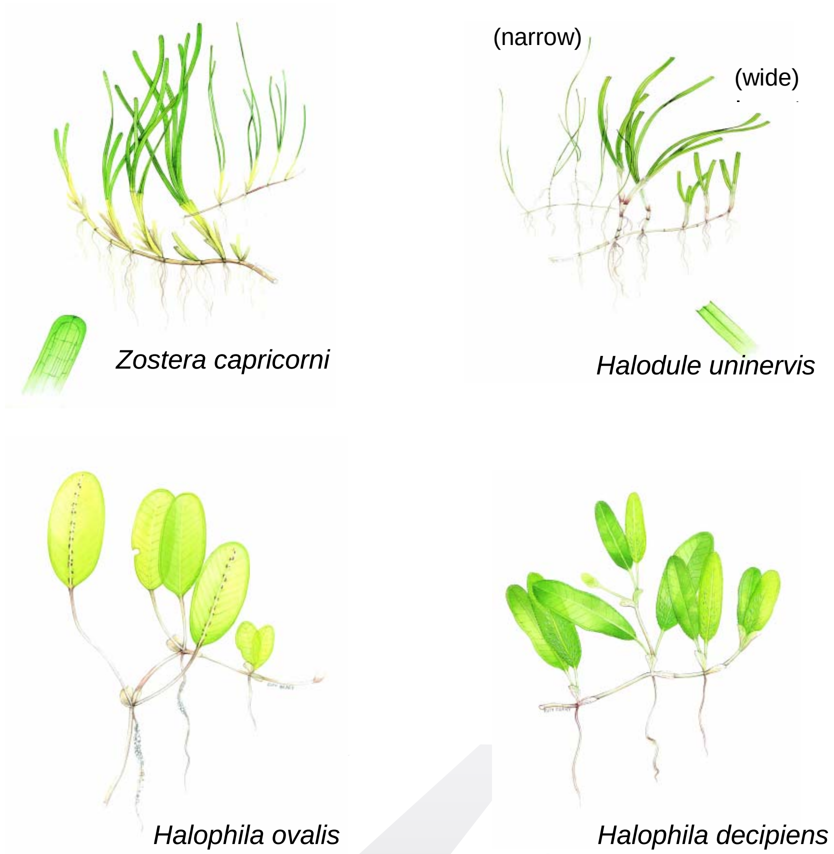


Figure 1. Seagrass species present during 2008 Port Mourilyan monitoring surveys.

Long term seagrass monitoring survey

A total of 188 sites (65 subtidal and 123 intertidal) were surveyed in October and December 2008, 39% of which had seagrass present. The total area of seagrass habitat mapped in the monitoring meadows was 32.3 ± 9.2 ha (Table 5), the area of individual monitoring meadows ranging from 0.1 ha to 27.8 ha (Table 5). The mean above-ground biomass for the meadows ranged from 0.03 ± 0.01 g DW m^{-2} to 28.8 ± 3.5 g DW m^{-2} (Table 5). This variability was dependent on the mix of species present. Each monitoring meadow comprised a different community type containing a different composition of seagrass species (Table 4; Map 1). Four of the meadows were classified as light biomass for their community type and one was classified as moderate biomass (Table 4).

The subtidal Channel (5) meadow was the largest monitoring meadow, comprising 86% (27.8 ± 7.6 ha) of the total seagrass area mapped (Table 5; Map 1). This meadow was classified as having light biomass (1.45 ± 0.3 g DW m^{-2}) and dominated by *Halodule uninervis* wide (78% of the species composition) (Table 5; Figure 2). Other species found in the meadow included *Halophila ovalis* and *Halophila decipiens* (Table 4; Figure 2).

Two of the four intertidal monitoring meadows were dominated by *Zostera capricorni* (Bradshaw (1) and Lily (2)), one by *Halodule uninervis* (narrow) (Seaforth Bank (3)) and one by *Halophila ovalis* (Seaforth Edge (4)) (Map 1; Figure 2). Of the two *Zostera* monitoring meadows, Bradshaw (1) was the larger (3.0 ± 0.5 ha) and continued to be the densest of all the monitoring meadows (in Mourilyan Harbour 28.8 ± 3.5 g DW m^{-2}) (Table 5; Map 1). The second smaller *Zostera* meadow, Lily (2) (0.5 ± 0.2 ha), had a substantially lower biomass (2.6 ± 1.8 g DW m^{-2}) than the Bradshaw meadow (Table 5; Map 1). *Halophila ovalis* also comprised a very small component of the Lily meadow (Table 4; Figure 2). Seaforth Bank (3) (1.0 ± 0.7 ha) was made up of small isolated patches of *Halodule uninervis* (narrow) with *Halophila ovalis* and classified as having light biomass (0.03 ± 0.01 g DW m^{-2}) (Table 4). The Seaforth Edge (4) monitoring meadow was also classified as light for the community type and was dominated by *Halophila ovalis*. No biomass values were obtained for the meadow due to the very low density and highly patchy nature of the seagrass.

Table 4 Community type, seagrass cover and species present in the five Mourilyan Harbour monitoring meadows, December 2008

Monitoring Meadow	No. of sites	Community Type	Species Present
Bradshaw (1)	35	Moderate *Z. capricorni*	*Z. capricorni*
Lily (2)	15	Light *Z. capricorni*	*Z. capricorni*, *H. ovalis*
Seaforth Bank (3)	4	Light *H. uninervis (narrow)* with *H. ovalis*	*H. uninervis (narrow), H. ovalis*
Seaforth Edge (4)	1	Light *H. ovalis*	*H. ovalis*
Channel (5)	23	Light *H. uninervis* (wide) with *H. decipiens*	*H. decipiens, H. uninervis* (wide), *H. ovalis*

Comparison with previous monitoring surveys

In 2008 seagrasses in Mourilyan Harbour remain well below their historical peak densities (biomass) and distribution (area) but were similar compared to 2007. The Bradshaw *Zostera capricorni* meadow increased in density from 2007 and the Seaforth Bank Meadow reappeared as a few small sparse isolated patches dominated by *Halodule uninervis* (Table 5; Figure 2; Appendix 1). The large, subtidal Channel meadow showed a significant decrease in biomass between 2007 and 2008 (Appendix 1).

All meadows have reduced in area in 2008 compared to 2007 except for the Channel monitoring meadow (Table 5; Figure 2; Map 2). The increase in area of the Channel meadow occurred along the western section adjacent to Armit Creek. The meadow also expanded in the southern section, extending further upstream in the harbour. The Channel meadow has been highly variable from year to year throughout the monitoring program. Species composition of the Channel Meadow has generally been dominated by *Halodule uninervis*, however in 2006 and 2007, post Cyclone Larry, there was a shift to dominance by *Halophila decipiens.* In 2008 this meadow had returned to be dominated by *Halodule uninervis* (Figure 2).

The small Lily *Zostera capricorni* meadow has been more variable in density and area since 2000 compared with the initial four years of monitoring between 1993 and 1996 (Table 5; Map 2). This meadow severely declined following Tropical Cyclone Larry with all above-ground components lost in the post cyclone survey in May 2006 (McKenna *et al.* 2007). By the November 2006 survey there were initial signs of recovery but this had failed to develop further in 2007. Results of the 2008 monitoring survey show that biomass and area declined again to the same low results of 2006, and well below levels previously recorded in the monitoring program (Figure 2).

The larger higher biomass, Bradshaw *Zostera capricorni* meadow has remained the most consistent meadow throughout the long-term monitoring program, with meadow area remaining similar between surveys (Table 5; Figure 2). However this meadow experienced a significant decline in biomass between 2006 and 2007 and had reached one of the lowest densities recorded in the monitoring program. In 2008 the meadow was showing signs of recovery with with a 42% increase in biomass compared to the 2007 survey (Table 5; Map 2; Appendix 1).

In recent years the intertidal *Halophila* meadows (Seaforth Bank and Seaforth Edge) have been highly variable. For example, in 2000 & 2006, the Seaforth Edge meadow had completely declined to the point where no above-ground structures remained (Table 5; Figure 2). This meadow showed initial signs of recovery in November 2007 following Cyclone Larry but has significantly declined again in 2008 with only a small remnant patch of *Halophila ovalis* remaining. The Seaforth Edge meadow has been comprised of very isolated patches of light seagrass for the last 7 years (Table 5; Map 2; Figure 2) and was generally dominated by *Halophila ovalis,* apart from 2007 when there was a species shift to *Halophila decipiens* post Cyclone Larry. In 2008 the meadow returned to be dominated by *Halophila ovalis.*

In 2008 the Seaforth Bank meadow had similarly contracted in area to a collection of small isolated patches (Map 1) and had one of the lowest recorded areas in the monitoring program. Area of seagrass in this meadow has been declining since 2006. A species change occured in the Seaforth Bank meadow from being previously dominated by *Halophila* species throughout the entire monitoring program to a dominance in *Halodule uninervis* (narrow) in 2008 (Table 4; Map 1; Figure 2).

Map 1. Port of Mourilyan seagrass distribution and community types December 2008

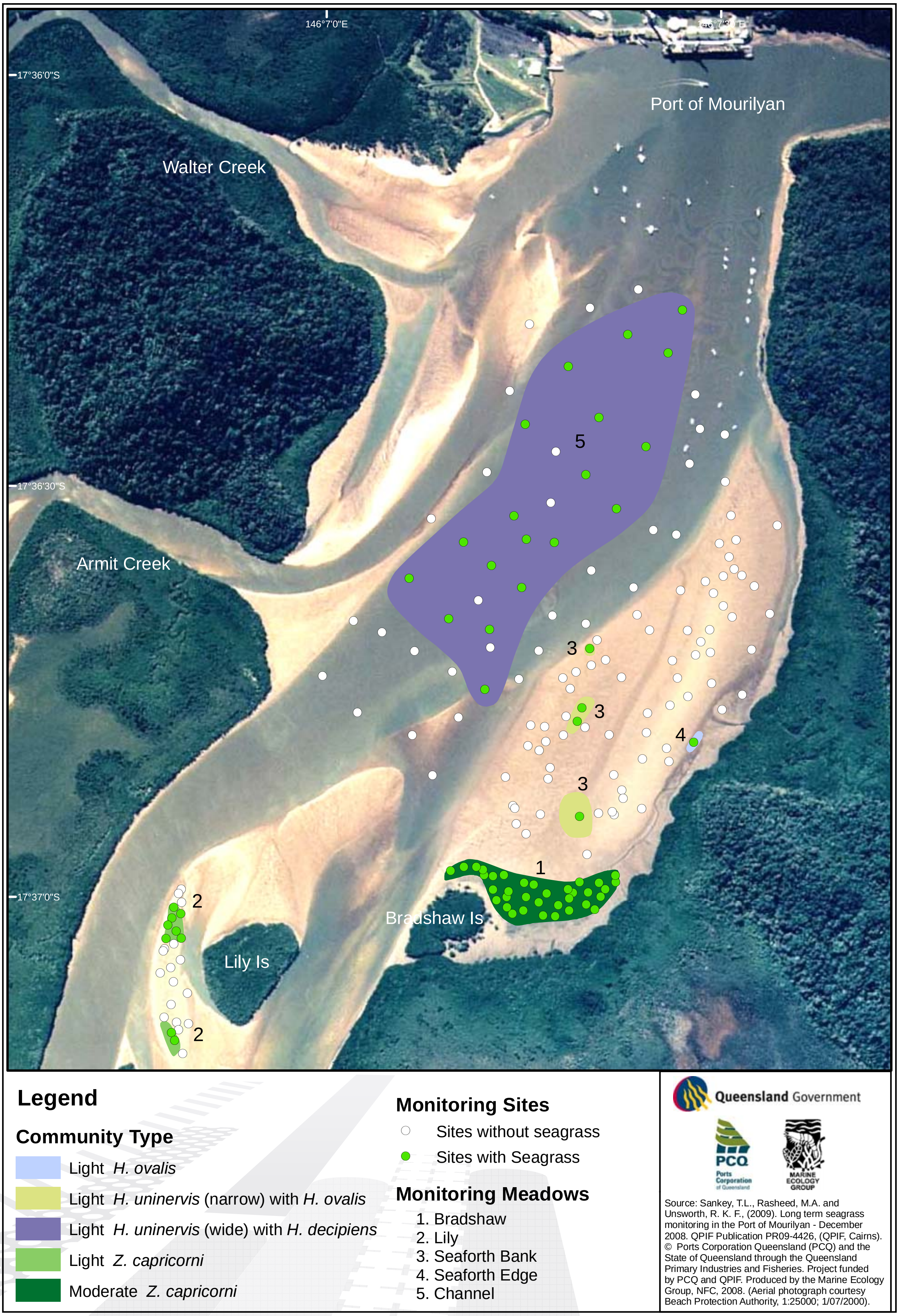


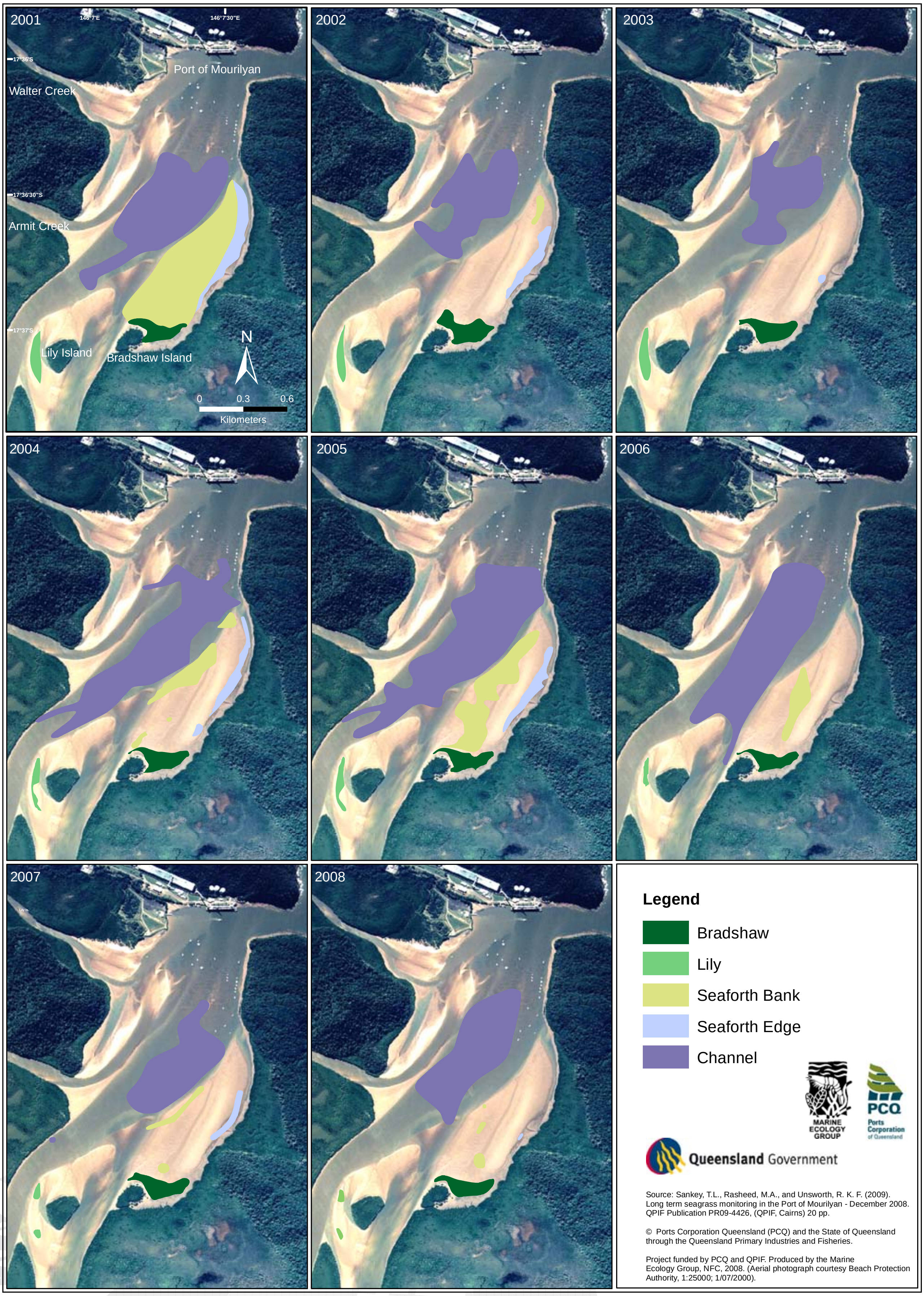
Table 5. Area and mean above-ground biomass for Mourilyan Harbour monitoring meadows from December 1993 to December 2008 (Note: no data collected in 1997, 1998 and 1999)

Meadow	Area (ha) (R)												
	Dec 1993	**Dec 1994**	**Dec 1995**	**Dec 1996**	**Dec 2000**	**Dec 2001**	**Dec 2002**	**Dec 2003**	**Nov 2004**	**Nov 2005**	**Nov 2006**	**Nov 2007**	**Nov 2008**
Bradshaw (1)	3.8 (1.9-6.2)	2.6 (1.8-3.4)	2.8 (2.0-3.7)	3.1 (2.1-4.1)	3.5 (2.2-4.8)	3.0 (2.5-3.5)	4.2 (3.7-4.7)	3.6 (3.1-4.1)	3.3 (2.8-3.8)	3.0 (2.5-3.5)	2.7 (2.2-3.3)	3.5 (3-4)	3.0 (2.5-3.5)
Lily (2)	1.0 (0.1-2.3)	1.1 (0.7-1.6)	0.8 (0.6-1.2)	0.7 (0.5-0.9)	1.1 (0.9-1.4)	1.8 (1.4-2.2)	1.4 (1.0-1.8)	1.9 (1.5-2.3)	1.1 (0.7-1.5)	1.2 (0.8-1.6)	0.5 (0.3-0.7)	0.6 (0.4-0.8)	0.5 (0.3-0.7)
Seaforth Bank (3)	22.3 (16.0-29.0)	27.7 (22.4-33.3)	23.2 (17.5-29.3)	19.9 (14.1-25.7)	8.4 (2.5-14.3)	30.0 (27.2-32.8)	0.8 (0.3-1.3)	NP*	6.5 (5.4-7.6)	13.1 (10.4-15.8)	4.1 (2.9-5.2)	2.0 (0.7-3.3)	1.0 (0.3-1.4)
Seaforth Edge (4)	2.7 (2.6-7.4)	3.1 (1.8-4.5)	3.4 (1.5-5.6)	3.4 (0.9-5.9)	NP*	5.3 (1.1-9.5)	3.0 (1.7-4.3)	0.2 (0.1-0.3)	3.3 (2.4-4.2)	3.3 (2.6-4.0)	NP*	1.6 (0.7-2.4)	0.1 (0-0.2)
Channel (5)	20.2 (15.9-24.8)	37.3 (31.1-43.7)	55.7 (46.7-64.9)	30.5 (15.5-45.5)	NP*	34.3 (24.4-44.2)	24.4 (15.5-33.3)	20.1 (12.5-27.7)	38.5 (23.2-53.8)	47.9 (34.0-61.8)	40.9 (29.7-52.1)	22.0 (14.3-29.7)	27.8 (20.2-35.4)
Total (ha) COMBINED	49.9 (36.6-69.7)	71.6 (57.3-85.6)	85.9 (68.2-104.6)	57.6 (33.2-82.0)	13.0 (6.3-19.7)	74.4 (56.6-92.2)	35.4 (23.1-47.7)	25.8 (17.2-34.4)	52.7 (34.5-70.9)	68.5 (50.3-86.7)	48.2 (35.1-61.3)	29.7 (19.1-40.2)	32.3 (23.3-41.2)

Meadow	Mean biomass ± SE (g DW m^{-2})												
	Dec 1993	**Dec 1994**	**Dec 1995**	**Dec 1996**	**Dec 2000**	**Dec 2001**	**Dec 2002**	**Dec 2003**	**Nov 2004**	**Nov 2005**	**Nov 2006**	**Nov 2007**	**Nov 2008**
Bradshaw (1)	42.2 ± 6.0	45.1 ± 2.1	49.3 ± 1.3	59.5 ± 2.0	17.6 ± 1.3	35.9 ± 5.4	32.1 ± 2.0	21.6 ± 3.4	59.3 ± 7.2	34.1 ± 3.7	46.5 ± 4.2	21.4 ± 2.4	28.8 ± 3.5 + 34.6%
Lily (2)	16.1 ± 4.4	30.5 ± 2.2	29.1 ± 0.9	29.8 ± 1.5	7.7 ± 0.6	5.6 ± 1.6	20.7 ± 3.1	5.1 ± 2.4	12.3 ± 3.6	0.2 ± 0.1	2.4 ± 0.9	2.8 ± 0.6	2.6 ± 1.8 - 0.1%
Seaforth Bank (3)	1.0 ± 0.1	0.7 ± 0.2	1.1 ± 0.1	2.8 ± 0.2	0.2 ± 0.04	2.5 ± 0.5	0.3 ± 0.2	NP*	0.6 ± 0.2	0.03 ± 0.01	0.06 ± 0.02	NR**	0.03 ± 0.01
Seaforth Edge (4)	2.2 ± 0.3	2.2 ± 0.3	1.6 ± 0.1	3.4 ± 0.3	NP*	2.8 ± 0.4	1.6 ± 0.3	0.02 ± 0.02	1.2 ± 0.4	0.2 ± 0.1	NP*	0.5 ± 0.3	NR**
Channel (5)	0.5 ± 0.1	1.8 ± 0.3	1.3 ± 0.1	3.8 ± 0.3	NP*	0.6 ± 0.1	1.0 ± 0.2	0.7 ± 0.3	1.0 ± 0.3	1.3 ± 0.5	2.4 ± 0.6	2.5 ± 0.4	1.45 ± 0.31 - 40.0 %

**NR signifies seagrass present but too sparse to record biomass
*NP signifies seagrass not present

Map 2. Port of Mourilyan seagrass monitoring meadows from December 1993 to December 2008.



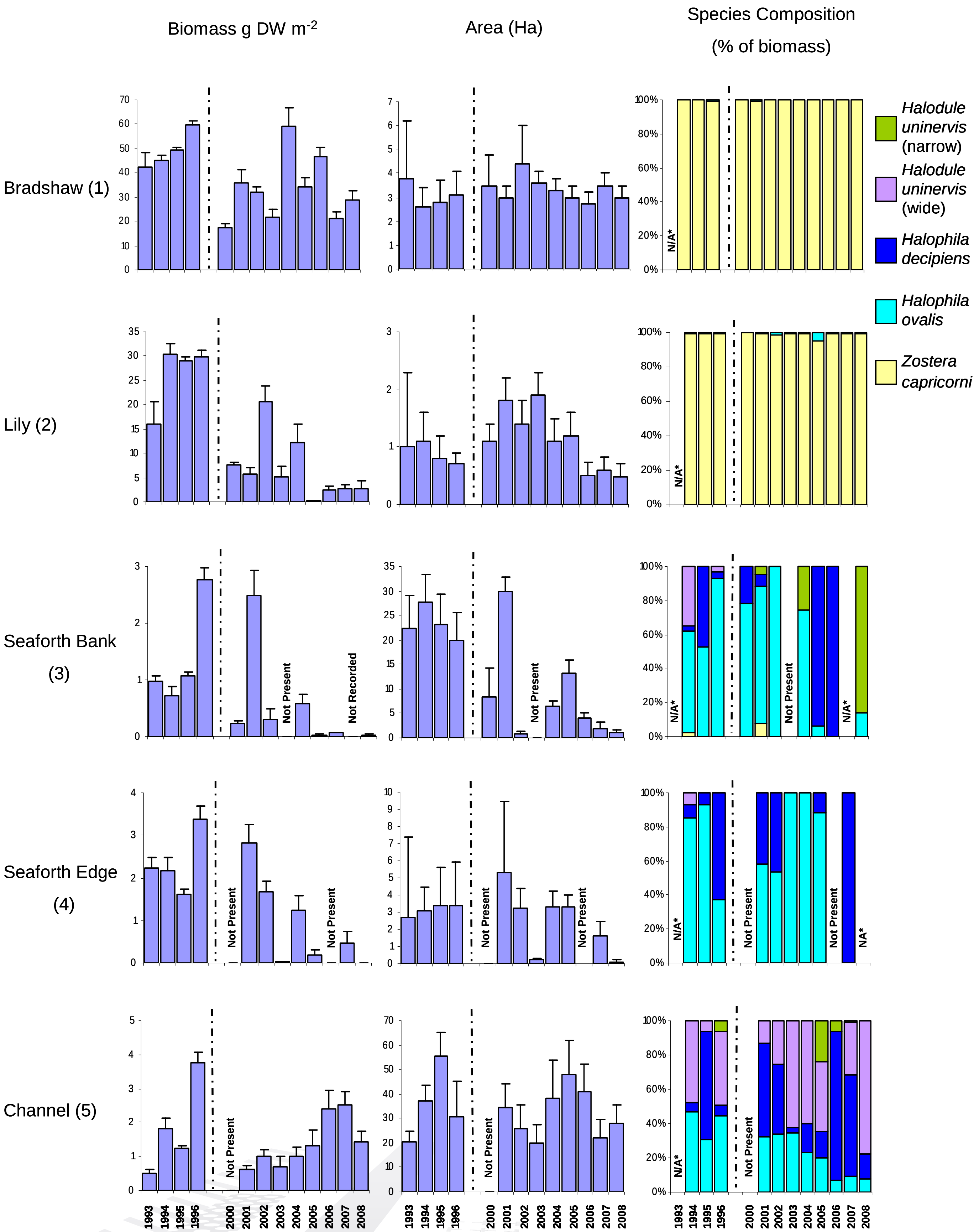


Figure 2 Changes in biomass, area and species composition for monitoring meadows from 1993 to 2008 (Biomass error bars = SE; Area error bars = "R" reliability estimate) (dashed line designates a four-year cycle interval between surveys; N/A* % composition of biomass not available)

Mourilyan Climate Data

Total annual rainfall in Mourilyan Harbour during 2008 was 3511 mm. The majority of this rainfall was recorded in the early period of the year. This was above the 15 year average of 3467 ± 241 mm and had been preceded by two years of additional above average rainfall in 2007 and 2006 (Figure 3).

The average maximum daily temperature was 27.9°C. This was below the 15 year average of 28.8 ± 0.4°C (Figure 4). This reflects the above average rainfall and high number of cloudy days (Figures 3 and 5).

The level of tidal exposure was low in 2008 (Figure 6). Low exposure compounded with high cloud cover and reduced temperature indicate that intertidal seagrasses were subjected to reduced thermal and desiccation stress during 2008.

Figure 3. Total monthly rainfall (mm) for Innisfail from 1998-2008 (Bureau of Meteorology, 2008)

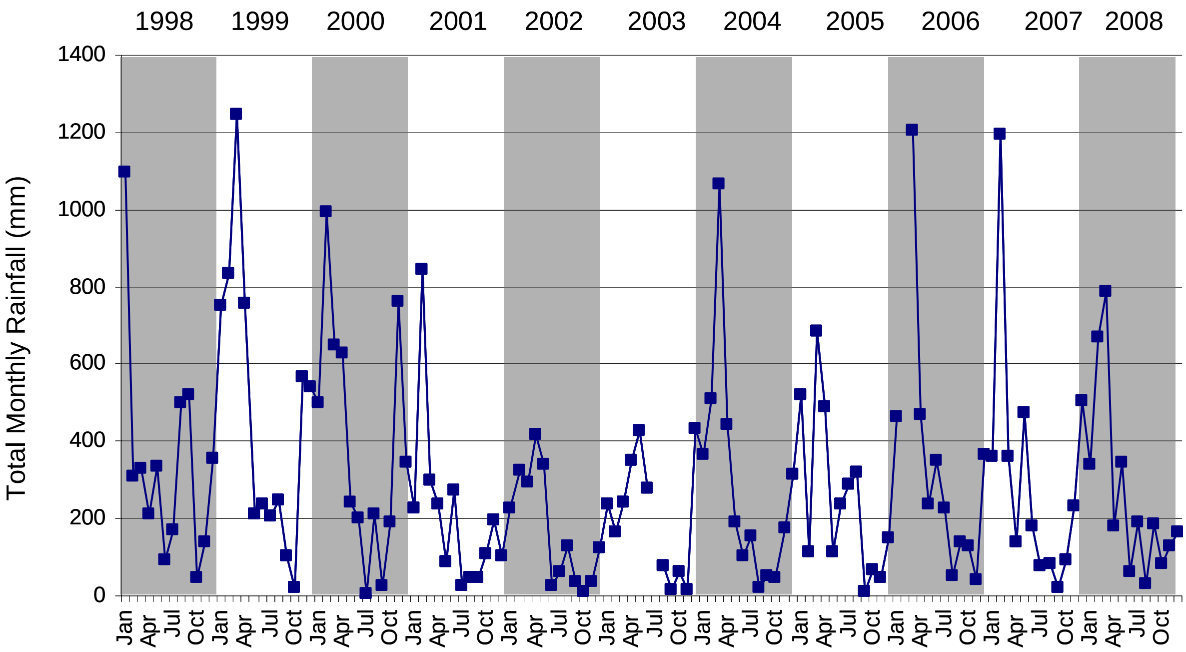


Figure 4. Mean monthly maximum air temperature (°C) for Innisfail from 1998-2008 (Bureau of Meteorology, 2008)

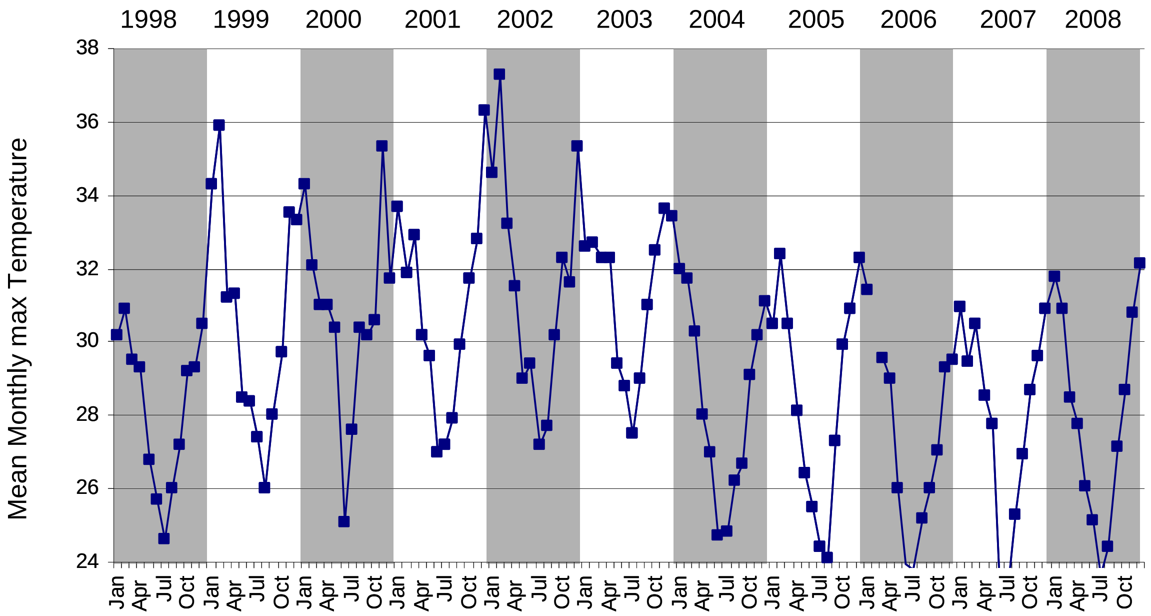


Figure 5. Total Monthly number of cloudy days for Innisfail from 1998-2008 (Bureau of Meterorology, 2008).

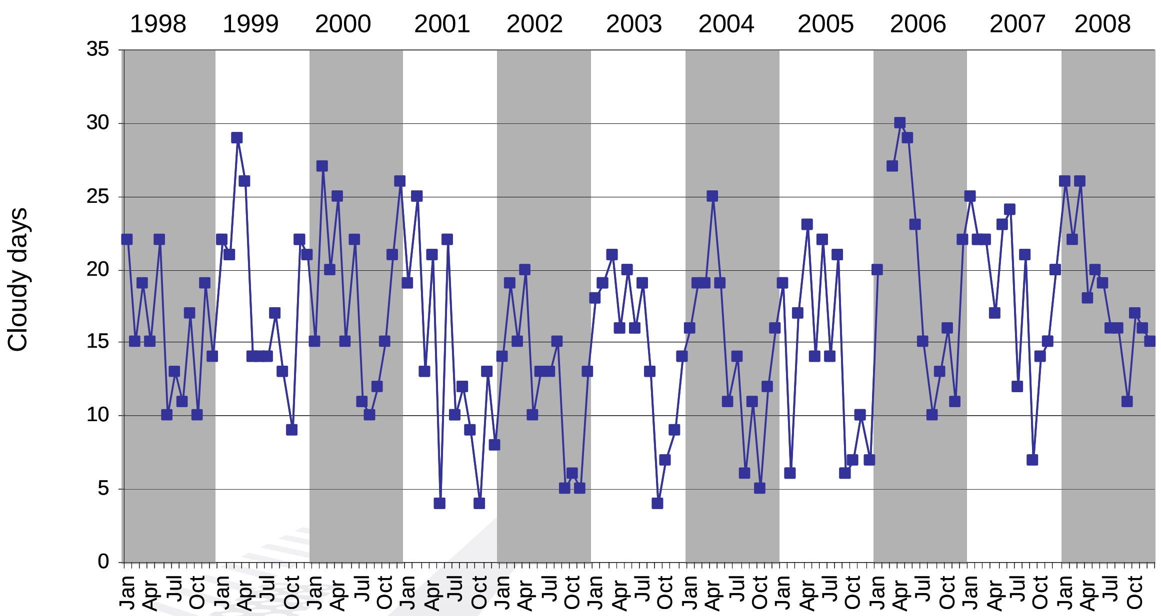
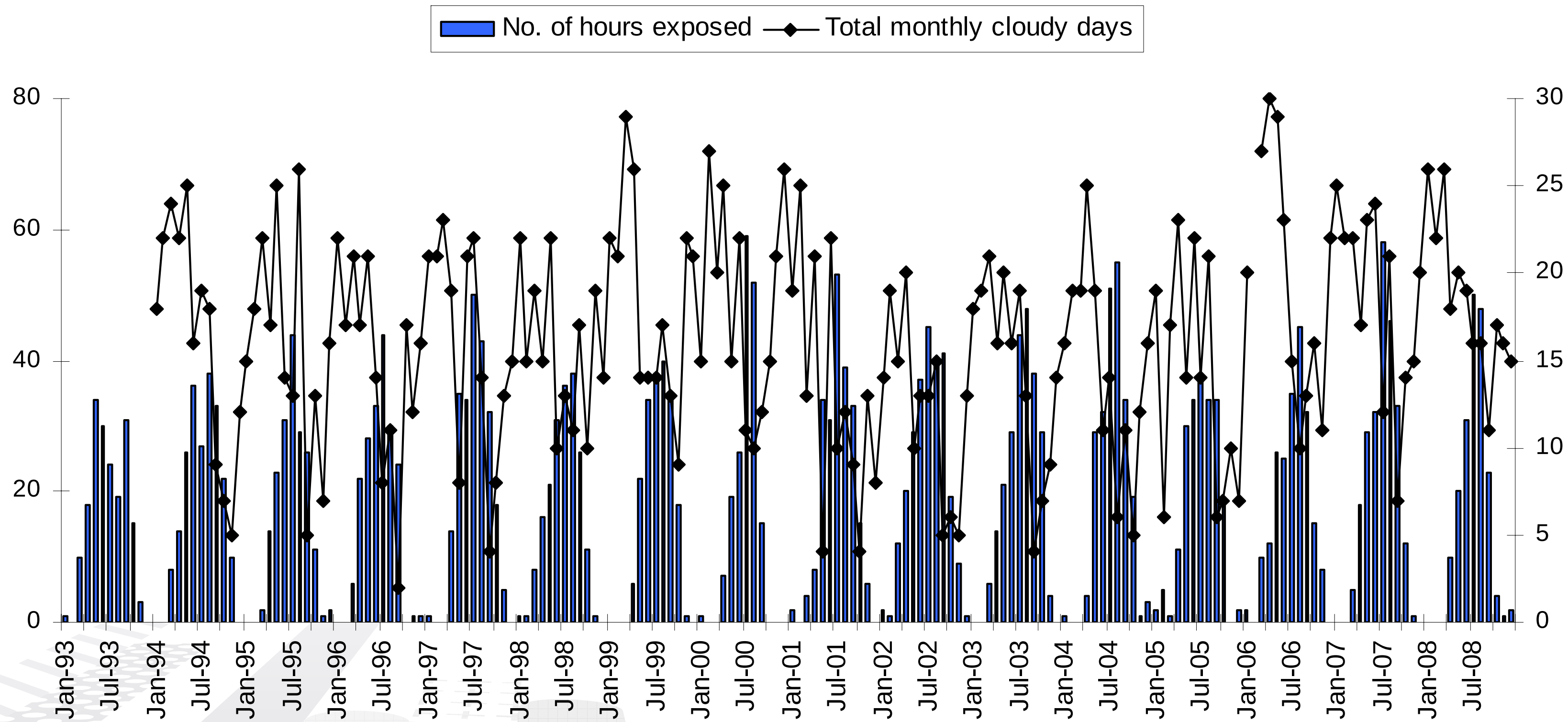


Figure 6. The total number of daylight hours per month that intertidal banks are exposed and the monthly number of cloudy days recorded from 1993 to 2008 (Source: Bureau of Meteorology, 2008).



DISCUSSION

The 2008 monitoring survey of Mourilyan Harbour recorded reductions in seagrass biomass and area for most meadows, adding to previous long-term trends of decline. Seagrasses within most of the Mourilyan Harbour monitoring meadows are now well below their peak density and distribution and remain in a vulnerable state. Declines are thought to be related to catchment level water quality issues and may be confounded by the long-term recovery from the impacts of Cyclone Larry. Further investigations into local water quality would assist in understanding and mitigating these impacts. At this time, declines are not considered to be the result of port activities.

Only one meadow substantially increased in biomass, the high density intertidal Bradshaw *Zostera capricorni* meadow which has maintained a relatively healthy condition throughout the monitoring program, despite the impact of Tropical Cyclone Larry in 2006. The *Zostera capricorni* intertidal Lily meadow, although well below past peak densities, remained relatively stable, with biomass and area not changing significantly over the past 3 years.

The 2008 survey found the intertidal Seaforth Edge meadow had come close to disappearing, with only one sparse patch of *Halophila ovalis* found and no biomass recorded during random sampling. This meadow had re-established in small isolated patches in 2007 after completely disappearing in 2006 due to Tropical Cyclone Larry. It appears that this meadow is struggling to establish a stable presence following the impacts of Cyclone Larry. The 2008 survey saw the re-establishment of the intertidal Seaforth Bank meadow in small isolated patches and a species composition change, following the disappearance of this meadow in 2007. The subtidal Channel meadow also saw a decrease in biomass, reducing back to levels that were recorded pre Cyclone Larry. The disappearance and reappearance of seagrasses in these meadows over the past few years indicates that they have become sparse and fragile. Their highly fragmented nature may place seagrasses under threat particularly in the event of any future stress.

Previous analysis of change in Mourilyan Harbour seagrass meadows has been related to climate, flood and storm events (McKenna *et al.* 2008). The effects of local catchment use, however, have not been quantified and may explain much of the seagrass change observed in the harbour (Thomas and Rasheed 2004; Thomas *et al*. 2006, Lewis *et al*. 2009). In 2006, Tropical Cyclone Larry had a major impact on many of the harbour’s seagrass meadows. These meadows, although initially showing signs of recovery in late 2006, have not been able to stabilise since the disturbance from the cyclone. The climate from 2007 to 2008 was generally favourable for seagrass growth with maximum air temperature, solar irradiance and tidal exposure remaining relatively low (Figures 3 ,4, 5 & 6). These conditions would tend to protect intertidal seagrasses from the effects of thermal stress and desiccation at low tide.

Water quality issues associated with agricultural practices may explain some of the observed changes to seagrasses. Agriculture comprises 43% of the Mourilyan catchment area and has impacted the marine environment in the past (Russell *et al*. 1996). Elevated herbicide concentrations associated with agriculture have been recorded in waterways of the Great Barrier Reef catchment area including in intertidal and subtidal sediments (Duke *et. al*. 2005, Haynes *et. al.* 2000, Ham 2007). The herbicides diuron, atrazine, hexazinone and ametryn have been frequently detected in relatively high concentrations at sites draining sugar cane in North Queensland catchment areas, with the highest concentrations of diuron recorded in the Tully-Murray region during a recent water quality study (Lewis *et. al.* 2009). These herbicides have been proven to inhibit the photosystem II in plants (Jones *et. al*, 2003). Currently there are no direct measures of water quality collected in Mourilyan Harbour to determine whether catchment and agricultural runoff are the drivers of seagrass change. The establishment of water quality monitoring along with sedimentary herbicide analysis in Mourilyan would help to strengthen the possible links between seagrass condition and catchment issues.

The position of seagrass meadows in the harbour may result in differences in their vulnerability to impacts associated with flooding and catchment run-off (herbicides, suspended sediments and nutrients and changes to salinity). The Bradshaw meadow is positioned in a protected corner of the harbour not directly in the river flow path (Map 1). Its position may also be favourable to greater tidal flushing than the upstream Lily meadow. This may explain the relative stability of the Bradshaw meadow compared to others in the Harbour. Conversely the Lily meadow is located in the southern end of the harbour (the furtherest upstream) and may receive a greater exposure to catchment runoff including potential negative effects of higher turbidity, herbicide residues, and changes to salinity.

The species change in the Seaforth Bank meadow from a *Halophila ovalis* dominated meadow in 2007 to a *Halodule uninervis* dominated meadow in 2008 is likely a response to the substantially lower rainfall recorded in 2008 (Figure 3). *Halophila ovalis* and *Halophila decipiens* are known to be highly adapted to low light levels, often resulting from highly turbid waters during high rainfall and flooding periods (Kenworthy *et al*. 1989; Birch & Birch 1984). The Channel meadow also reverted to a *Halodule uninervis* dominated meadow in 2008, from a previously *Halophila decipiens* dominated meadow in 2007. This may indicate that the light conditions in the channel area of the Harbour have improved since 2007 and the meadow is now being occupied by a higher light requiring species. This was the case in the Channel meadow during the drought years between 2002-2005, where *Halodule uninervis* dominated (McKenna *et al.* 2006)

The expansion of the Channel meadow may further indicate the improvement of light conditions in the Channel and the subsequent colonisation of *Halodule uninervis* to areas of the Channel that previously were light restricted. Since monitoring began in Mourilyan Harbour, the area of the Channel meadow has changed considerably from year to year (Map 2). Previously, the expansion and contraction in area has mainly occurred in the southern or upstream sections of the meadow, where runoff events and tidal flushing likely influenced seagrass colonisation. In 2008, meadow expansion primarily occurred on the Western side of the meadow adjacent to Armit Creek, suggesting that availability of light was the driving factor.

The repeated decline and recovery of meadows in Mourilyan Harbour, particularly the Seaforth Bank and Seaforth Edge meadows was likely to have considerably reduced their below-ground stores of energy and seed banks which form the basis of their resilience (McKenna and Rasheed 2007). The pioneering species *Halophila* and *Halodule* which dominate these meadows, have the potential to colonise quickly and the ability to form large seed bank reserves (Birch and Birch 1984; Preen *et. al.* 1995). The repeated declines of these meadows combined with the impacts of Cyclone Larry were likely to have substantially reduced this capacity for recovery. As a consequence these meadows are in a vulnerable state with a reduced resilience to further natural or human impacts.

It is unlikely that operations within the Port of Mourilyan were the cause of changes in seagrass biomass and area in 2008, as there have been no major changes in port activity since 2004. However the reduced resilience of seagrasses may make them more susceptible to impacts associated with port activity in the future, particularly if declines from other sources such as catchment runoff continue. The vulnerable state of seagrasses means that continued monitoring is important to ensure the long term viability of these valuable marine habitats. Further investigation into water quality within Mourilyan Harbour would also be of great benefit in determining whether land-based run-off is influencing the decline of seagrasses within the port.

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APPENDIX

Appendix 1.

Results of one-way ANOVA for mean above-ground biomass versus year for the Mourilyan Harbour monitoring meadows, 1993 to 2008

Bradshaw (1) [a]	DF	SS	MS	F	P
Between years	11	58640.1	5330.9	11.72	**<0.001**
Within years	310	140945.9	454.7		
Total	321	199586.0			
Lily (2) [a]					
Between years	11	31697.7	2881.6	24.40	**<0.001**
Within years	233	27511.9	118.1		
Total	244	59209.6			
Seaforth Bank (3) [b]					
Between years	10	284.9	28.5	13.2	**<0.001**
Within years	275	592.6	2.2		
Total	285	877.5			
Seaforth Edge (4) [c]					
Between years	n/a				
Within years					
Total					
Channel (5) [d#]					
Between years	11	20.6	1.87	4.52	**<0.001**
Within years	332	137.4	0.41		
Total	343	158.0			

[a] 1993 has been omitted from analyses due to low number of replicates
[b] Meadow was not present in 2003
[c] Meadow was not present in 2000, 2003, 2007 and 2008 has been omitted from analyses due to low number of replicates
[d] Meadow was not present in 2000
[#] One-way ANOVA using log+1 transformed data

Results of Least Significant Difference (LSD) pair-wise comparisons of mean above-ground biomass (g DW m^{-2}) for the Mourilyan Harbour monitoring meadows. Means that share a common letter for each meadow are not significantly different ($P < 0.05$)

Year	Mean Biomass (g DW m^{-2})				
	Bradshaw	Lily[#]	Seaforth Bank	Seaforth Edge	Channel[#]
1993	n/a	n/a	1.0 ab	2.2 ab	0.5 a
1994	45.1 bcd	30.5 d	0.7 a	2.2 ab	1.8 ab
1995	49.3 cd	29.1 d	1.1 abc	1.6 ab	1.4 ab
1996	59.5 d	29.8 d	2.8 c	3.4 b	2.8 ab
2000	17.6 a	7.7 ab	0.2 a	n/a	n/a
2001	35.9 abc	5.6 ab	2.5 bc	2.8 b	0.6 a
2002	32.1 abc	20.7 cd	0.3 a	1.6 ab	1.0 ab
2003	21.6 a	5.1 ab	n/a	n/a	0.7 a
2004	59.3 d	12.3 bc	0.6 a	1.2 ab	1.0 a
2005	34.1 abc	0.2 a	0.03 a	0.2 a	1.3 a
2006	46.5 bcd	2.4 ab	0.06 a	n/a	2.4 ab
2007	21.4 a	2.8 ab	n/a	n/a	2.5 b
2008	28.0 ab	1.5 ab	0.06 a	n/a	0.6 a

[#] One-way ANOVA using log+1 transformed data