Centre for Tropical Water and Aquatic Ecosystem Research

GLADSTONE HEALTHY HARBOUR PARTNERSHIP PILOT REPORT CARD

ISP011: SEAGRASS

Final Report

Bryant CV, Jarvis JC, York, PH & Rasheed MA

Report No. 14/53

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A Report for the Gladstone Healthy Harbour Partnership

Report No. 14/53

October 2014

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EXECUTIVE SUMMARY

The Seagrass Ecology Group within the Centre for Tropical Water and Aquatic Ecosystem Research at James Cook University (TropWATER) have developed a pilot approach for reporting on the condition of seagrasses in the Gladstone Harbour region for incorporation into the Gladstone Healthy Harbours Partnership (GHHP) 2014 pilot report card. Annual long term monitoring data collected at 15 representative seagrass meadows since 2002 were used to assess the status of three seagrass indicators (average above-ground biomass, total meadow area and species composition) relative to baseline conditions at each meadow.

We assessed various methods for setting baseline conditions including a running long term average; a ten year fixed average; and a five year fixed average applied across two different portions of the monitoring history. The ten year fixed average (calculated over the period from 2002 – 2012) was considered the most appropriate baseline for which to compare annual indicator values because it incorporated the greatest range of climate conditions known to influence seagrasses in the region.

Threshold levels determining the condition of indicators relative to the baseline were selected based on the historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region. We tested several ranges of threshold values to determine which ranges best fit the historical data, i.e. which ranges resulted in a grade that reflected our understanding of the condition of seagrasses over the course of the monitoring program.

A combination of threshold ranges were used, recognising that some seagrass meadows are historically more stable and others are expected to fluctuate substantially from year to year. These differences reflect the difference in species assemblages and growth characteristics at various monitoring meadows as well as regional difference between meadows growing in marginal inner harbour versus more favourable outer harbour conditions.

The pilot reporting framework assesses annual levels for each seagrass indicator against baseline conditions to determine a grade from A to E, where A indicates a condition of 'very good' and E indicates a condition of 'very poor'. The lowest of the three seagrass indicator grades dictates the overall grade for each monitoring meadow. The harbour has been divided up into several zones as part of the GHHP reporting process. The average of the individual meadow grades within each of these zones dictates the overall grade for each zone.

The report is separated into two parts. Part 1 presents the results of the 'pilot' report card approach applied to the results of the most recent annual survey conducted in November 2013 (in the GHHP 2014 reporting year). Part 2 is an accompanying technical report detailing the methods for data collection, justification for the pilot reporting framework and a detailed interpretation of monitoring results.

KEY FINDINGS

- Seagrasses in the Gladstone and Port Curtis region underwent significant declines following flooding and major rain and storm activity in 2010, similar to many areas of seagrass along the Queensland east coast.

- Annual monitoring has shown that during 2012 some recovery occurred at many meadows, but high rainfall and the biggest flow event for the Calliope River in over a decade in early 2013 saw a reversal of much of that recovery.

- Most monitoring meadows were assessed as being in a poor (D) or very poor (E) condition in November 2013, including the majority of meadows in The Narrows, Western Basin, Inner Harbour, South Trees Inlet (lower) and Rodds Bay Zones.

- In the Mid Harbour Zone, the large Pelican Banks and Quoin Island monitoring meadows were in a moderate (C) condition but above-ground seagrass biomass and/or total meadow area remained well below the baseline.

- Several consecutive years of decline have likely left seagrasses with a reduced resilience to further impacts and it may take some time for meadows to reach pre-flood (2009) levels.

- The generally poor condition of seagrasses in Gladstone is reflected in other monitoring locations on the east coast of Queensland. This is in contrast to many of the seagrass areas on Northern Cape York and the Gulf of Carpentaria which were in good condition and not impacted by the severe flooding that occurred on the east coast in recent years.

This is the first year of applying and testing the seagrass report card framework and there is scope for future modifications as the program is rolled out and implemented in 2015. The pilot approach relied heavily on expert opinion for setting baseline conditions and thresholds to determine grades. For future reporting we are exploring statistical approaches to potentially enhance the strength of the reporting framework.

CONTENTS

PART 1 - SEAGRASS PILOT REPORT CARD 2013

The Seagrass Ecology Group within the Centre for Tropical Water and Aquatic Ecosystem Research at James Cook University (TropWATER) has been monitoring seagrass at least annually in Port Curtis and Rodds Bay since 2002. This has included an annual Long Term Monitoring Program conducted in October/November each year around the peak of seagrass abundance (except 2003). The program currently assesses 15 representative intertidal and shallow subtidal seagrass meadows within Gladstone Harbour and Rodds Bay (Map 1) to monitor changes in seagrass biomass, total meadow area and species composition.

We have developed a pilot approach for reporting on the condition of seagrasses in the Gladstone Harbour region for incorporation into the GHHP 2014 pilot report card. The initial pilot approach was developed for each of the representative monitoring meadows based on three seagrass indicators (biomass, area and species composition) (see Part 2 & Bryant et al., 2014). The framework integrates this information to give each meadow a grade from A to E relative to baseline conditions, where A indicates a condition of 'very good' and E indicates a condition of 'very poor'. The lowest of the three indicator grades dictates the overall meadow grade. The harbour has been divided up into several zones as part of the GHHP reporting process (Map 1). The average of the individual meadow grades within each of these zones dictates the overall grade for each zone.

The grades presented in Table 1 reflect the condition of seagrasses during the most recent annual survey conducted in November 2013. The GHHP Report Card is based on a July-June year, thus the results fall within the 2014 reporting year. This is the first year of applying and testing the seagrass report card framework and there is scope for future modifications as the program is rolled out and implemented in 2015. The pilot approach relied heavily on expert opinion for setting baseline conditions and thresholds to determine grades (see Part 2 of this report). For future reporting we are exploring statistical approaches which may enhance the strength of the reporting framework.

It is important to note that tropical seagrass communities vary in condition naturally due to a number of factors including climate and season and being classified as in "poor" condition can be part of the natural range of expected conditions and not necessarily the result of anthropogenic (human) impacts. The report card framework provides a means of comparing current meadow condition with baseline conditions and provides some indication of the likely level of resilience to future impacts.

Table 1 Grades for seagrass indicators (biomass, area and species composition), meadows and zones of Gladstone Harbour in the GHHP 2014 reporting year relative to baseline conditions.

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION	MEADOW	ZONE
Western Basin	**4**	A	E	A	E	D
	5	B	E	D	E	
	6	B	C	B	C	
	7	A	D	A	D	
	8	B	D	D	D	
	9	E - NP	E - NP	E - NP	E - NP	
	52-57	A	A	B	B	
The Narrows	**21**	D	D	C	D	D
Inner Harbour	**58**	D	B	D	D	D
Mid Harbour	**43**	C	B	A	C	C
	48	C	C	B	C	
South Trees Inlet	**60**	D	D	D	D	D
Rodds Bay	**94**	E - NP	E - NP	E - NP	E - NP	E
	96	E	E	A	E	
	104	D	E	A	E	

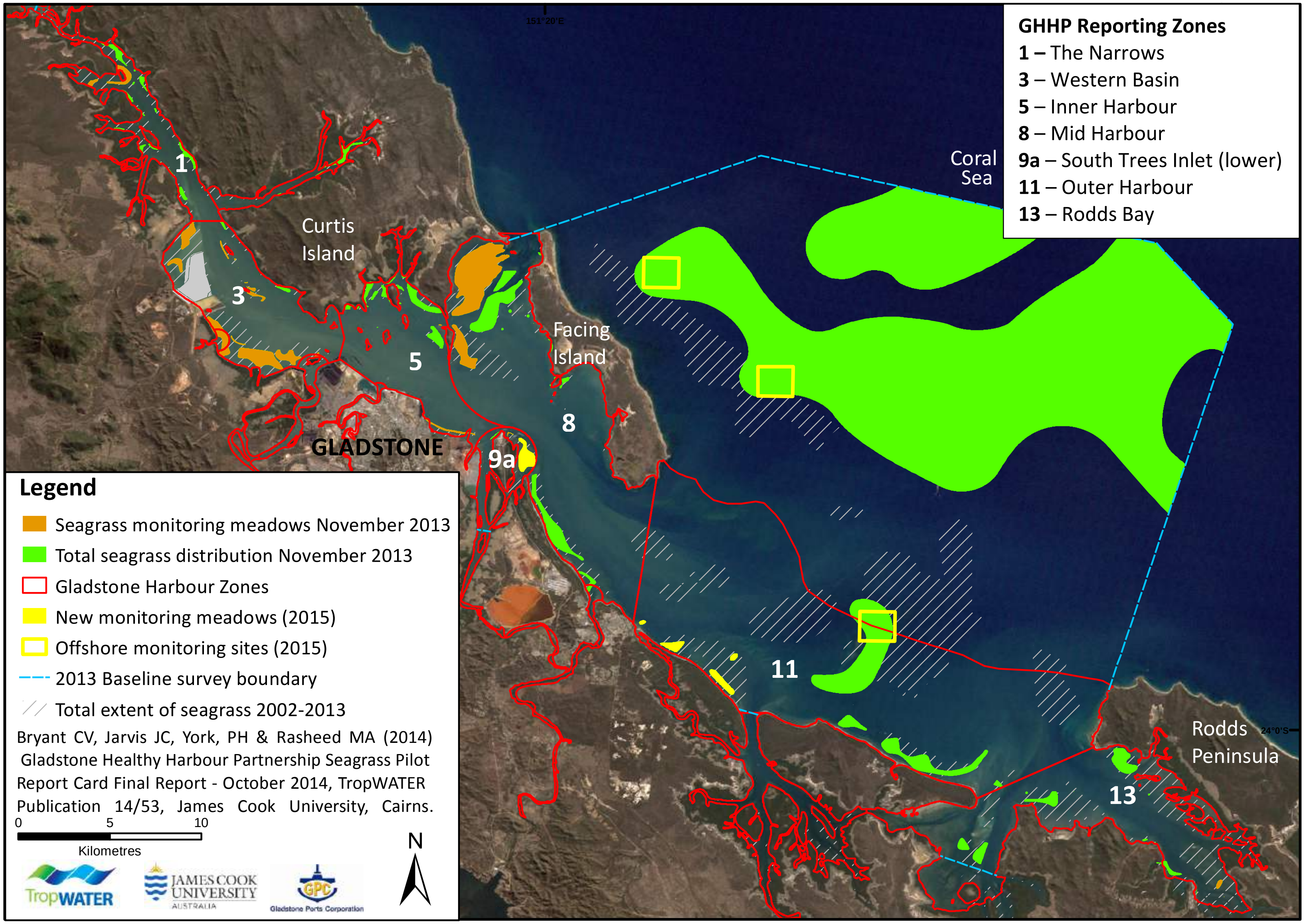
*NP – this seagrass meadow was not present during the November 2013 survey.

*Hashed lines indicate meadows where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until long term data are available.

*Meadows 52-57 are a group of small meadows surrounding the Passage Islands in the Western Basin Zone (see Map 1). These meadows are grouped for reporting purposes.

For further information on how grades were determined see the accompanying technical report (Part 2 of this document).

Map 1 Seagrasses in the Port Curtis Region.



PART 2 – TECHNICAL REPORT

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (Hemminga and Duarte, 2000, Costanza et al., 1997). Seagrass meadows also show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments such as ports (Dennison et al., 1993, Abal and Dennison, 1996, Orth et al., 2006).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) (Formally part of Fisheries Queensland/DAFF) in partnership with the various Queensland port authorities.

The strategic long term assessment and monitoring program for seagrasses in port locations provides managers and regulators with the key information to demonstrate that seagrasses and ports can co-exist as well as information to plan and implement port development and maintenance programs that will have a minimal impact on seagrasses.

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses and an understanding of the drivers of tropical seagrass change. It provides a measure of the marine environmental health of the ports as well as feeding into regional assessments of the status of seagrasses. For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld

1.2 Gladstone Seagrass Monitoring Program

Gladstone Ports Corporation (GPC) recognised that seagrasses are an important and sensitive component of the marine habitats within the port and are committed to maintaining the health of these habitats. In 2002, GPC in partnership with the James Cook University - Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER - formerly Fisheries Queensland) commissioned a fine-scale survey of seagrass resources within the port limits and nearby Rodds Bay (Rasheed et al., 2003). The 2002 baseline survey identified large areas of seagrass within the port limits.

An annual seagrass monitoring program was developed in 2004 by JCU – TropWATER (formally Fisheries Queensland) in response to a whole of port review (SKM, 2004) and following recommendations from the Port Curtis Integrated Monitoring Program (PCIMP). Thirteen seagrass meadows were selected for monitoring which represented the range of seagrass communities within the port as and include meadows considered in 2004 most likely to be impacted by port facilities and developments. Monitoring meadows included both intertidal and subtidal seagrasses as well as meadows preferred by dugong and those likely to support high fisheries productivity.

Three of these meadows are located in Rodds Bay (outside of the port limits) 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 reference sites). From 2009 an additional 2 monitoring meadows were added to the long term program reflecting the shift in focus of new port activity to the Curtis Island area as part of the Western Basin developments. The additional meadows are located in the vicinity of the development (Passage Islands) and upstream (the Narrows).

The annual monitoring since 2004 (Rasheed et al., 2005, 2006, 2008 & 2012; Taylor et al., 2007; Chartrand et al., 2009 & 2011; Thomas et al., 2010; Davies et al., 2013) and data collected in 2002 has documented considerable inter-annual variability in seagrass meadow biomass and area which is most likely the response of meadows to regional and local climatic factors (Chartrand et al., 2009). Such climate induced inter-annual variability is common throughout tropical seagrass meadows of the Indo-Pacific (Agawin et al., 2001). In addition to inter-annual variability, recent work has demonstrated that seagrasses in Gladstone are also highly seasonal. Two generalised seasons for seagrasses have been defined for Gladstone; the growing season between July and January, where seagrasses typically increase in biomass and distribution in response to favourable conditions for growth; and the senescent season, February to June, when seagrasses typically retract and rely on stores or seeds to get through wet season conditions, including flooding, poor water quality and a reduction in light (Chartrand et al., 2012). The peak of the growing season is generally around October or November (corresponding to the time of annual surveys) and seagrasses are at their lowest abundance around June.

In situ light and temperature data has also been collected at the seagrass canopy at a number of the monitoring meadows since late 2009. These data aid in the determination of the main drivers of seagrass change at the meadow scale and help differentiate anthropogenic impacts from natural inter and intra-annual variation.

As the 15 seagrass monitoring meadows were originally selected for their relevance to port activities, there is a large section from South Trees to Rodds Bay where there are no existing monitoring meadows. From 2015, it is planned to add two additional meadows to the annual monitoring program to fill a gap between the Western Basin Region and Rodds Bay. Three offshore seagrass monitoring sites will also be added (subject to funding) to report on the condition of deepwater seagrasses.

1.3 The Gladstone Healthy Harbour Partnership Report Card

The Gladstone Healthy Harbour Partnership (GHHP) is a forum to bring together parties (including community, industry, science, government, statutory bodies and management) to maintain, and where necessary, improve the health of Gladstone Harbour. The GHHP has undertaken to develop a report card system to track the ecosystem health of the harbour including important ecological assets (e.g., water quality, key species and habitats). Initially, a pilot report card will be developed in 2014 with full implementation of the program including annual reporting from 2015. The report card will incorporate the best available science and monitoring into a series of indicators to make annual assessments of each asset against the GHHP Vision.

Seagrasses are one of the most dominant and important habitats within the Gladstone Harbour precinct covering an area of approximately 12,000 ha at peak distribution including intertidal, shallow subtidal and deep-water habitats. These seagrasses offer a range of economically and ecologically important ecosystem services such as sediment stabilisation, nutrient cycling, carbon sequestration, nursery habitat for juvenile fisheries species and food for dugongs and turtles.

Recognising the long-standing association of TropWATER with seagrass research in Gladstone Harbour, the GHHP engaged TropWATER to develop a reporting framework for seagrasses making use of the annual long term monitoring data. This is the first year of applying and testing the seagrass report card framework and there is scope for future modifications as the program is rolled out and implemented in 2015. The pilot approach relied heavily on expert opinion for setting baseline conditions and thresholds to determine grades. For subsequent report cards, we are exploring statistical approaches to potentially enhance the strength of the reporting framework.

1.4 Seagrasses in the Port Curtis Region

Five seagrass species (from two families) are commonly found in the Gladstone Harbour area and referred to throughout this report (Figure 2).

Family HYDROCHARITACEAE Jussieu:

Halophila decipiens Ostenfeld
Halophila ovalis (R. Br.) Hook. F.
Halophila spinulosa (R.Br.) Aschers. In Neumayer
Halodule uninervis (wide and narrow leaf morphology) (Forsk.) Aschers in Boissier

Family ZOSTERACEAE Drummortier:

Zostera muelleri Aschers.

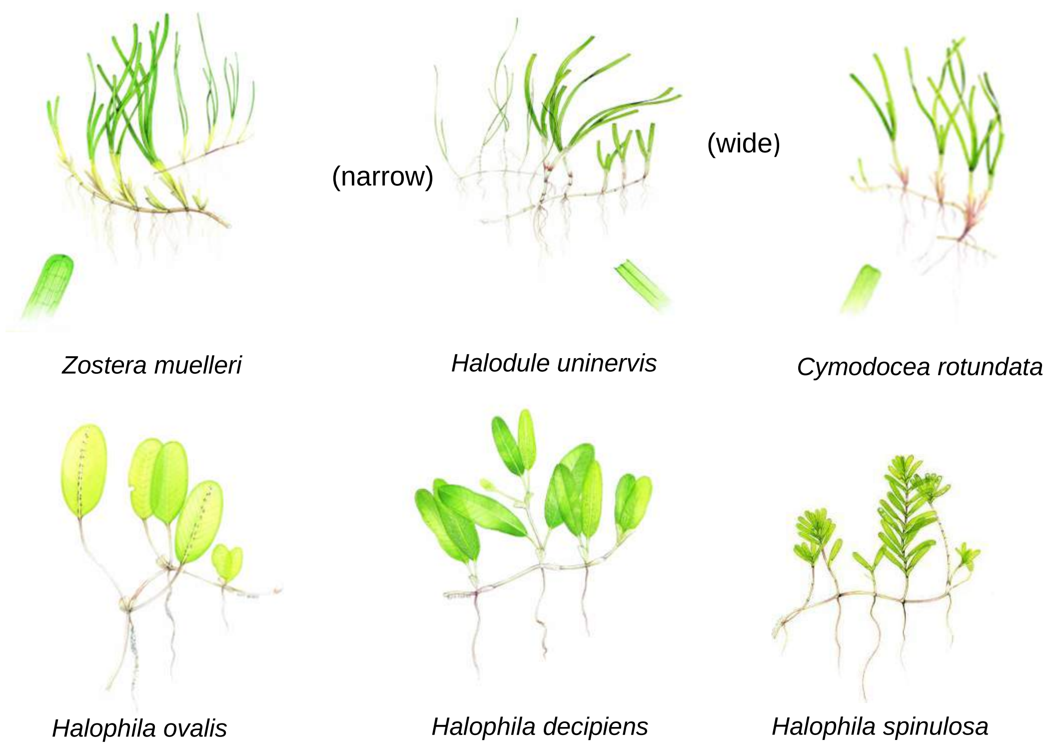


Figure 2 Seagrass species present in the Gladstone Harbour area.

2 METHODS

2.1 Sampling approach and data collection methods for seagrass indicators

The 15 representative seagrass monitoring meadows were surveyed between the 2nd of November and the 6th of December 2013 (within the GHHP 2014 reporting year) around the known peak in seagrass distribution and abundance in the region (Chartrand et al., 2012 & In review). The survey also formed part of a broader baseline survey of the entire Port Curtis Region (Bryant et al., 2014). Monitoring methodology followed the established techniques for the JCU state-wide ports seagrass monitoring program (Rasheed & Unsworth 2011; Unsworth et al*.,* 2012, Taylor & Rasheed 2011; Lee Long et al*.,* 1996). Detailed methodology for its application in Gladstone can be found in Rasheed et al*.,* (2003 & 2005) and Bryant et al., (2014).

Intertidal meadows were sampled at low tide from a helicopter. GPS was used to fix and record the position of meadow boundaries. Seagrass meadow characteristics (including seagrass above-ground biomass and species composition) were recorded at sites scattered within the seagrass meadow as the helicopter hovered within two metres above the seagrass.

Shallow (<8m) subtidal meadows were sampled from a small boat using free divers. Seagrass meadow characteristics were recorded at sites located along transects perpendicular to the shoreline. Sites were located at approximately 50 to 200 m intervals along each transect or where major changes in bottom topography occurred. Transects extended to the offshore edge of seagrass meadows with random sites used to measure continuity of habitat between transects.

Biomass and species composition

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (see (Kirkman, 1978; Mellors, 1991). A 0.25m^2 quadrat was placed randomly three times at each site. For each quadrat, an observer assigned a biomass rank made in reference to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass had previously been measured. Two separate 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 quadrat was also recorded. At the completion of ranking, the observer also ranked a series of photos of calibration quadrats that represented the range of seagrass observed during the survey. These calibration quadrats had previously been harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks given in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}).

Area

The total area of monitoring meadows was determined in ArcGIS® using the GPS position of meadow boundary and sampling sites (see 2.2 below).

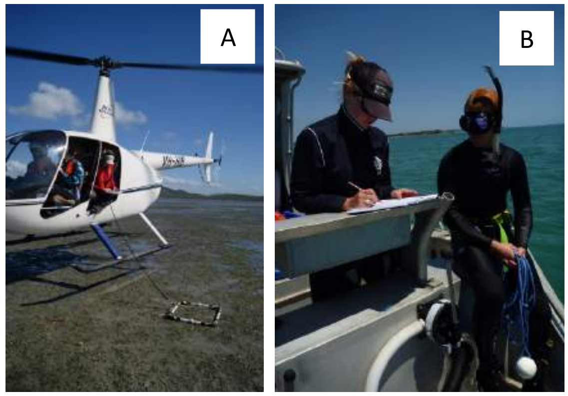


Figure 3 Seagrass monitoring utilising (A) helicopter aerial surveillance; (B) boat based free divers

2.2 Seagrass meadow mapping and Geographic Information System

Spatial data from the 2013 survey were entered into the Port Curtis Geographic Information System (GIS). Three seagrass GIS layers were created in ArcGIS® - site information, seagrass meadow characteristics and seagrass landscape category.

- ***Site information-*** data containing seagrass per cent cover and above-ground biomass (for each species), depth below mean sea level (dbMSL), sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.

- ***Seagrass meadow characteristics-*** 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 Queensland (Table 2). Abundance categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 3).

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

Table 2 Nomenclature for community types in Port Curtis and Rodds Bay, November 2013.

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 3 Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in Port Curtis and Rodds Bay, November 2013.

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 4). The mapping precision for coastal seagrass meadows ranged from ± 3m for isolated seagrass patches to ± 50m for some subtidal boundaries. 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.

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

Figure 4 Seagrass landscape categories

Table 4 Mapping precision and methodology for seagrass meadows in Port Curtis and Rodds Bay, November 2013.

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 & diver/grab surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from survey sites & aerial photography, Moderately high density of mapping and survey sites.
20m	Meadow boundaries determined from helicopter & diver/grab surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from diver/grab survey sites, Lower density of survey sites for some sections of boundary.
50m	Meadow boundaries determined from helicopter & diver/grab surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from diver/grab survey sites, Low density of survey sites for some sections of boundary.

2.3 Selection of baseline conditions

To select the baseline conditions at each of the monitoring meadows, we compared four different methods.

Running long term average

The first method uses a running long term average to set the baseline conditions for average biomass and total area at each meadow.

Fixed ten year average (2002-2012)

The second method uses a fixed ten year average calculated over the period from 2002 to 2012 (note there was no survey in 2003). This ten year period incorporates a range of conditions present in the harbour including:

- Both El Nino and La Nina periods
- Multiple extreme rainfall and river flow events (Figures 29 and 30)
- Large scale capital dredging (Western Basin Dredging and Disposal Project, 2011-2013)
- Annual maintenance dredging

Fixed five year average (2002-2007)

The third method uses a fixed five year average calculated over the period from 2002 to 2007 (note there was no survey in 2003). This five year period incorporates a shorter period when conditions were considered more favourable for seagrass growth, including:

- El Nino period only
- Few extreme rainfall and river flow events (Figures 29 and 30)
- Annual maintenance dredging only (no large scale capital dredging projects)

Fixed five year average (2008-2012)

The fourth method uses a fixed five year average calculated over the period from 2008 to 2012. This five year period incorporates a shorter period where conditions were considered less favourable for seagrass growth, including:

- La Nina period only
- Multiple extreme rainfall and river flow events (Figures 29 and 30)
- Large scale capital dredging (Western Basin Dredging and Disposal Project, 2011-2013)
- Annual maintenance dredging

A comparison of these methods is presented in section 3.1 and Appendix A.

2.4 Selection of threshold levels for grading indicators

Threshold levels determining the condition of indicators relative to the baseline were selected based on the historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region. We tested several ranges of threshold values to determine which ranges best fit the historical data, i.e. which ranges resulted in a grade that reflected our understanding of the condition of seagrasses over the course of the monitoring program. Results of the selected approach are presented in section 3.2.

TropWATER have a long history of monitoring seagrass in Gladstone and elsewhere in Queensland with members of the GHHP seagrass report card team directly involved in annual surveys at monitoring meadows since 2002, and over 20 years of monitoring seagrass condition and trend throughout Queensland (see Coles et al., In press). For this “pilot” report card, we relied on expert opinion to guide the process of setting threshold levels around baseline conditions. For subsequent report cards, we are exploring statistical approaches which may enhance the strength of the reporting framework.

We developed two different threshold ranges for biomass and three different threshold ranges for area, recognising that some seagrass meadows are historically more stable and others are expected to fluctuate substantially from year to year. These differences reflect the different growth characteristics of species than comprise different meadows, as well as the meadow setting. For example meadows dominated by “pioneering” species from the genus *Halophila* have a higher year to year variation than meadows made up of larger growing species such as *Zostera muelleri*. There are also regional differences within a meadow type that reflect the natural growing conditions. For example the outer harbour conditions are naturally more favourable for seagrass growth, compared with the inner harbour where more marginal seagrass growing conditions result in a much higher natural variability in seagrass. This resulted in four classes of monitoring meadow for grading purposes.

- **Class 1 Meadows -** stable biomass, stable distribution
- **Class 2 Meadows -** variable biomass, stable distribution
- **Class 3 Meadows -** variable biomass, variable distribution (intertidal)
- **Class 4 Meadows -** variable biomass, variable distribution (subtidal)

Table 5 Threshold levels for grading seagrass indicators for various meadow classes.

Seagrass Indicators/Grades		A Very good	B Good	C Moderate	D Poor	E Very Poor
Biomass	Stable	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Highly variable	More than 40% above the baseline	Within 40 % of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Area	Stable	More than 10% above the baseline	Within 10% of the baseline (above or below)	Between 10% and 30% below the baseline	Between 30% and 50% below the baseline	More than 50% below the baseline
	Highly variable intertidal	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Highly variable subtidal	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species composition		Composition remains stable	Some loss of climax species	Shift towards colonising species	Colonising species dominant	Complete loss of climax species

Species composition was assessed qualitatively as “very good” when the species composition had remained relatively stable; “good” when there had been only some loss of the climax species; “moderate” when there had been a substantial shift in species toward colonising species indicating disturbance or stress; “poor” when the meadow had shifted to become clearly dominated by colonising species; and “very poor” when there was a complete loss of the climax species.

It is important to note that species shifts are relative and determined on a meadow by meadow basis taking into account both the current years’ species composition and historical trends. Some monitoring meadows in their stable state are always dominated by colonising species and not necessarily in a “poor” condition. In future report cards we are exploring the use of multivariate approaches for analysing changes in species composition.

2.5 Meadow grades

The overall grade for each monitoring meadow was determined by the lowest grade of the three indicators (biomass, area and species composition). In the future, where additional information is available, such as seagrass seed-bank status, light and temperature stress or other measures of resilience such as flowering and fruiting and carbohydrate stores, these may be used to modify the overall grade if they indicate the meadow may be under increased stress.

2.6 Zone grades

The grade for each zone of the harbour was determined by the average grade of the meadows within that zone.

2.7 Harbour grade

We did not provide an overall grade for seagrasses in Gladstone Harbour in this pilot framework. Any process to combine grades from individual meadows/zones to reach a Gladstone Harbour grade should allow for differential weighting of meadows/zones recognising differences in the ecological importance of particular seagrass habitats.

2.8 Local climate conditions

Rainfall (mm) and river discharge (MegaLitres) data were obtained from the Australian Bureau of Meteorology website (http://www.bom.gov.au/climate/data/). Data for the nearest weather station at Gladstone Airport (station # 039123) were used.

3 RESULTS

3.1 Comparison of baseline methods

Using the threshold levels presented in table 5 (above) we plotted the historical data for the indicators *a)* biomass and *b)* area, using each of the four different baseline methods described in section 2.4. A full comparison of methods at each of the monitoring meadows is presented in appendix A. Here we highlight important considerations for each approach and justify our selection of the fixed ten year average.

Running long term average

The running long term average uses each consecutive data point to inform and adjust the baseline value over time. We have identified two main issues to this approach; a) early values are based on very few data points and assume 'good' conditions'; and b) sustained increases/declines in indicators drive the baseline up/down with the potential to mask the magnitude of impacts (or conversely recovery). Figure 5 highlights these points.

At meadow 5, average biomass at the meadow was initially low (<2 gDW m^{-2}) but was graded a B (good) because of the lack of data points informing the baseline (Figure 5 a). When biomass peaked in 2007, the baseline was driven upward making it difficult to achieve a grade of B (good) in subsequent years even at levels higher than the initial year.

Using the fixed ten year average, the initial low biomass at the start of monitoring was graded a C (moderate) accounting for the variability over subsequent years (Figure 5 b). This fixed baseline allows for equal grades in years where values are similar. For example, biomass values in 2002 and 2012 are similar and both graded a C.

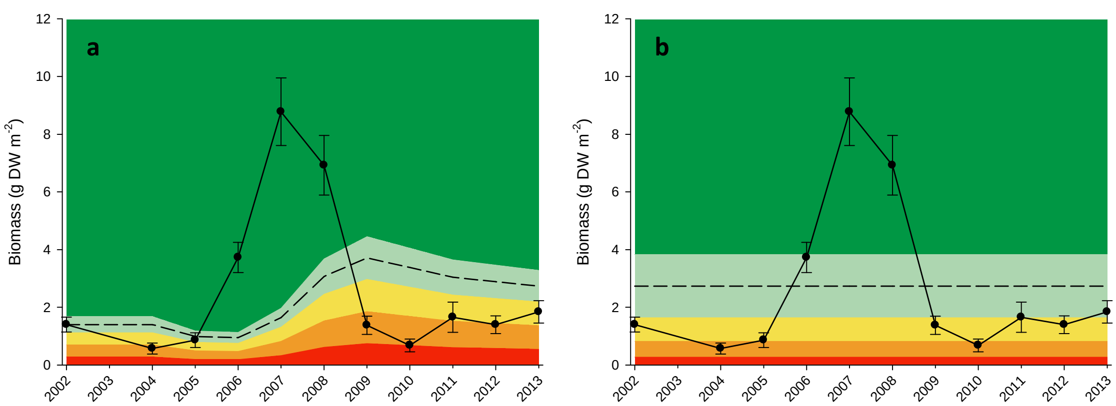


Figure 5 Average biomass during annual (November) surveys at monitoring meadow 5 in relation to a) the running long term average baseline versus b) the fixed ten year average baseline.

Fixed five year average

We examined using a shorter 5 year fixed average to set the baseline condition using two periods, from 2002-2007 and 2008-2012. The main issue to consider when fixing the baseline over a shorter five year history is how well this represents the range of natural conditions and hence natural variability in seagrass meadow conditions. Both 5 year periods examined resulted in a bias either to a high or low level reflecting the climate conditions during each period.

2002-2007

The main issue is that the period underrepresents the number of natural climatic events known to impact seagrasses. The onset of El Nino around 2002 meant that the following 5 years (with the exception of 2003) were relatively dry with very few significant rainfall and river flow events. On the east coast of Queensland, these conditions are considered favourable for seagrass growth largely due to the positive influence on water quality and light available for photosynthesis (Chartrand et al., 2014). Fixing the baseline over these 'favourable' years can make the baseline artificially high. Figure 6 highlights this point.

At meadow 4, the total area of the meadow was stable over the first seven years of monitoring and declined significantly following extreme flooding in 2010. Although total area has increased in recent years, several above average wet seasons are limiting full recovery at the meadow. If the baseline was set using the first five years of data (Figure 6a), the significant recovery seen in 2012 would have only just brought the grade up to a C (moderate). Using ten years of data (Figure 6b) however brings the 2012 grade up to almost a B (good).

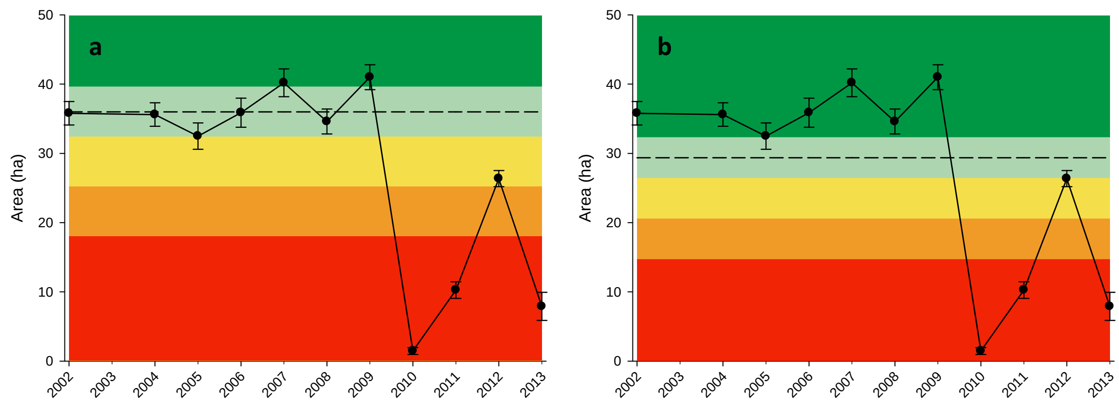


Figure 6 Total meadow area during annual (November) surveys at monitoring meadow 4 graded in relation to a) the fixed five year average baseline calculated from 2002-2007 b) the fixed ten year average baseline.

2008-2012

The main issue is that the period over represents the number of natural climatic events known to impact seagrasses. The onset of La Nina around 2010 meant that the following years were characterised by several extreme wet seasons with peak rainfall and flood events (see section 3.4). On the east coast of Queensland, these conditions have been extremely unfavourable for seagrasses due to the deterioration in water quality and light available for photosynthesis (Rasheed et al., 2014). Fixing the baseline over these 'unfavourable' years can make the baseline artificially low. Figure 7 highlights this point.

At meadow 96, the total area of the meadow was stable over the first seven years of monitoring but fluctuated widely over the final five years. If the baseline was set using the last five years of data (Figure 7a), significant declines in 2009 would barely bring the grade down to a B (good). Using ten years of data (Figure 7b) however brings the 2009 grade down to a C (moderate).

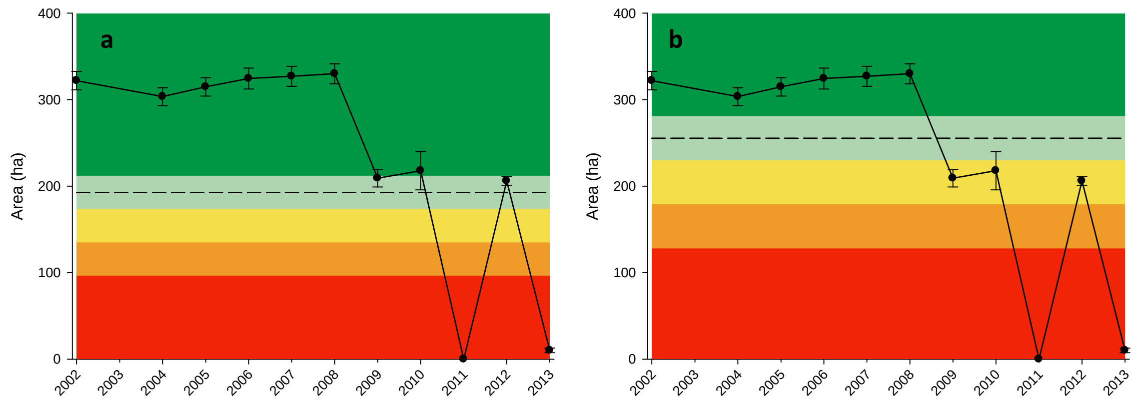


Figure 7 Total meadow area during annual (November) surveys at monitoring meadow 96 graded in relation to a) the fixed five year baseline calculated from 2008-2012 b) the fixed ten year average baseline.

Based on the results of these analyses, the ten year fixed mean was selected as the most appropriate baseline for which to compare annual indicator values. At meadows 21 and 52-57 baselines were calculated over a shorter (5 year) period due to the shorter monitoring history at those meadows. For the current reporting year, scores for average biomass and total area were equal regardless of the baseline methodology (see Appendix A) however future reporting should consider alternate methodologies. In the absence of a historical long term data set that spans ten years, a running average condition may be the best option for assessing initial conditions until sufficient data is collected to fix a meadow baseline condition.

3.2 Performance of thresholds across historical monitoring data

Tables 6 to 8 show the resulting grades for each of the indicators (biomass, area and species composition) when the selected thresholds (Table 5 above) were applied across the historical data using the ten year fixed average as a baseline value. There was a very high level of agreement between indicator and meadow grades and expert knowledge of the condition of seagrasses across time.

The prevailing climate conditions over the course of monitoring provide an important context for changes in seagrass indicator and meadow grades. Over the history of the monitoring program the years 2003, 2010 and 2013 have featured the most extreme rainfall and river flow events (see Figures 29 and 30 in section 3.4).

Biomass

Biomass grades ranged from C (moderate) to A (very good) in the initial year of monitoring but most grades were downgraded in 2004 following extreme rainfall and peak river flows in 2003 (Table 6). Biomass at most meadows had improved by 2005 however meadows in the Western Basin were slower to respond to more favourable conditions. By 2006, the majority of meadows had reached grades of B (good) or A (very good) which were largely sustained in most regions throughout the drier years from 2006 to 2009. The downgrading of biomass grades in recent years coincide with the onset of the La Nina period in 2010 with heavy rainfall and peak river flows continuing over several consecutive years.

Table 6 Grades for average seagrass biomass from annual (November) surveys at each of the monitoring meadows relative to baseline conditions.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Western Basin	4	B		B	C	B	A	B	A	E	C	A	A
	5	C		D	C	A	A	A	C	D	C	C	B
	6	C		E	C	A	A	B	A	E	D	B	B
	7	B		A	E	A	A	B	D	E	E	E	A
	8	A		E	E	B	A	C	B	C	C	B	B
	9	C		E	E	A	A	C	A	E	E	E	E
	52-57								A	E	E	A	A
The Narrows	21								A	B	C	C	D
Inner Harbour	58	B		D	C	D	A	A	A	E	D	C	D
Mid Harbour	43	B		B	A	C	C	A	B	B	C	C	C
	48	B		C	B	A	A	B	E	D	D	B	C
South Trees Inlet (lower)	60	A		E	E	B	A	A	C	D	E	C	D
Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E
	96	B		D	C	B	A	A	B	D	E	D	E
	104	B		D	B	B	A	A	C	E	E	D	D

*Hashed lines indicate meadows where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until a long term data are available.

*Meadows 52-57 are grouped for reporting purposes.

Area

Area grades were mostly B (good) or A (very good) for the first seven years of monitoring (2002 to 2009) reflecting the stability in total area at most meadows despite declines in average biomass (Table 7). The exceptions are the patchy intertidal meadows in the Inner Harbour and South Trees Inlet where the total area of meadows declined along with biomass in 2004 following extreme rainfall and peak river flows in 2003. The subtidal meadows 7 and 9 have come and gone over the course of monitoring, responding quickly to smaller shifts in environmental conditions and also showed lower grades over this period. Area grades were downgraded across most meadows following extreme flooding in the region in 2010. The exception is the large *Zostera muelleri* meadow at Pelican Banks (meadow 43) where the total area has remained stable over the course of monitoring.

Table 7 Grades for total area from annual (November) surveys at each of the monitoring meadows relative to baseline conditions.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Western Basin	4	A		A	A	A	A	A	A	E	E	B	E
	5	A		B	B	B	B	A	A	B	D	B	E
	6	A		B	B	B	B	B	B	D	C	C	C
	7	B		A	A	A	D	B	B	E	E	E	D
	8	B		B	B	B	A	A	A	B	D	C	D
	9	A		A	E	B	B	A	B	E	B	E	E
	52-57								A	E	E	A	A
The Narrows	21								A	B	B	B	D
Inner Harbour	58	A		D	B	B	C	B	B	E	E	A	B
Mid Harbour	43	B		B	B	B	B	B	B	B	B	B	B
	48	A		B	A	A	A	A	E	D	C	D	C
South Trees Inlet (lower)	60	A		E	A	A	A	A	B	D	D	C	D
Rodds Bay	94	A		B	A	B	A	A	B	A	E	C	E
	96	A		A	A	A	A	A	C	C	E	C	E
	104	A		A	A	B	A	A	A	B	E	B	E

*Hashed lines indicate meadows where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until a long term data are available.

*Meadows 52-57 are grouped for reporting purposes.

Species composition

Species composition grades were mostly B (good) or A (very good) for the first seven years of monitoring (2002 to 2009) (Table 8). The exceptions were the intertidal meadows near Wiggins Island in the Western Basin Zone (meadow 4 and 5) where the proportion of *Zostera muelleri* declined following extreme rainfall and peak river flows in 2003. Species composition grades were downgraded across intertidal meadows in the Western Basin, Inner Harbour and South Trees Zones following extreme flooding in the region in 2010. The loss of *Zostera muelleri* at these meadows is a reflection of the degraded light environment that has persisted in nearshore areas following flood events.

Table 8 Grades for seagrass species composition from annual (November) surveys at monitoring meadows relative to baseline conditions.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Western Basin	4	A		C	C	B	A	B	A	B	A	B	A
	5	A		C	C	B	A	A	A	B	C	C	D
	6	A		B	A	B	A	A	A	A	D	A	B
	7	A		A	A	A	A	A	A	A	A	A	A
	8	A		A	A	B	B	A	B	A	D	C	D
	9	A		A	A	A	A	A	A	E	B	E	E
	52-57								A	E	B	A	B
The Narrows	21								A	B	B	B	C
Inner Harbour	58	A		B	A	B	A	A	A	E	C	C	D
Mid Harbour	43	A		A	A	A	A	A	A	A	A	A	A
	48	B		A	A	A	A	A	A	A	A	A	B
South Trees Inlet (lower)	60	A		A	B	A	A	A	A	E	C	C	D
Rodds Bay	94	A		B	A	A	A	A	D	B	E	A	E
	96	A		A	A	A	A	A	A	A	E	A	A
	104	A		A	A	A	A	A	A	A	E	A	A

*Hashed lines indicate meadows where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until a long term data are available.
*Meadows 52-57 are grouped for reporting purposes.

Monitoring Meadows

Table 9 shows the combined grades for each of the monitoring meadows across the historical data. Like the individual indicator grades, the combined meadow grades highlight periods where the majority of meadows were in a moderate (C) to very good (A) condition (2002 and 2006 to 2009); and periods where the majority of meadows were in a moderate (C) to very poor (E) condition (2004/05 and 2009/10 to 2013). These grades correspond well with impacts detected following extreme climate events.

Table 9 Grades for individual monitoring meadows from annual (November) surveys (equal to the lowest of the three grades for seagrass indicators at each meadow).

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Western Basin	4	B		C	C	B	A	B	A	E	E	B	E
	5	C		D	C	B	B	A	C	D	D	C	E
	6	C		E	C	B	B	B	B	E	D	C	C
	7	B		A	E	A	D	B	D	E	E	E	D
	8	B		E	E	B	B	C	B	C	D	C	D
	9	C		E	E	B	B	C	B	E	E	E	E
	52-57								A	E	E	A	B
The Narrows	21								A	B	C	C	D
Inner Harbour	58	B		D	C	D	C	B	B	E	E	C	D
Mid Harbour	43	B		B	B	C	C	B	B	B	C	C	C
	48	B		C	B	A	A	B	E	D	D	D	C
South Trees Inlet (lower)	60	A		E	E	B	A	A	C	E	E	C	D
Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E
	96	B		D	C	B	A	A	C	D	E	D	E
	104	B		D	B	B	A	A	C	E	E	D	E

*Hashed lines indicate meadows where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until a long term data are available.
*Meadows 52-57 are grouped for reporting purposes.

Harbour Zones

Table 10 shows the combined grades for each of the Gladstone Harbour Zones across the historical data. The grade for each zone was derived from the average of grade for meadows within that zone. These grades also highlight periods where seagrasses were in a moderate (C) to very good (A) condition (2002 and 2006 to 2009); and periods where seagrasses were in a moderate (C) to very poor (E) condition (2004/05 and 2009/10 to 2013). These grades correspond well with impacts detected following extreme climate events.

Table 10 Grades for individual zones of the harbour from annual (November) surveys (equal to the average of the meadow grades in each zone).

Subzone	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Western Basin	C		D	D	B	B	B	B	E	E	C	D
The Narrows								A	B	C	C	D
Inner Harbour	B		D	C	D	C	B	B	E	E	C	D
Middle Harbour	B		C	B	B	B	B	D	C	D	D	C
South Trees	A		E	E	B	A	A	C	E	E	C	D
Rodds Bay	B		D	B	B	A	A	D	E	E	D	E

*Hashed lines indicate zonesn where <10yrs data were available to calculate baseline values. Results should be interpreted with caution until a long term data are available.

3.3 Report Card Grades for the 2014 reporting year

Below is a detailed justification for the grading of individual indicators, meadows and zones in the 2014 reporting year. Individual monitoring meadows have been allocated to the zone where the majority of the meadow area lies.

Note: The results presented here reflect the condition of seagrasses during the most recent annual survey conducted in November 2013. The GHHP Report Card is based on a July-June year, thus the results fall within the 2014 reporting year.

The Narrows Zone

The Narrows Zone was given an overall grade of a D (poor). There is one monitoring meadow in the Narrows Zone (Figure 8). Meadow 21 is an intertidal meadow comprised of aggregated patches of *Zostera muelleri* and *Halophila* spp. Both the average biomass and total area of the meadow has declined significantly over the course of monitoring and the meadow is classified as a class 3 meadow (variable biomass, variable area) for grading purposes.

Note: This meadow has only been surveyed as part of the annual monitoring program since 2009 (5 years total). Baseline levels and resulting grades should be interpreted with caution until the full ten years of data are available.

Biomass

Average biomass at the monitoring meadow declined significantly from 2009 to 2011 and has followed a decreasing trend over the course of monitoring (Figure 9). Further declines in average biomass in 2013 have resulted in a grade of D (poor).

Area

The total area of the monitoring meadow declined in 2010 and remained at a similar level for the following three years (Figure 9). Further declines in area in 2013 have resulted in a grade of D (poor).

Species Composition

There has been a shift in species composition at the monitoring meadow with a gradual decrease in the proportion of the climax species *Zostera muelleri* and an increase in the proportion of the colonising species *Halophila ovalis* and *Halophila decipiens* (Figure 9). Further declines in the proportion of *Zostera muelleri* in 2013 have resulted in a grade of C (moderate).

The Narrows Zone

D

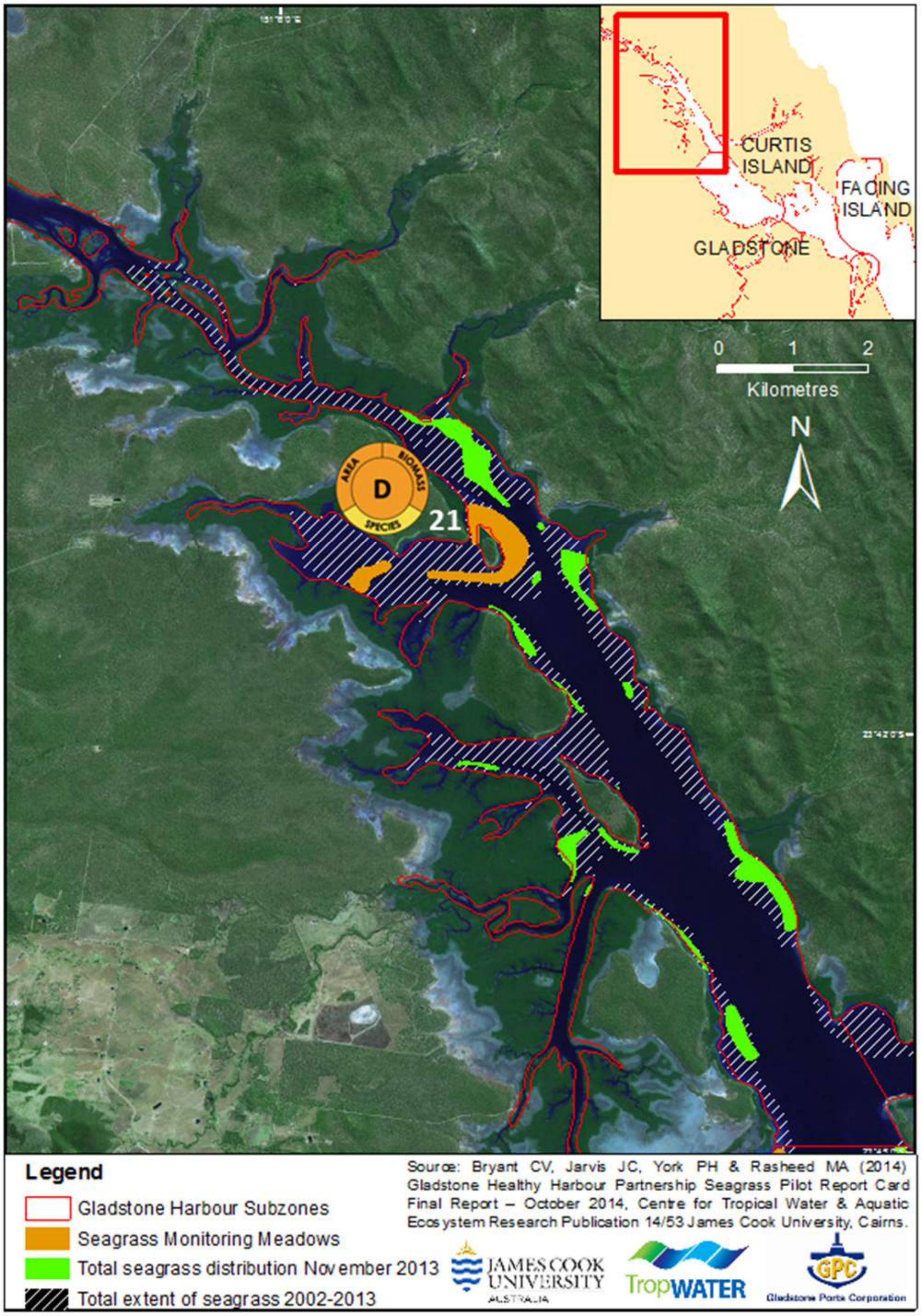
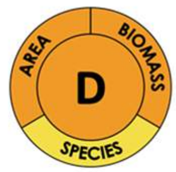
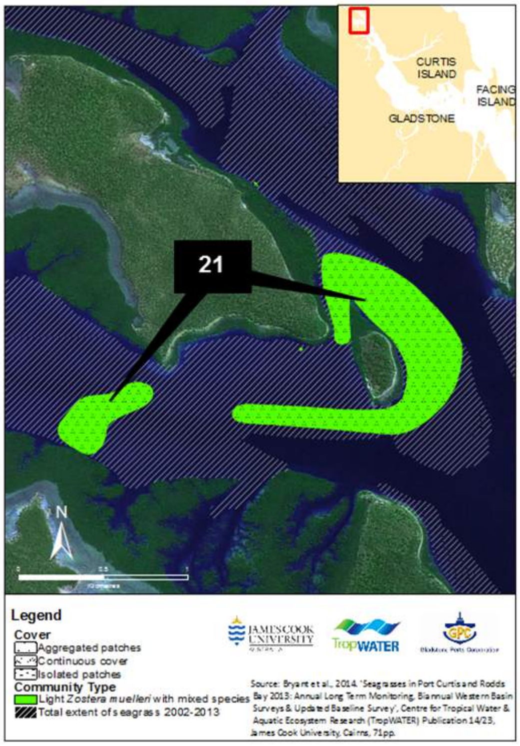


Figure 8 Seagrasses in the Narrows Zone in November 2013.

Meadow 21





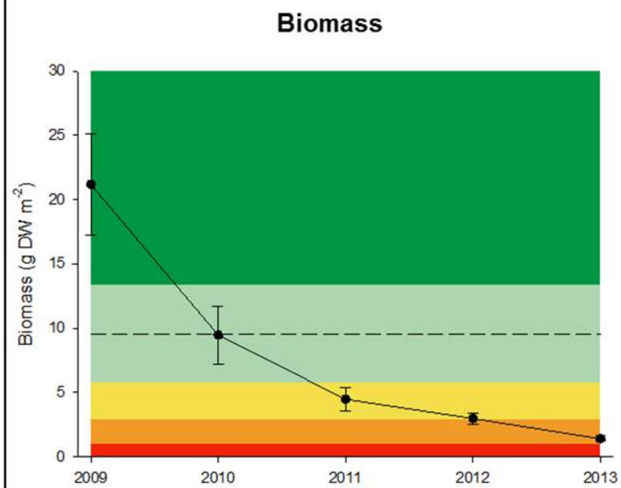
	A	B	C	D	E
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

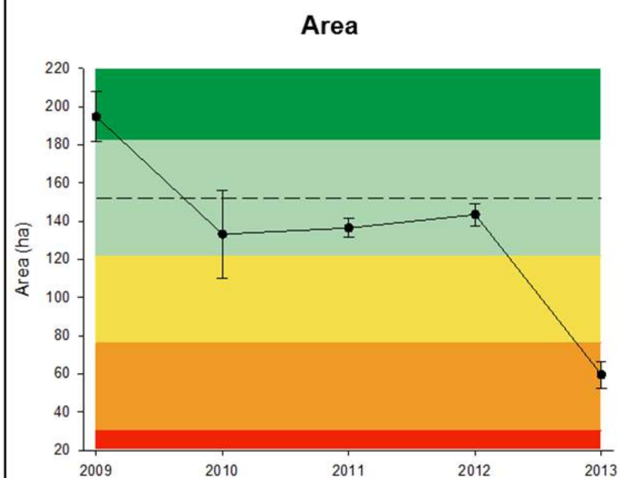
—●— Annual mean

– – – Baseline

Species composition

- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila decipiens*





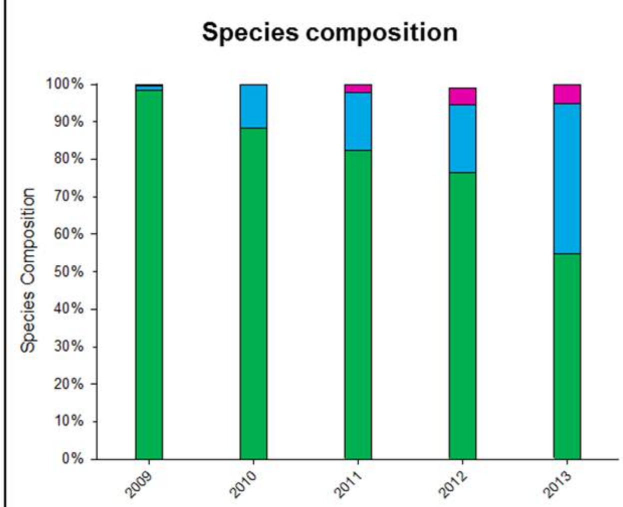


Figure 9 Changes in average biomass, meadow area and species composition for seagrass Meadow 21 in The Narrows Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

<u>Western Basin Zone</u>

The Western Basin Zone was given an overall grade of a D (poor). There are seven monitoring meadows in the Western Basin Zone (Figure 10).

Meadows 4 & 5

Meadows 4 and 5 near Wiggins Island (Figure 10) are intertidal meadows comprised of aggregated patches of *Zostera muelleri* and *Halophila* spp. The average biomass at these meadows has been highly variable over the course of monitoring but total meadow area remained relatively stable until declines in 2010. Meadows 4 and 5 are classified as class 2 meadows (variable biomass, stable area) for grading purposes.

Biomass

Average biomass at meadow 4 (Figure 11) has remained low (<2gDW m^{-2}) over the duration of monitoring but reached higher levels at meadow 5 (Figure 12) from 2006-2008. Following significant declines in 2009 and 2010 there have been gradual increases in average biomass at both meadows. In 2013, these increases resulted in a grade of A (very good) at meadow 4 and B (good) at meadow 5.

Area

The total area of meadows 4 and 5 remained stable from 2002 until declines beginning in 2010 (Figure 11 and 12). In 2012 the recovery of several patches of seagrass across both meadows brought total meadow area back towards the baseline but further declines in 2013 have resulted in grades of E (very poor).

Species Composition

Species composition at meadow 4 has fluctuated over the course of monitoring between a *Zostera muelleri* and *Halophila ovalis* dominated community (Figure 11). Despite declines in the total area of meadow 4 in 2013, *Zostera muelleri* comprised a substantial proportion of the remaining biomass resulting in a grade of A (very good).

Species composition at meadow 5 has shown a clear trend over the course of monitoring with a shift from the climax species *Zostera muelleri* to the colonising *Halophila ovalis* coinciding with major declines in seagrass (Figure 12). The proportion of *Zostera muelleri* has been declining steadily since 2008, resulting in 2013 in a grade of D (very poor).

Meadows 6 & 8

Meadows 6 and 8 to the south and north of Fishermans Landing (Figure 10) are intertidal meadows comprised of isolated patches of *Halophila* spp and *Zostera muelleri*. Both the average biomass and the total area of these meadows have been highly variable over the course of monitoring. Meadows 6 and 8 are classified as class 3 meadows (variable biomass, variable are) for grading purposes.

Note: Indicator data at meadow 8 have been standardised to account for the area of the Fishermans Landing reclamation. Only the area outside of the reclamation has been used in calculations of average biomass and total area.

Biomass

Average biomass has shown a very similar trend at both meadows with very low levels recorded in 2004, peaks in 2007 and declines from 2008 (Figures 13 and 14). Since 2010 we have seen a gradual increase in average biomass with the recovery of small patches of seagrass across the meadows. In 2013, these increases have resulted in grades of B (very good).

Area

The total area of meadows 6 & 8 remained relatively stable until declines in 2010 (Figures 13 and 14). The recovery of patches of seagrass at meadow 6 since 2010 has shifted the total area of the meadow back towards the baseline resulting in a grade of C (moderate). There were similar signs of recovery at meadow 8 in 2012, however further declines in total area in 2013 have resulted in a grade of D (very poor).

Species Composition

Species composition at meadow 6 has shown a clear trend over the course of monitoring with a shift from the climax species *Zostera muelleri* to the colonising *Halophila ovalis* coinciding with major declines in seagrass (Figure 13). In 2013, average biomass and total area remained stable but there was a decline in the proportion of *Zostera muelleri*. The shift in species composition has resulted in a grade of B (good).

At meadow 8, *Zostera muelleri* has consistently dominated the community composition until recent years when *Halophila ovalis* and *Halophila decipiens* have become more prevalent (Figure 14). The shift in species composition has resulted in a grade of D (poor).

Meadows 7 & 9

Meadows 7 and 9 to the south and north of Fishermans Landing (Figure 10) are subtidal meadows comprised of isolated patches of *Halophila decipiens*. Both the average biomass and the total area of these meadows have been highly variable over the course of monitoring. Meadows 7 and 9 are classified as class 4 meadows (variable biomass, variable area - subtidal) for grading purposes.

Note: Indicator data at meadow 9 have been standardised to account for the area of the Fishermans Landing reclamation. Only the area outside of the reclamation has been used in calculations of average biomass and total area.

Biomass

Subtidal meadows 7 and 9 have come and gone over the course of monitoring, responding quickly to environmental conditions. Average biomass peaked at both meadows in 2006/2007 with significant declines in 2008/2009 (Figure 15 and 16). In 2013, several dense patches of *Halophila decipiens* had returned at meadow 7 bringing average biomass well above the baseline for a grade of A (very good). Meadow 9 was absent for the second consecutive year in 2013, resulting in a grade of E (very poor).

Area

The total area of meadow 7 declined in 2007, recovered to baseline conditions in 2008 and disappeared entirely in 2010 (Figure 15). Despite the recovery of dense patches of *Halophila decipiens* in 2013, the total meadow area remains more than 90% below the baseline resulting in a grade of E (very poor).

The total area of meadow 9 declined in 2005, made a full recovery in 2008 and disappeared entirely in 2010 (Figure 16). Since this time, construction of the Fishermans Landing reclamation has caused a build-up of sediment at the southern end of the meadow reducing the area of the subtidal portion of the bank. Meadow 9 was absent for the second consecutive year in 2013, resulting in a grade of E (very poor).

Species Composition

The species composition of both subtidal meadows has been consistently dominated by *Halophila decipiens* (Figure 15 and 16). In November 2013 the presence of *Halophila decipiens* at meadow 7 resulted in a grade of A (very good), while the absence of meadow 9 resulted in a grade of E (very poor).

Meadows 52-57

Meadows 52-57 around the Passage Islands (Figure 10) are a group of predominantly intertidal meadows comprised of isolated and aggregated patches of *Zostera muelleri* and *Halophila ovalis.* In 2013 there was also a long strip of continuous cover of *Halophila decipiens* along the low tide line at the northern island (Figure 17). Both the average biomass and the total area of these meadows have been highly variable over the course of monitoring. This group of meadows are classified as class 3 meadows (variable biomass, variable area - intertidal) for grading purposes.

Note: This meadow has only been surveyed as part of the annual monitoring program since 2009 (5 years total). Baseline levels and resulting grades should be interpreted with caution until the full ten years of data are available.

Biomass

Average biomass has remained low (<2gDW m^{-2}) over the short history of monitoring. Declines in 2010 mirror those at other intertidal meadows in the Western Basin (Figure 17). The recovery of several patches of seagrass since 2011 has resulted in a grade of A (very good) in 2013.

Area

The total area of this group of meadows declined in 2010 along with other intertidal meadows in the Western Basin but recovered to previous levels in 2012 (Figure 17). The total area of meadow in 2013 remained well above the baseline resulting in a grade of A (very good).

Species Composition

Declines in seagrass in 2010 resulted in a shift in species composition from *Zostera muelleri* to the colonising *Halophila ovalis* (Figure 17). Despite the return of patches of *Zostera muelleri* at the site in recent years, in 2013 *Halophila* spp remained dominant in the species composition of seagrass biomass resulting in a grade of B (good).

Western Basin Zone

D

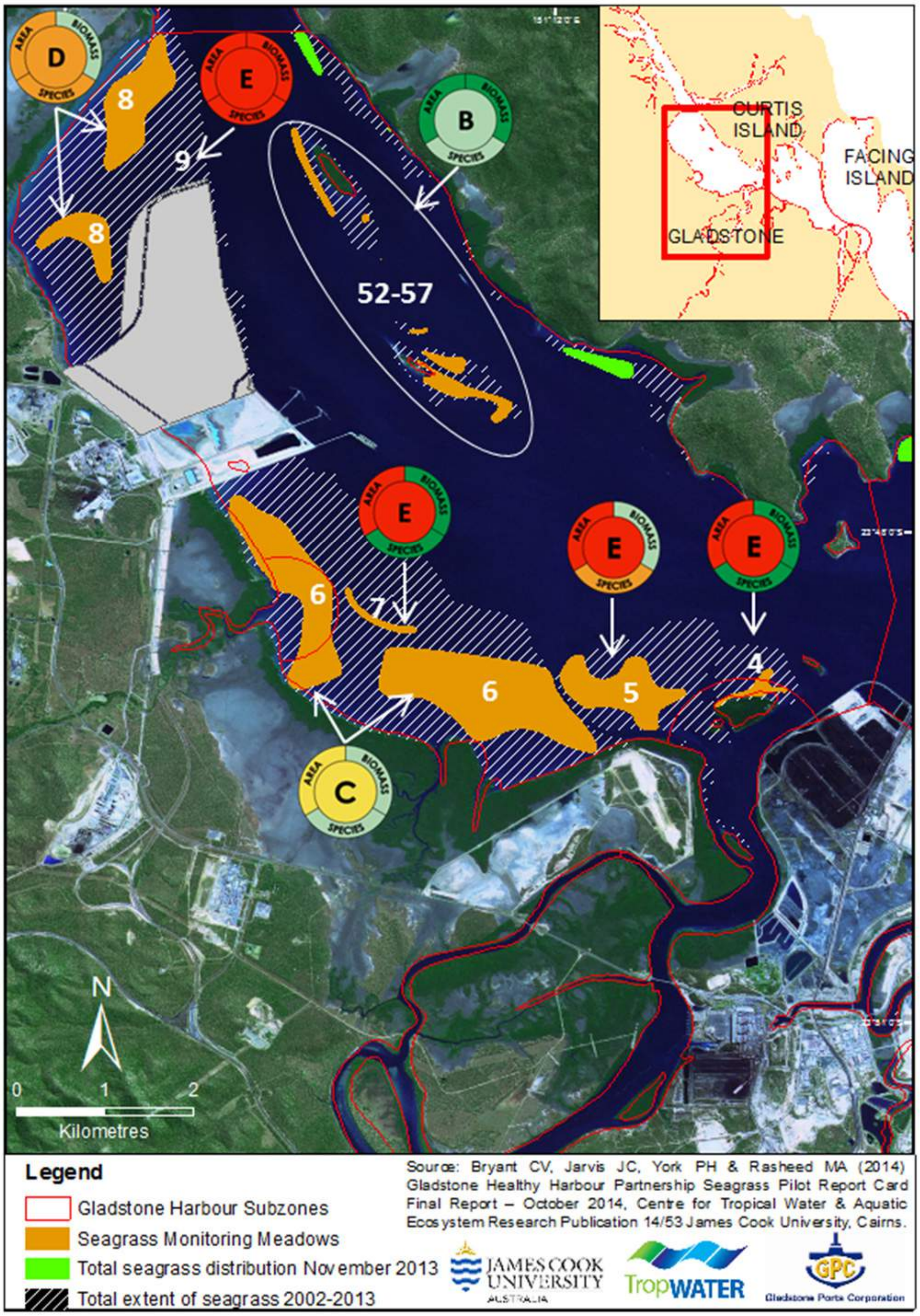
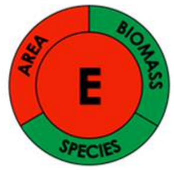
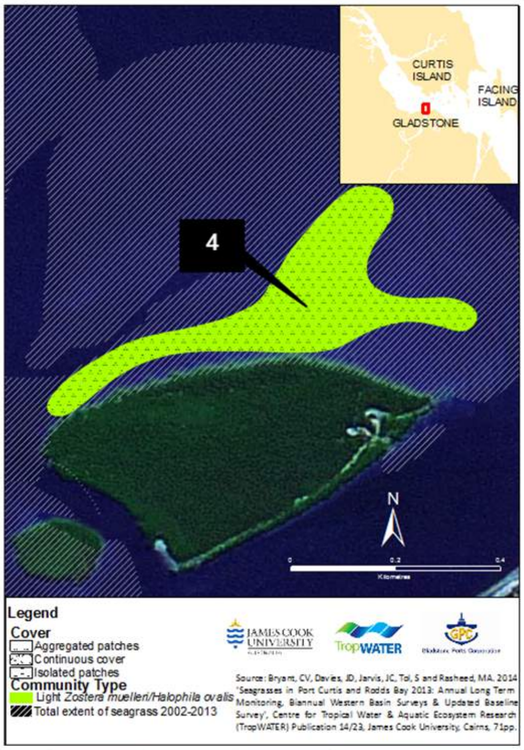


Figure 10 Seagrasses in the Western Basin Zone in November 2013.

Meadow 4





	A	B	C	D	E
Biomass	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

Zostera muelleri

Halophila ovalis

Halophila decipiens

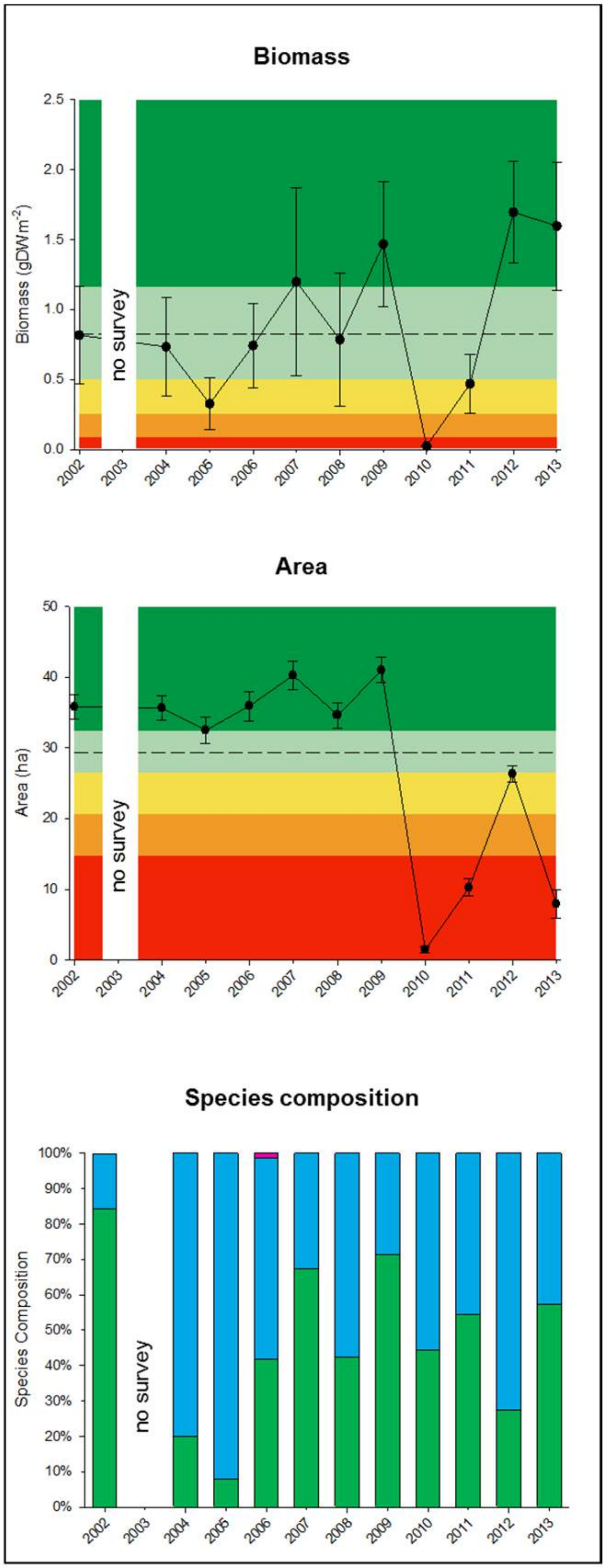
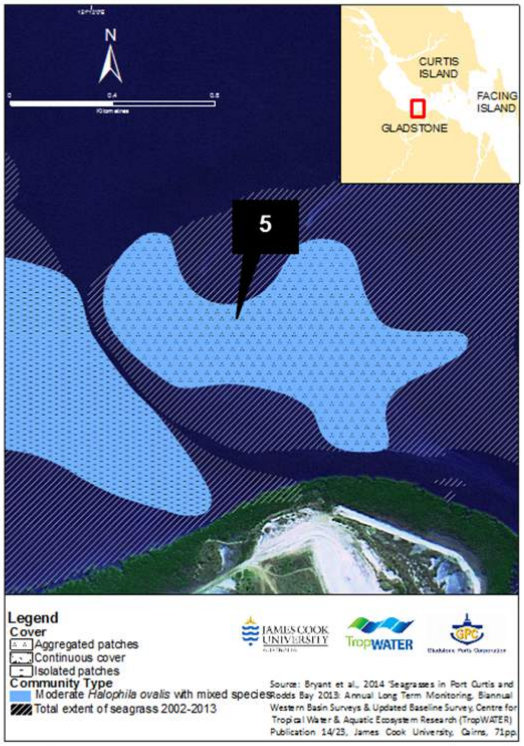
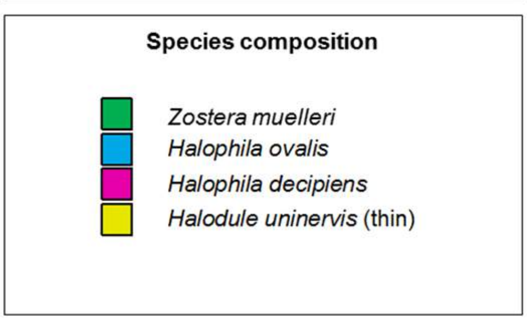


Figure 11 Changes in average biomass, meadow area and species composition for seagrass Meadow 4 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).



	A	B	C	D	E
Biomass	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp



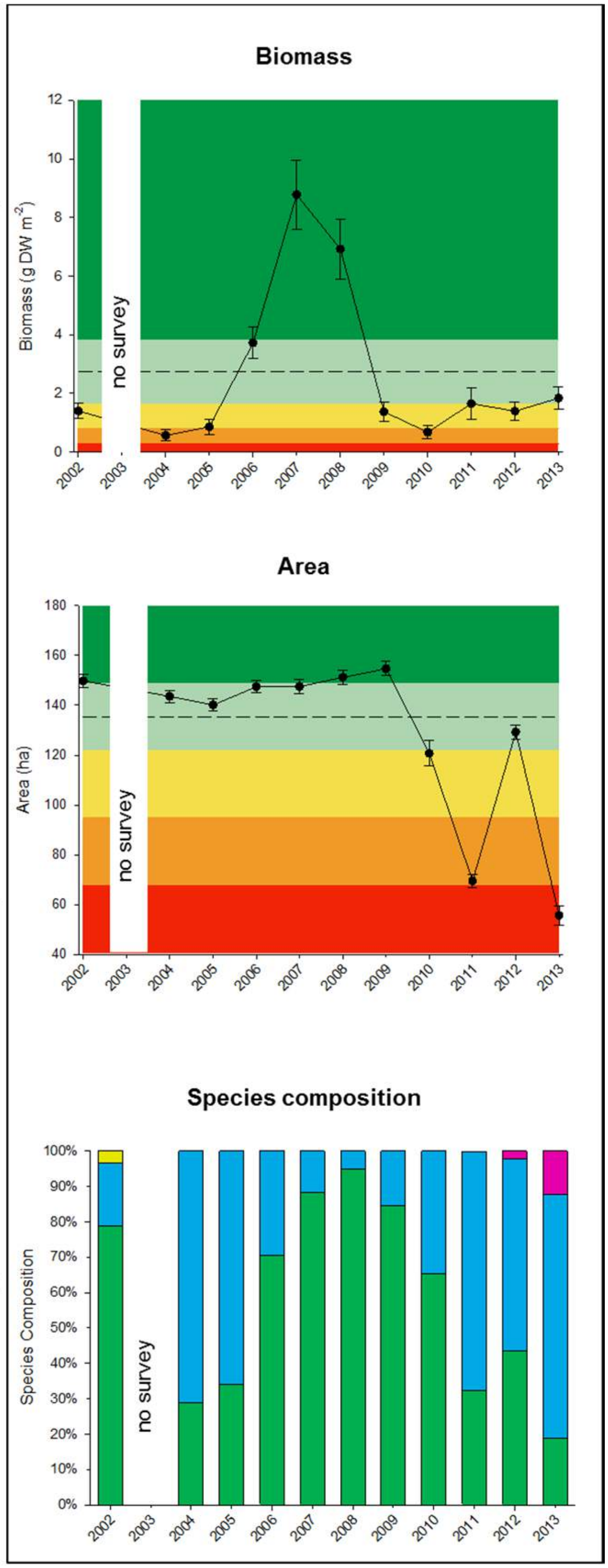
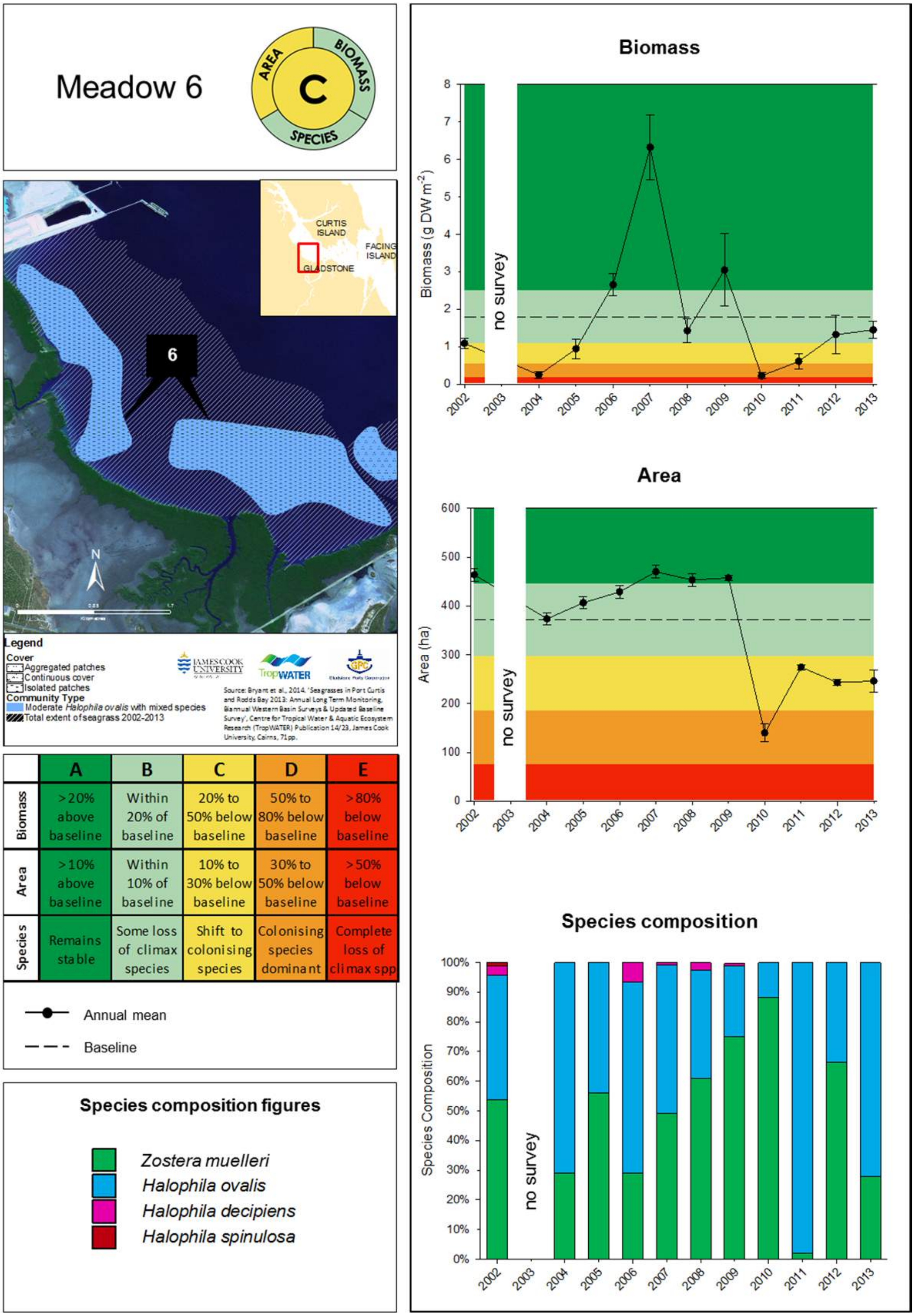
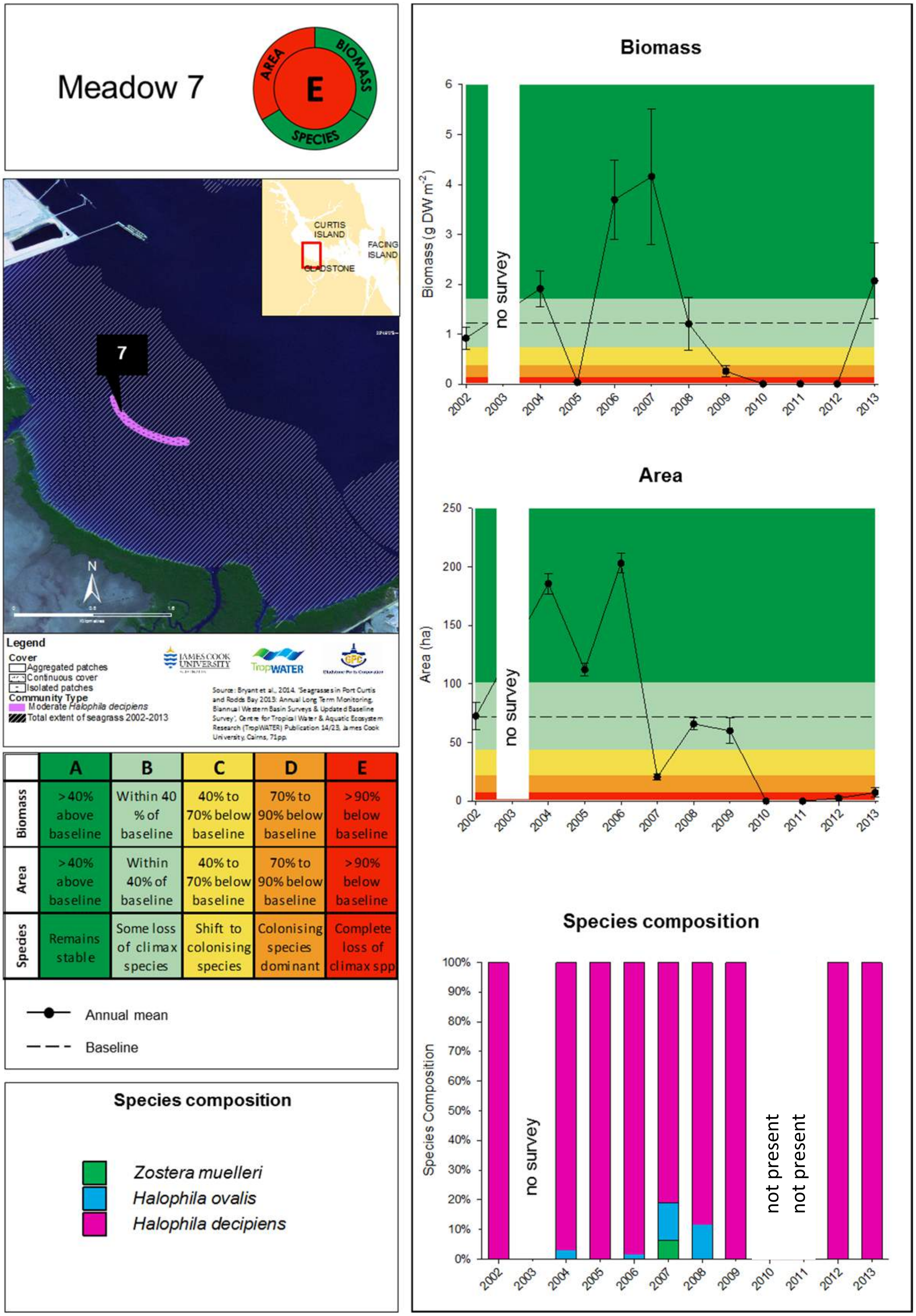


Figure 12 Changes in average biomass, meadow area and species composition for seagrass Meadow 5 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).



	A	B	C	D	E
Biomass	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

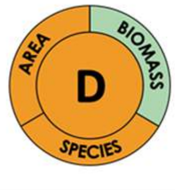
Figure 13 Changes in average biomass, meadow area and species composition for seagrass Meadow 6 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

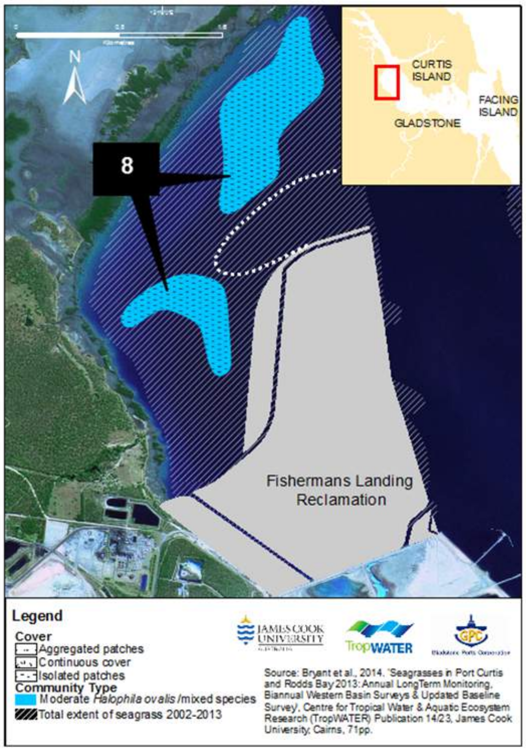


	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Figure 14 Changes in average biomass, meadow area and species composition for seagrass Meadow 7 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 8





	A	B	C	D	E
Biomass	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila decipiens*
- *Halophila spinulosa*

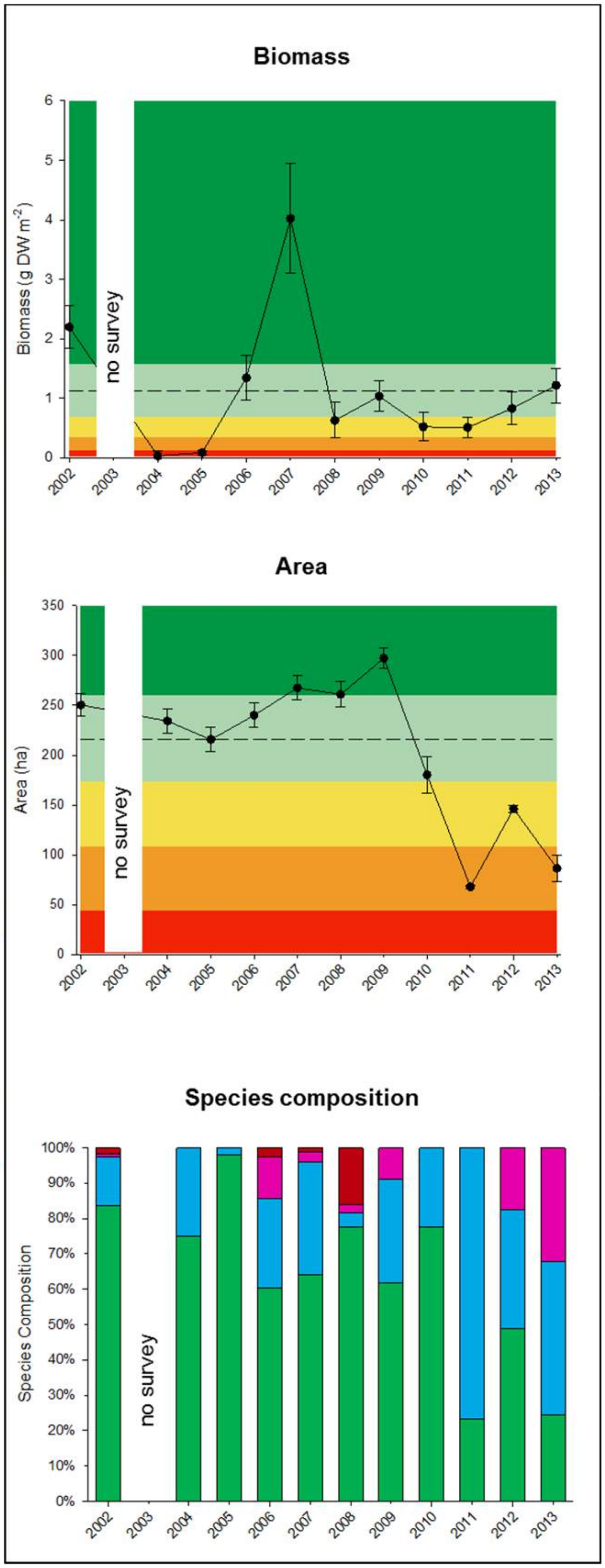
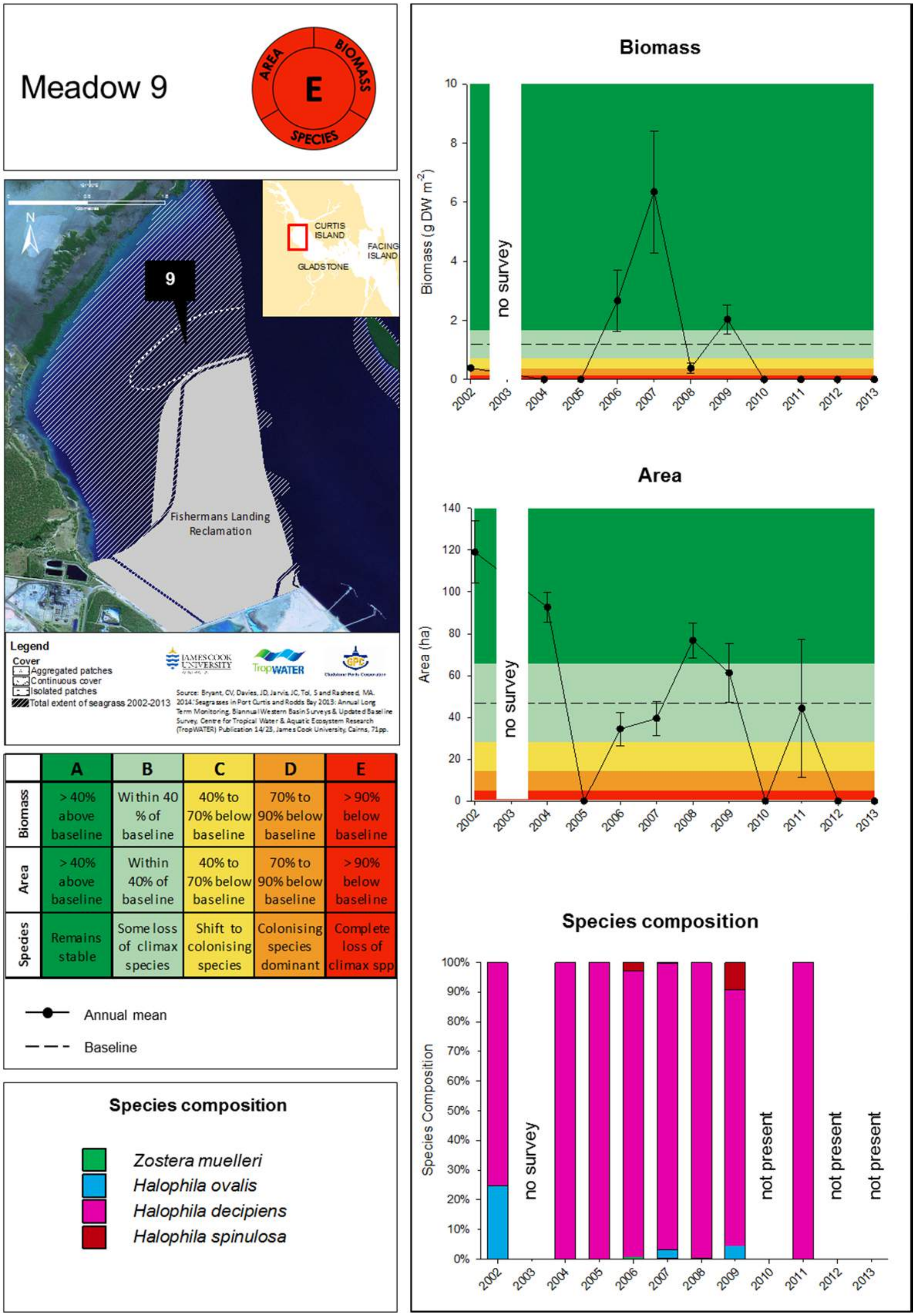
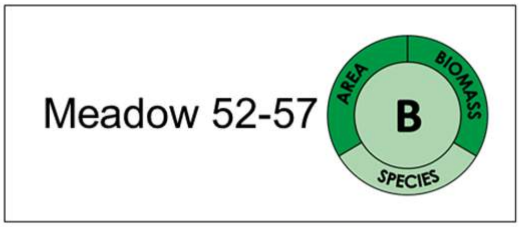


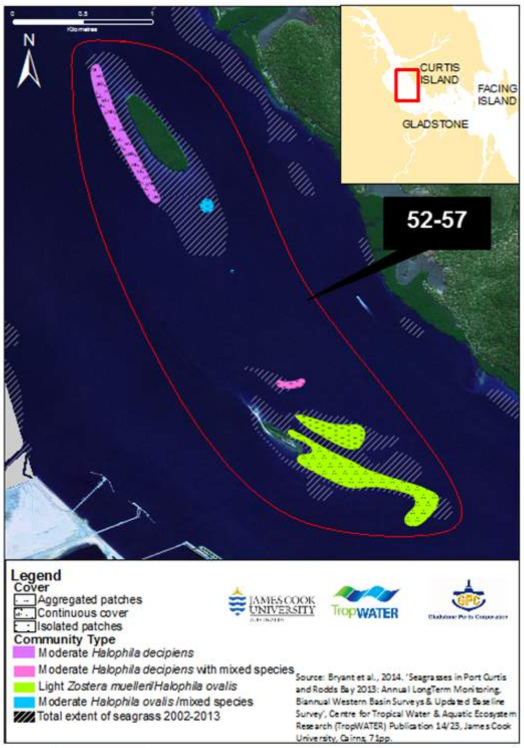
Figure 15 Changes in average biomass, meadow area and species composition for seagrass Meadow 8 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).



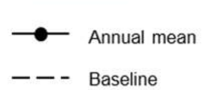
	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

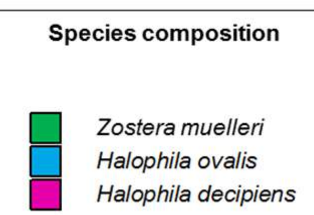
Figure 16 Changes in average biomass, meadow area and species composition for seagrass Meadow 9 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).





	A	B	C	D	E
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp





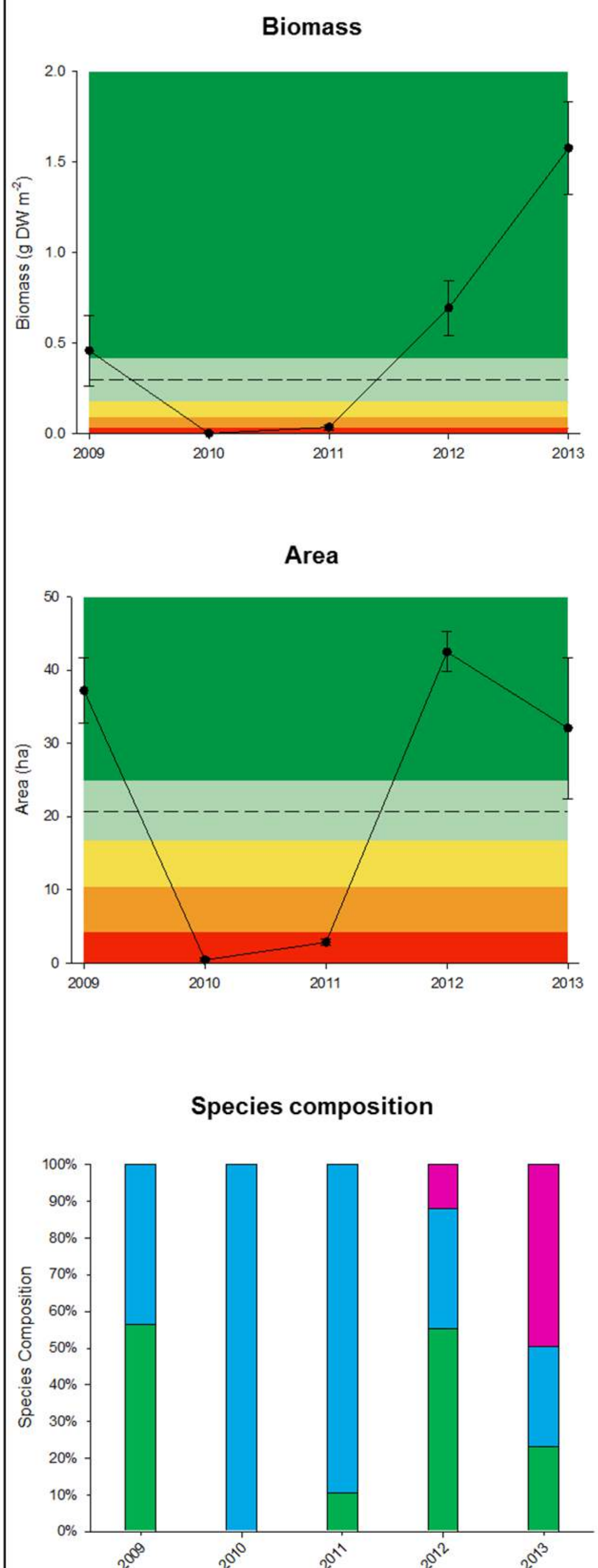


Figure 17 Changes in average biomass, meadow area and species composition for seagrass Meadow 52-57 in the Western Basin Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate). Meadows 52-57 are grouped for reporting purposes.

Inner Harbour Zone

The Inner Harbour Zone was given an overall grade of D (poor). There is one monitoring meadow in the Inner Harbour Zone (Figure 18). Meadow 58 is an intertidal meadow comprised of isolated patches of *Zostera muelleri* and *Halophila* spp. Both the average biomass and total area of the meadow have been highly variable over the course of monitoring and the meadow is classified as a class 3 meadow (variable biomass, variable area - intertidal) for grading purposes.

Biomass

Average biomass at the monitoring meadow declined in 2004 and remained low for the following two years (Figure 19). In 2007 there was a significant increase in average biomass which was sustained until declines in 2010 when the meadow was absent. Despite the return of some patches of seagrass in recent years, average biomass remains more than 70% below the baseline resulting in a grade of D (poor).

Area

The total area of the monitoring meadow declined in 2004 then remained relatively stable until the decline in seagrass in 2010 (Figure 19). The return of sparse patches of seagrass since 2010 has brought the total area of the meadow back to baseline levels resulting in a grade of B (good).

Species Composition

Recovery at the monitoring meadow in recent years has consisted predominantly of patches of the colonising species *Halophila ovalis* and only a few sparse patches of *Zostera muelleri* remain (Figure 19). The shift in species composition in 2013 has resulted in a grade of D (poor).

Inner Harbour Zone

D

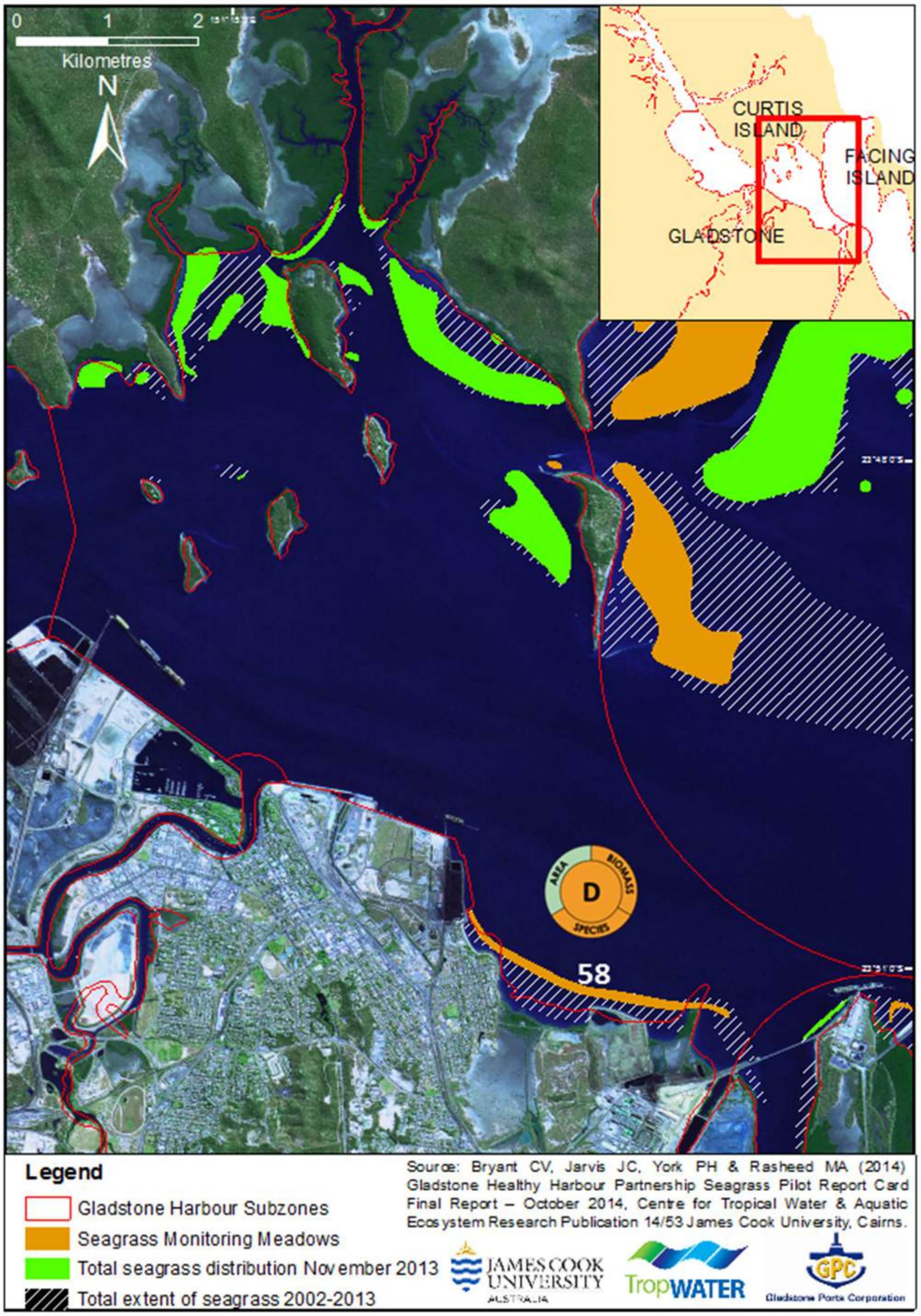
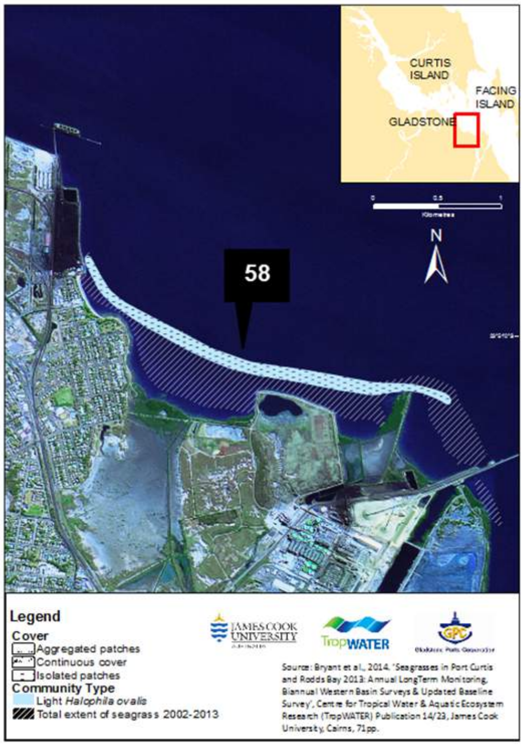


Figure 18 Seagrasses in the Inner Harbour Zone in November 2013.



	A	B	C	D	E
Biomass	>40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

Zostera muelleri

Halophila ovalis

Halophila decipiens

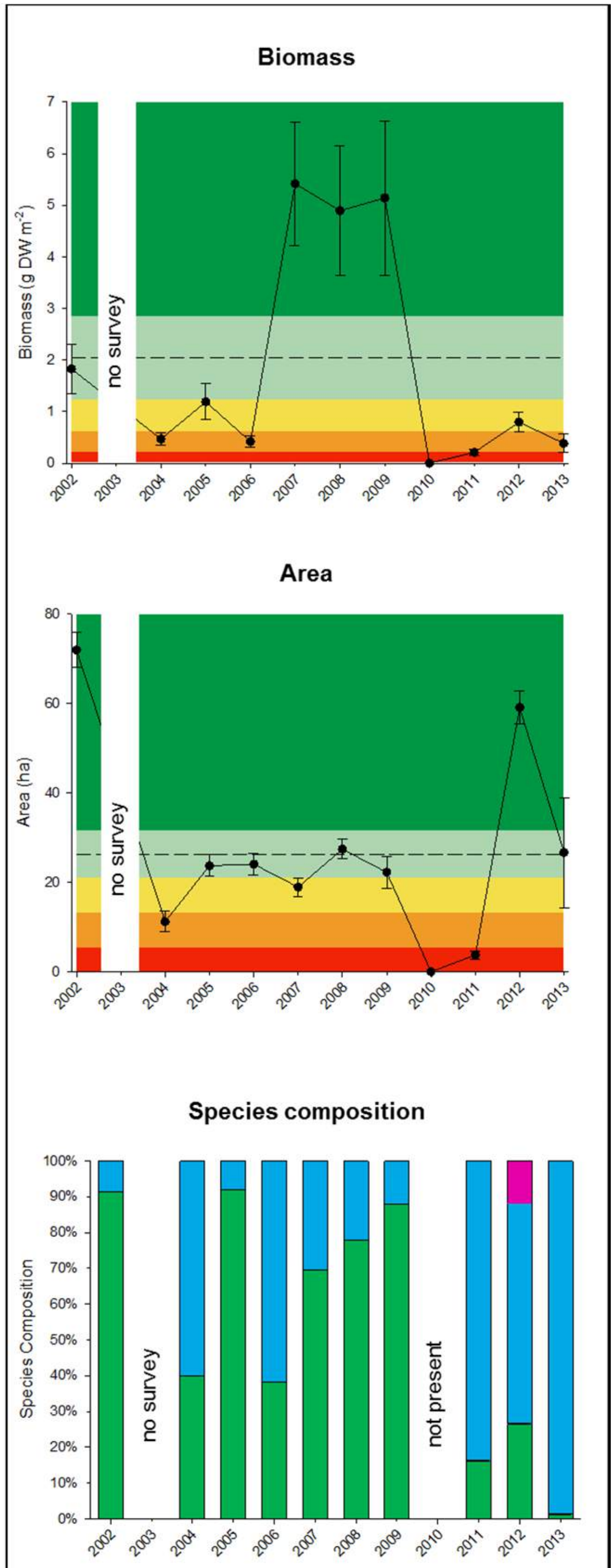


Figure 19 Changes in average biomass, meadow area and species composition for seagrass Meadow 58 in the Inner Harbour Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Mid Harbour Zone

The Mid Harbour Zone was given an overall grade of C (moderate). There are two monitoring meadows in the Mid Harbour Zone (Meadow 43 and 48; Figure 20).

Meadow 43

Meadow 43 is a large intertidal meadow comprised predominantly of a continuous cover of *Zostera muelleri* (Figure 21). The meadow, known locally as 'Pelican Banks,' is recognised as supporting the most abundant and productive seagrass in the Gladstone area (McCormack et al., 2012). Both the average biomass and total area of the meadow have remained relatively stable over the course of monitoring and the meadow is classified as a class 1 meadow (stable biomass, stable area) for grading purposes.

Biomass

Average biomass decreased significantly from 2008 to 2011 and has remained at a similar level (Figure 21). In 2013, biomass displayed an increasing trend but remains more than 20% below the long term average due to the increasing patchiness of the meadow at the southern end. The sustained decline in average biomass has resulted in a grade of C (moderate).

Area

The total area of the meadow has remained stable over the course of monitoring resulting in a grade of B (good) (Figure 21).

Species Composition

Species composition has remained consistent over the course of monitoring resulting in a grade of A (very good) (Figure 21).

Meadow 48

Meadow 48 is a large meadow to the west of Quoin Island that extends across intertidal and subtidal areas of the bank (Figure 22). The meadow is comprised of a light but continuous cover of seagrass and is the most species rich meadow in the Gladstone area. Both the average biomass and total area of the meadow have been highly variable over the course of monitoring and the meadow is classified as a class 3 meadow (variable biomass, variable area - intertidal) for grading purposes.

Biomass

Average biomass peaked in 2006 well above the baseline and declined steadily over the next three years until 2009 when very little seagrass remained (Figure 22). Gradual recovery from 2010 to 2012 has brought the average biomass of the meadow back in line with earlier years in the program. In 2013 average biomass was >40% below the baseline resulting in a grade of C (moderate).

Area

The total area of the meadow declined in 2009 when very little seagrass remained (Figure 22). Since this time there has been a gradual recovery of seagrasses in the intertidal portion of the meadow however the total area remains >40% below the baseline resulting in a grade of C (moderate).

Species Composition

Species composition has remained relatively consistent over the course of monitoring with the exception of the period from 2009 to 2011 when declines in biomass and area were accompanied by a loss of species diversity at the meadow (Figure 22). In 2013, all five species were present at the meadow however there was some loss of the climax species *Halodule uninervis* resulting in a grade of B (good).

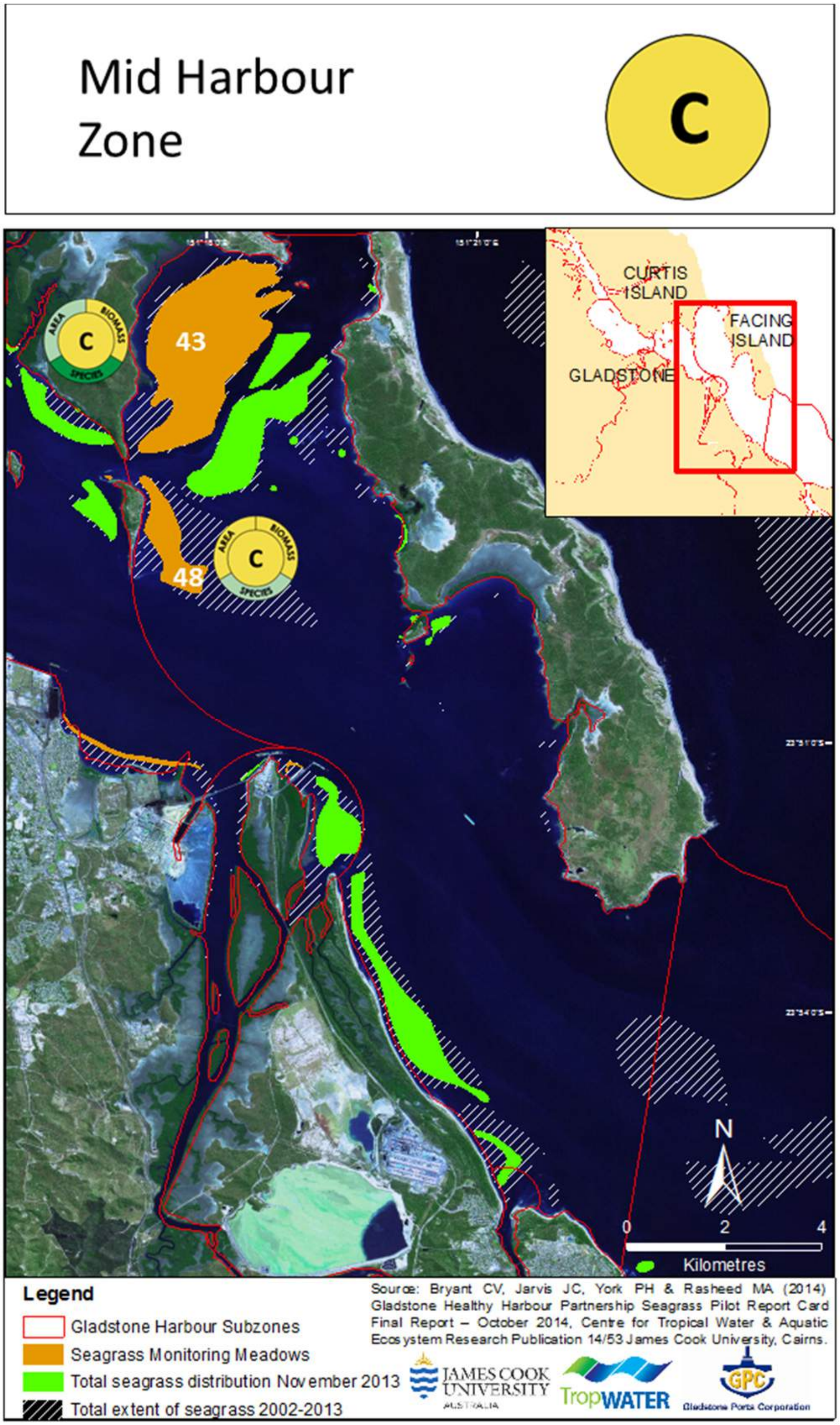
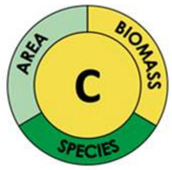
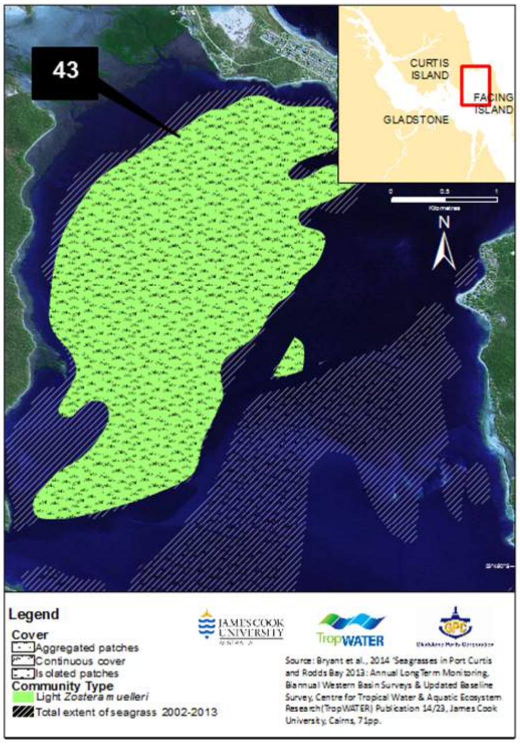


Figure 20 Seagrasses in the Mid Harbour Zone in November 2013.

Meadow 43





	A	B	C	D	E
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila spinulosa*
- *Halodule uninervis* (wide)

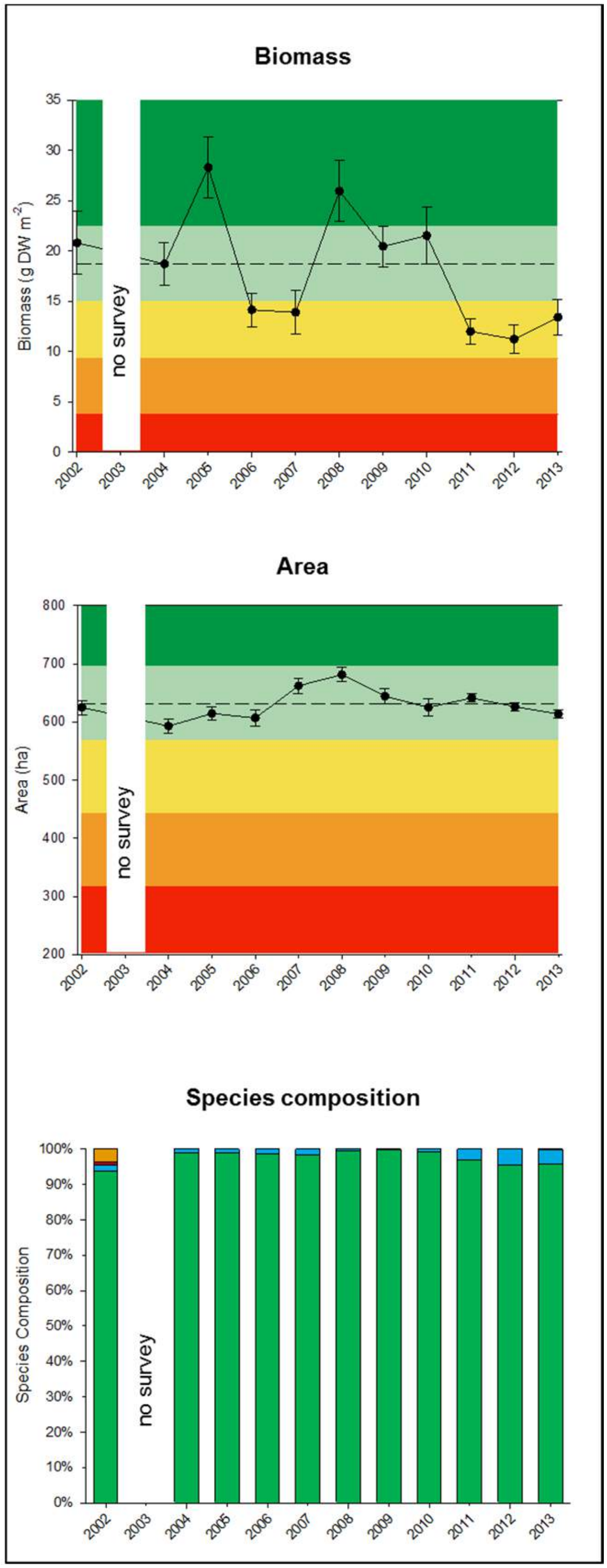
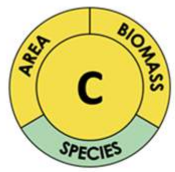
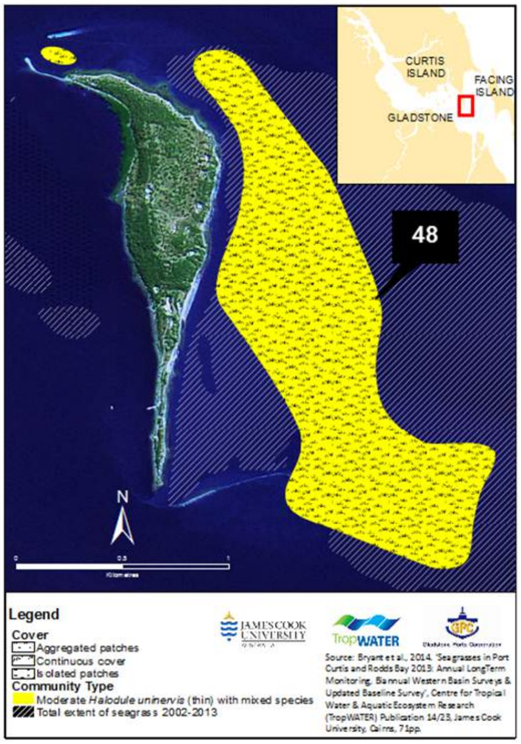


Figure 21 Changes in average biomass, meadow area and species composition for seagrass Meadow 43 in the Mid Harbour Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 48





	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila decipiens*
- *Halophila spinulosa*
- *Halodule uninervis* (wide)
- *Halodule uninervis* (thin)

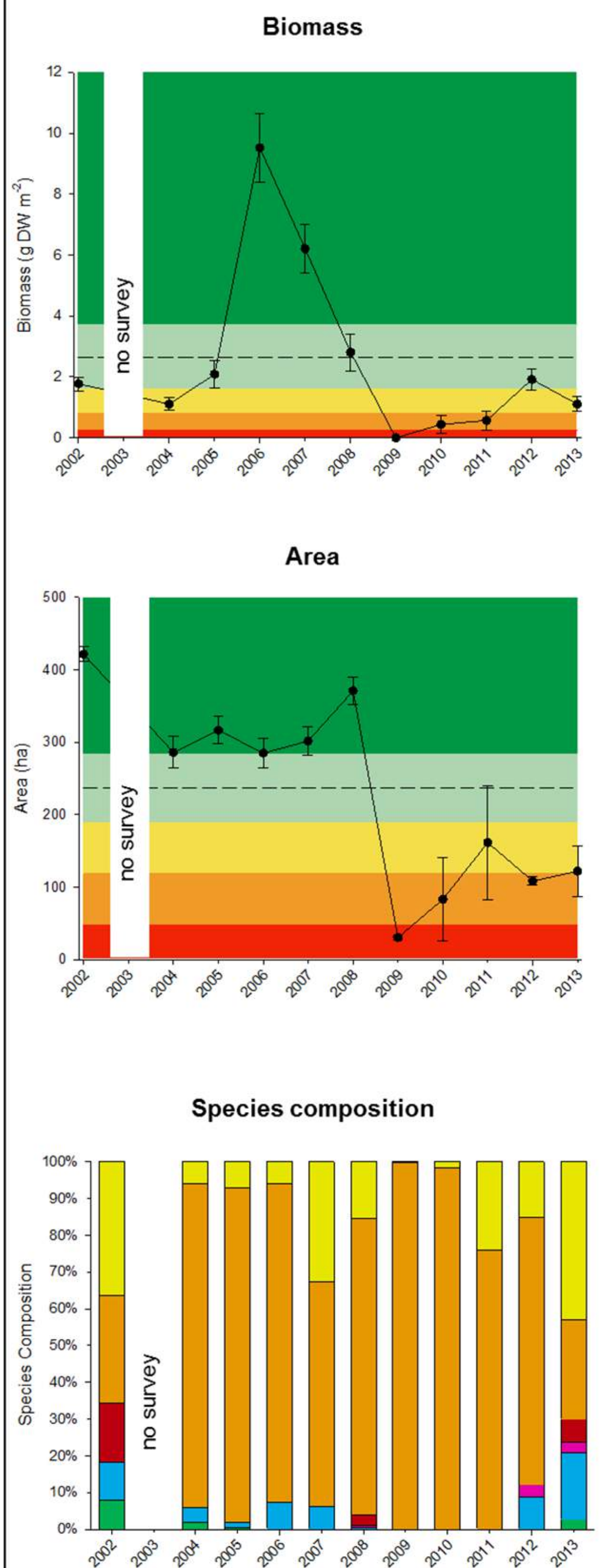


Figure 22 Changes in average biomass, meadow area and species composition for seagrass Meadow 48 in the Mid Harbour Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

South Trees Inlet (lower) Zone

The South Trees Inlet (lower) Zone was given an overall grade of D (poor). There is one monitoring meadow in the South Trees Inlet (lower) Zone (Figure 23). Meadow 60 is an intertidal meadow located between the two wharves at South Trees Inlet. In 2002, the meadow was comprised of a fairly continuous cover of *Zostera muelleri* however significant declines over the course of monitoring have left only isolated patches of seagrass at the site. Both the average biomass and total area of the meadow have been highly variable and the meadow is classified as a class 3 meadow (variable biomass, variable area - intertidal) for grading purposes.

Biomass

Average biomass declined significantly in 2004 but recovered completely by 2007. In 2009, average biomass declined once again to very low levels and continued to trend downwards (Figure 24). In 2012 average biomass had begun to recover slightly however further declines in 2013 have resulted in a grade of D (poor).

Area

The total area of the monitoring meadow has followed a similar trend as average biomass with declines in 2004 and again from 2009 (Figure 24). In 2013, the total area of the meadow remained >50% below the baseline resulting in a grade of D (poor).

Species Composition

While there has been some recovery of seagrass since the significant declines in 2009/2010, there has been a clear shift in species composition from the once dominant *Zostera muelleri* to *Halodule uninervis* (Figure 24). Some recovery of *Zostera muelleri* was detected in 2011 and 2012, however in 2013 only a few sparse patches remained. The shift in species composition in 2013 has resulted in a grade of D (poor).

South Trees Inlet (lower) Zone

D

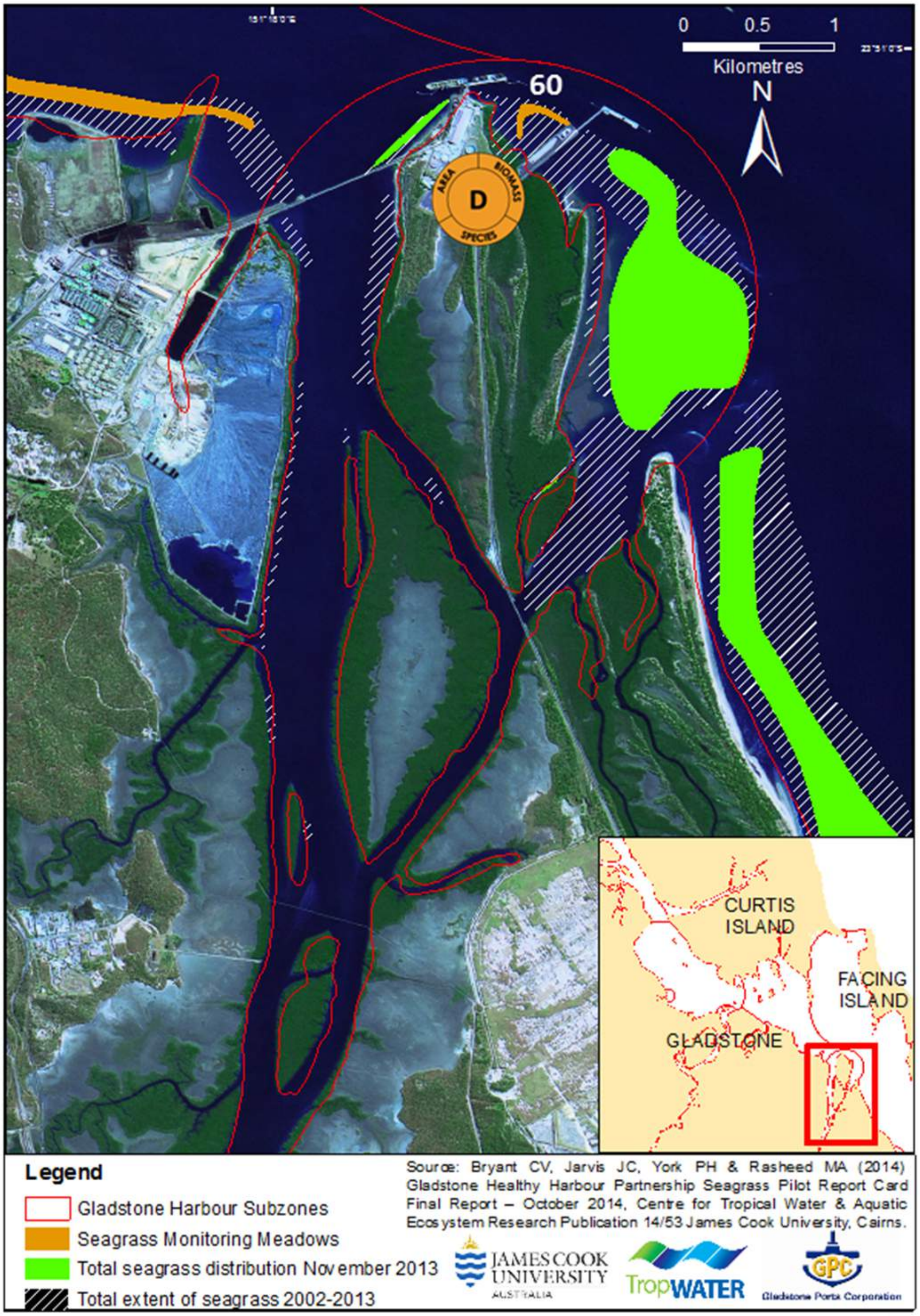
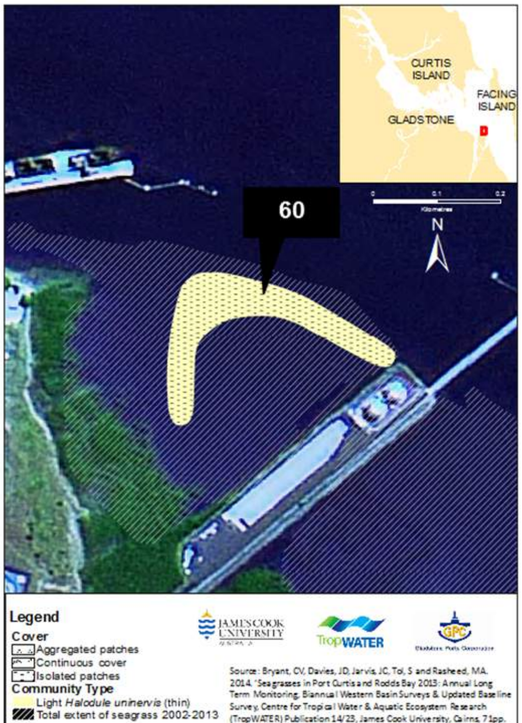
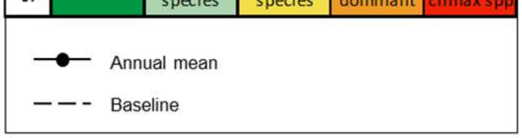
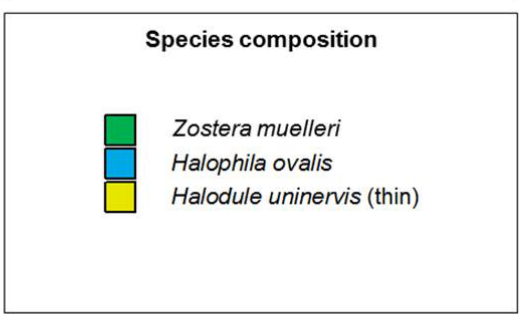


Figure 23 Seagrasses in the South Trees Inlet (lower) Zone in November 2013.



	A	B	C	D	E
Biomass	>40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	>80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp





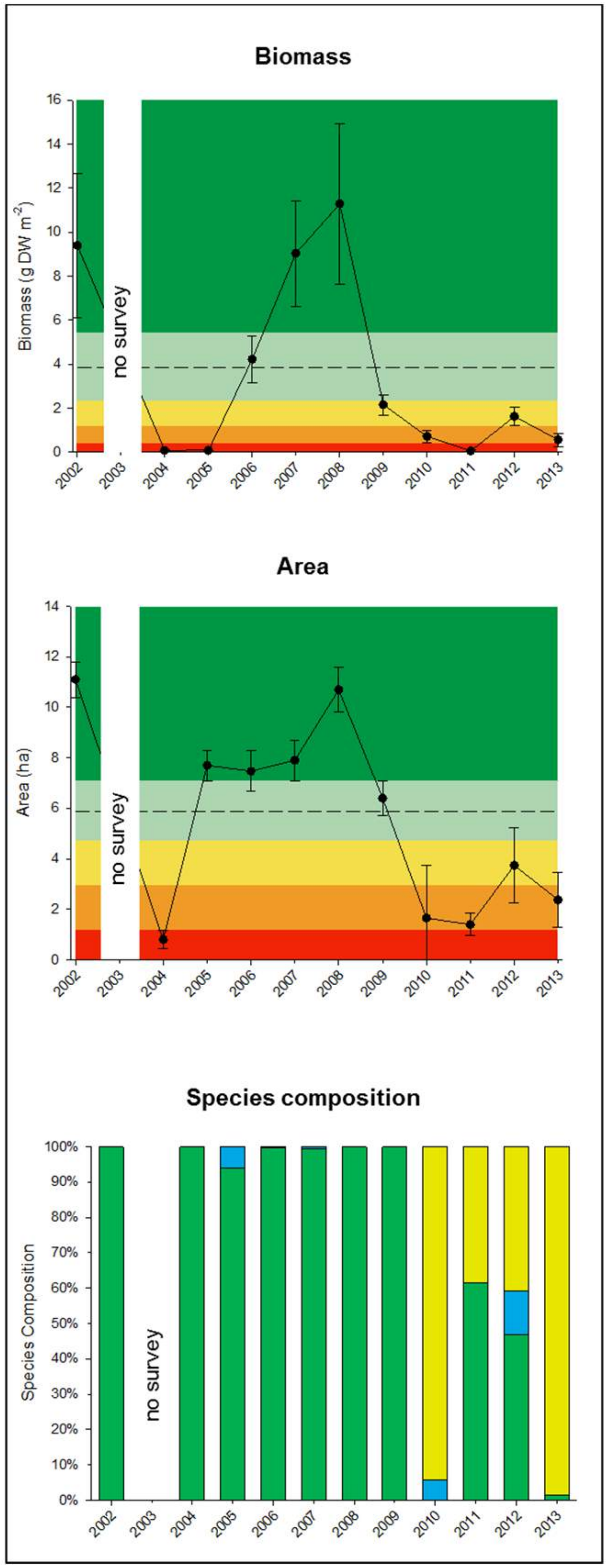


Figure 24 Changes in average biomass, meadow area and species composition for seagrass Meadow 60 in the South Trees Inlet (lower) Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Rodds Bay Zone

The Rodds Bay Zone was given an overall grade of E (very poor).There are three monitoring meadows in the Rodds Bay Zone (Figure 25). Meadows 94, 96 and 104 are intertidal meadows comprised predominantly of *Zostera muelleri*. At times these meadows have consisted of a continuous cover of seagrass however declines over the course of monitoring have left only isolated patches. The average biomass at these meadows has been highly variable over the course of monitoring but total meadow area remained relatively stable until declines in 2011. Meadows 94, 96 and 104 are classified as class 2 meadows (variable biomass, stable area) for grading purposes.

Biomass

Average biomass declined to extremely low levels at all three monitoring meadows in 2004 but recovered well over the following years, peaking in 2007 at around 20 to 30 gDW m^{-2}, the highest of all of the monitoring meadows that year (Figures 26 to 28). Biomass remained high in 2008 but declined significantly from 2009 until 2011 when no seagrass remained. There has been very little recovery since these declines with only a few sparse patches remaining in 2013. The absence of meadow 94 has resulted in a grade of E (very poor) and the lack of recovery at meadows 96 and 104 have resulted in grades of D (poor).

Area

There has been very little recovery at Rodds Bay monitoring meadows following the complete loss of seagrass in 2011 (Figures 26 to 28). The return of very sparse patches of seagrass in 2012 brought the total area of meadows back to the baseline; however further declines in 2013 have resulted in grades of E (very poor) at all three meadows.

Species Composition

Zostera muelleri has remained the dominant species at the Rodds Bay monitoring meadows with the exception of meadow 94 (Figure 26) when declines caused a shift in composition to the pioneering *Halophila ovalis.* The few patches of seagrass that remained at Rodds Bay in 2013 were comprised of *Zostera muelleri* resulting in a grade of A (very good). The absence of meadow 94 has resulted in a grade of E (very poor).

Rodds Bay Zone

E

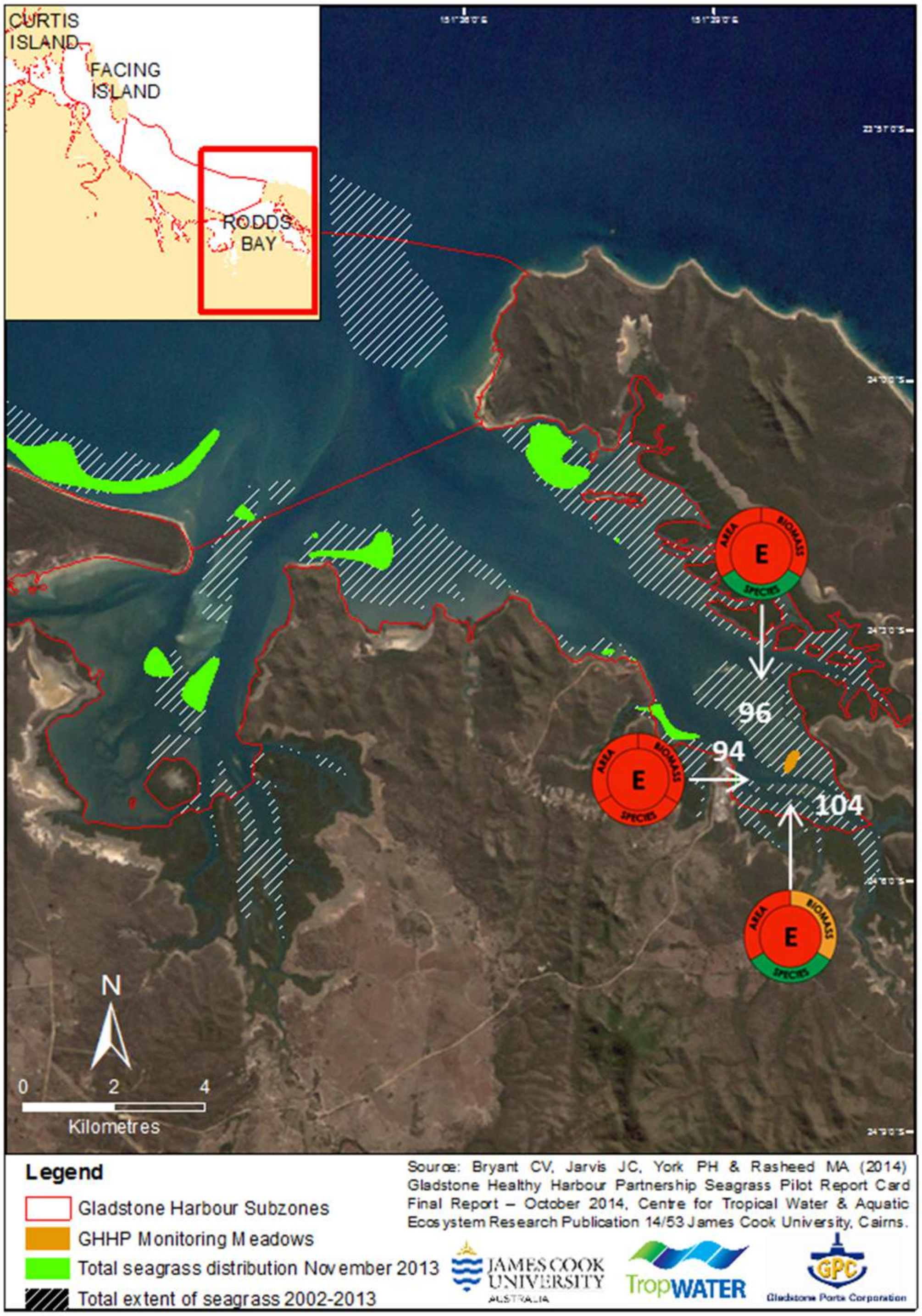
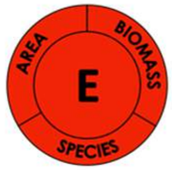
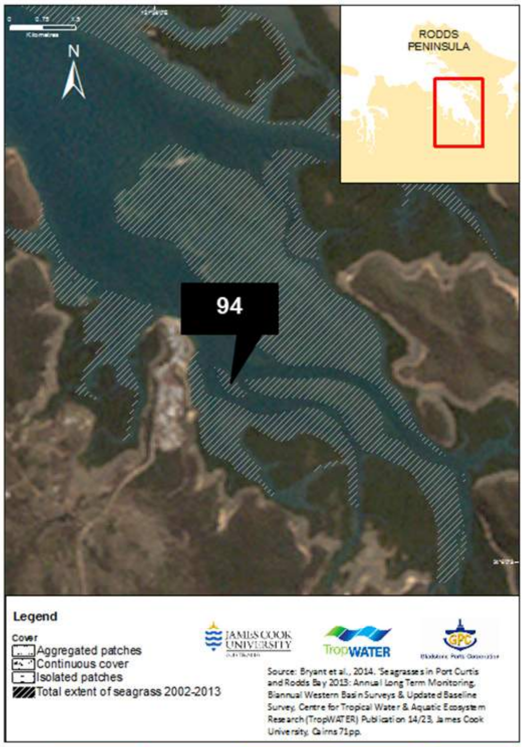


Figure 25 Seagrasses in the Rodds Bay Zone in November 2013.

Meadow 94





	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

Zostera muelleri

Halophila ovalis

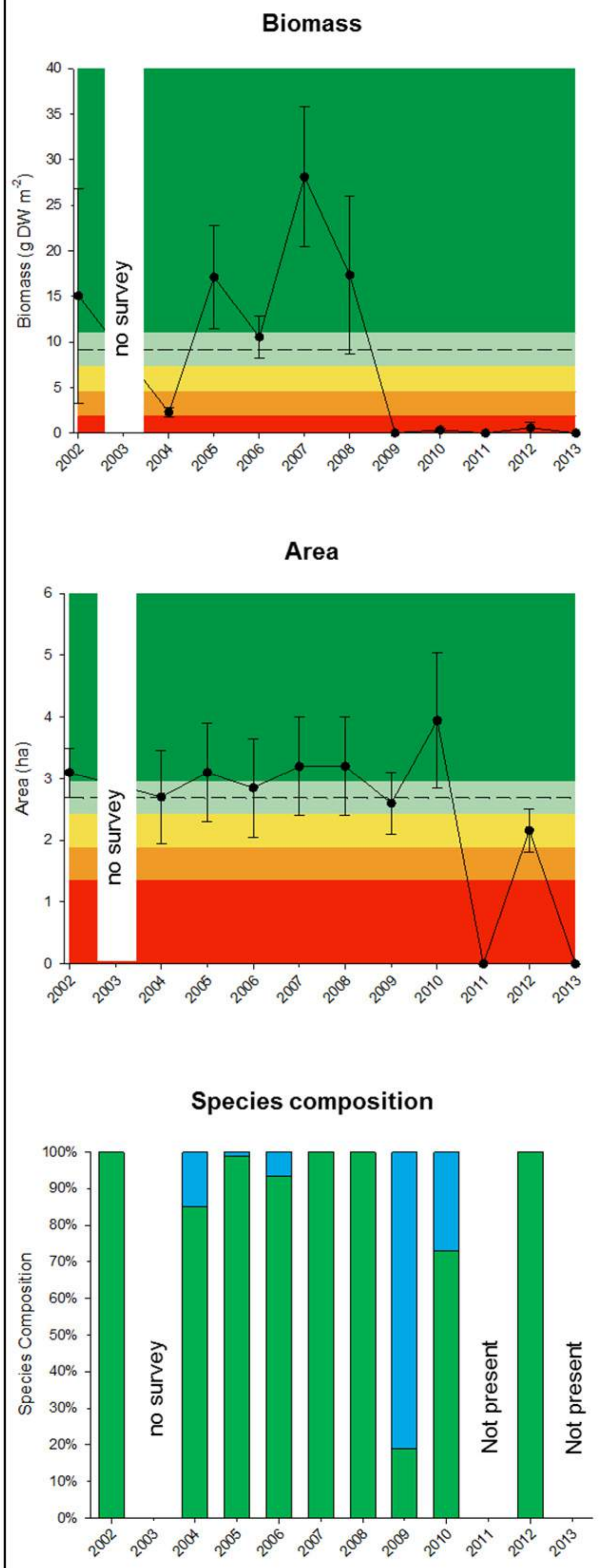
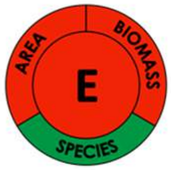
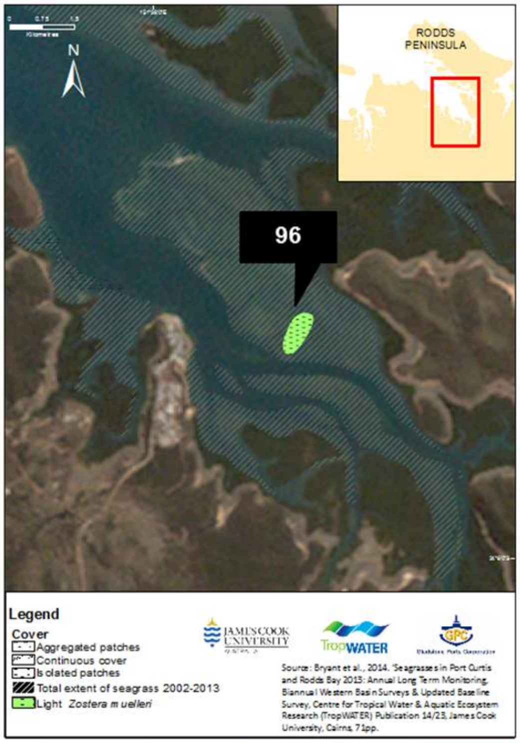


Figure 26 Changes in average biomass, meadow area and species composition for seagrass Meadow 94 in the Rodds Bay Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 96





	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

Zostera muelleri

Halophila ovalis

Halophila decipiens

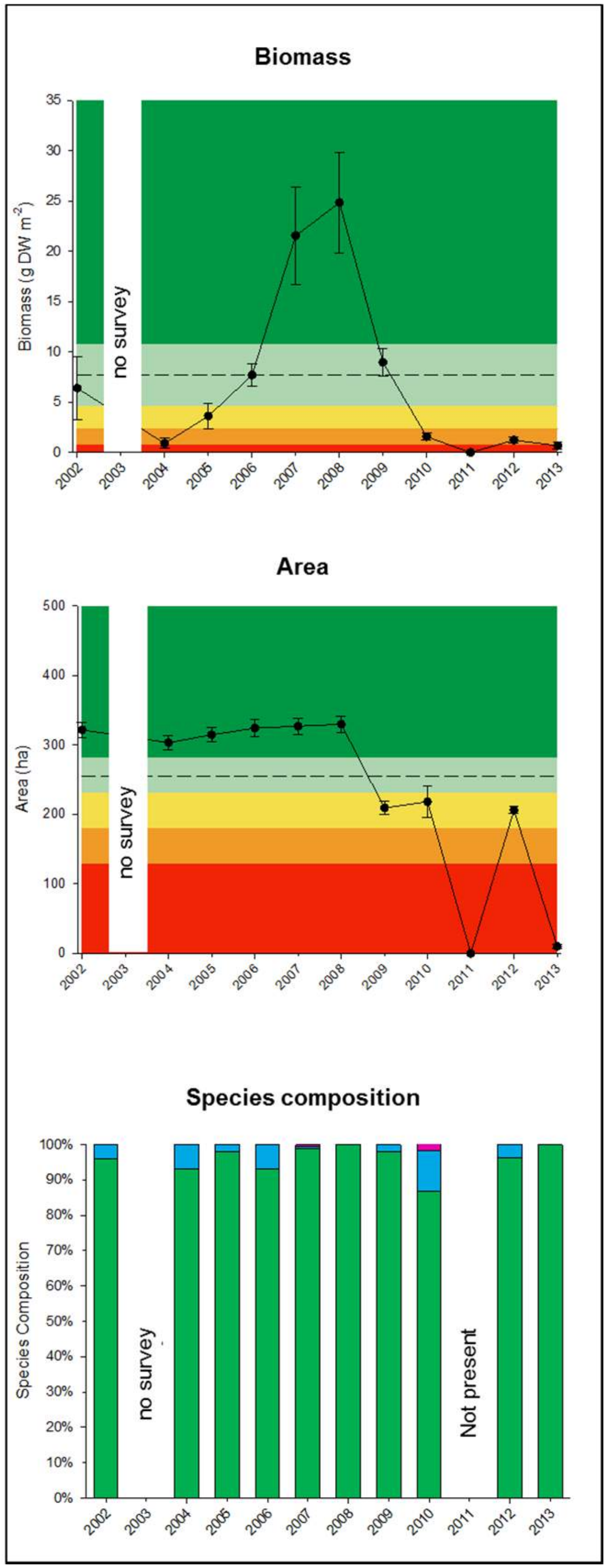
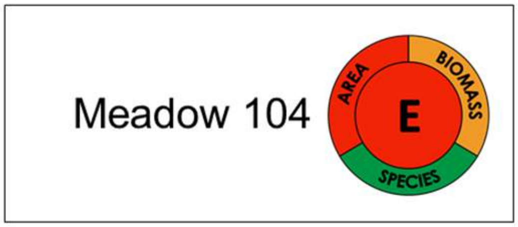
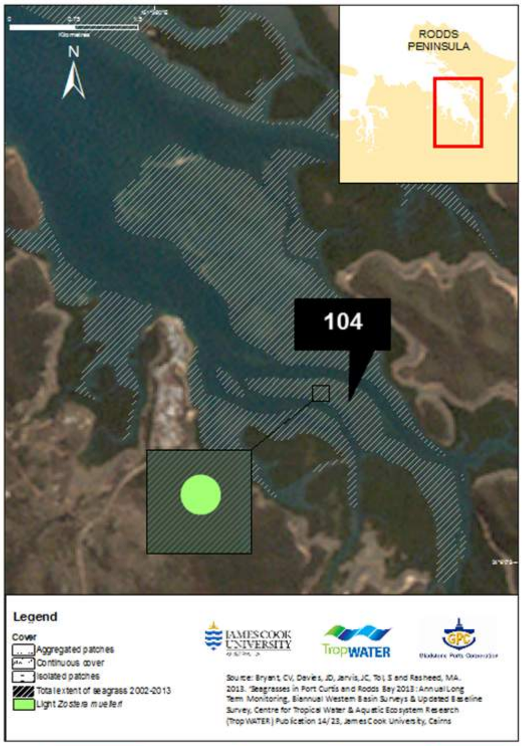


Figure 27 Changes in average biomass, meadow area and species composition for seagrass Meadow 96 in the Rodds Bay Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).





	A	B	C	D	E
Biomass	>40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	>90% below baseline
Area	>10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	>50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Annual mean

Baseline

Species composition

- *Zostera muelleri*
- *Halophila ovalis*
- *Halophila decipiens*
- *Halodule uninervis* (thin)

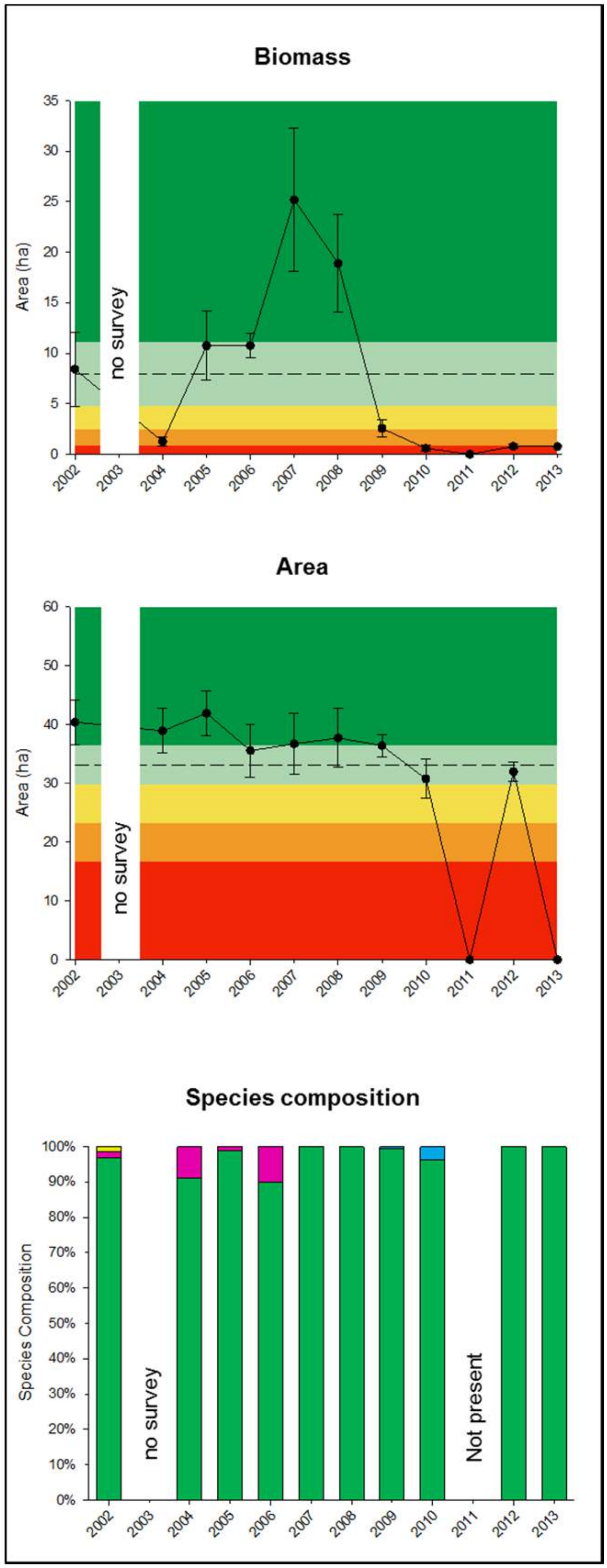


Figure 28 Changes in average biomass, meadow area and species composition for seagrass Meadow 104 in the Rodds Bay Zone, November 2002 - 2013 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4 Local climate conditions

Total annual rainfall in the year preceding the November 2013 survey was the highest recorded over the course of the monitoring program and well above the long term average annual rainfall (since 2002). January 2013 was the wettest month recorded over the course of monitoring with 841mm of rain falling in a single month (Figure 29). In 2013, the total monthly rainfall from March through to May was also above the long term average (since 1957) (Figure 29). River flow from the Calliope river peaked in January 2013 with an average flow of over 600,000ML/day, the most intense flow event recorded over the course of the seagrass monitoring program (Figure 30). For information on other environmental conditions (tidal exposure, water temperature and Photosynthetically Active Radiation) in the harbour see Bryant et al., (2014).

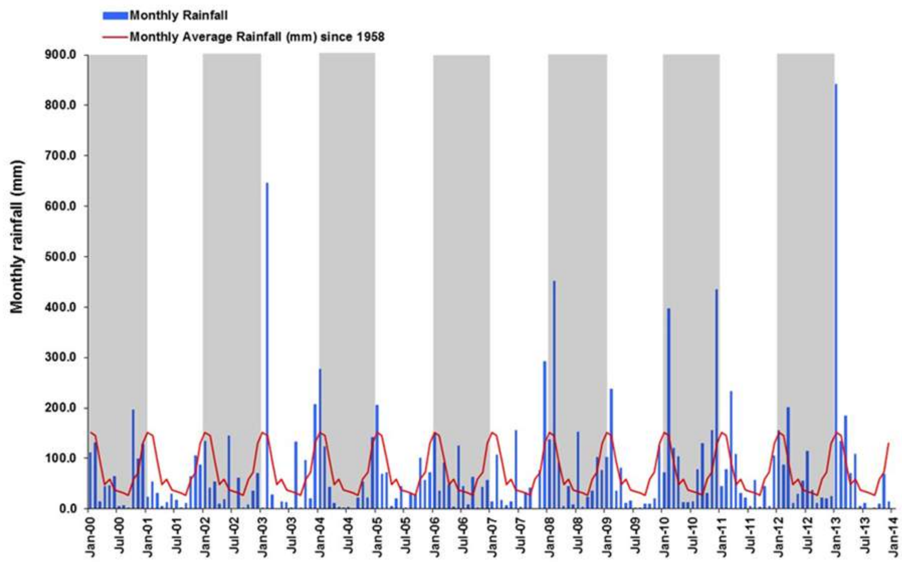


Figure 29 Total monthly rainfall (mm) for Gladstone, from January 2000 to December 2013. Data taken from station number 039123 (Gladstone Airport); from Bureau of Meteorology (http://www.bom.gov.au/climate/data/).

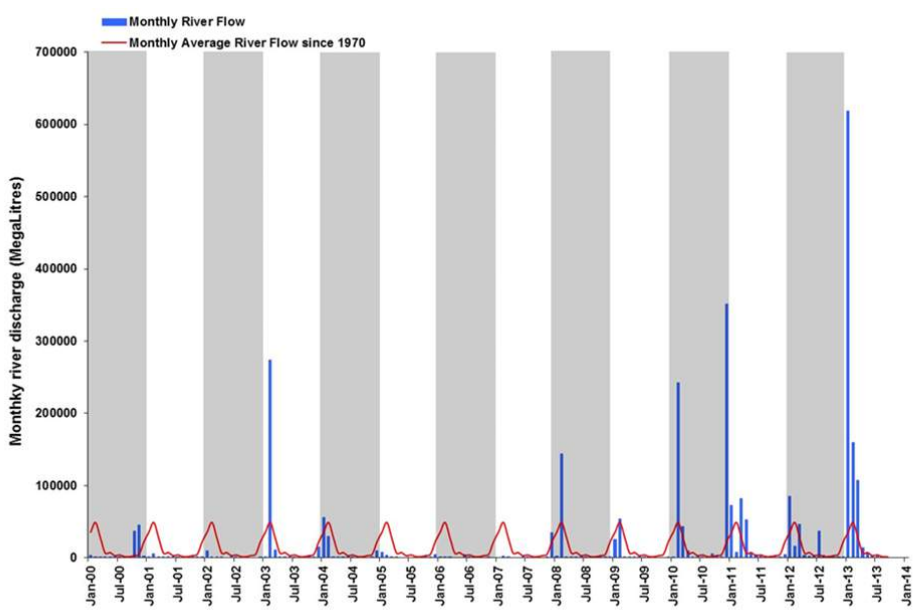


Figure 30 Total monthly river discharge (volume MegaLitres) for Calliope River at Castlehope, Gladstone, from January 2000 to September 2013. Data taken from Calliope Basin, site 132001A; from DERM Water Monitoring (http://watermonitoring.derm.qld.gov.au/host.htm).

4 DISCUSSION

Seagrasses in the Gladstone and Port Curtis region underwent significant declines following flooding and major rain and storm activity in 2010, similar to many areas of seagrass along the Queensland east coast. Annual monitoring has shown that during 2012 some recovery occurred at many meadows, but high rainfall and the biggest flow event for the Calliope River in over a decade in early 2013 saw a reversal of much of that recovery. As a consequence most of the monitoring meadows were classified as being in a moderate (C) to very poor (E) condition in 2013.

The loss of coastal seagrasses has been more concentrated in the Western Basin region, closest to the source of epesodic flood impacts and Western Basin Dredging operations. Light availability is considered the key environmental determinant of the distribution, abundance and species composition of seagrass assemblages (Duarte et al., 1997; Vermaat et al., 1997) and flood plumes and dredging have both been linked to seagrass declines at other sites through a reduction in available light (Campbell & McKenzie 2004; Erftemeijer & Lewis 2006). Frequent severe climate events, rather than dredging activities are likely the main driver of the declines we have recorded in the Gladstone Region, given that declines in seagrass area occcurred before the onset of the major capital dredging activities and occurred at the Rodds Bay Zone (outside of the influences of Port activities) as well as in other seagrass monitoring areas of the Queensland east coast (Chartrand et al., 2011; Fairweather et al., 2011a&b; Taylor & Rasheed 2011). The degree to which dredging has had an effect on the capacity for seagrasses to recover is not well understood but a comprehensive water quality monitoring program has shown that light levels were maintained above locally derived light requiremnets during the dredging campaign. Repeated climate impact events in recent years have likely reduced the resilience of seagrasses at these sites and reduced their capacity for recovery.

Major declines in seagrass over the course of the monitoring program appear to be largely driven by extreme climate events including heavy rainfall and in particular coincide with major flooding of the Calliope River. The large declines recorded in 2010 and 2011 (Chartrand et al., 2011; Rasheed et al., 2012) coincide with above average rainfall over much of the two year period and significant river flow events in both February and December 2010. In comparison, 2012 was a relatively dry year with below average rainfall likely improving water quality conditions and allowing seagrasses the opportunity for the recovery detected that year (Davies et al., 2013). The reversal of these gains in 2013 also occurred following an extreme rainfall and riverflow event in January 2013.

The repeated climatic impacts have left seagrasses in a relatively poor condition, both in the Western Basin region and Rodds Bay where some meadows have been reduced to only a few isolated patches. A species shift was also detected at several meadows from the Narrows to the Inner Harbour Zone, where *Zostera muelleri* dominated communities had become increasingly dominated by *Halophila* species. Given that light levels remained favourable for seagrass growth in 2013, the lack of recovery of *Zostera muelleri* at these meadows may be attributed to other factors such as a lack of propagules or successful propagule germination. Dense *Zostera muelleri* seed banks have been detected in the Western Basin Zone over the course of monitoring however there have been no flowering events recorded in the past three years to replenish seeds and the age and viability of remaining seeds is unknown (McCormack et al., 2013). The Marine Ecology Group at TropWATER are currently investigating the viability of seedbanks in the region.

Further from the mainland in the clearer waters at Pelican Banks, seagrasses were in a moderate condition. Although not immune to the impacts of climate events (McCormack et al., 2013; Amies et al., 2013; Bryant et al., 2013) the permanent and relatively dense adult population of *Zostera muelleri* at Pelican Banks affords this meadow a high level of resilience compared with the naturally sparse Western Basin meadows. Light levels at Pelican Banks remained favourable for seagrass growth in 2013, however seagrasses are yet to fully recover from impacts associated with intense flooding in 2010/2011. This particular climate event caused a severe and persistent reduction in light levels below those required to sustain *Zostera muelleri* and average seagrass biomass declined as a result. Since this time, average biomass has remained well below the long term average. Results of monitoring at permanent transects on Pelican Banks show seagrasses to be increasingly more sparse at the southern part of the meadow compared with the north (Bryant et al*.,* 2013). This is likely driving the apparent plateau in recovery across the meadow as a whole. During the November 2013 survey, seagrasses in the northern section of the meadow appeared healthy and robust (Bryant 2014; pers obs).

4.1 Comparisons with State wide Monitoring Program

Large scale declines in seagrass area and biomass have been reported throughout the north-eastern coast of Queensland over the past several years. Declines in Cairns (Jarvis et al., 2014), Mourilyan (York et al., 2014), Townsville (Davies et al., 2014), Abbot Point (Rasheed et al., 2014; McKenna & Rasheed 2014) as well as in Gladstone (Chartrand et al., 2011; Rasheed et al., 2012) have been principally attributed to regional, rather than local drivers of change including heavy rainfall and severe flooding events. Seagrass monitoring locations in the Gulf of Carpentaria and Torres Strait have not followed the same patterns of decline, with seagrasses remaining relatively stable in biomass and distribution (Weipa and Karumba; Taylor et al., 2014a&b and Thursday Island; Davies et al., 2012) having escaped the severe flooding impacts that occurred along the urban east coast.

Tropical seagrasses in Queensland are generally highly resilient and have demonstrated the ability to recover from impacts (Rasheed 2004; Rasheed & Unsworth 2011; Davies et al., 2013). In numerous locations along the east coast of Queensland several years of decline and repeated climate impacts have reduced adult plant populations and therefore limited sources available to initiate recovery. Seagrass meadows at these sites have remained in a vulnerable state. With limited adult plants remaining, recovery will depend upon seed banks in the sediment or sexual propagules sourced from nearby locations (Duarte & Sand-Jensen 1990; Jarvis & Moore 2010; Phillips & Lewis 1983).

4.2 Implications for Port Management

The current low levels of resilience for the majority of seagrasses in the Gladstone area has some implications for management of activities that could potentially create additional stressors to seagrasses. Natural recovery from large declines can take up to five years (Preen et al., 1995) or potentially longer, with recovery delayed if additional stressors such as high turbidity or poor water quality continue to be present. Substantial seed banks detected at several sites may be available to assist recovery over the 2014 growing season; however the age and viability of existing seeds is largely unknown. The Marine Ecology Group at TropWATER are currently investigating the viability of seedbanks in the region.In March 2014, the Gladstone region experienced another high rainfall event, with 370mm falling in one month. This event may have further impacted seagrasses in the region and recovery over the current (2014) growing season will be critical.

Results of seagrass monitoring in November 2014 will provide a good insight into the capacity of seagrasses to be resilient to human activities. If seagrasses remain at reduced levels then the management tools and thresholds established through major research programs in Gladstone (Chartrand et al., 2012 & In review; Schleip et al., 2014) will be critical in ensuring successful management of their recovery. Gladstone seagrasses have previously shown a capacity to recover from impacts; however like other Queensland locations, repeated disturbances over multiple years may lead to long term loss with recovery trajectories far less certain (Rasheed et al., 2014; Pollard & Greenway 2013). The extensive seagrass monitoring and research efforts in Gladstone are enhancing our understanding of these processes so that measures can implemented to reduce the chances of exacerbating natural impacts by human activities.

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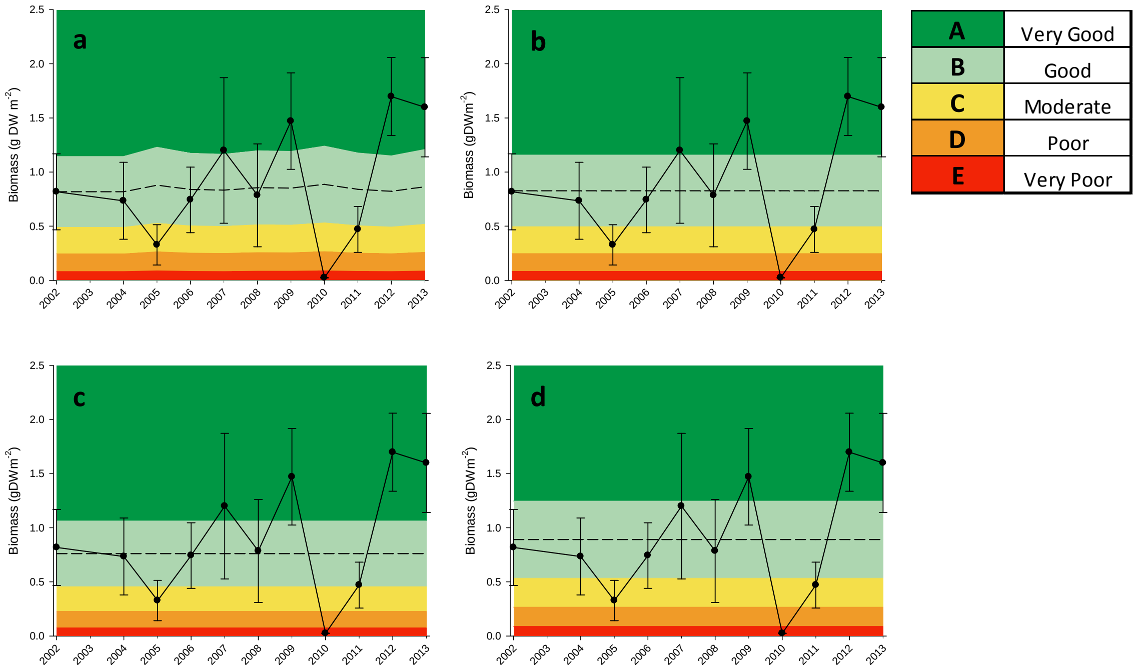
6 APPENDIX A: Comparison of baseline methods

Meadow 4

Biomass



Area

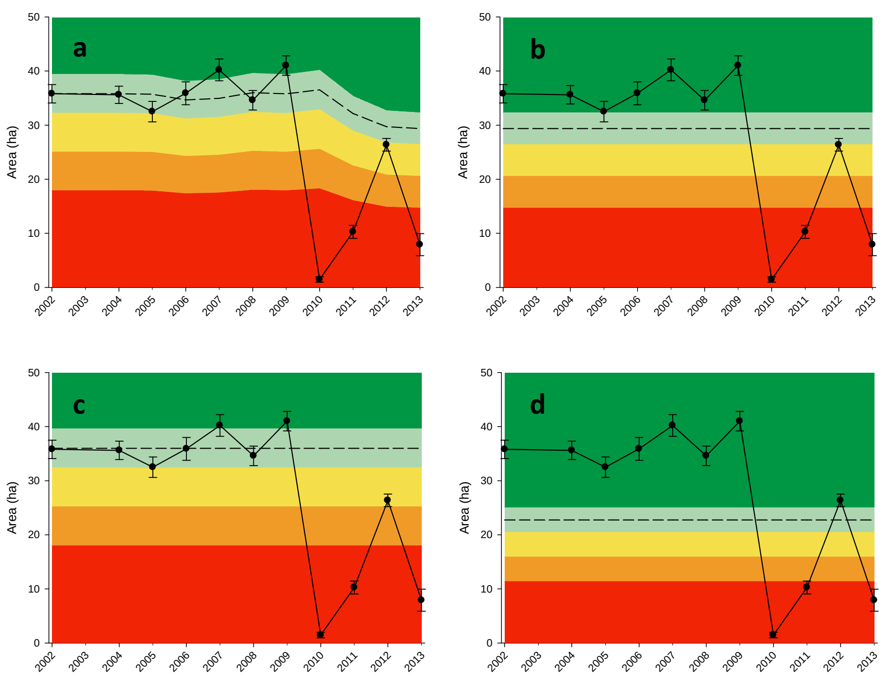
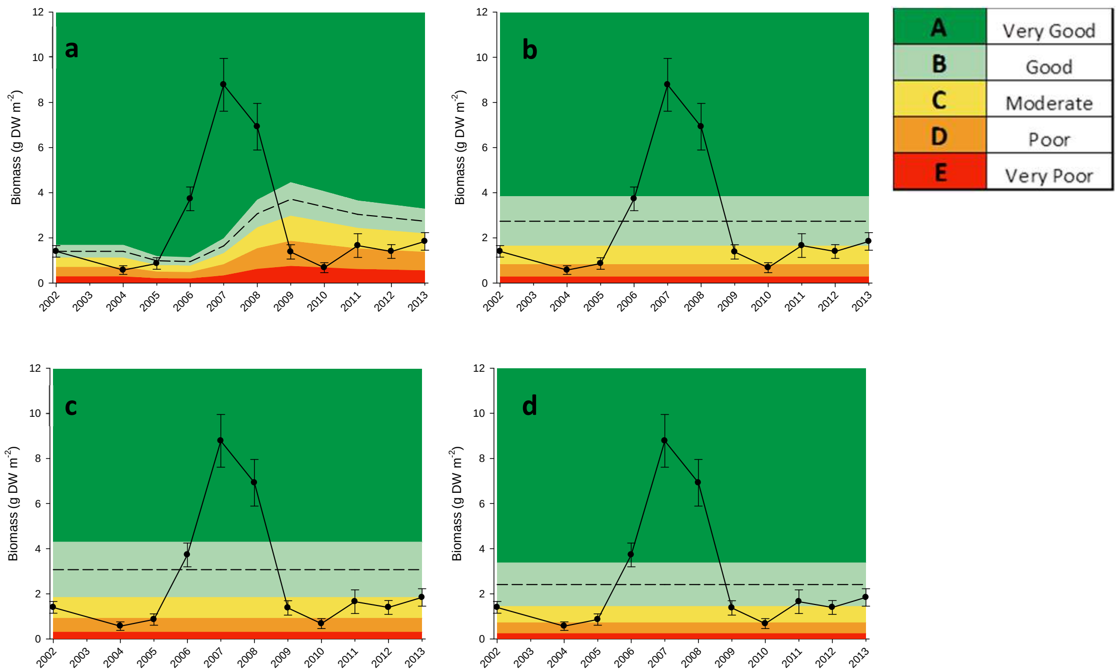


Figure 31 Annual long term monitoring data for biomass (above) and area (below) at Meadow 4 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 5

Biomass



Area

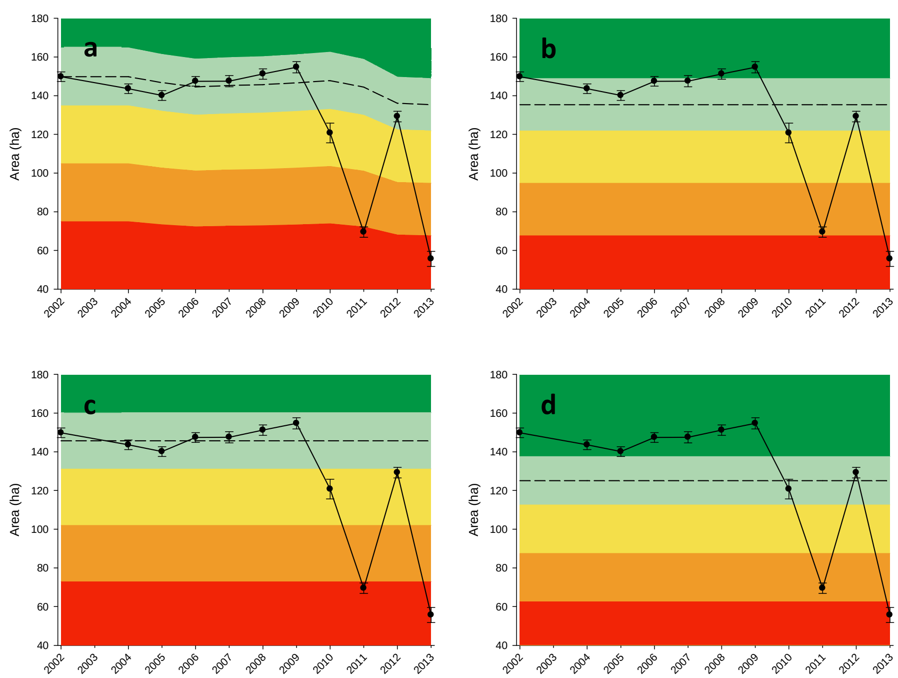
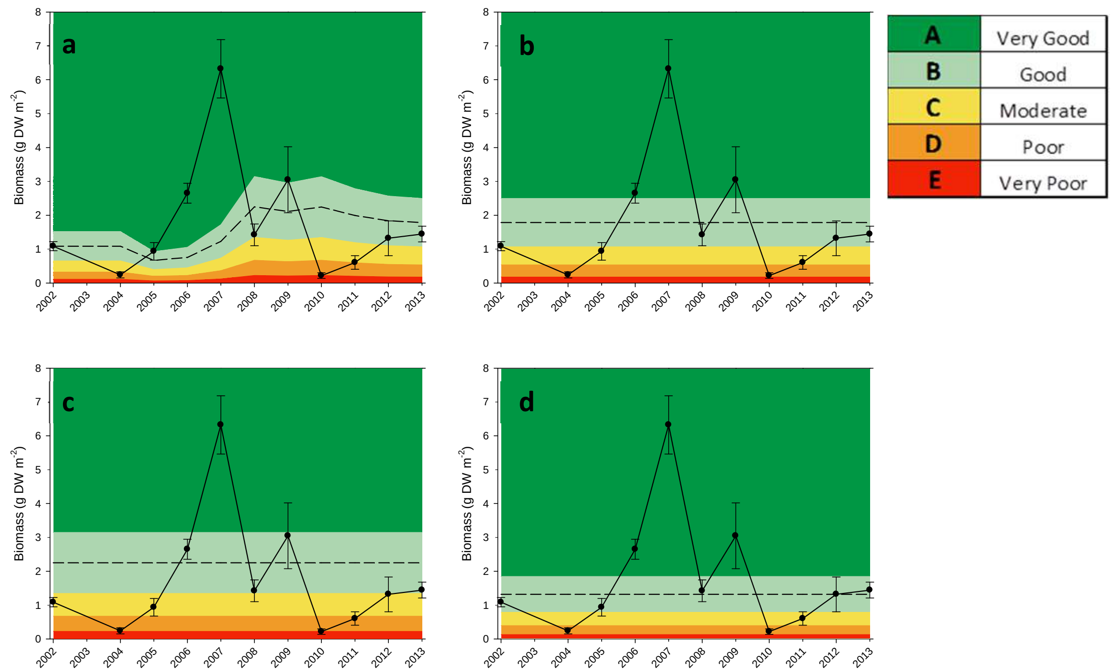


Figure 32 Annual long term monitoring data for biomass (above) and area (below) at Meadow 5 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 6

Biomass



Area

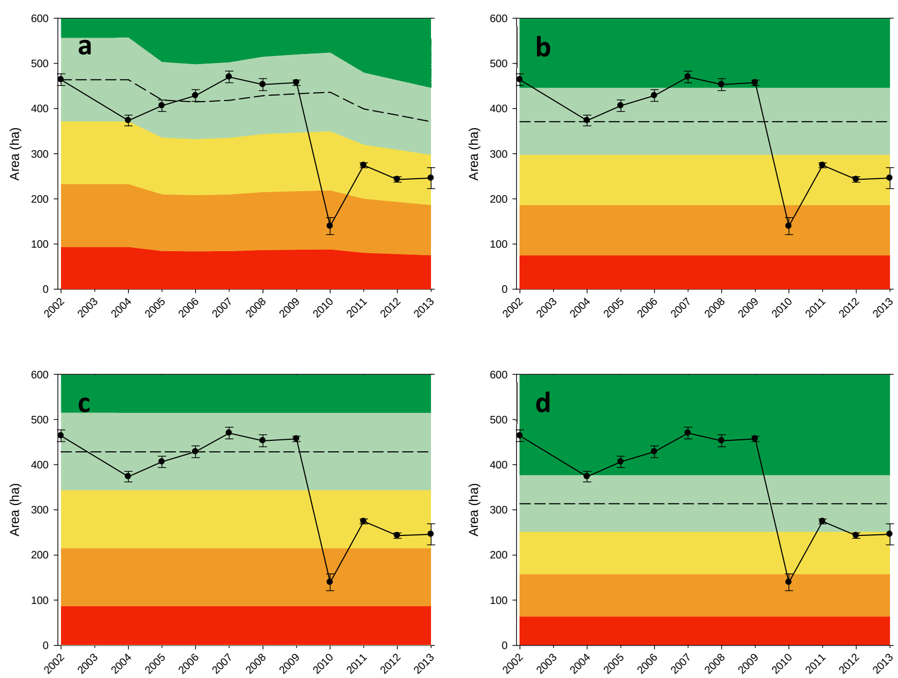
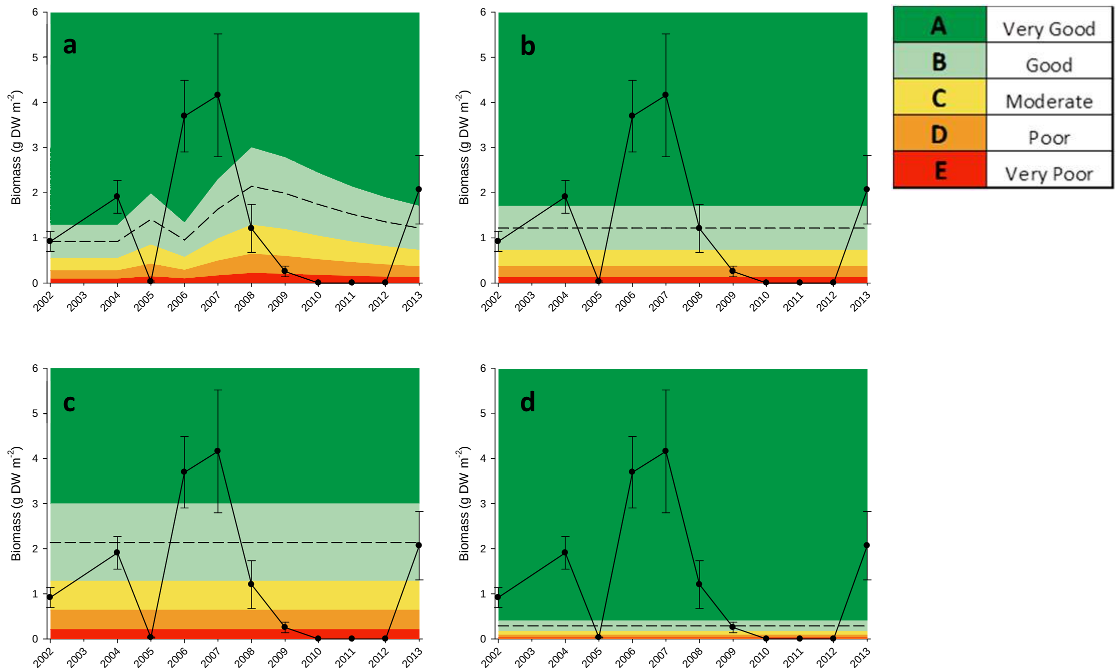


Figure 33 Annual long term monitoring data for biomass (above) and area (below) at Meadow 6 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 7

Biomass



Area

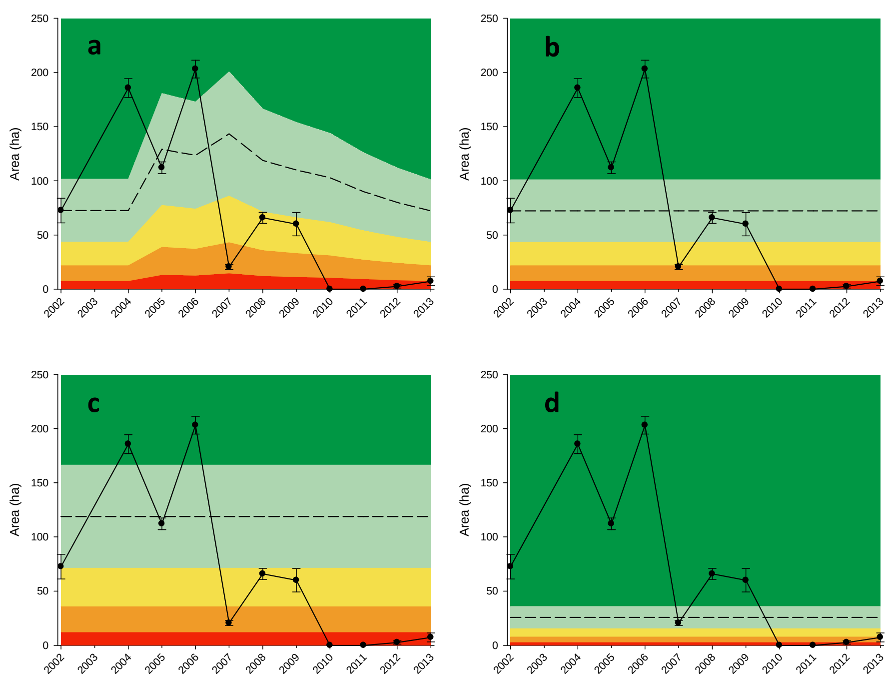
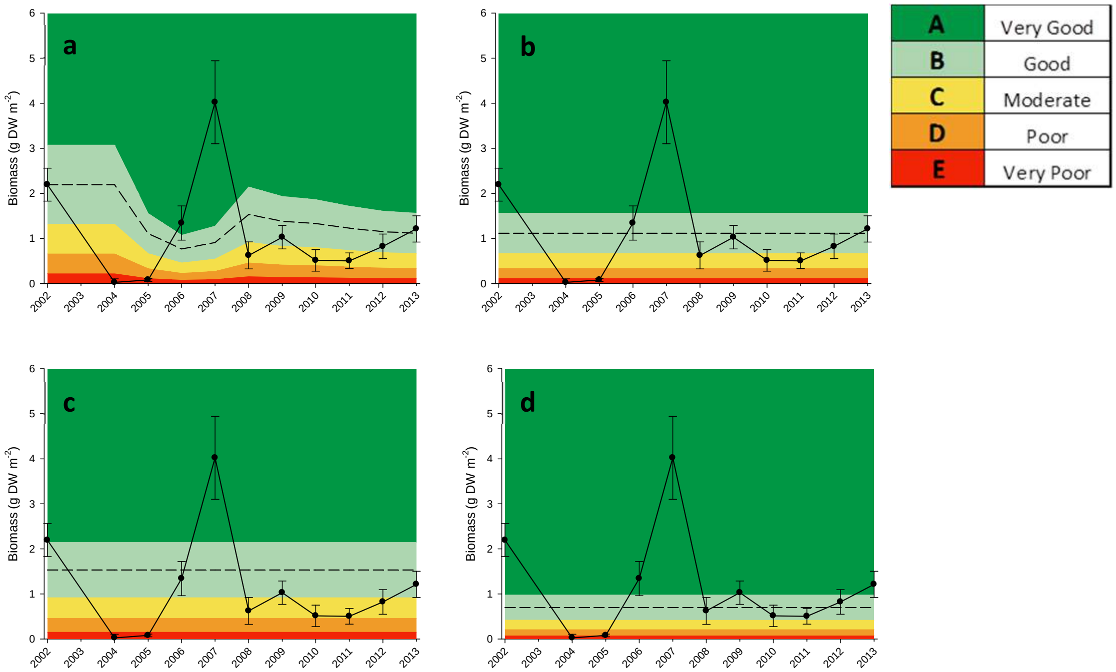


Figure 34 Annual long term monitoring data for biomass (above) and area (below) at Meadow 7 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 8

Biomass



Area

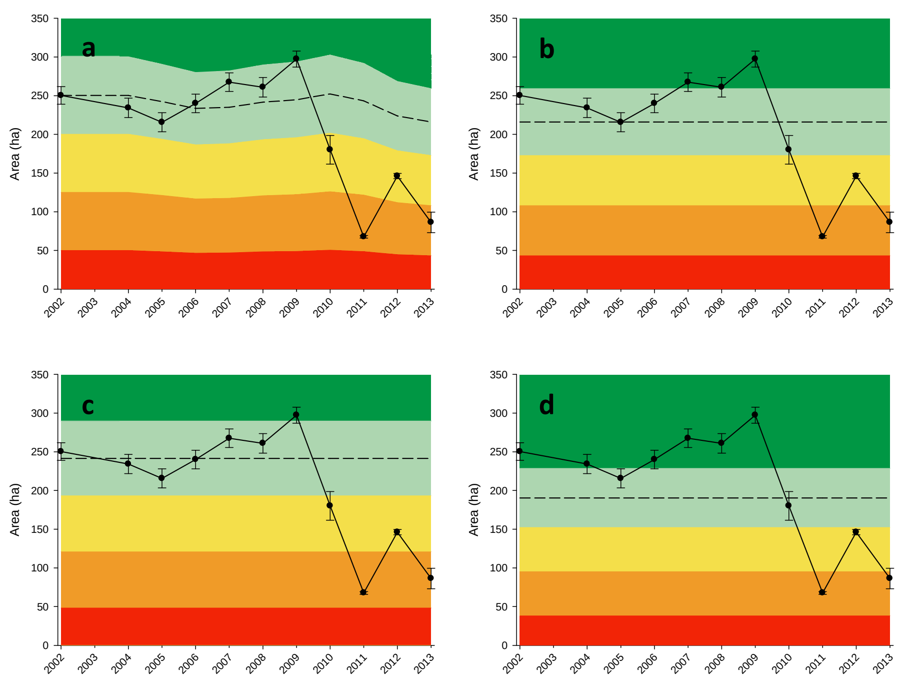
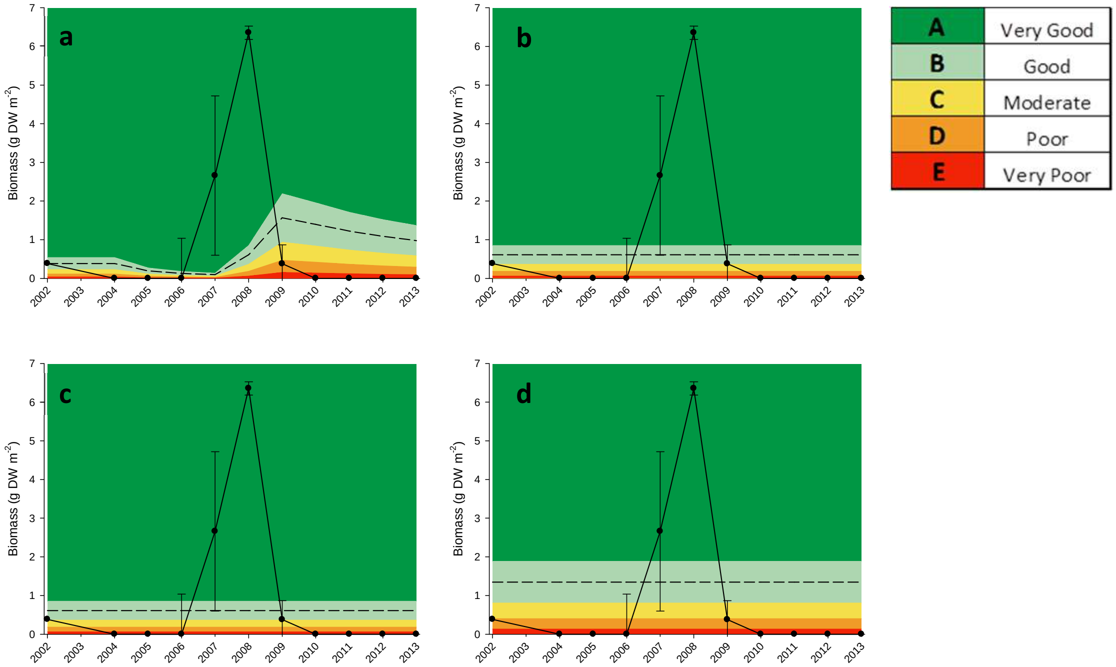


Figure 35 Annual long term monitoring data for biomass (above) and area (below) at Meadow 8 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 9

Biomass



Area

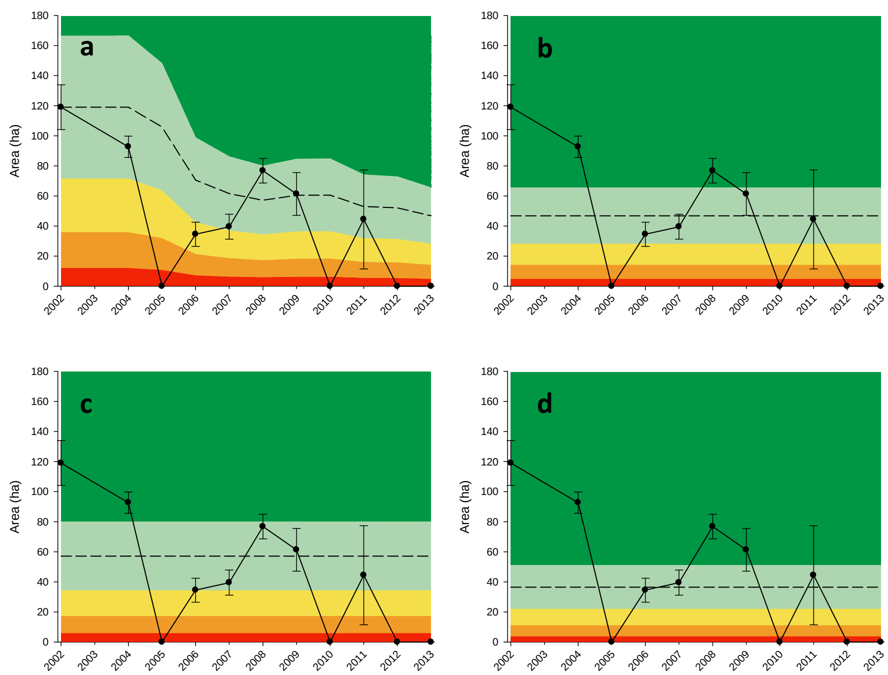
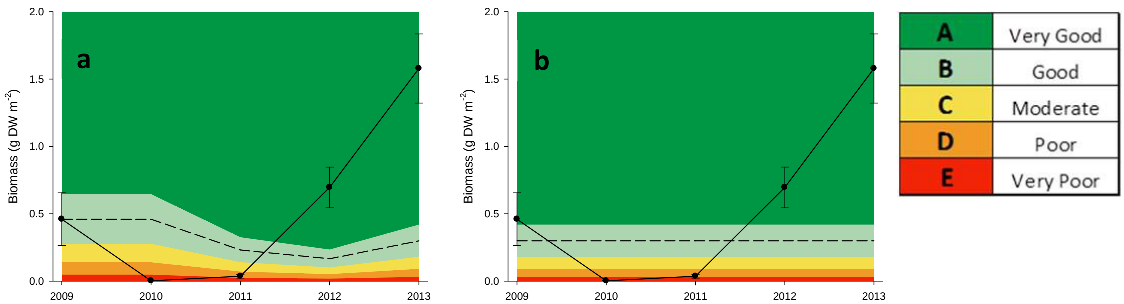


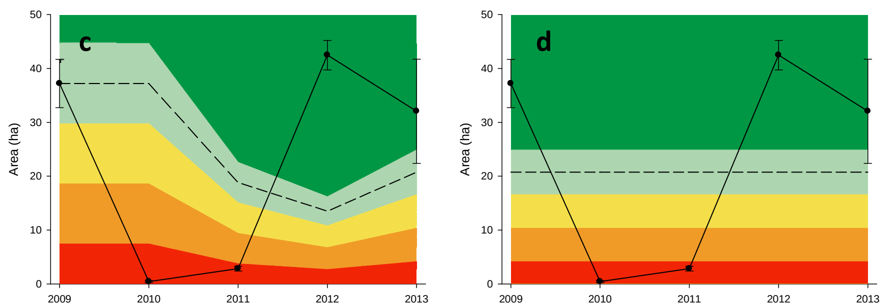
Figure 36 Annual long term monitoring data for biomass (above) and area (below) at Meadow 9 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 52-57

Biomass

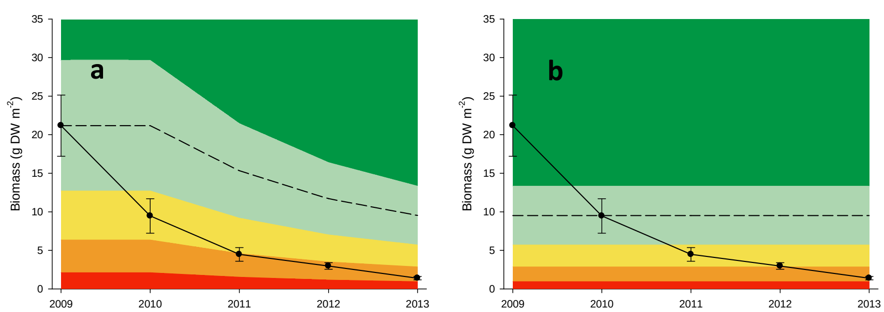


Area



Meadow 21

Biomass



Area

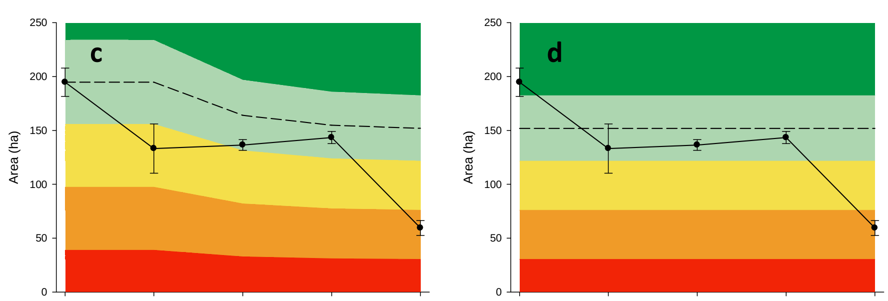
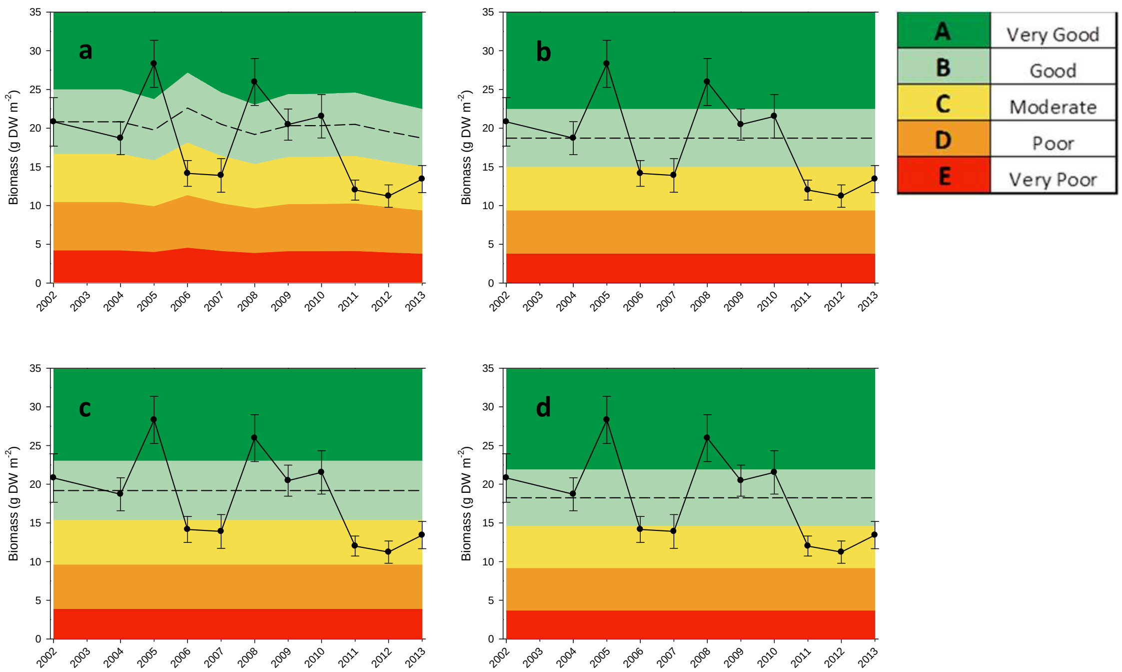


Figure 37 Annual long term monitoring data for biomass and area at Meadow 52-57 (above) and Meadow 21 (below) and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 43

Biomass



Area

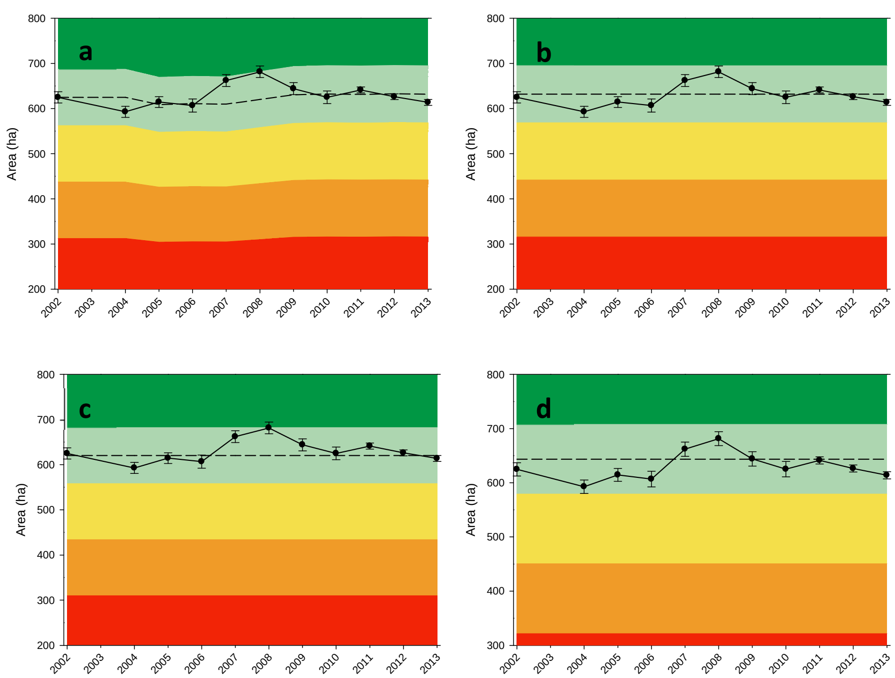
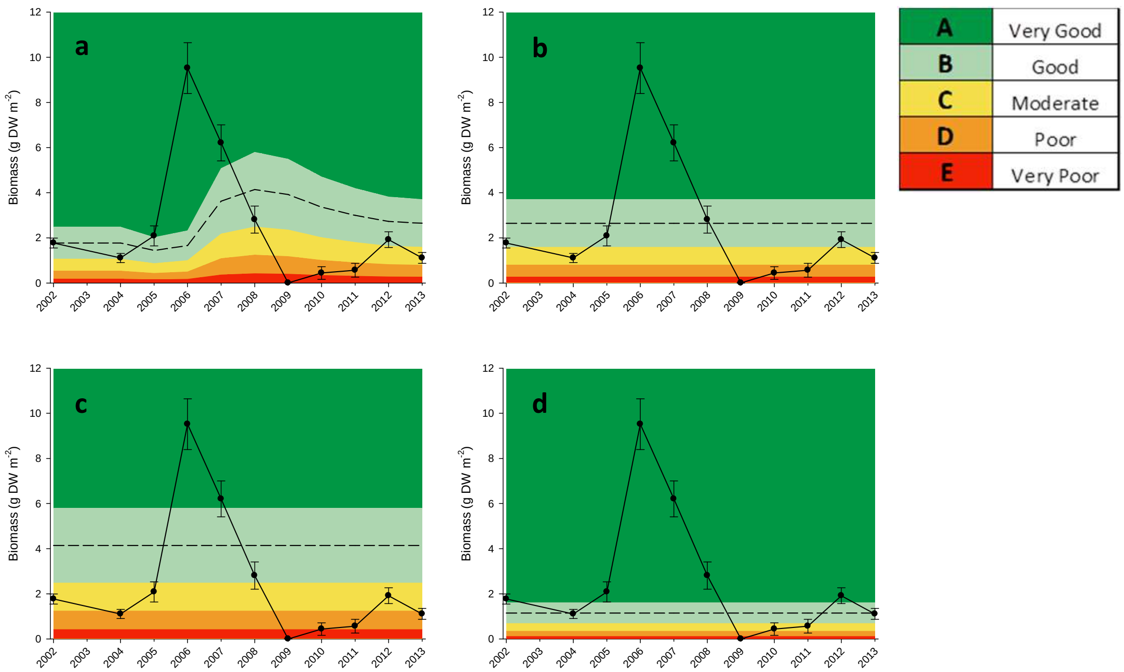


Figure 38 Annual long term monitoring data for biomass (above) and area (below) at Meadow 43 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 48

Biomass



Area

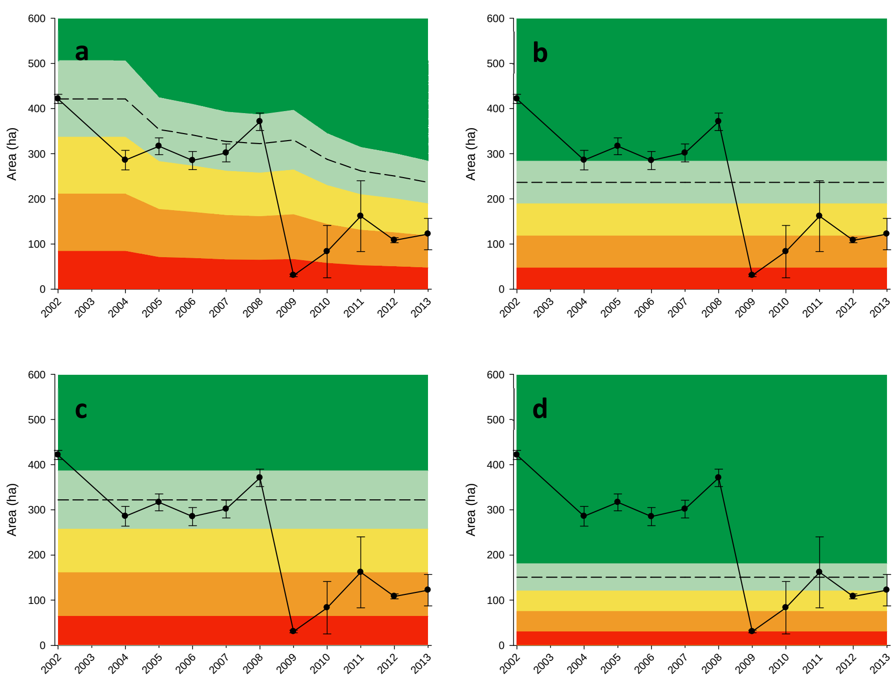
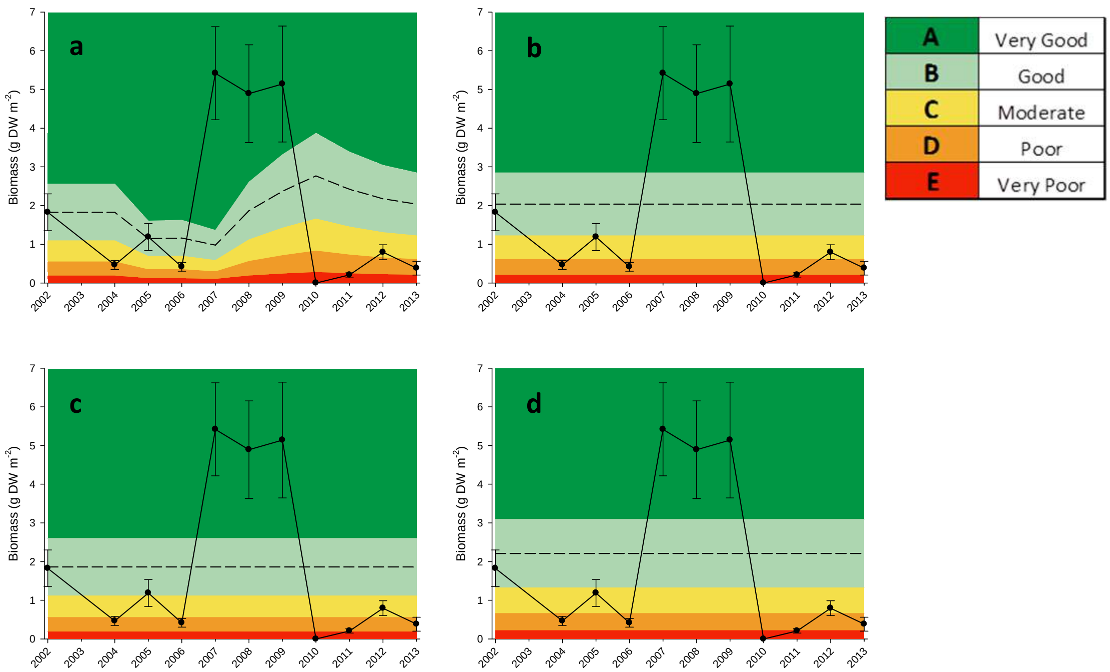


Figure 39 Annual long term monitoring data for biomass (above) and area (below) at Meadow 48 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 58

Biomass



Area

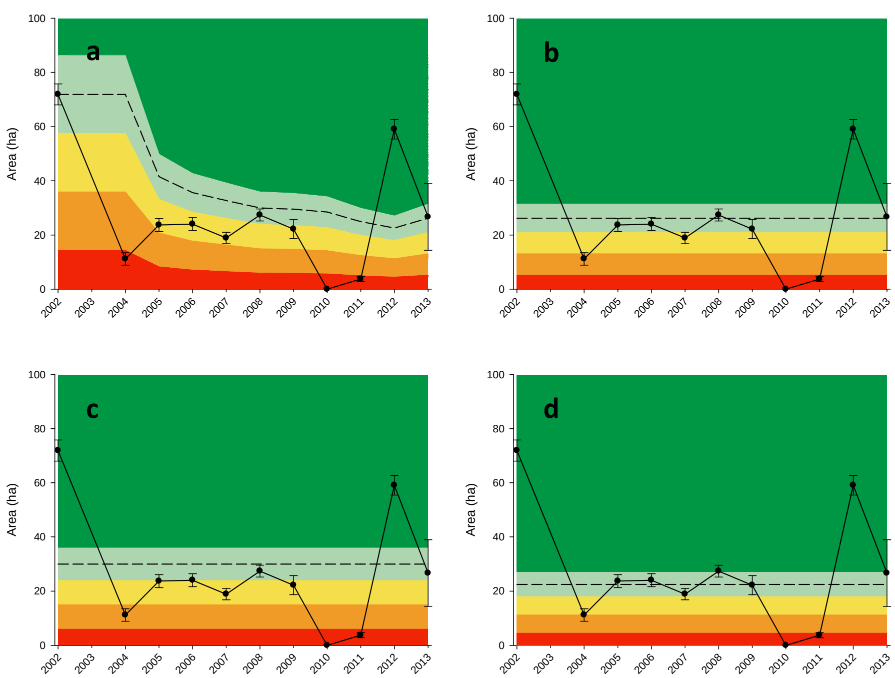
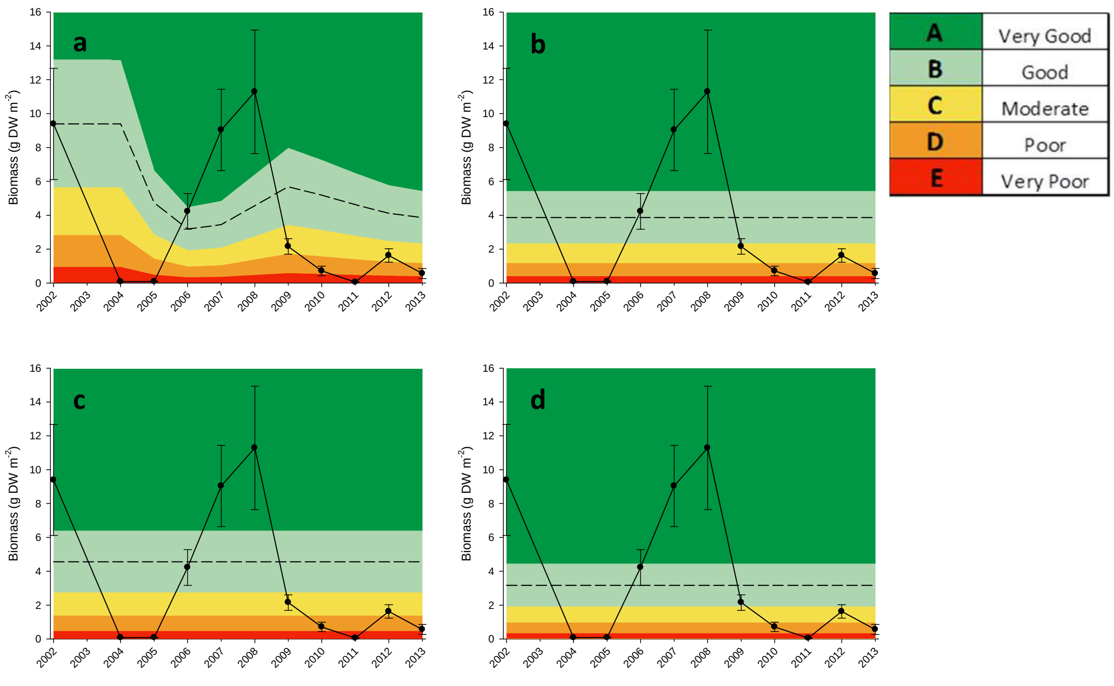


Figure 40 Annual long term monitoring data for biomass (above) and area (below) at Meadow 58 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 60

Biomass



Area

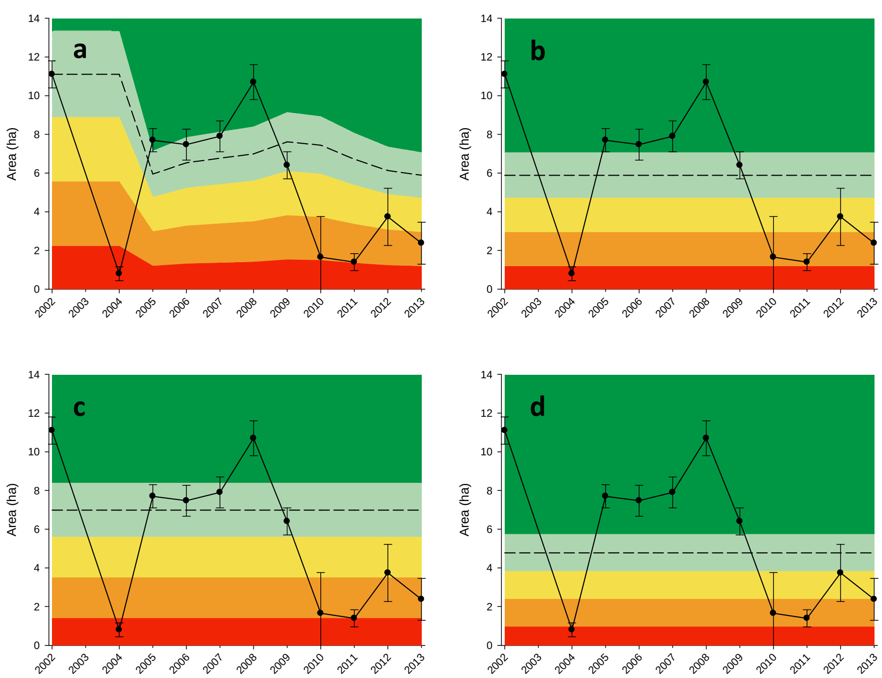
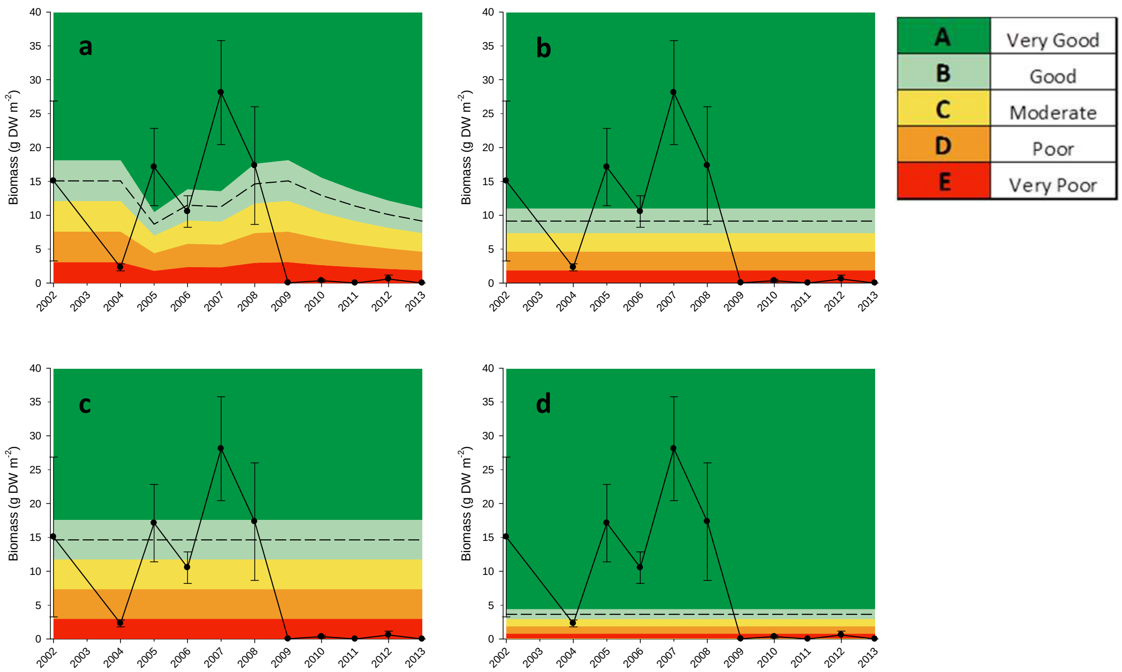


Figure 41 Annual long term monitoring data for biomass (above) and area (below) at Meadow 60 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 94

Biomass



Area

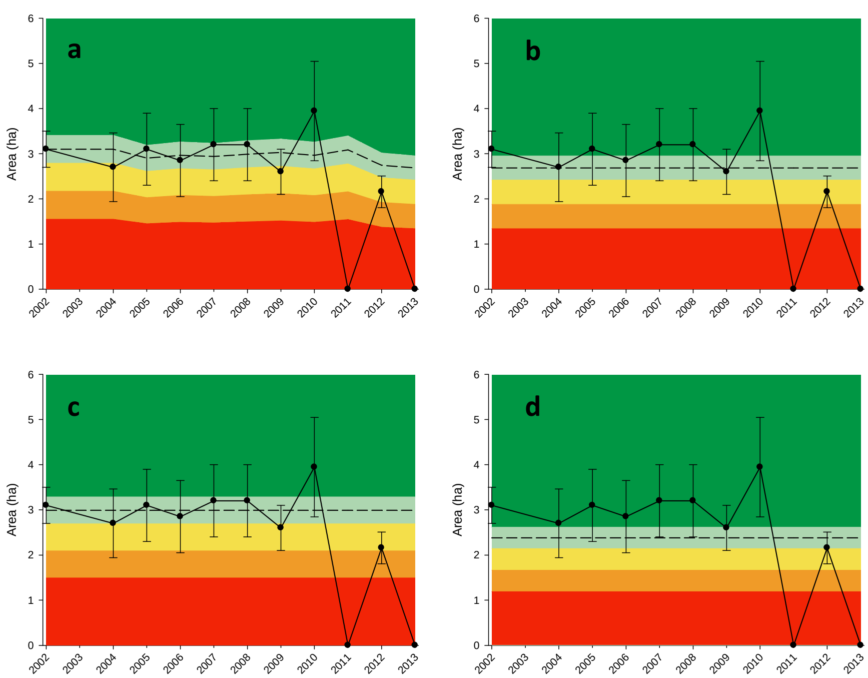
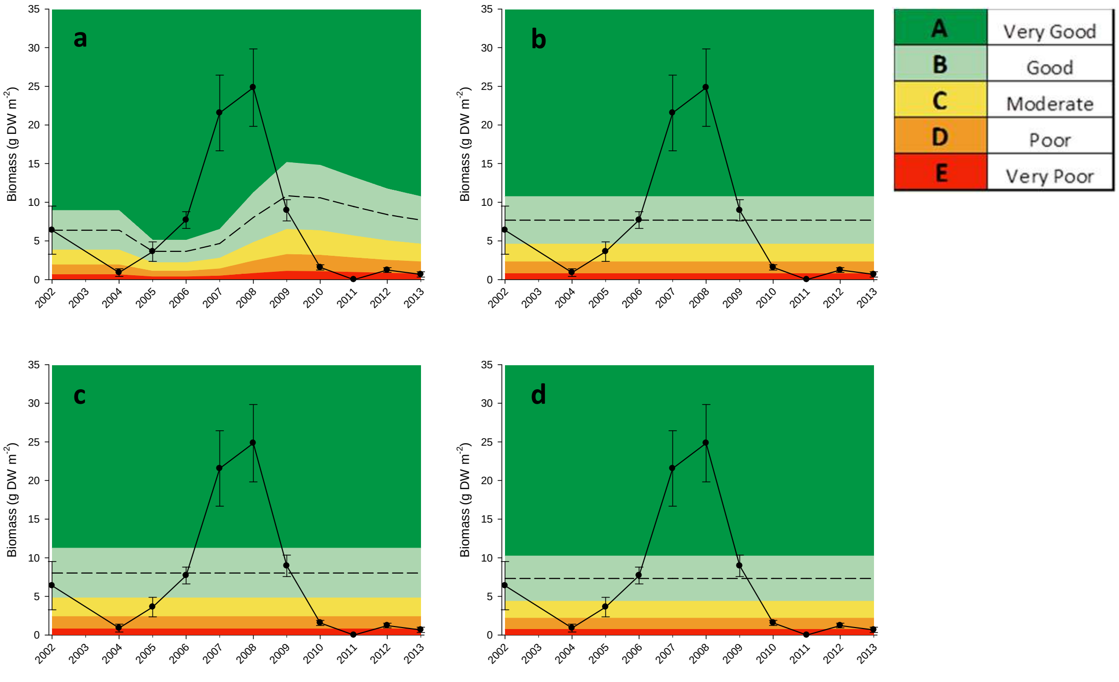


Figure 42 Annual long term monitoring data for biomass (above) and area (below) at Meadow 94 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 96

Biomass



Area

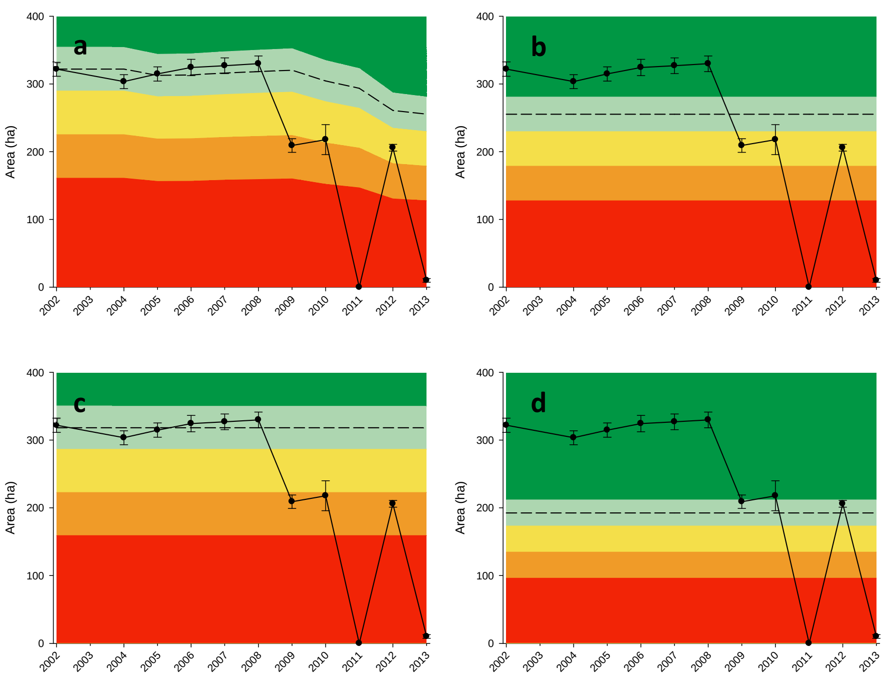
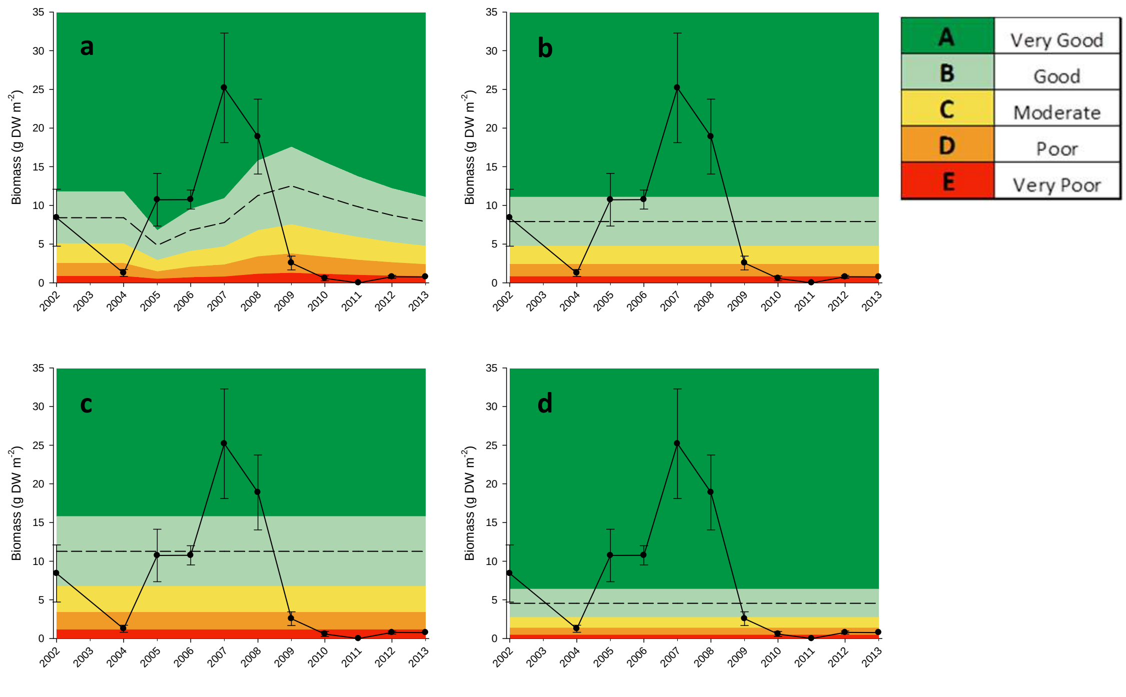


Figure 43 Annual long term monitoring data for biomass (above) and area (below) at Meadow 96 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

Meadow 104

Biomass



Area

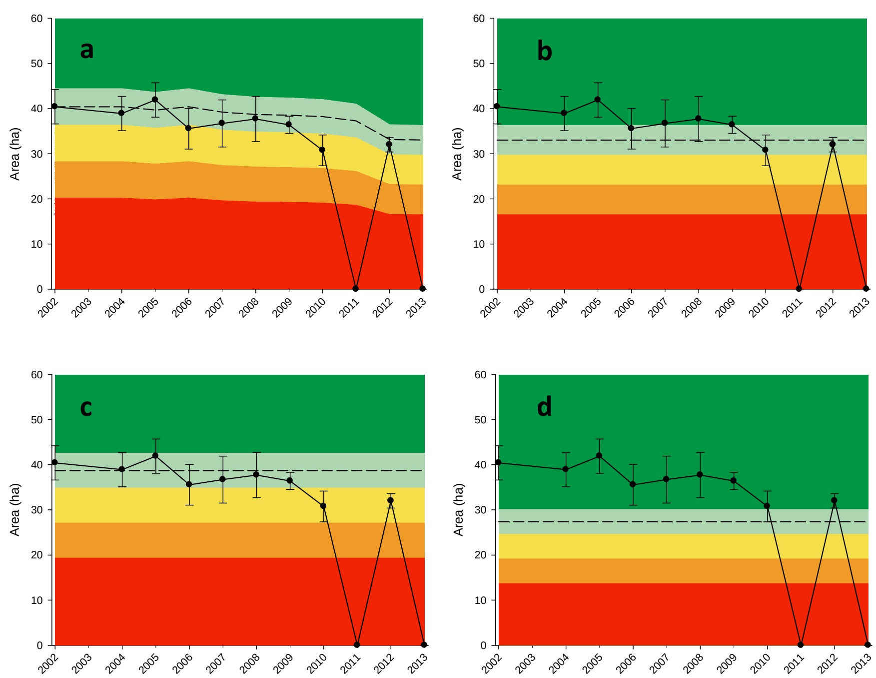


Figure 44 Annual long term monitoring data for biomass (above) and area (below) at Meadow 104 and grades resulting from each of the four baseline methods a) running long term average; b) fixed 10 year average; c) fixed 5 year average (2002-2007); d) fixed 5 year average (2008-2012).

7 APPENDIX B: Statistical analysis of changes in average biomass

Summary of statistical results for average above-ground biomass versus time (year) at monitoring meadows in Port Curtis and Rodds Bay (2002 to 2013).

One-way analysis of variance (ANOVA) was conducted on each monitoring meadow to test for differences in average biomass among years. Prior to statistical analysis each meadow's data was examined for normality and homogeneous variance and transformations applied to meet these assumptions. Pairwise comparisons were conducted using Tukey's HSD post hoc tests to determine where significant differences occurred.

Table 11 Results of one-way analysis of variance (ANOVA) conducted to test for differences in mean biomass among years. Meadows 43 and 48 were square root transformed all other meadows were log (x+1) transformed to better satisfy the assumptions of ANOVA.

Meadow 4	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 48**	**DF**	**SS**	**MS**	**F**	**P**
Year	9	6.72	0.75	1.68	0.10	Year	10	85.82	8.582	17.14	**<0.001**
Residuals	181	80.35	0.44			Residuals	302	151.18	0.50		
Total	190	87.07	1.19			Total	312	237	9.08		
Meadow 5	**DF**	**SS**	**MS**	**F**	**P**	**M 52-57**	**DF**	**SS**	**MS**	**F**	**P**
Year	10	94.37	9.44	17.71	**<0.001**	Year	2	7.12	3.56	9.56	**<0.001**
Residuals	322	171.60	0.53			Residuals	82	30.55	0.37		
Total	332	265.97	9.97			Total	84	37.67	3.93		
Meadow 6	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 58**	**DF**	**SS**	**MS**	**F**	**P**
Year	10	115.1	11.51	15.03	**<0.001**	Year	9	32.05	3.56	5.09	**<0.001**
Residuals	400	306.2	0.77			Residuals	244	170.89	0.70		
Total	410	421.3	12.28			Total	253	202.94	4.26		
Meadow 7	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 60**	**DF**	**SS**	**MS**	**F**	**P**
Year	6	27.76	4.62	11.67	**<0.001**	Year	10	56.54	5.65	10.14	**<0.001**
Residuals	107	42.41	0.40			Residuals	116	64.69	0.56		
Total						Total	126	121.23	6.21		
Meadow 8	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 94**	**DF**	**SS**	**MS**	**F**	**P**
Year	10	59.16	5.92	10.9	**<0.001**	Year	8	124.34	15.54	22.01	**<0.001**
Residuals	323	175.36	0.543			Residuals	99	69.91	0.71		
Total	333	234.52	6.46			Total	107	194.25	16.25		
Meadow 9	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 96**	**DF**	**SS**	**MS**	**F**	**P**
Year	6	57.77	9.63	26.83	**<0.001**	Year	8	123.1	15.38	10.79	**<0.001**
Residuals	166	59.57	0.36			Residuals	275	329.0	1.43		
Total	132	117.34	9.99			Total	283	452.1	16.81		
Meadow 21	**DF**	**SS**	**MS**	**F**	**P**	**Meadow 104**	**DF**	**SS**	**MS**	**F**	**P**
Year	4	46.03	11.51	9.918	**<0.001**	Year	8	132.1	16.51	1.68	**<0.001**
Residuals	166	192.62	1.16			Residuals	185	194.8	1.05		
Total	200	238.65	12.67			Total	193	326.9	17.56		
Meadow 43	**DF**	**SS**	**MS**	**F**	**P**						
Year	10	218	21.76	4.04	**<0.001**						
Residuals	657	3541	5.39								
Total	667	3759	27.15								

Meadow 4

There was no significant difference detected in mean above-ground biomass among years at meadow 4.

Meadow 5

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	yes	yes								
2007	yes	yes	yes	yes							
2008	yes	yes	yes	no	no						
2009	no	no	no	yes	yes	yes					
2010	no	no	no	yes	yes	yes	no				
2011	no	no	no	no	yes	yes	no	no			
2012	no	no	no	yes	yes	yes	no	no	no		
2013	no	no	no	no	yes	no	no	no	no	no	

Meadow 6

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	no	no								
2007	no	no	no	no							
2008	no	no	no	no	no						
2009	no	no	no	no	no	no					
2010	no	no	no	no	no	no	no				
2011	no	no	no	no	no	no	no	no			
2012	no	no	no	no	no	no	no	no	no		
2013	no	no	no	no	no	no	no	no	no	no	

Meadow 7

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	n.a.										
2005	n.a.	yes									
2006	n.a.	no	yes								
2007	n.a.	no	yes	no							
2008	n.a.	no	no	no	no						
2009	n.a.	yes	no	yes	yes	no					
2010	n.a.	n.p	n.p	n.p	n.p	n.p	n.p				
2011	n.a.	n.p	n.p	n.p	n.p	n.p	n.p	n.p			
2012	n.a.	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p		
2013	n.a.	no	no	no	no	no	no	n.p	n.p	n.p	

n.a. data not included in analysis (n≤3), n.p. no seagrass present

Meadow 8

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	yes										
2005	yes	no									
2006	no	yes	yes								
2007	no	yes	yes	yes							
2008	yes	no	no	no	yes						
2009	yes	no	no	no	yes	no					
2010	yes	no	no	no	yes	no	no				
2011	no	no	no	no	yes	no	no	no			
2012	no	no	no	no	yes	no	no	no	no		
2013	no	no	yes	no	no	no	no	no	no	no	

Meadow 9

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	yes									
2006	yes	no	yes								
2007	yes	yes	yes	no							
2008	no	yes	no	yes	yes						
2009	no	no	yes	yes	yes	yes					
2010	n.p	n.p	n.p	n.p	n.p	n.p	n.p				
2011	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.			
2012	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p		
2013	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p	

n.a. data not included in analysis (n≤3), n.p. no seagrass present

Meadow 21

YEAR	2009	2010	2011	2012	2013
2009					
2010	no				
2011	yes	no			
2012	yes	no	no		
2013	yes	yes	no	no	

Meadow 43

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	no	no								
2007	no	no	yes	no							
2008	no	no	no	no	yes						
2009	no	no	no	no	no	no					
2010	no	no	no	no	no	no	no				
2011	no	no	yes	no	no	yes	no	no			
2012	no	no	yes	no	no	yes	no	no	no		
2013	no	no	yes	no	no	no	no	no	no	no	

Meadow 48

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	yes	yes	yes								
2007	yes	yes	yes	no							
2008	no	no	no	yes	yes						
2009	no	no	no	yes	yes	no					
2010	no	no	no	yes	yes	no	no				
2011	yes	no	no	yes	yes	yes	no	no			
2012	no	no	no	yes	yes	no	no	no	no		
2013	no	no	no	yes	yes	no	no	no	no	no	

Meadow 52-57

YEAR	2009	2010	2011	2012	2013
2009					
2010	n.a				
2011	n.a	n.a			
2012	no	n.a	n.a		
2013	yes	n.a	n.a	yes	

n.a. data not included in analysis (n≤3)

Meadow 58

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	no	no								
2007	no	yes	yes	yes							
2008	no	yes	no	yes	no						
2009	no	yes	no	yes	no	no					
2010	n.p	n.p	n.p	n.p	n.p	n.p	n.p				
2011	no	no	no	no	yes	no	no	n.p			
2012	no	no	no	no	yes	no	no	n.p	no		
2013	no	no	no	no	no	no	no	n.p	no	no	

n.p. no seagrass present

Meadow 60

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	yes										
2005	yes	no									
2006	no	yes	yes								
2007	no	yes	yes	no							
2008	no	yes	yes	no	no						
2009	yes	no	no	no	yes	yes					
2010	yes	no	no	no	yes	yes	no				
2011	yes	no	no	yes	yes	yes	no	no			
2012	no	no	no	no	no	yes	no	no	no		
2013	yes	no	no	no	yes	yes	no	no	no	no	

Meadow 94

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	n.a.										
2005	n.a.	yes									
2006	n.a.	no	no								
2007	n.a.	yes	no	no							
2008	n.a.	no	no	no	yes						
2009	n.a.	yes	yes	yes	yes	yes					
2010	n.a.	no	yes	yes	yes	yes	no				
2011	n.p	n.p	n.p	n.p	n.p	n.p	n.p	n.p			
2012	n.a.	no	yes	yes	yes	no	no	no	n.p		
2013	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p	n.p.	

n.a. data not included in analysis (n≤3), n.p. no seagrass present

Meadow 96

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	yes	no								
2007	no	yes	yes	no							
2008	yes	yes	yes	no	no						
2009	no	yes	no	no	no	yes					
2010	no	no	no	yes	yes	no	yes				
2011	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.			
2012	no	no	no	yes	no	yes	yes	no	n.p.		
2013	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

n.a. data not included in analysis (n≤3), n.p. no seagrass present

Meadow 104

YEAR	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2002											
2004	no										
2005	no	no									
2006	no	yes	no								
2007	yes	yes	no	no							
2008	no	yes	no	no	no						
2009	no	yes	no	yes	yes	yes					
2010	yes	no	yes	yes	yes	yes	no				
2011	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.			
2012	no	no	yes	yes	yes	yes	no	no	n.p.		
2013	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

n.a. data not included in analysis (n≤3), n.p. no seagrass present