Centre for Tropical Water and Aquatic Ecosystem Research

DEVELOPMENT OF SEAGRASS INDICATORS FOR THE GLADSTONE HEALTHY HARBOUR PARTNERSHIP REPORT CARD

ISP011: SEAGRASS

2015 Report

Carter AC, Jarvis JC, Bryant CV and Rasheed MA

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A Report for the Gladstone Healthy Harbour Partnership

Report No. 15/29

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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 an approach for reporting on the condition of seagrasses in the Gladstone Harbour region for incorporation into the Gladstone Healthy Harbour Partnership (GHHP) 2015 report card. Annual long-term monitoring data collected since 2002 at 14 representative seagrass meadows were used to assess the status of three seagrass indicators (mean above-ground biomass, total meadow area and species composition) relative to baseline conditions at each meadow.

We assessed various methods for setting condition thresholds around baseline conditions for meadow biomass, meadow area, and percent composition of species in each meadow. These methods included percentile bands, standard deviations, and percent change above and below the baseline. The 10 year fixed mean (calculated over the period from 2002 – 2012) was considered the most appropriate baseline for which to compare annual indicator values because it incorporates the greatest range of climate conditions known to influence seagrasses in the region for the different assessment periods examined.

Several threshold ranges were used, recognising that the biomass, area and species composition in some seagrass meadows are historically stable, while others are relatively variable over time. These differences reflect the changes in species assemblages and growth characteristics at individual monitoring meadows, and spatial variation between meadows growing in marginal inner harbour conditions, versus more favourable mid harbour conditions.

The Gladstone Harbour Report Card assesses annual levels for each seagrass condition 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’. In 2015 a scale was applied to each grade so a score between 0 and 1 could be calculated for each indicator. The lowest of the three indicator scores dictates the overall meadow score and grade.

The harbour is divided into 13 reporting zones as part of the GHHP reporting process, 6 of which contain seagrass monitoring meadows. Where multiple monitoring meadows were present within a zone, the mean of the overall meadow scores dictates the overall zone score and grade. Three Gladstone Harbour Zones were determined to be in satisfactory condition (Western Basin, Mid Harbour and South Trees Inlet (lower)), two zones were in poor condition (Inner Harbour and Rodds Bay), and one zone was in very poor condition (The Narrows). The Gladstone Harbour score is the mean of the overall zone scores. An assessment of 14 seagrass monitoring meadows determined that the overall condition of seagrass in the Gladstone Harbour region in 2014 was poor (grade D).

The report is presented into two parts. Part 1 presents the report card results for the most recent annual survey conducted in November 2014 (in the GHHP 2014-2015 reporting year). Part 2 is an accompanying technical report detailing the methods for data collection, a comparison of different methods tested to set thresholds, justification for the threshold methods used for the 2015 report card, and a detailed presentation and interpretation of the results.

KEY FINDINGS

- An assessment of 14 seagrass monitoring meadows within the Gladstone Healthy Harbour Partnership reporting zones determined that the overall condition of seagrass in the Gladstone Harbour region was poor (grade D).

- Most monitoring meadows were assessed as being in a poor or satisfactory (grade C) condition in November 2014, including all of the monitoring meadows in the Inner Harbour, Mid Harbour, South Trees Inlet (lower) and Rodds Bay Zones. The single monitoring meadow at The Narrows was in very poor condition (grade E). In the Western Basin Zone three meadows were in poor condition, one meadow was in satisfactory condition, and two meadows were in good condition (grade B). No overall meadow condition was graded as very good in 2014 (grade A).

- Three Gladstone Harbour Zones were determined to be in satisfactory condition (Western Basin, Mid Harbour and South Trees Inlet (lower)), two zones were in poor condition (Inner Harbour and Rodds Bay), and one zone was in very poor condition (The Narrows).

- Overall meadow scores (the lowest of the three indicator scores for each meadow) were mainly driven by low biomass scores in The Narrows, Inner Harbour, Mid Harbour, South Trees Inlet (lower) and Rodds Bay Zones. In the Western Basin Zone biomass determined the overall meadow score in three meadows, poor meadow area determined the overall score in two meadows, and species composition determined the overall score in one meadow.

- Gladstone seagrass condition declined following flooding and major rain and storm activity in 2003, and again in 2010-2013. Sampling for this report occurred prior to Tropical Cyclone Marcia which crossed the coast just north of Gladstone in February 2015.

- Consecutive years of relatively low condition, particularly for biomass, have likely left seagrasses with reduced resilience to further impacts.

CONTENTS

PART 1 - SEAGRASS REPORT CARD 2015

The Seagrass Ecology Group within the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University 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 (not surveyed in 2003). The program currently assesses 14 representative intertidal and shallow subtidal seagrass meadows within Gladstone Harbour and Rodds Bay (Figure 1) to monitor changes in seagrass biomass, total meadow area and species composition.

In 2014 the Seagrass Ecology Group developed a pilot approach for reporting on the condition of seagrasses in the Gladstone Harbour region. The pilot approach was developed for each of the representative monitoring meadows based on three seagrass indicators - biomass, area and species composition (Bryant et al. 2014). The method 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' (Table 1). In 2015 a scale was applied to each grade so a score between 0 and 1 could be calculated for each indicator. The lowest of the three indicator scores dictates the overall meadow score and grade (Figure 1). The harbour is divided into zones as part of the GHHP reporting process (Figure 2). Where multiple monitoring meadows were present within a zone, the mean of the overall meadow scores dictates the overall zone score and grade. The Gladstone Harbour score is the mean of the overall zone scores.

The grades presented in this report reflect the condition of seagrasses during the most recent annual survey, conducted in November 2014 (GHHP 2014-2015 reporting year). This is the second year of applying and testing the seagrass report card method and includes modifications from the GHHP 2014 pilot report card as the program has been reviewed and refined. The pilot approach relied heavily on expert opinion for setting baseline conditions and thresholds to determine meadow classes (e.g. stable or variable) and grades (Bryant et al. 2014). In 2015, alternative statistical approaches were explored to strengthen reporting. Comparisons between methods trialled in 2015 are described in Part 2 of this report.

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

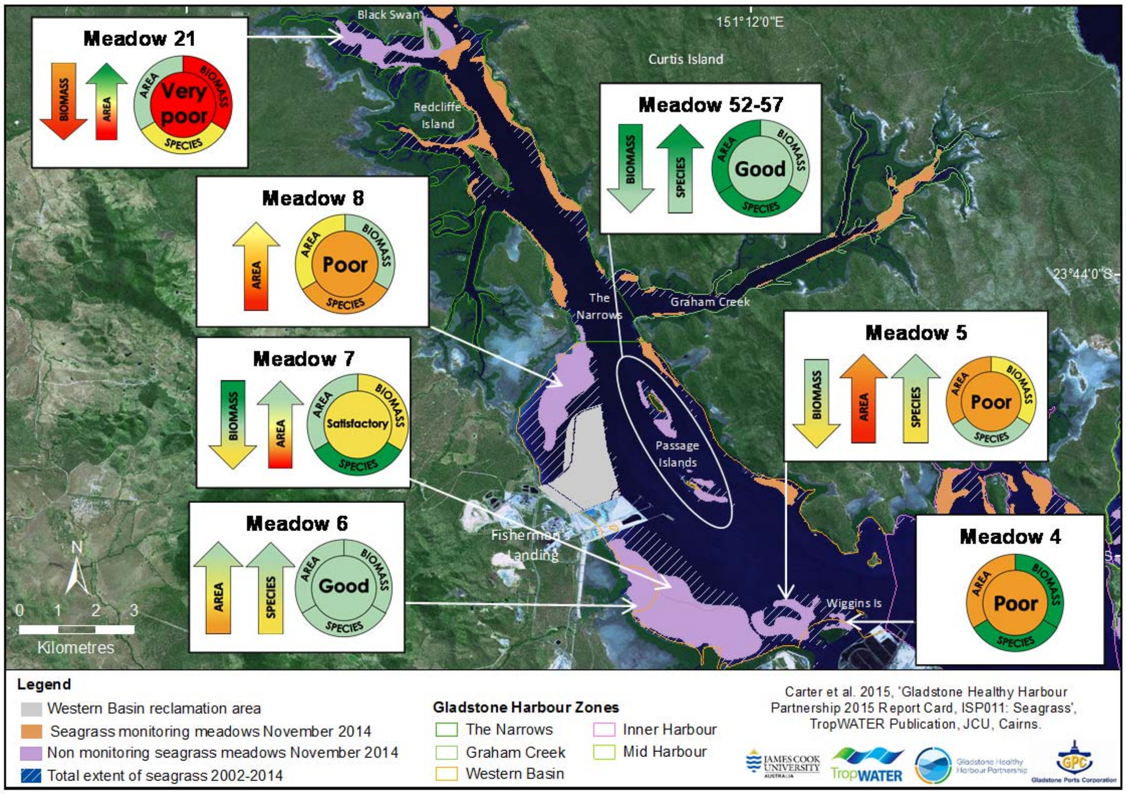
Table 1. Grades and scores for seagrass indicators (biomass, area and species composition), overall meadow, zone and region scores for Gladstone Harbour, GHHP 2014-2015 reporting year. See Table 7 for grading scale.

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION	OVERALL MEADOW SCORE	OVERALL ZONE SCORE
Western Basin	**4**	0.85	0.42	0.85	0.42	0.51
	5	0.53	0.41	0.66	0.41	
	6	0.67	0.83	0.67	0.67	
	7	0.53	0.68	1.00	0.53	
	8	0.66	0.60	0.35	0.35	
	52-57	0.67	0.94	0.88	0.67	
The Narrows	**21**	0.15	0.74	0.60	0.15	0.15
Inner Harbour	**58**	0.41	0.96	0.75	0.41	0.41
Mid Harbour	**43**	0.58	0.69	0.85	0.58	0.56
	48	0.58	0.54	0.61	0.54	
South Trees Inlet (lower)	**60**	0.52	0.96	1.00	0.52	0.52
Rodds Bay	**94**	0.42	0.92	0.84	0.42	0.45
	96	0.38	0.71	0.56	0.38	
	104	0.55	0.96	0.68	0.55	
Gladstone Harbour						**0.43**

*Cells with white diagonal lines indicate meadows where <10 years of data were available to calculate baseline values. Results for these meadows should be interpreted with caution until long-term data are available.

**Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 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).



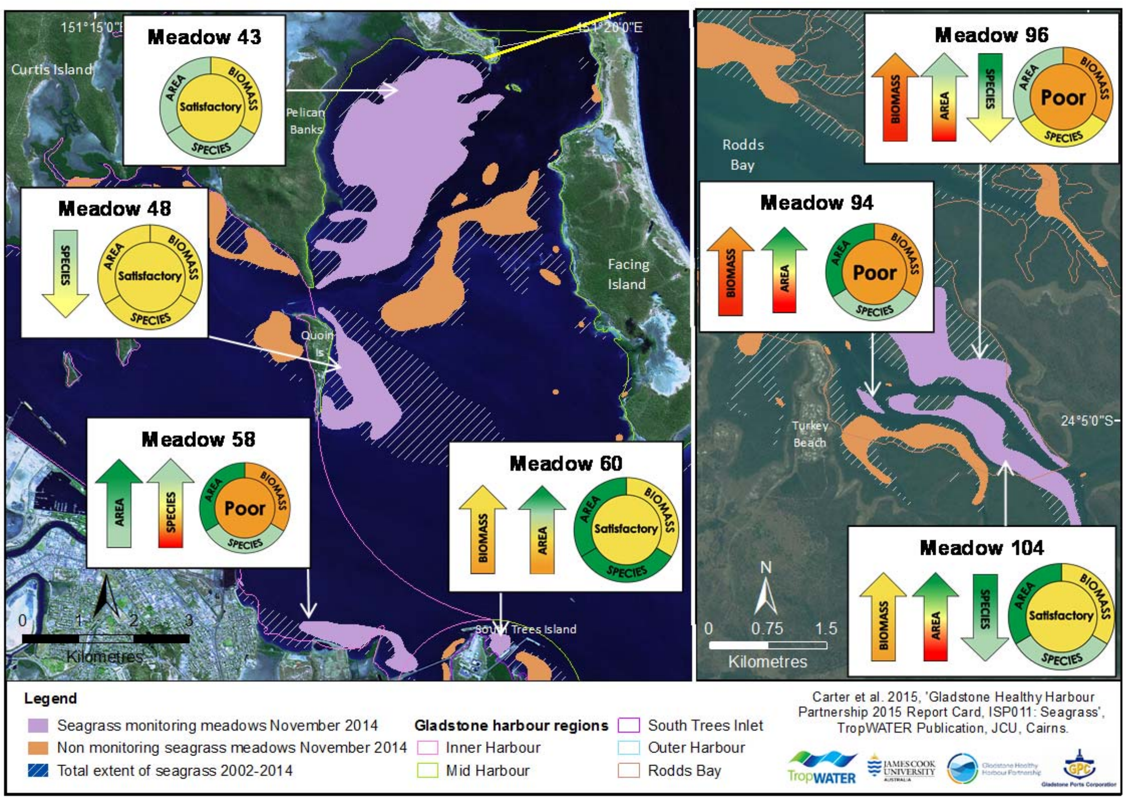
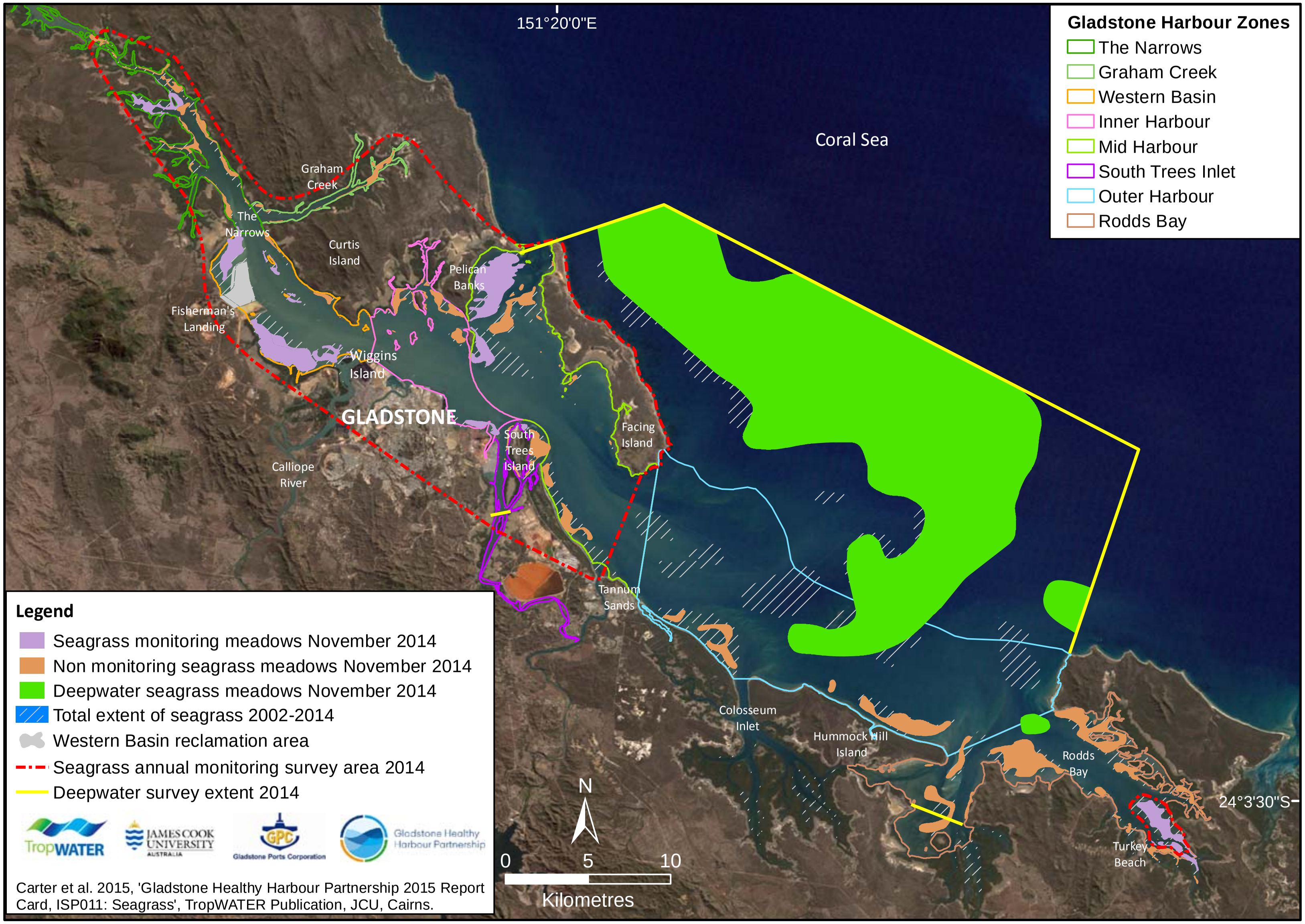


Figure 1. Seagrass condition for each indicator, and overall meadow condition for 14 monitoring meadows within six Gladstone Harbour Zones, November 2014.

Figure 2. Seagrasses in the Gladstone region and GHHP Gladstone Harbour Zones.



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, particle trapping and as carbon sinks (Costanza et al. 2014; Fourqurean et al. 2012; Hemminga and Duarte 2000). Seagrass meadows show measurable responses to changes in water quality, making them ideal sensitive receptors for monitoring the health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland's commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with various Queensland port authorities. The seagrass monitoring data that informs the Gladstone Harbour Report Card is part of this program and funded by Gladstone Ports Corporation (GPC).

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure effective management of seagrass resources. It is useful information for planning and implementing port development and maintenance programs so they have a minimal impact on seagrasses. The program also provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland.

The program delivers key information for the management of port activities to minimise impacts on seagrasses, and 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 limits and are committed to maintaining the health of these habitats. In 2002, GPC commissioned TropWATER to conduct a fine-scale baseline 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 including 7,246 ± 421 ha of coastal seagrass habitat. Subsequent surveys confirm the Gladstone Harbour region contains diverse and productive seagrass meadows and macro-benthic fauna (McKenna et al. 2014; Rasheed et al. 2003; Lee Long et al. 1992). Seagrasses in the Gladstone region are of particular value as a food source to dugong, recognised by the declaration of the Rodds Bay Dugong Protection Area (DPA).

The annual seagrass monitoring program commenced in 2004 in response to a whole of port review (SKM 2004) and following recommendations from the Port Curtis Integrated Monitoring Program (PCIMP). Initially 10 seagrass meadows representative of the range of seagrass communities within the port were selected for monitoring, and included meadows considered in 2004 most likely to be impacted by port facilities and developments. Monitoring locations include intertidal and subtidal seagrass meadows, meadows preferred by dugong, and those likely to support high fisheries productivity. Three meadows in Rodds Bay (outside port limits) were also selected as reference sites for monitoring to provide information on seagrasses unlikely to be impacted by port activity and to assist in identifying port-related versus regional causes of seagrass change.

From 2009 an additional two monitoring meadows were added to the long-term monitoring program to reflect the shift in new port activity to the Curtis Island area as part of the Western Basin developments, and these meadows are in the vicinity of the development (Meadows 21 and 52-57). Due to the expansion of the reclamation area at Fisherman's Landing, Meadow 9 is no longer monitored as part of this program.

There remains a large section from South Trees Inlet (lower) to Rodds Bay where no monitoring meadows have been included. This is because the 14 monitoring meadows were originally selected for their relevance to monitoring port activities. Ideally an additional two coastal meadows and three deepwater offshore seagrass monitoring sites should be included to fill this gap. As part of investigations associated with potential shipping channel duplication these areas were assessed in 2014 and early 2015 but there is currently no arrangement for ongoing funding for these assessments and are therefore not included at this stage in the report card.

Monitoring since 2002 has documented considerable inter-annual variability in seagrass meadow biomass and area. Variation in seagrass meadows is most likely a response to regional and local climatic conditions (Chartrand et al. 2009). Climate induced inter-annual variability is common throughout tropical seagrass meadows of the Indo-Pacific (Agawin et al. 2001). Seagrasses in Gladstone also are highly seasonal. Two broad seasons for seagrass growth have been identified in Gladstone; the growing season (July – January) where seagrasses typically increase in biomass and distribution in response to favourable conditions for growth; and the senescent season (February – June) when seagrasses typically retract and rely on stores or seeds to endure wet season conditions such as flooding, poor water quality and light reductions (Chartrand et al. 2012). The peak of the growing season occurs between October - November (corresponding to the time of annual surveys) and seagrass biomass and area is at its lowest around June.

1.2.1 **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 report on 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). The report card incorporates the best available science and monitoring into a series of indicators to make annual assessments of the condition of each asset, and Gladstone Harbour as a whole (Gladstone Healthy Harbour Partnership (GHHP) 2014).

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 (Carter et al. 2015). Recognising the long-standing association of TropWATER with seagrass research in Gladstone Harbour, the GHHP engaged TropWATER to develop a reporting method for seagrasses making use of the annual long-term monitoring data. A pilot report card was developed in 2014 (Bryant et al. 2014), with full implementation of the program including annual reporting to commence from 2015. The objectives of the 2015 report card were to:

1. Provide seagrass grades and scores for the 2015 Gladstone Harbour report card using the GHHP approved grades and scores.
2. Provide a technical report that details the methods used for collection of data over the 2014-2015 reporting period, the statistical methods used to determine the report card grades and scores, and

provide an assessment of Gladstone Harbour seagrass meadows for the 2014-2015 reporting year relative to the historical trends.

3. Provide a GIS shapefile and metadata for the seagrass monitoring meadows analysed, raw seagrass data, and R scripts used to calculate grades and scores.

1.2.2 **Seagrasses in the Gladstone Harbour Region**

Five seagrass species from two families are commonly found in the Gladstone Harbour area and referred to throughout this report (Figure 3).

Family HYDROCHARITACEAE:

Halophila decipiens
Halophila ovalis
Halophila spinulosa
Halodule uninervis (wide and narrow leaf morphology)

Family ZOSTERACEAE:

Zostera muelleri subsp. *capricorni**

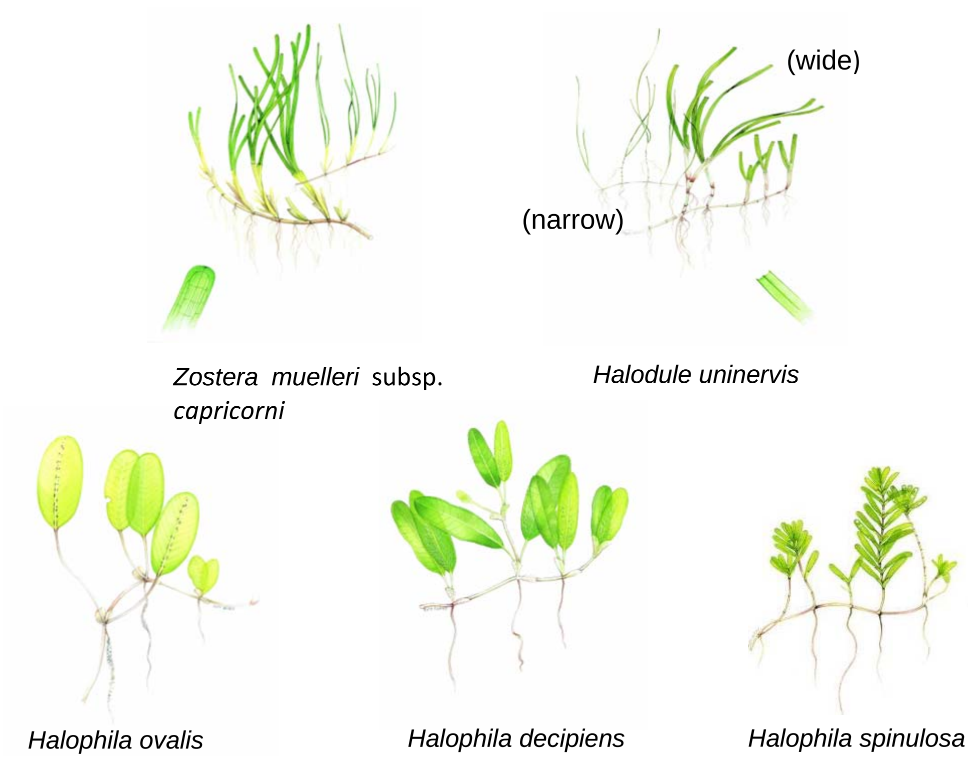


Figure 3. Seagrass species present in the Gladstone Harbour region.

*The naming convention used in previous reports has been updated to align with the accepted nomenclature for this species.

2 METHODS

2.1 Sampling Approach and Data Collection Methods for Seagrass Indicators

Fourteen representative seagrass monitoring meadows were surveyed 4-10 November 2014 (within the GHHP 2014-2015 reporting year). Surveys are conducted in the growing season (late spring) as seagrass meadows are likely to contain maximum biomass and cover the largest area (Chartrand et al. 2012). This also allows appropriate comparisons with long-term monitoring program surveys that have occurred since 2002 (Carter et al. 2015).

Survey and monitoring methods followed the established techniques for the TropWATER Queensland-wide ports seagrass monitoring program (see Unsworth et al. 2012; Rasheed and Unsworth 2011; Taylor and Rasheed 2011; Lee Long et al. 1996). Two sampling techniques were used - helicopter surveys in intertidal areas, and boat-based free diving/grab surveys in shallow subtidal areas (Figure 4). Detailed methods are described in previous Gladstone monitoring reports (Rasheed et al. 2005; Rasheed et al. 2003).

Intertidal meadows were sampled at low tide using a helicopter. GPS was used to record the position of meadow boundaries. Seagrass characteristics were recorded at sites scattered within the seagrass meadow as the helicopter hovered two metres above the seagrass. Power analysis techniques were used to determine the appropriate number of sampling sites for each meadow in order to detect seagrass meadow change (Rasheed et al. 2003).

Shallow subtidal meadows were sampled from a small boat using free divers. Seagrass characteristics were recorded at sites located along transects perpendicular to the shoreline at ~100 - 500 m intervals, 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.

2.1.1 **Biomass and proportion contribution of each species**

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (see Mellors 1991; Kirkman 1978). A 0.25 m^2 quadrat was placed randomly three times at each site. For each quadrat, an observer assigned a biomass rank between 0 and 10 made in reference to a series of 12 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 at least six photographs 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}).

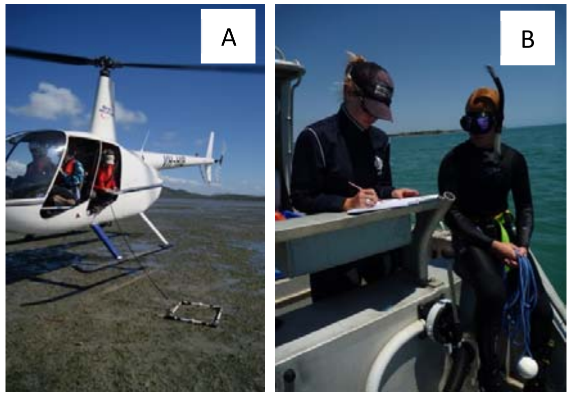


Figure 4. Seagrass monitoring conducted using (A) helicopter aerial surveillance; (B) boat based free divers.

2.1.2 Seagrass Meadow Mapping and Geographic Information System

Seagrass meadows were assigned a meadow identification number which was used to compare individual meadows between annual monitoring surveys. Monitoring meadows are referred to by these identification numbers throughout this report. The total area of monitoring meadows was determined in ArcGIS® using the GPS position of meadow boundary and sampling sites. Meadows were also assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 2). 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.

Table 2. Mapping precision and methodology for seagrass meadows in Gladstone.

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.

Spatial data from the 2014 survey were entered into the Gladstone Geographic Information System (GIS). Two seagrass GIS layers were created in ArcGIS® - site information and seagrass meadow information:

- **Site information** - Includes seagrass percent cover, seagrass above-ground biomass for each species, depth below mean sea level (dbMSL), sediment type, algal cover, time, date, latitude, longitude, sampling method, and any comments.

- **Seagrass meadow information** - Includes meadow monitoring number, meadow area and meadow reliability estimate (ha), Gladstone Harbour Zone, mean meadow biomass ± standard error, seagrass community type to describe species composition (Table 3; calculated using the proportion that each species contributes to mean meadow biomass for all sites within the meadow boundary), seagrass density categories (Table 4; categorised as light, moderate, dense according to above-ground biomass of the dominant species), seagrass meadow landscape category (Figure 5), and the meadow class, grade and score for each condition indicator (Table 6 [Section 2.2]; meadow biomass, area, species composition).

Table 3. Nomenclature for seagrass community types in Gladstone.

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 4. Seagrass density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in Gladstone.

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

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 5. Seagrass meadow landscape categories: (A) Isolated seagrass patches, (B) Aggregated seagrass patches, (C) continuous seagrass cover.

2.2 Seagrass Condition Matrix

A condition index was developed for the 14 seagrass monitoring meadows within Port Curtis based on changes in mean above-ground biomass, total meadow area and species composition. Meadow condition was divided into one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor) by comparing the current meadow condition against the baseline. We compared three different methods to set thresholds to define conditions at each monitoring meadow (Section 2.2.3).

2.2.1 **Baseline Conditions**

Baseline conditions for biomass and area were established from a fixed 10 year mean calculated over the period from 2002 - 2012 (nb. no survey conducted in 2003). This baseline was set based on results of the 2014 pilot report card (Bryant et al. 2014). The 2002 - 2012 period incorporates a range of conditions present in Gladstone Harbour, including El Niño and La Niña periods, multiple extreme rainfall and river flow events (Carter et al. 2015), large-scale capital dredging (Western Basin Dredging and Disposal Project, 2011-2013), and annual maintenance dredging. In some cases less than 10 years of data were available, e.g. meadows 21 and 52-57 have only been surveyed since 2009, or species composition data were unavailable for years where no seagrass was present. In this instance the baseline was calculated over the longest available time period excluding the year of interest (i.e. 2014).

Baseline conditions for species composition were determined at the meadow level based on the percent contribution of each species to the mean meadow biomass. Meadows were classified as either single species dominated (one species comprising ≥80% of mean meadow biomass over the baseline period), or mixed species (all species comprise <80% of mean meadow biomass over the baseline period). As with biomass and area, the species composition baseline was calculated from a fixed 10 year mean calculated over the period from 2002 - 2012 (nb. no survey conducted in 2003). However, the calculation was based only on the percent composition of what was considered the "stable state" species in each meadow. For most meadows the stable state species was also the dominant species, i.e. comprised >50% of mean meadow biomass. However, in meadows 4 and 52-57 it was determined that the stable state species was *Z. muelleri* subsp. *capricorni*, despite this species comprising 46% and 32% of mean meadow biomass respectively. This determination was made for these meadows as the rest of the species mix was made up of typically ephemeral *Halophila* species, with the higher successional species, *Z. muelleri* subsp. *capricorni* considered to be a key feature for maintenance of a desired state for these meadows.

2.2.2 Meadow Classification

A meadow classification system was developed for biomass, area and species composition in recognition that for some seagrass meadows these condition indicators are historically stable, while in other meadows they are relatively variable. The objective of classifying meadows was to impose smaller (more sensitive) thresholds on meadows that, based on their history, are not expected to vary greatly in terms of biomass, area or species composition, compared with more ephemeral meadows. The coefficient of variation (CV) was used to determine the historical variability for each meadow and classify meadows as stable or variable for biomass and species composition (Table 5). A third classification for meadow area was used, "highly variable" recognising that some subtidal ephemeral meadows have a naturally extreme level of variation (Table 5). The CV was calculated by dividing the standard deviation of the baseline by the baseline (i.e. 10 year mean) for each of the three condition indicators.

Classifications were then used to define which set of threshold levels were appropriate to apply around each monitoring meadow's biomass, area and species composition baseline (Section 2.2.3).

Table 5. Coefficient of variation (CV) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

Indicator	Class		
	Stable	**Variable**	**Highly variable**
Biomass	CV < 40%	CV $\geq$ 40%	-
Area	CV < 40%	CV $\geq$ 40, <80%	CV $\geq$ 80%
Species composition	CV < 40%	CV $\geq$ 40%	-

2.2.3 Selection of Threshold Levels for Grading Indicators

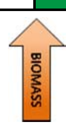
Three different approaches were investigated to determine appropriate thresholds around the baseline for each indicator, and to determine their suitability for application in the GHHP seagrass report card. These approaches were percent above and below the baseline, percentiles, and standard deviation from the baseline.

2.2.3.1 *Percent Above and Below the Baseline*

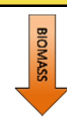
Threshold levels determining the condition of indicators (biomass, area, species composition) relative to the baseline (long-term mean, 2002-2012) were selected based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region. During the pilot report card in 2014 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 for both stable and variable meadow types (Bryant et al. 2014). We also determined during this assessment phase that for many years where the meadow was determined to be in good condition based on expert opinion, data points were often slightly below the baseline. Therefore the thresholds for good condition were set above and below the baseline, rather than using the baseline as a demarcation between good and satisfactory condition. The final range of threshold values was then applied across all monitoring meadows in 2015 (Table 6).

Table 6. Threshold levels for grading seagrass indicators for various meadow classes.

Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very good	**B Good**	**C Satisfactory**	**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
	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
	Variable	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
Species composition	Stable; Single species dominated	More than 0% above the baseline	<20% below the baseline	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Stable; Mixed species	More than 20% above the baseline	<40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
	Variable; Single species dominated	More than 0% above the baseline	<20% below the baseline	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
	Variable; Mixed species	More than 20% above the baseline	<40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline



Increase above threshold from the previous year



Decrease below threshold from the previous year

2.2.3.2 ***Percentiles***

The 75th, 50th, 20th and 10th percentiles of biomass and area data from each monitoring meadow were calculated over the period from 2002 to 2013 and assessed for appropriateness in determining category thresholds, similar to that used in the Reef Rescue Marine Monitoring Program seagrass abundance guidelines (McKenzie et al. *in review*). Due to the large number of zeros in the dataset (> 60%) percentiles were calculated using the mean biomass/area for each year. A two parameter exponential rise to maximum regression was then fitted to biomass/area percentile values at each sampling event with the model:

$$y = a\left(1 - e^{-bx}\right)$$

Where *y* is seagrass biomass/area at each sampling event (x), *a* is the asymptotic mean of the seagrass biomass/area percentile and *b* is the rate coefficient (McKenzie et al. *in review*). The asymptotic mean was then used to define the corresponding percentile values. Meadow condition was scored as follows:

- > 75th percentile = very good
- >50th to 75th percentile = good
- >20th to 50th percentile = satisfactory
- >10th to 20th percentile = poor
- $\leq$ 10th percentile = very poor

2.2.3.3 ***Standard Deviation from Baseline***

Standard deviations (SD) from the baseline (long-term mean, 2002-2012) were calculated using the annual mean biomass and area for all monitoring meadows. A range of different thresholds based on number of standard deviations from the baseline were assessed to determine how well they could describe meadow condition. Meadow condition thresholds were scored following recommendations from the GHHP Statistics Team (ISP008) as follows:

- >+2 SD from the mean = very good
- >+1 to +2 SD from the mean = good
- ± 1 SD from the mean = satisfactory
- >-1 to -2 SD from the mean =poor
- >-2 SD from the mean = very poor

2.2.4 Grades and Scores

For the 2015 report card, GHHP requested that a grading scale be adopted so that a score between 0 and 1 could be calculated for each condition indicator, each meadow, each Gladstone Harbour Zone, and for the whole Gladstone Harbour (Table 7).

Table 7. The grading scale used in the 2015 Gladstone Harbour report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥0.25	<0.50
E	Very poor	0.00	<0.25

2.2.4.1 ***Biomass, Area and Species Composition Score Calculations***

Calculating the score for each condition indicator required determining the 2014 grade for each indicator, then scaling the 2014 value for biomass, area or species composition against the prescribed score range for that grade. Scaling was required because the score range in each grade was not equal (Table 7). This involved several steps. An example of calculating a meadow score for area in satisfactory condition is provided below. A worked example with R script for Meadow 8 area is provided in the Appendix.

1. Determine the grade for the 2014 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2014 area value (A_{2014}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$\mathrm{A_{diff}} = \mathrm{A_{2014}} - \mathrm{A_{satisfactory}}$$

Where $A_{satisfactory}$ or any other threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (stable, variable, highly variable [area only]), and whether the meadow is dominated by a single species or mixed species.

3. Calculate the range for area values (A_{range}) in that grade:

$$\mathrm{A_{range}} = \mathrm{A_{good}} - \mathrm{A_{satisfactory}}$$

Where $A_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.
Note: For species composition, the upper limit for the very good grade was set as 100%. For area and biomass, the upper limit for the very good grade was set as the mean plus the standard error (i.e. the top of the error bar) for the maximum recorded mean annual value for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (A_{prop}) that A_{2014} takes up:

$$\mathrm{A_{prop}} = \frac{\mathrm{A_{diff}}}{\mathrm{A_{range}}}$$

5. Determine the area score for 2014 ($Score_{2014}$) by scaling A_{prop} against the GHHP score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$\mathrm{Score_{2014}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{A_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

Where $LB_{satisfactory}$ is the GHHP defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

Each overall meadow grade and score was determined by the lowest grade and score of the three condition indicators (biomass, area and species composition) within that meadow. The lowest score, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these three fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method was also applied to the 2014 pilot report card to enable the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

2.2.4.2 ***Species Composition Grades and Scores***

Where species composition was determined to be anything less than in very good condition, a decision tree was used to determine whether "equivalent" or "more stable" species (based on Kendrick et al. 2012; Waycott et al. 2007) were driving this grade (Figure 6). If this was the case then the species composition score and grade for that year was recalculated including the equivalent/stable species. Judgement regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern. This would occur when the stable state species is replaced by species considered to be earlier "colonisers" (Waycott et al. 2007). Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *Z. muelleri* subsp. *capricorni* and *H. uninervis*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. spinulosa* or any other species).

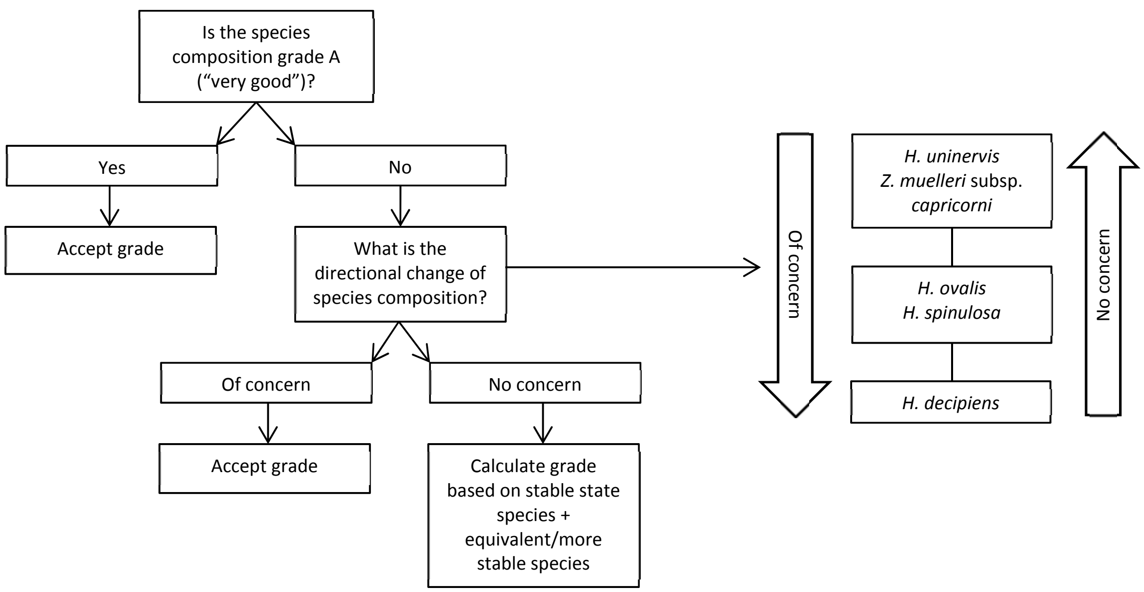


Figure 6. Decision tree and directional change assessment for grading and scoring species composition in Gladstone.

2.2.4.3 ***Zone Grades and Scores***

The overall score and grade for each Gladstone Harbour Zone was determined by averaging the overall score for each monitoring meadow within a given zone, and assigning the corresponding grade to that score (Figure 7; Table 7). Where multiple meadows were present within a zone, meadows were not subjected to a weighting system at this stage of the analysis. The classification process (Section 2.2.2) at the meadow analysis stage applied smaller and therefore more sensitive thresholds for meadows considered stable, and applied less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Zone grades are therefore more sensitive to changes in stable than variable meadows.

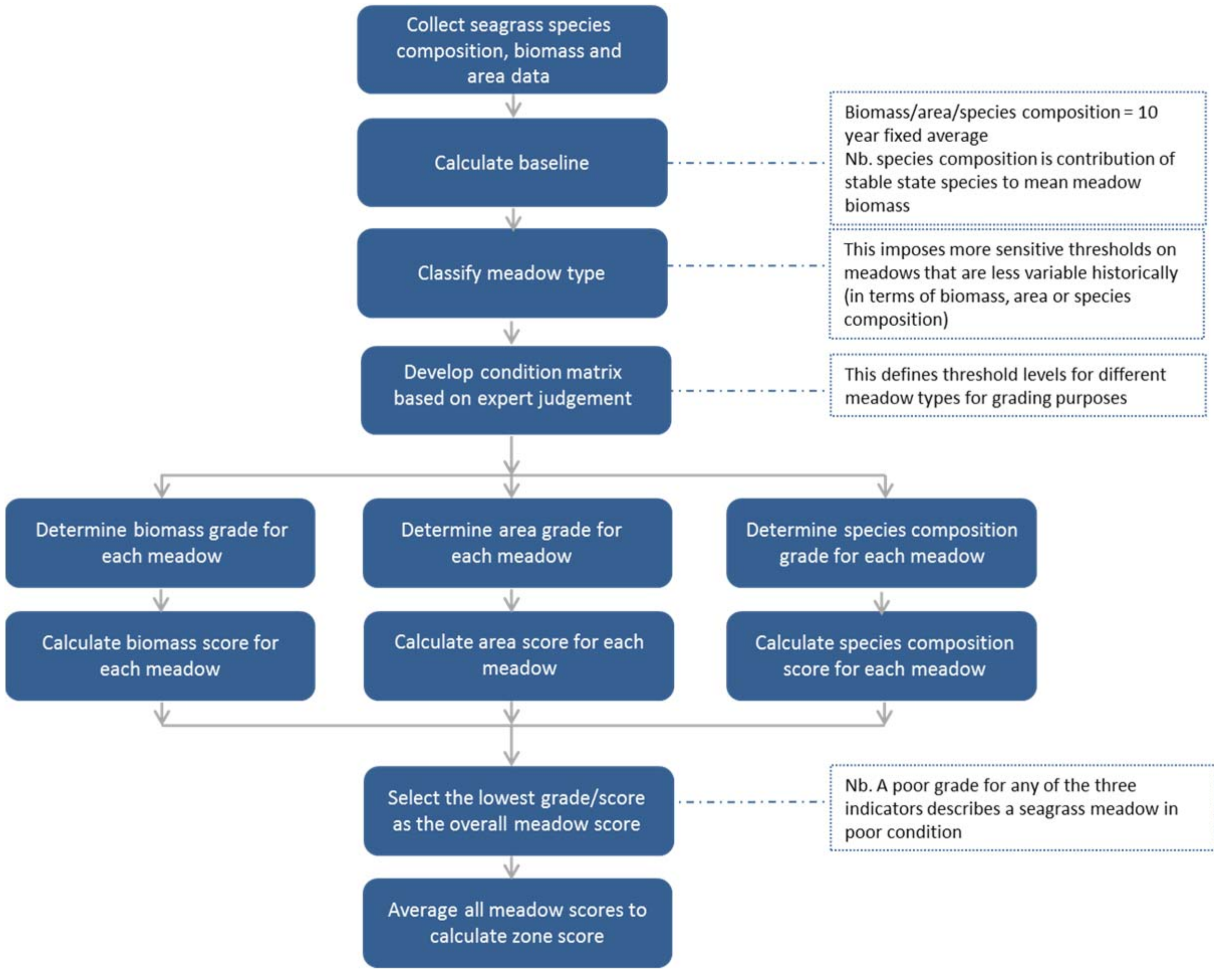


Figure 7. Flow chart to develop Gladstone Harbour Zone grades and scores.

2.2.4.4 ***Harbour Grade and Score***

The overall score and grade for Gladstone Harbour was determined by averaging the overall zone scores for each zone where monitoring meadows were present, and assigning the corresponding grade to that score (Table 7).

3 RESULTS

3.1 Meadow Classifications

Biomass was classed as variable in 13 of the 14 monitoring meadows (Table 8). Meadows were more likely to be stable in terms of area or species composition. Fifty percent of meadows were classed as having stable area, while the majority of meadows contained a stable species composition. All meadows where a single species dominated (>80% of mean meadow biomass) were classed as having stable species composition. Only one meadow was classed as stable across all three condition indicators – the large (~600 ha), high biomass (~19 g DW m^{-2}), *Z. muelleri* subsp. *capricorni* dominated (~98%) meadow at Pelican Banks (meadow 43) (Table 8).

Table 8. Classifications representing the historical stability or variability of seagrass meadow biomass, area and species composition within Gladstone Harbour Zones. Classifications were based on the coefficient of variation of the 10 year mean for each indicator (baseline; 2002-2012).

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION
Western Basin	**4**	Variable	Variable	Variable - mixed species
	5	Variable	Stable	Variable - mixed species
	6	Variable	Stable	Variable - mixed species
	7	Variable	Highly Variable	Stable - single species
	8	Variable	Stable	Stable - mixed species
	52-57	Variable	Highly Variable	Variable - mixed species
The Narrows	**21**	Variable	Stable	Stable - mixed species
Inner Harbour	**58**	Variable	Highly Variable	Variable - mixed species
Mid Harbour	**43**	Stable	Stable	Stable - single species
	48	Variable	Variable	Stable - single species
South Trees Inlet (lower)	**60**	Variable	Variable	Stable - single species
Rodds Bay	**94**	Variable	Stable	Stable - single species
	96	Variable	Variable	Stable - single species
	104	Variable	Stable	Stable - single species

*Classification of meadows 52-57 and 21 was assessed on <10 years of data. Results should be interpreted with caution until long-term data are available.

**Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

3.2 Comparison of Threshold Selection Methods

3.2.1 **Percent Above and Below the Baseline**

This was the only method trialled that successfully described seagrass condition across all three indicators and for all 14 meadows. Threshold values established as part of the 2014 pilot report card were used to score seagrass biomass and area for all monitoring meadows in 2015 (Table 9). 2015 was the first GHHP reporting year that this method was also applied to species composition. The 10 year mean, based on data from 2002-2012, was selected as this time period represents a number of natural climatic events known to impact seagrasses as well as years of favourable growing conditions. Threshold values set based on expert opinion and meadow classification incorporated natural variability within the meadow, allowing for scores to reflect external drivers rather than inherent meadow variation.

3.2.2 Percentiles

Both the biomass and area raw value datasets contained >60% zeros. To overcome this issue the annual value for each metric was used to calculate percentiles for each monitoring meadow. As a result the asymptotic mean used to define the corresponding percentile values was based on 12 points, which is less than the recommended range of 15-20 sampling points used to determine percentile values for seagrass cover in the Reef Rescue MMP program (McKenzie et al. *in review*). Regardless of classification, the equations calculated from the reduced dataset failed to accurately describe the data and the calculated percentile values resulted in threshold values that were not stable (Figure 8).

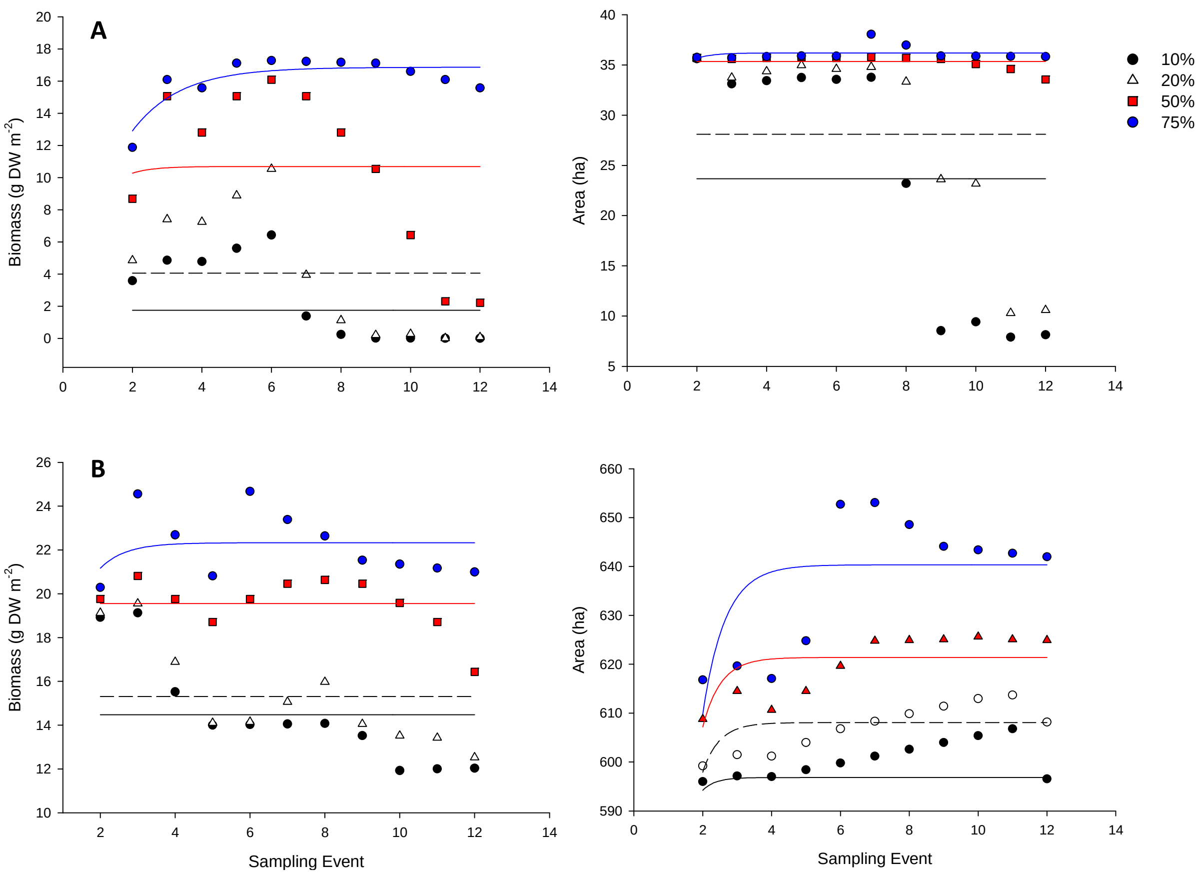


Figure 8. Relationship between sample size and error in estimation in percentile values for A) biomass and area of meadow 4 (variable biomass/ variable area) and B) meadow 43 (stable biomass/ stable area).

Percentiles were deemed unsuitable for threshold setting because of the inherent assumption that a percentage of the historical dataset represents each condition or category. For example, if the 20th percentile is deemed the threshold for “poor” condition, then 20% of the historical records fall below this threshold regardless of whether this is an accurate description of seagrass condition. For some meadows this holds true, but for the majority of meadows in Gladstone (and other sites in our Queensland monitoring network we examined) this is not the case. Analysis of meadow 43 illustrates the problem with percentiles well. Seagrass meadow area and biomass were classed as stable and the meadow was graded as being in satisfactory condition for biomass and good condition for area in 2014, based on the 10 year fixed mean (Figures 9b and 10b). However, thresholds based on percentiles meant the grade for meadow 43 dropped to poor condition for biomass and very poor condition for area (Figures 9a and 10a). This resulted in meadow area being graded as poor or very poor condition for 8 of the 12 years seagrass was monitored, despite area never declining to a concerning level and remaining relatively stable above 600 ha throughout the 12 years of monitoring (Figure 10a). The large variation in threshold bandwidth for all threshold values also reflects the unstable threshold values in the percentile analysis (Figures 9a and 10a).

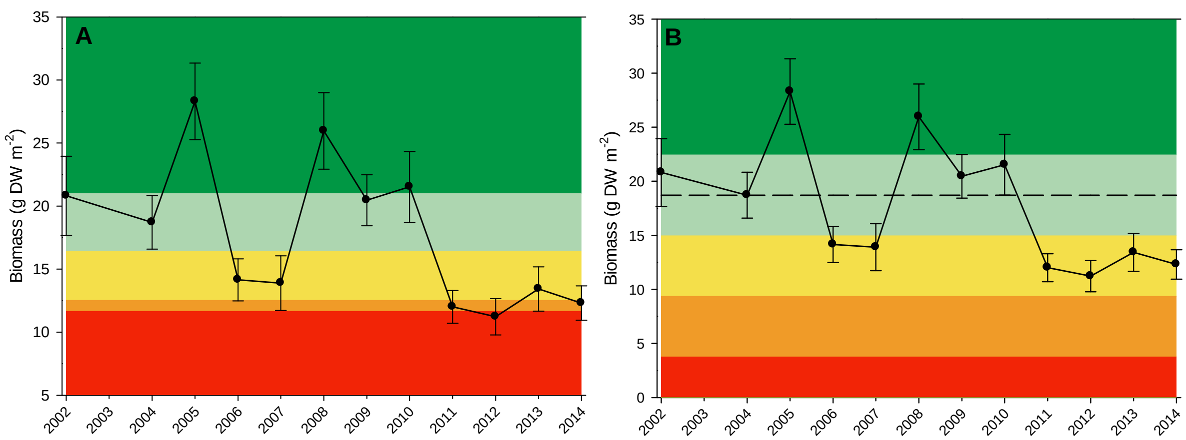


Figure 9. Mean meadow biomass (+ standard error) during annual (November) surveys at monitoring meadow 43 graded in relation to A) the percentiles based on 12 sampling points, and B) the fixed 10 year mean baseline.

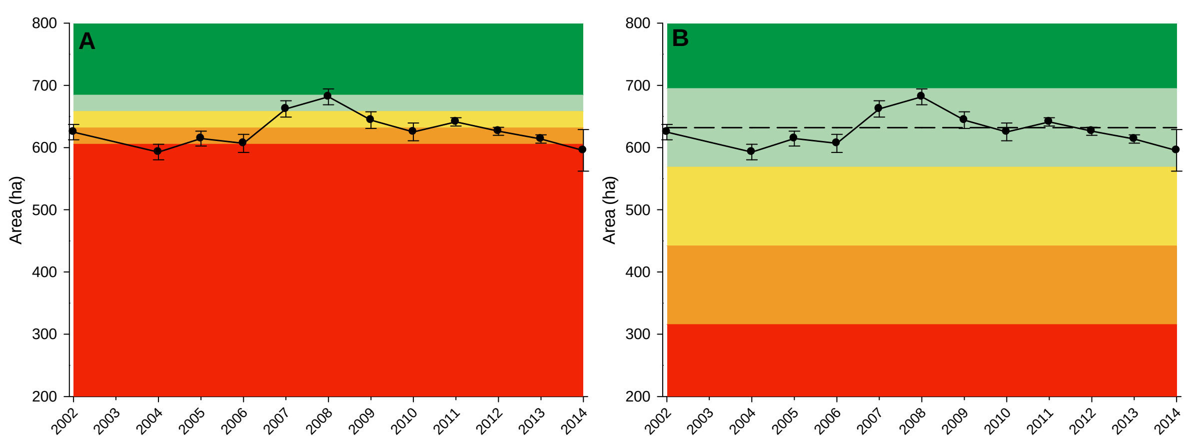


Figure 10. Total meadow area (+ reliability estimate) during annual (November) surveys at monitoring meadow 43 graded in relation to A) the percentiles based on 12 sampling points and B) the fixed 10 year mean baseline.

3.2.3 **Standard Deviation from Baseline**

Due to the large natural variation inherent in some monitoring meadows (see Table 8) calculating standard deviations (SD) from the mean resulted in negative values for meadow biomass and area in meadows classified as variable or highly variable. For example, in meadow 94 biomass thresholds were negative (-0.81 g DW m^{-2}) at 1 SD below the mean (Figure 11a). As a result, SD-based biomass grades in this meadow could not fall below satisfactory condition, as biomass cannot be a negative number. In comparison, scores based on the 10-year fixed mean grade biomass in meadow 94 in poor condition (Figure 11b). Issues of large variation in threshold bandwidth also were apparent in highly variable meadows when SD-based threshold values were applied (Figure 12a) versus those calculated based on the fixed long-term mean (Figure 12b). As a result using standard deviation as a means of setting thresholds was deemed unsuitable.

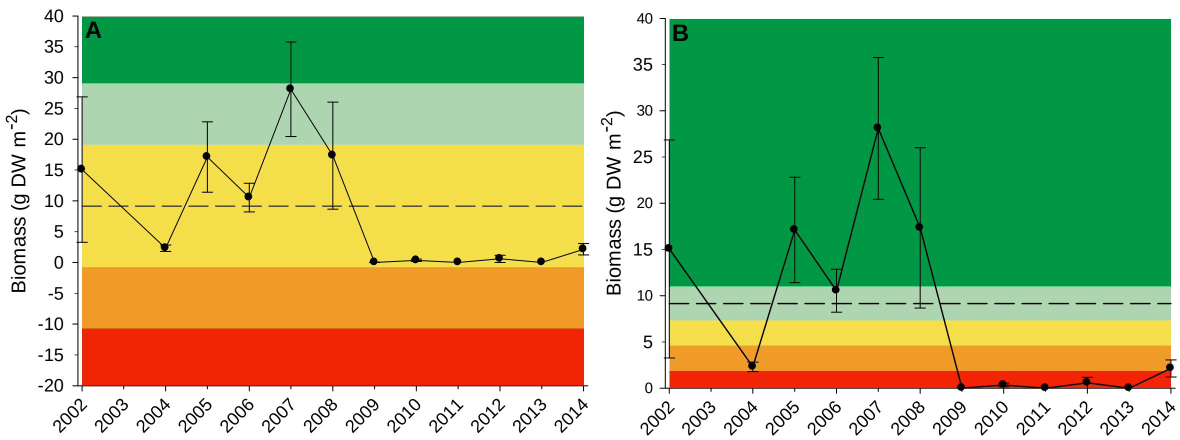


Figure 11. Mean biomass (± standard error) during annual (November) surveys at monitoring meadow 94 in relation to A) standard deviation based threshold values, and B) the fixed 10 year mean baseline. Note the negative biomass axis in A.

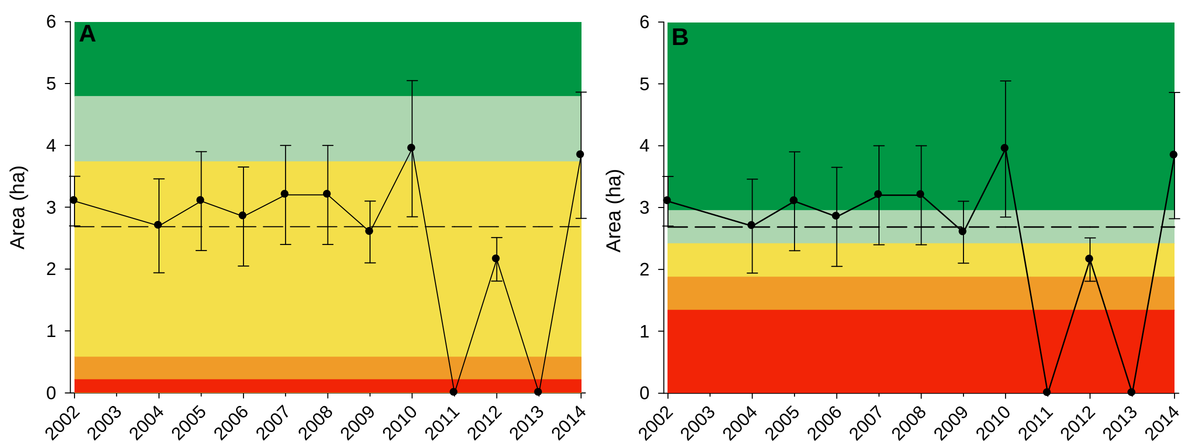


Figure 12. Mean area (± reliability estimate) during annual (November) surveys at monitoring meadow 94 in relation to A) standard deviation based threshold values, and B) the fixed 10 year mean baseline.

3.3 Overall Meadow, Zone and Harbour Scores

An assessment of 14 seagrass monitoring meadows determined that most meadows were in a poor or satisfactory condition in November 2014 (Table 9). This included all of the monitoring meadows in the Inner Harbour, Mid Harbour, South Trees Inlet (lower) and Rodds Bay Zones. The single monitoring meadow at The Narrows was in very poor condition. In the Western Basin Zone three meadows were in poor condition, one meadow was in satisfactory condition, and two meadows were in good condition. No overall meadow condition was graded as very good.

Three Gladstone Harbour Zones were determined to be in satisfactory condition (Western Basin, Mid Harbour and South Trees Inlet (lower)), two zones were in poor condition (Inner Harbour and Rodds Bay), and one zone was in very poor condition (The Narrows). The overall condition of seagrass in the Gladstone Harbour region was graded as poor based on the mean of the six zone scores (Table 9).

Overall meadow scores (the lowest of the three indicator scores for each meadow) were mainly driven by low biomass scores in The Narrows, Inner Harbour, Mid Harbour, South Trees Inlet (lower) and Rodds Bay Zones. In the Western Basin Zone biomass determined the overall meadow score in three meadows, poor meadow area determined the overall score in two meadows, and species composition determined the overall score in one meadow (Table 9).

Table 9. Grades and scores for seagrass indicators (biomass, area and species composition), overall meadow, zone and region scores for Gladstone Harbour in the GHHP 2014-2015 reporting year. See Table 7 for grading scale.

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION	OVERALL MEADOW SCORE	OVERALL ZONE SCORE
Western Basin	**4**	0.85	0.42	0.85	0.42	0.51
	5	0.53	0.41	0.66	0.41	
	6	0.67	0.83	0.67	0.67	
	7	0.53	0.68	1.00	0.53	
	8	0.66	0.60	0.35	0.35	
	52-57	0.67	0.94	0.88	0.67	
The Narrows	**21**	0.15	0.74	0.60	0.15	0.15
Inner Harbour	**58**	0.41	0.96	0.75	0.41	0.41
Mid Harbour	**43**	0.58	0.69	0.85	0.58	0.56
	48	0.58	0.54	0.61	0.54	
South Trees Inlet (lower)	**60**	0.52	0.96	1.00	0.52	0.52
Rodds Bay	**94**	0.42	0.92	0.84	0.42	0.45
	96	0.38	0.71	0.56	0.38	
	104	0.55	0.96	0.68	0.55	
Gladstone Harbour						**0.43**

*Cells with white diagonal lines indicate meadows where <10 years of data were available to calculate baseline values. Results for these meadows should be interpreted with caution until long-term data are available.
**Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

3.4 Report Card Grades for the 2014-2015 Reporting Year

Below is a detailed justification for the grading of individual indicators, meadows and zones in the GHHP 2014-2015 reporting year. The results presented here reflect the condition of seagrasses during the most recent annual survey conducted in November 2014. Individual monitoring meadows were allocated to the zone where the majority of the meadow area lies.

3.4.1 **Zone 3 Western Basin**

Zone 3 Western Basin was given an overall grade of a C (satisfactory). There are six monitoring meadows in the Western Basin Zone (Figure 13).

Note: Meadow 9 was included in the GHHP 2014 pilot report card but is excluded from 2015 assessments. This is because the meadow was covered by the Fisherman's Landing reclamation so has no potential for recovery.

Meadow 4

Meadow 4 at Wiggins Island (Figure 14) is an intertidal meadow comprised of aggregated patches of seagrass. Species composition is variable; the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2014 the dominant species was *Z. muelleri* subsp. *capricorni.* The mean biomass and area of the meadow is classed as variable. Mean biomass has remained low (<2 g DW m^{-2}) since monitoring began. The total area of meadow 4 was relatively consistent between 2002 and 2009 (~30 – 40 ha), after which time meadow area declined. This meadow was graded as being in poor condition in 2014 due to the relatively small meadow area compared with the baseline area of 29 ha.

Meadow 5

Meadow 5 west of Wiggins Island (Figure 15) is an intertidal meadow comprised of aggregated patches of seagrass. Species composition is variable; the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2014 the dominant species was *H. ovalis.* The mean biomass of the meadow has been variable over the course of monitoring, ranging from <1 g DW m^{-2} in 2004 and 2010 to >8 g DW m^{-2} in 2007. Meadow area is classed as stable, although this meadow also underwent area declines after 2009. This meadow was graded as being in poor condition in 2014 due to the relatively small meadow area compared with the baseline area of 135 ha.

Meadow 6

Meadow 8 at South Fisherman's Landing (Figure 16) is an intertidal meadow comprised of aggregated patches of seagrass. Species composition is variable; the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2014 the dominant species was *H. ovalis.* The mean biomass of the meadow has been variable over the course of monitoring, ranging from <1 g DW m^{-2} in 2004 and 2010 to >6 g DW m^{-2} in 2007. Meadow area is classed as stable, although this meadow underwent area declines from 2009. Biomass, area and species composition were all graded as being in good condition in 2014.

Meadow 7

Meadow 7 at South Fisherman's Landing (Figure 17) is a subtidal meadow comprised of aggregated patches of seagrass. Species composition is stable; the dominant species is traditionally *H. decipiens* (96% of mean meadow biomass). *H. ovalis* also is often present in the meadow. Meadow area is classed as highly variable, ranging from >200 ha in 2006 to 0 ha in 2010. The meadow was graded as being in very poor condition between 2010 and 2012 following the loss of meadow area and biomass. Biomass of the meadow is classed as variable, ranging from <0 g DW m^{-2} (2005, 2010 – 2012) to >4 g DW m^{-2} in 2007. Meadow 7 was graded as being in satisfactory condition in 2014 due to biomass being >40% below the baseline of 1.4 g DW m^{-2}.

Meadow 8

Meadow 8 at North Fisherman's Landing (Figure 18) is an intertidal meadow comprised of aggregated patches of seagrass. Species composition is stable; the dominant species is traditionally *Z. muelleri* subsp. *capricorni* (67% of mean meadow biomass). However, between 2010 and 2014 the meadow was dominated by *H. ovalis* and *H. decipiens.* The meadow was graded as being in poor condition in 2014 due to the lack of *Z. muelleri* subsp. *capricorni* (21% of mean meadow biomass). Biomass of the meadow has been variable over the course of monitoring, ranging from <0.1 g DW m^{-2} to 4 g DW m^{-2} in 2007. Meadow area is classed as stable, although this meadow also underwent area declines from 2010.

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

Meadows 52-57

Meadows 52-57 around the Passage Islands (Figure 19) are a group of predominantly intertidal meadows comprised of aggregated patches of *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens.* Species composition is variable; the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2014 species composition was graded as very good because meadow biomass was comprised of a greater proportion of *Z. muelleri* subsp. *capricorni* (48%) than the baseline of 29%*.* Meadow area is classed as highly variable, ranging from <0.5 ha in 2010 to 44 ha in 2014 (very good condition for area). Mean biomass has remained low (<2 g DW m^{-2}) and variable since monitoring began. This meadow was graded as being in good condition in 2014 due to biomass being <40% below the baseline value of 0.55 g DW m^{-2}.

Note: This meadow has only been surveyed as part of the annual monitoring program since 2009. Baseline levels and resulting grades should be interpreted with caution until the full 10 years of data are available.

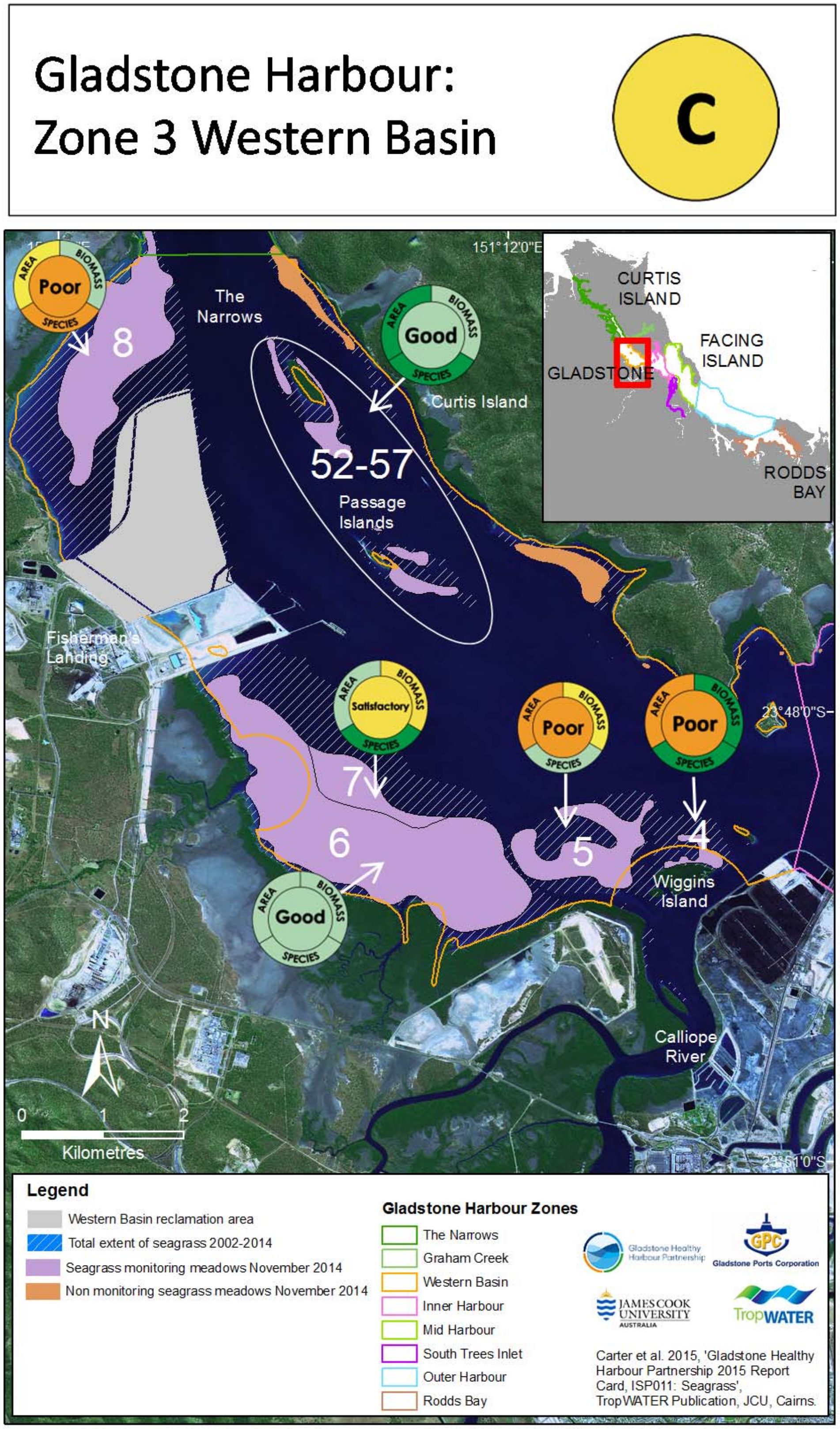


Figure 13. Seagrass condition in Zone 3 Western Basin in November 2014.

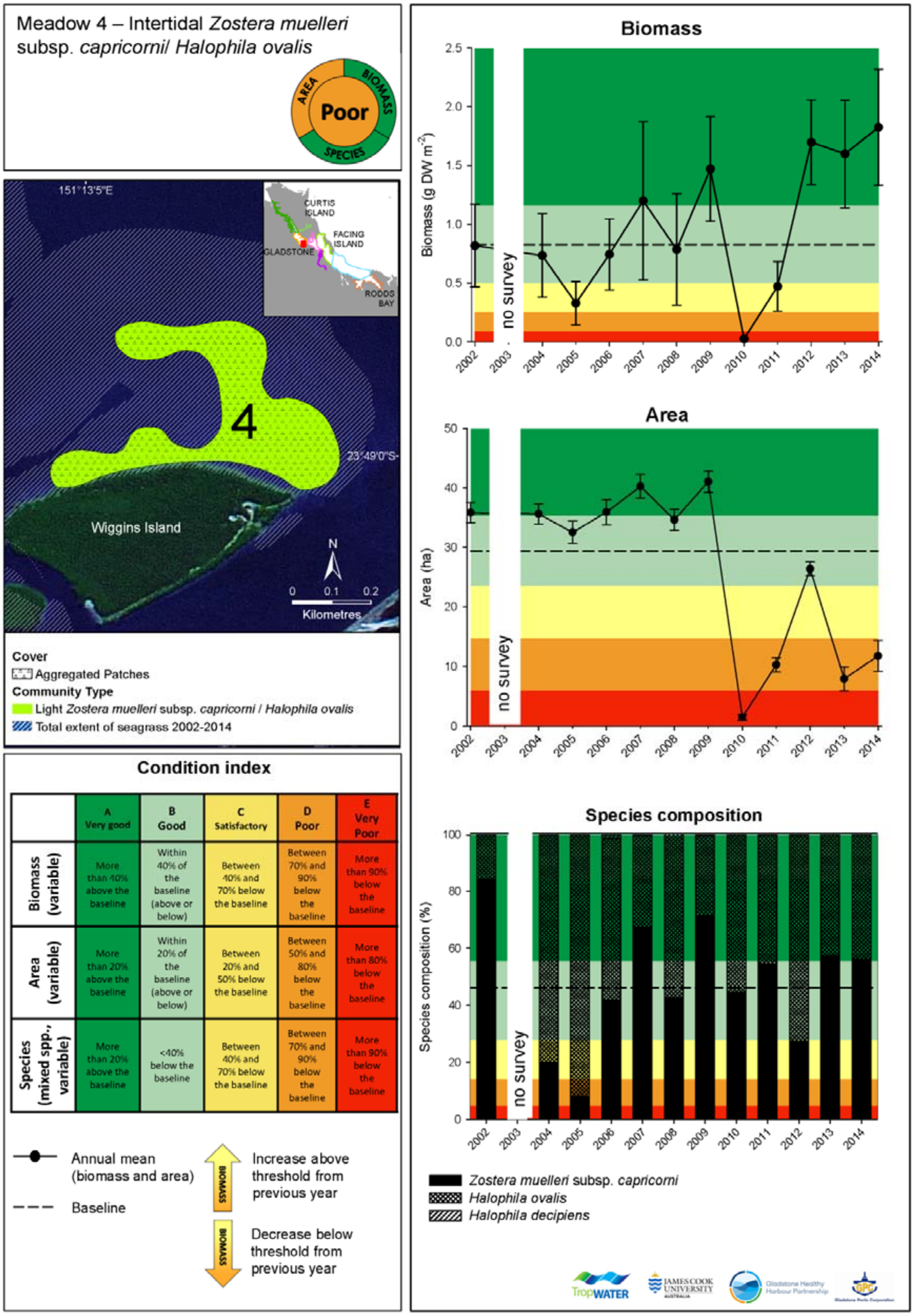


Figure 14. Changes in meadow area, biomass and species composition for seagrass in Zone 3 Western Basin, Meadow 4, Wiggins Island, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

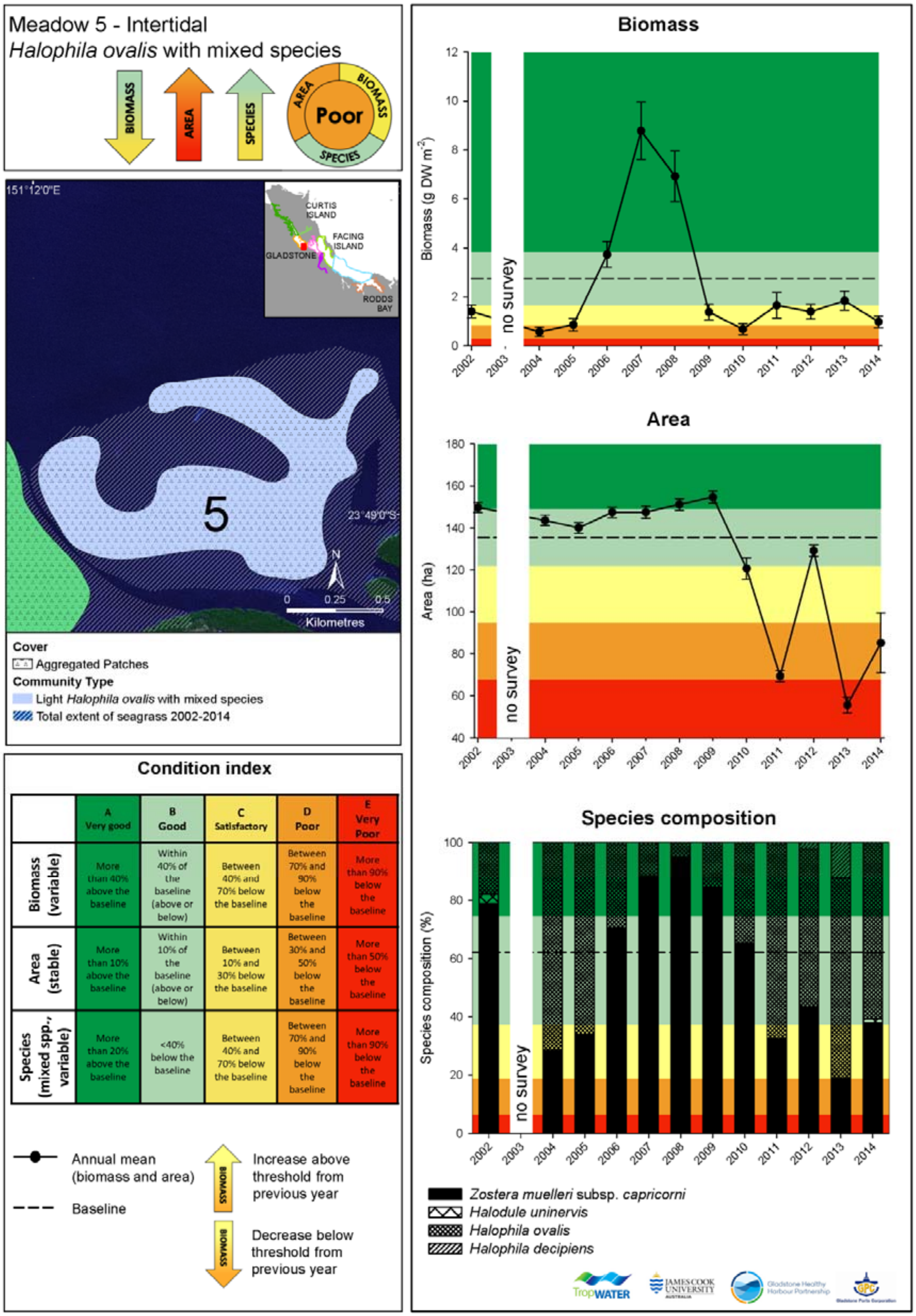


Figure 15. Changes in mean biomass, meadow area and species composition for seagrass in Zone 3 Western Basin, Meadow 5, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

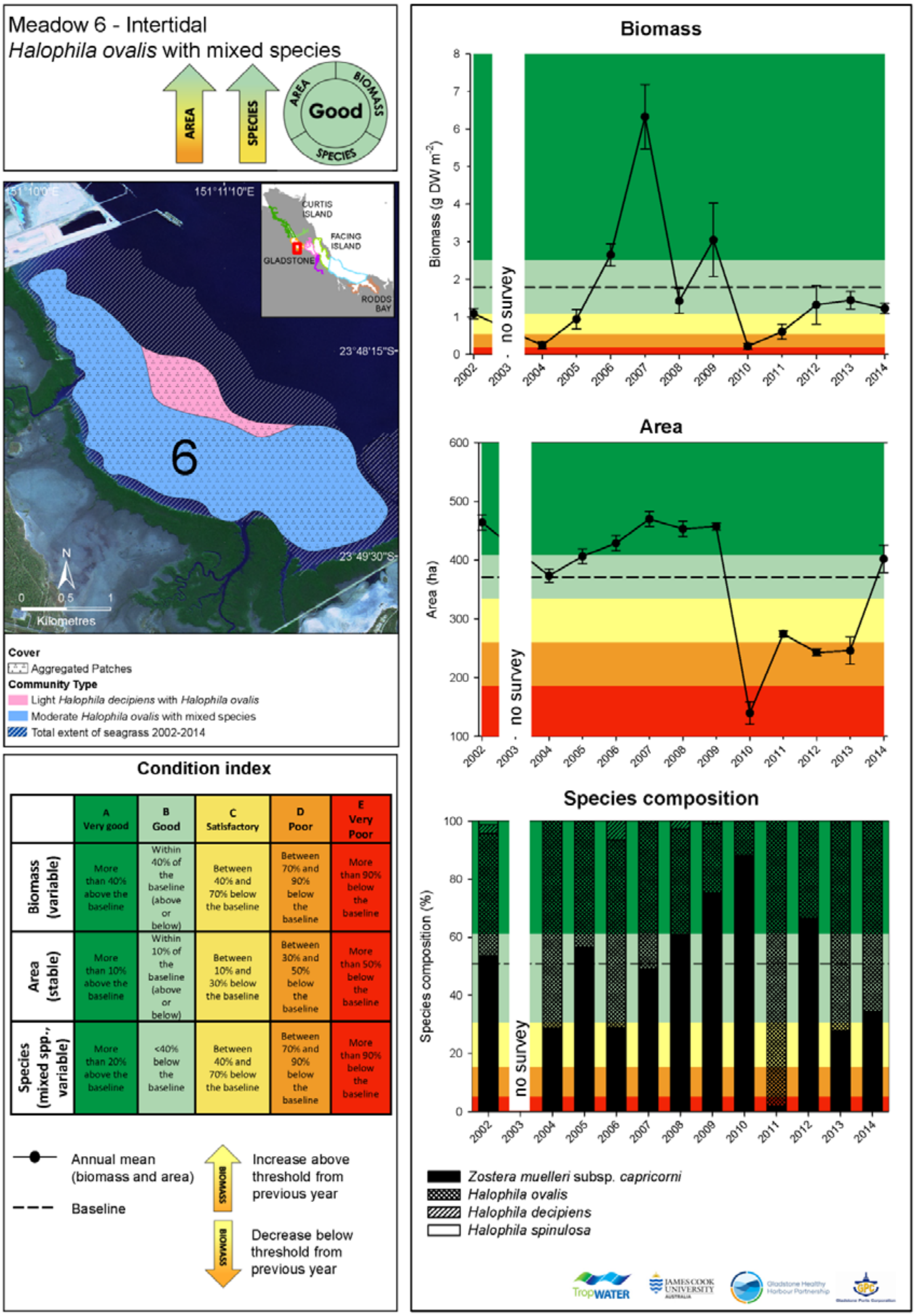


Figure 16. Changes in mean biomass, meadow area and species composition for seagrass in Zone 3 Western Basin, Meadow 6, South Fisherman's Landing, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

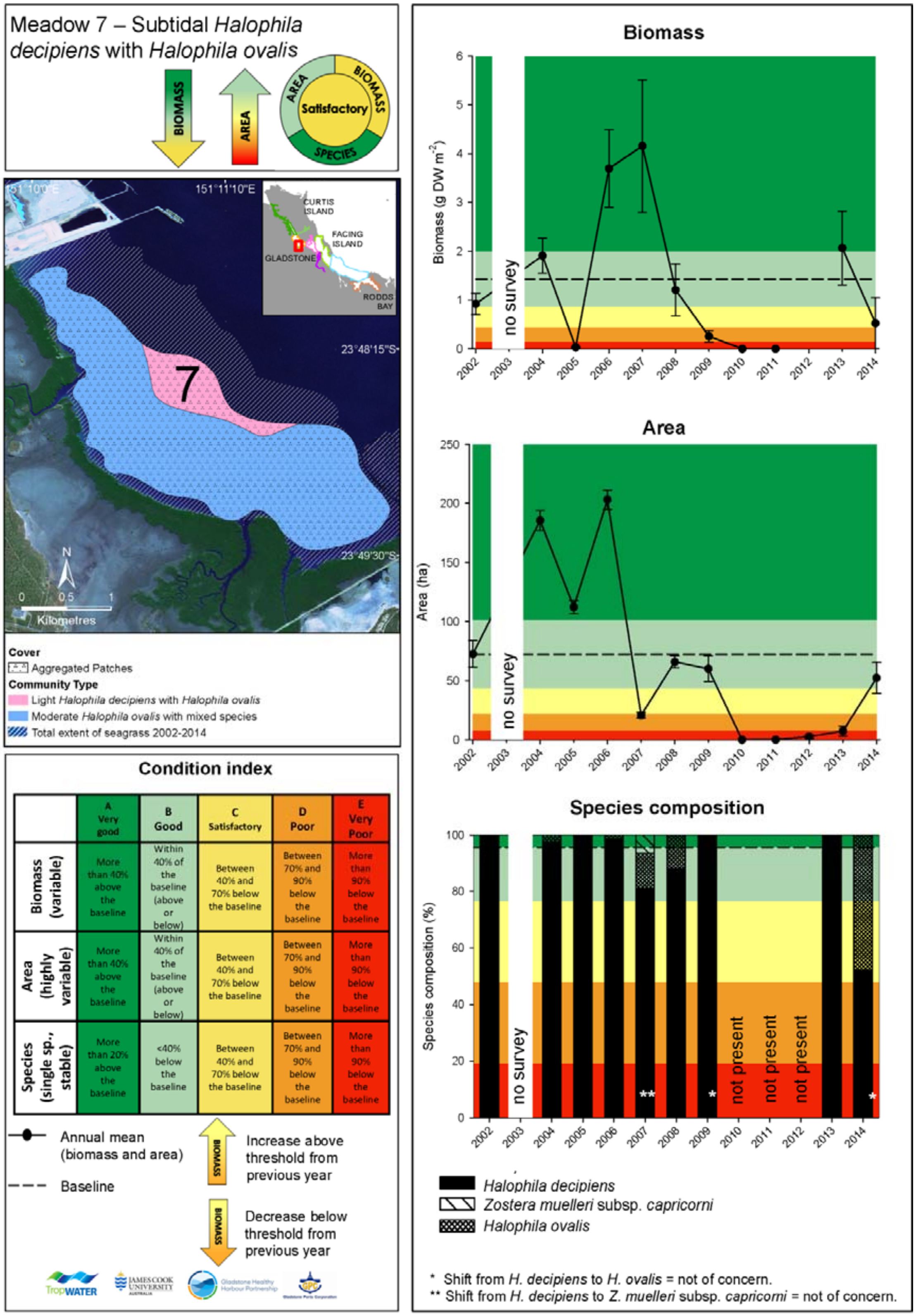


Figure 17. Changes in mean biomass, meadow area and species composition for seagrass in Zone 3 Western Basin, Meadow 7, South Fisherman's Landing, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

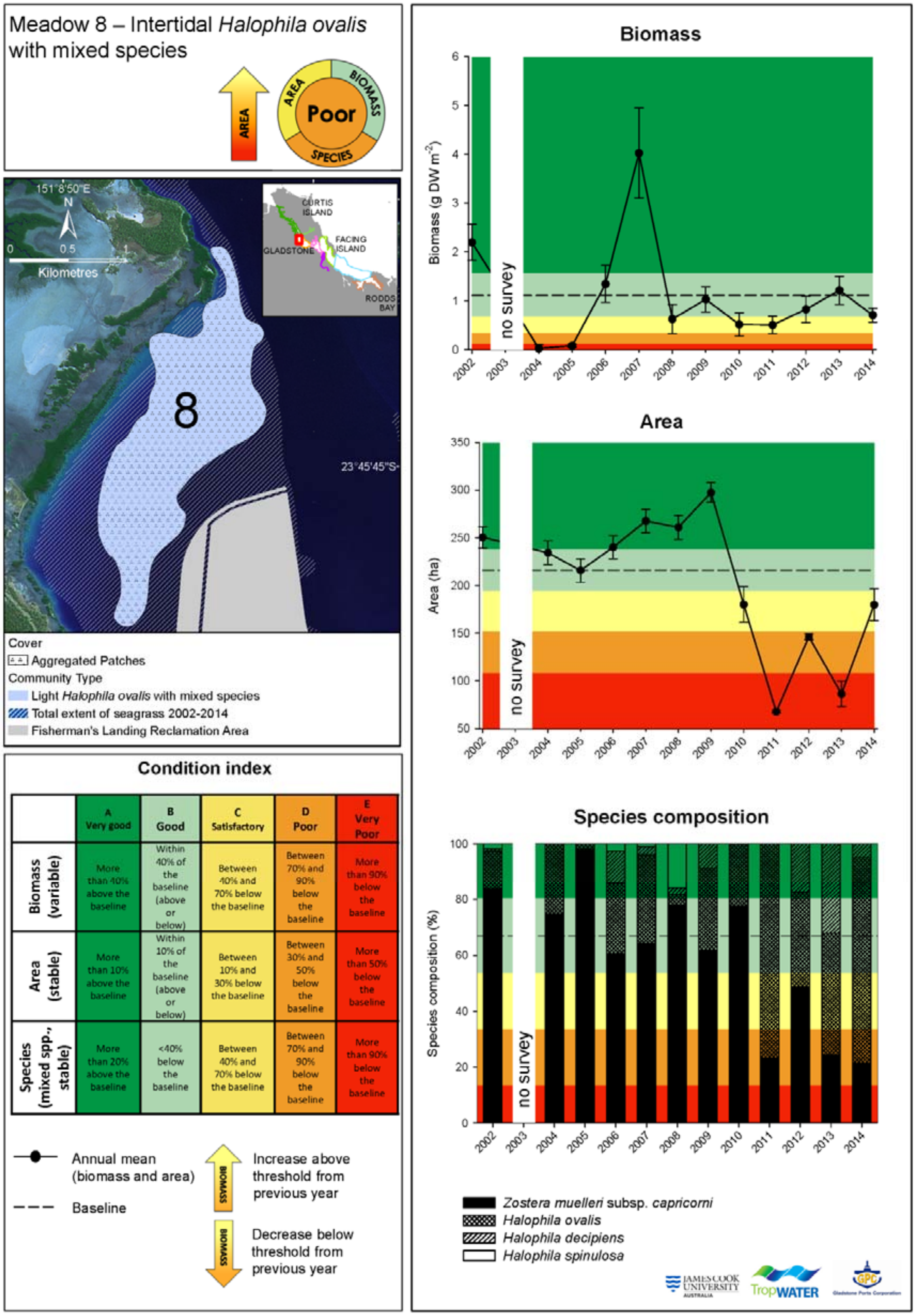


Figure 18. Changes in mean biomass, meadow area and species composition for seagrass in Zone 3 Western Basin, Meadow 8, North Fisherman's Landing, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

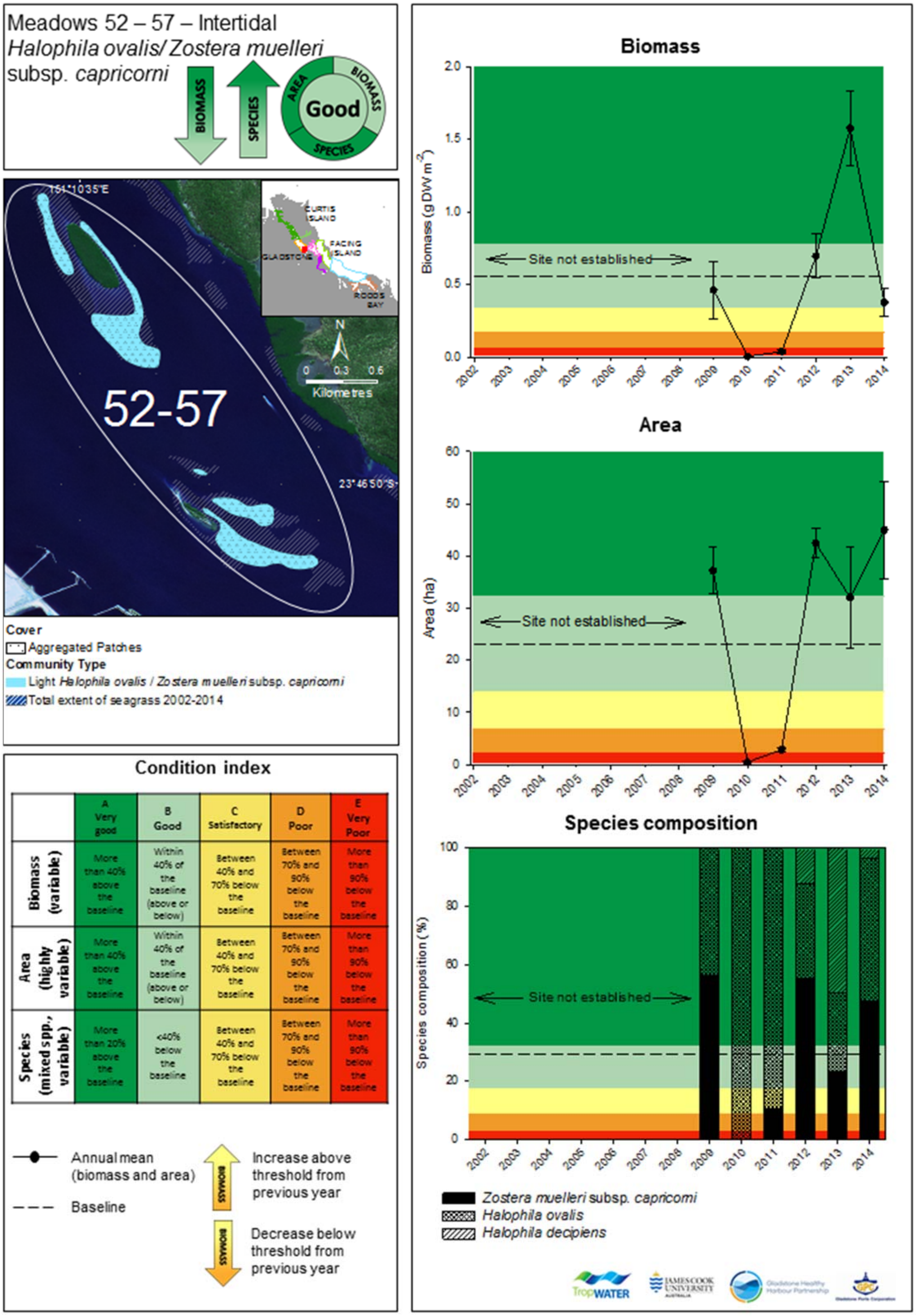


Figure 19. Changes in mean biomass, meadow area and species composition for seagrass in Zone 3 Western Basin, Meadows 52-57, Passage Islands, November 2009 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate). Meadows 52-57 are grouped for reporting purposes.

3.4.2 **Zone 1 The Narrows**

Zone 1 The Narrows was given an overall grade of E (very poor). There is one monitoring meadow in The Narrows Zone (Figure 20). Meadow 21 at Black Swan Island is an intertidal meadow comprised of aggregated patches of seagrass (Figure 21). Species composition is stable; the dominant species is traditionally *Z. muelleri* subsp. *capricorni* (80% of mean meadow biomass). Over six years of monitoring the proportion of *H. ovalis* has steadily increased. Species composition was graded as being in satisfactory condition in 2014 due to declines in *Z. muelleri* subsp. *capricorni* (56% of mean meadow biomass) compared to *H. ovalis*. Meadow area is classed as stable; in 2014 meadow area was approximately equivalent with the baseline value of 133 ha. Mean biomass at the monitoring meadow declined for the fifth consecutive year in 2014, from 21 g DW m^{-2} in 2009 to 0.5 g DW m^{-2} in 2014. This meadow was graded as being in very poor condition in 2014 due to biomass being >90% below the baseline value of 7.9 g DW m^{-2}.

Note: This meadow has only been surveyed as part of the annual monitoring program since 2009. Baseline levels and resulting grades should be interpreted with caution until the full 10 years of data are available.

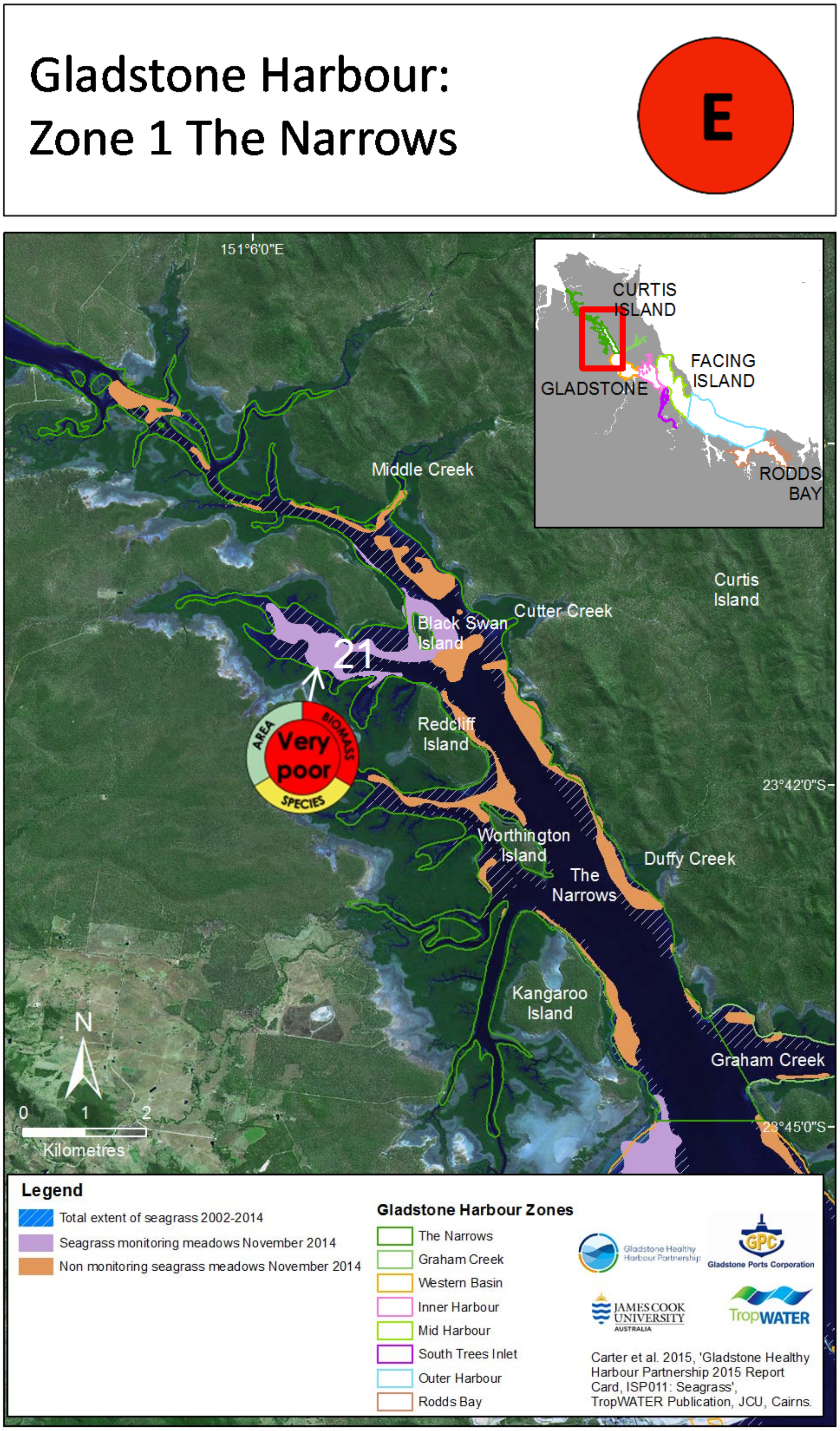


Figure 20. Seagrass condition in Zone 1 The Narrows, November 2014.

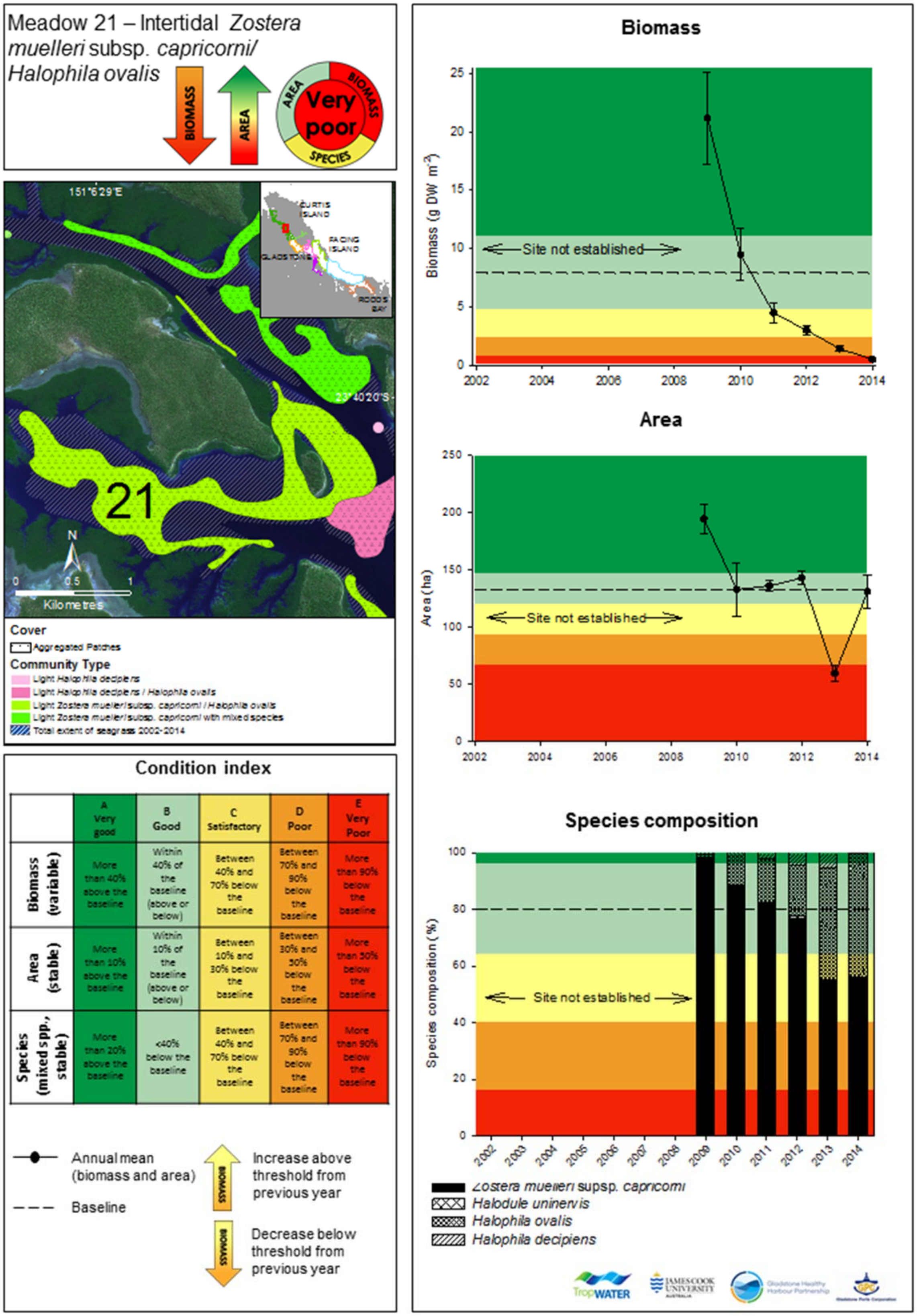


Figure 21. Changes in mean biomass, meadow area and species composition for seagrass in Zone 1 The Narrows, Meadow 21, Black Swan Island, November 2009 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4.3 **Zone 5 Inner Harbour**

Zone 5 Inner Harbour was given an overall grade of D (poor) (Figure 22). There is one monitoring meadow in the Inner Harbour Zone (Figure 23). Meadow 58 is an intertidal meadow comprised of isolated patches of seagrass. Species composition is variable; the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2013 there was an almost complete loss of *Z. muelleri* subsp. *capricorni*, with *H. ovalis* accounting for 98% of mean meadow biomass. In 2014 *Z. muelleri* subsp. *capricorni* accounted for 16% of mean meadow biomass, while *H. uninervis* accounted for 33%, the first time this species has been recorded in meadow 58 since monitoring began. As a shift from *Z. muelleri* subsp. *capricorni* to *H. uninervis* is not considered a decline in meadow condition, the combined contribution of these species to mean meadow biomass (49%) meant the species composition of this meadow was graded as being in good condition. Meadow area has been highly variable over the course of monitoring. In 2014 the largest area since monitoring began was recorded (64 ± 12 ha), resulting in area condition being graded as very good. The mean meadow biomass was classed as variable. Mean biomass has remained low (<1 g DW m^{-2}) since 2010 following biomass peaks of ~5 g DW m^{-2} recorded between 2007 and 2009. Meadow 58 was graded as being in poor condition in 2014 as mean biomass remains >70% below the baseline.

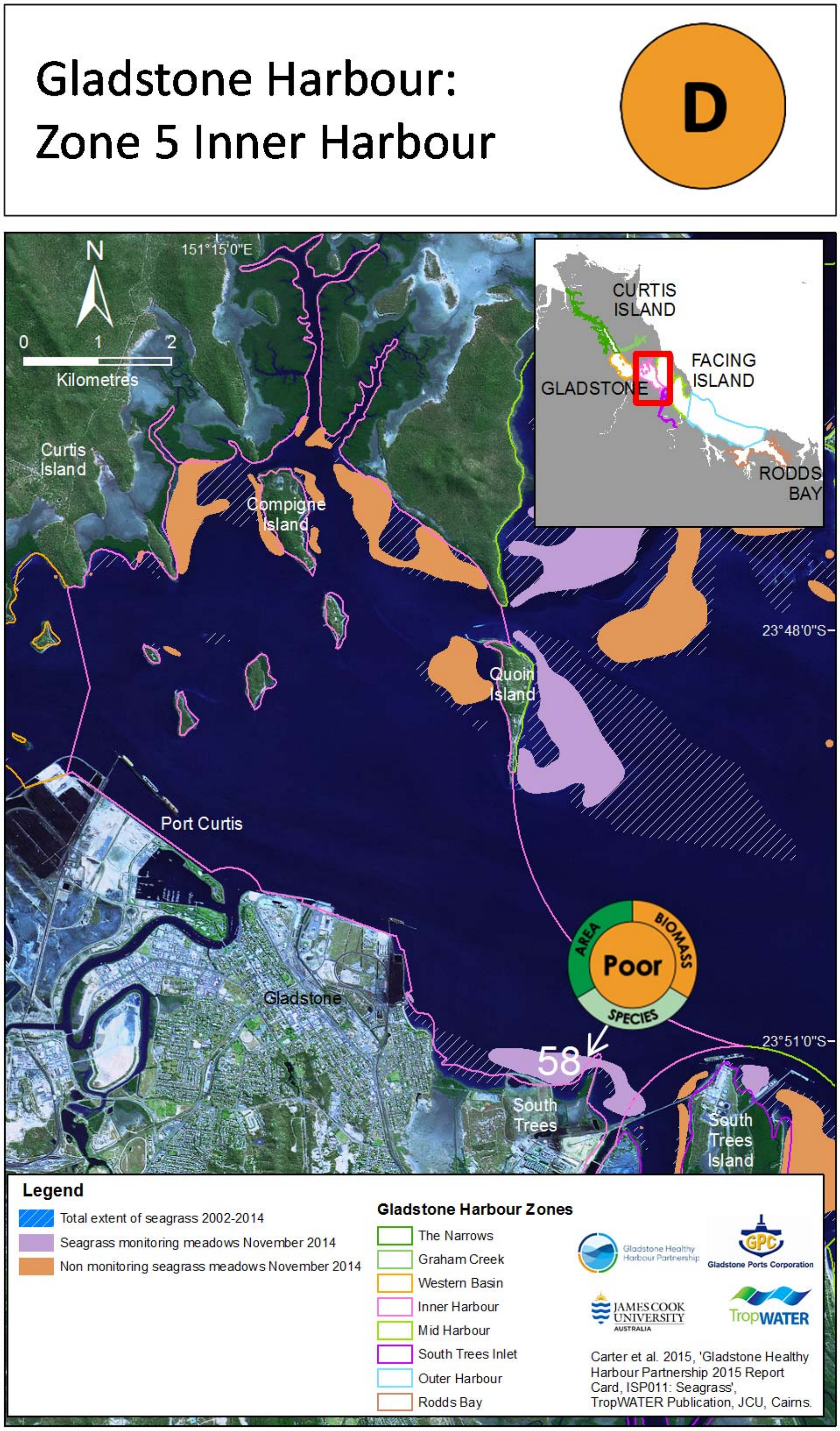


Figure 22. Seagrass condition in Zone 5 Inner Harbour, November 2014.

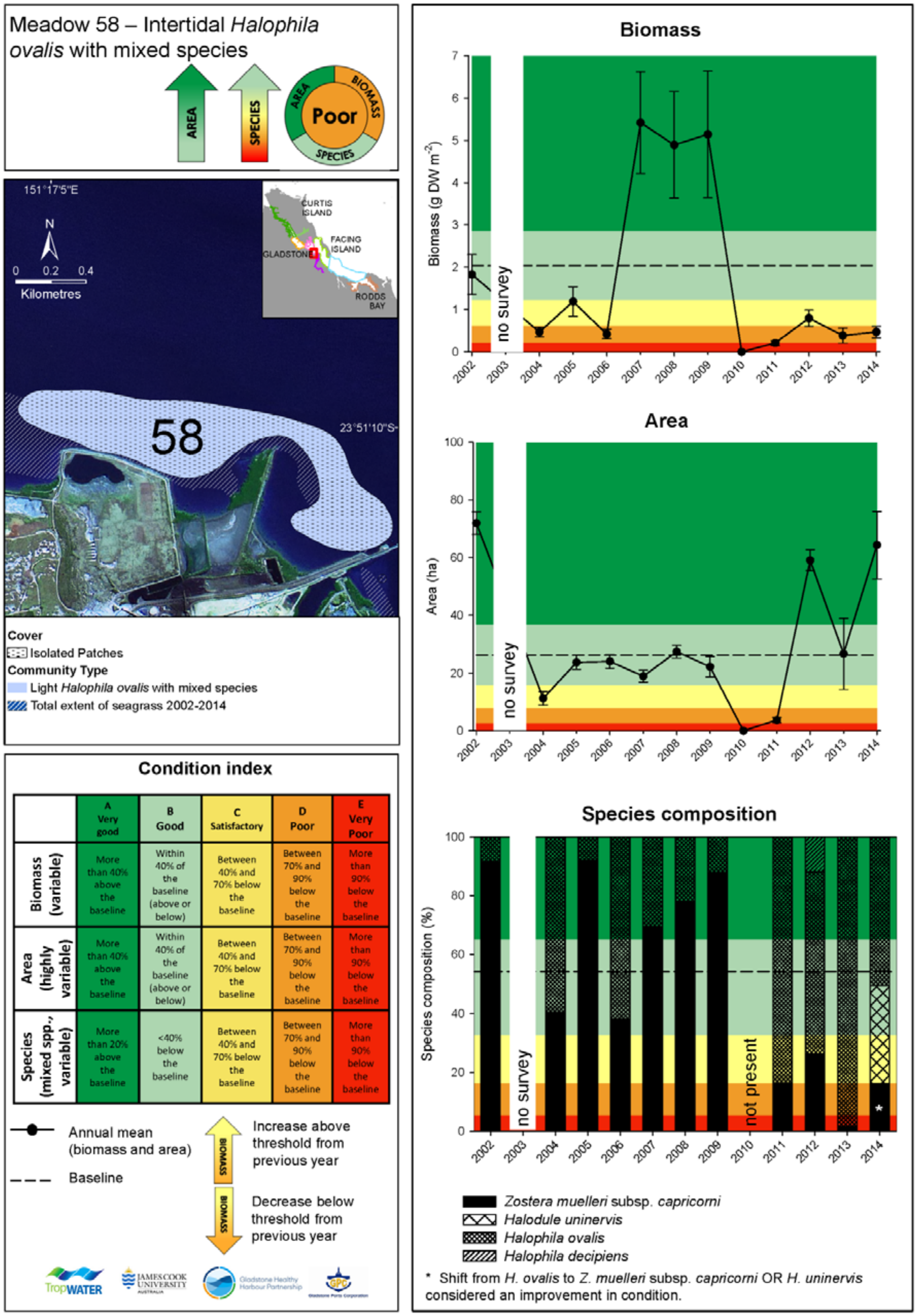


Figure 23. Changes in mean biomass, meadow area and species composition for seagrass in Zone 5 Inner Harbour, Meadow 58, November 2009 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4.4 **Zone 8 Mid Harbour**

Zone 8 Mid Harbour was given an overall grade of C (satisfactory) (Figure 24). There are two monitoring meadows in the Mid Harbour Zone - meadows 43 and 48.

Meadow 43

Meadow 43 is a large intertidal meadow comprised predominantly of continuous seagrass cover (Figure 25). The meadow, known locally as 'Pelican Banks', supports the most abundant and productive seagrass in the Gladstone area. This is the only meadow where all three condition indicators are classed as stable. Species composition is stable; the dominant species is *Z. muelleri* subsp. *capricorni* which on average accounts for 98% of mean meadow biomass. In 2014 the species composition of this meadow as graded as being in good condition because the proportion of *Z. muelleri* subsp. *capricorni* was slightly below the baseline. Biomass and area of the meadow are classed as stable. In 2014 meadow area was graded as being in good condition (<20% below the baseline). Overall meadow condition was graded as satisfactory in 2014 because biomass was 12 $\pm$ 1 g DW m^{-2}, 20-50% below the baseline of 19 g DW m^{-2}.

Meadow 48

Meadow 48 is a large meadow east of Quoin Island that extends across intertidal and subtidal areas of the bank and is comprised of aggregated patches of seagrass (Figure 26). The meadow is the most species rich meadow in the Gladstone area. Species composition is stable; the dominant species is *H. uninervis*, which on average accounts for 91% of mean meadow biomass. Increasing proportions of *H. ovalis* and *H. decipiens* in this meadow since 2011, at the expense of *H. uninervis* and *Z. muelleri* subsp. *capricorni*, meant that in 2014 species composition was graded as being in satisfactory condition. Both biomass and meadow area are classed as variable. Mean biomass peaked in 2006 well above the baseline and declined steadily over the next three years until 2009 when very little seagrass remained (Figure 26). In 2014 biomass was graded as being in satisfactory condition as biomass remained between 40% and 70% below the baseline. Meadow area was 135 $\pm$ 39 ha in 2014, 20-50% below the baseline of 237 ha; meadow area was also graded as being in satisfactory condition.

Gladstone Harbour: Zone 8 Mid Harbour

C

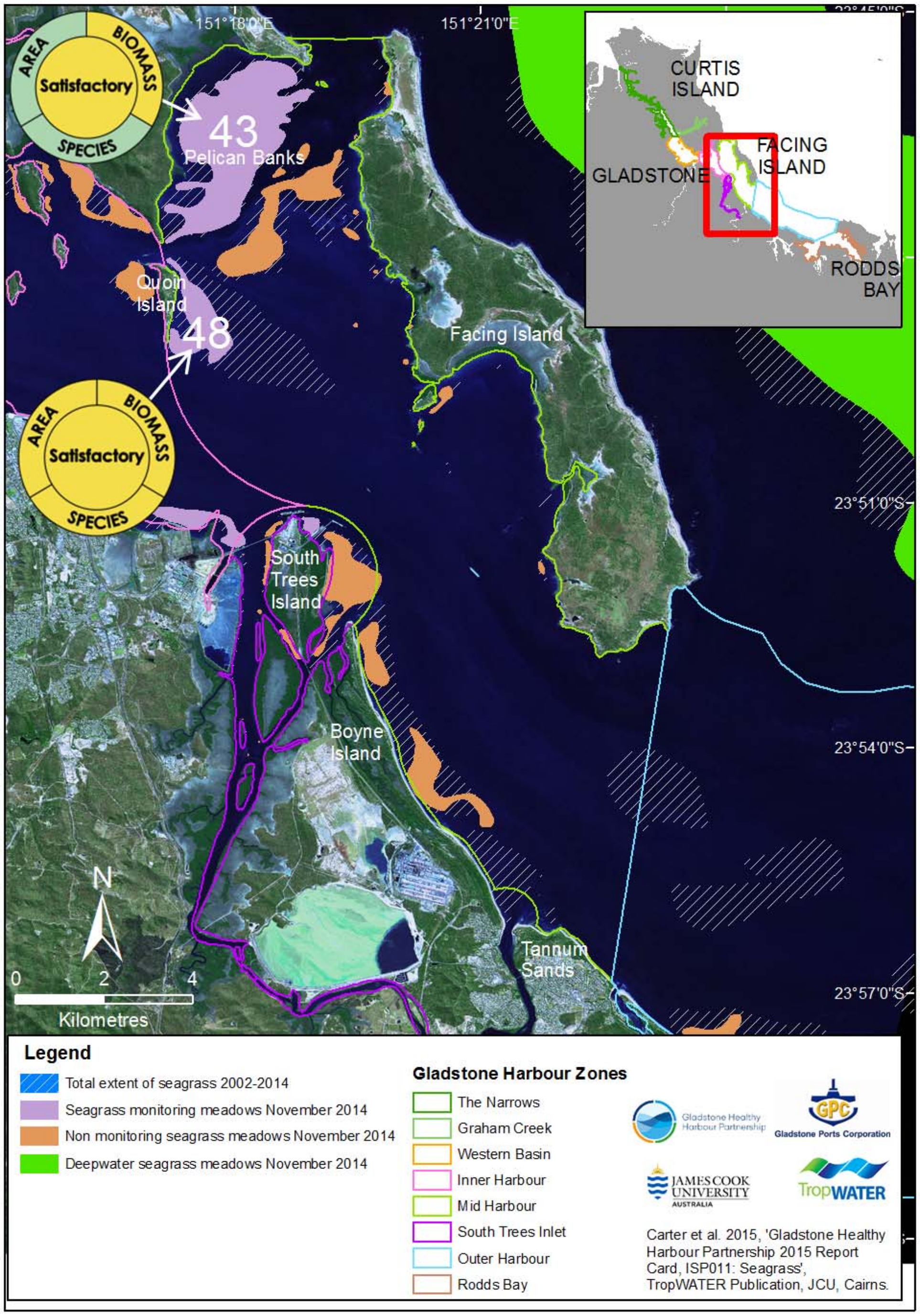


Figure 24. Seagrass condition in Zone 8 Mid Harbour, November 2014.

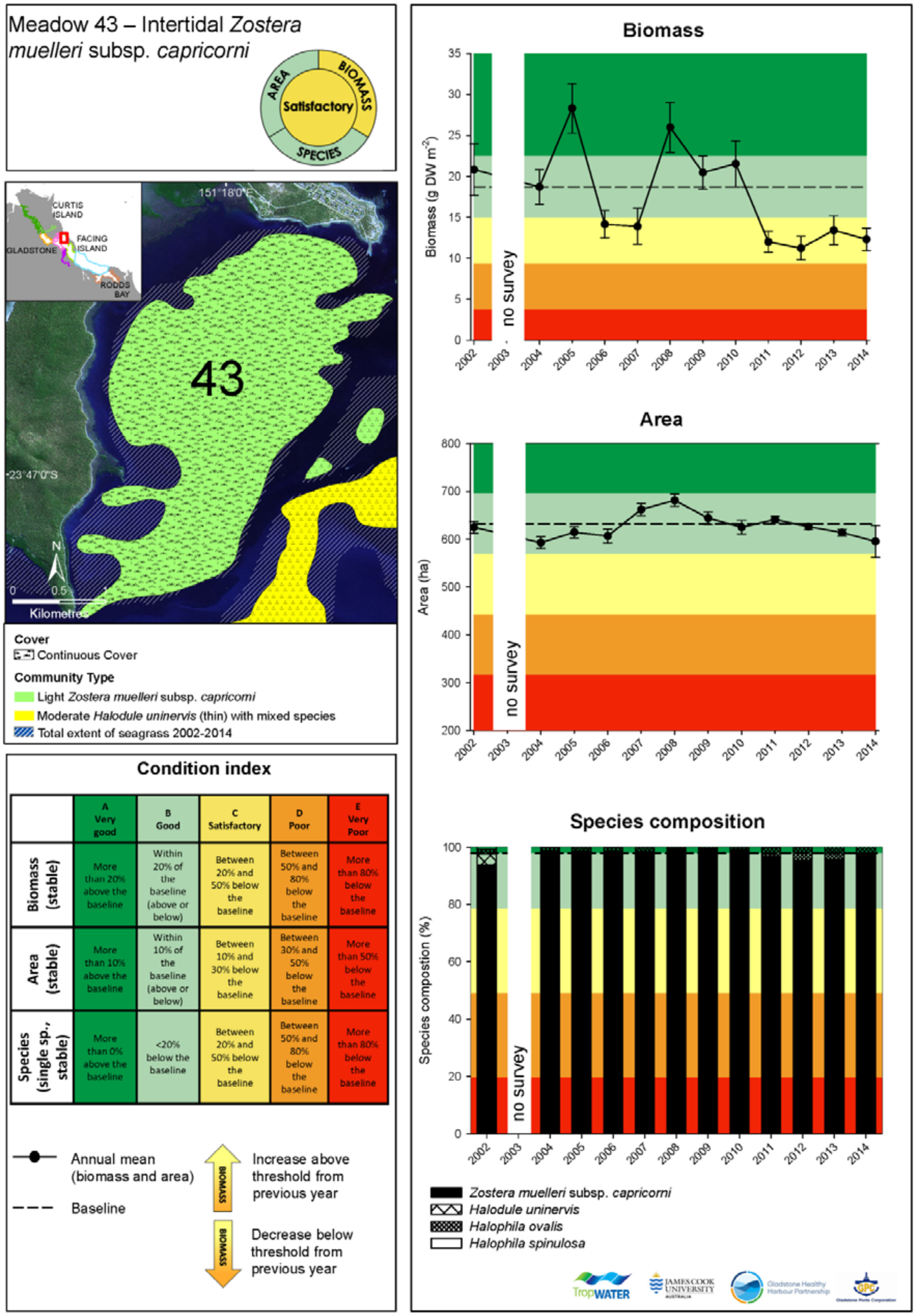


Figure 25. Changes in mean biomass, meadow area and species composition for seagrass in Zone 8 Mid Harbour, Meadow 43, Pelican Banks, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

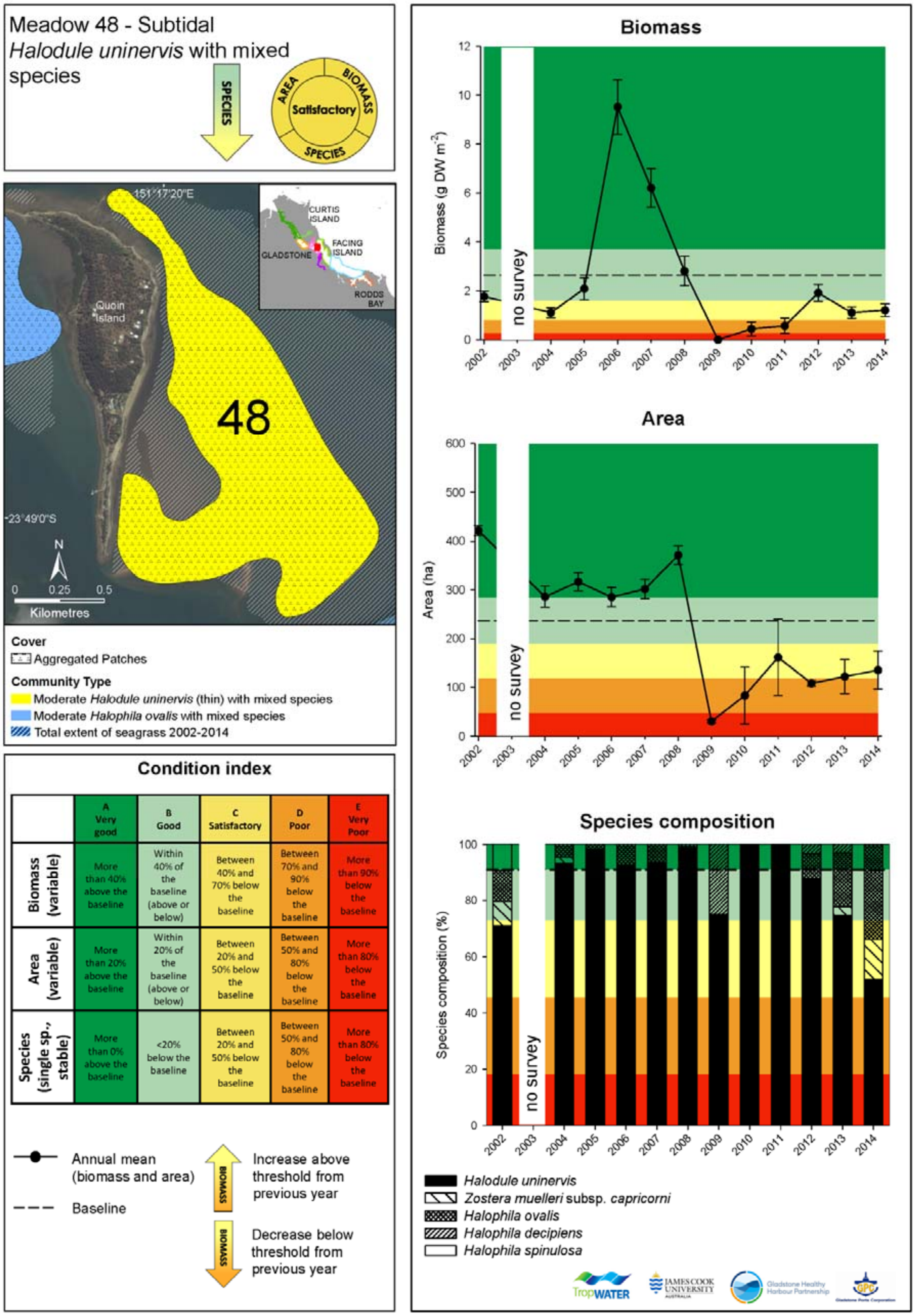


Figure 26. Changes in mean biomass, meadow area and species composition for seagrass in Zone 8 Mid Harbour, Meadow 48, Quoin Island, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4.5 **Zone 9 South Trees Inlet (lower)**

Zone 9 South Trees Inlet (lower) was given an overall grade of C (satisfactory) (Figure 27). There is one monitoring meadow in the South Trees Inlet (lower) Zone, located between the two wharves at South Trees Inlet (Figure 28). Meadow 60 is an intertidal meadow comprised of aggregated seagrass patches. Species composition is stable; the dominant species is *Z. muelleri* subsp. *capricorni* which on average accounts for 80% of mean meadow biomass. Between 2002 and 2009 *Z. muelleri* subsp. *capricorni* accounted for >94% of mean meadow biomass, but since 2010 the dominant species has fluctuated between *Z. muelleri* subsp. *capricorni* and *H. uninervis*. In 2014, 100% of the mean meadow biomass was *Z. muelleri* subsp. *capricorni*. The lack of pioneering *Halophila* spp. in meadow 60 meant species composition was graded as being in very good condition. The mean biomass and area of the meadow are classed as variable. In 2014 meadow area was graded as being in very good condition (>20% above the baseline). Overall meadow condition was graded as satisfactory in 2014 because biomass was 1.3 $\pm$ 0.4 g DW m^{-2}, 40-70% below the baseline of 3.7 g DW m^{-2}.

Gladstone Harbour: Zone 9 South Trees Inlet (lower)

C

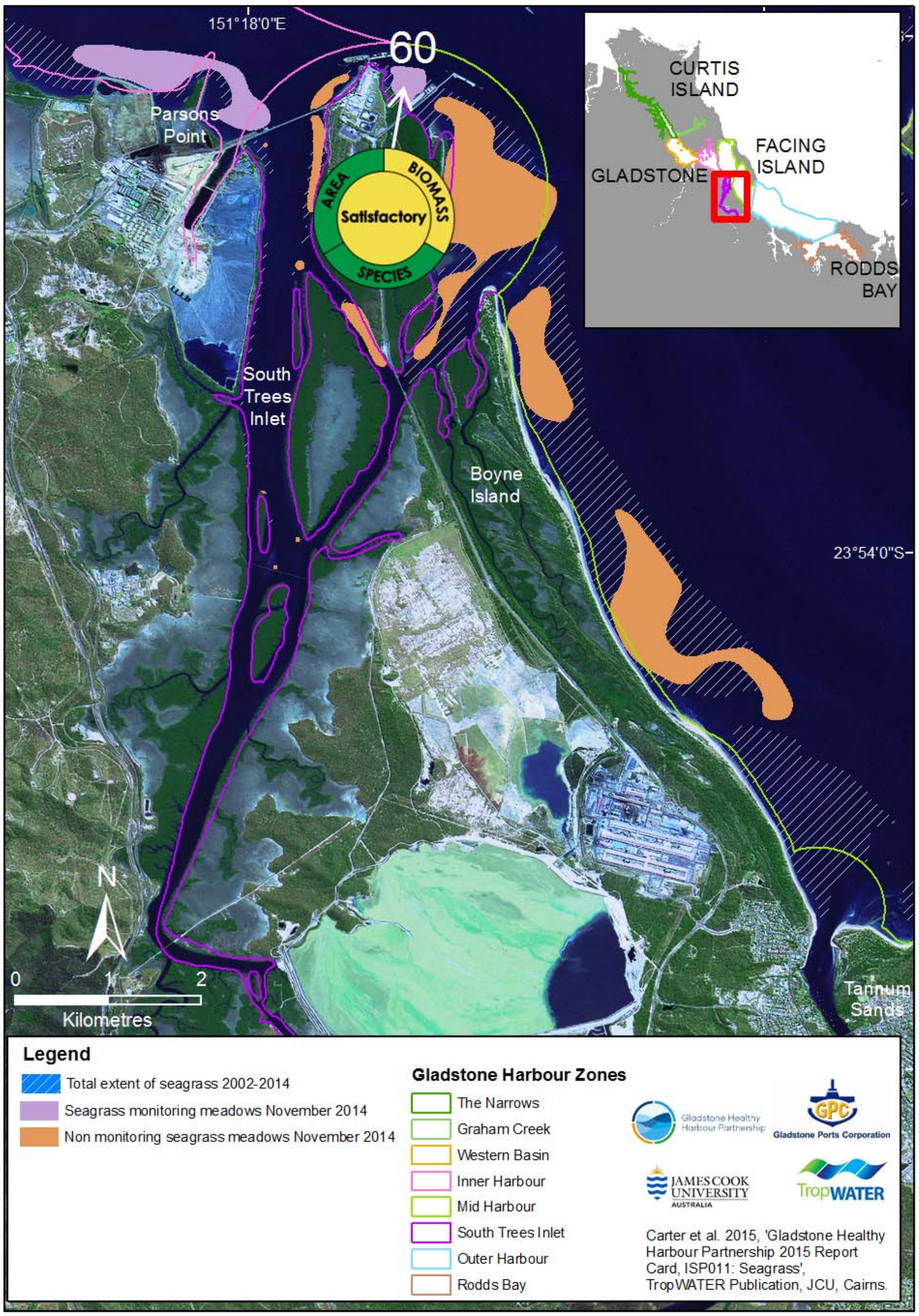


Figure 27. Seagrass condition in Zone 9 South Trees Inlet (lower), November 2014.

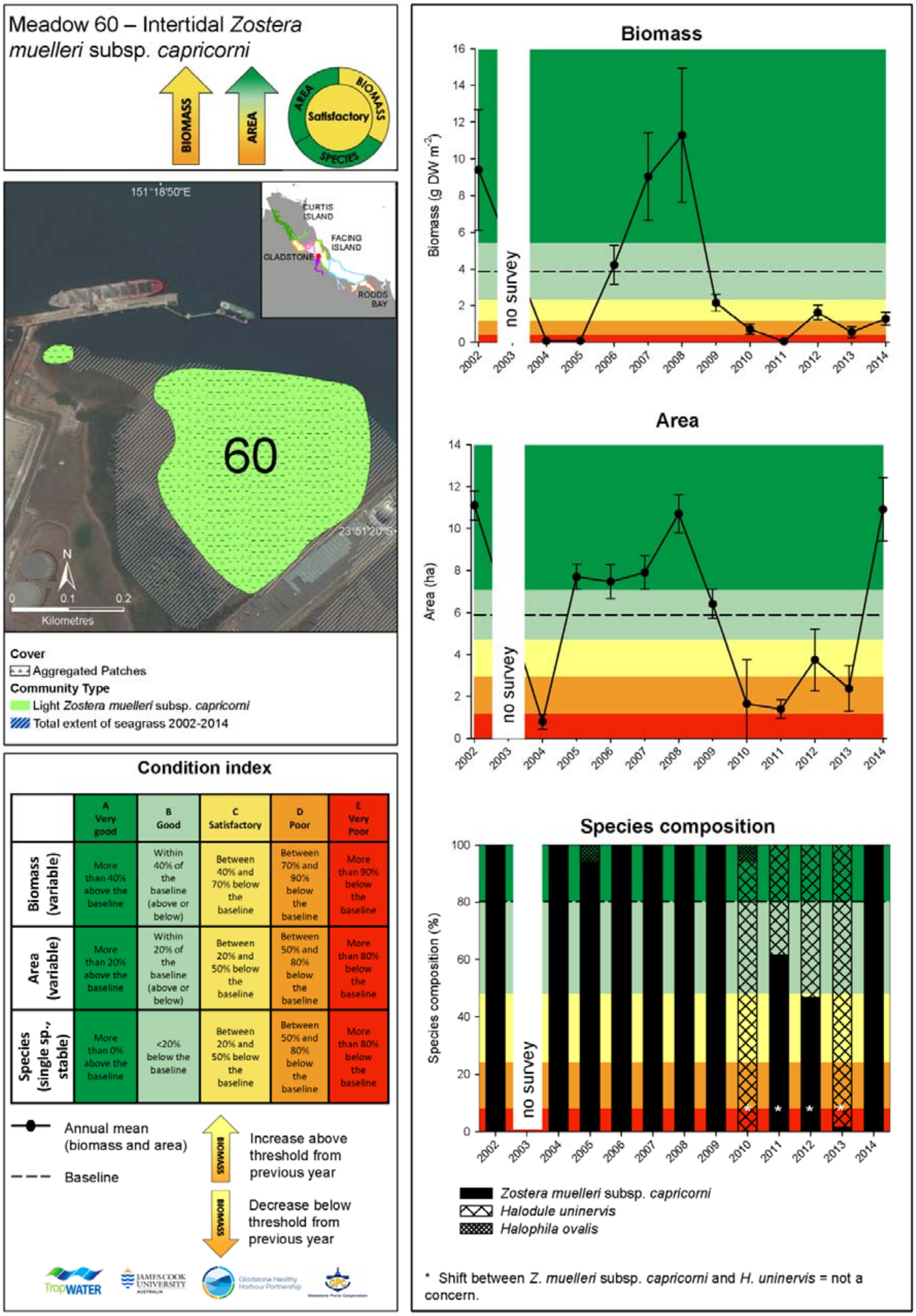


Figure 28. Changes in mean biomass, meadow area and species composition for seagrass in Zone 9 South Trees Inlet (lower), Meadow 60, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4.6 **Zone 13 Rodds Bay**

Zone 13 Rodds Bay was given an overall grade of D (poor) (Figure 29). There are three monitoring meadows in the Rodds Bay Zone – meadows 94, 96 and 104. Meadows 94, 96 and 104 are intertidal meadows comprised predominantly of aggregated patches of seagrass. At times these meadows have consisted of a continuous cover of seagrass; however declines over the course of monitoring have left only aggregated patches.

Meadow 94

Meadow 94 is an intertidal meadow comprised of aggregated seagrass patches (Figure 30). Species composition is stable; the dominant species is *Z. muelleri* subsp. *capricorni* which on average accounts for 86% of mean meadow biomass. Species composition was graded as being in good condition in 2014 due to the proportion of *Z. muelleri* subsp. *capricorni* being slightly below the baseline of 86%. Meadow area is classed as stable. In 2014 meadow area was graded as being in very good condition (>10% above the baseline). Biomass is classed as variable. Overall meadow condition was graded as poor in 2014 because biomass was 2.1 $\pm$ 0.9 g DW m^{-2}, 70-90% below the baseline of 9.1 g DW m^{-2}.

Meadow 96

Meadow 96 is an intertidal meadow comprised of aggregated seagrass patches (Figure 31). Species composition is stable; the dominant species is *Z. muelleri* subsp. *capricorni* which on average accounts for 96% of mean meadow biomass. Species composition was graded as being in satisfactory condition in 2014 due to *Z. muelleri* subsp. *capricorni* accounting for just 59% of mean meadow biomass. The mean biomass and area of the meadow are classed as variable. In 2014 meadow area was graded as being in good condition (<20% below the baseline). Overall meadow condition was graded as poor in 2014 because biomass was 1.5 $\pm$ 0.5 g DW m^{-2}, 70-90% below the baseline of 7.7 g DW m^{-2}.

Meadow 104

Meadow 104 is an intertidal meadow comprised of aggregated seagrass patches (Figure 32). Species composition is stable; the dominant species is *Z. muelleri* subsp. *capricorni* which on average accounts for 97% of mean meadow biomass. Species composition was graded as being in good condition in 2014 due to *Z. muelleri* subsp. *capricorni* accounting for 81% of mean meadow biomass. Meadow area is classed as stable. In 2014 meadow area was graded as being in very good condition, with meadow area 70 $\pm$ 14 ha, approximately double the baseline value. Biomass is graded as variable. Overall meadow condition was graded as satisfactory in 2014 because biomass was 3.2 $\pm$ 0.9 g DW m^{-2}, 40-70% below the baseline of 7.9 g DW m^{-2}.

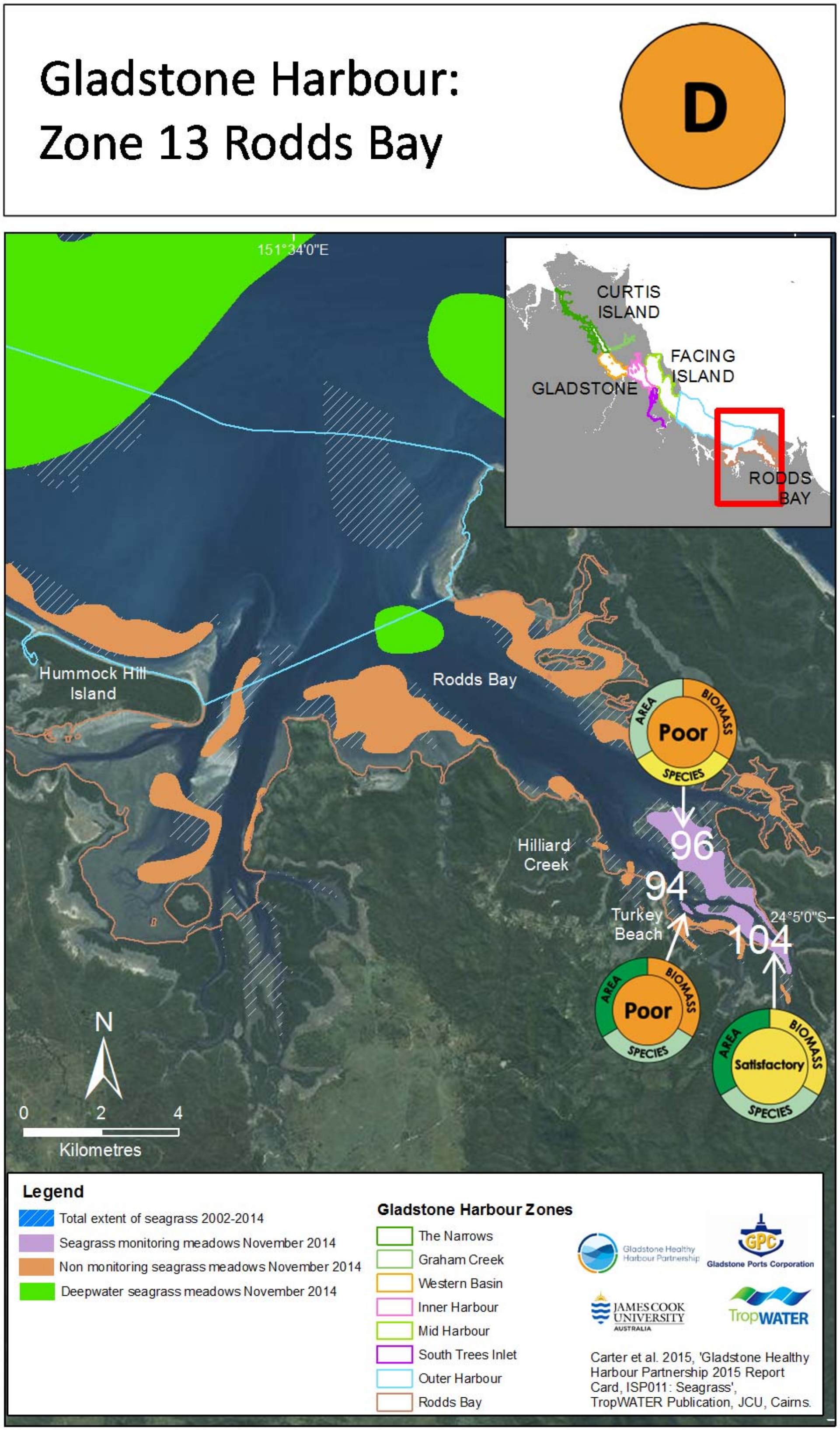


Figure 29. Seagrass condition in Zone 13 Rodds Bay in November 2014.

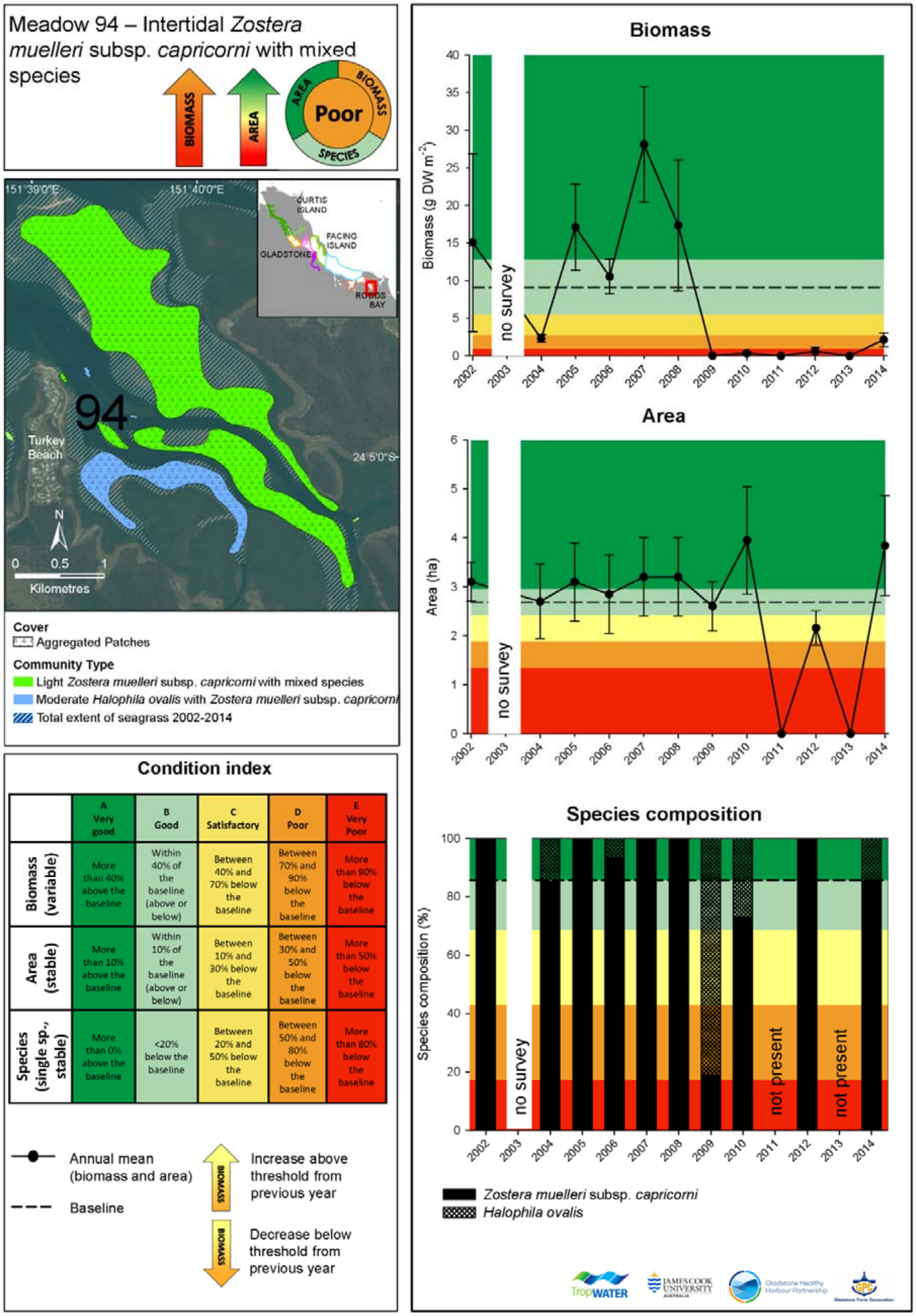


Figure 30. Changes in mean biomass, meadow area and species composition for seagrass in Zone 13 Rodds Bay, Meadow 94, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

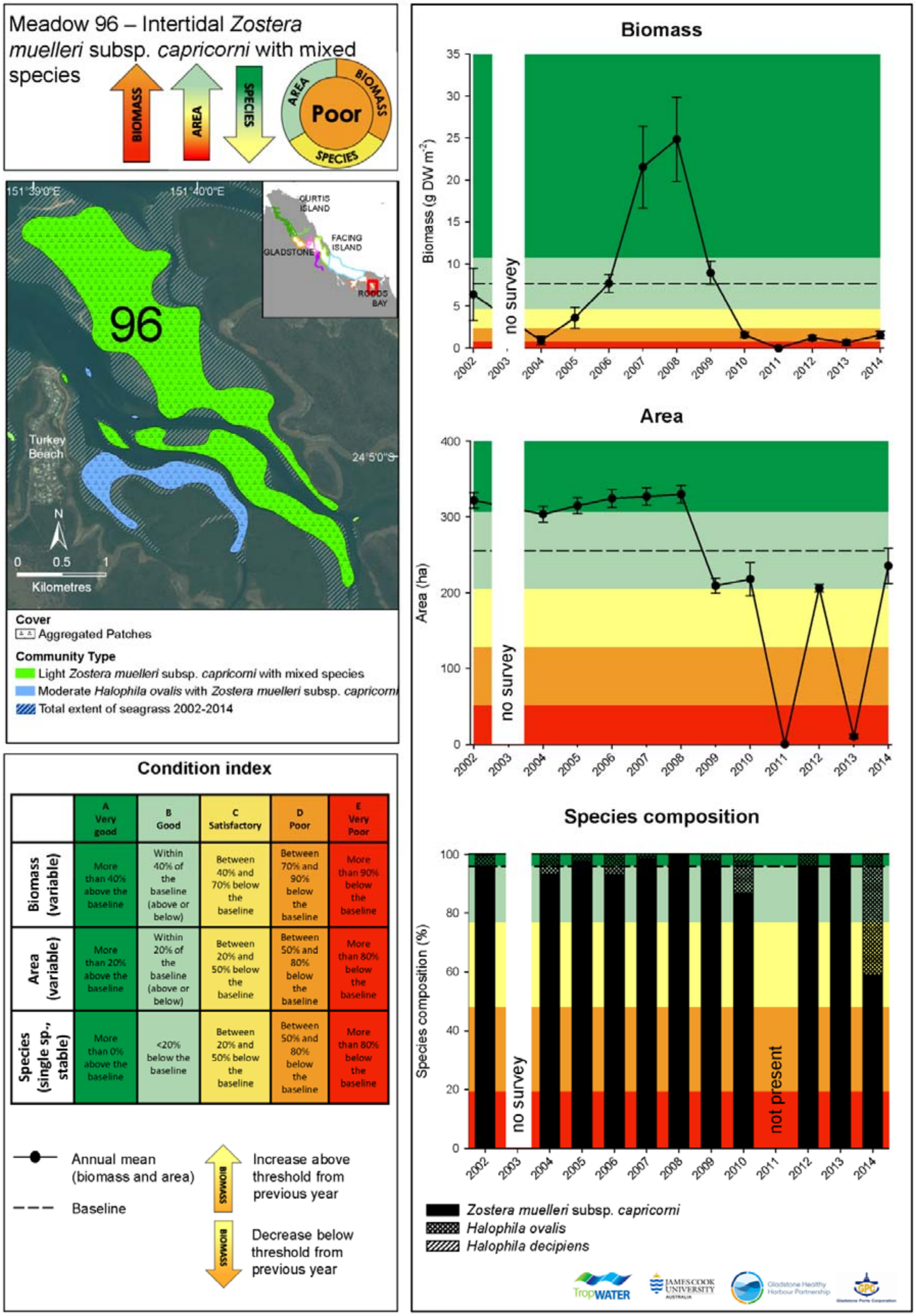
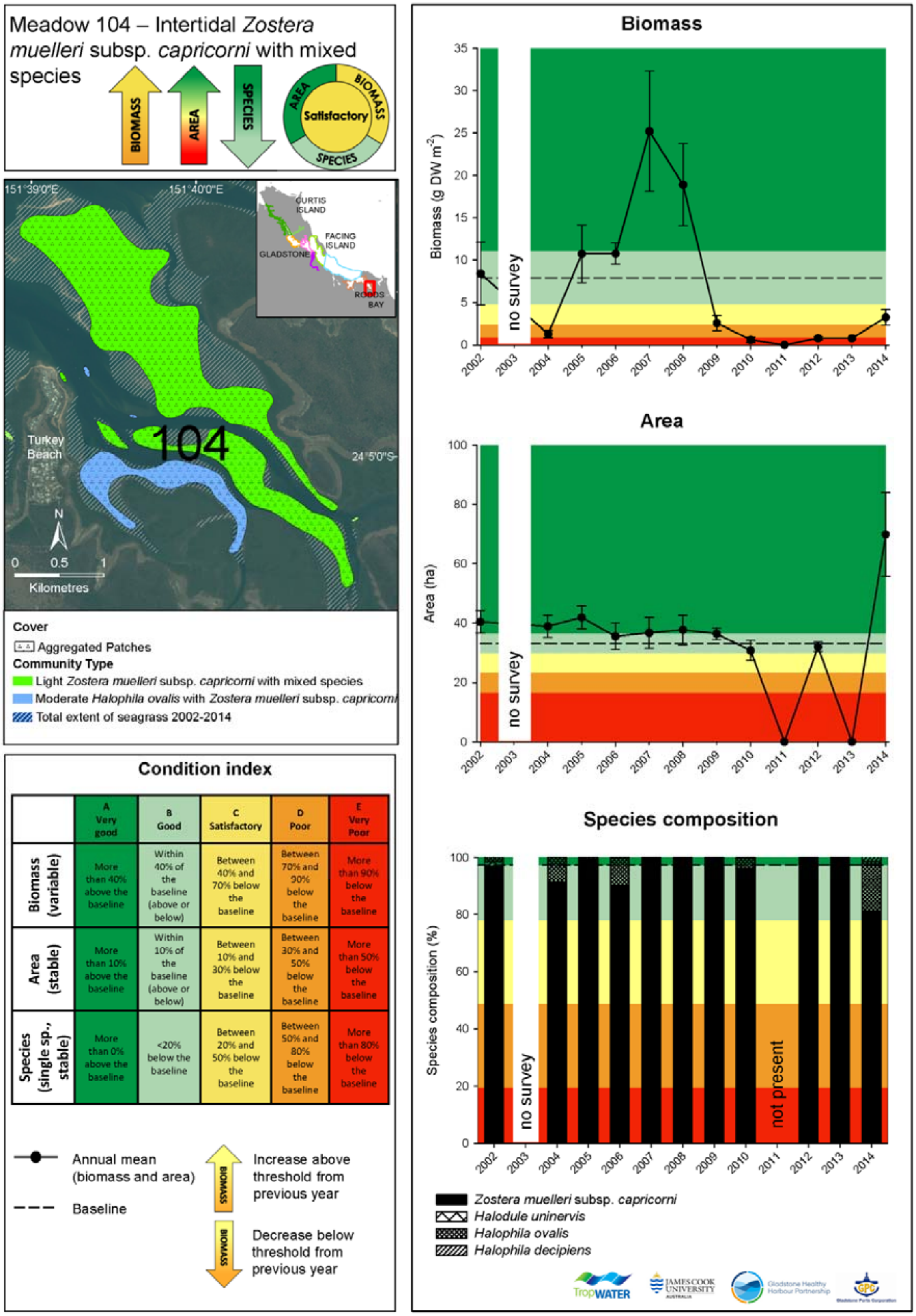


Figure 31. Changes in mean biomass, meadow area and species composition for seagrass in Zone 13 Rodds Bay, Meadow 96, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).



	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (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
Species (single sp., stable)	More than 0% above the baseline	<20% below the baseline	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline

Figure 32. Changes in mean biomass, meadow area and species composition for seagrass in Zone 13 Rodds Bay, Meadow 104, November 2002 - 2014 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.5 Performance of Thresholds across Historical Monitoring Data

Grades for each of the indicators (biomass, area and species composition) were obtained across all years of monitoring (2002-2014) using the methods outlined in Section 2.2.3.1. There was a high level of agreement between 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. There appears to be a good link between seagrass condition in Gladstone and major climate events, especially high rainfall and river flow from the Calliope River (McCormack et al. 2013). Above average rainfall and flow from the Calliope River was recorded in 2003, 2010, 2011 and 2013, often coinciding with tropical cyclones in the region (http://www.bom.gov.au/climate/data/) (Figures 33 and 34). For seagrasses in the Gladstone region, these years were characterised by significant declines in seagrass biomass and meadow area and a shift in species composition from *Z. capricorni* subsp. *muelleri* to the colonising *H. ovalis* in many of the monitoring meadows.

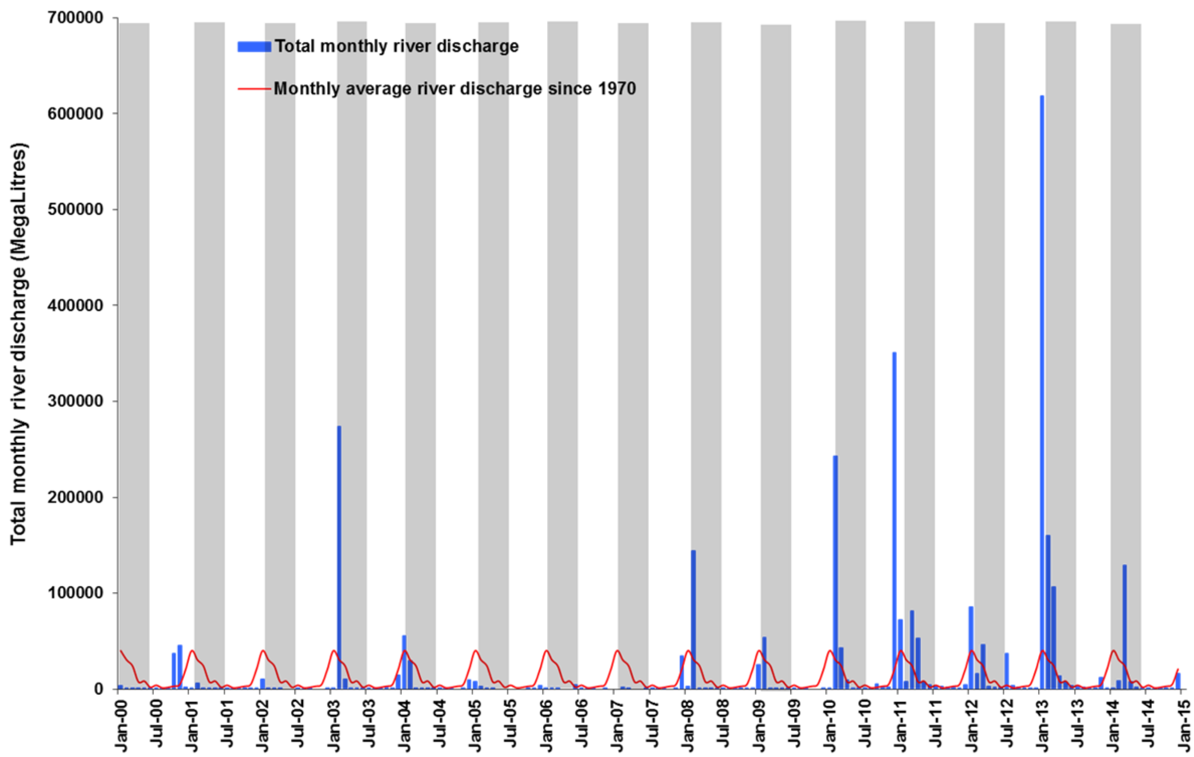


Figure 33. Monthly total river flow for the Calliope River (megalitres), January 2000 – January 2015. Shaded areas represent the seagrass senescent season. Data obtained from the Department of Natural Resources and Mines (station # 132001A; www.watermonitoring.derm.qld.gov.au).

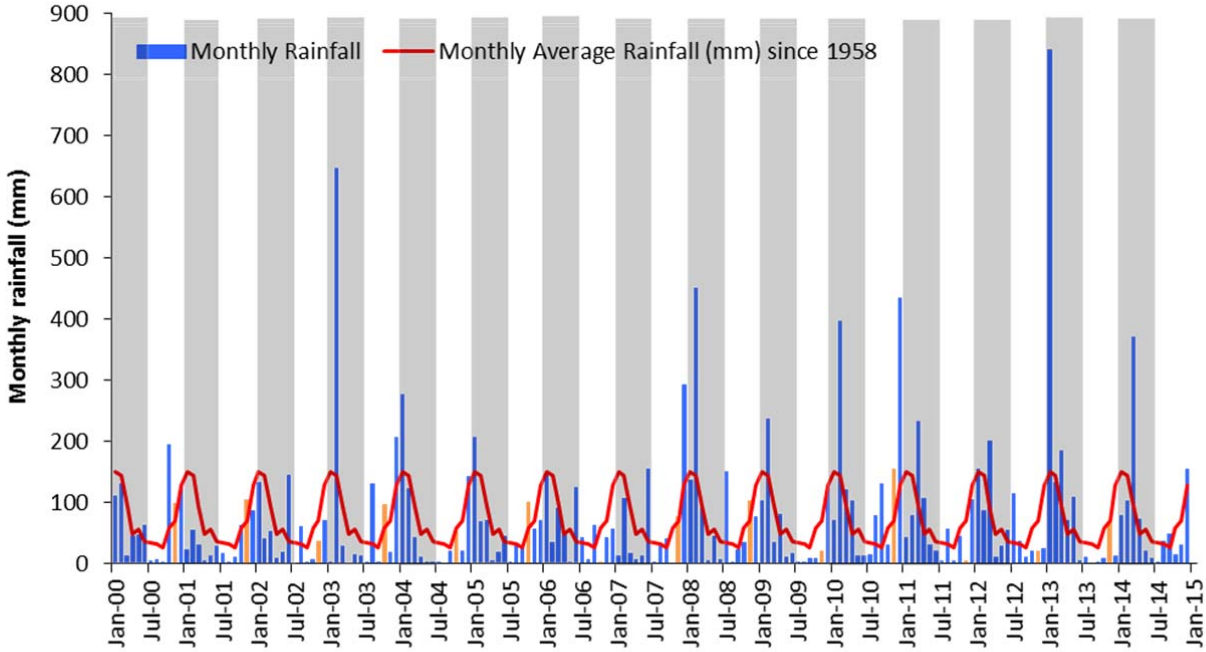


Figure 34. Total monthly rainfall (mm), January 2000 – January 2015. Orange bars indicate November rainfall when seagrass was sampled (spring peak growth period). Shaded areas represent the seagrass senescent season. Data obtained for the nearest weather station (Gladstone Airport, station # 039123) from the Australian Bureau of Meteorology website (http://www.bom.gov.au/climate/data/) for the 12 months preceding each November survey.

3.5.1 **Biomass**

Biomass condition was graded as good or very good in all but one meadow in 2002 (Table 10). In 2004 the biomass condition for most meadows were downgraded following above average rainfall and Calliope River flow in 2003 (Figures 33 and 34). Biomass condition for meadows at Rodds Bay and in the Mid Harbour Zone had improved by 2005, while Western Basin Zone meadows were slower to respond to more favourable seagrass growing conditions. By 2006, the majority of meadows had returned to good or very good condition; these grades were largely sustained in most regions throughout the drier years from 2006 to 2009. The downgrading of biomass condition between 2010 and 2013 coincided with the onset of a La Niña period, characterised by above average rainfall and river flow. Environmental conditions experienced by Gladstone seagrass meadows in 2014 were characterised by below average rainfall and relatively low river flow compared with 2010, 2011 and 2013. Biomass condition in 2014 had improved for meadows in the South Trees Inlet (lower) and Rodds Bay Zones, while Western Basin and The Narrows Zone meadows were graded in similar or worse condition compared with 2013 (Table 10).

Table 10. Grades for mean seagrass biomass from annual (November) surveys at each of the monitoring meadows relative to baseline conditions, 2002-2014. See Table 7 for grading scale.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western Basin	4	B		B	C	B	A	B	A	E	C	A	A	A
	5	C		D	C	B	A	A	C	D	B	C	B	C
	6	B		D	C	A	A	B	A	D	C	B	B	B
	7	B		B	E	A	A	B	D	E	E	E	A	C
	8	A		E	E	B	A	C	B	C	C	B	B	B
	52-57								B	E	E	B	A	B
The Narrows	21								A	B	C	C	D	E
Inner Harbour	58	B		D	C	D	A	A	A	E	D	C	D	D
Mid Harbour	43	B		B	A	C	C	A	B	B	C	C	C	C
	48	B		C	B	A	A	B	E	D	D	B	C	C
South Trees Inlet (lower)	60	A		E	E	B	A	A	C	D	E	C	D	C
Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E	D
	96	B		D	C	B	A	A	B	D	E	D	E	D
	104	B		D	B	B	A	A	C	E	E	E	E	C

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

** Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

3.5.2 **Area**

Area grades were mostly good or very good for the first seven years of monitoring (2002 to 2009), reflecting the stability in area at most meadows despite declines in mean biomass (Table 11). Two exceptions are the intertidal meadows in the Inner Harbour and South Trees Inlet where the total meadow area declined along with biomass in 2004. Area condition was downgraded across most meadows following above average rainfall and river flow during the 2010-2013 period, similar to declines in meadow biomass condition (Table 10). The exception is the large and stable *Z. muelleri* subsp. *capricorni* meadow at Pelican Banks (meadow 43) where the total area remained in good condition over the course of monitoring. The subtidal *H. decipiens* meadow at South Fisherman's Landing (meadow 7) appears to be most sensitive to above average rainfall and river flow, with the lowest condition grades for area recorded during the 2010-2013 period.

Table 11. Grades for total area from annual (November) surveys at each of the monitoring meadows relative to baseline conditions, 2002-2014. See Table 7 for grading scale.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western Basin	**4**	A		A	B	A	A	B	A	E	D	B	D	D
	5	A		B	B	B	B	A	A	C	D	B	E	D
	6	A		B	B	A	A	A	A	E	C	D	D	B
	7	B		A	A	A	D	B	B	E	E	E	D	B
	8	A		B	B	A	A	A	A	C	E	D	E	C
	52-57								A	E	D	A	B	A
The Narrows	**21**								A	B	B	B	E	B
Inner Harbour	**58**	A		C	B	B	B	B	B	E	D	A	B	A
Mid Harbour	**43**	B		B	B	B	B	B	B	B	B	B	B	B
	48	A		A	A	A	A	A	E	D	C	D	C	C
South Trees Inlet (lower)	**60**	A		E	A	A	A	A	B	D	D	C	D	A
Rodds Bay	**94**	A		B	A	B	A	A	B	A	E	C	E	A
	96	A		B	A	A	A	A	B	B	E	B	E	B
	104	A		A	A	B	A	A	A	B	E	B	E	A

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

** Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

3.5.3 **Species Composition**

Species composition grades were mostly good or very good for the first seven years of monitoring (2002 to 2009) (Table 12). Exceptions were the intertidal meadows near Wiggins Island in the Western Basin Zone (meadow 4 and 5) where the proportion of *Z. muelleri* subsp. *capricorni* declined following above average rainfall and river flows in 2003. Species composition condition was downgraded across intertidal meadows in the Western Basin, The Narrows, and Inner Harbour Zones during the 2010-2013 period. The decline of *Z. muelleri* subsp. *capricorni* at the majority of these meadows is likely a reflection of the degraded light environment that occurs in nearshore areas during flood events.

Table 12. Grades for seagrass species composition from annual (November) surveys at monitoring meadows relative to baseline conditions, 2002-2014. See Table 7 for grading scale.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western Basin	4	A		C	D	B	A	B	A	B	B	C	A	A
	5	A		C	C	B	A	A	A	B	C	B	D	B
	6	B		C	B	C	B	B	A	A	E	A	C	B
	7	A		A	A	A	A	A	A				A	A
	8	A		B	A	B	B	B	B	B	D	C	D	D
	52-57								A	E	C	A	B	A
The Narrows	21								A	B	B	B	C	C
Inner Harbour	58	A		B	A	B	A	A	A		C	C	E	B
Mid Harbour	43	A		A	A	A	A	A	A	A	B	B	B	B
	48	B		A	A	A	A	A	B	A	A	B	B	C
South Trees Inlet (lower)	60	A		A	A	A	A	A	A	A	A	A	A	A
Rodds Bay	94	A		B	A	A	A	A	D	B		A		B
	96	A		B	A	B	A	A	A	B		A	A	C
	104	A		B	A	B	A	A	A	B		A	A	B

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

** Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

3.5.4 **Overall Meadow Grades**

The overall meadow grades, based on the lowest of the three condition indicator grades for each meadow, highlight periods where the majority of meadows were in a satisfactory to very good condition (2002 and 2006- 2009), and periods where ≥50% of meadows were in a poor to very poor condition (2004 and 2010-2014) (Table 13). As with the grades for the three condition indicators, years with a large number of poor and very poor overall meadow grades either correspond with (2010-2013) or directly follow (2004, 2014) years of above average rainfall and river flow in the Gladstone region.

Table 13. Grades for individual monitoring meadows from annual (November) surveys (equal to the lowest of the three seagrass indicator grades at each meadow), 2002-2014. See Table 7 for grading scale.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western Basin	4	B		C	D	B	A	B	A	E	D	C	D	D
	5	C		D	C	B	B	A	C	D	D	C	E	D
	6	B		D	C	C	B	B	A	E	E	D	D	B
	7	B		B	E	A	D	B	D	E	E	E	D	C
	8	A		E	E	B	B	C	B	C	E	D	E	D
	52-57								B	E	E	B	B	B
The Narrows	21								A	B	C	C	E	E
Inner Harbour	58	B		D	C	D	B	B	B	E	D	C	E	D
Mid Harbour	43	B		B	A	C	C	B	B	B	C	C	C	C
	48	B		C	B	A	A	B	E	D	D	D	C	C
South Trees Inlet (lower)	60	A		E	E	B	A	A	C	D	E	C	D	C
Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E	D
	96	B		D	C	B	A	A	B	D	E	D	E	D
	104	B		D	B	B	A	A	C	E	E	E	E	C

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

** Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.

4 DISCUSSION

This report card incorporates the best available data on the fundamental characteristics of seagrass meadows – biomass, area, and species composition – into a series of grades and scores that enable comparisons among meadows, and among Gladstone Harbour Zones. The method also allows for comparisons over the monitoring time frame, in this case 12 years. Our assessment of the 14 monitoring meadows determined that the overall condition of most meadows was poor or satisfactory in November 2014. This included all of the monitoring meadows in the Inner Harbour, Mid Harbour, South Trees Inlet (lower) and Rodds Bay Zones. The overall condition of seagrass in the Gladstone Harbour region was poor.

Seagrasses in the Gladstone region underwent significant declines during and immediately following years of above average rainfall and flow from the Calliope River. Years with a large number of poor and very poor overall meadow grades either correspond with (2010-2013) or directly follow (2004, 2014) flooding and major rain or storm activity in the region. Declines in monitoring meadow condition were indicative of wider declines in seagrasses across the Port Curtis region. Between November 2009 and 2013 reductions in meadow area of ~75% and ~50% occurred for deepwater and coastal seagrasses, respectively (Carter et al. 2015). Reductions in coastal seagrasses were mostly concentrated in The Narrows and Western Basin Zones; these meadows are closest to the source of episodic flooding from the Calliope River and potential impacts from 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 been linked to seagrass declines at other sites due to a reduction in available light (Erftemeijer and Lewis III 2006; Campbell and McKenzie 2004). Frequent severe climate events between 2010 and 2013, rather than dredging activities, are likely the main driver of poor seagrass condition recorded in the Gladstone region. Declines in seagrass biomass and area generally occcurred before the onset of the Western Basin Project capital dredging activities, with declines also occurring at the out of port reference sites in Rodds Bay, and more broadly on the east coast of Queensland south of Cairns during the same period (see Section 4.1). An analysis of the relationship between a broad range of environmental variables and seagrass change in Gladstone Harbour and Rodds Bay monitoring sites found significant negative relationships between Calliope River flow and seagrass biomass. The strongest relationships were reported for seagrass meadows closest to the mouth of the Calliope River (Wiggins Island and Pelican Banks South) (McCormack et al. 2013). The timing of flood-related declines in seagrass during 2010 and 2011 immediately prior to the onset of the major capital dredging activities makes it difficult to ascertain what additional impact dredging and dredge material placement may have had on seagrass condition, or the influence it played on the subsequent rate of recovery. However, a comprehensive water quality monitoring program during the Western Basin Dredging and Disposal Project (WBDDP) has shown that light levels were maintained above locally derived light requirements at seagrass meadows outside of the immediate dredging locations during the dredging campaign (Davies et al. 2015a; Chartrand et al. 2012).

Species compostion grades below very good were mostly driven by a change from *Z. muelleri* subsp. *capricorni* dominated communities to those increasingly dominated by colonising *H. ovalis* between 2009 and 2014. Improvements in species compositon condition between 2013 and 2014 in some meadows, driven by increases in *Z. muelleri* subsp. *capricorni* as a proportion of mean meadow biomass, indicate propagule availability for successful recruitment. Viable *Z. muelleri* subsp. *capricorni* seed banks have been detected during monitoring in Gladstone Harbour (McCormack et al. 2013). The age and viability of remaining seeds will be critical in understanding the ongoing ability of these meadows to regenerate. Investigations of the viability of seed banks at these sites is currently being undertaken by TropWATER as part of research funded throught the Ecosystem Research and Monitoring Program (ERMP).

4.1 Comparisons with State-wide Monitoring Program

Reduced seagrass meadow condition in 2010-2014 observed in Gladstone is generally consistent with seagrass declines recorded on Queensland's east coast between Cairns and Gladstone. Large scale declines in seagrass meadow area and biomass occurred in 2009/2010 throughout the north-eastern coast of Queensland, including in Cairns (Jarvis et al. 2014), Mourilyan (York et al. 2014), Townsville (Davies et al. 2014), and Abbot Point (McKenna and Rasheed 2014; Rasheed et al. 2014). These declines coincided with above average rainfall and river flow (McKenna et al. 2015b) often associated with tropical cyclones (TC) that have impacted the Cairns to Gladstone region such as TC Hamish (March 2009), TC Ului (March 2010), TC Anthony (January 2011), TC Yasi (March 2011) and TC Oswald (January 2013). There was a reprieve from cyclones in the region in 2012, reflected by below-average rainfall and river flow in these locations. In Gladstone this corresponded with improvements in overall meadow condition for 8 of the 14 monitoring meadows (and no declines in overall meadow condition in any of the meadows) (Table 13). Declines in overall meadow condition in 2013 followed above average rainfall and fiver flow in that year (Figures 33 and 34; Table 13). The impact of TC Marcia, which crossed the coast just north of Gladstone in February 2015, was not captured by the sampling for this report. Sampling of monitoring meadows will next occur in November 2015.

On the northern Cape York, Torres Strait and Gulf of Carpentaria seagrasses have fared much better over recent times. Seagrass meadows at monitoring locations in Thursday Island (Carter et al. 2014), Weipa (Taylor et al. 2015) and Karumba (Sozou et al. 2015) did not follow the same trend in condition decline. These meadows were graded as being in good condition in 2014, with meadows remaining relatively stable in biomass and area. These regions generally experienced a lower frequency or severity of the extreme weather events, rainfall and flooding, than along the east coast south of Cooktown.

Tropical seagrasses in Queensland have demonstrated an ability to recover from previous impacts (Davies et al. 2013; Rasheed and Unsworth 2011; Rasheed 2004). Coastal seagrass meadows in monitoring locations such as Townsville (Davies et al. 2015b) have returned to conditions similar to the pre-2009 levels, and at other locations such as Abbot Point foundation species have returned and signs of ongoing recovery are positive (McKenna et al. 2015a). Little improvement was recorded in 2014 at other monitoring locations such as Cairns (Jarvis et al. 2015) and Mourilyan (York et al. 2015), although recent information from 2015 suggests recovery may have begun in Cairns (Jarvis et al. 2015). In Mourilyan there seems little prospect of the foundation seagrass species returning to the site without some form of restoration.

Reductions in meadow area and biomass during years of extreme weather events reduce not only the adult plant population but also limit the resources available for that meadow to initiate recovery. When limited or no adult plants remain, recovery will depend upon seed banks in the sediment or sexual propagules sourced from nearby locations (Jarvis and Moore 2010; Duarte and Sand-Jensen 1990; Phillips and Lewis 1983). Under these circumstances the rate of recovery is likely to be much slower, particularly where no local or nearby sources of propagules exist. In this regional context, meadows in Gladstone have shown reasonable resilience and capacity for recovery. However conditions over the next 12 months may prove critical to ensure replenishment of seed reserves and an opportunity for the adult populations to increase in biomass to re-establish resilience buffers.

4.2 Implications for Port Management

The current poor condition of seagrasses in Gladstone Harbour has management implications regarding activities that could potentially reduce water quality in the region. As in other Queensland locations, multiple years of high rainfall, river flow and cyclone activity in the region may have reduced resilience and capacity for recovery (McKenna et al. 2015b; Rasheed et al. 2014; Pollard and Greenway 2013). Condition improvements recorded for some meadows in 2014 indicate seagrasses in Gladstone Harbour remain resilient to recent impacts. Increases in seagrass meadow area and biomass within Gladstone Harbour are likely in 2015 providing the absence of another severe weather event as occurred in January 2013. However, natural recovery from large declines can take up to five years (Preen et al. 1995) or potentially longer. An improvement in the grades and scores of meadows within Gladstone Harbour may be delayed if anthropogenic activities in the region cause additional stressors to seagrass meadows such as high turbidity, poor water quality or low light levels.

The seagrass management tools and thresholds established through major research and assessment programs in Gladstone (Schliep et al. 2014; Chartrand et al. 2012), including GHHP, provide a basis to assess changes in seagrass condition and in other environmental assets in the region. The extensive seagrass monitoring and research efforts in Gladstone are enhancing our understanding of these processes so that measures can be implemented to reduce the chances of exacerbating natural impacts by human activities.

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APPENDIX A

Worked example of R-script to calculate Gladstone GHHP meadow area analysis

```
#Aim:
#Calculate for meadow 8:
#1. Calculate baseline meadow area (mean of 2002-2012)
#2. Calculate standard deviation of baseline
#3. Calculate coefficient of variation of baseline
#4. Define meadow as stable, variable or highly variable (see report for definitions)
#5. Calculate lower bounds of thresholds against the baseline (see report for threshold values depending on meadow class)
#6. Determine grade for 2014 meadow area
#7. Determine the final score meadow 8 area for 2014

#Data is for Meadow 8 (M8)
```

#1. Calculate baseline meadow area (2002-2012)

```
#Calculate 10 year mean area
BaselineM8<-subset(M8, year %in% c("2002", "2004", "2005", "2006", "2007", "2008", "2009", "2010", "2011", "2012"))
meanAREA<-mean(BaselineM8$area)
#mean meadow area for baseline is 215.98 ha
```

#2. Calculate standard deviation of baseline

```
sdAREA<-sd(BaselineM8$area)
# Standard deviation of area is 67.9179
```

#3. Calculate coefficient of variation of baseline

```
CV<- sdAREA/meanAREA*100
#Coefficient of variation is 31.44639
```

#4. Define meadow area as stable, variable or highly variable

```
#If CV<40% = stable meadow
#If CV is 40-80% = variable meadow
#If CV>80% = highly variable meadow (area only)

#CV = 31.44639 so therefore a stable meadow
```

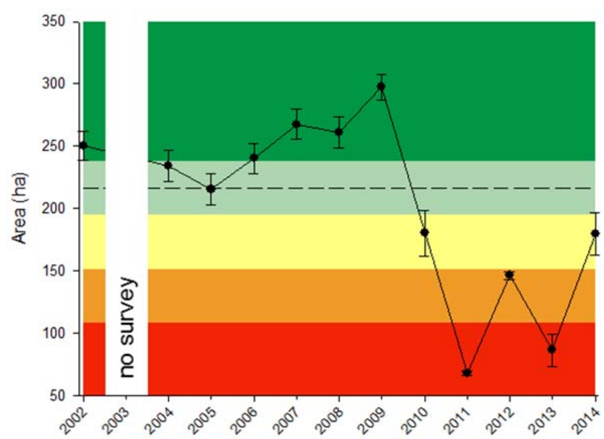
#5. Calculate lower bounds of thresholds against the baseline (see report for threshold values depending on meadow class)

```
#area stable meadow thresholds are +10%, -10%, -30%, -50%
AREAvg <- meanAREA + (meanAREA*0.1) #237.578
AREAg <- meanAREA - (meanAREA*0.1)  #194.382
AREAs <- meanAREA - (meanAREA*0.3)  #151.186
AREAp <- meanAREA - (meanAREA*0.5)  #107.99
AREAvp <- 0.00
#where vg = very good, g = good, s = satisfactory, p = poor, vp = very poor
```

#6. Determine grade for 2014 meadow area

```
#Open data frame for meadow of interest
M8
```

#2014 meadow area value is 179.7 ha
#Define Current Grade (AREA2014)
AREA2014 <- 179.7
#This value sits above lower threshold for "satisfactory" and below lower threshold for "good", therefore species composition condition is "satisfactory" (see graph below).



#7. Calculate indicator score
#Define ISP defined Score Range (SR) in units for very good (VG), good (G), satisfactory (S), poor (P) and very poor (VP) (see Table 7 of main report)
SRvg <- 0.15
SRg <- 0.20
SRs <- 0.15
SRp <- 0.25
SRvp <- 0.25
#where vg = very good, g = good, s = satisfactory, p = poor, vp = very poor

#Define ISP defined Lower Bound (LB) score threshold in units for very good (VG), good (G), satisfactory (S), poor (P) and very poor (VP) (see Table 7 of main report)
LBvg <- 0.85
LBg <- 0.65
LBs <- 0.50
LBp <- 0.25
LBvp <- 0.00
#where vg = very good, g = good, s = satisfactory, p = poor, vp = very poor

#Calculate difference between area for 2014 and lower threshold for the area condition grade 2014 falls in (refer back to Steps 5 and 6 for values to use in calculation)
AREAdiff <- (AREA2014 - AREAs)
#AREAdiff is 28.514

#Define range for "satisfactory" area condition for meadow of interest (refer back to Step 5 for values to use in calculation)
AREArange <- (AREAg - AREAs)
#AREArange is 43.196

#Calculate the proportion of the "satisfactory" category that AREA2014 is taking up
AREAprop <- (AREAdiff/AREArange)
#AREAprop is 0.6601074

#8. Determine the final score meadow 8 area for 2014
Score2014 <- LBs + (AREAprop*SRs)
#Score2014 is 0.5990161

#Where (see step 7 for more details):
#LBs is the ISP defined lower bound score threshold for the satisfactory category, i.e. 0.50
#AREAprop is the proportion of the "satisfactory" category that area in 2014 takes up, i.e. 0.6601074
#SRs is the ISP defined Score Range (SR) for satisfactory i.e. 0.15 units