GLADSTONE HEALTHY HARBOUR PARTNERSHIP 2016 REPORT CARD

ISP011: SEAGRASS

Carter AC, Bryant CV, Davies JD and Rasheed MA

Report No. 16/23

July 2016

GLADSTONE HEALTHY HARBOUR PARTNERSHIP
2016 REPORT CARD

ISP011: SEAGRASS

Report No. 16/23

July 2016

Alex Carter, Catherine Bryant, Jaclyn Davies and Michael Rasheed

Centre for Tropical Water & Aquatic Ecosystem Research
(TropWATER)
James Cook University
PO Box 6811
Cairns Qld 4870
Phone : (07) 4781 4262
Email: seagrass@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

Information should be cited as:
Carter AB, Bryant CV, Davies JD & Rasheed MA (2016). 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass'. Centre for Tropical Water & Aquatic Ecosystem Research Publication 16/23, James Cook University, Cairns, 62 pp.

For further information contact:
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
seagrass@jcu.edu.au
PO Box 6811
Cairns QLD 4870

This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:
This project is funded by Gladstone Healthy Harbour Partnership.

EXECUTIVE SUMMARY

- Seagrass condition was assessed for 14 monitoring meadows across 6 Gladstone Healthy Harbour Partnership reporting zones in November 2015 (GHHP 2016 reporting year).

- Seagrass condition in the Gladstone Harbour region was poor (D).

- Half of the monitoring meadows were assessed as being in poor condition, including all of the monitoring meadows in The Narrows, Mid Harbour and South Trees Inlet Zones. In the Western Basin Zone two meadows were in satisfactory condition, two meadows were in good condition, and two meadows were in poor condition. No meadows were graded as very good for overall meadow condition.

- Seagrass was in poor condition in four Gladstone Harbour Zones (The Narrows, Mid Harbour, South Trees Inlet and Rodds Bay); the Inner Harbour Zone was in very poor condition; and the Western Basin Zone was in satisfactory condition.

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

- Environmental conditions influence seagrass condition in Gladstone. Years where overall meadow condition was poor/very poor in the majority of meadows either correspond with (2010-2015) or directly follow (2004) years of above average rainfall and discharge in the region, particularly from the Calliope River. These rainfall/river flow peaks are often associated with tropical cyclones. Tropical Cyclone Marcia crossed the coast just north of Gladstone in February 2015, bringing with it short but significant rainfall and flooding from the Fitzroy River (just north of Gladstone) and south to the Upper Brisbane River.

- There was no sign of seagrass recovery at the Gladstone Harbour scale from the previous year. Overall seagrass condition improved from very poor to poor in The Narrows; remained stable in the Western Basin (satisfactory) and Rodds Bay (poor); and declined in the Inner Harbour (poor to very poor), Mid Harbour and South Trees inlet (satisfactory to poor). Consecutive years of poor seagrass condition have likely reduced meadow resilience to further impacts.

- This report is presented into two parts. Part 1 summarises report card results for the most recent annual survey conducted in November 2015. Part 2 is an accompanying technical report that details methods, analysis, results and interpretation.

- Several minor changes to the methods used to assess seagrass condition were applied in the 2016 reporting year. This resulted in minor grade changes in some meadows in some years (e.g. meadow 43 area in 2008). These changes are detailed in Section 2.2 of the report.

CONTENTS

PART 1 - SEAGRASS REPORT CARD 2016

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 Gladstone Harbour and Rodds Bay since 2002. This includes an annual long-term monitoring program conducted each October/November during the peak seagrass growth period (not surveyed in 2003). The program monitors seagrass condition in 14 representative intertidal and shallow subtidal seagrass meadows (Figure 1).

A pilot approach for reporting on seagrass condition in the 14 monitoring meadows was developed by the Seagrass Ecology Group for the Gladstone Healthy Harbour Partnership (GHHP) in 2014. Three indicators of seagrass condition were assessed—biomass, area and species composition—and each meadow graded from A (very good) to E (very poor) relative to baseline conditions (Bryant et al. 2014b). In 2015 seagrass condition indicators were also scored on a 0–1 scale; allowing for average scores to be calculated among differing spatial scales (Table 1). The lowest of the three indicator scores dictates the overall meadow score and grade (Figure 1; Table 1).

Gladstone Harbour is divided into reporting zones as part of the GHHP reporting process, six of which contain seagrass monitoring meadows (Figure 2). Where multiple monitoring meadows are present within a zone, the mean of the overall meadow scores dictates the zone score and grade. The grades presented in this report reflect the condition of seagrasses during the most recent annual survey, conducted in November 2015 (GHHP 2016 reporting year). The Western Basin Zone was determined to be in satisfactory condition; The Narrows, Mid Harbour, South Trees and Rodds Bay Zones were in poor condition; and the Inner Harbour Zone was in very poor condition (Table 1). The Gladstone Harbour region score is the mean of the zone scores. In 2016 seagrass condition in the region was poor (D; Table 1).

This is the third year of applying the seagrass report card method and includes modifications from previous years as methods have been reviewed and refined. The 2014 pilot approach relied heavily on expert opinion to determine meadow class (e.g. stable or variable) (Bryant et al. 2014b). In 2015, statistical approaches were explored to strengthen reporting, particularly around meadow class definitions, threshold values, and assessing species composition changes. In 2016, minor adjustments were made following a statistical review. These changes are described in Section 2.2 and had only very minor effects on some scores and grades.

It is important to note that tropical seagrass communities naturally vary in condition due to environmental factors; a meadow classified as being in poor condition can reflect the natural range of expected conditions and is not necessarily due to human impacts. The report card provides a means of evaluating current meadow condition against 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 Gladstone Harbour scores for the GHHP 2016 reporting year. See Table 7 for grading scale.

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION	OVERALL MEADOW SCORE	OVERALL ZONE SCORE
1. The Narrows	**21**	0.33	0.87	0.57	0.33	0.33
3. Western Basin	**4**	0.83	0.52	0.78	0.52	0.55
	5	0.49	0.58	0.34	0.34	
	6	0.68	0.82	0.67	0.67	
	7	CR*	0.78	1.00	0.78	
	8	0.88	0.51	0.38	0.38	
	52-57**	0.60***	0.96	1.00	0.60	
5. Inner Harbour	**58**	0.42	0.92	0.14	0.14	0.14
8. Mid Harbour	**43**	0.25	0.78	0.68	0.25	0.36
	48	0.46	0.54	0.51	0.46	
9. South Trees Inlet	**60**	0.48	0.88	0.59	0.48	0.48
13. Rodds Bay	**94**	0.08	0.28	0.36	0.08	0.25
	96	0.40	0.76	0.66	0.40	
	104	0.28	0.29	0.46	0.28	
Gladstone Harbour						**0.35**

* CR = calculation restriction - a biomass score could not be calculated due to small sample size.

**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.

***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.

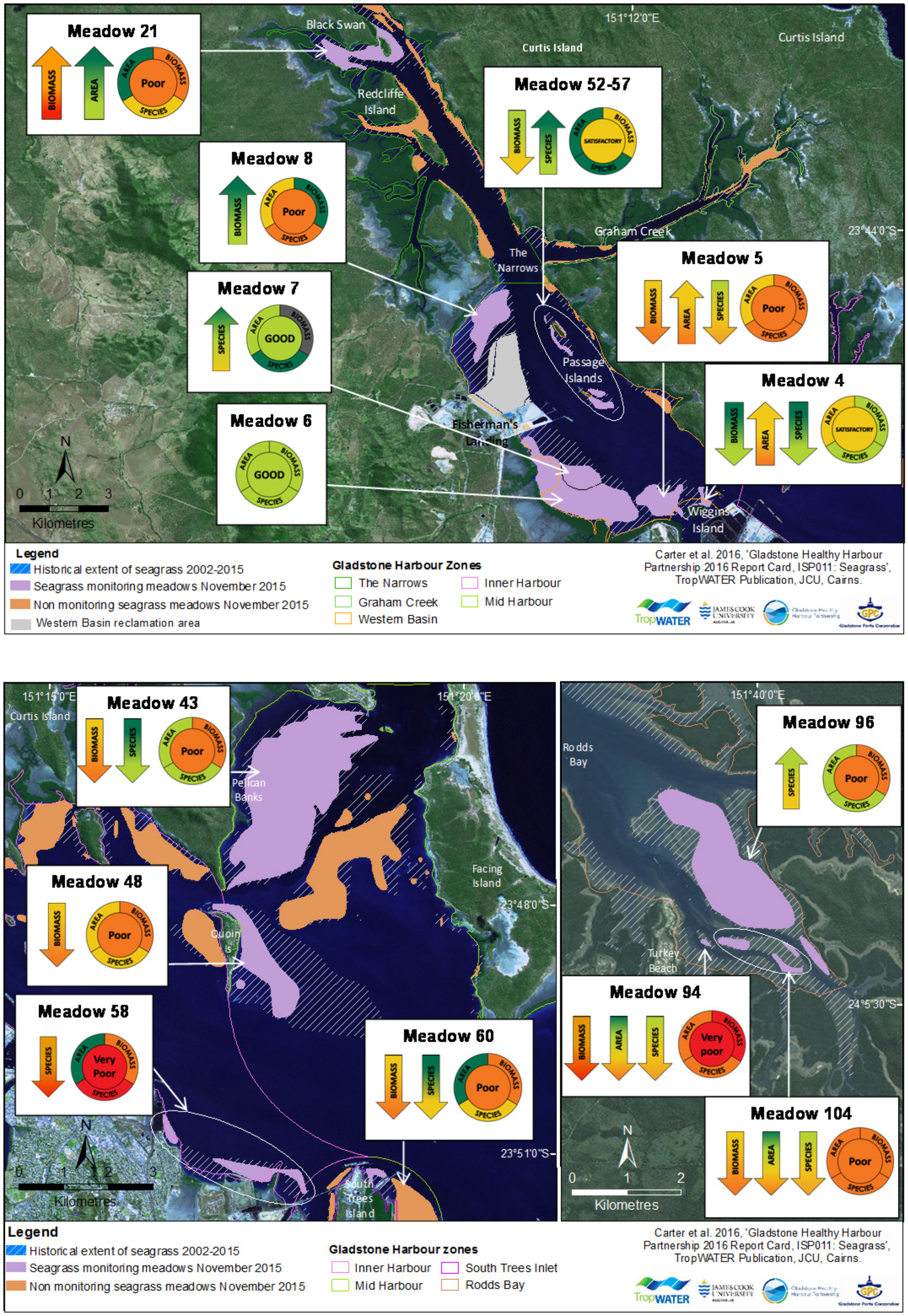
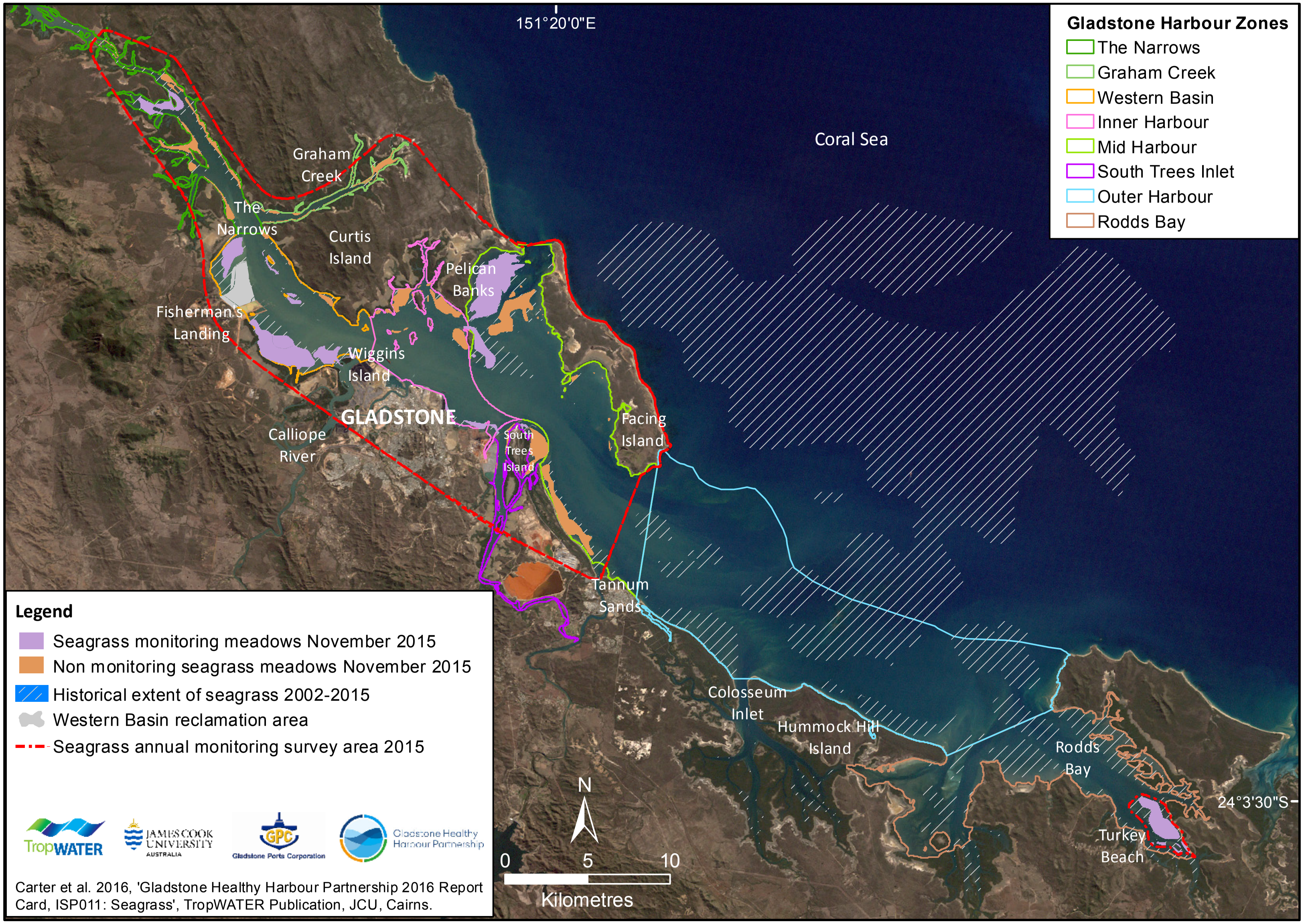


Figure 1. Seagrass condition for each indicator, and overall meadow condition for 14 monitoring meadows within six Gladstone Harbour Zones. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year



Carter et al. 2016, 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass', TropWATER Publication, JCU, Cairns.

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

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program is 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 is 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 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 and feeds into regional assessments of seagrass condition. 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

The Gladstone region contains diverse and productive seagrass meadows and macro-benthic fauna (Lee Long et al. 1992; Rasheed et al. 2003; McKenna et al. 2014). Seagrasses in the region are of particular value as a food source for dugong, recognised by the declaration of the Rodds Bay Dugong Protection Area (DPA). In 2002, Gladstone Ports Corporation (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.

Annual seagrass monitoring 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. In 2009 two 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; 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 (Meadow 9 was included in the GHHP 2013–14 reporting year).

Monitoring since 2002 has documented considerable inter-annual variability in seagrass condition. Variation in seagrass meadows is most likely a response to regional and local environmental 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 area 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 and November.

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 developed a report card to track ecosystem health in the harbour which includes 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 (Figure 2) (Carter et al. 2015a). 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 annual long-term monitoring data. A pilot report card was developed in 2014 (Bryant et al. 2014b). Full implementation of the program including annual reporting commenced in 2015. The objectives of the 2016 Gladstone Harbour report card were to provide:

1. Seagrass grades and scores for the 2016 reporting year using GHHP approved grades and scores.
2. A project report describing data collection, statistical methods used to determine the report card grades and scores, and an assessment of Gladstone Harbour seagrass meadow condition in 2016 relative to historical trends.
3. A GIS shapefile and metadata for the seagrass monitoring meadows analysed, and raw seagrass data.

1.2.2 **Seagrasses in the Gladstone Harbour Region**

Five seagrass species from three families are commonly found in the Gladstone Harbour area (Figure 3).

Family CYMODOCEACEAE:
    Halodule uninervis (wide and thin leaf morphology)

Family HYDROCHARITACEAE:
    Halophila decipiens
    Halophila ovalis
    Halophila spinulosa

Family ZOSTERACEAE:
    Zostera muelleri subsp. *capricorni*

Zostera muelleri subsp. *capricorni*   *Halodule uninervis*

Halophila ovalis   *Halophila decipiens*   *Halophila spinulosa*

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

2 METHODS

2.1 Sampling Approach and Data Collection Methods for Seagrass Indicators

Fourteen representative seagrass monitoring meadows were surveyed 23–28 November 2015 (GHHP 2016 reporting year). Annual surveys are always conducted in the peak seagrass growing season (late spring) when meadows are likely to contain maximum biomass and area (Chartrand et al. 2012). Sampling at the same time of year also allows for assessments of annual change by controlling for seasonal variation (Carter et al. 2015a).

Survey methods followed the established techniques for the TropWATER Queensland-wide ports seagrass monitoring program (see Lee Long et al. 1996; Rasheed and Unsworth 2011; Taylor and Rasheed 2011; Unsworth et al. 2012). Intertidal meadows were sampled at low tide using a helicopter (Figure 4a). GPS was used to record the position of meadow boundaries. Seagrass presence/absence and characteristics were recorded at sites scattered within the seagrass meadow as the helicopter hovered within 1 metre above the seagrass. Shallow subtidal meadows were sampled from a small boat using free divers (Figure 4b) or a Van Veen grab (grab area 625 cm^2) where visibility was too poor for free diving (Figure 4c). 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. 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).

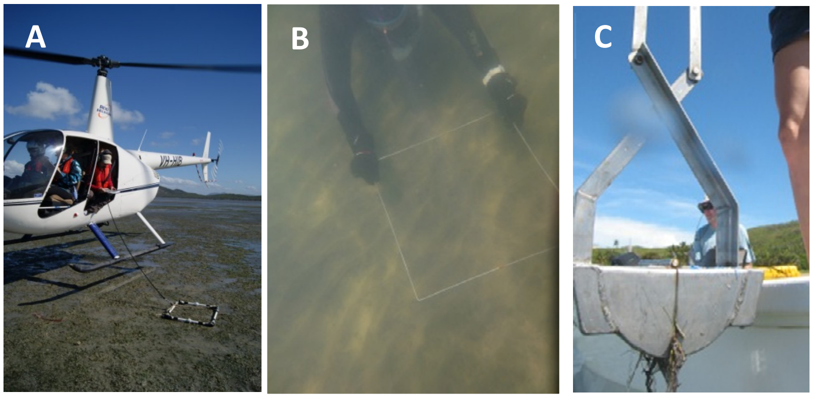


Figure 4. Seagrass monitoring conducted using (A) helicopter aerial surveillance; (B) boat based free divers; and (C) Van Veen grab.

2.1.1 Biomass and proportion contribution of each species

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (Kirkman 1978; Mellors 1991). A 0.25 m^2 quadrat was placed randomly three times at each site (Figure 4a, b). At 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. The percentage contribution of each seagrass species to above-ground biomass within each quadrat was also recorded. Two separate ranges were used - low biomass and high biomass. At the completion of ranking, the observer also ranked a series of at least four 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 (gDW m^{-2}). Seagrass biomass could not be determined from sites sampled by Van Veen grab, but seagrass presence/absence and species composition was recorded.

2.1.2 **Seagrass Meadow Mapping and Geographic Information System**

Seagrass presence/absence site data was used to construct the meadow (polygon) layer. Seagrass meadows were assigned a meadow identification number 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.

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 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 (R; hectares), and Gladstone Harbour Zone. Also provides summary information of all sites within the meadow, including 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 (Tables 5-7; Section 2.2 of report).

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 (gDW 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 un-vegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches

Meadows are comprised of numerous seagrass patches but still feature substantial gaps of un-vegetated 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 un-vegetated sediment

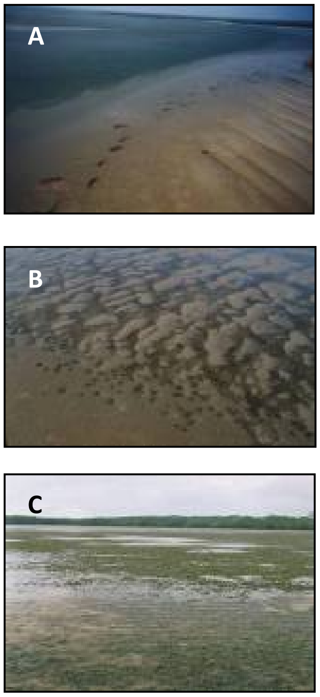


Figure 5. Seagrass meadow landscape categories: (A) Isolated seagrass patches, (B) aggregated seagrass patches, (C) continuous seagrass cover.

2.2 Seagrass Condition Index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in Gladstone Harbour was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 6 summarises the methods used to calculate seagrass condition.

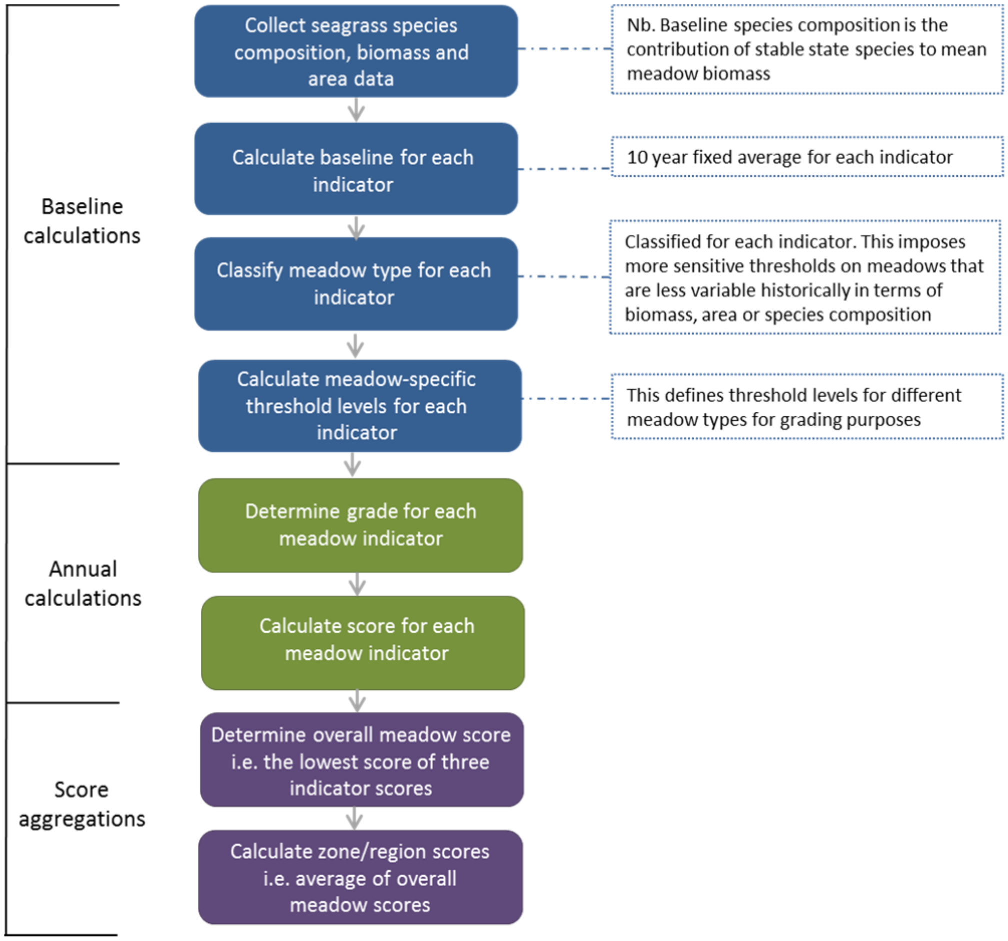


Figure 7. Flow chart to develop Gladstone Harbour grades and scores.

2.2.1 Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2002–2012; nb. no survey conducted in 2003). This baseline was set based on results of the 2014 pilot report card (Bryant et al. 2014b). 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. 2015a), 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 which 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. November 2015 data). Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). In 2016 an additional rule was applied: where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Section 2.2.4 and Figure 7).

2.2.2 Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass, area and species composition was classified as either stable or variable (Table 5). One further classification for meadow area was added in the 2016 reporting year: highly stable (Table 5). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

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

Indicator	**Class**			
	Highly stable	**Stable**	**Variable**	**Highly variable**
Biomass	-	< 40%	≥ 40%	-
Area	< 10%	≥ 10, < 40%	≥ 40, <80%	≥ 80%
Species composition	-	< 40%	≥ 40%	-

2.2.3 Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and 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 (Table 6).

Table 6. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

Seagrass condition indicators/ Meadow class		**Seagrass grade**				
		A Very good	**B Good**	**C Satisfactory**	**D Poor**	**E Very Poor**
Biomass	Stable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area	Highly stable	>5% above	5% above - 10% below	10-20% below	20-40% below	>40% below
	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Highly variable	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species composition	Stable and variable; Single species dominated	>0% above	0-20% below	20-50% below	50-80% below	>80% below
	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable; Mixed species	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below
	Increase above threshold from previous year		↑ BIOMASS	Decrease below threshold from previous year		↓ BIOMASS

2.2.4 Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows, Gladstone Harbour Zones, and for the Gladstone Harbour region (Table 7; see Carter et al. 2015b for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year (described in Section 2.1), allocating a grade for each indicator by comparing 2015 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table 7). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period. For meadows 21 and 52-57 this upper limit will be recalculated each year until the 10 year baseline period is complete. In previous report cards the upper limit was based on the mean + SE of any survey year, meaning biomass and area values in the very good range potentially would require constant recalculation; defining the upper limit using baseline years is a new approach in 2016 that “locks in” the upper value. Scores and grades are not included where biomass was estimated from <3 sites; this generally occurred where visibility was too poor for visual estimates of biomass and sampling was conducted mostly using a Van Veen grab. This led to calculation restrictions on biomass scores for meadow 7 in 2012, 2014 and 2015 (see Table 11, Section 3.4).

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 1.

Table 7. Score range and grading colours used in the 2016 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

Where species composition was determined to be anything less than in “perfect” condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure 7). If this was the case then the species composition score and grade for that year was recalculated including those species. Concern 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 (Figure 7). This would occur when the stable state species is replaced by species considered to be earlier colonisers. 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 *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found in Gladstone Harbour, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure 7).

The decision tree used in 2016 expands on the 2015 model and provides a more thorough assessment of species composition condition. Specific changes include the separation and positioning of *Z. muelleri* subsp. *capricorni* above *H. uninervis* (grouped as equivalent species in 2015), the separation and positioning of *H. spinulosa* above *H. ovalis* (also grouped as equivalent species in 2015), and triggering the directional change assessment if the species composition score was <1 (the trigger was based on a grade less than very good in 2015, meaning no score adjustment occurred in the highest grade even if more persistent species present could have improved the score).

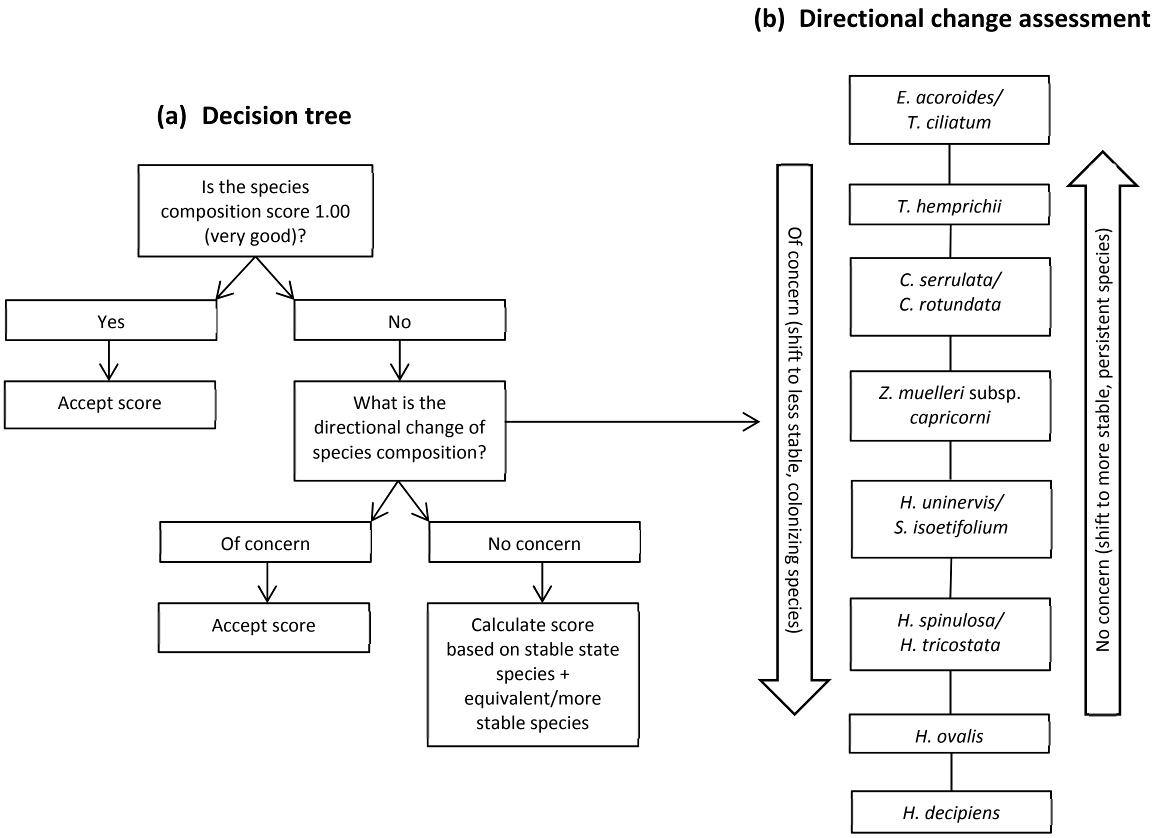


Figure 7. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Gladstone.

2.2.5 **Score Aggregation**

Each overall meadow grade/score was defined as the lowest grade/score of the three condition indicators 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 allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014b).

Gladstone Harbour zone grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within a given zone, and assigning the corresponding grade to that score (Figure 6; 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 (outlined in Section 2.2.2) at the meadow analysis stage applied smaller and therefore more sensitive thresholds for meadows considered stable, and 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.

The Gladstone Harbour regional score/grade 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 variable in 13 of the 14 monitoring meadows (Table 8). Area was stable for only half of the meadows. Half of the monitoring meadows were dominated by a single species (accounting for >80% of mean meadow biomass). Only one meadow was classed as stable across all three condition indicators – the large (~600 ha), high biomass (~19 gDW 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
1. The Narrows	**21***	Variable	Stable	Stable - mixed species
3. 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	Variable	Variable - mixed species
5. Inner Harbour	**58**	Variable	Highly Variable	Variable - mixed species
8. Mid Harbour	**43**	Stable	Highly Stable	Stable - single species
	48	Variable	Variable	Stable - single species
9. South Trees Inlet	**60**	Variable	Variable	Variable - single species
13. Rodds Bay	**94**	Variable	Stable	Stable - single species
	96	Variable	Variable	Stable - single species
	104	Variable	Stable	Stable - single species

* <10 years of data available to classify meadows. Results for these meadows should be interpreted with caution until long-term data are available.

3.2 Overall Meadow, Zone and Harbour Scores for the 2016 Reporting Year

Half of the monitoring meadows were in poor condition in November 2015 (Table 9), including all of the monitoring meadows in The Narrows, Mid Harbour and South Trees Inlet Zones. In the Western Basin Zone two meadows were in satisfactory condition, two meadows were in good condition, and two meadows were in poor condition. The single monitoring meadow at Inner Harbour was in very poor condition. No meadows were graded as very good for overall meadow condition.

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

The overall seagrass condition in Gladstone Harbour received a poor score 0.35 (D) based on average zone scores (Table 9). Four Gladstone Harbour Zones were in poor condition (The Narrows, Mid Harbour, South

Trees Inlet and Rodds Bay), the Inner Harbour Zone was in very poor condition, and the Western Basin Zone was in satisfactory condition (Table 9).

Table 9. Grades and scores for seagrass indicators (biomass, area, species composition), meadows, Gladstone Harbour zones and region for the GHHP 2016 reporting year (November 2015 surveys). Scores are on 0-1 scale; cells are coloured according to grade, where dark green = very good, light green = good, yellow = satisfactory, orange = poor, red = very poor.

ZONE	MEADOW ID	BIOMASS	AREA	SPECIES COMPOSITION	OVERALL MEADOW SCORE	OVERALL ZONE SCORE
1. The Narrows	**21**	0.33	0.87	0.57	0.33	0.33
3. Western Basin	**4**	0.83	0.52	0.78	0.52	0.55
	5	0.49	0.58	0.34	0.34	
	6	0.68	0.82	0.67	0.67	
	7	CR*	0.78	1.00	0.78	
	8	0.88	0.51	0.38	0.38	
	52-57**	0.60***	0.96	1.00	0.60	
5. Inner Harbour	**58**	0.42	0.92	0.14	0.14	0.14
8. Mid Harbour	**43**	0.25	0.78	0.68	0.25	0.36
	48	0.46	0.54	0.51	0.46	
9. South Trees Inlet	**60**	0.48	0.88	0.59	0.48	0.48
13. Rodds Bay	**94**	0.08	0.28	0.36	0.08	0.25
	96	0.40	0.76	0.66	0.40	
	104	0.28	0.29	0.46	0.28	
Gladstone Harbour						**0.35**

* CR = calculation restriction - a biomass score could not be calculated due to small sample size.
**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.
***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.

3.3 Report Card Grades by Gladstone Harbour Zone

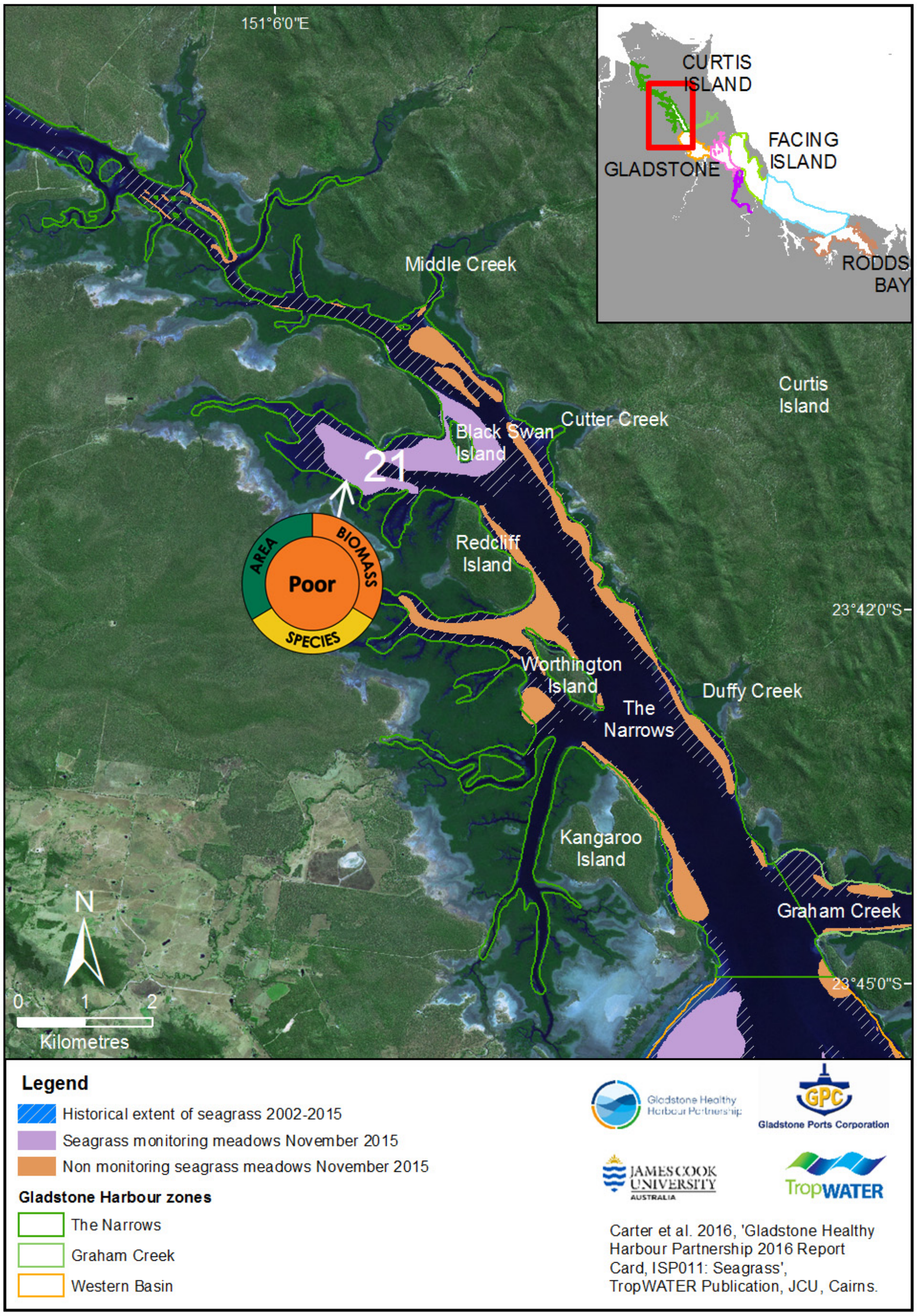
3.3.1 Zone 1: The Narrows

Seagrass in Zone 1: The Narrows was in poor condition (Figure 8). This was driven by a poor biomass grade for Meadow 21 (intertidal, variable biomass meadow) at Black Swan Island, the only monitoring meadow in the zone (Figure 9). Biomass in 2015 was 1.1 ± 0.2 gDW m^{-2}. The poor grade was an improvement from very poor biomass and overall meadow condition in 2014, when biomass was just 0.5 gDW m^{-2} following five consecutive years of decline. Meadow area increased from good to very good condition following a 20 ha area increase from the previous year. Species composition remained in satisfactory condition. Meadow 21 is traditionally a mixed species meadow dominated by *Z. muelleri* subsp. *capricorni* (76% of mean meadow biomass) but the proportion of *Z. muelleri* subsp. *capricorni* has declined relative to less persistent *H. ovalis* over seven years of monitoring. In 2015 *Z. muelleri* subsp. *capricorni* accounted for 48% of mean meadow biomass (Figure 9; Appendix 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.

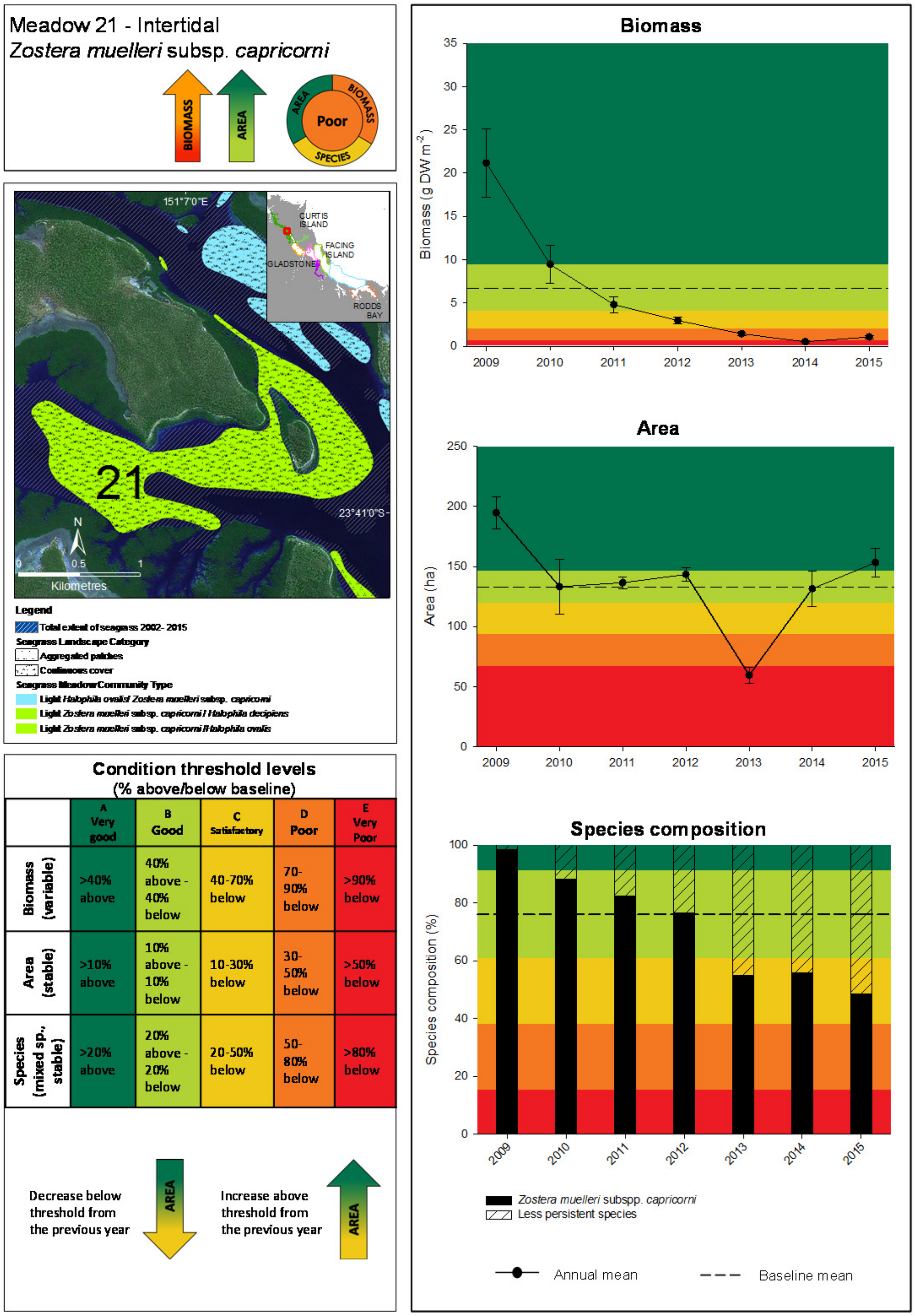
Gladstone Harbour Zone: The Narrows

D



Carter et al. 2016, 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass', TropWATER Publication, JCU, Cairns.

Figure 8. Seagrass condition in Zone 1: The Narrows.



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (mixed sp., stable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below

Figure 9. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 21, Zone 1: The Narrows, November 2009 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.2 **Zone 3: Western Basin**

Seagrass condition in Zone 3: Western Basin was satisfactory for the second consecutive year (Figure 10). There are six monitoring meadows in the Western Basin Zone, including five intertidal and one subtidal meadow, comprised of either isolated or aggregated seagrass patches.

Meadow 4

Meadow 4 at Wiggins Island was in satisfactory condition (Figure 11). This was driven by meadow area being ~50% below the 29 ha baseline, but is an improvement from 2013 and 2014 when area condition was poor. Biomass and species composition were in good condition. Meadow 4 is traditionally a mixed species meadow that fluctuates between *Z. muelleri* subsp. *capricorni* and less persistent *H. ovalis*. In 2015 the composition of *Z. muelleri* subsp. *capricorni* was approximately equal to the baseline at 46%, a slight decline from 2014 (Figure 11; Appendix 2).

Meadow 5

Meadow 5 west of Wiggins Island was in poor condition due to biomass and species composition (Figure 12). Meadow biomass has been variable over the course of monitoring, ranging from >8 gDW m^{-2} in 2007 to lows of <1 gDW m^{-2} in 2004, 2010 and 2015. Meadow 5 is a mixed species meadow that fluctuates between *Z. muelleri* subsp. *capricorni* and less persistent *H. ovalis*. In 2015 the composition of *Z. muelleri* subsp. *capricorni* was 11%, the lowest on record, and the fifth consecutive year *Z. muelleri* subsp. *capricorni* composition was below the baseline of 62% (Figure 12; Appendix 2). Meadow area continued to improve from very poor condition in 2013 and poor condition in 2014 (Figure 12).

Meadow 6

Biomass, area and species composition were all in good condition for Meadow 6 at South Fisherman's Landing (Figure 13), with all grades remaining unchanged from 2014. As with meadows 4 and 5, meadow 6 is a mixed species intertidal meadow where the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*, with *H. ovalis* the dominant species in 2015 (Figure 13; Appendix 2). Biomass remained slightly below the 1.8 gDW m^{-2} baseline for the fourth consecutive year. Meadow area has increased by ~300 ha since the dramatic area reduction recorded in 2010 (Figure 13).

Meadow 7

Meadow 7 condition was good in 2015, driven by improvements in meadow area to above baseline levels, for the first time since 2006 (Figure 14). Meadow area is highly variable, ranging from ~200 ha in 2006 to 0 ha in 2010. The meadow was in very poor condition between 2010 and 2012 following the loss of meadow area and biomass. Biomass also has continued to increase since 2012. Species composition was very good; Meadow 7 is a single species *H. decipiens* dominated meadow (96% of mean meadow biomass) (Figure 14; Appendix 2).

Meadow 8

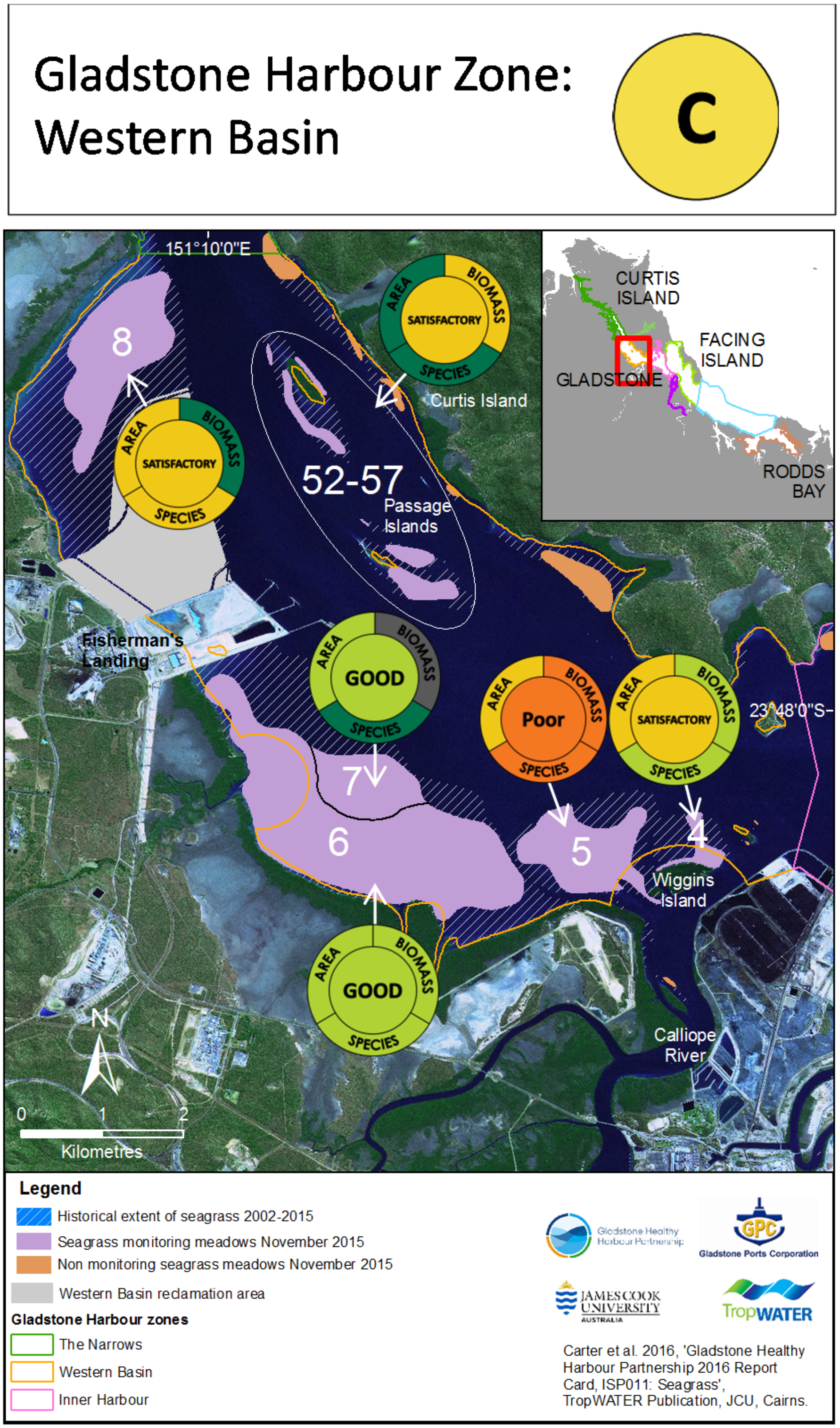
Meadow 8 at North Fisherman's Landing was in poor condition, driven by species composition (Figure 15). Meadow 8 was dominated by *Z. muelleri* subsp. *capricorni* until 2010, when the meadow shifted to a *H. ovalis* and *H. decipiens* dominated community (Figure 15; Appendix 2). In 2015 *H. decipiens* became the dominant species for the first time since monitoring began. The meadow also underwent area declines from 2010, was in either poor or very poor condition between 2011 and 2013, and has improved to satisfactory condition for the past two years. Biomass of the meadow has been variable over the course of monitoring, ranging from <0.1 to 4 gDW m^{-2} in 2007. Biomass was in very good condition in 2015 (Figure 15).

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

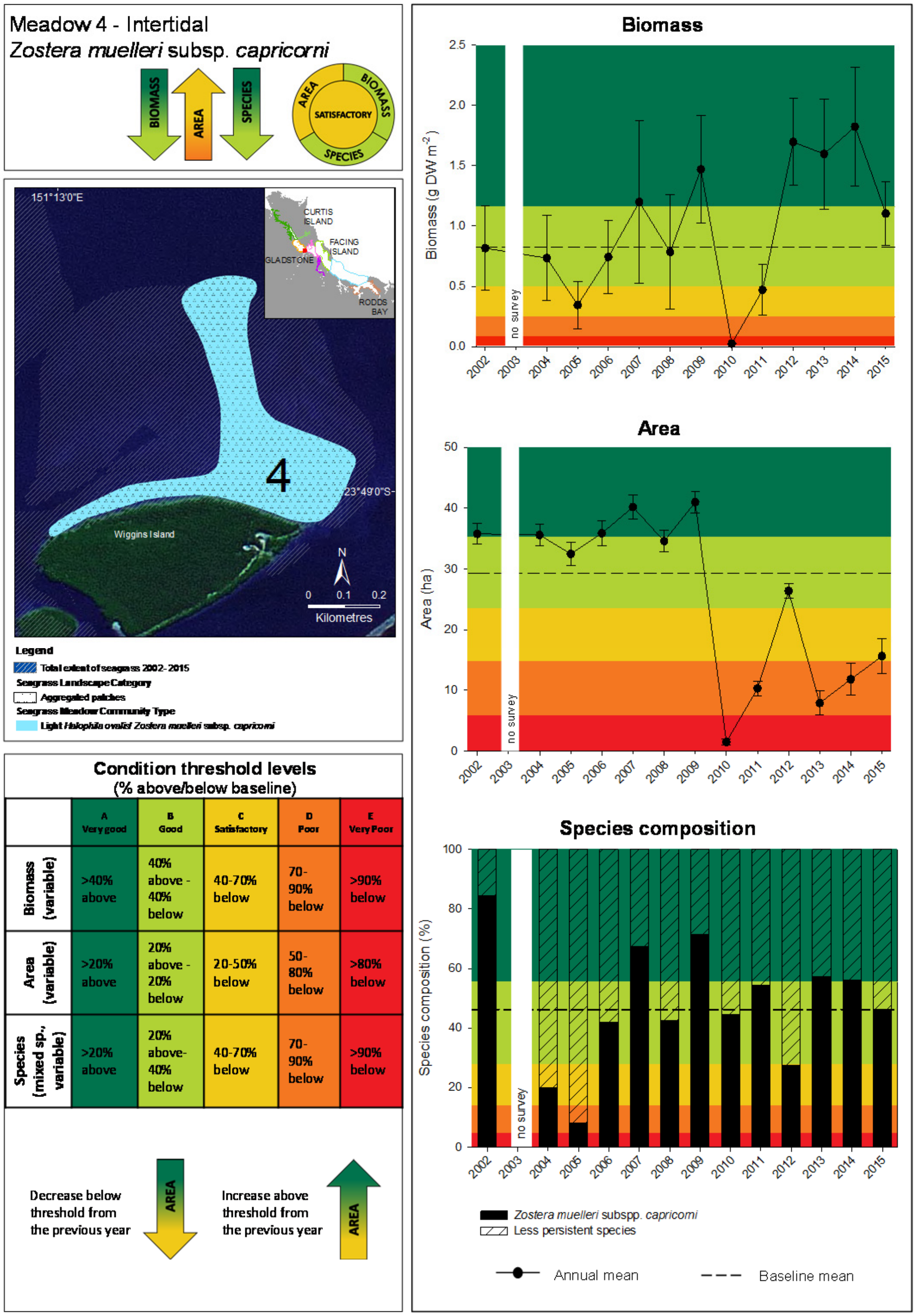
Meadows 52-57 around the Passage Islands were in satisfactory condition due to biomass being 40-70% below the baseline (Figure 16). Mean biomass has remained low (<2 gDW m^{-2}) and variable since monitoring began. This mixed species meadow consists of a group of predominantly intertidal meadows comprised of *H. ovalis* (the dominant species), *Z. muelleri* subsp. *capricorni*, and *H. decipiens* (Figure 16; Appendix 2). In 2015 species composition was graded as very good because of the absence of *H. decipiens.* Meadow area in 2015 was the largest since monitoring began (49 ha; very good condition) but is also variable, reaching lows of <3 ha in 2010 and 2011 (Figure 16).

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.



Carter et al. 2016, 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass', TropWATER Publication, JCU, Cairns.

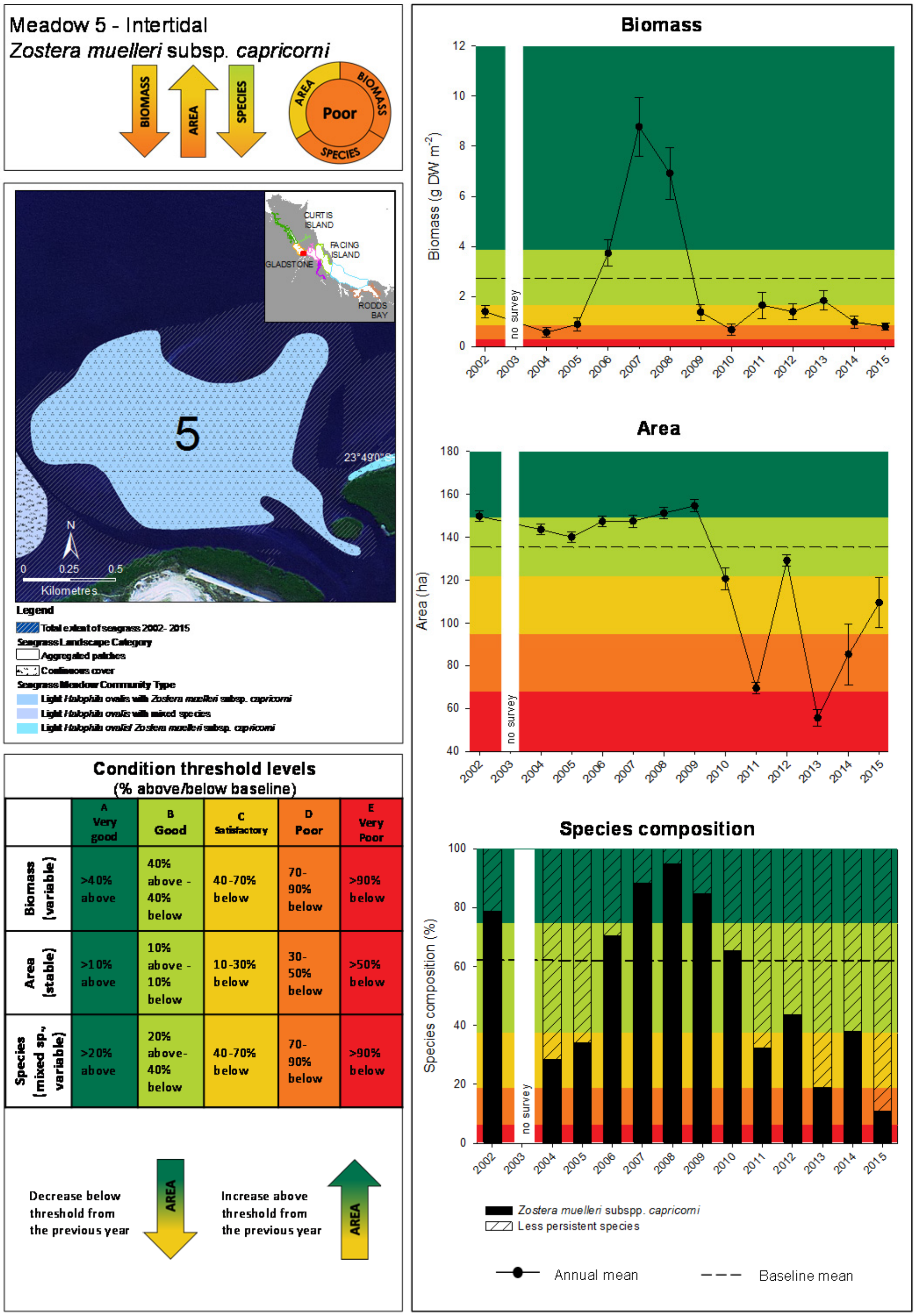
Figure 10. Seagrass condition in Zone 3: Western Basin.



Condition threshold levels
(% above/below baseline)

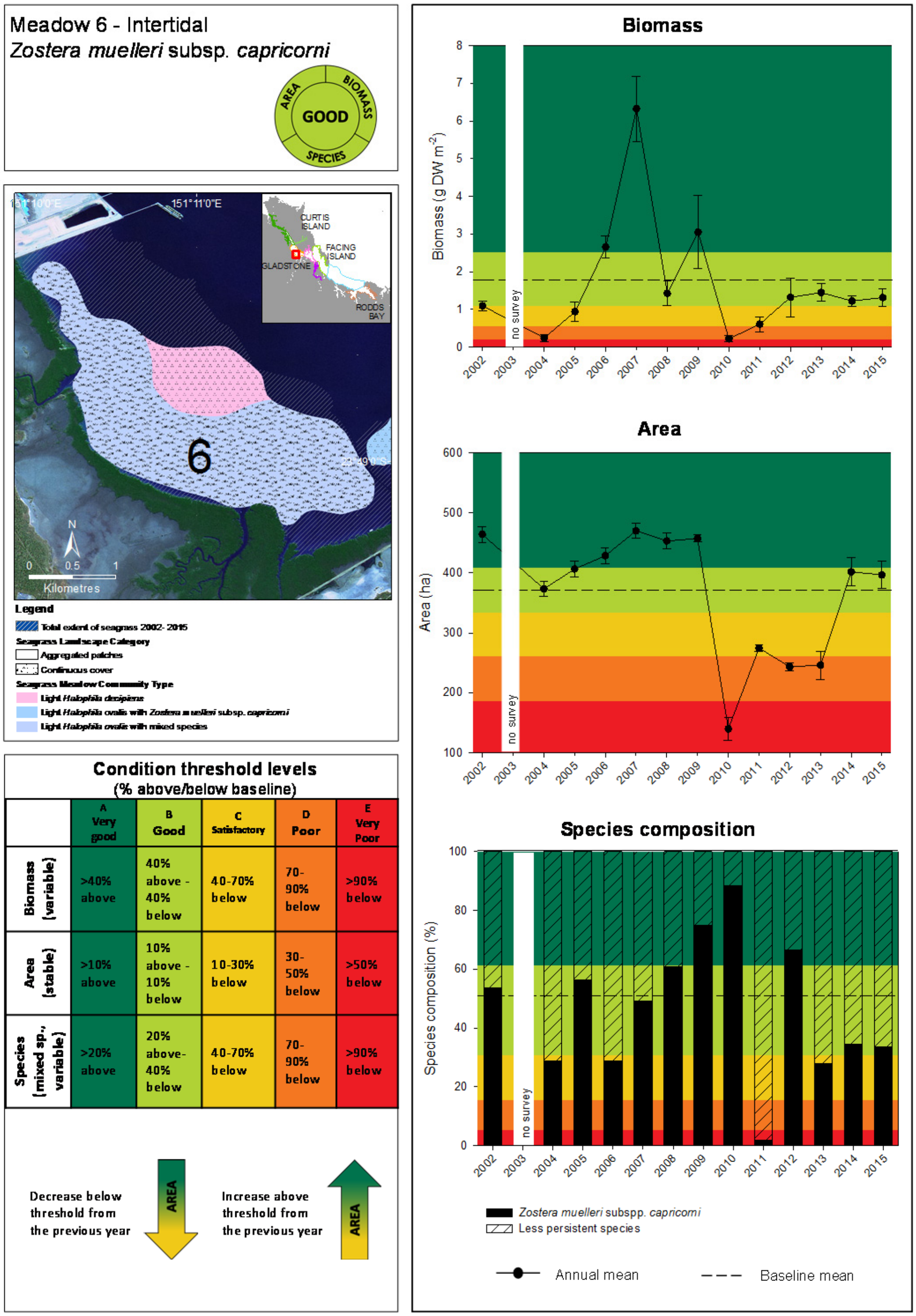
	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (variable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species (mixed sp., variable)	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below

Figure 11. Changes in meadow area, biomass and species composition for seagrass in Meadow 4, Zone 3: Western Basin, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



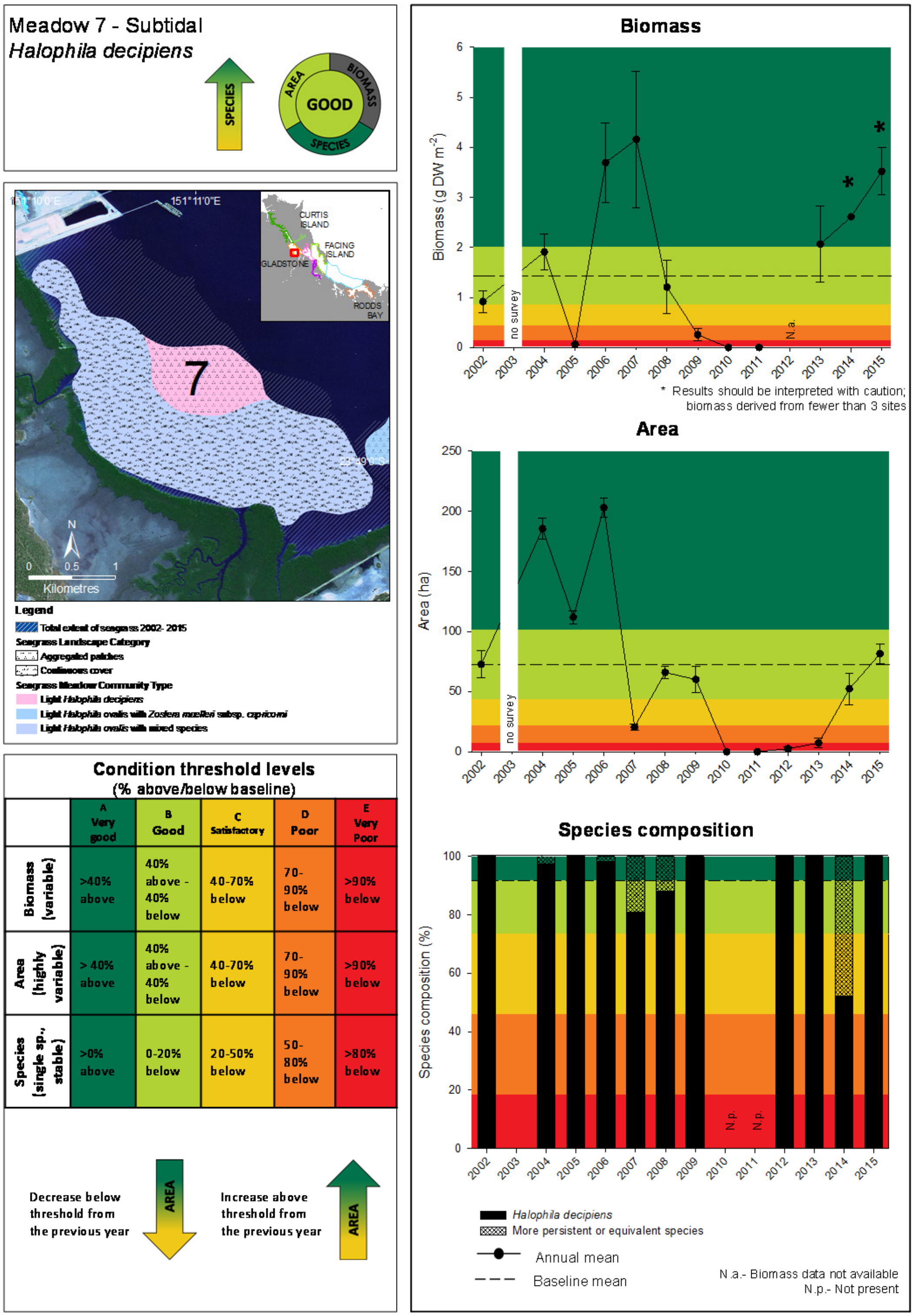
	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (mixed sp., variable)	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below

Figure 12. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 5, Zone 3: Western Basin, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (mixed sp., variable)	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below

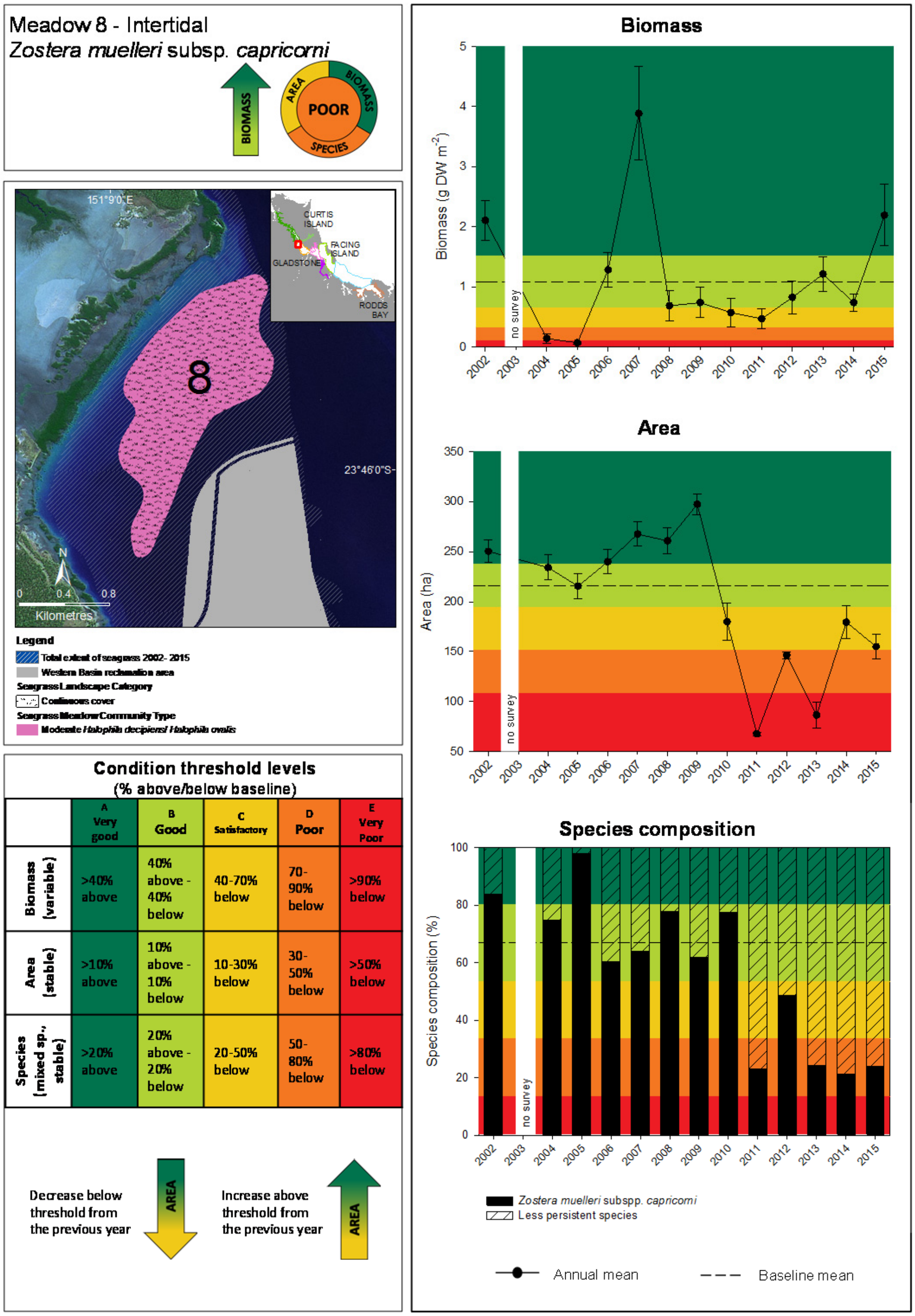
Figure 13. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 6, Zone 3: Western Basin, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (highly variable)	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

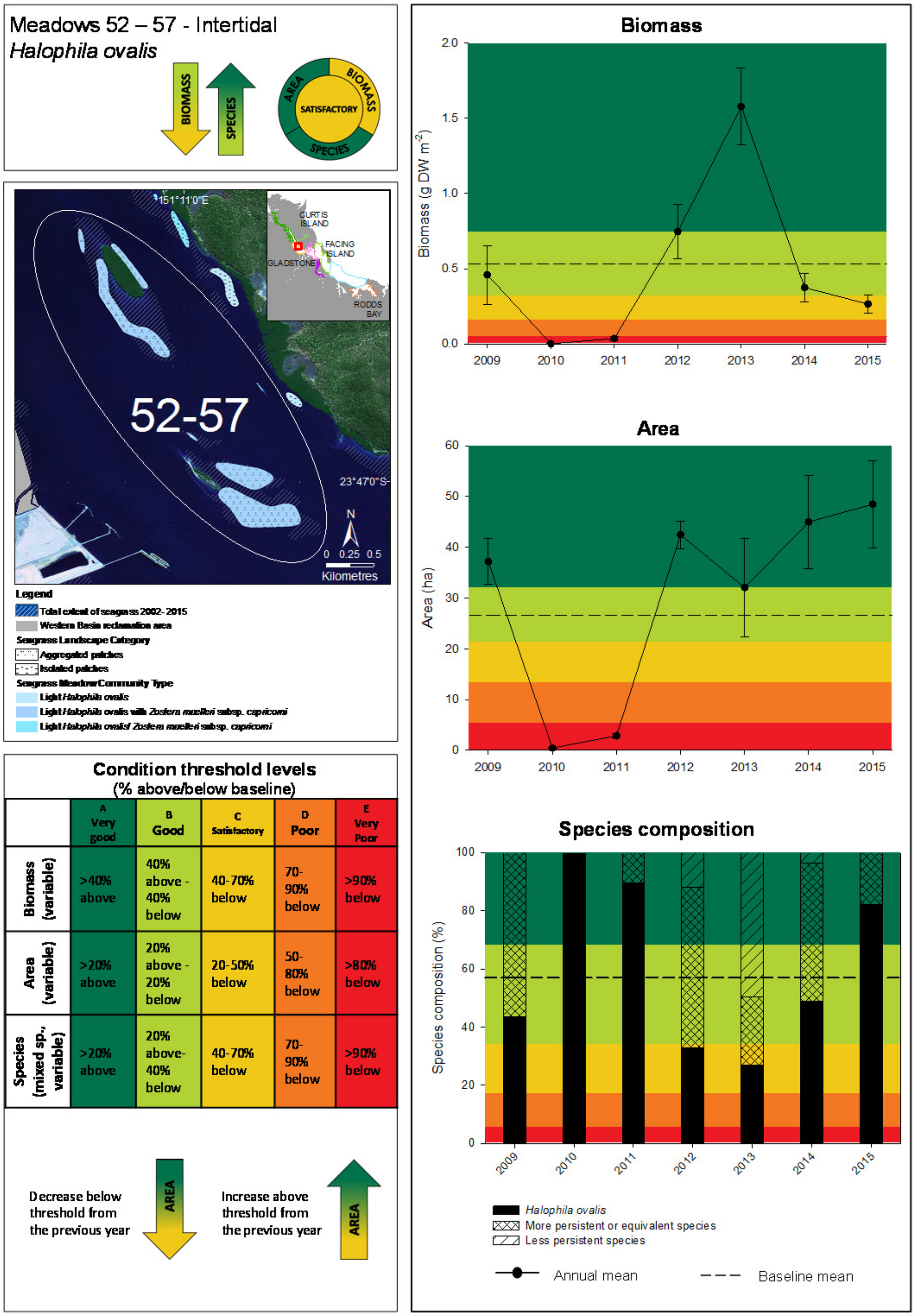
Figure 14. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 7, Zone 3: Western Basin, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (mixed sp., stable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below

Figure 15. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 8, Zone 3: Western Basin, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (variable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species (mixed sp., variable)	>20% above	20% above-40% below	40-70% below	70-90% below	>90% below

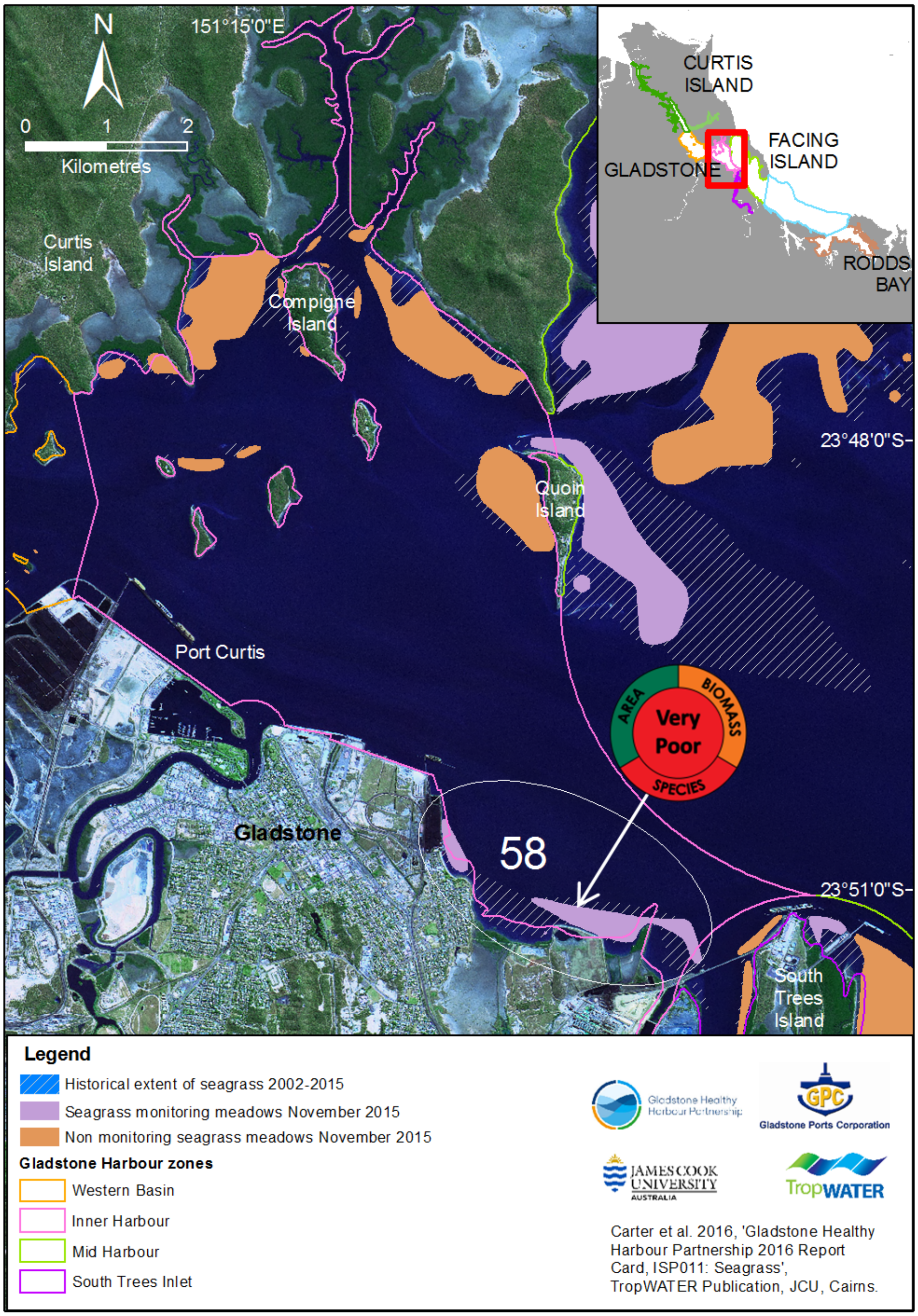
Figure 16. Changes in mean biomass, meadow area and species composition for seagrass in Meadows 52-57, Zone 3: Western Basin, November 2009 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate). Meadows 52-57 are grouped for reporting purposes.

3.3.3 **Zone 5: Inner Harbour**

Seagrass condition in Zone 5: Inner Harbour declined from poor in 2014 to very poor in 2015. The very poor grade was due to species composition in Meadow 58, the only monitoring meadow in this zone (Figure 17). This meadow disappeared in 2010 (Figure 18). When the meadow re-established in 2011, most of the previously dominant species *Z. muelleri* subsp. *capricorni* was lost and replaced by *H. ovalis*. By 2015 *Z. muelleri* subsp. *capricorni* accounted for just 3% of the seagrass biomass in the meadow, resulting in a decline from poor to very poor for the species composition (Figure 17; Appendix 2). Meadow biomass has remained low (<1 gDW m^{-2}) since the meadow's return in 2011 and was in poor condition. Meadow area is highly variable and has been in very good condition for the majority of years following the meadow's 2010 disappearance (Figure 17).

Gladstone Harbour Zone: Inner Harbour

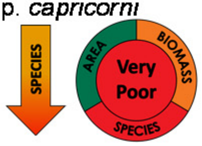
E

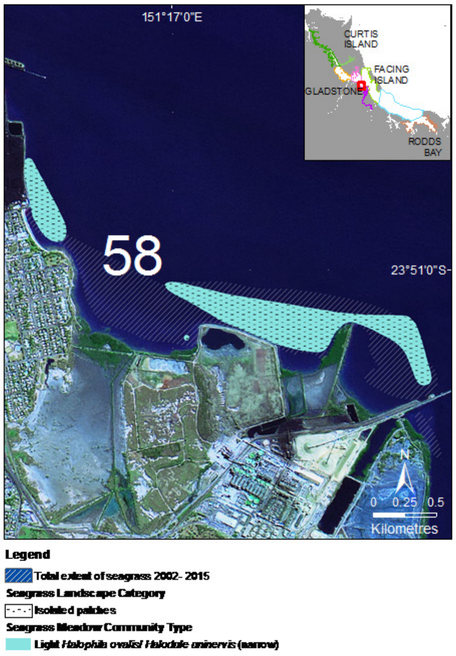


Carter et al. 2016, 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass', TropWATER Publication, JCU, Cairns.

Figure 17. Seagrass condition in Zone 5: Inner Harbour.

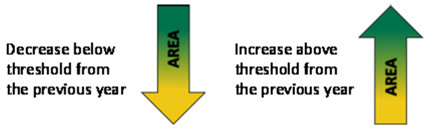
Meadow 58 – Intertidal
Zostera muelleri subsp. *capricorni*





Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (highly variable)	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species (mixed sp., variable)	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below



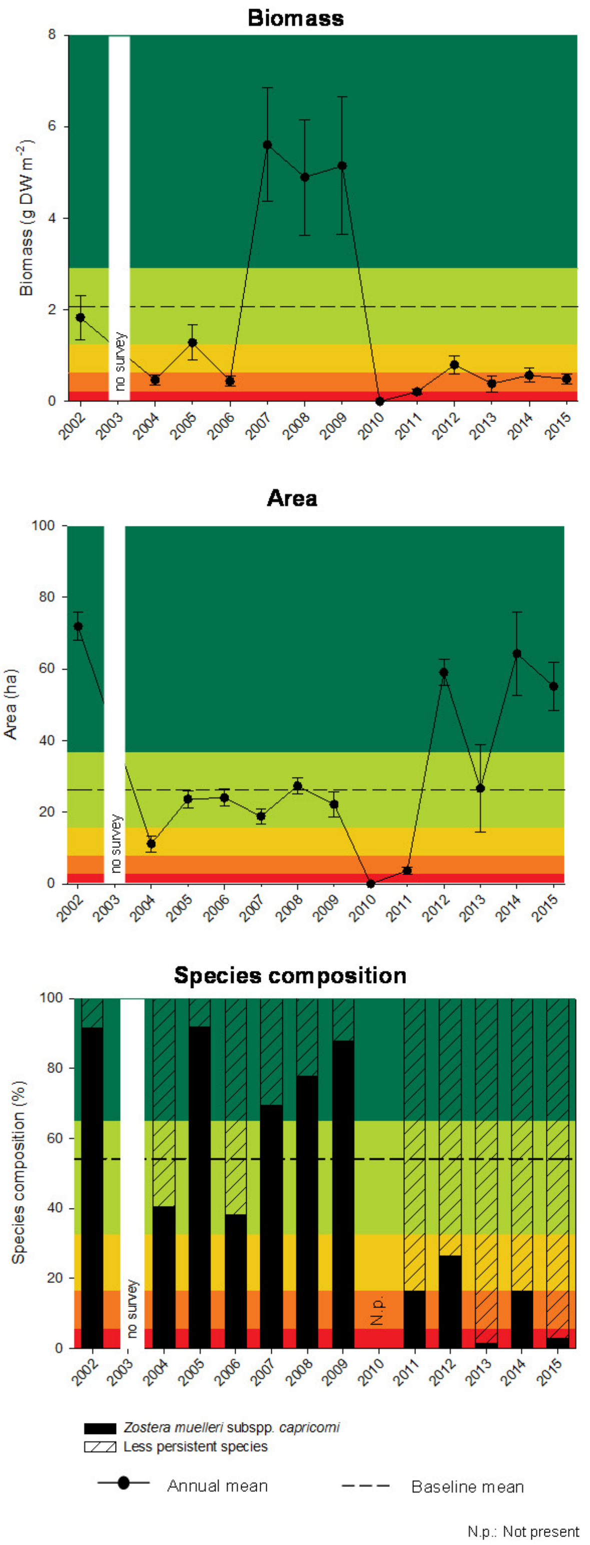


Figure 18. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 58, Zone 5: Inner Harbour, November 2009 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.4 **Zone 8: Mid Harbour**

Seagrass condition in Zone 8: Mid Harbour declined from satisfactory to poor between 2014 and 2015 due to decreased biomass (Figure 19). There are two monitoring meadows in the Mid Harbour Zone, a large intertidal meadow known locally as 'Pelican Banks' (meadow 43) and a subtidal meadow along the eastern side of Quoin Island (meadow 48).

Meadow 43

Meadow 43 supports the most abundant and productive seagrass in the Gladstone area. This meadow was in poor condition due to biomass declining to just under 80% below the baseline (Figure 20). Similarly large declines were observed between 2005-2006, and 2010-2011; however, biomass had been relatively stable at ~12 gDW m^{-2} between 2011 and 2014. Meadow area is highly stable and, at 630 ha in 2015, was approximately equal to the baseline area value (Figure 20). Species composition declined from very good to good condition following increases in *H. uninervis* and *H. ovalis* relative to *Z. muelleri* subsp. *capricorni*; 2015 was the first year *Z. muelleri* subsp. *capricorni* did not account for >90% of meadow biomass (Figure 20; Appendix 2).

Meadow 48

Meadow 48 flanks the eastern side of Quoin Island. The meadow was in poor condition due to biomass declining to just over 50% below the baseline (Figure 21). Biomass in this meadow has fluctuated around the threshold between the satisfactory and poor conditions since 2009. Species composition and area were both in satisfactory condition. Meadow area has been relatively stable in a satisfactory condition since 2011 following a substantial decline in condition from very good in 2008 to very poor in 2009 (Figure 21). Species composition was mostly in very good condition between 2004 and 2011. Between 2012 and 2015 species composition condition steadily declined as the dominant *H. uninervis* declined relative to less persistent *H. ovalis* and *H. decipiens* (Figure 21; Appendix 2).

Gladstone Harbour Zone: Mid Harbour

D

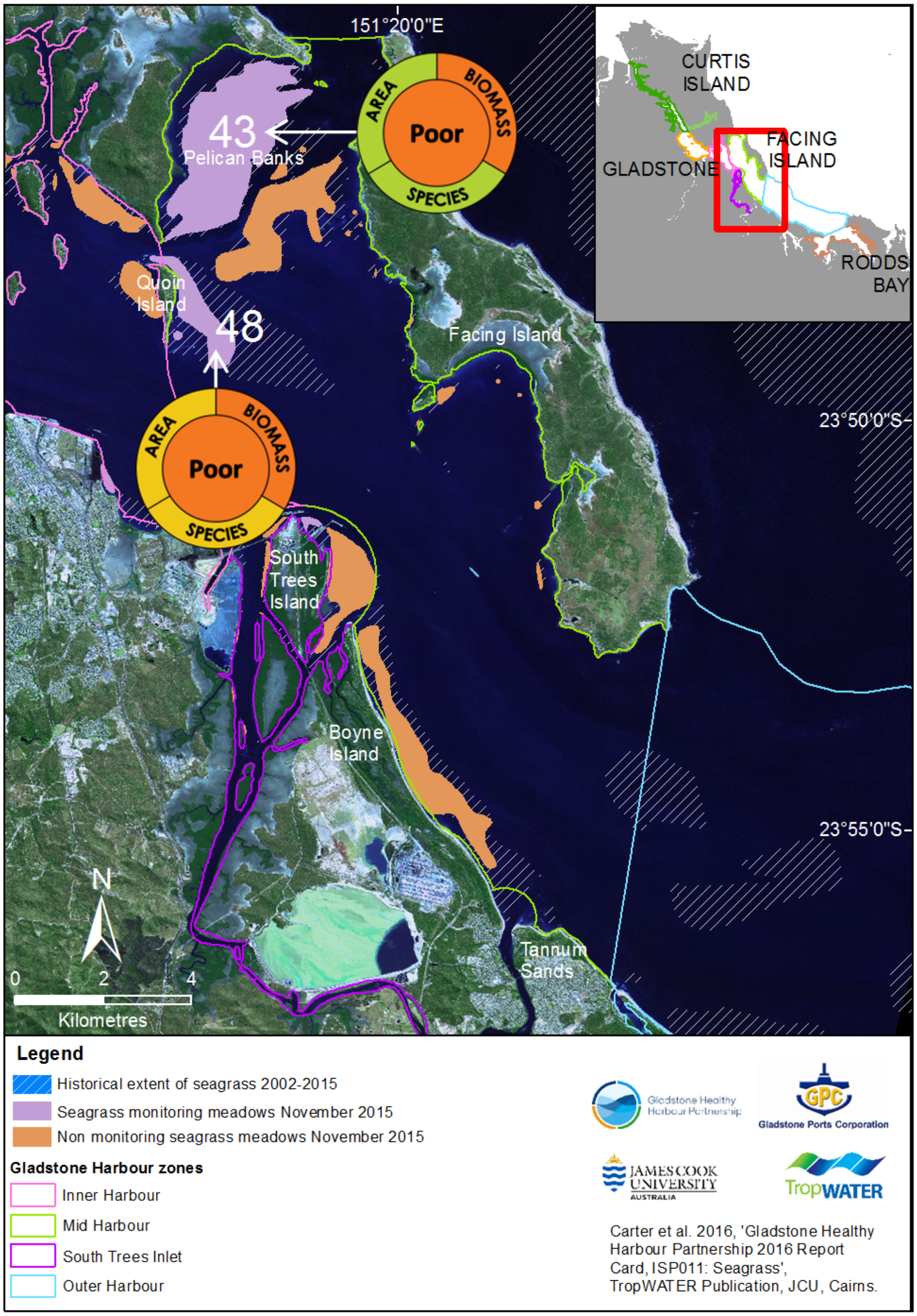
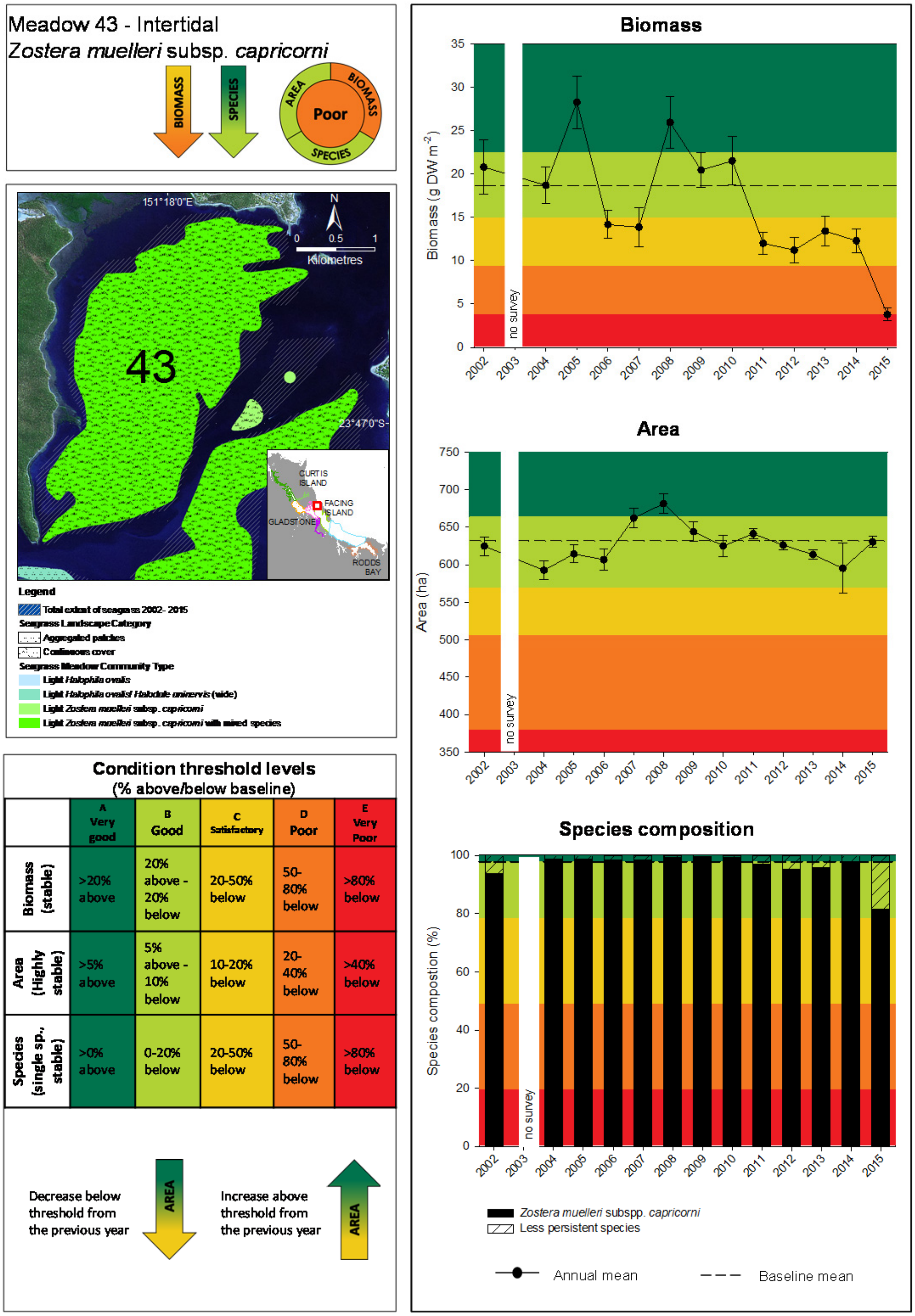


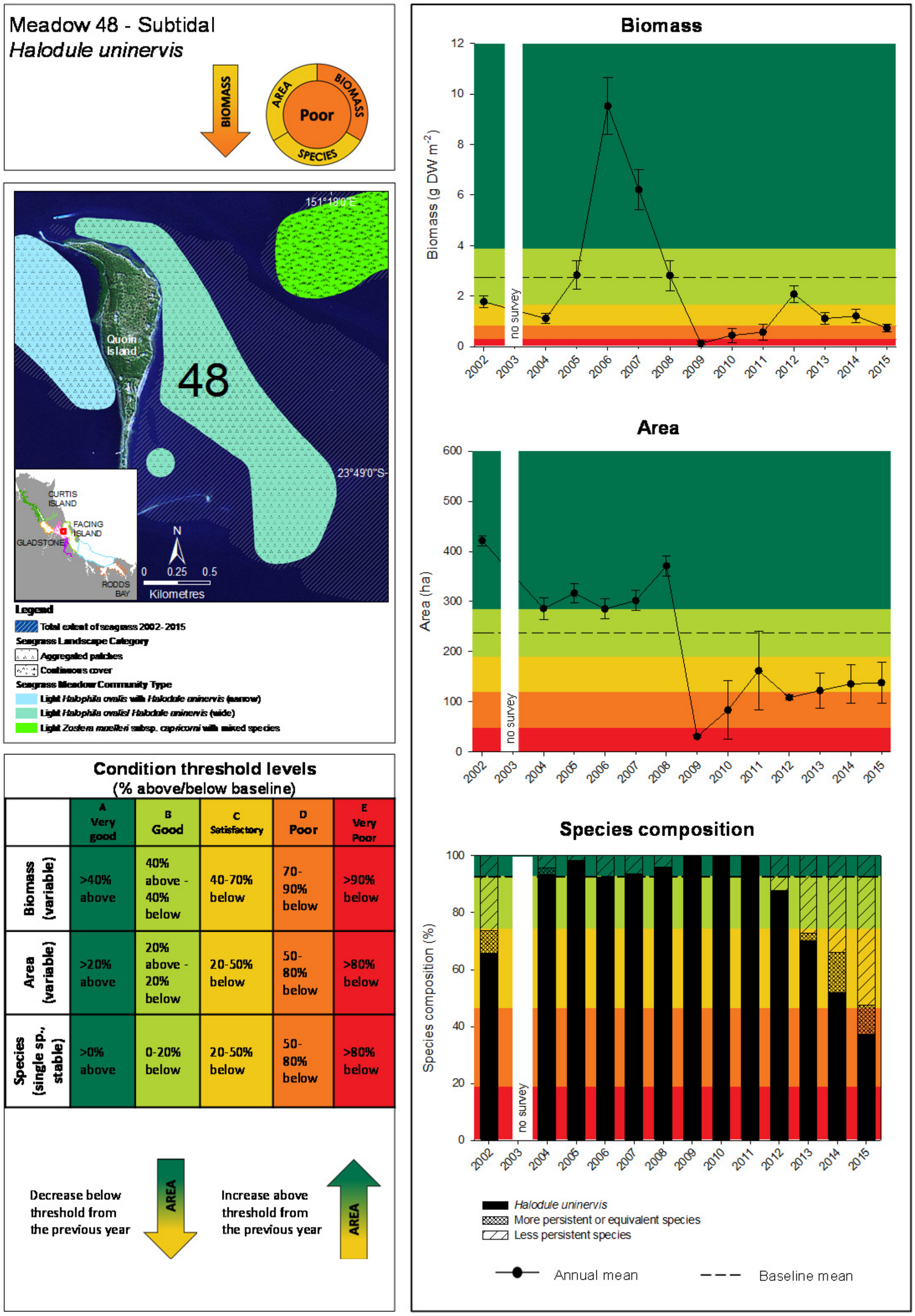
Figure 19. Seagrass condition in Zone 8: Mid Harbour.



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (stable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Area (Highly stable)	>5% above	5% above - 10% below	10-20% below	20-40% below	>40% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

Figure 20. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 43, Zone 8: Mid Harbour, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (variable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

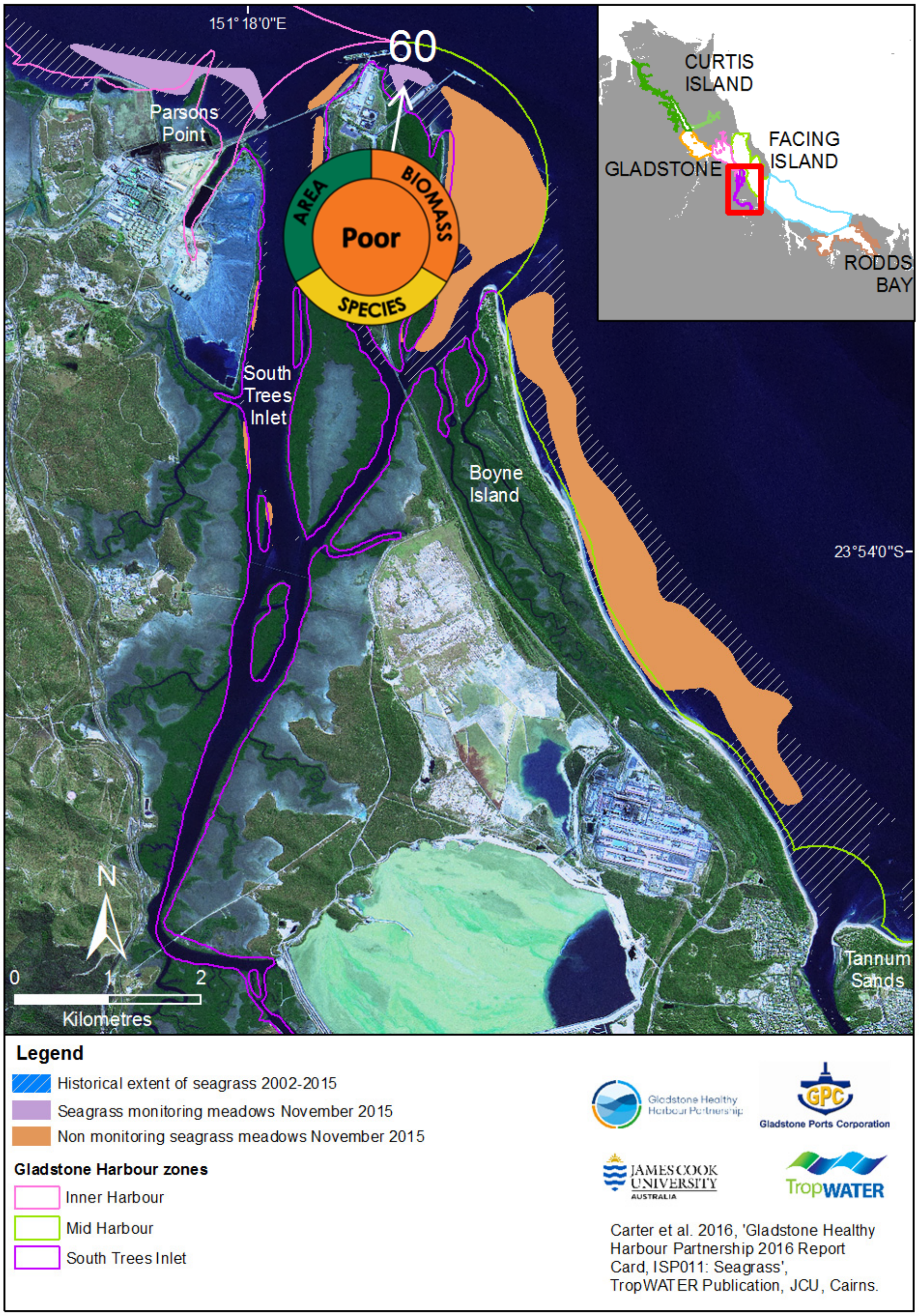
Figure 21. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 48, Zone 8: Mid Harbour, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.5 **Zone 9: South Trees Inlet (lower)**

Seagrass condition in Zone 9: South Trees Inlet declined from satisfactory in 2014 to poor in 2015 (Figure 22). Condition was driven by poor biomass in the intertidal monitoring meadow located between the two wharves at South Trees Inlet (Figure 23). Biomass in Meadow 60 has fluctuated between satisfactory and poor condition since 2009 following a decline from very good condition in 2007-2008. Meadow area was graded as being in very good condition for the second consecutive year (>20% above the baseline). Species composition was in satisfactory condition. Between 2002 and 2009 the dominant species *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*, with an approximately equal split between these species in 2015 (Figure 23; Appendix 2).

Gladstone Harbour Zone:
South Trees Inlet (lower)

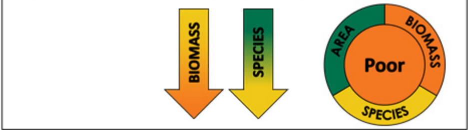
D

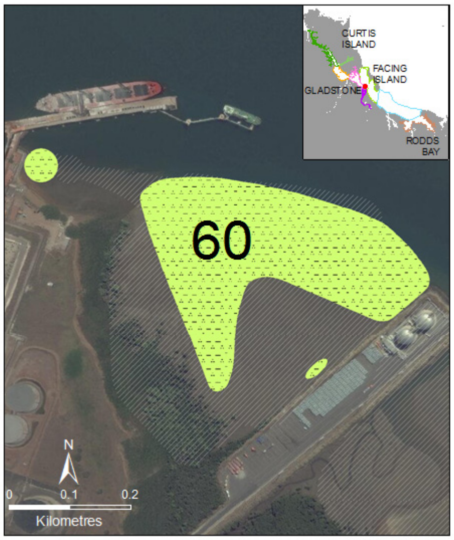


Carter et al. 2016, 'Gladstone Healthy Harbour Partnership 2016 Report Card, ISP011: Seagrass', TropWATER Publication, JCU, Cairns.

Figure 22. Seagrass condition in Zone 9: South Trees Inlet (lower).

Meadow 60- Intertidal
Zostera muelleri subsp. *capricorni*





Legend
▨ Total extent of seagrass 2002- 2015
Seagrass Landscape Category
☐ Aggregated patches
Seagrass Meadow Community Type
🟩 Light *Zostera muelleri* subsp. *capricorni* with *Halodule uninervis* (narrow)

Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (variable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species (single sp., variable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

Decrease below threshold from the previous year — AREA

Increase above threshold from the previous year — AREA

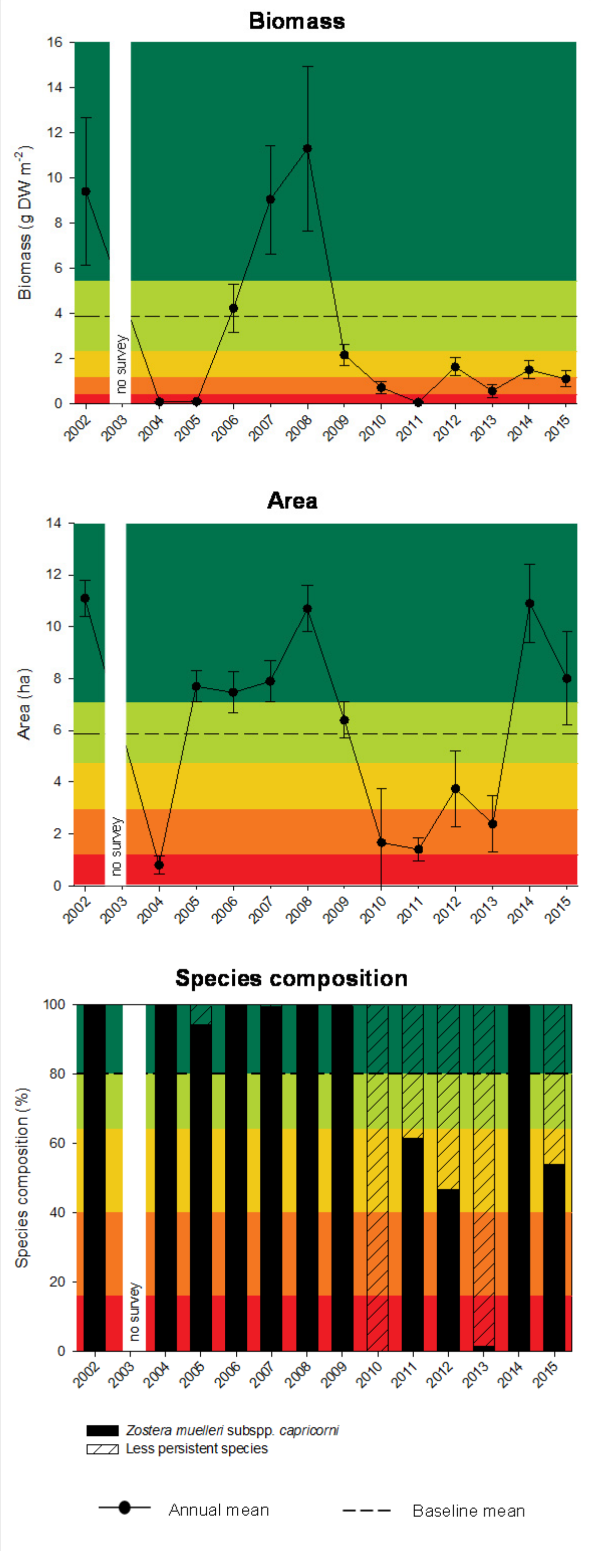


Figure 23. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 60, Zone 9: South Trees Inlet (lower), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.6 **Zone 13: Rodds Bay**

Seagrass condition in Zone 13: Rodds Bay was poor for the second consecutive year (Figure 24). There are three intertidal monitoring meadows in the Rodds Bay Zone – meadows 94, 96 and 104. At times these meadows have consisted of continuous seagrass cover; however declines over the course of monitoring have left only aggregated patches in meadow 96 and isolated patches in meadows 94 and 104 (Figures 25-27).

Meadow 94

Meadow 94 is the smallest monitoring meadow in Rodds Bay and was in very poor condition (Figure 25). Condition declined for all three indicators from 2014. Biomass condition was very poor, and has remained extremely low (<2 gDW m^{-2}) for the past seven years following substantial declines from 2007 to 2009. Species composition was in poor condition. The dominant species *Z. muelleri* subsp. *capricorni* accounts for ~86% of mean meadow biomass; in 2015 this was ~30% due to declines in *Z. muelleri* subsp. *capricorni* relative to *H. ovalis* (Appendix 2). Meadow area declined from very good to poor condition (Figure 25).

Meadow 96

Biomass has remained in poor to very poor condition in the large intertidal meadow 96. In 2015 biomass and overall meadow condition was poor (Figure 26). The dominant species is *Z. muelleri* subsp. *capricorni* and accounts for ~96% of mean meadow biomass. In 2015 species composition was good due to increases in *Z. muelleri* subsp. *capricorni* relative to *H. ovalis* from the previous year, but remained below the baseline level. (Appendix 2).

Meadow 104

Biomass, area and species composition were all in poor condition for Meadow 104 (Figure 27). Condition declined for all three indicators from 2014. Biomass followed similar trends to meadow 94, with peak biomass in 2007, two years of decline, and generally poor to very poor biomass condition since 2009. The dominant species *Z. muelleri* subsp. *capricorni* accounts for ~97% of mean meadow biomass in meadow 104; in 2015 this declined to <50% due to an increased proportion of *H. ovalis*. Meadow area declined from 38 ha to 18 ha from 2014 to 2015.

Gladstone Harbour Zone: Rodds Bay

D

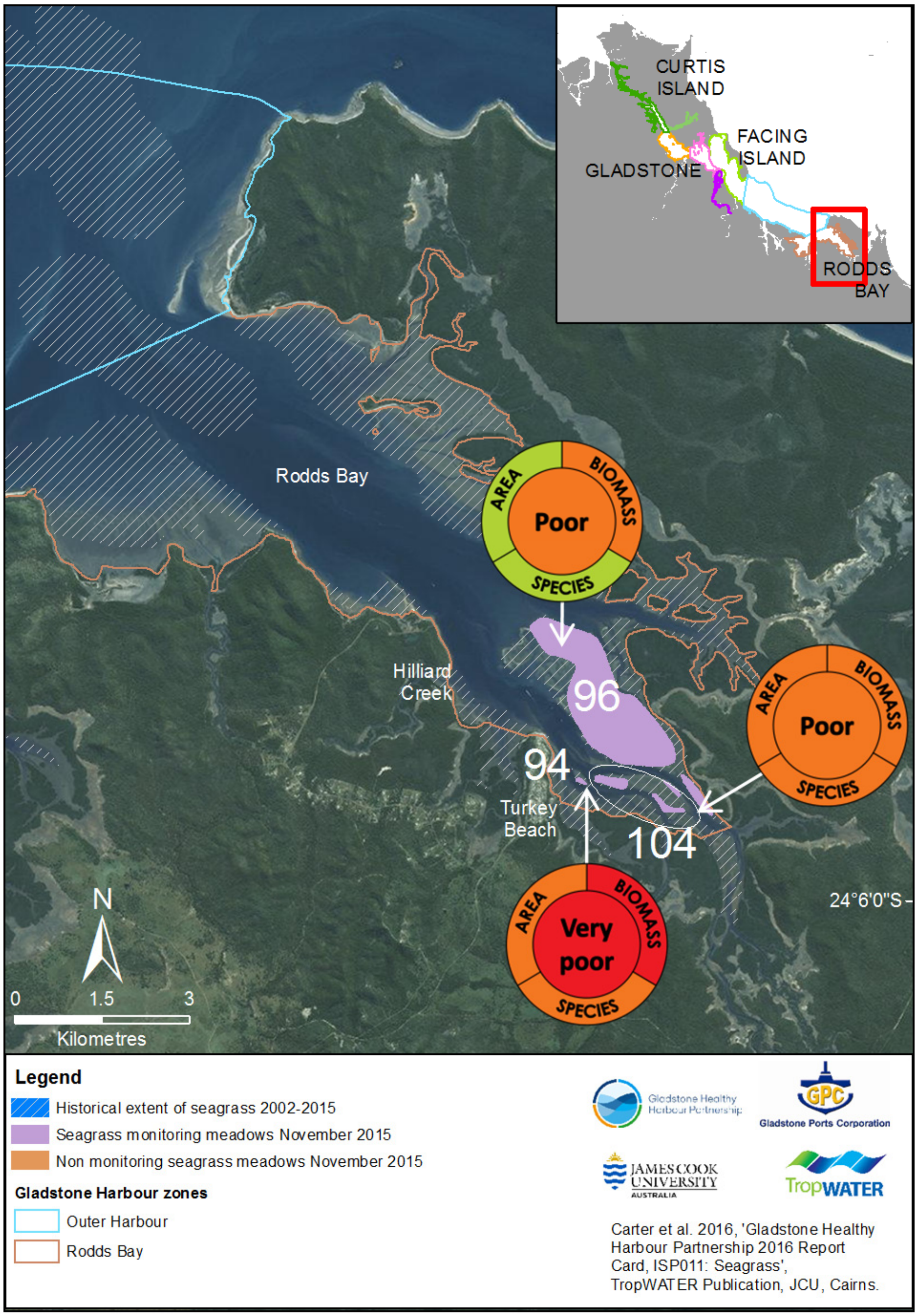
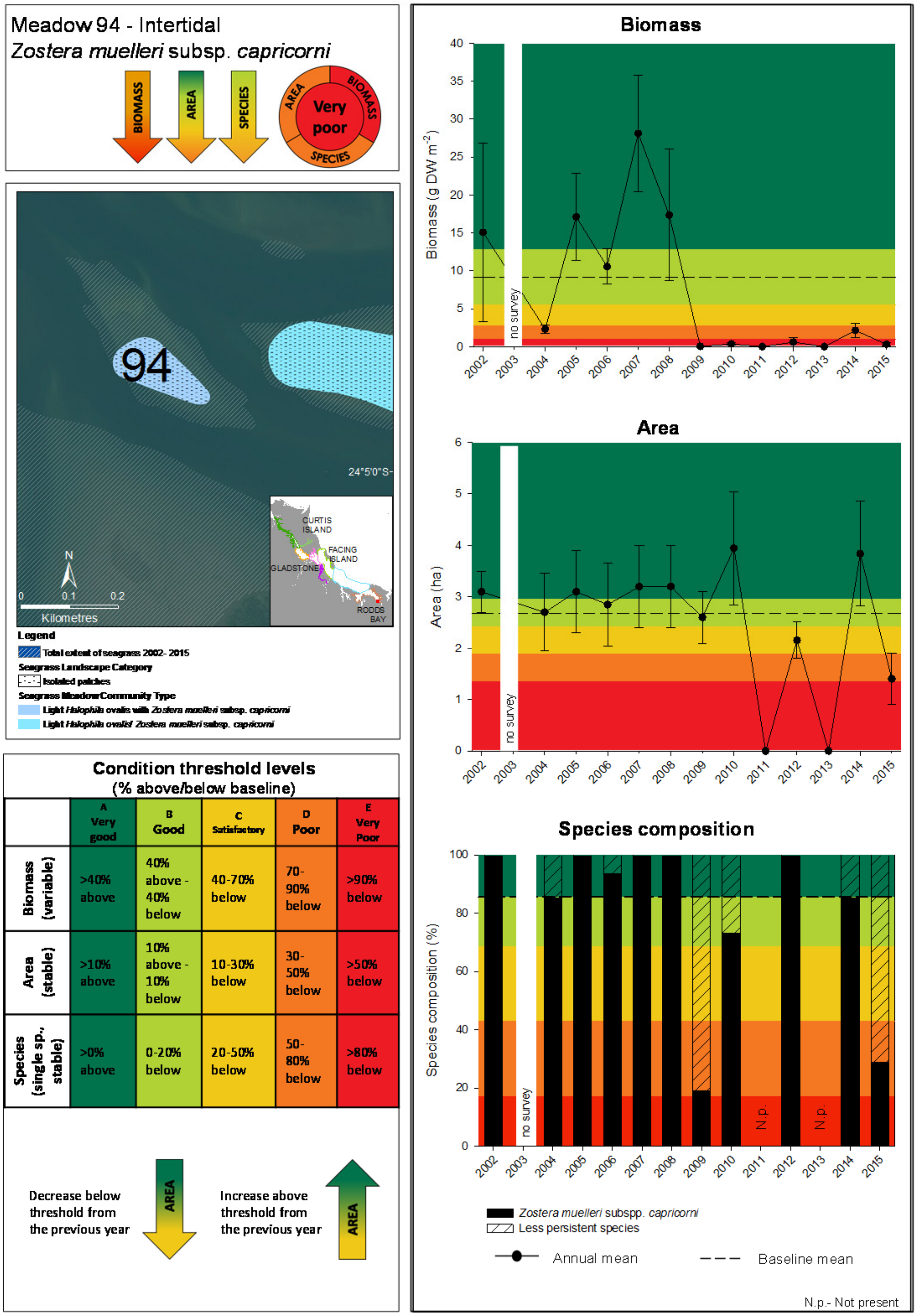


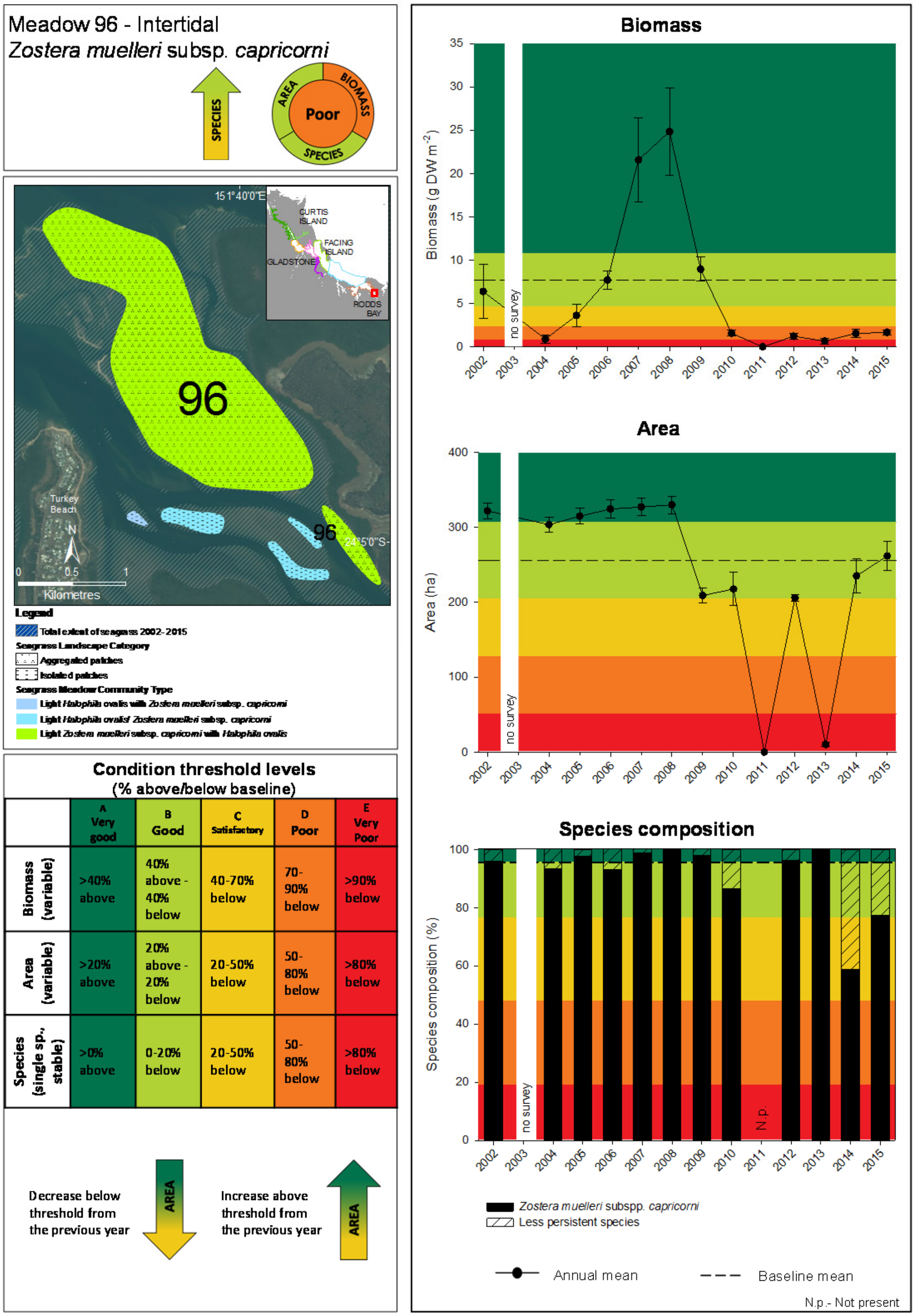
Figure 24. Seagrass condition in Zone 13: Rodds Bay. Note: only monitoring meadows were surveyed in November 2015.



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

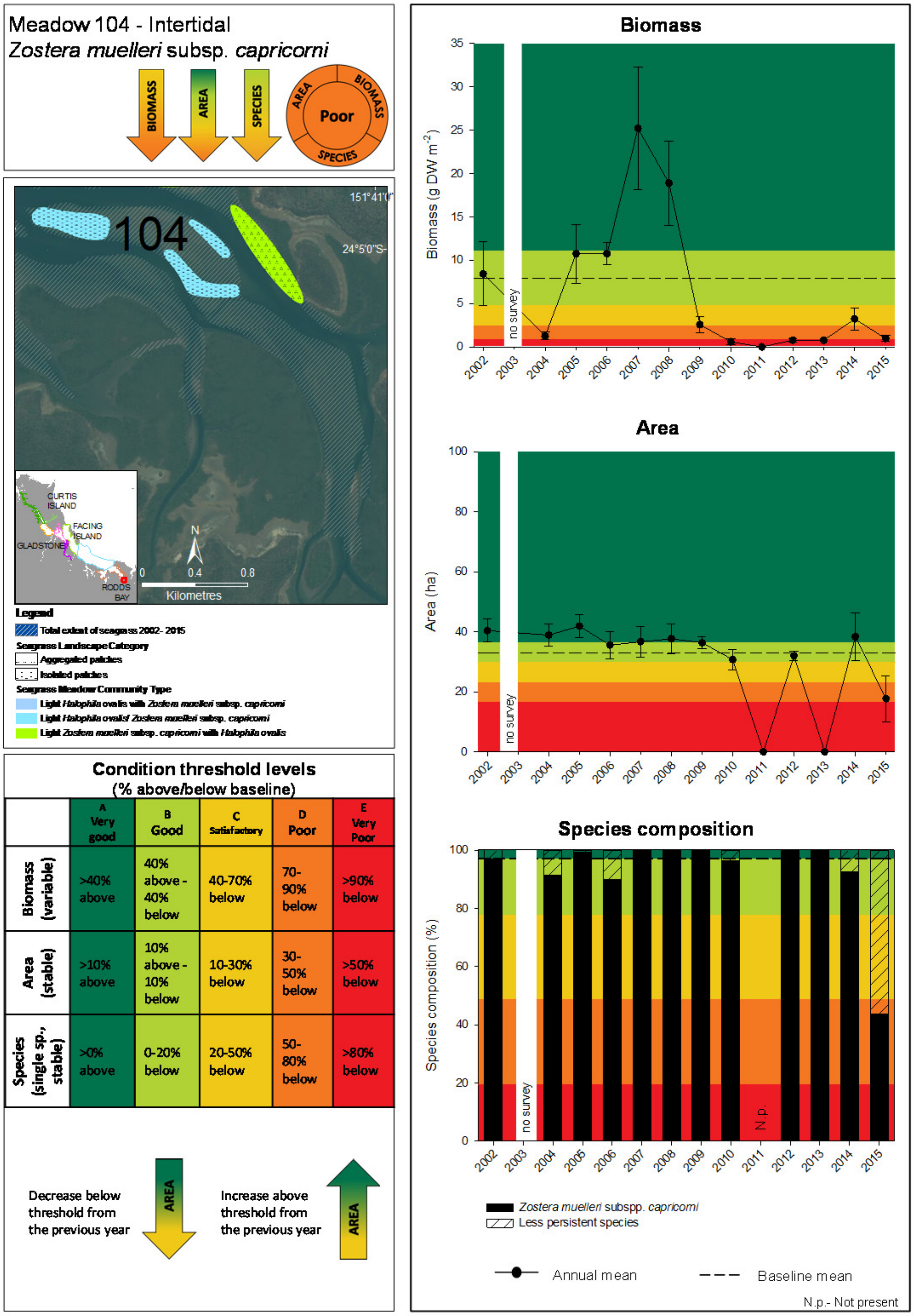
Figure 25. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 94, Zone 13: Rodds Bay, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (variable)	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

Figure 26. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 96, Zone 13: Rodds Bay, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area (stable)	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Species (single sp., stable)	>0% above	0-20% below	20-50% below	50-80% below	>80% below

Figure 27. Changes in mean biomass, meadow area and species composition for seagrass in Meadow 104, Zone 13: Rodds Bay, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4 Historical Monitoring Data

Gladstone seagrass meadows are influenced by environmental conditions, particularly rainfall and discharge from the Calliope River (McCormack et al. 2013). Years where $\geq$50% of meadows were assigned an overall meadow condition of poor/very poor either correspond with (2010-2015) or directly follow (2004) years of above average rainfall and river flow in the region, often attributed to tropical cyclones (Figure 28; Table 10). This includes Tropical Cyclone Marcia which crossed the coast just north of Gladstone in February 2015, bringing with it short but significant rainfall and flooding in the region from the Fitzroy River (just north of Gladstone) south to the Upper Brisbane River (Bureau of Meteorology 2015), and above average river flow for the Calliope River (Figure 28a).

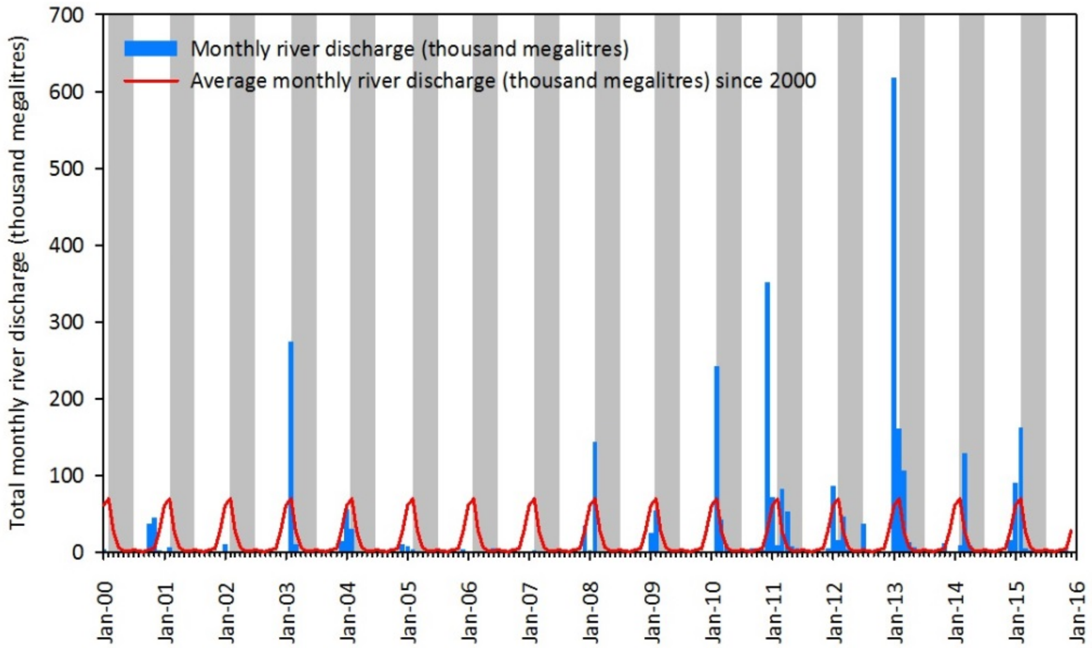
Seagrass biomass appears to be a highly sensitive indicator of recent environmental change. Biomass was the main influence on overall meadow condition in The Narrows, Inner Harbour, Mid Harbour, South Trees Inlet, and Rodds Bay since monitoring commenced (Tables 10 and 11). In Western Basin meadows, biomass was the main influence on overall meadow condition up to 2009. Meadow area declines and a shift in species composition, predominantly from *Z. muelleri* subsp. *capricorni* to the colonising and less persistent *H. ovalis*, have had a greater influence than biomass on overall meadow condition in the Western Basin since 2010 (Tables 12 and 13).

Biomass condition in the Gladstone region undergoes cycles of deterioration and recovery. Biomass was good/very good in all but one meadow in 2002, then deteriorated in most meadows in 2004 following above average rainfall and river flow in 2003 (Figure 28; Table 11). Meadow biomass at the Inner Harbour, Mid Harbour and Rodds Bay largely recovered to good/very good condition by 2005, followed by meadows in the Western Basin and South Trees Inlet in 2006. Biomass condition was good/very good in the majority of meadows in the drier years of 2006 and 2007. Above average rainfall and river flow occurred again in 2008, but biomass only declined in the two subtidal monitoring meadows 7 and 48, and the smallest (<3 ha) monitoring meadow 94 at Rodds Bay (Figures 14, 21, 25). Biomass condition declined to poor/very poor condition in three meadows in 2009, and the majority of meadows in 2010 and 2011. This coincided with the onset of a La Niña period, characterised by above average rainfall and river flow that characterised each wet season from 2010 to 2015 (Figure 28).

Meadow area condition was good/very good for nearly all meadows between 2002 and 2009, reflecting stability in area despite fluctuations in biomass condition. Following above average rainfall and river flow in 2010, meadow area condition declined to satisfactory-very poor in the Western Basin, Inner Harbour, South Trees Inlet and meadow 48 in the Mid Harbour, and by 2011 area was reduced to very poor at all Rodds Bay meadows (Table 12). Area condition improved in many meadows from 2011 to 2012, was reduced again in 2013 following the largest recorded rainfall and river flow volumes since monitoring began, and again showed signs of recovery in 2014/2015 (Table 12). In 2015 meadow area was very good at South Trees Inlet, The Narrows, Inner Harbour, and in meadow 52-57 (Western Basin) (Table 12). Area has remained consistently good/very good over the course of monitoring for the large and stable meadow 43 at Pelican Banks.

Species composition grades were mostly good or very good for the first seven years of monitoring (2002 to 2010) (Table 13). Exceptions were the Western Basin intertidal meadows near Wiggins Island and South Fisherman's Landing (meadows 4, 5 and 6) where the proportion of *Z. muelleri* subsp. *capricorni* declined relative to *H. ovalis* and/or *H. decipiens* for several years following the 2003 rainfall and river flow events (Figure 28; Table 13). Similar declines in species composition condition have occurred across the Gladstone region since 2011, with the dominant species *Z. muelleri* subsp. *capricorni* or *H. uninervis* (meadow 48) making smaller contributions to meadow biomass compared with the 10 year baseline. In 2015 species composition was in very good condition for just two meadows, and these were meadows traditionally dominated by *H. ovalis* (meadow 52-57) or *H. decipiens* (meadow 7) (Table 13).

(a)



(b)

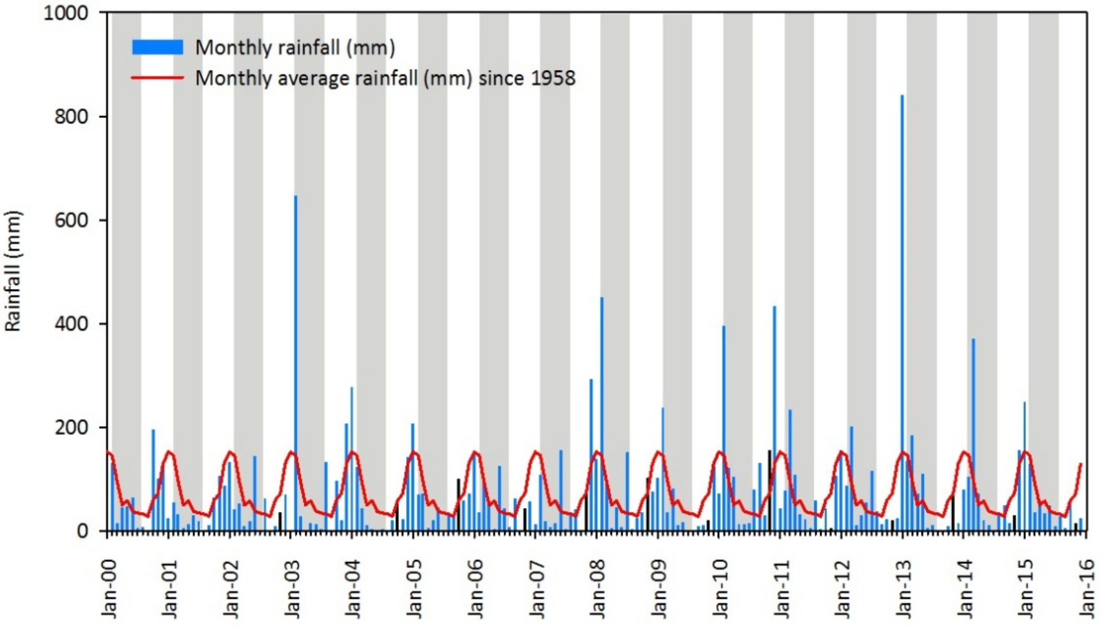


Figure 28. (a) Total monthly river discharge and average monthly discharge (thousand megalitres) for the Calliope River (data source: Department of Natural Resources and Mines, station # 132001A; www.water-monitoring.derm.qld.gov.au); (b) Total monthly rainfall and monthly average rainfall (mm) at Gladstone (data source: Australian Bureau of Meteorology, station # 039123; (http://www.bom.gov.au/climate/data/). Black bars in (b) indicate seagrass survey month. Data range is January 2000 – January 2016. Shaded areas represent the seagrass senescent season.

Table 10. Overall grades for individual monitoring meadows, 2002, 2004-2015. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A	B	B	C	E	E	D
3. Western Basin	4	B	C	D	B	A	B	A	E	D	C	D	D	C
	5	C	D	C	B	B	A	C	D	D	C	E	D	D
	6	B	D	C	C	B	B	A	E	E	D	D	B	B
	7	B	B	E	A	D	B	D	E	E	E	D	B	B
	8	A	D	E	B	B	B	B	C	E	D	E	D	D
	52-57*	NS	NS	NS	NS	NS	NS	B**	E	E	B	B	B	C
5. Inner Harbour	58	B	D	B	D	B	B	B	E	D	C	E	D	E
8. Mid Harbour	43	B	B	B	C	C	A	B	B	C	C	C	C	D
	48	C	C	B	B	A	B	E	D	D	D	C	C	D
9. South Trees Inlet	60	A	E	E	B	A	A	C	E	E	C	E	C	D
13. Rodds Bay	94	A	D	B	B	A	A	E	E	E	E	E	D	E
	96	B	D	C	B	A	A	B	D	E	D	E	D	D
	104	B	D	B	B	A	A	C	E	E	E	E	C	D

* 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.

** 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.

NS: not surveyed.

Table 11. Biomass grades for individual monitoring meadows, 2002, 2004-2015. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A	B	B	C	D	E	D
3. Western Basin	4	B	B	C	B	A	B	A	E	C	A	A	A	B
	5	C	D	C	B	A	A	C	D	B	C	B	C	D
	6	B	D	C	A	A	B	A	D	C	B	B	B	B
	7	B	B	E	A	A	B	D	E	E	CR	A	CR	CR
	8	A	D	E	B	A	B	B	C	C	B	B	B	A
	52-57*	NS	NS	NS	NS	NS	NS	B**	E	E	B	A	B	C
5. Inner Harbour	58	B	D	B	D	A	A	A	E	D	C	D	D	D
8. Mid Harbour	43	B	B	A	C	C	A	B	B	C	C	C	C	D
	48	B	C	B	A	A	B	E	D	D	B	C	C	D
9. South Trees Inlet	60	A	E	E	B	A	A	C	D	E	C	D	C	D
13. Rodds Bay	94	A	D	A	B	A	A	E	E	E	E	E	D	E
	96	B	D	C	B	A	A	B	D	E	D	E	D	D
	104	B	D	B	B	A	A	C	E	E	E	E	C	D

* 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.

** 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.

NS: not surveyed.

CR: calculation restriction (biomass) - a score was not calculated due to small sample size (<3 sites) or seagrass sampled by grab only (precludes biomass assessment).

Table 12. Area grades for individual monitoring meadows, 2002, 2004-2015. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. The Narrows	**21**	NS	NS	NS	NS	NS	NS	A	B	B	B	E	B	A
3. Western Basin	**4**	A	A	B	A	A	B	A	E	D	B	D	D	C
	5	A	B	B	B	B	A	A	C	D	B	E	D	C
	6	A	B	B	A	A	A	A	E	C	D	D	B	B
	7	B	A	A	A	D	B	B	E	E	E	D	B	B
	8	A	B	B	A	A	A	A	C	E	D	E	C	C
	52-57*	NS	NS	NS	NS	NS	NS	A**	E	E	A	A	A	A
5. Inner Harbour	**58**	A	C	B	B	B	B	B	E	D	A	B	A	A
8. Mid Harbour	**43**	B	B	B	B	B	A	B	B	B	B	B	B	B
	48	A	A	A	A	A	A	E	D	C	D	C	C	C
9. South Trees Inlet	**60**	A	E	A	A	A	A	B	D	D	C	D	A	A
13. Rodds Bay	**94**	A	B	A	B	A	A	B	A	E	C	E	A	D
	96	A	B	A	A	A	A	B	B	E	B	E	B	B
	104	A	A	A	B	A	A	A	B	E	B	E	A	D

* 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.

** 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.

NS: not surveyed.

Table 13. Species composition grades for individual monitoring meadows, 2002, 2004-2015. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. The Narrows	**21**	NS	NS	NS	NS	NS	NS	A	B	B	B	C	C	C
3. Western Basin	**4**	A	C	D	B	A	B	A	B	B	C	A	A	B
	5	A	C	C	B	A	A	A	B	C	B	D	B	D
	6	B	C	B	C	B	B	A	A	E	A	C	B	B
	7	A	A	A	A	A	A	A	CR	CR	A	A	A	A
	8	A	B	A	B	B	B	B	B	D	C	D	D	D
	52-57*	NS	NS	NS	NS	NS	NS	A**	A	A	A	B	A	A
5. Inner Harbour	**58**	A	B	A	B	A	A	A	CR	C	C	E	B	E
8. Mid Harbour	**43**	B	A	A	A	A	A	A	A	B	B	B	B	B
	48	C	A	A	B	A	A	A	A	A	B	C	C	C
9. South Trees Inlet	**60**	A	A	A	A	A	A	A	E	C	C	E	A	C
13. Rodds Bay	**94**	A	B	A	A	A	A	D	B	CR	A	CR	B	D
	96	A	B	A	B	A	A	A	B	CR	A	A	C	B
	104	A	B	A	B	A	A	B	B	CR	A	A	B	D

* 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.

** 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.

NS: not surveyed.

CR: calculation restriction (species composition) - a score could not be calculated because seagrass was absent.

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 7–13 years. Our assessment of the 14 monitoring meadows determined that the overall condition of most meadows was poor or satisfactory in November 2015. The overall seagrass condition in Gladstone Harbour was poor due to poor condition in The Narrows, Mid Harbour, South Trees Inlet, and Rodds Bay zones, very poor condition in the Inner Harbour, and satisfactory seagrass condition in the Western Basin.

Seagrasses in the Gladstone region generally were in good to very good condition prior to 2010 when rainfall and river flow was below average, followed by declines during and immediately following years of above average rainfall and flow from the Calliope River (Figure 28). Years with a large number of overall meadow grades of poor and very poor either correspond with (2010-2015) or directly follow (2004) 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. 2015a). 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 and Fitzroy Rivers 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). Flood plumes and dredging have been linked to seagrass declines due to a reduction in available light (Campbell and McKenzie 2004; Erftemeijer and Lewis III 2006). Frequent, severe climate events between 2010 and 2015 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 (May 2011 to Spetember 2013), with declines also occurring at the out of port reference meadows in Rodds Bay, and more broadly along the east coast of Queensland 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 rainfall with 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 determine 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 (Chartrand et al. 2012; Bryant et al. 2014a).

Species composition grades were mostly driven by fluctuations between the more stable and persistent *Z. muelleri* subsp. *capricorni* dominated communities and those dominated by colonising *H. ovalis.* There was little sign of improvement in species composition in the Gladstone region in 2015 following declines that began in 2011. A briefer period of decline and recovery has been observed in meadows 4, 5, and 6, where the proportion of *Z. muelleri* subsp. *capricorni* declined during 2004-2006, then recovered to good/very good condition during 2007-2010. The role of asexual versus sexual reproduction in recovery of more stable and persistent species in these meadows is not well understood. Viable *Z. muelleri* subsp. *capricorni* seed banks have been detected during monitoring in Gladstone Harbour (Jarvis et al. 2015). The age and viability of 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). Viable seeds were found in the sediment seed bank at Pelican Banks, Wiggins Island and Rodds Bay at the end of the growing season in February 2015; however, seed bank viability decreased after an additional 4 months in the sediment including a complete loss of viability at Pelican Banks (Jarvis et al. 2015). Additional information on the persistence of seagrass seeds is necessary to quantify the resilience to disturbance provided by seed banks in these meadows. Ongoing sampling in 2016 and 2017 will provide a better understanding of the dynamics in density and seed viability in Port Curtis.

4.1 Comparisons with 2015 Report Card

There was no sign of seagrass recovery at the Gladstone Harbour scale between 2014 (2015 report card) and 2015 (2016 report card). The overall poor condition of Gladstone Harbour seagrass for both years indicates meadows in the region remain in a stable but vulnerable state. Relative to 2014, overall seagrass condition in 2015 improved in just one zone (The Narrows), from very poor to poor; yet this was driven by very small improvements in meadow biomass with both years remaining well below the long-term average. Overall meadow condition declined from poor in 2014 to very poor in 2015 in the Inner Harbour zone, driven by reductions in the more persistent *Z. muelleri* subsp. *capricorni* relative to *H. ovalis*. Biomass declines between 2014 and 2015 were responsible for reductions in overall meadow condition from satisfactory to poor in the Mid Harbour and South Trees inlet zones. Overall meadow condition remained stable in the Western Basin (satisfactory) and Rodds Bay (poor).

4.2 Comparisons with State-wide Monitoring Program

Reduced seagrass meadow condition in 2010-2015 observed in Gladstone is generally consistent with seagrass trends along Queensland’s east coast between Cairns and Gladstone. Large scale declines in seagrass meadow area and biomass occurred in 2009/2010 at Cairns (York et al. 2016), Mourilyan (Reason et al. 2016), Townsville (Davies and Rasheed 2016), and Abbot Point (McKenna et al. 2016b). These declines coincided with above average rainfall and river flow (McKenna et al. 2015) 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) TC Oswald (January 2013), TC Dylan (January 2014), TC Ita (April 2014), and TC Marcia (February 2015). 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 9 of the 14 monitoring meadows (and no declines in overall meadow condition in any of the meadows) (Table 10). Declines in overall condition for 7 meadows in 2013 followed above average rainfall and river flow in that year (Figure 28; Table 10).

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 (Sozou et al. 2016b), Weipa (McKenna et al. 2016a) and Karumba (Sozou et al. 2016a) did not follow the same trend in condition decline and the regional seagrass grades at these locations was good condition in 2015/2016. 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 (Rasheed 2004; Rasheed et al. 2014; York et al. 2015). Coastal seagrass meadows in monitoring locations such as Townsville have returned to conditions similar to pre-2010, and Abbot Point offshore meadows’ foundation species have returned and signs of ongoing recovery are positive (McKenna et al. 2016b). In the Cairns region small condition improvements (very poor to poor) were recorded in 2015 (York et al. 2016). In the Mourilyan region seagrass remains in very poor condition and there seems little prospect of meadow biomass, area, or species compositon recovering without some form of restoration (Reason et al. 2016).

Reductions in meadow area, biomass, and stable/persistent species 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 (Phillips and Lewis 1983; Duarte and Sand-Jensen 1990; Jarvis and Moore 2010). 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. Seagrass growth 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.

4.3 Implications for Management

The current poor condition of seagrasses in Gladstone Harbour has management implications regarding activities that could potentially reduce water quality in the region. Multiple years of high rainfall, river flow and cyclone activity in the region has likely reduced seagass resilience and recovery capacity, as in other Queensland locations (Pollard and Greenway 2013; Rasheed et al. 2014; McKenna et al. 2015). Natural recovery from large declines can take up to five years (Preen et al. 1995) or potentially longer. An improvement in meadow condition 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 (Chartrand et al. 2012; Schliep et al. 2014), 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.

4.4 Limitations of the Study

There remains a large section from South Trees Inlet to Rodds Bay with no monitoring meadows. 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 added to the monitoring program to fill this gap.

REFERENCES

Abal, E. and Dennison, W. 1996. Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research, **47**: 763-771

Agawin, N., Duarte, C. M., Fortes, M. D., Uri, J. and Vermaat, J. 2001. Temporal changes in the abundance, leaf growth and photosynthesis of three co-occurring Philippine seagrasses. Journal of Experimental Marine Biology and Ecology, **260**: 217-239

Bryant, C., Davies, J., Sankey, T. and Jarvis, J. 2014a. Long Term Seagrass Monitoring in the Port Curtis Western Basin: Quarterly Seagrass Assessments & Permanent Transect Monitoring Progress Report 2009 to 2013. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/18, James Cook University. Cairns, 84 pp.

Bryant, C., Jarvis, J. C., York, P. and Rasheed, M. 2014b. Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/53, James Cook University, Cairns, 74 pp.

Bureau of Meteorology. 2015. Tropical Cyclone Marcia flood report, April 2015. Bureau of Meteorology, Melbourne, Victoria, http://www.bom.gov.au/qld/flood/fld_reports/TC_Marcia_floods.pdf

Campbell, S. J. and McKenzie, L. J. 2004. Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. Estuarine, Coastal and Shelf Science, **60**: 477-490

Carter, A. B., Davies, J. D., Bryant, C. V., Jarvis, J. C., McKenna, S. A. and Rasheed, M. A. 2015a. Seagrasses in Port Curtis and Rodds Bay 2014: Annual long-term monitoring, biannual Western Basin, and updated baseline survey. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns, 72 pp.

Carter, A. B., Jarvis, J. C., Bryant, C. V. and Rasheed, M. A. 2015b. Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 15/29, James Cook University, Cairns, 71 pp.

Chartrand, K. M., Ralph, P. J., Petrou, K. and Rasheed, M. A. 2012. Development of a light-based seagrass management approach for the Gladstone Western Basin dredging program. DEEDI Publication, Fisheries Queensland, Cairns, 92 pp.

Chartrand, K. M., Rasheed, M. A. and Unsworth, R. K. F. 2009. Long-term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2008. DPI&F, Fisheries Queensland, Cairns, 32 pp.

Collier, C. J., Chartrand, K., Honchin, C., Fletcher, A. and Rasheed, M. 2016. Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme, Cairns, 41 pp.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S. and Turner, R. K. 2014. Changes in the global value of ecosystem services. Global Environmental Change, **26**: 152-158

Davies, J. N. and Rasheed, M. A. 2016. Port of Townsville Annual Seagrass Monitoring: September 2015. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 16/03, James Cook University. Cairns, 49 pp.

Dennison, W., Orth, R., Moore, K., Stevenson, J., Carter, V., Kollar, S., Bergstrom, P. and Batiuk, R. 1993. Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. BioScience, **43**: 86-94

Duarte, C. M. and Sand-Jensen, K. 1990. Seagrass colonization: Biomass development and shoot demography in *Cymodocea nodosa* patches. Marine Ecology Progress Series, **67**: 93-103

Duarte, C. M., Terrados, J., Agawin, N. S. R., Fortes, M. D., Bach, S. and Kenworthy, W. J. 1997. Response of a mixed Philippine seagrass meadow to experimental burial. Marine Ecology Progress Series, **147**: 285-294

Erftemeijer, P. L. A. and Lewis III, R. R. R. 2006. Environmental impacts of dredging on seagrasses: A review. Marine pollution bulletin, **52**: 1553-1572

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause-Jensen, D. and McGlathery, K. J. 2012. Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience, **5**: 505-509

Gladstone Healthy Harbour Partnership (GHHP). 2014. Technical report for the Gladstone Harbour 2014 pilot report card: 1 Methodology and Results, Technical Report No.1. GHHP, Rockhampton, 11 pp.

Hemminga, M. A. and Duarte, C. M. 2000. Seagrass ecology. Cambridge University Press, Cambridge, United Kingdom

Jarvis, J., Scott, E., Bryant, C. and MA, R. 2015. Gladstone Seagrass Seed Bank Density and Viability Studies-Year 1 Report. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns, 20 pp.

Jarvis, J. C. and Moore, K. A. 2010. The role of seedlings and seed bank viability in the recovery of Chesapeake Bay, USA, *Zostera marina* populations following a large-scale decline. HYDROBIOLOGIA, **649**: 55-68

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G. A., Scanes, P., McKenzie, L., O'Brien, K. R., Lyons, M., Ferguson, A., Maxwell, P., Glasby, T. and Udy, J. 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of The Total Environment, **534**: 97-109

Kirkman, H. 1978. Decline of seagrass in northern areas of Moreton Bay, Queensland. Aquatic Botany, **5**: 63-76

Lee Long, W. J., Coles, R. G., Miller, K. J., Vidler, K. P. and Derbyshire, K. J. 1992. Seagrass beds and juvenile prawn and fish nursery grounds: Water Park Point to Hervey Bay, Queensland. Information Series. Queensland Department of Primary Industries, Brisbane, 39 pp.

Lee Long, W. J., McKenzie, L. J., Rasheed, M. A. and Coles, R. G. 1996. Monitoring seagrasses in tropical ports and harbours. Page 345-350. In J. Kuo, R. C. Phillips, D. I. Walker and H. Kirkman (eds), Seagrass

Biology: Proceedings of an International Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Faculty of Sciences, The University of Western Australia, Perth

McCormack, C., Rasheed, M., Davies, J., Carter, A., Sankey, T. and Tol, S. 2013. Long term Seagrass Monitoring in the Port Curtis Western Basin: Quarterly Seagrass Assessments and Permanent Transect Monitoring Progress Report November 2009 to November 2012. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns, 88 pp.

McKenna, S., Bryant, C., Tol, S. and Rasheed, M. 2014. Baseline assessment of benthic communities (algae and macro-invertebrates) in the Port Curtis Region November 2014. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/54, James Cook University. Cairns, 27 pp.

McKenna, S., Sozou, A., Carter, A., Scott, E. and Rasheed, M. 2016a. Port of Weipa long-term seagrass monitoring, 2000 - 2015. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 16/16, James Cook University. Cairns, 38 pp.

McKenna, S., Sozou, A., Scott, E. and Rasheed, M. 2016b. Port of Abbot Point Long-Term Seagrass Monitoring: Annual Report 2014-2015. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University. Cairns, 47 pp.

McKenna, S. A., Jarvis, J. C., Sankey, T., Reason, C., Coles, R. and Rasheed, M. A. 2015. Declines of seagrasses in a tropical harbour, North Queensland Australia - not the result of a single event. Journal of biosciences, **40**: 389-398

Mellors, J. E. 1991. An evaluation of a rapid visual technique for estimating seagrass biomass. Aquatic Botany, **42**: 67-73

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Randall Hughes, A., Kendrick, G. A., Judson Kenworthy, W., Olyarnik, S., Short, F. T., Michelle, W. and Williams, S. L. 2006. A global crisis for seagrass ecosystems. BioScience, **56**: 987-996

Phillips, R. C. and Lewis, R. L. 1983. Influence of environmental gradients on variations in leaf widths and transplant success in North American seagrasses. Journal of the Marine Technological Society, **17**: 59-68

Pollard, P. C. and Greenway, M. 2013. Seagrasses in tropical Australia, productive and abundant for decades decimated overnight. Journal of biosciences, **38**: 157-166

Preen, A. R., Lee Long, W. J. and Coles, R. G. 1995. Flood and cyclone related loss, and partial recovery, of more than 1000 km^2 of seagrass in Hervey Bay, Queensland, Australia. Aquatic Botany, **52**: 3-17

Rasheed, M. A. 2004. Recovery and succession in a multi-species tropical seagrass meadow following experimental disturbance: the role of sexual and asexual reproduction. Journal of Experimental Marine Biology and Ecology, **310**: 13-45

Rasheed, M. A., McKenna, S. A., Carter, A. B. and Coles, R. G. 2014. Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia. Marine pollution bulletin, **83**: 491-499

Rasheed, M. A., Thomas, R., Roelofs, A. J., Neil, K. M. and Kerville, S. P. 2003. Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey - November/December 2002. DPI&F, Fisheries Queensland, Cairns, 48 pp.

Rasheed, M. A. and Unsworth, R. K. F. 2011. Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. Marine Ecology Progress Series, **422**: 93-103

Reason, C., York, P., Scott, E., McKenna, S. and Rasheed, M. 2016. Seagrass habitat of Mourilyan Harbour: Annual Monitoring Report – 2015. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University. Cairns, 39 pp.

Schliep, M., Rasheed, M., Bryant, C., Chartrand, K., York, P., Petrou, K. and Ralph, P. 2014. Development of a molecular biology toolkit to monitor dredging-related stress in *Zostera muelleri* subsp. *capricorni* in the Port of Gladstone- Interim Report. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/08, James Cook University, Cairns, 19 pp.

SKM. 2004. Port Curtis Integrated Monitoring Program: Sampling design and statistical methods package. Report to PCIMP, pp.

Sozou, A., McKenna, S. and Rasheed, M. 2016a. Port of Karumba Long-term Annual Seagrass Monitoring: September 2015. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University. Cairns, 28 pp.

Sozou, A., Scott, E. and Rasheed, M. 2016b. Long-term Seagrass Monitoring in the Port of Thursday Island: March 2016. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University. Cairns, 43 pp.

Taylor, H. A. and Rasheed, M. A. 2011. Impacts of a fuel oil spill on seagrass meadows in a subtropical port, Gladstone, Australia - The value of long-term marine habitat monitoring in high risk areas. Marine pollution bulletin, **63**: 431-437

Unsworth, R. K. F., Rasheed, M. A., Chartrand, K. M. and Roelofs, A. J. 2012. Solar radiation and tidal exposure as environmental drivers of *Enhalus acoroides* dominated seagrass meadows. PLoS ONE, **7**: e34133

Vermaat, J. E., Agawin, N. S. R., Fortes, M. D., Uri, J., Duarte, C. M., Marba, N., Enriquez, S. and Van Vierssen, W. 1997. The capacity of seagrasses to survive increased turbidity and siltation: the significance of growth form and light use. Ambio, **26**: 499-504

York, P., Carter, A., Chartrand, K., Sankey, T., Wells, L. and Rasheed, M. 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program. Scientific Reports, **5**: 13167

York, P. H., Reason, C., Scott, E. L., Sankey, T. and Rasheed, M. A. 2016. Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2015. Cairns, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 16/13, James Cook University, 58 pp.

APPENDICES

Appendix 1. An example of calculating a meadow score for area in satisfactory condition.

1. Determine the grade for the 2015 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2015 area value (A_{2015}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$\mathrm{A_{diff}} = \mathrm{A_{2015}} - \mathrm{A_{satisfactory}}$$

Where $A_{satisfactory}$ or any other threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (highly stable [area only], 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 is set as 100%. For area and biomass, the upper limit for the very good grade is set as the maximum value of the mean plus the standard error (i.e. the top of the error bar) for a given year during the baseline period for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (A_{prop}) that A_{2015} takes up:

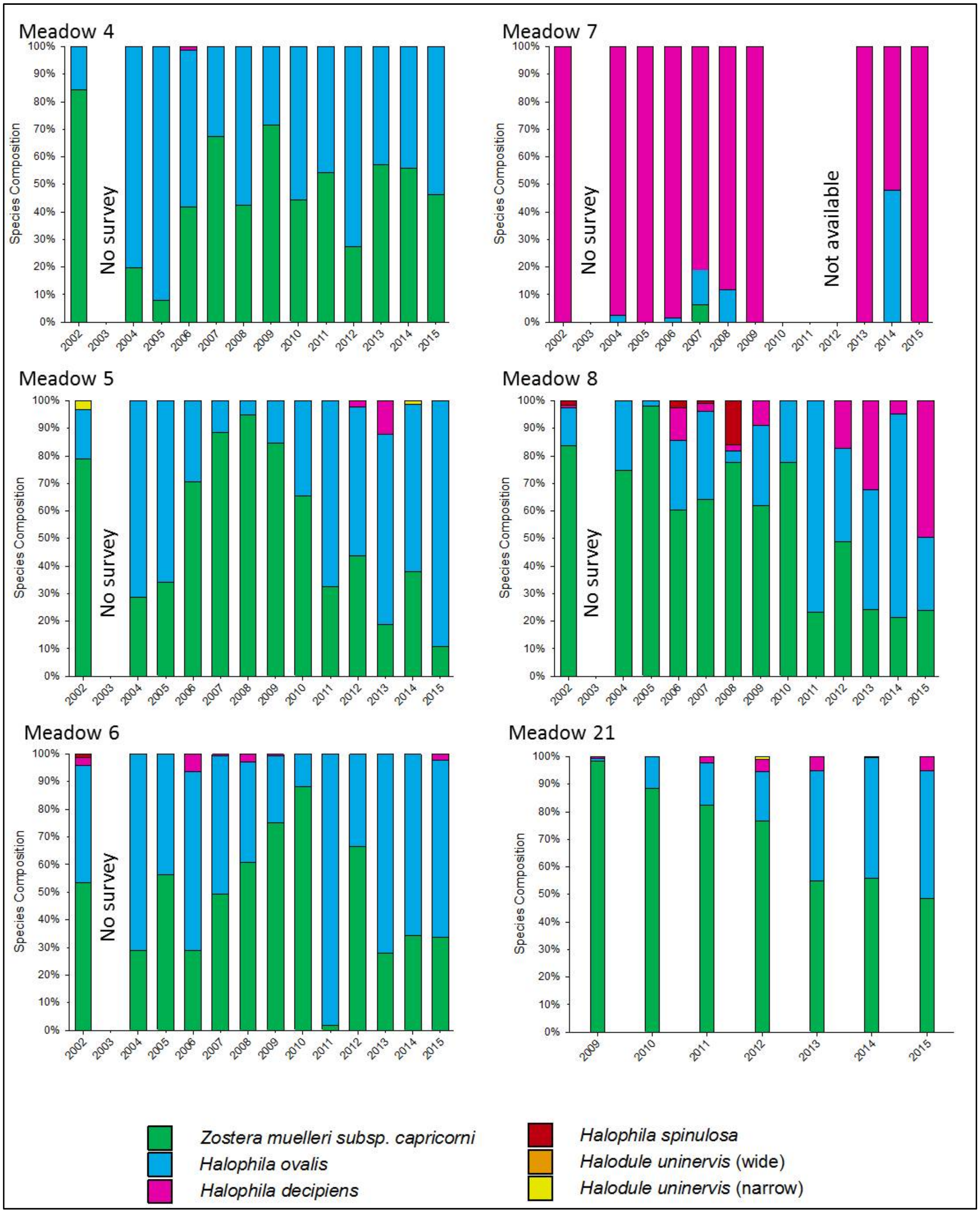
$$\mathrm{A_{prop}} = \frac{\mathrm{A_{diff}}}{\mathrm{A_{range}}}$$

5. Determine the area score for 2015 ($Score_{2015}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

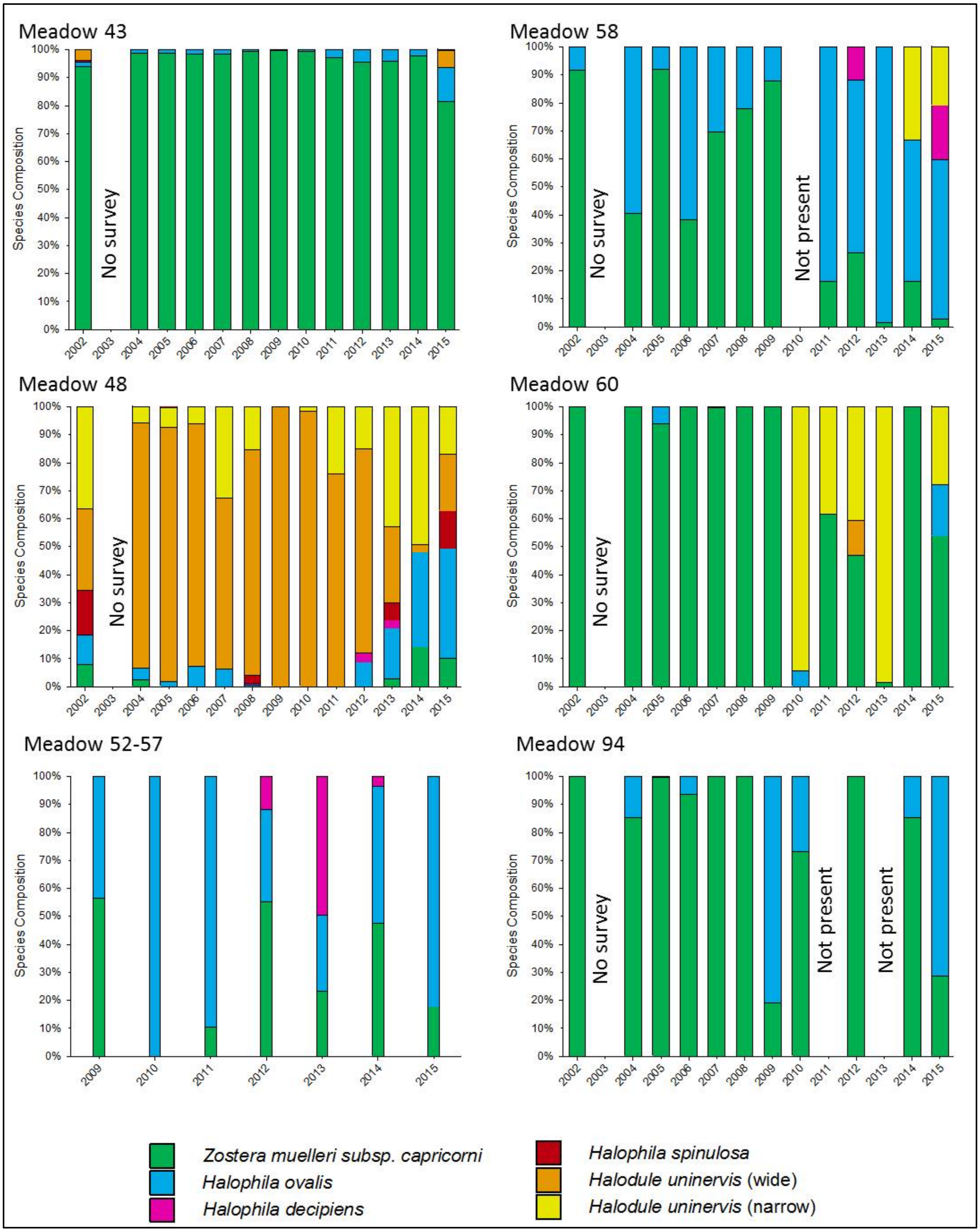
$$\mathrm{Score_{2015}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{A_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

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

Appendix 2. Species composition for Meadows 4-8 (2002-2015) and Meadow 21 (2009- 2015).



Appendix 2. (continued) Species composition for Meadows 43, 48, 58, 60 and 94 (2002-2015) and Meadow 52-57 (2009-2015).



Appendix 2. (continued) Species composition for Meadows 96 and 104 (2002-2015).