GLADSTONE HEALTHY HARBOUR PARTNERSHIP 2017 REPORT CARD

ISP011: SEAGRASS

Carter AC, Wells JN and Rasheed MA

Report No. 17/29

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EXECUTIVE SUMMARY

- Seagrass condition was assessed for 14 monitoring meadows across six Gladstone Healthy Harbour Partnership (GHHP) reporting zones in November 2016 (GHHP 2017 reporting year).

- Seagrass condition in the Gladstone Harbour region remained poor (D, 0.39) in the 2017 reporting year.

- Survey results were mixed for individual meadows and zones within the survey area. The overall score for each meadow is the lowest of the three indicator scores. Area determined the overall meadow score in seven of the monitoring meadows, species composition in four meadows, and biomass in three meadows.

- Seagrass condition improved in The Narrows (poor to satisfactory), South Trees Inlet (poor to good), in the Passage Islands meadow (satisfactory to good) and two Wiggins Island meadows (satisfactory to good, and poor to satisfactory) in the Western Basin Zone, and at Quoin Island (poor to satisfactory) in the Mid Harbour.

- Seagrass condition declined in Rodds Bay (poor to very poor), in the meadow immediately north (poor to very poor) and two meadows to the south (good to poor, and good to satisfactory) of Fishermans Landing in the Western Basin Zone, and at Pelican Banks (poor to very poor) in the Mid Harbour. Condition remained very poor in the Inner Harbour.

- Condition declines in the Pelican Banks meadow - the largest and most stable seagrass meadow in the Gladstone region - is concerning. The meadow is now in very poor condition, driven by the lowest ever recorded biomass. Meadow area and percent composition of the dominant species *Z. muelleri* subsp. *capricorni* were also at record lows. The reasons for these declines are unclear. Light monitoring indicated favourable conditions for seagrass growth in 2016, daytime tidal exposure had reduced from 2015, and there were far fewer instances of water temperatures occurring above 33^{o}C for extended periods of time than in 2015. Potential contributors to the decline include high levels of dugong and turtle herbivory, sediment changes, and cumulative impacts of multiple stressors over multiple years, but require further investigation.

- Environmental conditions influence seagrass condition in Gladstone. Years where >50% of meadows were assigned an overall meadow condition of poor or very poor either correspond with (2010-2016) or directly follow (2004) periods of above average rainfall and river flow in the region. There was no cyclone-related flooding in the 12 months preceding the November 2016 survey, however total monthly rainfall was above the long-term (1958-2016) average in March, June, July and September 2016. Calliope River flow also peaked above the long-term (1970-2016) average in February and July 2016, but otherwise was below or close to the long-term average leading up to the November 2016 survey. High rainfall and flooding of the Fitzroy and Calliope Rivers associated with Tropical Cyclone Debbie in March 2017 may further impact seagrass condition in 2017.

- There was no sign of seagrass recovery at the Gladstone Harbour scale from the previous year. Resilience of seagrasses to further natural or anthropogenic impacts in the Gladstone Harbour region is likely to be low.

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

CONTENTS

PART 1 - SEAGRASS REPORT CARD 2017

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). Three indicators of seagrass condition are assessed — biomass, area and species composition. Each meadow is graded from A (very good) to E (very poor) relative to baseline conditions and 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 Gladstone Healthy Harbour Partnership (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 provides 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 2016 (GHHP 2017 reporting year). The South Trees Zone was in good condition; The Narrows and Western Basin Zones were in satisfactory condition; the Mid Harbour Zone was in poor condition; and the Rodds Bay and Inner Harbour Zones were in very poor condition (Table 1). The Gladstone Harbour region score is the mean of the zone scores. In 2017 seagrass condition in the region was poor (Table 1).

This is the fourth consecutive year of reporting seagrass condition to GHHP. The 2014 pilot report card 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 (Carter et al. 2015b). In 2016, minor adjustments were made following a statistical review (Carter et al. 2016). No changes were made to reporting methods for this 2017 report card.

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 2017 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**	0.60**	0.59	0.63	0.59	0.59
3. Western Basin	**4**	1.00	0.66	0.73	0.66	0.50
	5	0.70	0.69	0.52	0.52	
	6	0.78	0.76	0.54	0.54	
	7	0.68	0.36	1.00	0.36	
	8	0.87	0.29	0.18	0.18	
	52-57*	0.97	0.77	0.98	0.77	
5. Inner Harbour	**58**	0.73	0.87	0.00	0.00	0.00
8. Mid Harbour	**43**	0.14	0.66	0.60	0.14	0.34
	48	0.75	0.54	0.58	0.54	
9. South Trees Inlet	**60**	0.75	0.96	0.98	0.75	0.75
13. Rodds Bay	**94**	0.17	0.06	1.00	0.06	0.19
	96	0.42	0.65	0.57	0.42	
	104	0.13	0.07	0.28	0.07	
Gladstone Harbour						**0.39**

*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.

** Seven years of baseline data are now available for meadow 21 (The Narrows) and meadows 52-57 (Western Basin). 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 10-year baseline data are available.

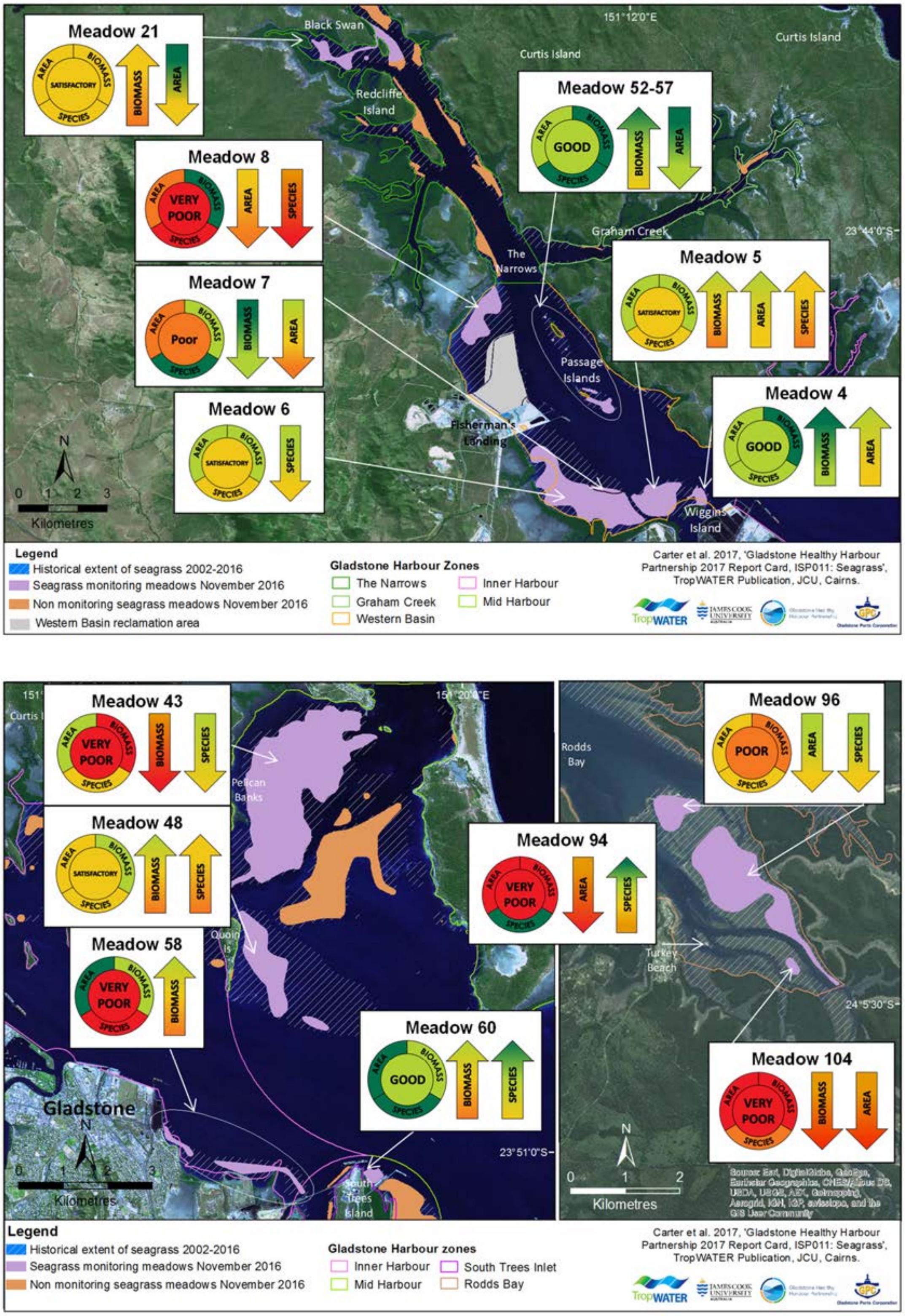


Figure 1. Seagrass condition for each indicator, and overall meadow condition, for 14 monitoring meadows within six Gladstone Harbour Zones. Upwards/ downwards arrows are included where a change in condition grade has occurred in any of the three condition indicators (biomass, area, species composition)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

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, removal of bacterial pathogens, and act as carbon sinks (Lamb et al. 2017; Costanza et al. 2014; Fourqurean et al. 2012; Hemminga and Duarte 2000). Seagrass meadows show measurable responses to changes in water quality, making them ideal sensitive receptors for monitoring the health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program 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).

This strategic long-term assessment and monitoring program provides port managers and regulators with 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 seagrass communities most at risk from cumulative threats in Queensland (Grech et al. 2011).

The program also has 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 understanding 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 (McKenna et al. 2014; Rasheed et al. 2003; Lee Long et al. 1992). 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, TropWATER conducted 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 meadows likely to support high fisheries productivity. Three meadows in Rodds Bay (outside port limits) also were 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 was dropped as a monitoring meadow in this program (Meadow 9 was included in the GHHP 2014 reporting year only).

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), when 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 partnership between community, industry, science, government, statutory bodies and management, that reports on the health of Gladstone Harbour. The GHHP report card tracks ecosystem health in the harbour; this 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 enable 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 region, covering an area of approximately 12,000 ha at peak distribution including intertidal, shallow subtidal and deep-water habitats (Figure 2) (Davies et al. 2016). The GHHP engaged TropWATER's Seagrass Ecology Group to develop a seagrass report card using 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 2017 Gladstone Harbour report card were to provide:

1. Seagrass grades and scores for the 2017 reporting year using GHHP approved grades and scores.
2. A project report describing data collection, statistical methods used to determine report card grades and scores, and an assessment of Gladstone Harbour seagrass condition in 2017 relative to historical trends.
3. A GIS shapefile and metadata for the seagrass monitoring meadows, 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 region (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*

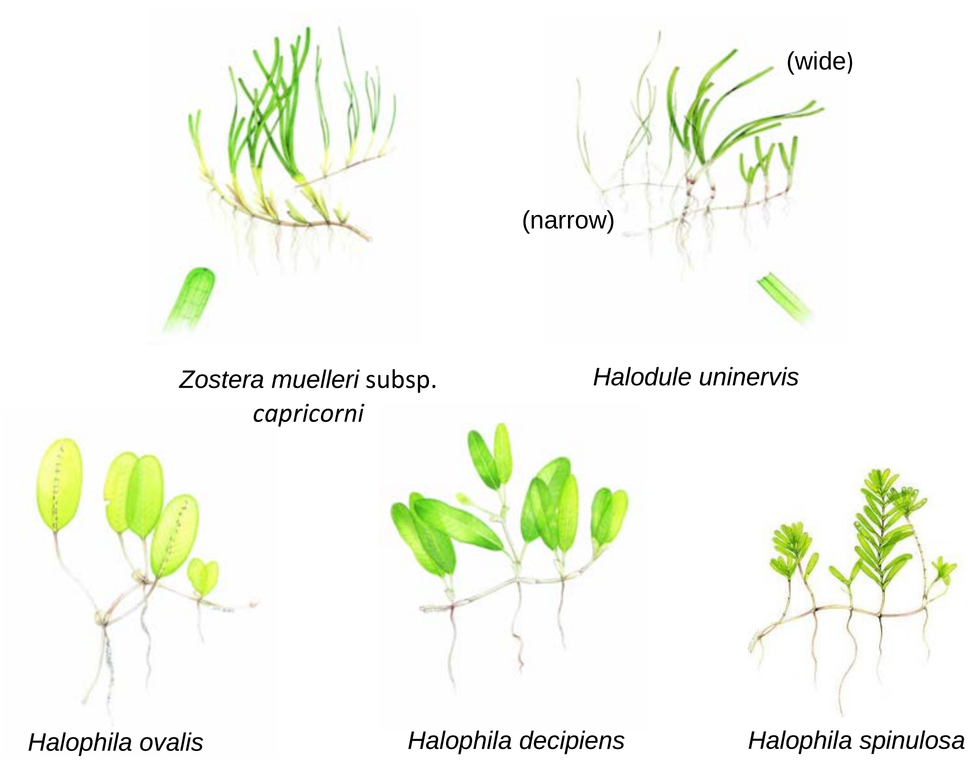


Figure 3. Seagrass species present in the Gladstone Harbour region.

2 METHODS

2.1 Sampling Approach and Data Collection Methods for Seagrass Indicators

Fourteen representative seagrass monitoring meadows were surveyed November 12 – 18, 2016 (GHHP 2017 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 (Davies et al. 2016).

Survey methods followed the established techniques for the TropWATER Queensland-wide ports seagrass monitoring program (see Unsworth et al. 2012; Rasheed and Unsworth 2011; Taylor and Rasheed 2011; Lee Long et al. 1996). 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 <1 m above the seagrass. Shallow subtidal meadows were sampled by boat using free divers (Figure 4b) or a van Veen grab where visibility was too poor to dive (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).

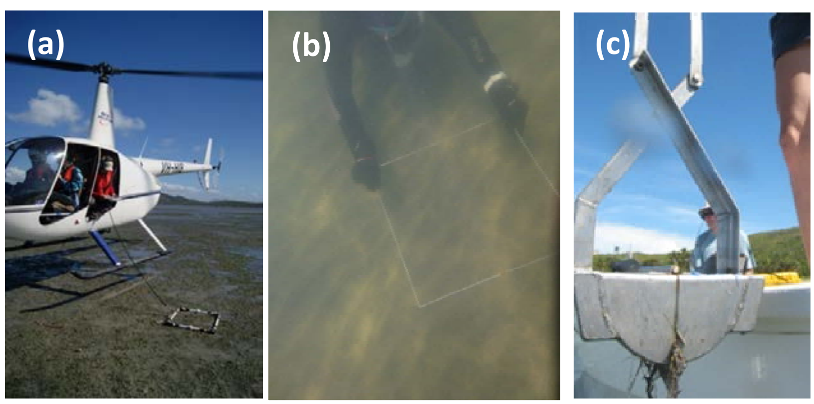


Figure 4. Seagrass monitoring conducted using (a) helicopter aerial surveillance with quadrat; (b) boat based free diver with quadrat; and (c) van Veen grab.

2.1.1 Biomass and Species Composition

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (Mellors 1991; Kirkman 1978). 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, 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 percent 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 were 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 were used to construct the meadows (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. Meadow area was determined using the calculate geometry function in ArcGIS®. 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 ±5 m for intertidal seagrass meadows mapped by helicopter, to ±50 m for subtidal boundaries mapped by boat. 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
≤5 m	Meadow boundary mapped in detail by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide.
10 m	Meadow boundary determined from helicopter and boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from survey sites and aerial photography, Moderately high density of mapping and survey sites.
20 m	Meadow boundaries determined from helicopter and boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from boat survey sites, Lower density of survey sites for some sections of boundary.
50 m	Meadow boundaries determined from boat surveys, Low density of survey sites for some sections of boundary.

Spatial data from the survey were entered into the Gladstone Harbour Geographic Information System (GIS). Site information was used to create the seagrass meadow layer. The meadow layer includes:

- Meadow monitoring number and Gladstone Harbour Zone
- Meadow area ± meadow reliability estimate (R; hectares),
- 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 category (Table 4; categorised as light, moderate, dense according to above-ground biomass of the dominant species),
- Seagrass meadow landscape category (Figure 5),
- 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 unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
Meadows consist of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries.

Continuous seagrass cover
The majority of meadow area consists of continuous seagrass cover interspersed with a few gaps of unvegetated sediment.

Figure 5. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

2.2 Seagrass Condition

Seagrass condition was determined using a condition index to assess changes in mean above-ground biomass, meadow area and species composition relative to each meadow's baseline. Seagrass condition for each indicator in each meadow was scored from 0 - 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 6. Flow chart of steps used to determine Gladstone Harbour grades and scores.

2.2.1 Baseline Calculations

Baseline conditions for meadow biomass, 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 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 2016 data). Once the monitoring program has collected over 10 years of data, the 10-year long-term average will be used for all 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. Meadows were classified as single species (one species comprising ≥80% of baseline species composition) or mixed species dominated (no species comprise ≥80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two dominant species (i.e. two 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 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 and species composition were classified as stable or variable (Table 5). Meadow area also has additional highly stable and highly variable classes (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 stability or variability of meadow biomass, area and species composition baselines.

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

Each seagrass condition 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).

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 2016 biomass, area and species 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.

Calculation restrictions (CR) were placed on scores and grades for a given meadow and year for two reasons: (1) for species composition where seagrass was absent from a meadow for a particular sampling year, or (2) for biomass where sampling was conducted using a van Veen grab only, precluding biomass estimates. Years where calculation restrictions were applied are detailed in Tables 11 and 13, Section 3.4.

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

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

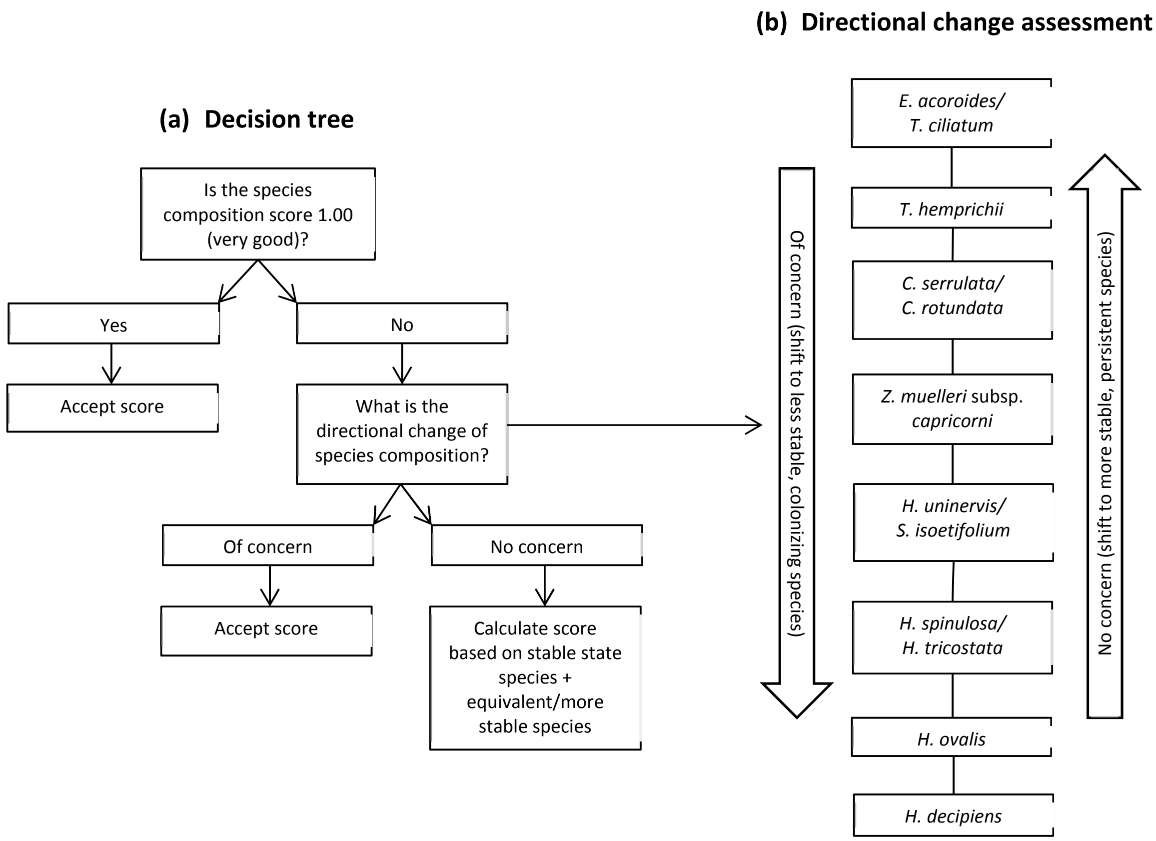
Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very good	**B Good**	**C Satisfactory**	**D Poor**	**E Very Poor**
Biomass	Stable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Biomass	Variable	>40% above	40% above - 40% below	40-70% below	70-90% below	>90%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

Table 7. Score range and grading colours used in the 2017 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/stable species were driving this grade/score (Figure 7). If this was the case, the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species was 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 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. 2016b) (Figure 7).

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 indicator 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 calculated 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 more sensitive thresholds for stable meadows, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the stable meadows was more likely to trigger a meadow grade reduction compared with more variable, ephemeral meadows. Zone grades therefore are 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 classed as variable in 13 of the 14 monitoring meadows (Table 8). Area was classed as stable for half of the meadows. Half of the monitoring meadows were classed as single-species dominated. The large (~630 ha), high biomass (~19 gDW m^{-2}), *Z. muelleri* subsp. *capricorni* dominated (~98%) meadow at Pelican Banks (meadow 43) is the only meadow classed as stable across all three condition indicators (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 (baseline years 2009 – 2015). Results for these meadows should be interpreted with caution until 10-year baselines are available.

3.2 Overall Seagrass Condition for the 2017 Reporting Year

3.2.1 Overall Meadow Condition

Half of the monitoring meadows were assessed as being in poor or very poor condition, including the Inner Harbour meadow, three Rodds Bay meadows, and the Pelican Banks meadow in the Mid Harbour. In the Western Basin Zone two meadows were in satisfactory condition, two meadows were in good condition, one meadow was in poor condition and one meadow was in very poor condition. Seagrass in the South Trees Inlet Zone was in good condition. No meadows were graded as very good for overall meadow condition.

The overall meadow score for each meadow is the lowest of the three indicator scores. Area determined the overall meadow scores in seven of the 14 monitoring meadows, including meadows in The Narrows, Western Basin, Mid Harbour and Rodds Bay Zones. Species composition determined overall scores in three of the six Western Basin meadows and the Inner Harbour meadow. Biomass was responsible for overall meadow condition in the South Trees Inlet meadow, the large Rodds Bay meadow (96), and the Pelican Banks meadow (43) (Table 9).

3.2.2 Overall Zone and Harbour Condition

Two Gladstone Harbour Zones were in very poor condition (Inner Harbour and Rodds Bay), the Mid Harbour Zone was in poor condition, the Western Basin and The Narrows Zones were in satisfactory condition, and the South Trees Inlet Zone was in good condition (Table 9). The overall seagrass condition in Gladstone Harbour received a poor score 0.39 (D) based on average zone scores (Table 9).

Table 9. Grades and scores for seagrass indicators (biomass, area, species composition), meadows, Gladstone Harbour zones and region for the GHHP 2017 reporting year (November 2016 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	0.60**	0.59	0.63	0.59	0.59
3. Western Basin	4	1.00	0.66	0.73	0.66	0.50
	5	0.70	0.69	0.52	0.52	
	6	0.78	0.76	0.54	0.54	
	7	0.68	0.36	1.00	0.36	
	8	0.87	0.29	0.18	0.18	
	52-57*	0.97	0.77	0.98	0.77	
5. Inner Harbour	58	0.73	0.87	0.00	0.00	0.00
8. Mid Harbour	43	0.14	0.66	0.60	0.14	0.34
	48	0.75	0.54	0.58	0.54	
9. South Trees Inlet	60	0.75	0.96	0.98	0.75	0.75
13. Rodds Bay	94	0.17	0.06	1.00	0.06	0.19
	96	0.42	0.65	0.57	0.42	
	104	0.13	0.07	0.28	0.07	
Gladstone Harbour						**0.39**

*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. Seven years of baseline data are now available for meadow 21 (The Narrows) and meadows 52-57 (Western Basin). Results for these meadows should be interpreted with caution until 10-year baseline 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 satisfactory condition (Figure 8), an improvement from poor overall condition in 2015. Meadow 21 is an intertidal, variable biomass meadow at Black Swan Island, and the only monitoring meadow in the zone. All three indicators were in satisfactory condition (Figures 8, 9). Biomass increased from 1.1 gDW m^{-2} in 2015 (poor condition), following five consecutive years of decline from 2009 – 2014, to 3.0 gDW m^{-2} in 2016 (good condition). Meadow area condition declined from very good to satisfactory following a loss of nearly 42 ha area between 2015 and 2016. Species composition remained in satisfactory condition. The dominant species *Z. muelleri* subsp. *capricorni* continued to account for ~55% of mean meadow biomass, as it has since 2013, following declines from almost 100% *Z. muelleri* subsp. *capricorni* relative to less persistent species *H. ovalis* in 2009 (Figure 9; Appendix 2).

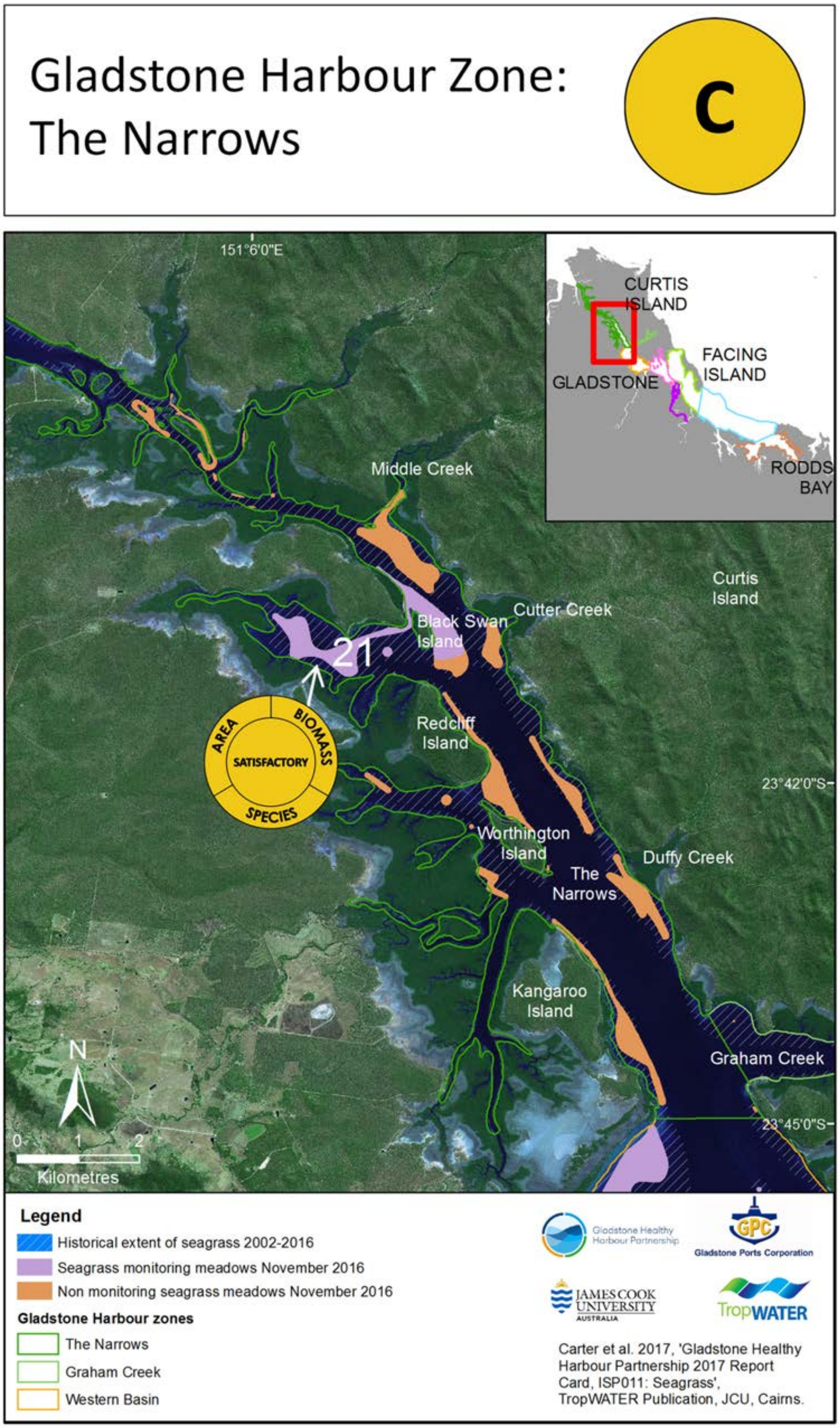
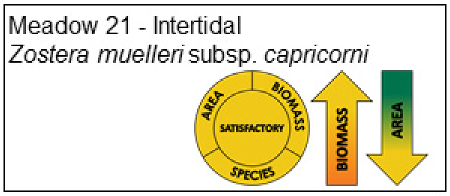
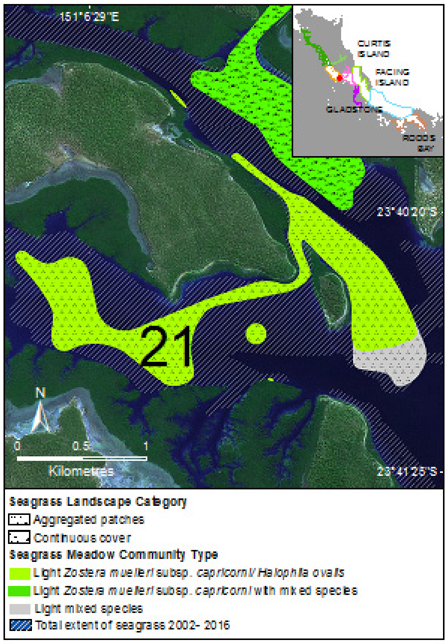


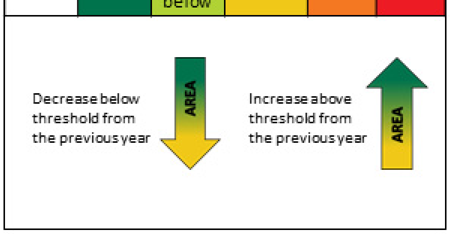
Figure 8. Seagrass condition in Zone 1: The Narrows.





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 (stable mixed)	>20% above	20% above 20% below	20-50% below	50-80% below	>80% below



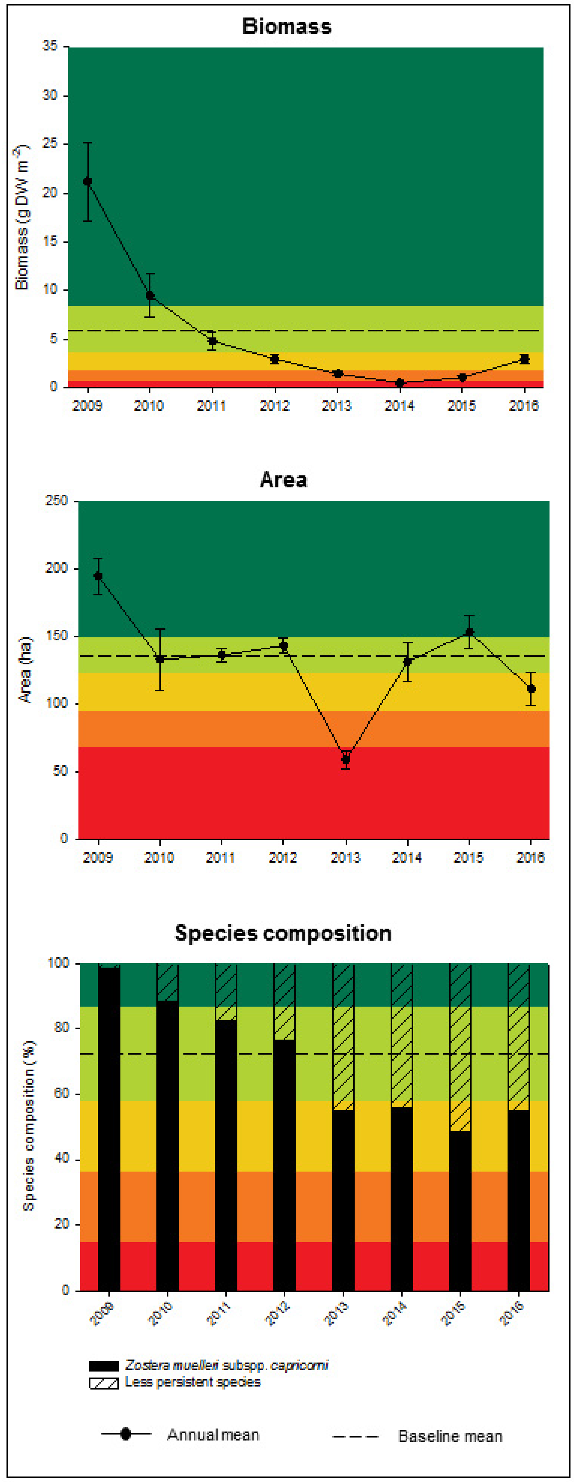


Figure 9. Meadow area, biomass and species composition for seagrass in Meadow 21, Zone 1: The Narrows, November 2009 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate). Note: This meadow has only been surveyed as part of the annual monitoring program since 2009. Baseline levels and resulting grades should be interpreted with caution until the full 10-year baseline is available.

3.3.2 Zone 3: Western Basin

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

Meadow 4

Meadow 4 at Wiggins Island was in good condition due to the meadow area score (Figure 11). Area was in good condition after steady improvements from poor condition in 2013. Biomass was in very good condition and, at 2.05 gDW m^{-2}, the highest value recorded since monitoring began. Meadow 4 is a variable mixed species meadow where the dominant species fluctuates between *Z. muelleri* subsp. *capricorni* and the less persistent *H. ovalis*. In 2016, the composition of *Z. muelleri* subsp. *capricorni* remained good, despite declines for the second consecutive year (Figure 11; Appendix 2).

Meadow 5

Meadow 5 west of Wiggins Island was in satisfactory condition due species composition, which drove the overall meadow score (Figure 12). Meadow 5 is an intertidal, variable mixed species meadow that fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2016, the composition of *Z. muelleri* subsp. *capricorni* was 21%, well below the 62% baseline, but an improvement from poor species composition in 2015 (Figure 12; Appendix 2). Meadow biomass improved from poor to good condition between 2015 and 2016. Meadow area was in good condition and continued to improve a grade each year from being in very poor condition in 2013 (Figure 12).

Meadow 6

At South Fisherman's Landing meadow 6's overall condition declined from good to satisfactory due to species composition (Figure 13). Meadow 6 is an intertidal, variable mixed species meadow where the dominant species *Z. muelleri* subsp. *capricorni* has declined relative to *H. ovalis* since 2010. In 2016, *H. ovalis* comprised over 80% of biomass (Figure 13; Appendix 2). Biomass was in good condition and surpassed the 1.8 gDW m^{-2} baseline for the first time since 2009. Meadow area condition remained good for the third consecutive year (Figure 13).

Meadow 7

Overall condition of meadow 7 declined from good to poor between 2015 and 2016 due to a reduction in area for this subtidal meadow, from 81 ha to just 13 ha (Figure 14). Biomass also declined below the baseline of 1.4 gDW m^{-2} in 2016 but remains in good condition. Meadow 7 is a single species *H. decipiens* dominated meadow (baseline = 96% of mean meadow biomass); species composition remained in very good condition in 2016 (Figure 14; Appendix 2).

Meadow 8

The intertidal Meadow 8 at North Fisherman's Landing was in very poor condition, driven by further reductions in the previously dominant species *Z. muelleri* subsp. *capricorni*, relative to *H. ovalis* and *H. decipiens* (Figure 15; Appendix 2). *Z. muelleri* subsp. *capricorni* has remained far below the baseline level of 67% since 2011, and in 2016 was just 10% of biomass. Meadow area also declined from 155 to 114 ha, from satisfactory to poor condition. Biomass remained in very good condition between 2015 and 2016 (Figure 15).

Meadows 52-57

The Passage Island meadows 52-57 are a group of predominantly intertidal meadows. In 2016, overall meadow condition was good because meadow area was approximately equal to the 31 ha baseline (Figure 16). Biomass is variable and has remained low (<2 gDW m^{-2}) since monitoring began. Between 2015 and 2016 biomass condition improved from satisfactory to very good. Species composition also was very good - the proportion of *Z. muelleri* subsp. *capricorni* was greater than *H. ovalis* for the first time since 2012 (Figure 16; Appendix 2).

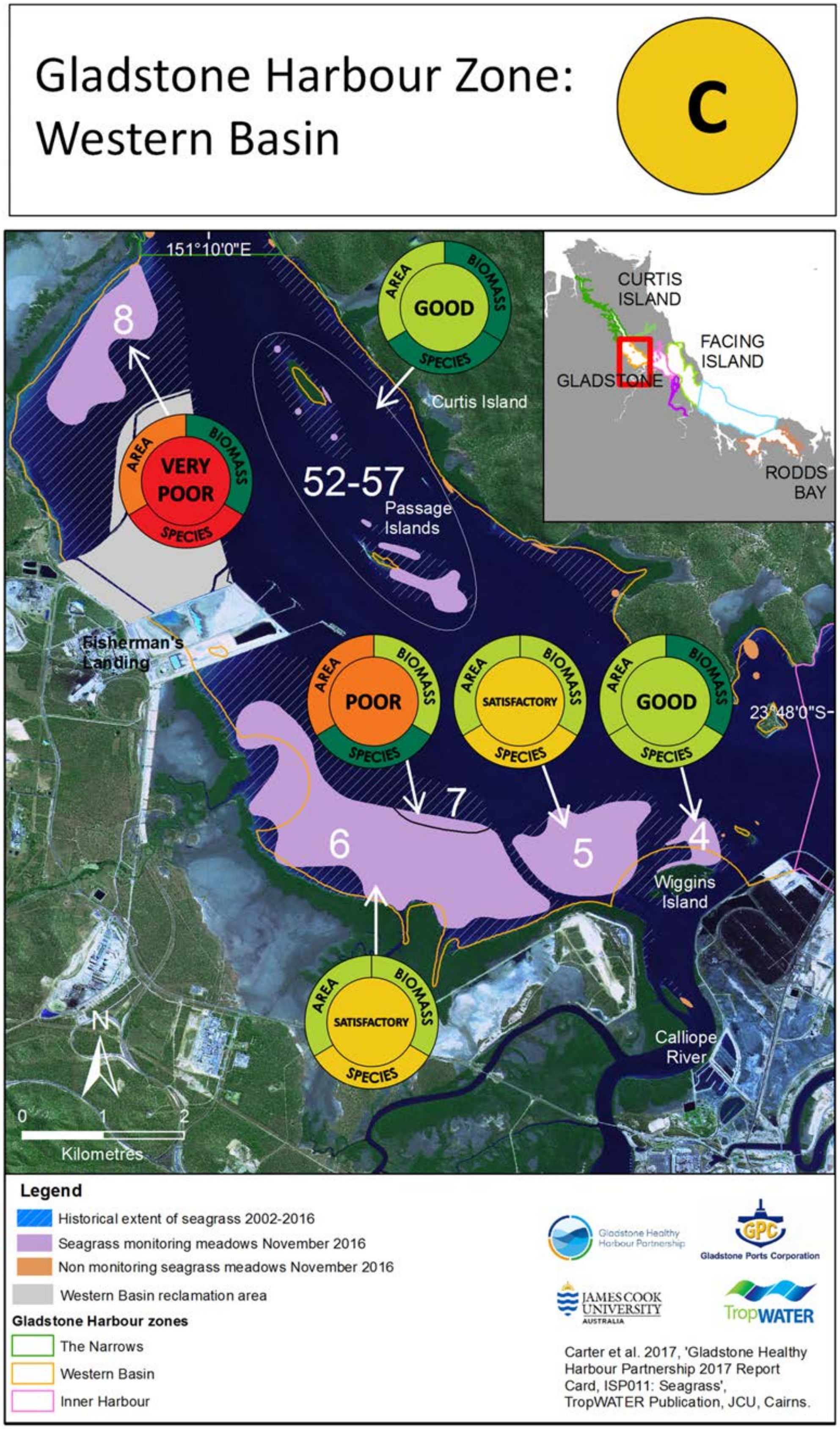


Figure 10. Seagrass condition in Zone 3: Western Basin.

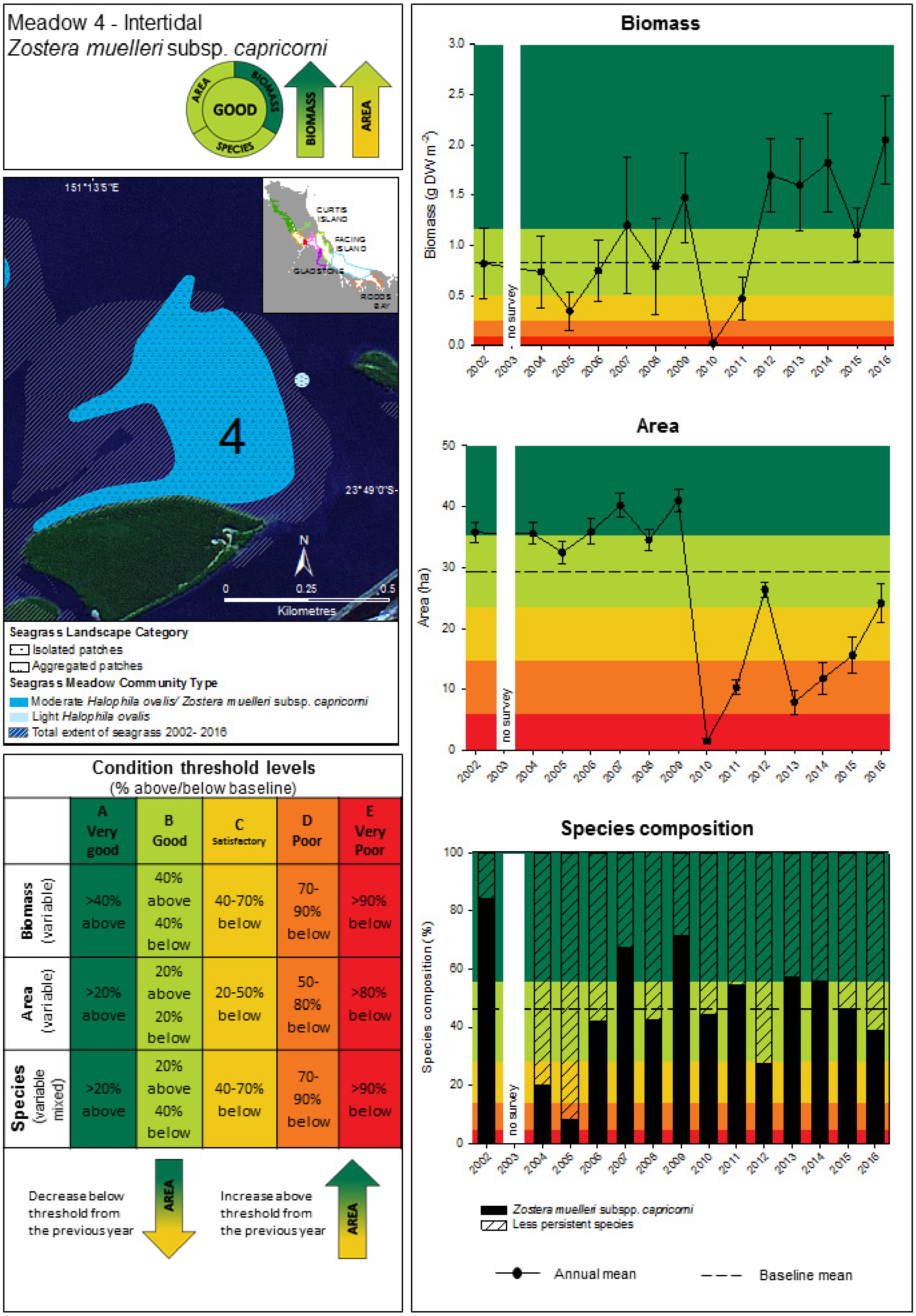


Figure 11. Meadow area, biomass and species composition for seagrass in Meadow 4, Zone 3: Western Basin, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

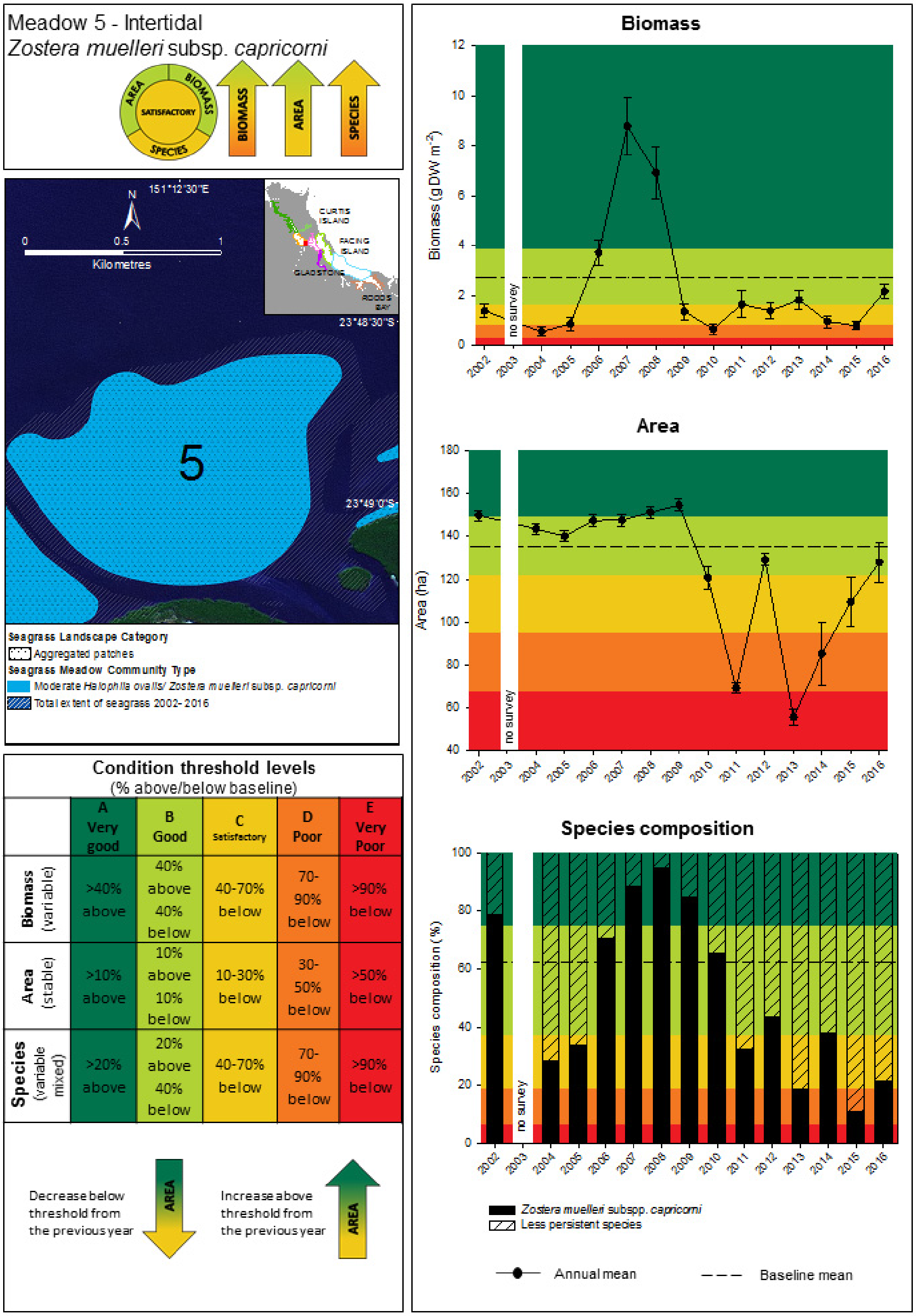


Figure 12. Meadow area, biomass and species composition for seagrass in Meadow 5, Zone 3: Western Basin, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

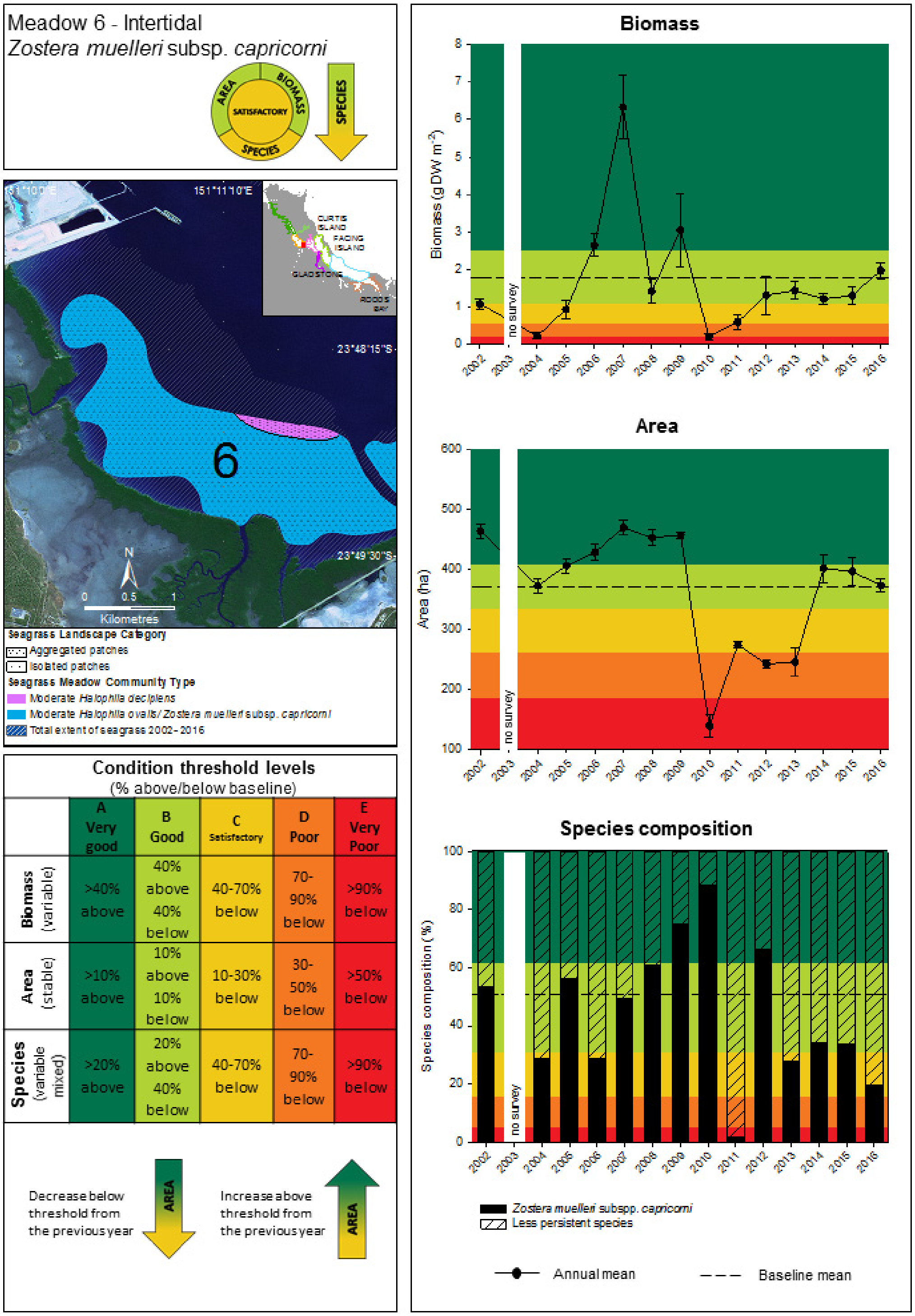
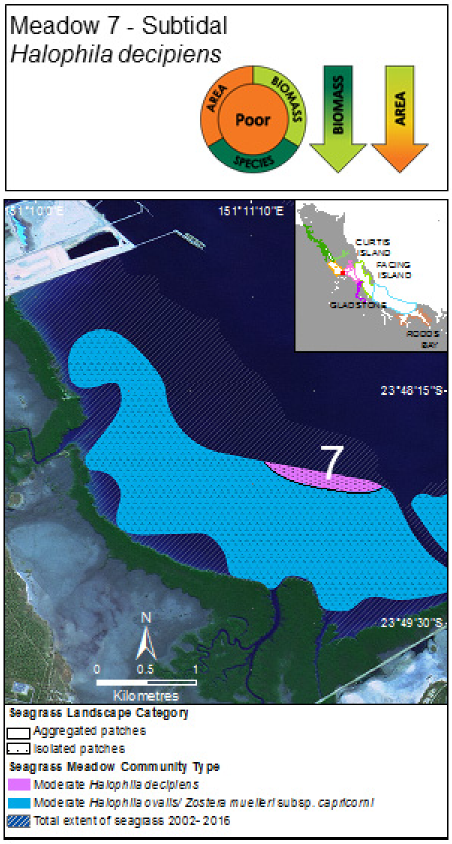
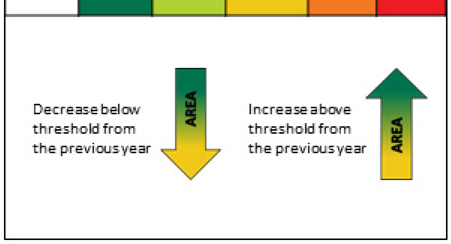


Figure 13. Meadow area, biomass and species composition for seagrass in Meadow 6, Zone 3: Western Basin, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).



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 (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below



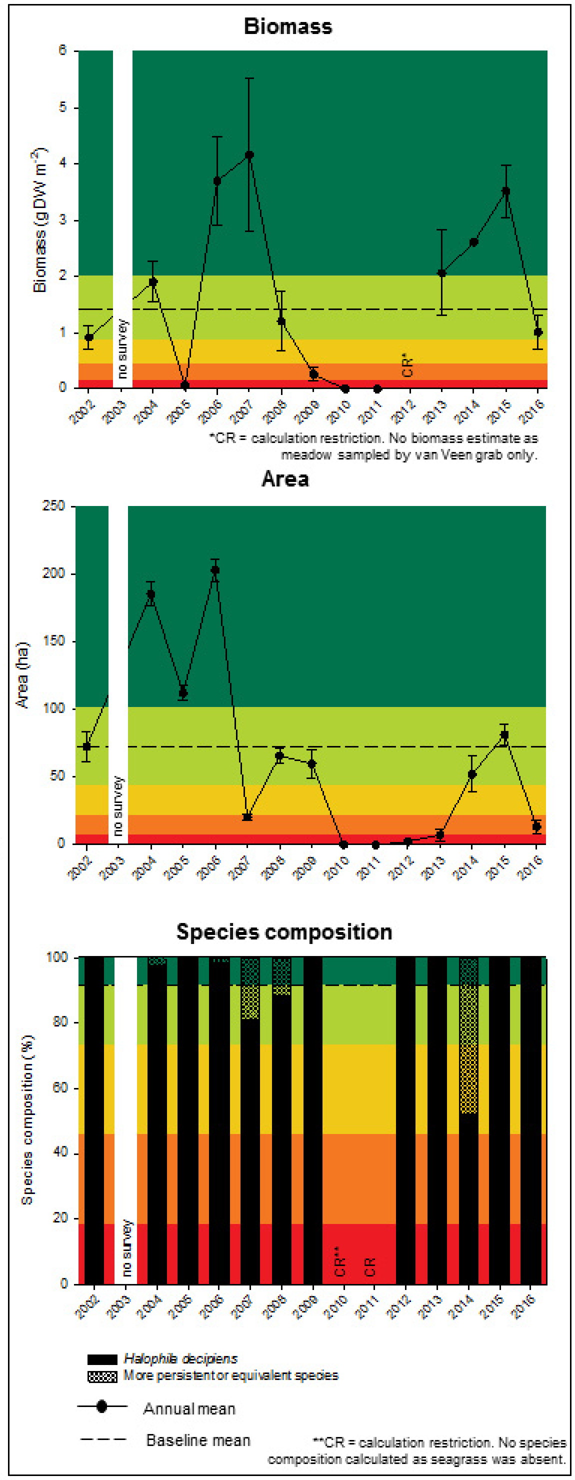


Figure 14. Meadow area, biomass and species composition for seagrass in Meadow 7, Zone 3: Western Basin, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

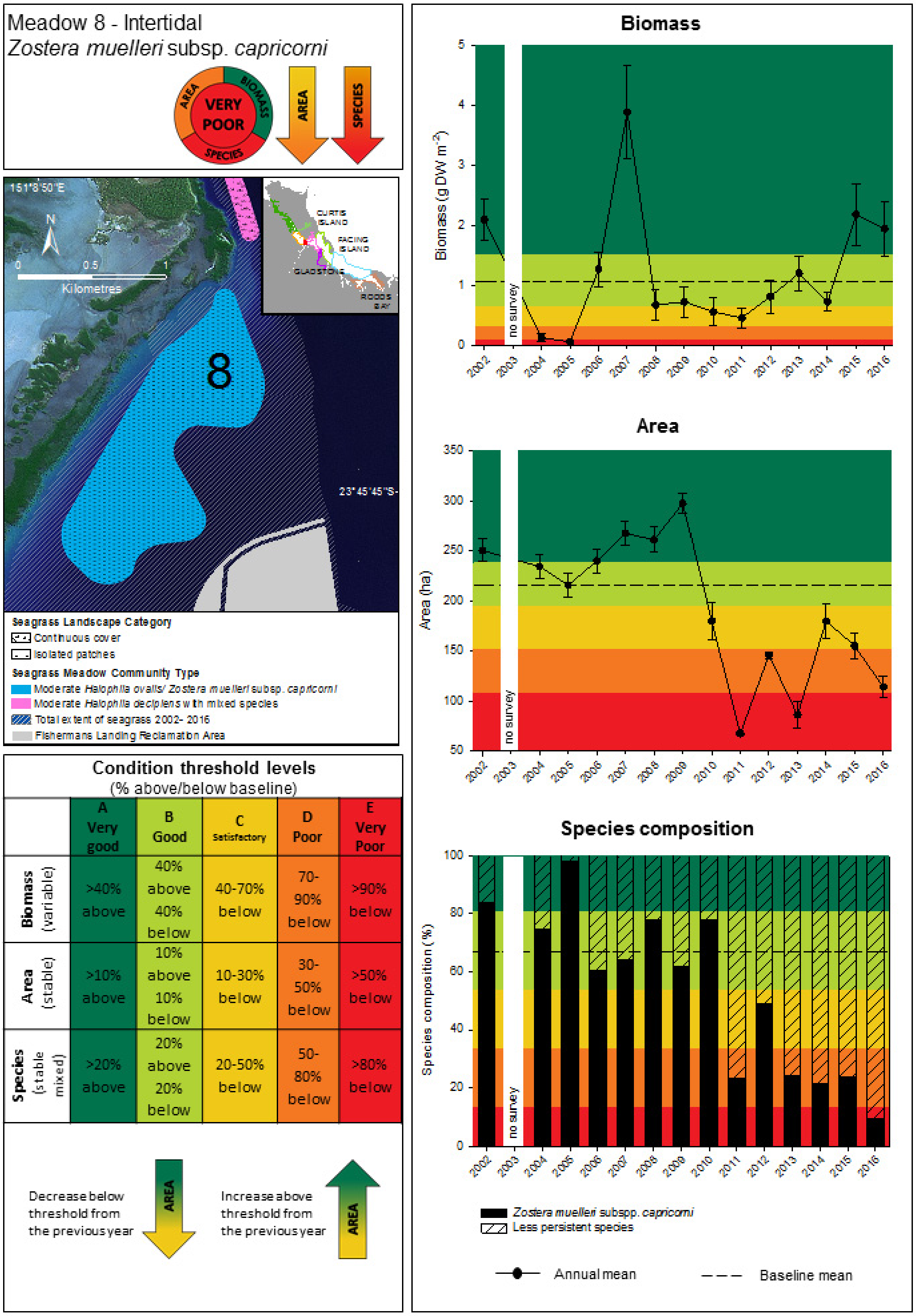


Figure 15. Meadow area, biomass and species composition for seagrass in Meadow 8, Zone 3: Western Basin, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

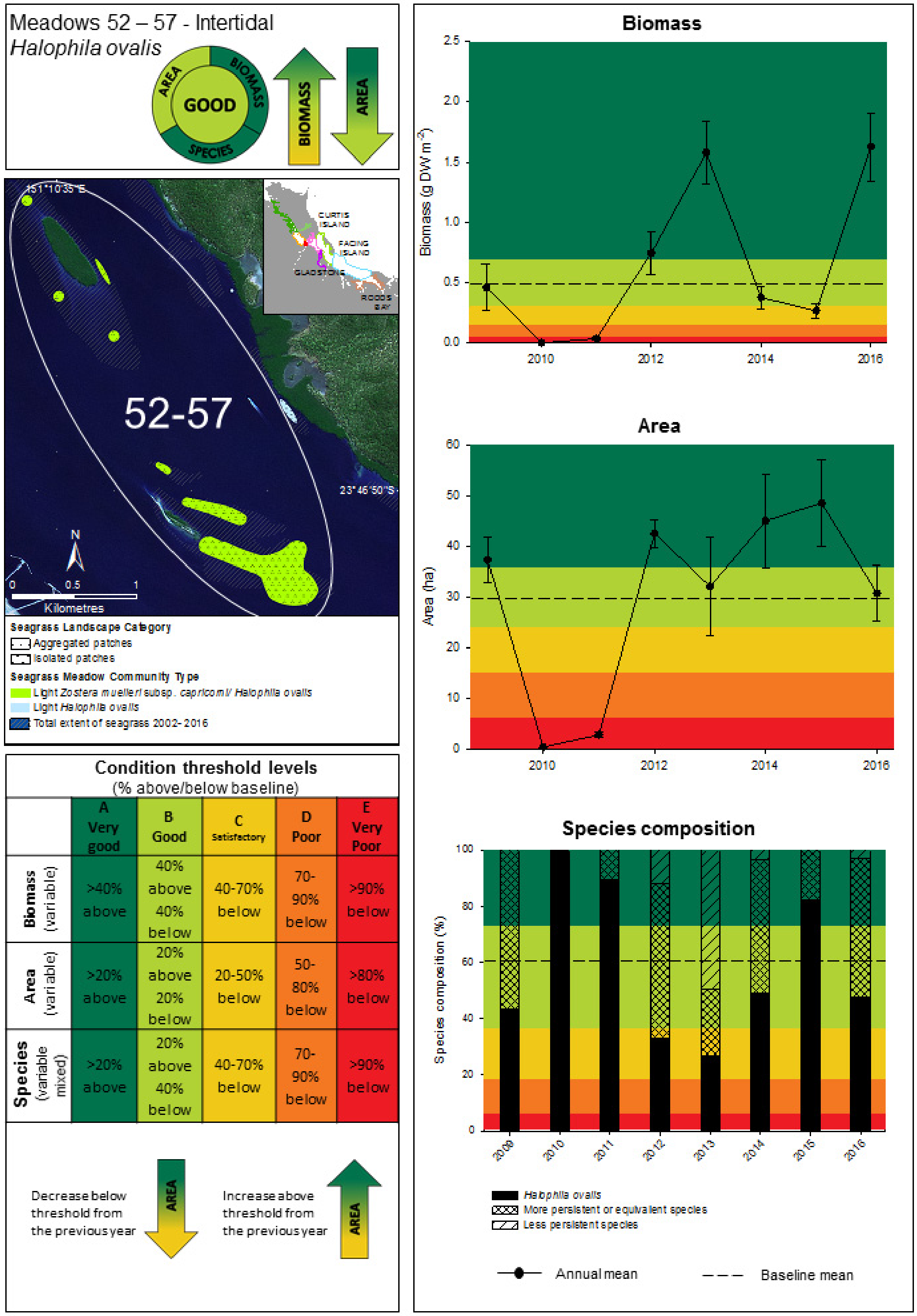


Figure 16. Meadow area, biomass and species composition for seagrass in Meadows 52-57, Zone 3: Western Basin, November 2009 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate). Meadows 52-57 are grouped for reporting purposes. Note: This meadow has only been surveyed as part of the annual monitoring program since 2009. Baseline levels and resulting grades should be interpreted with caution until the full 10-year baseline is available.

3.3.3 Zone 5: Inner Harbour

Seagrass condition in Zone 5: Inner Harbour remained in very poor condition in 2016 (Figure 17). This was due to species composition in the intertidal Meadow 58, the only monitoring meadow in this zone (Figure 17). In 2016, meadow 58 suffered a complete loss of the previously dominant *Z. muelleri* subsp. *capricorni* with replacement by *H. ovalis* (Figure 18, Appendix 2). This shift followed the meadow's 2010 disappearance and 2011 re-establishment dominated by colonising *Halophila* spp. (Figure 18; Appendix 2). Growth of colonising species in 2016 meant that meadow biomass improved from poor to good in 2016, with biomass just below the 2.06 gDW m^{-2} baseline, and meadow area remained in very good condition despite two subsequent years of declines in this highly variable meadow (Figure 18). The presence of *Z. muelleri* subsp. *capricorni* in previous years, and proximity to other *Z. muelleri* subsp. *capricorni* meadows as propagule sources, indicates this meadow should transition to a *Z. muelleri* subsp. *capricorni* dominated meadow if growing conditions remain favourable.

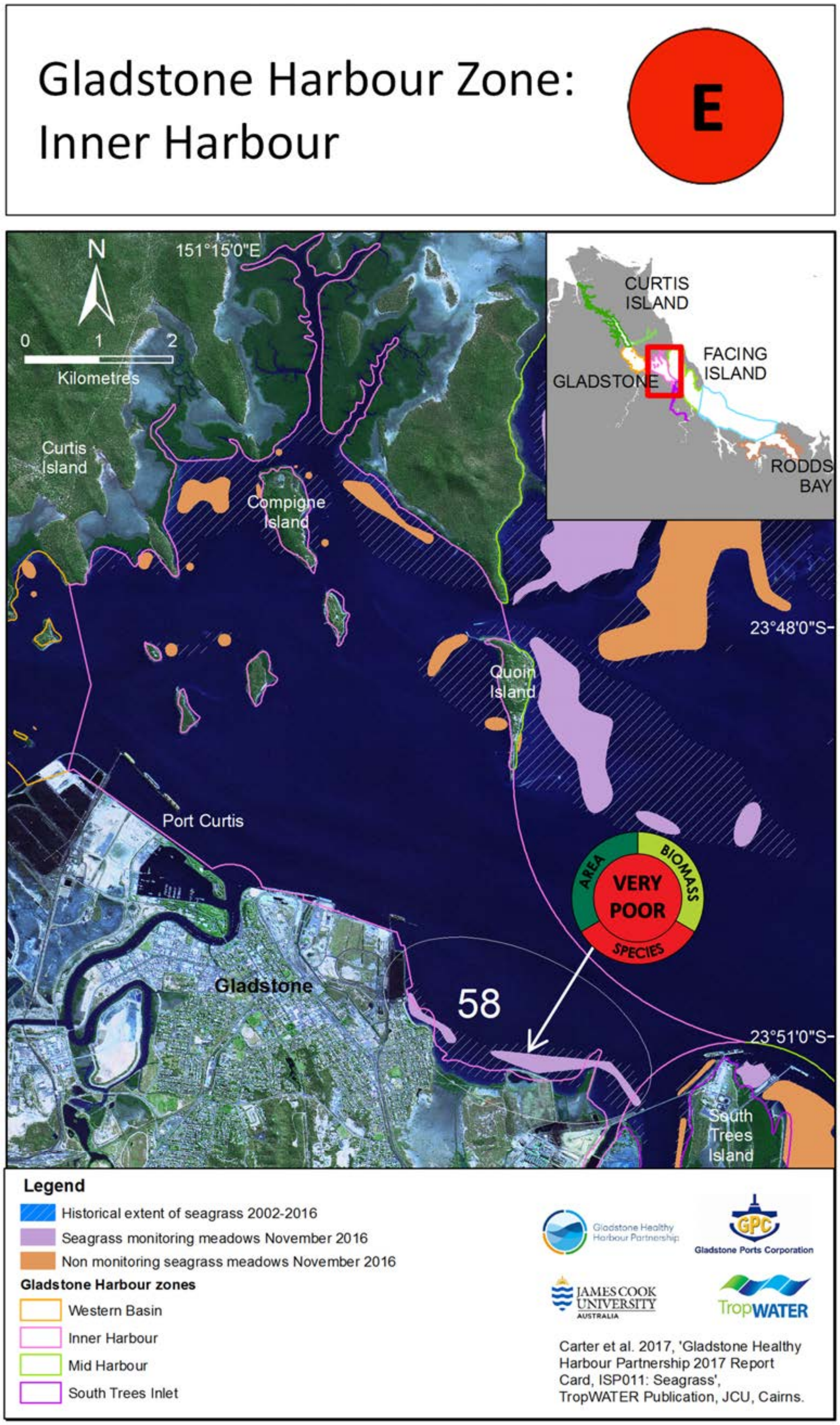


Figure 17. Seagrass condition in Zone 5: Inner Harbour.

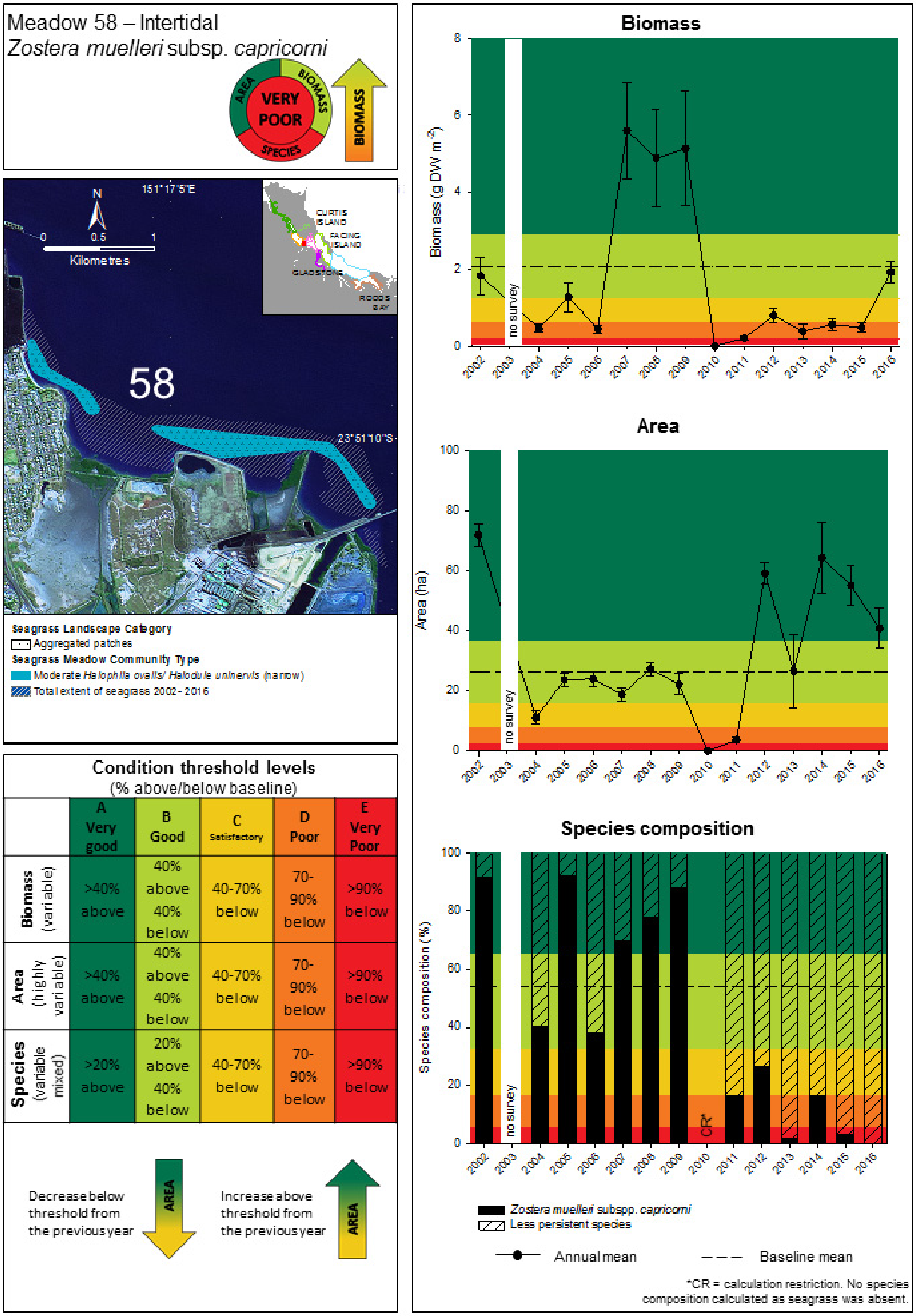


Figure 18. Meadow area, biomass and species composition for seagrass in Meadow 58, Zone 5: Inner Harbour, November 2009 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.4 Zone 8: Mid Harbour

Seagrass condition in Zone 8: Mid Harbour remained poor in 2016 (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 is the Gladstone Harbour region's largest (baseline = 632 ha), highest biomass (baseline = 19 gDW m^{-2}), and most stable seagrass meadow. For the first time since monitoring began, overall meadow condition was very poor, driven by biomass reaching an all-time low of ~2 gDW m^{-2} in 2016, or 80% below the baseline (Figure 20). Meadow area was the smallest recorded but remained (just) in good condition (Figure 20). Species composition was satisfactory but the dominance of *Z. muelleri* subsp. *capricorni*, relative to the less persistent *H. uninervis* and *H. ovalis*, was at its lowest level since monitoring began (Figure 20; Appendix 2).

Meadow 48

Meadow 48 is a subtidal meadow on the eastern side of Quoin Island. Overall meadow condition was satisfactory due to meadow area remaining ~100 ha below the 240 ha baseline (Figure 21). Biomass condition improved from poor in 2015 with <0.70 gDW m^{-2}, to good in 2016 with a return to baseline biomass of ~2.7 gDW m^{-2}. Species composition improved from poor to satisfactory condition in 2016. This is the first improvement in species composition recorded since declines in the dominant species *H. uninervis* relative to *H. ovalis* and *H. decipiens* began in 2012 (Figure 21; Appendix 2).

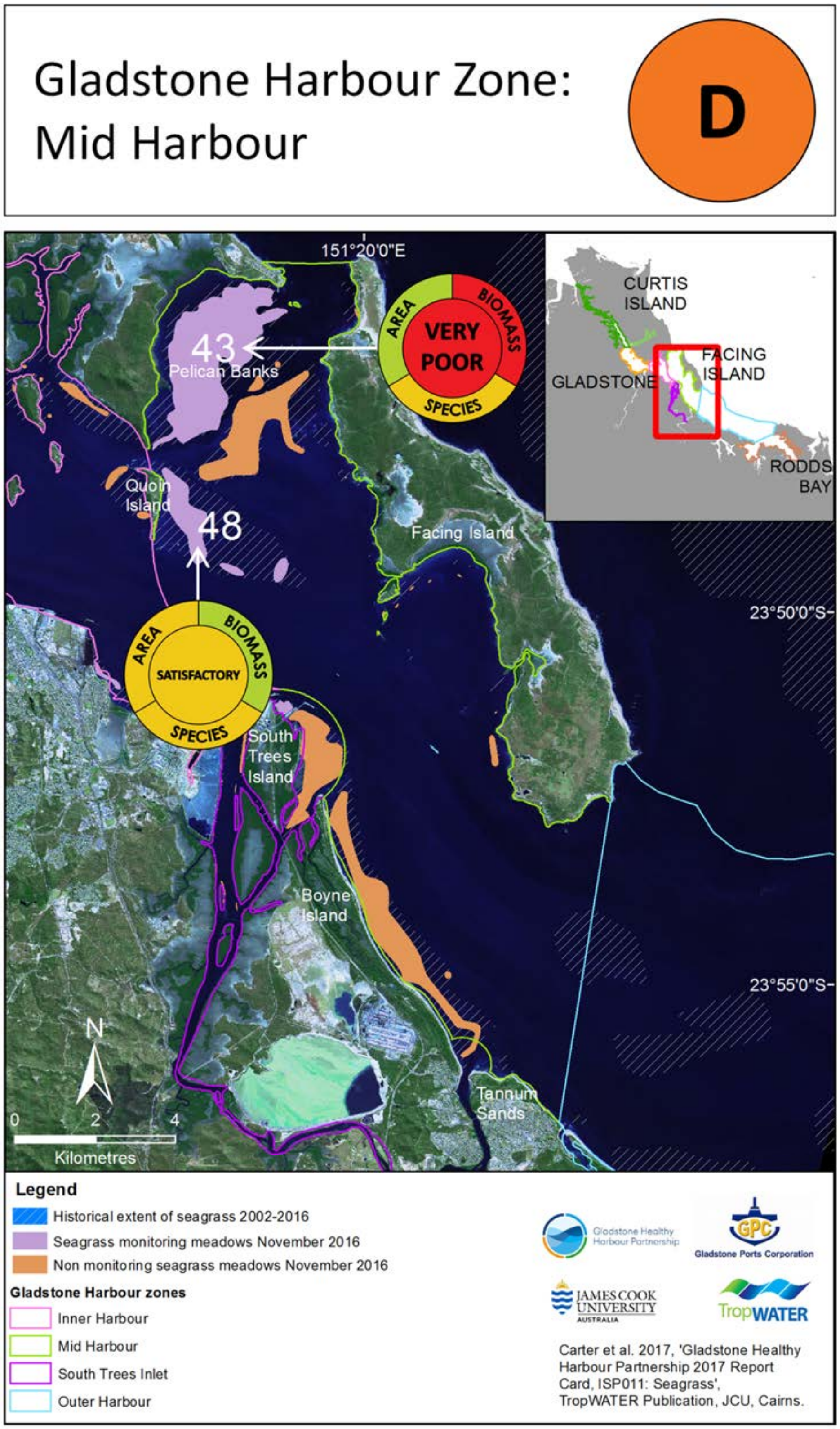
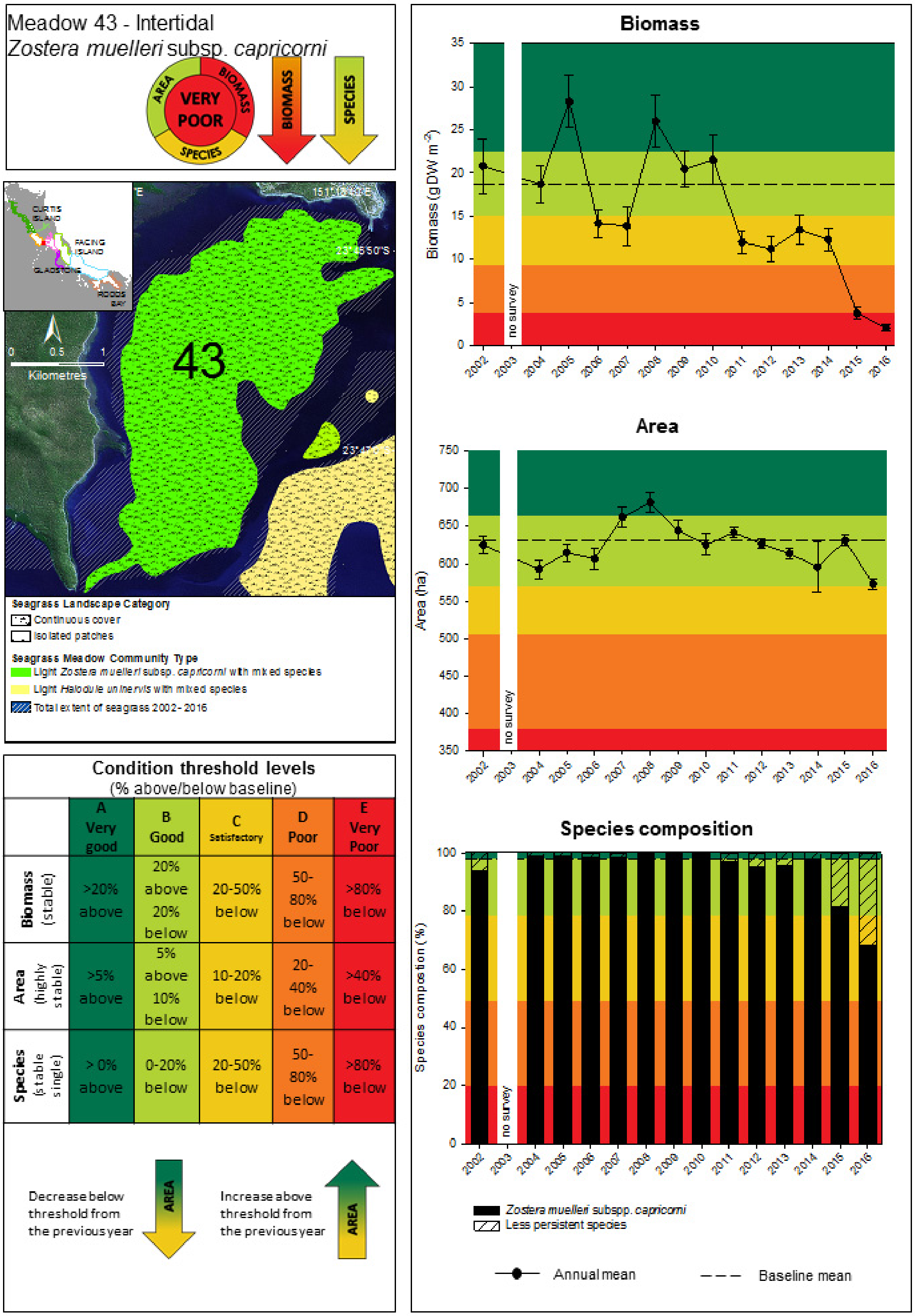


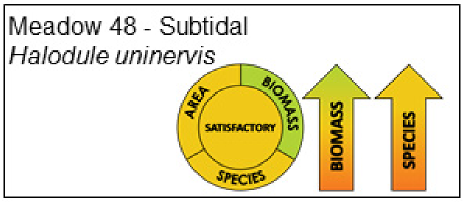
Figure 19. Seagrass condition in Zone 8: Mid Harbour.

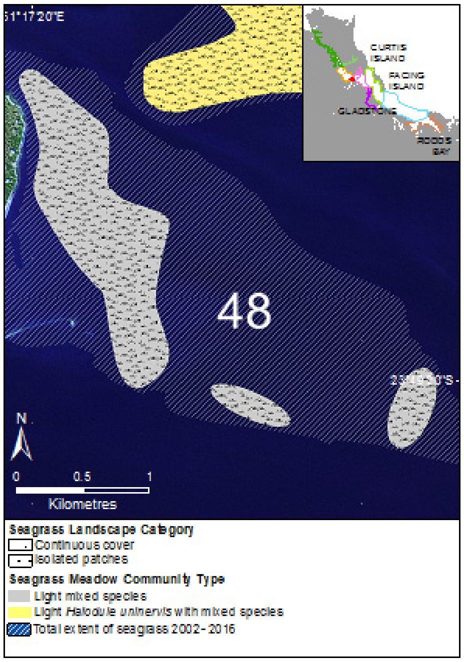


Condition threshold levels (% above/below baseline)

	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 (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below

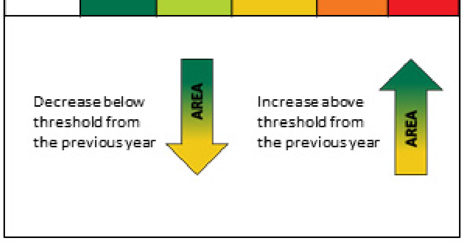
Figure 20. Meadow area, biomass and species composition for seagrass in Meadow 43, Zone 8: Mid Harbour, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).





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 (stable single)	> 0% above	0-20% below	20-50% below	50-80% below	>80% below



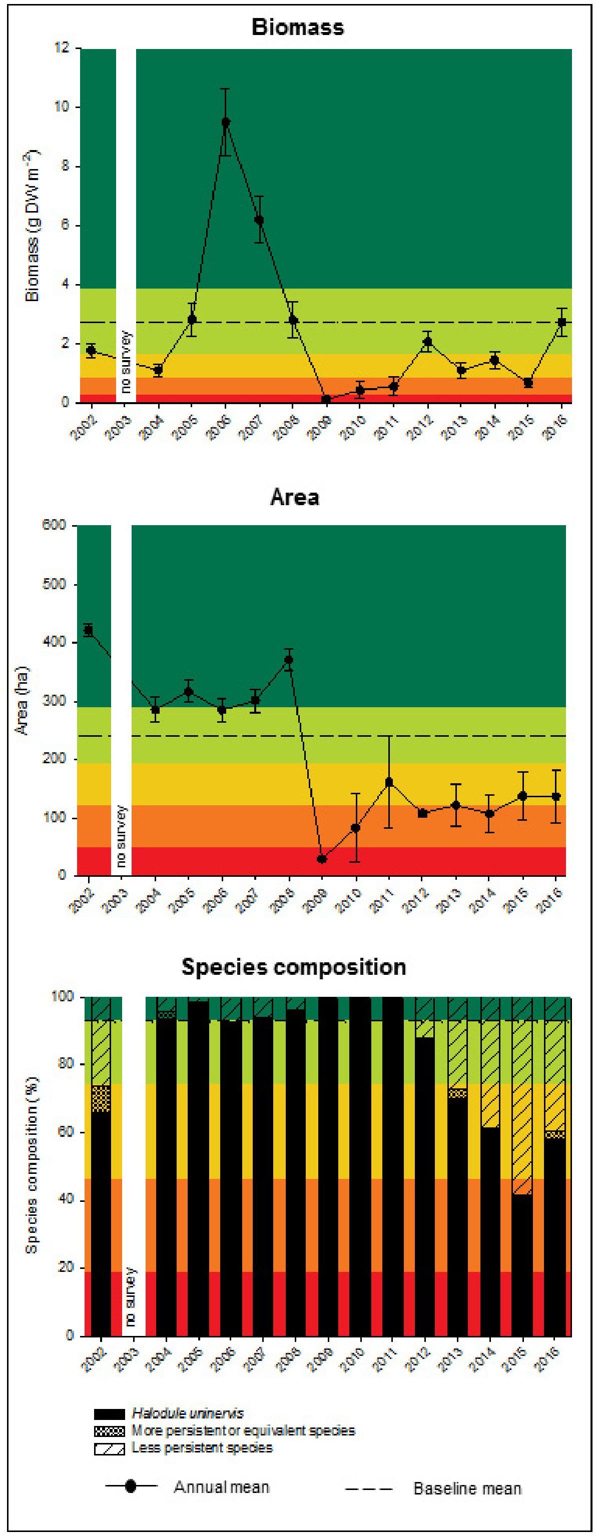


Figure 21. Meadow area, biomass and species composition for seagrass in Meadow 48, Zone 8: Mid Harbour, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.5 Zone 9: South Trees Inlet (lower)

Seagrass condition in Zone 9: South Trees Inlet improved from poor in 2015 to good in 2016 (Figure 22). Overall condition was driven by good biomass in the only monitoring meadow in this zone, an intertidal meadow between the two wharves at South Trees Inlet (Figure 23). 2016 marked the first time biomass was greater than 2.5 gDW m^{-2} and above satisfactory condition since biomass peaked above 11 gDW m^{-2} in 2008. Meadow area remained in very good condition for the third consecutive year (>20% above the baseline). Species composition improved from satisfactory to very good condition with the almost complete return of the dominant species *Z. muelleri* subsp. *capricorni* (98%) relative to *H. uninervis*, following six years of fluctuations between the two species (Figure 23; Appendix 2).

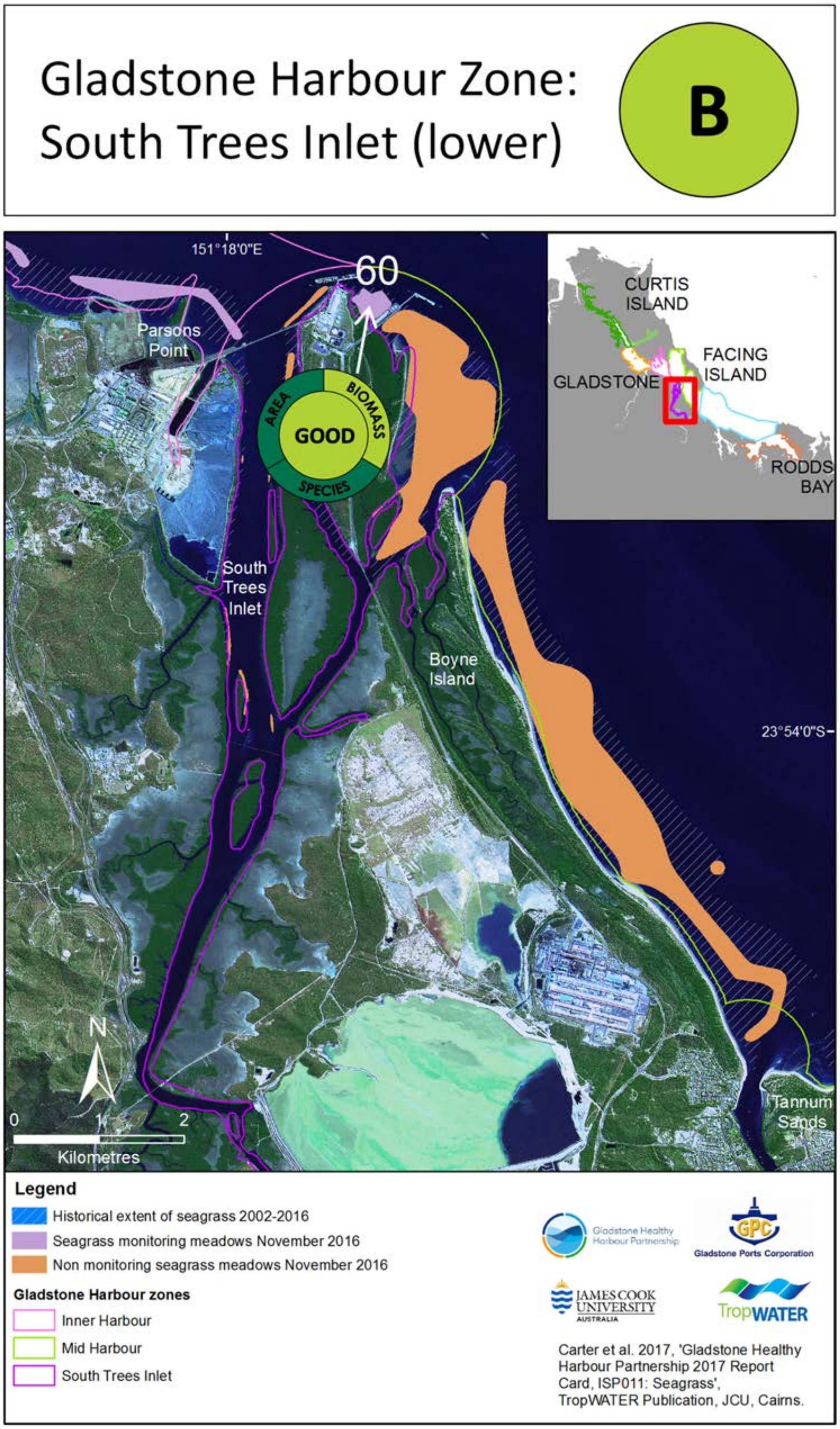


Figure 22. Seagrass condition in Zone 9: South Trees Inlet (lower).

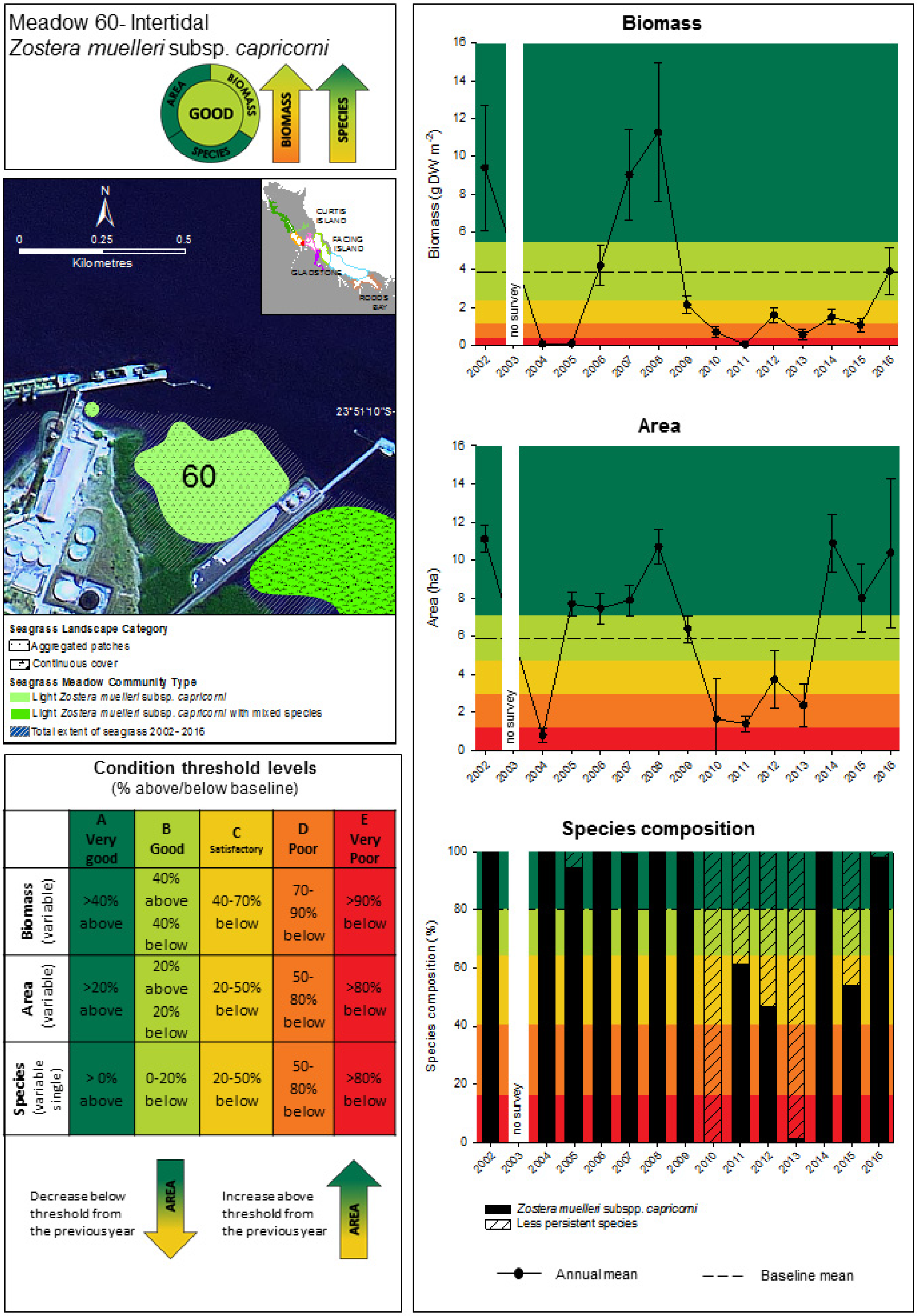


Figure 23. Meadow area, biomass and species composition for seagrass in Meadow 60, Zone 9: South Trees Inlet (lower), November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3.6 Zone 13: Rodds Bay

Seagrass condition in Zone 13: Rodds Bay declined from poor in 2015 to very poor in 2016 (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 the largest 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 remained in overall very poor condition due to extremely reduced meadow area – 0.3 ha in 2016 compared to 3.8 ha just two years earlier (Figure 25). Biomass has remained extremely low (<2 gDW m^{-2}) for the past eight years following substantial declines between 2007 and 2009, and in 2016 biomass remained in very poor condition. Species composition improved from poor condition in 2015 to very good condition in 2016, with the dominant species *Z. muelleri* subsp. *capricorni* accounting for 100% of mean meadow biomass (Figure 25; Appendix 2).

Meadow 96

Overall condition of meadow 96 was poor in 2016 due to poor biomass condition (Figure 26). Biomass has remained in poor or very poor condition and below 2 gDW m^{-2} since 2010, following dramatic biomass declines from peaks of over 20 gDW m^{-2} in 2007 and 2008. Area also declined by ~60 ha between 2015 and 2016, reducing area condition from good to satisfactory. Species composition declined from good to satisfactory condition due to historical lows in the dominant species *Z. muelleri* subsp. *capricorni,* relative to *H. ovalis* (Figure 26; Appendix 2).

Meadow 104

Overall condition of meadow 104 declined from poor to very poor from 2015 to 2016. Like meadow 94, the very poor condition was driven by extremely reduced meadow area – ~5 ha in 2016 compared to ~20 ha two years earlier (Figure 27). Biomass also was in very poor condition in 2016, less than 0.5 gDW m^{-2} compared with a baseline biomass of almost 8 gDW m^{-2}. Biomass followed similar trends to meadow 94 - a 2007 peak, two years of rapid decline, and generally poor to very poor biomass since 2009. Species composition remained in poor condition between 2015 and 2016; the dominant species *Z. muelleri* subsp. *capricorni* has reduced from 100% in 2013 to ~23% in 2016 as the proportion of *H. ovalis* has grown (Figure 27; Appendix 2).

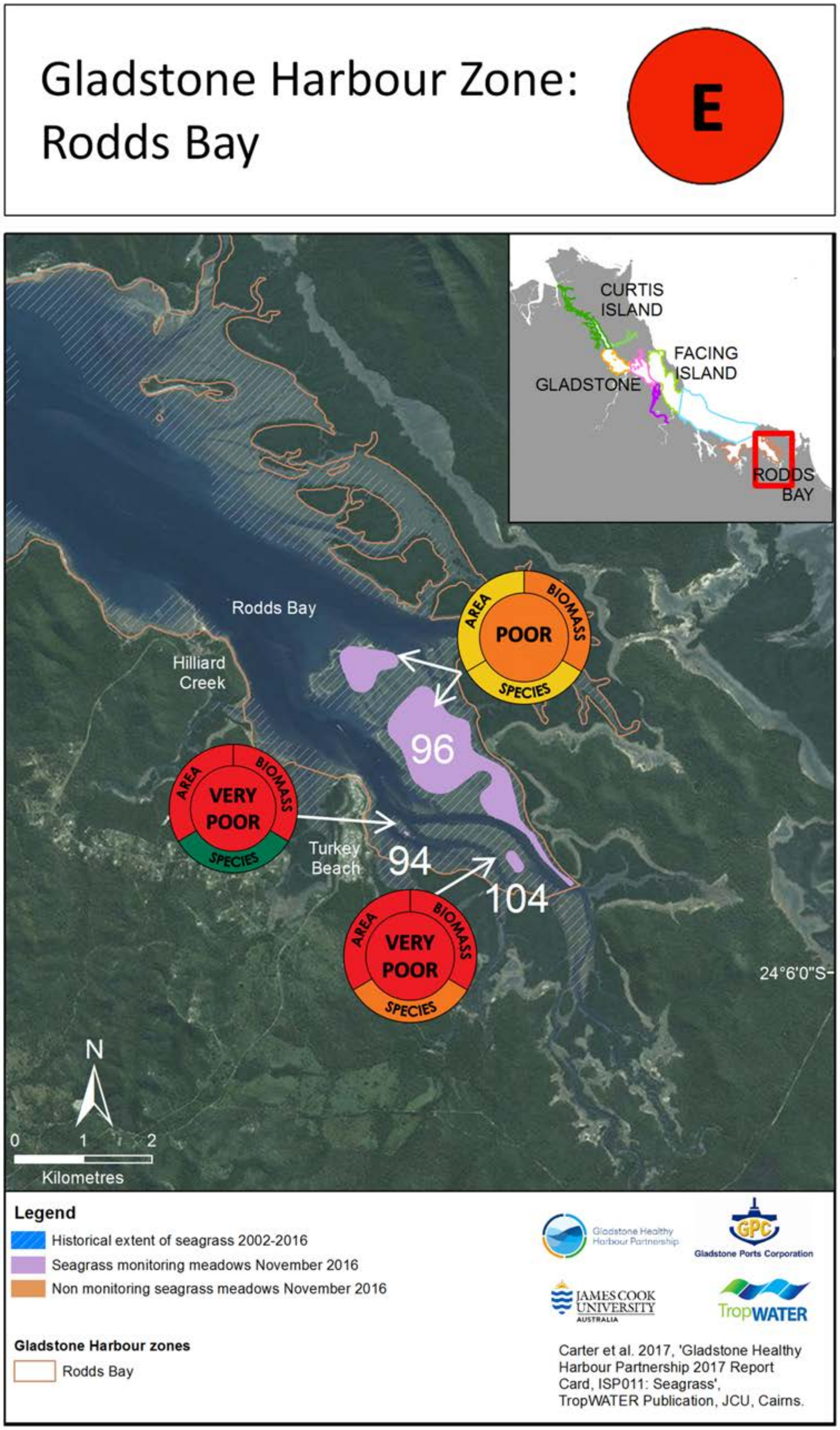


Figure 24. Seagrass condition in Zone 13: Rodds Bay. Note: only monitoring meadows were surveyed in November 2016.

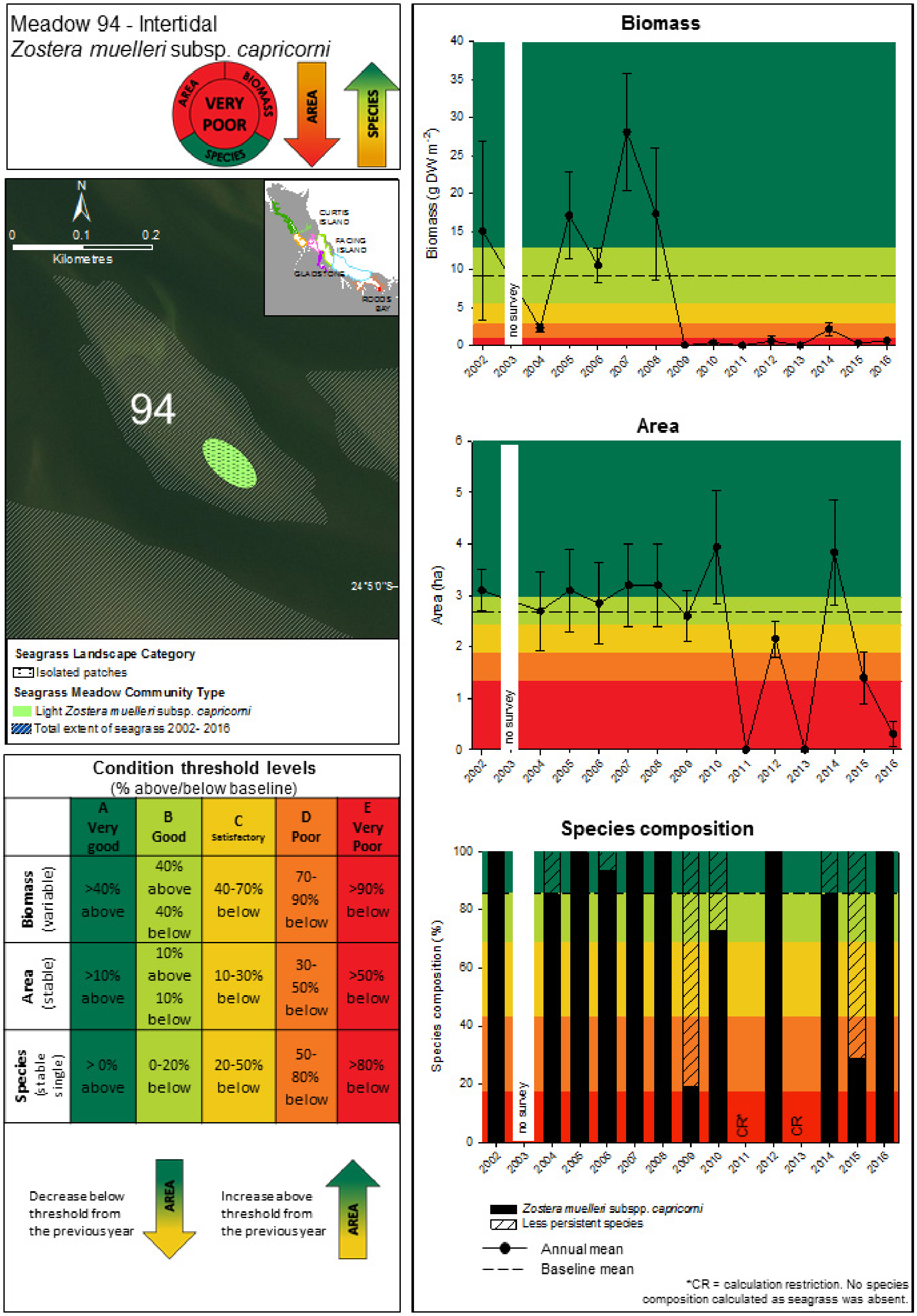


Figure 25. Meadow area, biomass and species composition for seagrass in Meadow 94, Zone 13: Rodds Bay, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

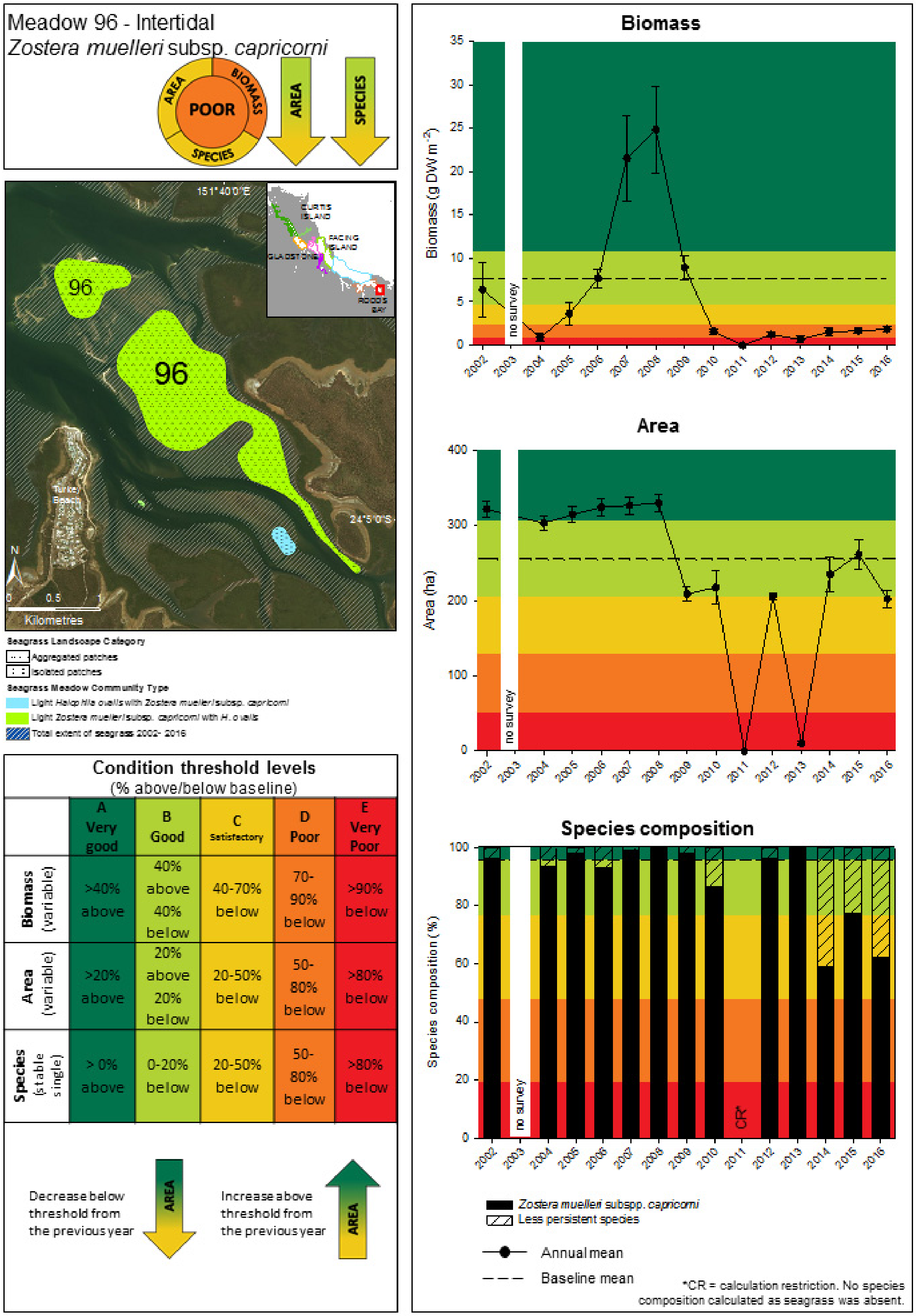


Figure 26. Meadow area, biomass and species composition for seagrass in Meadow 96, Zone 13: Rodds Bay, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

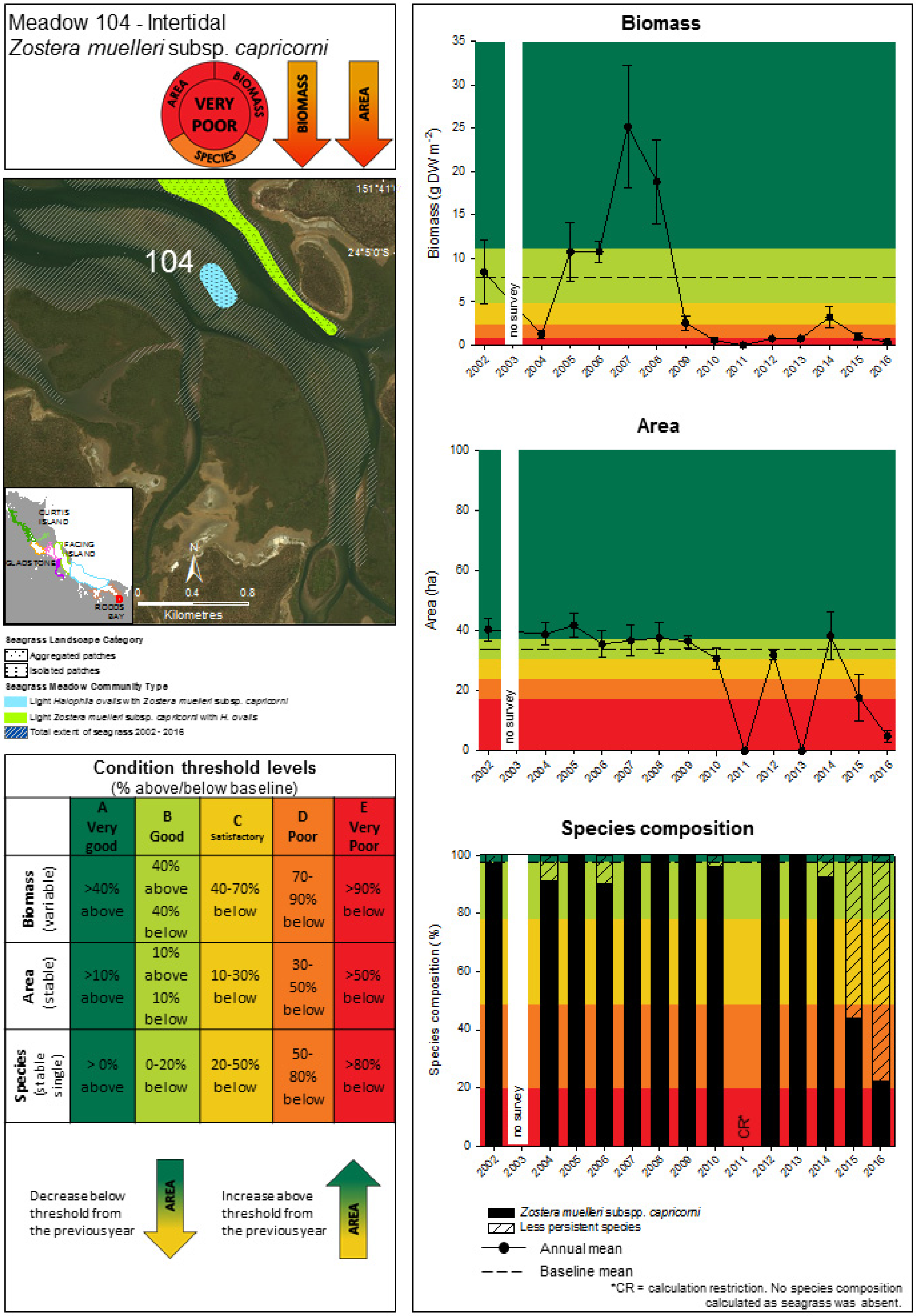


Figure 27. Meadow area, biomass and species composition for seagrass in Meadow 104, Zone 13: Rodds Bay, November 2002 - 2016 (biomass error bars = SE; area error bars = "R" reliability estimate).

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 >50% of meadows were assigned an overall meadow condition of poor or very poor either correspond with (2010-2016) or directly follow (2004) years of above average rainfall and river flow in the region (Figure 28; Table 10). Rainfall and river flow peaks often are attributed to tropical cyclones. For example, in February 2015 Tropical Cyclone Marcia crossed the coast just north of Gladstone, 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). There was no cyclone-related flooding in the 12 months preceding the November 2016 survey, however total monthly rainfall was above the long-term (1958-2016) average in March, June, July and September 2016 (Figure 28b). Calliope River flow also peaked above the long-term (1970-2016) average in February and July 2016, but otherwise was below or close to the long-term average leading up to the November 2016 survey (Figure 28a).

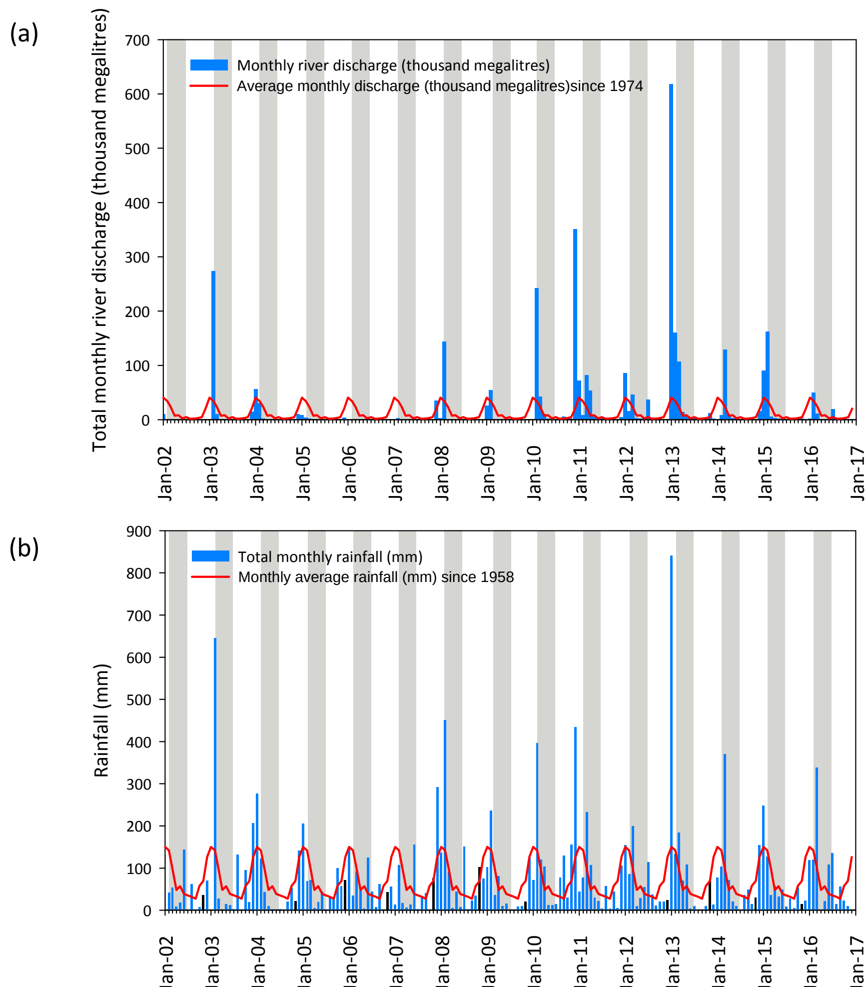


Figure 28. (a) Total monthly river discharge and average monthly discharge (thousand megalitres) for the Calliope River (Department of Natural Resources and Mines, station # 132001A; www.water-monitoring.derm.qld.gov.au); (b) Total monthly rainfall and monthly average rainfall (mm) at Gladstone (Australian Bureau of Meteorology, station # 039123; (http://www.bom.gov.au/climate/data/). Black bars in (b) indicate seagrass survey month. Data range is January 2002 – January 2017. Shaded areas represent the seagrass senescent season.

Meadow area was responsible for overall meadow condition in seven of the 14 monitoring meadows in 2016. Meadow area was in either good or very good condition for nearly all meadows between 2002 and 2009, reflecting stability in area despite fluctuations in biomass condition during this period (Tables 10 – 12). Following above average rainfall and river flow in 2010, meadow area declined to satisfactory-very poor condition 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, but was reduced again in 2013 following the largest recorded rainfall and river flow since seagrass monitoring began. During the past three years, meadow area condition grades stabilised in most meadows between 2014 and 2015, and remained stable in 2016 in the Inner Harbour, Mid Harbour, and South Trees Inlet. Exceptions include the small intertidal meadows 94 and 104 in Rodds Bay where area condition declined from very good (2014) to poor (2015) to very poor (2016), and the larger meadow 96 area declined from good (2015) to satisfactory (2016). Area condition also declined between 2015 and 2016 at The Narrows', meadows 52-57 at the Passage Islands and meadows 7 and 8 north and south of Fishermans Landing in the Western Basin (Table 12). Area improved from satisfactory to good at meadows 4 and 5 near Wiggins Island (Western Basin Zone).

Seagrass biomass is highly sensitive to environmental conditions and, more than area and species composition, undergoes cycles of deterioration and recovery in the Gladstone region. Biomass was good or 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 or very good condition by 2005, followed by meadows in the Western Basin and South Trees Inlet in 2006. Biomass condition was good or very good in the majority of meadows during 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 or very poor condition in the majority of meadows in 2010 and 2011. This coincided with the onset of two major La Niña events in 2010-2011 and 2011-2012 characterised by above average rainfall and river flow (Bureau of Meteorology 2012); above average wet season rainfall and river flow have continued through to 2016 (Figure 28).

Seagrass biomass was the main influence on overall meadow condition in The Narrows, Inner Harbour, Mid Harbour, South Trees Inlet, and Rodds Bay between 2002 and 2015 (Tables 10 and 11). In Western Basin meadows, biomass was the main driver of overall meadow condition up to 2009. 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). In 2016, biomass was responsible for overall meadow condition in only three meadows – South Trees Inlet, at the largest monitoring meadow (96) in Rodds Bay, and at Pelican Banks (meadow 43) in the Mid Harbour where biomass is now at the lowest recorded level and in very poor condition (Tables 10 and 11).

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 Harbour region since 2010, 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. Species composition remained in very good condition between 2015 and 2016 for the *H. ovalis* dominated intertidal meadow 52-57, and the subtidal *H. decipiens* meadow 7 in the Western Basin Zone (Table 13). In 2016, two additional *Z. muelleri* subsp. *capricorni* dominated meadows were in very good condition – meadow 60 in South Trees Inlet and meadow 94 in Rodds Bay (Table 13).

Table 10. Overall grades for individual monitoring meadows, 2002, 2004-2016. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A**	B	B	C	E	E	D	C
3. Western Basin	4	B	C	D	B	A	B	A	E	D	C	D	D	C	B
	5	C	D	C	B	B	A	C	D	D	C	E	D	D	C
	6	B	D	C	C	B	B	A	E	E	D	D	B	B	C
	7	B	B	E	A	D	B	D	E	E	E	D	B	B	D
	8	A	D	E	B	B	B	B	C	E	D	E	D	D	E
	52-57*	NS	NS	NS	NS	NS	NS	B	E	E	B	B	B	C	B
5. Inner Harbour	58	B	D	B	D	B	B	B	E	D	C	E	D	E	E
8. Mid Harbour	43	B	B	B	C	C	A	B	B	C	C	C	C	D	E
	48	C	C	B	B	A	B	E	D	D	D	C	C	D	C
9. South Trees Inlet	60	A	E	E	B	A	A	C	E	E	C	E	C	D	B
13. Rodds Bay	94	A	D	B	B	A	A	E	E	E	E	E	D	E	E
	96	B	D	C	B	A	A	B	D	E	D	E	D	D	D
	104	B	D	B	B	A	A	C	E	E	E	E	C	D	E

* 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, 2004-2016. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A**	B	B	C	D	E	D	C
3. Western Basin	4	B	B	C	B	A	B	A	E	C	A	A	A	B	A
	5	C	D	C	B	A	A	C	D	B	C	B	C	D	B
	6	B	D	C	A	A	B	A	D	C	B	B	B	B	B
	7	B	B	E	A	A	B	D	E	E	CR	A	A	A	B
	8	A	D	E	B	A	B	B	C	C	B	B	B	A	A
	52-57*	NS	NS	NS	NS	NS	NS	B	E	E	B	A	B	C	A
5. Inner Harbour	58	B	D	B	D	A	A	A	E	D	C	D	D	D	B
8. Mid Harbour	43	B	B	A	C	C	A	B	B	C	C	C	C	D	E
	48	B	C	B	A	A	B	E	D	D	B	C	C	D	B
9. South Trees Inlet	60	A	E	E	B	A	A	C	D	E	C	D	C	D	B
13. Rodds Bay	94	A	D	A	B	A	A	E	E	E	E	E	D	E	E
	96	B	D	C	B	A	A	B	D	E	D	E	D	D	D
	104	B	D	B	B	A	A	C	E	E	E	E	C	D	E

* 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 because seagrass was sampled by van Veen grab only (precludes biomass assessment).

Table 12. Area grades for individual monitoring meadows, 2002, 2004-2016. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A**	B	B	B	E	B	A	C
3. Western Basin	4	A	A	B	A	A	B	A	E	D	B	D	D	C	B
	5	A	B	B	B	B	A	A	C	D	B	E	D	C	B
	6	A	B	B	A	A	A	A	E	C	D	D	B	B	B
	7	B	A	A	A	D	B	B	E	E	E	D	B	B	D
	8	A	B	B	A	A	A	A	C	E	D	E	C	C	D
	52-57*	NS	NS	NS	NS	NS	NS	A	E	E	A	A	A	A	B
5. Inner Harbour	58	A	C	B	B	B	B	B	E	D	A	B	A	A	A
8. Mid Harbour	43	B	B	B	B	B	A	B	B	B	B	B	B	B	B
	48	A	A	A	A	A	A	E	D	C	D	C	C	C	C
9. South Trees Inlet	60	A	E	A	A	A	A	B	D	D	C	D	A	A	A
13. Rodds Bay	94	A	B	A	B	A	A	B	A	E	C	E	A	D	E
	96	A	B	A	A	A	A	B	B	E	B	E	B	B	C
	104	A	A	A	B	A	A	A	B	E	B	E	A	D	E

* 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, 2004-2016. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. The Narrows	21	NS	NS	NS	NS	NS	NS	A**	B	B	B	C	C	C	C
3. Western Basin	4	A	C	D	B	A	B	A	B	B	C	A	A	B	B
	5	A	C	C	B	A	A	A	B	C	B	D	B	D	C
	6	B	C	B	C	B	B	A	A	E	A	C	B	B	C
	7	A	A	A	A	A	A	A	CR	CR	A	A	A	A	A
	8	A	B	A	B	B	B	B	B	D	C	D	D	D	E
	52-57*	NS	NS	NS	NS	NS	NS	A	A	A	A	B	A	A	A
5. Inner Harbour	58	A	B	A	B	A	A	A	CR	C	C	E	B	E	E
8. Mid Harbour	43	B	A	A	A	A	A	A	A	B	B	B	B	B	C
	48	C	A	A	B	A	A	A	A	A	B	C	C	C	C
9. South Trees Inlet	60	A	A	A	A	A	A	A	E	C	C	E	A	C	A
13. Rodds Bay	94	A	B	A	A	A	A	D	B	CR	A	CR	B	D	A
	96	A	B	A	B	A	A	A	B	CR	A	A	C	B	C
	104	A	B	A	B	A	A	B	B	CR	A	A	B	D	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

The GHHP seagrass 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. In 2016, Gladstone Harbour seagrasses remained in an overall poor condition. For individual meadows and regions within the survey area the results were mixed. Overall condition of seagrasses by zone was very poor in the Inner Harbour and Rodds Bay, poor in the Mid Harbour, satisfactory in The Narrows and Western Basin, and good in South Trees Inlet. Seagrasses in the Gladstone Harbour region generally were in good to very good condition prior to 2010 when rainfall and river flow was below average (Figure 28). However, seagrasses have failed to recover following the major declines in biomass, area and species composition that occurred from 2009/2010. This is likely due to a range of repeated disturbances from climate, floods and cyclones that have included two major La Niña events in 2010-2011 and 2011-2012 (Bureau of Meteorology 2012) and, potentially, anthropogenic activities. These results indicate seagrasses are likely to be vulnerable to future pressures or impacts.

Flood plumes and dredging have been linked to seagrass declines due to a reduction in available light (Erftemeijer and Lewis III 2006; Campbell and McKenzie 2004). 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). 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 (McCormack et al. 2013). Declines in monitoring meadow condition from 2009/2010 were indicative of wider declines in seagrasses across the Gladstone region. Between November 2009 and 2013 reductions in meadow area of ~75% and ~50% occurred for deep-water and coastal seagrasses, respectively (Carter et al. 2015a). Area 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. High rainfall and flooding of the Fitzroy and Calliope Rivers associated with Tropical Cyclone Debbie in March 2017 may further reduce seagrass condition following the November 2016 survey.

Dredging is unlikely to have been a major contributor to the period of significant decline in Gladstone Harbour seagrasses. Condition declines from 2009/2010 commenced before the onset of the Western Basin capital dredging activities (May 2011 to September 2013), and declines also occurring at the out of port reference meadows in Rodds Bay, and more broadly along Queensland's east coast during the same period (see Section 4.1). The timing of flood-related declines in seagrass during 2010 and 2011 immediately prior to the onset of capital dredging 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 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 (Bryant et al. 2014a; Chartrand et al. 2012).

The very poor condition of the Pelican Banks meadow in 2016 was concerning. This is the largest and most stable seagrass meadow monitored in Gladstone Harbour. In 2016 the meadow had the lowest recorded biomass, smallest area, and smallest composition of the "stable state" species. Reproductive capacity of the meadow also has been greatly reduced over recent years with a reduction in the density of reproductive shoots containing seeds (spathes) on Pelican Banks and signs of a decreased seed bank density (Bryant et al. 2016b). The reasons for the decline in Pelican Banks seagrass, particularly of biomass, is unclear. Potential contributors include high levels of herbivory and a change in sediment composition. The Pelican Banks meadow is frequently grazed by dugong and turtle. Dugong feeding trails were observed within the meadow during every seagrass monitoring survey and also as part of a detailed study of dugong feeding over the past two years (Rasheed et al. 2017b). Green turtles also regularly feed on the meadow (Hamann et al. 2016;

TropWATER field staff, pers. comm.). Both of these large herbivores have the potential to significantly impact seagrass condition, with major meadow loss recorded in other locations from herbivory (Christianen et al. 2014). Anecdotal observations from field surveys in November 2016 indicated a large number of green turtles (TropWATER field staff, pers. comm.), but it is unclear if numbers had substantially increased from previous years.

Sediment dynamics on Pelican Banks have not been measured directly as part of this project, but field staff examining permanent transect sites reported seagrasses appeared to be buried deeper in the sediments in 2016 than in previous years (TropWATER field staff, pers. comm.). Also, seagrass seed bank assessments at Pelican Banks found the proportion of seeds at greater depths (>50 mm) has gradually increased since November 2013 (Bryant et al. 2016a), potentially indicating some burial had occurred. Sediment dynamics at Pelican Banks should be investigated further if seagrass condition declines continue.

Environmental conditions in 2016 are unlikely candidates for the decline at Pelican Banks. Daytime tidal exposure had reduced from 2015, and there were far fewer instances of water temperatures occurring above 33^{o}C for extended periods of time than in 2015 (Rasheed et al. 2017a). Regardless, local species are able to cope with temperatures well in excess of this (Collier and Waycott 2014; Massa et al. 2009; Campbell et al. 2006). A lack of available light for seagrass growth also is an unlikely contributor. Rainfall and river flow were relatively low compared with recent years (Figure 28), and light monitoring at Pelican Banks and elsewhere in Gladstone demonstrated light was above the requirements for local seagrasses (Rasheed et al. 2017a; Chartrand et al. 2016). At no time during the seagrass growing season did light fall below the locally derived threshold of 6 mol m^{-2} day^{-1} (Rasheed et al. 2017a) and even if the more conservative threshold for longer term survival of 10 mol m^{-2} day^{-1} suggested by Collier et al. (2016a) were applied, light was ample to support seagrass growth (Rasheed et al. 2017a).

4.1 Comparisons with 2016 Report Card

There were limited signs of seagrass recovery at the Gladstone Harbour scale between 2015 (2016 report card) and 2016 (2017 report card). The overall poor condition of Gladstone Harbour seagrass for four consecutive years indicates meadows in the region remain in a stable but vulnerable state. Seagrass condition improved between 2015 and 2016 in The Narrows, South Trees Inlet, in three of the six Western Basin Zone meadows, and at Quoin Island (Mid Harbour). In contrast, seagrass condition declined in Rodds Bay, in the three meadows immediately north and south of Fishermans Landing in the Western Basin Zone, and at Pelican Banks in the Mid Harbour. Seagrass condition did not change between 2015 and 2016 in the Inner Harbour. Overall meadow scores primarily were determined by biomass condition in 2015. In 2016, area determined overall meadow scores in seven of the monitoring meadows, species composition in four meadows, and biomass in three meadows.

4.2 Comparisons with State-wide Monitoring Program

Reduced seagrass meadow condition in 2010-2015 observed in Gladstone was 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 and 2010 at Cairns (York et al. 2016), Mourilyan (Reason et al. 2016), Townsville (Davies and Rasheed 2016), and Abbot Point (McKenna et al. 2016). 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. These include 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). A reprieve from cyclones in the region in 2012 was reflected by lower rainfall and river flow relative to 2010 and 2011 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). High rainfall and flooding associated with TC Debbie (March 2017) may further reduce seagrass condition at Hay Point, Abbot Point, and Gladstone in 2017.

Tropical seagrasses in Queensland have demonstrated an ability to recover from previous impacts (York et al. 2015; Rasheed et al. 2014; Rasheed 2004; Birch and Birch 1984). In Queensland, recovery has differed by location and is likely influenced by local climate as well as the severity of the initial decline. In 2016, Townsville's seagrass meadows had largely recovered and were in good condition, with biomass, area and species composition similar to peaks recorded in 2007 - 2009 (Wells and Rasheed 2017). Abbot Point's inshore seagrass also returned to good condition, but offshore meadow condition remained poor (McKenna et al. 2017b). Hay Point offshore seagrass condition declined from satisfactory in 2015 to very poor in 2016, driven by biomass declines (McKenna and Rasheed 2017). Cairns seagrass condition improved from very poor in 2015 to poor in 2016 but, like Gladstone, recovery was variable among meadows (York and Rasheed 2017).

Reductions in meadow area, biomass, and stable/persistent species during years of extreme weather events reduce both the adult plant population and limit the resources available for that meadow to initiate recovery. When limited or no adult plants remain, recovery will depend upon seed banks in the sediment or sexual propagules sourced from nearby locations (Jarvis and Moore 2010; Duarte and Sand-Jensen 1990; Phillips and Lewis 1983). Under these circumstances the rate of recovery is likely to be much slower, particularly where no local or nearby sources of propagules exist. In 2016, Mourilyan Harbour seagrass remains in very poor condition and there seems little prospect of seagrass recovery without some form of restoration (Reason et al. 2017). In this context, meadows in Gladstone have shown reasonable resilience and ability to recover. Seagrass growth during 2017 is critical to ensure replenishment of seed reserves and an opportunity for the adult populations to increase in biomass to re-establish resilience buffers. Regional variation in mega herbivore grazing pressure on meadows, such as by green turtles and dugong, across the State-wide monitoring program currently is unknown. The impact of grazing on meadow condition, particularly at a regional scale, warrants further study.

Seagrass meadows away from Queensland's east coast have fared much better over recent times. These regions generally experienced a lower frequency or severity of extreme weather events, rainfall and flooding, than along Queensland's east coast south of Cooktown. Seagrass condition at monitoring locations in Thursday Island (Torres Strait) (Sozou et al. 2016), Weipa (McKenna et al. 2017a) and Karumba (Sozou and Rasheed 2017) did not experience the same declines in 2010 - 2015. Seagrass condition at Thursday Island and Karumba was good in 2016 (Sozou and Rasheed 2017; Sozou et al. 2016). Weipa seagrass condition declined from good in 2015 to satisfactory in 2016, largely due to area declines in two meadows closest to recent port and coastal infrastructure development (McKenna et al. 2017a).

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 seagrass resilience and recovery capacity, as in other Queensland locations (McKenna et al. 2015; Rasheed et al. 2014; Pollard and Greenway 2013). In 2016, seed banks remained in key meadows and some seagrass was maintained across most of the historical extent of seagrass distribution. However, both were at substantially reduced levels and flooding and rainfall events in March 2017 were likely to have further reduced these. Natural recovery from large declines can take up to five years (Preen et al. 1995) or potentially longer (Birch and Birch 1984). 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 role of mega herbivore grazing on seagrass meadow condition along Queensland's east coast also requires a better understanding.

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

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 deep-water offshore seagrass monitoring sites should be added to the monitoring program to fill this gap.

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APPENDICES

Appendix 1. An example of calculating a meadow score for area in satisfactory condition in 2016.

1. Determine the grade for the 2016 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2016 area value (A_{2015}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{2016} - A_{satisfactory}$$

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:

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

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_{2016} takes up:

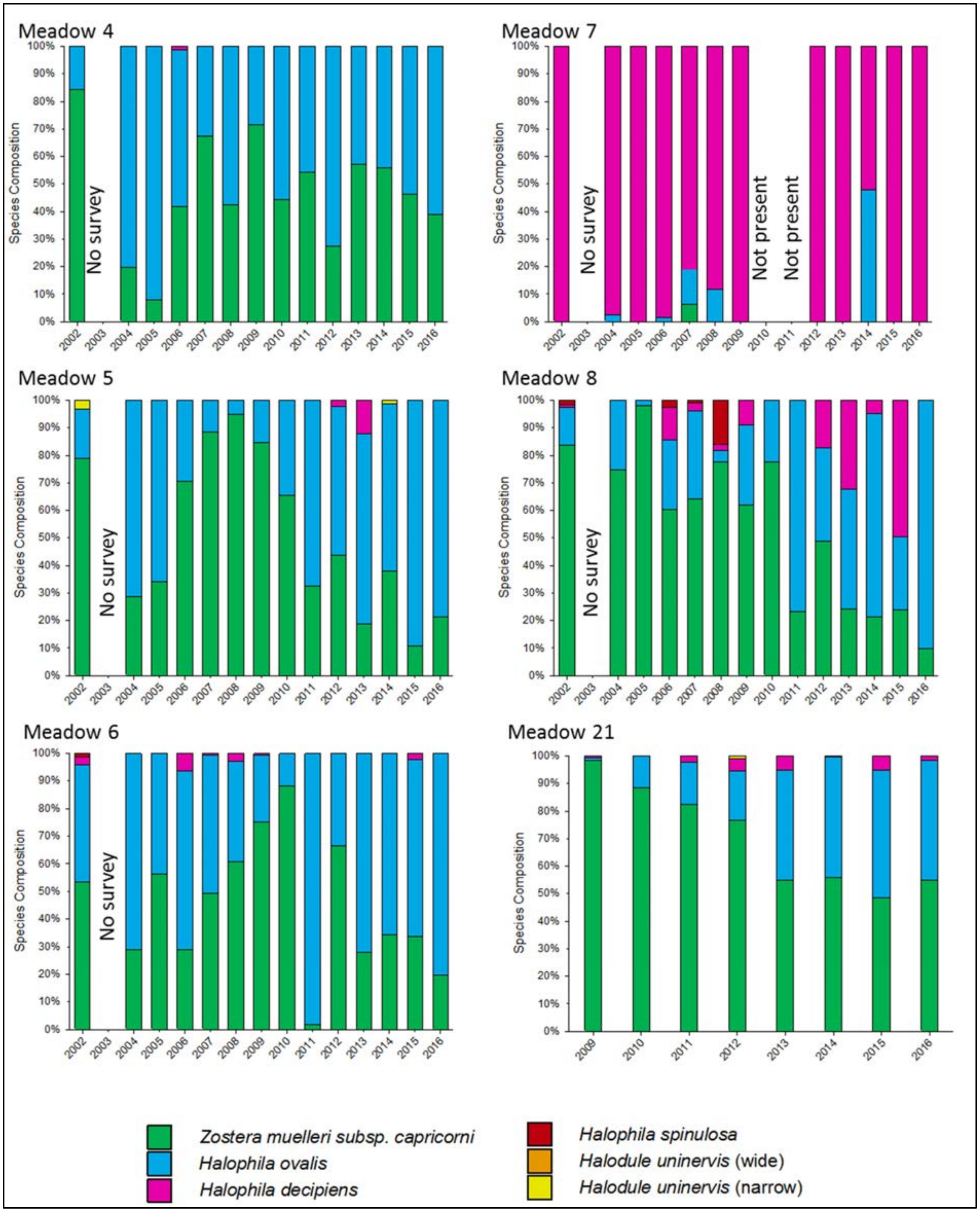
$$A_{prop} = \frac{A_{diff}}{A_{range}}$$

5. Determine the area score for 2016 ($Score_{2016}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

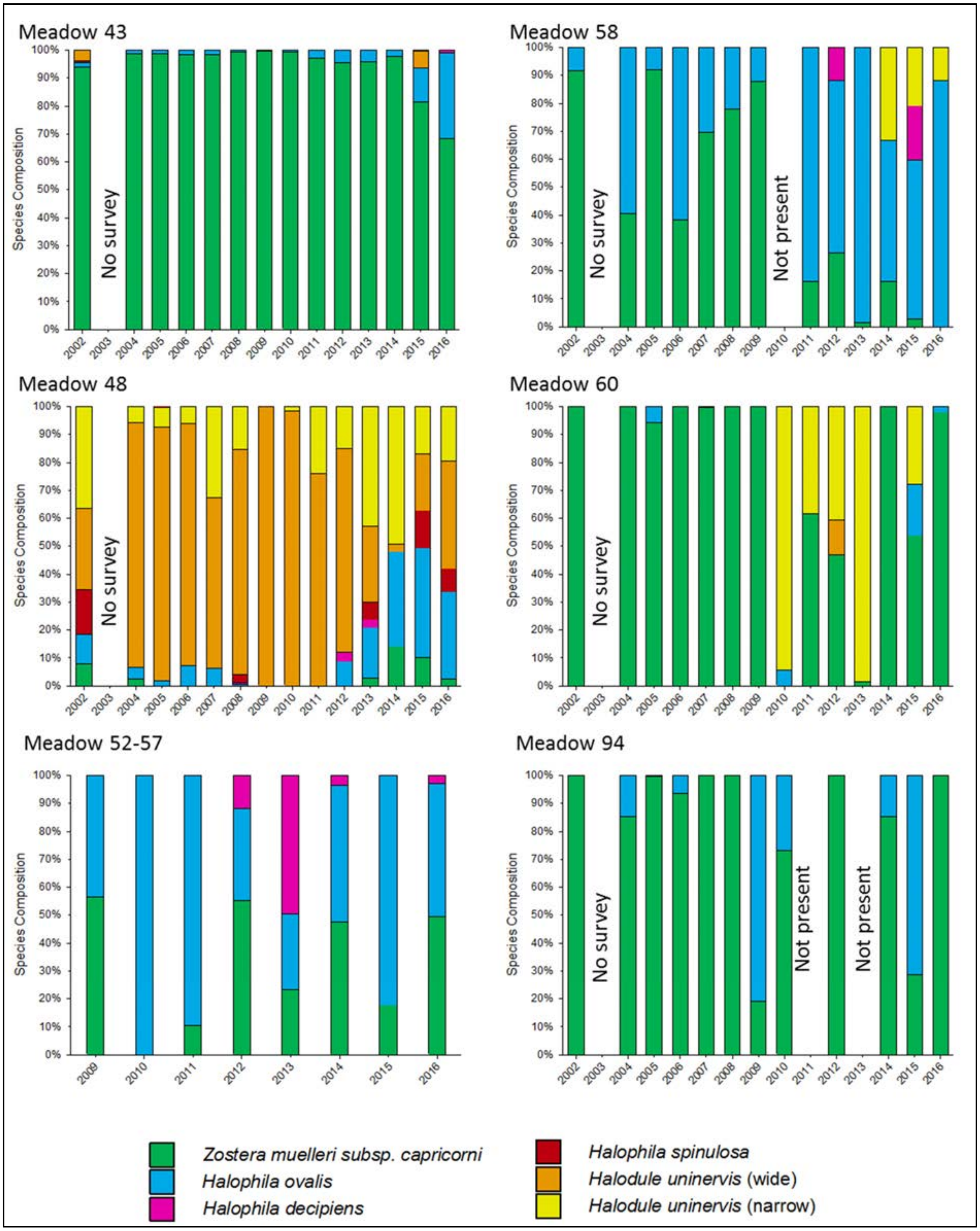
$$Score_{2016} = LB_{satisfactory} + (A_{prop} \times SR_{satisfactory})$$

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 (2002-2016) and Meadow 21 (2009- 2016).



Appendix 2. (continued) Species composition for Meadows 43, 48, 58, 60 and 94 (2002-2016) and Meadow 52-57 (2009-2016).



Appendix 2. (continued) Species composition for Meadows 96 and 104 (2002-2016).