Centre for Tropical Water and Aquatic Ecosystem Research

GLADSTONE HEALTHY HARBOUR PARTNERSHIP 2019 REPORT CARD

ISP011: SEAGRASS

Carter AB, Chartrand KM, Wells JN and Rasheed MA

Report No. 19/15

June 2019

GLADSTONE HEALTHY HARBOUR PARTNERSHIP 2019 REPORT CARD

ISP011: SEAGRASS

Report No. 19/15

June 2019

Alex Carter, Katie Chartrand, Jaclyn Wells
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, Chartrand KM, Wells JN & Rasheed MA (2019). 'Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass'. Centre for Tropical Water & Aquatic Ecosystem Research Publication 19/15, James Cook University, Cairns, 63 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:
The Gladstone Healthy Harbour Partnership fund this report. Gladstone Ports Corporation Ltd. fund seagrass data collection and the larger seagrass monitoring program from which this report is generated. We wish to thank the many TropWATER staff for their valuable work in the field and with data processing.

EXECUTIVE SUMMARY

- Seagrass condition was assessed for 14 monitoring meadows across six Gladstone Healthy Harbour Partnership (GHHP) reporting zones in November 2018 (GHHP 2019 reporting year).

- Gladstone Harbour's satisfactory seagrass condition this year is a noteworthy improvement. This is the first time since reporting began for GHHP (2014 reporting year) that the harbour's overall seagrass condition has improved beyond poor.

- Overall condition scores increased in every monitoring zone from the previous year. In particular, condition scores in The Narrows and Western Basin zones increased from the poor range in the 2018 reporting year to the good range this year.

- Substantial seagrass recovery occurred in the Rodds Bay zone for the first time since major loss a decade ago.

- Subtidal Meadow 7 returned, and in very good condition, following the meadow's disappearance just 12 months prior.

- The continued dominance of less persistent and colonising *Halophila* species relative to the more stable *Z. muelleri* subsp. *capricorni* is an indication that many meadows are yet to fully recover to their baseline conditions. Species composition was the lowest of the three indicator scores in 50% of the meadows, meaning that overall meadow scores were often in the poor to satisfactory range despite good to very good biomass and area condition.

- This is the first GHHP report card where a 10-year baseline is available for all indicators in all meadows.

- Improved seagrass condition in the Gladstone Harbour region is likely due to the relatively dry and benign environmental conditions optimal for seagrass growth throughout 2018. Seagrass condition should continue to improve if conditions remain favourable during 2019.

- This report is presented in 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 2019

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 in partnership with Gladstone Ports Corporation (GPC). This includes an annual long-term monitoring program conducted each October/November (not surveyed in 2003). The program monitors seagrass condition in 14 representative intertidal and shallow subtidal seagrass meadows. 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 (Table 1). The lowest of the three indicator scores dictates the overall meadow score and grade (Figure 2; Table 1). Where species composition is the lowest of the three indicator scores, it contributes 50% of the overall meadow score, with the remaining 50% coming from the lowest of either biomass or area scores.

Gladstone Harbour is divided into 13 reporting zones as part of the Gladstone Healthy Harbour Partnership (GHHP) reporting process, six of which contain seagrass monitoring meadows (Figures 1, 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 2018 (GHHP 2019 reporting year). Overall zone scores increased in every zone from 2017. The South Trees Zone was in very good condition; The Narrows and Western Basin zones were in good condition; Mid Harbour and Rodds Bay zones were in satisfactory condition; and the Inner Harbour zone was in very poor condition (Table 1). Seagrass in the Gladstone Harbour region was satisfactory in 2019 (Table 1). This is the first time in since 2009 that the region's seagrass has moved beyond poor – very poor condition.

Table 1. Grades and scores for seagrass indicators (biomass, area and species composition), overall meadow, zone, and Gladstone Harbour scores for the GHHP 2019 reporting year. See Table 7 for grading 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**	0.75	0.91	0.67	0.71†	0.71
3. Western Basin	**4**	1.00	0.82	0.43	0.62†	0.69
	5	0.91	0.74	0.54	0.64†	
	6	0.95	0.76	0.43	0.59†	
	7	0.94	0.91	1.00	0.91	
	8	1.00	0.55	0.22	0.38†	
	52-57	0.97	0.98	1.00	0.97	
5. Inner Harbour	**58**	0.21	0.57	0.56	0.21	0.21
8. Mid Harbour	**43**	0.45	0.75	0.62	0.45	0.52
	48	0.91	0.76	0.44	0.60†	
9. South Trees Inlet	**60**	0.89	0.93	0.95	0.89	0.89
13. Rodds Bay	**94**	0.53	0.56	0.65	0.53	0.49
	96	0.72	1.00	0.65	0.69†	
	104	0.44	0.27	0.64	0.27	
Gladstone Harbour						**0.59**

† Where species composition is the lowest of the three indicator scores, it contributes 50% of the overall meadow score with the remaining 50% coming from the lowest of the biomass or area scores (see Section 2.2.5).

This is the sixth 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. 2014). 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). In 2018, minor changes were made to how the overall meadow score is calculated where species composition is the lowest of the three indicator scores (Bryant et al. 2018).

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 environmental 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.

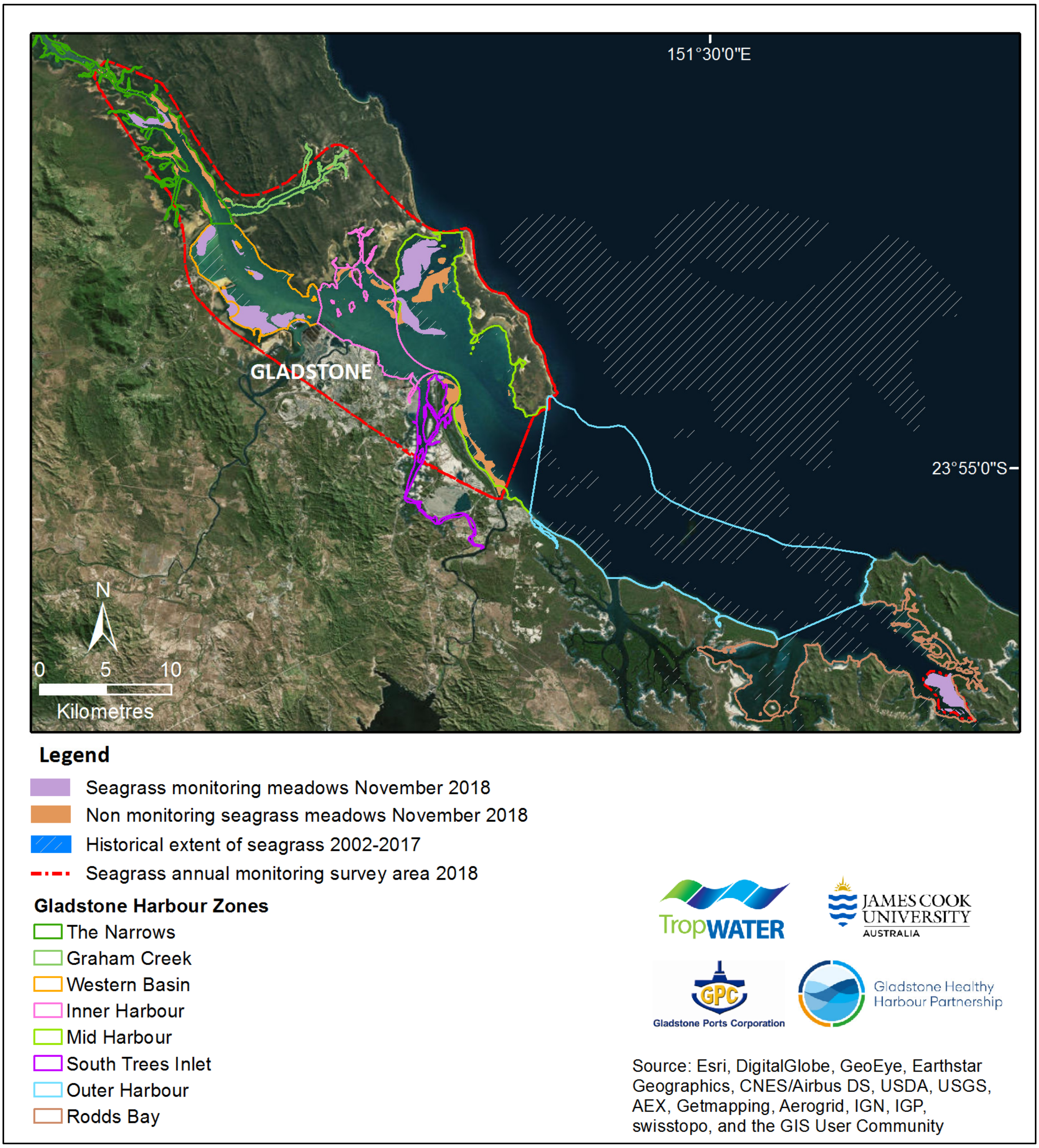


Figure 1. Seagrass extent in the Gladstone region and GHHP Gladstone Harbour zones, 2019 reporting year.

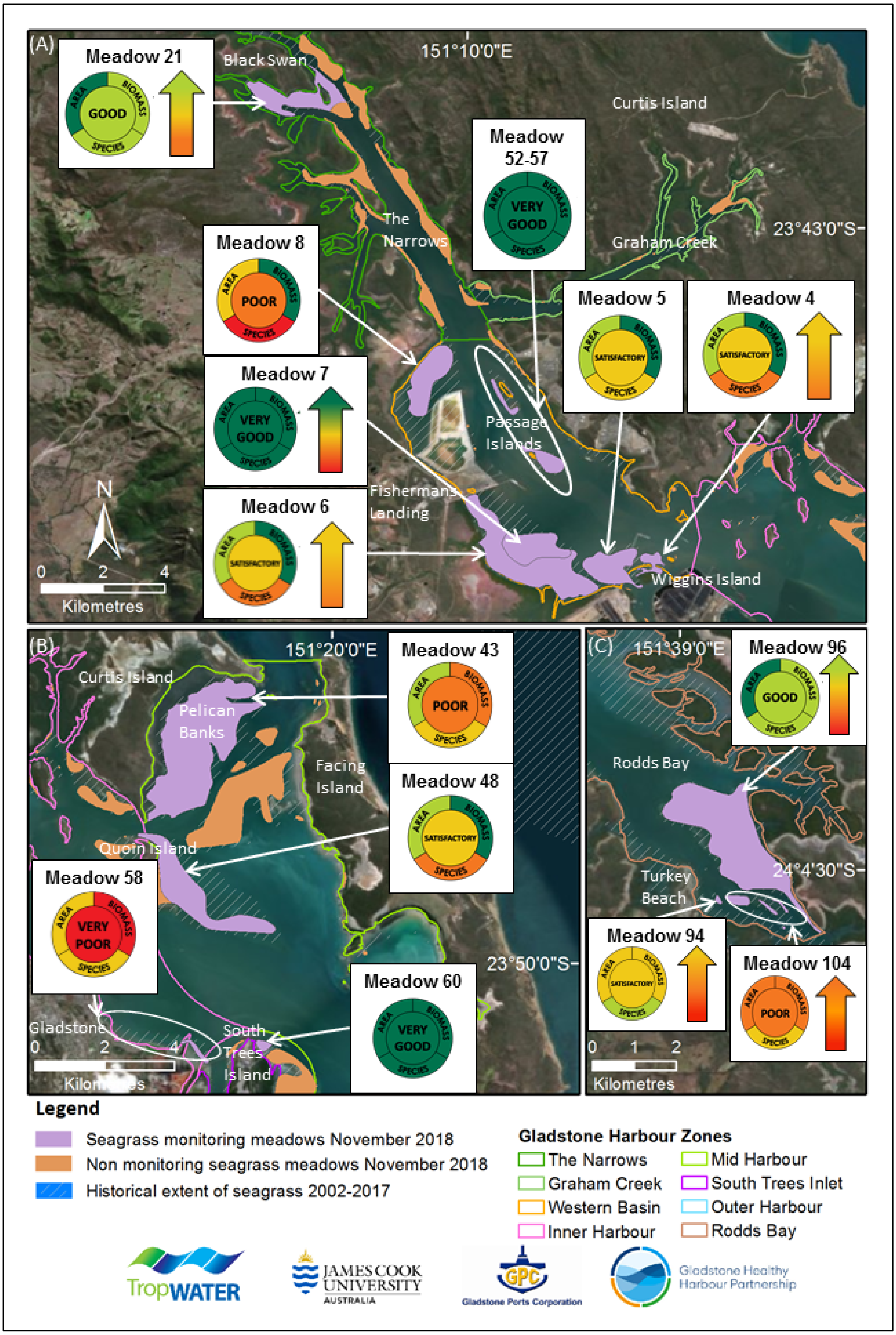


Figure 2. Seagrass condition for each indicator, and overall meadow condition, for 14 monitoring meadows within six Gladstone Harbour zones, November 2018 survey (2019 reporting year). Up/down arrows are included where the overall condition grade has improved/declined from the previous year.

PART 2 - TECHNICAL REPORT

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services; these include 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 and program 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 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, see https://www.tropwater.com/project/management-of-ports-and-coastal-facilities.

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 baseline survey of seagrass resources within the port limits and nearby Rodds Bay. The survey identified large areas of seagrass within the port limits, including 7,246 ± 421 ha of coastal seagrass habitat (Rasheed et al. 2003).

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). Ten seagrass meadows were initially selected for monitoring that were representative of the range of seagrass communities within the port. This 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 (Meadow 21 and 52-57) were added to the long-term monitoring program to reflect a shift in new port activity to the Curtis Island area as part of the Western Basin developments. Due to the expansion of the reclamation area at Fisherman's Landing, Meadow 9 was discontinued 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 largely 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 occur in Gladstone. During the growing season (July – January) seagrasses typically increase in biomass and area in response to favourable conditions for growth. The peak of the growing season occurs between October and November. In the senescent season (February – June) 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).

1.2.1 **The Gladstone Harbour 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 Gladstone Harbour report card tracks ecosystem health in the harbour, including important ecological assets such as 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 each asset's condition, 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 1) (Davies et al. 2016). In 2014, 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 (Bryant et al. 2014), and full implementation of the program including annual reporting commenced the following year (Carter et al. 2015b). The objectives of the 2019 Gladstone Harbour report card for seagrass is to provide:

1. Seagrass grades and scores for the 2019 reporting year using GHHP approved grades and scores.
2. A report describing data collection, statistical methods used to determine report card grades and scores, and an assessment of Gladstone Harbour seagrass condition in 2019 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*

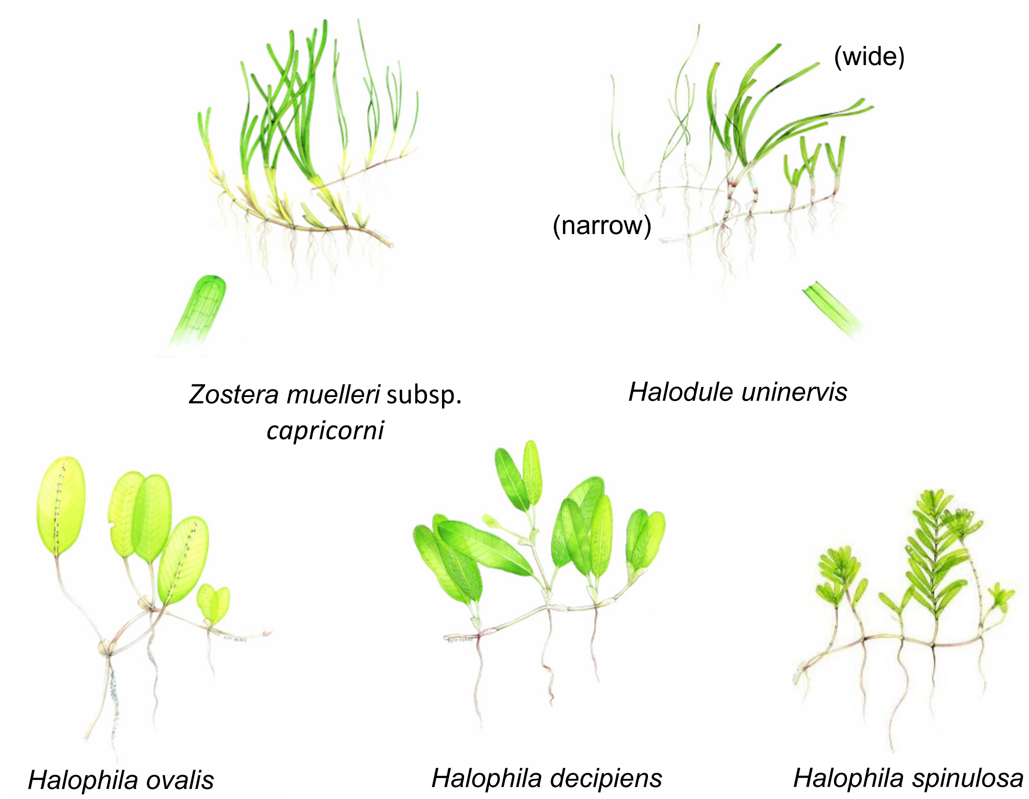


Figure 3. Seagrass species present in the Gladstone Harbour region.

2 METHODS

2.1 Sampling Approach and Data Collection Methods for Seagrass Indicators

Fourteen representative seagrass monitoring meadows were sampled November 4 - 10, 2018 (GHHP 2019 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). Standardising surveys to every October-December allows for appropriate comparisons of seagrass condition among years (2002-2018).

Survey methods followed the established techniques for TropWATER's Queensland-wide ports seagrass monitoring program. Detailed methods used in Gladstone are described in Rasheed et al. (2005; 2003). 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 (no free diving in 2018 survey), camera drops, and van Veen grab (Figure 4b - d). 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. Random sites also were surveyed within each subtidal meadow. 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).

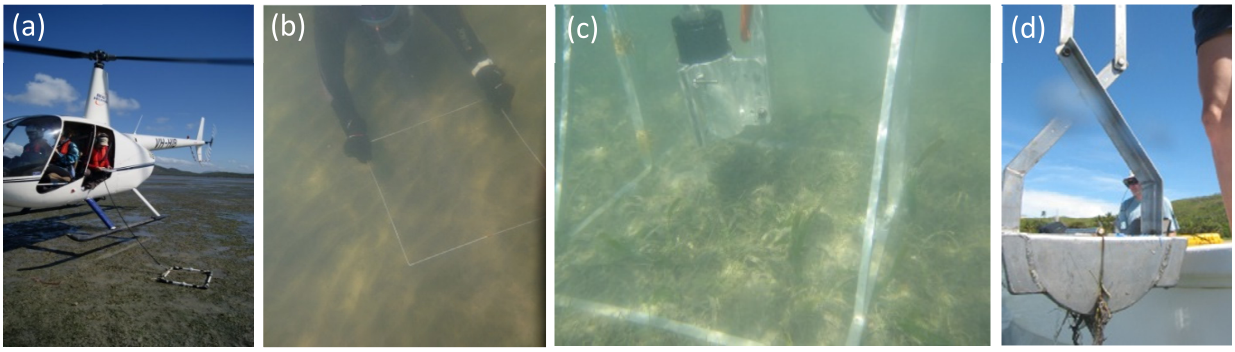


Figure 4. Seagrass monitoring conducted using (a) helicopter aerial surveillance with quadrat; (b) boat based free diver, (c) boat-based camera-drop; and (d) van Veen grab.

2.1.1 Biomass and Species Composition

Seagrass above-ground biomass was determined using the 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. Two separate ranges were used – low biomass and high biomass. The percent contribution of each seagrass species to above-ground biomass within each quadrat was recorded. At the completion of ranking, the observer ranked a series of at least four photographs of calibration quadrats that represented the range of seagrass observed during the survey. These calibration quadrats were previously harvested and the biomass weighed 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 were recorded.

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

Meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, colour satellite imagery of the survey region (Source: Landsat 2018, courtesy ESRI), and aerial photographs taken during helicopter surveys. Seagrass meadows were assigned a meadow identification number used to compare individual meadows between annual monitoring surveys. Monitoring meadows are referred to by identification numbers throughout this report. Meadow area was determined using the calculate geometry function in ArcGIS 10.4®. 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 <u><</u>5 m for intertidal seagrass meadows mapped by helicopter, to ±50 m for subtidal boundaries mapped by boat using distance between sites. The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Table 2. Mapping precision according to method for Gladstone seagrass meadows.

Mapping precision	Mapping method
≤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 Species B (2 species present) Species A with mixed species (>2 species)	Species A is >60-90% 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

<u>*Isolated seagrass patches*</u>
The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass.

<u>*Aggregated seagrass patches*</u>
Meadows consist of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries.

<u>*Continuous seagrass cover*</u>
The majority of meadow area consists of continuous seagrass cover interspersed with a few gaps of unvegetated sediment.

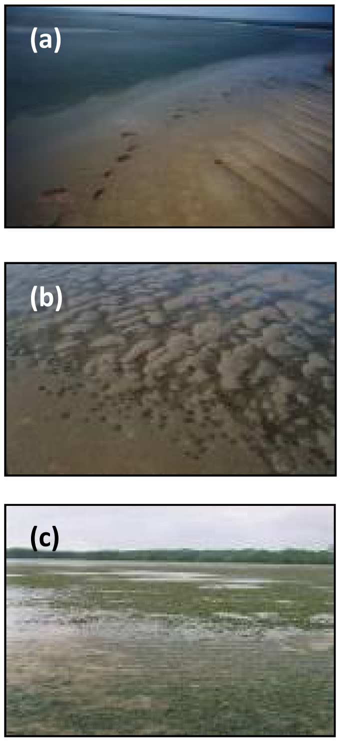


Figure 5. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

2.2 Seagrass Condition

Seagrass condition was determined using a condition index to assess changes in meadow area, mean above-ground biomass, 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.

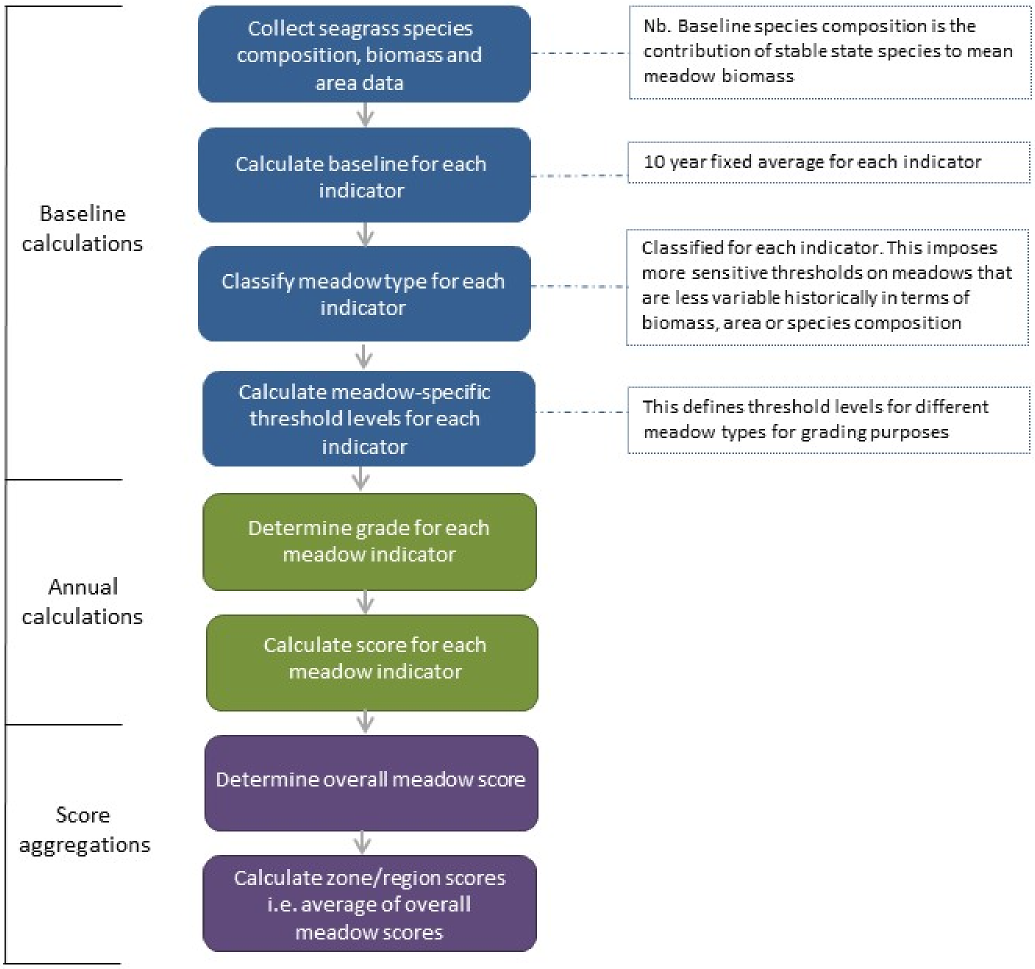


Figure 6. Process used to determine Gladstone Harbour grades and scores.

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 (generally 2002 – 2012; nb. no survey conducted in 2003). This baseline was set based on results of the 2014 pilot report card (Bryant et al. 2014). The 2002 – 2012 period incorporates a range of conditions 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. monitoring of meadows 21 and 52 – 57 commenced in 2009, or species composition data were unavailable for years where no seagrass was present. In these instances, the baseline was calculated over the longest available period until the monitoring program collected 10 years of data for that meadow. This 2019 report card is the first year where a 10-year baseline is available for all indicators across all meadows.

Baseline species composition was determined as the annual percent contribution of each species to mean meadow biomass of the baseline years. Meadows were classified as single species dominated (one species comprising ≥80% of baseline species composition) or mixed species (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**

The meadow classification system recognises that for some seagrass meadows the three condition indicators 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 over time (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 the current year's biomass, area and species composition values against meadow-specific thresholds for each grade. Biomass, area and species composition values were then scaled 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.

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 presented on relevant maps in Section 3.3, and in Tables 11 and 13 in 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 according to meadow class relative to the baseline. Up/down arrows are included on individual meadow maps in Section 3.3 where a condition grade has improved/declined for 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
	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 grade threshold from previous year			Decrease below grade threshold from previous year		

Table 7. Score range and grading colours used in the 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

The species composition of a seagrass meadow is the percent (%) that each species contributes to a meadow's mean above-ground biomass. As with the biomass and area indicators, species composition condition is assessed relative to a ten-year baseline. Therefore, meadows that have only ever had colonising species present will not be graded poorly unless there is a shift to a lower colonising species, e.g. from *H. ovalis* to *H. decipiens* (see Figure 7).

Species composition is a fundamental characteristic of a seagrass meadow. Species vary in their morphologies, growth rates, root structures and leaf turnover rates, which influences their capacity to provide important ecosystem services. Changes in species composition influences the role seagrasses play in coastal ecosystems (Christiaen et al. 2016). These roles include:

1. Fisheries habitat - Fish species display a distinct preference for particular seagrasses characterised by different architecture (Hyndes et al. 2003). A shift in species composition can lead to a change in the abundance and diversity of fish and other macrofauna such as crabs and shrimp (Ray et al. 2014).
2. Infaunal invertebrate diversity - The abundance and diversity of infaunal invertebrates differs between seagrass species. For example, Micheli et al. (2008) found significantly lower abundance and diversity of infaunal invertebrates in seagrass meadows dominated by *Halodule* spp. than those dominated by *Zostera* spp. or mixtures of the two species. Micheli et al. concluded that the continued loss of *Zostera* would result in the loss of important habitat functions and a decline in the secondary productivity of the meadow.
3. Coastal protection - Stiffness, biomass, density, leaf length and morphology all influence the coastal protection value of seagrasses, with large, long living, slow growing seagrass species affording the greatest protection (Ondiviela et al. 2014).
4. Carbon sequestration - Species composition is a known driver of variability in carbon stocks (Lavery et al. 2013) with larger bodied species generally associated with higher sedimentary organic carbon stocks.
5. Resistance to disturbance - Larger bodied, persistent species generally have a higher physiological resistance to disturbance, while small bodied, colonising species have a rapid ability to recover (Kilminster et al. 2015).

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 as 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 end of the species 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 because *H. decipiens* has a lower light requirement (Collier et al. 2016) (Figure 7).

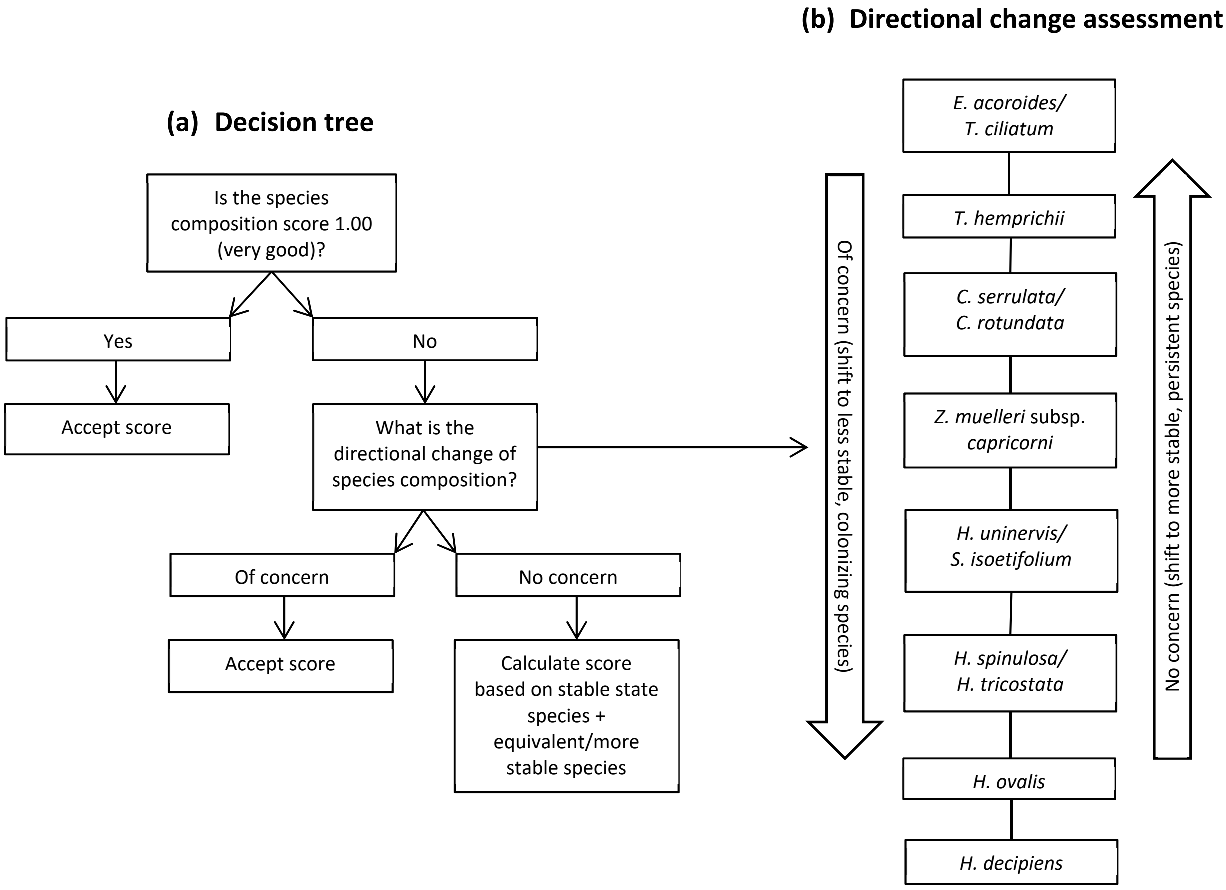


Figure 7. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Gladstone.

2.2.5 **Score Aggregation**

Overall meadow condition was defined as the lowest indicator score where this was driven by biomass or area. The lowest score, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for either of these indicators described a seagrass meadow in poor condition. This method allows the most conservative estimate of meadow condition to be made (Bryant et al. 2014). Where species composition was the lowest score, it contributes 50% to the overall meadow score, and the next lowest indicator score (area or biomass) contributes the remaining 50%. This weighting is applied to prevent a meadow receiving a zero score due to species composition, despite having substantial area and biomass of less persistent species. The weighting acknowledges that species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition.

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 (see 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 therefore served 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 and 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 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 stable for half of the meadows. Half of the meadows were classed as single-species dominated. The large *Z. muelleri* subsp. *capricorni* dominated meadow at Pelican Banks (Meadow 43) is the only monitoring meadow classed as stable for all 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 based on the coefficient of variation of the 10-year mean for each indicator.

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

3.2 Overall Seagrass Condition for the 2019 Reporting Year

3.2.1 Overall Meadow Condition

The majority of monitoring meadows were in satisfactory, good, or very good condition in the 2019 reporting year (Table 9). The exceptions were Meadow 58 (Inner Harbour) which was in very poor condition, and Meadows 8 (Western Basin), 43 (Mid Harbour), and 104 (Rodds Bay) which were all in poor condition.

The high prevalence of less stable, colonising species was the most frequent driver of overall meadow scores. Species composition was the lowest of the three indicator scores in seven of the 14 monitoring meadows, with four of these meadows in the Western Basin Zone (Table 9). Area alone was responsible for the overall condition of Meadow 7 in the Western Basin and Meadow 104 in Rodds Bay, and in combination with species composition in a further five meadows. Biomass determined the overall scores in five meadows, including meadows in the Western Basin, Inner Harbour, Mid Harbour, South Trees Inlet and Rodds Bay zones (Table 9).

3.2.2 Overall Zone and Harbour Condition

Seagrass in the majority of zones was in satisfactory or better condition in the 2019 reporting year (Table 9). Condition was very good in the South Trees Inlet zone, good in The Narrows and Western Basin zones, and satisfactory in the Mid Harbour. The Inner Harbour zone was in very poor condition and Rodds Bay was in poor condition. The overall condition of Gladstone Harbour seagrass was satisfactory (Table 9).

Table 9. Grades and scores for seagrass indicators (biomass, area and species composition), overall meadow, zone, and Gladstone Harbour scores for the GHHP 2019 reporting year. 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**	0.75	0.91	0.67	0.71†	0.71
3. Western Basin	**4**	1.00	0.82	0.43	0.62†	0.69
	5	0.91	0.74	0.54	0.64†	
	6	0.95	0.76	0.43	0.59†	
	7	0.94	0.91	1.00	0.91	
	8	1.00	0.55	0.22	0.38†	
	52-57*	0.97	0.98	1.00	0.97	
5. Inner Harbour	**58**	0.21	0.57	0.56	0.21	0.21
8. Mid Harbour	**43**	0.45	0.75	0.62	0.45	0.52
	48	0.91	0.76	0.44	0.60†	
9. South Trees Inlet	**60**	0.89	0.93	0.95	0.89	0.89
13. Rodds Bay	**94**	0.53	0.56	0.65	0.53	0.49
	96	0.72	1.00	0.65	0.69†	
	104	0.44	0.27	0.64	0.27	
Gladstone Harbour						**0.59**

*Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 2). These meadows are grouped for reporting purposes.

† Where species composition is the lowest of the three indicator scores, it contributes 50% of the overall meadow score with the remaining 50% coming from the lowest of either biomass or area scores (see Section 2.2.5).

3.3 Seagrass Condition by Gladstone Harbour Zone and Meadow

3.3.1 Zone 1: The Narrows

Seagrass in Zone 1: The Narrows was in good condition (Figure 8), an improvement from poor condition the previous year due to below average biomass. Meadow 21 is an intertidal, variable biomass meadow at Black Swan Island, and the only monitoring meadow in this zone. Biomass and species composition were both in good condition. The dominant species *Z. muelleri* subsp. *capricorni* changed little from 2017 (2018 reporting year), contributing ~57% of mean meadow biomass relative to the less persistent species *H. ovalis* and *H decipiens* (Figure 9; Appendix 2). Area improved for the second consecutive year, increasing from 132 ± 14 ha in 2017 (2018 reporting year; good condition) to 172 ± 11 ha in 2018 (2019 reporting year; very good condition) (Figure 9). This is the first year that the complete 10 years of data is available to define baseline conditions for Meadow 21.

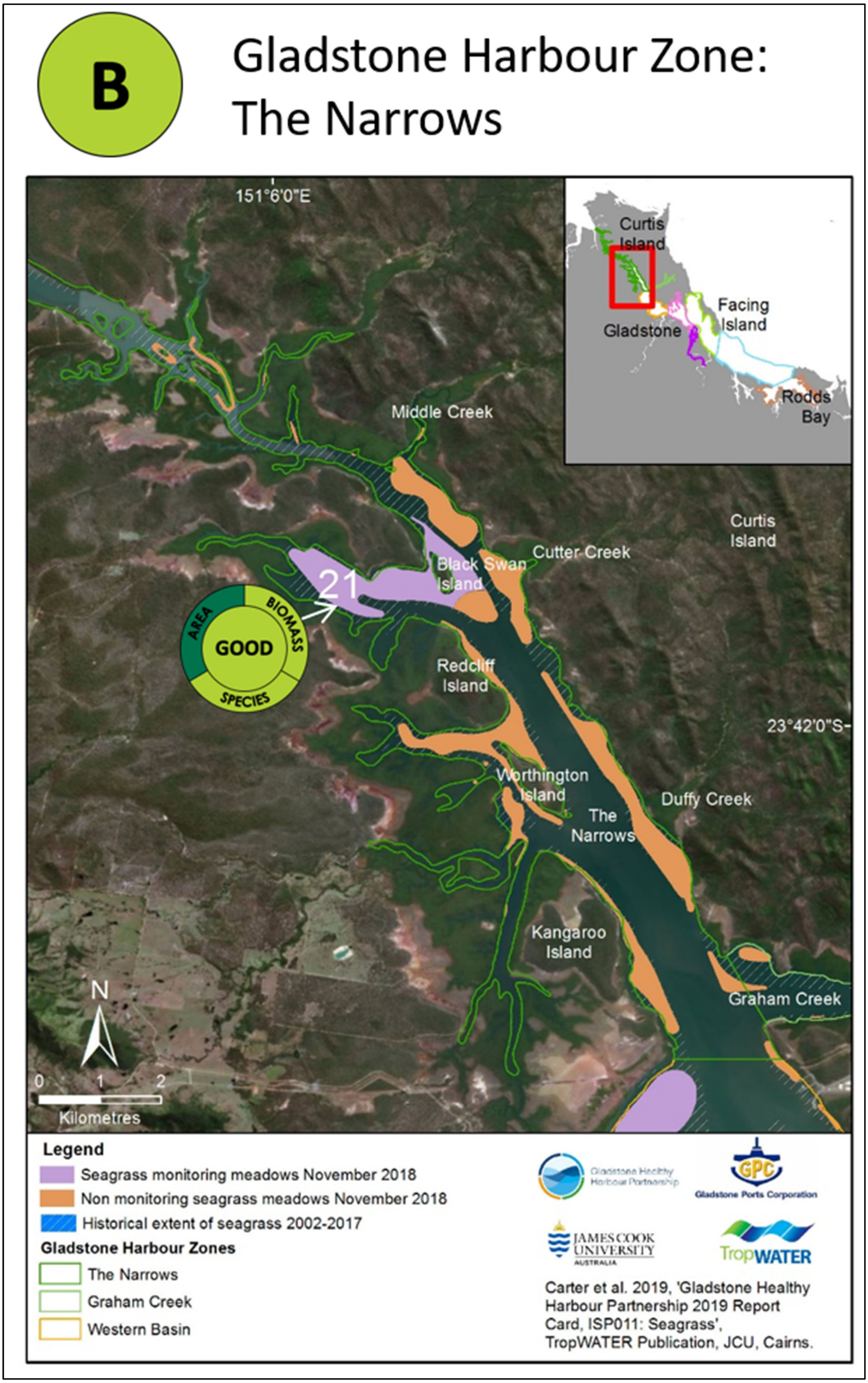


Figure 8. Seagrass condition in Zone 1: The Narrows, November 2018 survey (2019 reporting year).

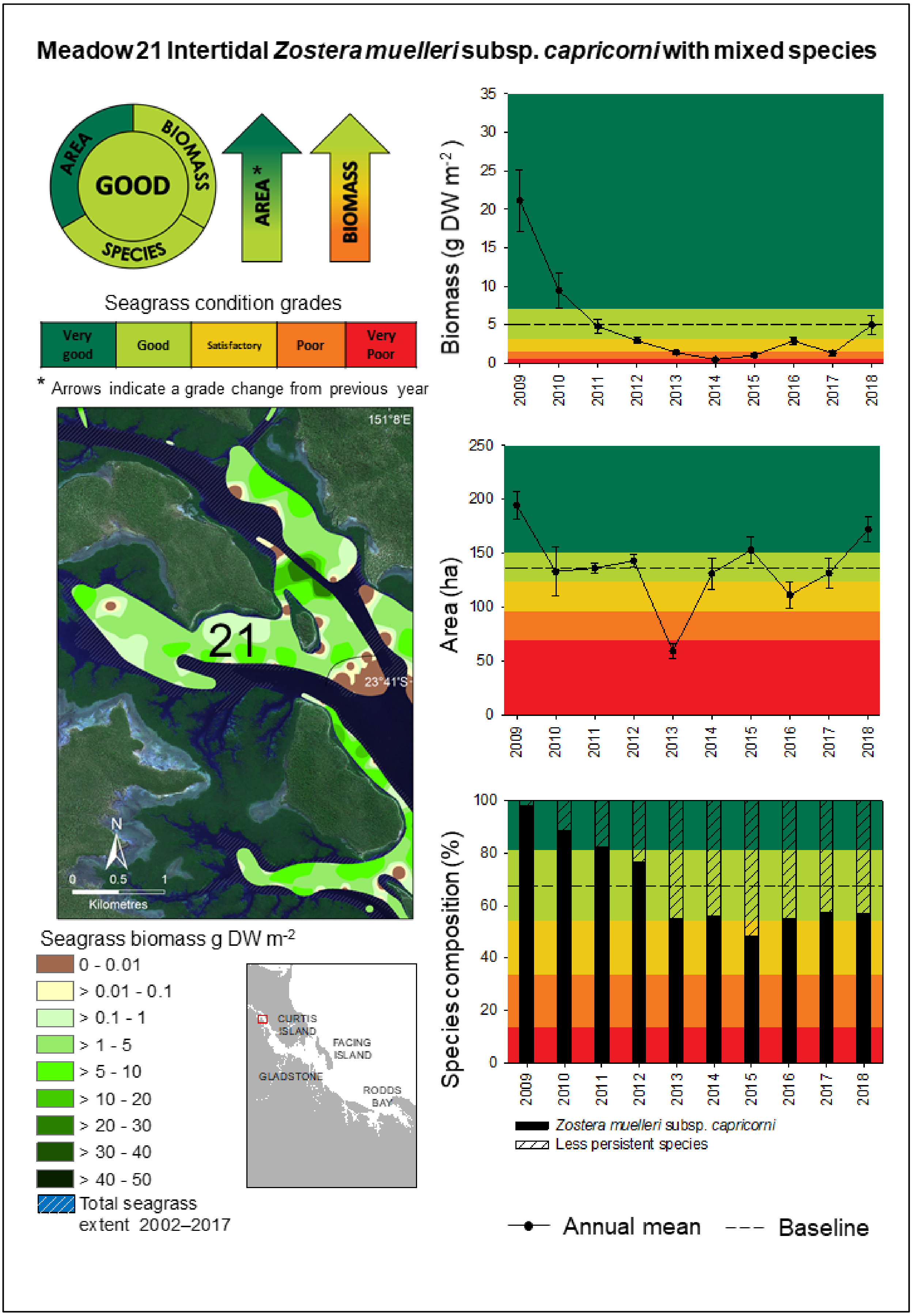


Figure 9. Meadow area, biomass and species composition for seagrass in Meadow 21, Zone 1: The Narrows, 2009 – 2018 (2010 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

3.3.2 **Zone 3: Western Basin**

Seagrass condition in Zone 3: Western Basin improved considerably between the 2018 and 2019 reporting years, from poor to good condition. Overall meadow scores were largely driven by improvements in species composition and meadow area (Figure 10). There are six monitoring meadows in the Western Basin Zone, including five intertidal meadows and one subtidal meadow. All meadows experienced substantial biomass increases from the previous year, and biomass condition was very good in all meadows for the first time since 2007.

Meadow 4

Meadow 4 at Wiggins Island was in an overall satisfactory condition for the 2019 reporting year (Figure 11). The improvement from poor to satisfactory was due to an increase in the presence of *Z. muelleri* subsp. *capricorni*, the historically persistent species in the meadow (Figure 11; Appendix 2). Meadow area changed little from the previous year (~33 ha; good condition). Biomass continued to increase well beyond the baseline value of 0.83 gDW m^{-2} (current biomass = 4.3 ± 0.8 gDW m^{-2}) and remained in very good condition for the third consecutive year (Figure 11).

Meadow 5

Meadow 5, west of Wiggins Island, was in satisfactory condition for the third consecutive year. The overall score was determined by satisfactory species composition and good area scores (Figure 12). Meadow 5 is an intertidal, variable mixed species meadow that fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. The composition of *Z. muelleri* subsp. *capricorni* was 23% in the 2019 reporting year, an improvement from 11% in the previous year, but well below the 62% baseline (Figure 12; Appendix 2). Meadow biomass was in very good condition following a substantial increase from ~2 gDW m^{-2} in 2017 to ~6 gDW m^{-2} in 2018, the greatest biomass recorded in a decade (Figure 12).

Meadow 6

Overall condition of Meadow 6 improved from poor to satisfactory between the 2018 and 2019 reporting years and was driven by area and species composition scores (Figure 13). Meadow 6 is an intertidal, variable mixed species meadow at South Fisherman's Landing. The dominant species *Z. muelleri* subsp. *capricorni* has declined relative to *H. ovalis* since 2010. Species composition was poor this year because *H. ovalis* constituted 88% of meadow biomass (Figure 13; Appendix 2). Biomass condition was very good, with the second greatest value recorded (5.5 + 0.5 gDW m^{-2}) since monitoring began, approximately three times greater than the 1.8 gDW m^{-2} baseline value (Figure 13). Meadow area condition declined from very good to good, but at 375 ± 14 ha remained just above the baseline level (Figure 13).

Meadow 7

This ephemeral meadow is historically extremely variable due to the marginal light environment and high sensitivity of the dominant species *H. decipiens* in this subtidal habitat. In the 2019 reporting year, Meadow 7 had re-established following its' complete absence the previous year (Figure 14). Meadow 7's overall condition was very good, with area and biomass values the largest recorded in over a decade.

Meadow 8

The intertidal Meadow 8 at North Fisherman's Landing remained in poor condition in the 2019 reporting year. Very poor species composition and satisfactory area scores dictated the overall meadow condition (Figure 15). As with other intertidal monitoring meadows in the Western Basin zone, *Z. muelleri* subsp. *capricorni* has historically dominated Meadow 8 relative to *H. ovalis.* However, since 2011 (2012 reporting year) *Z. muelleri* subsp. *capricorni* has remained well-below the 67% baseline level (Figure 15; Appendix 2).

Meadow area increased slightly from 160 to 165 ha over the past year. Biomass condition was very good for the fourth consecutive year. Mean biomass hovered around 2 gDW m^{-2} between 2015 (2016 reporting year) and 2017 (2018 reporting year), but increased substantially this year to the greatest recorded value (5.4 ± 0.9 g DW m^{-2}) since monitoring began (Figure 15).

Meadow 52-57

Meadow 52-57 is a group of predominantly intertidal meadows surrounding the Passage Islands. The overall condition of Meadow 52-57 was very good in the 2019 reporting year, an improvement from good condition the previous year (Figure 16). Biomass and area were at the greatest values recorded since monitoring began in 2009 (2010 reporting year), and the species mix is comprised of the dominant species *H. ovalis* and the more stable and persistent species *Z. muelleri* subsp. *capricorni* (Figure 16; Appendix 2). This is the first year that the complete 10 years of data is available to define baseline conditions for Meadow 52-57.

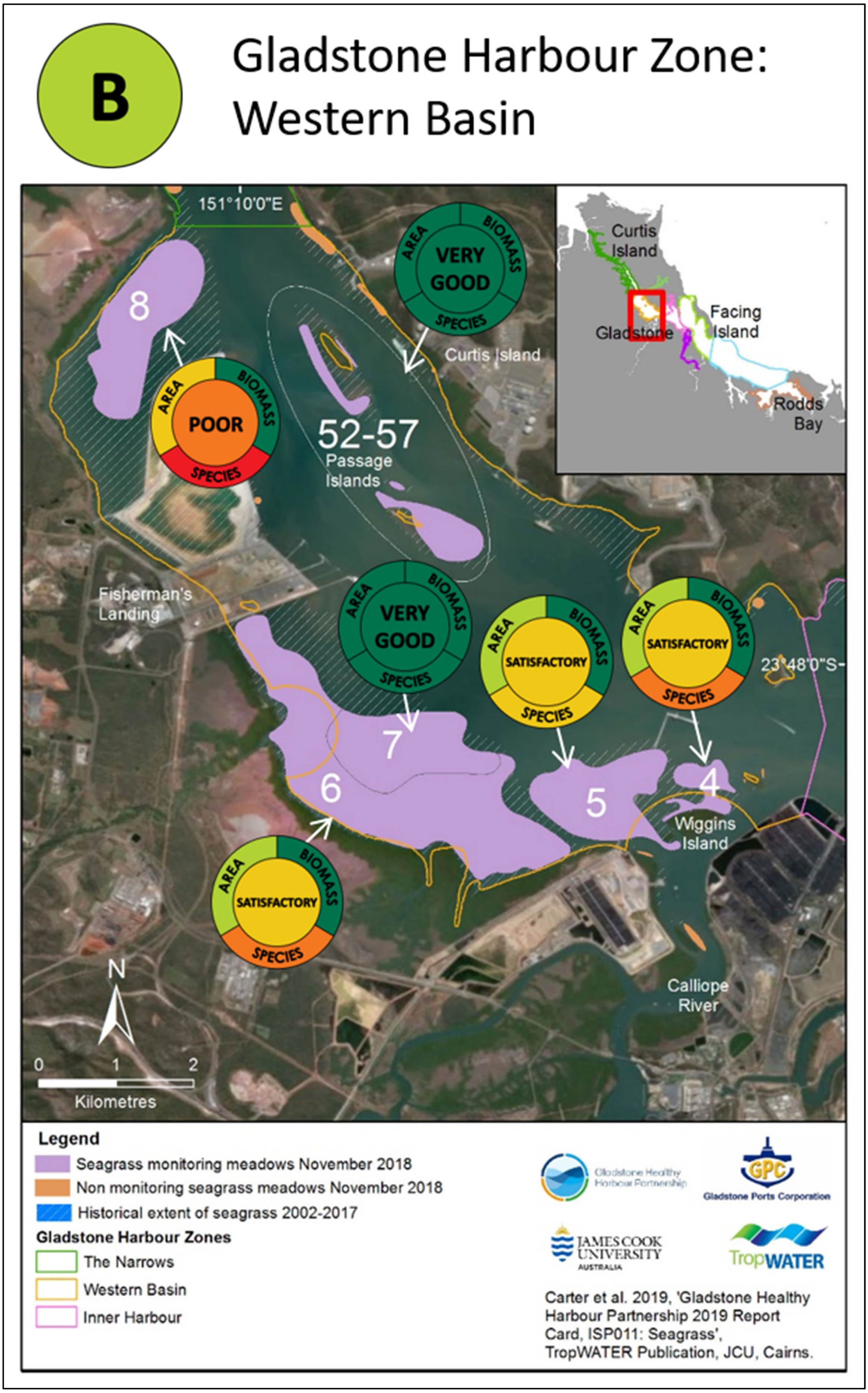


Figure 10. Seagrass condition in Zone 3: Western Basin, November 2018 survey (2019 reporting year).

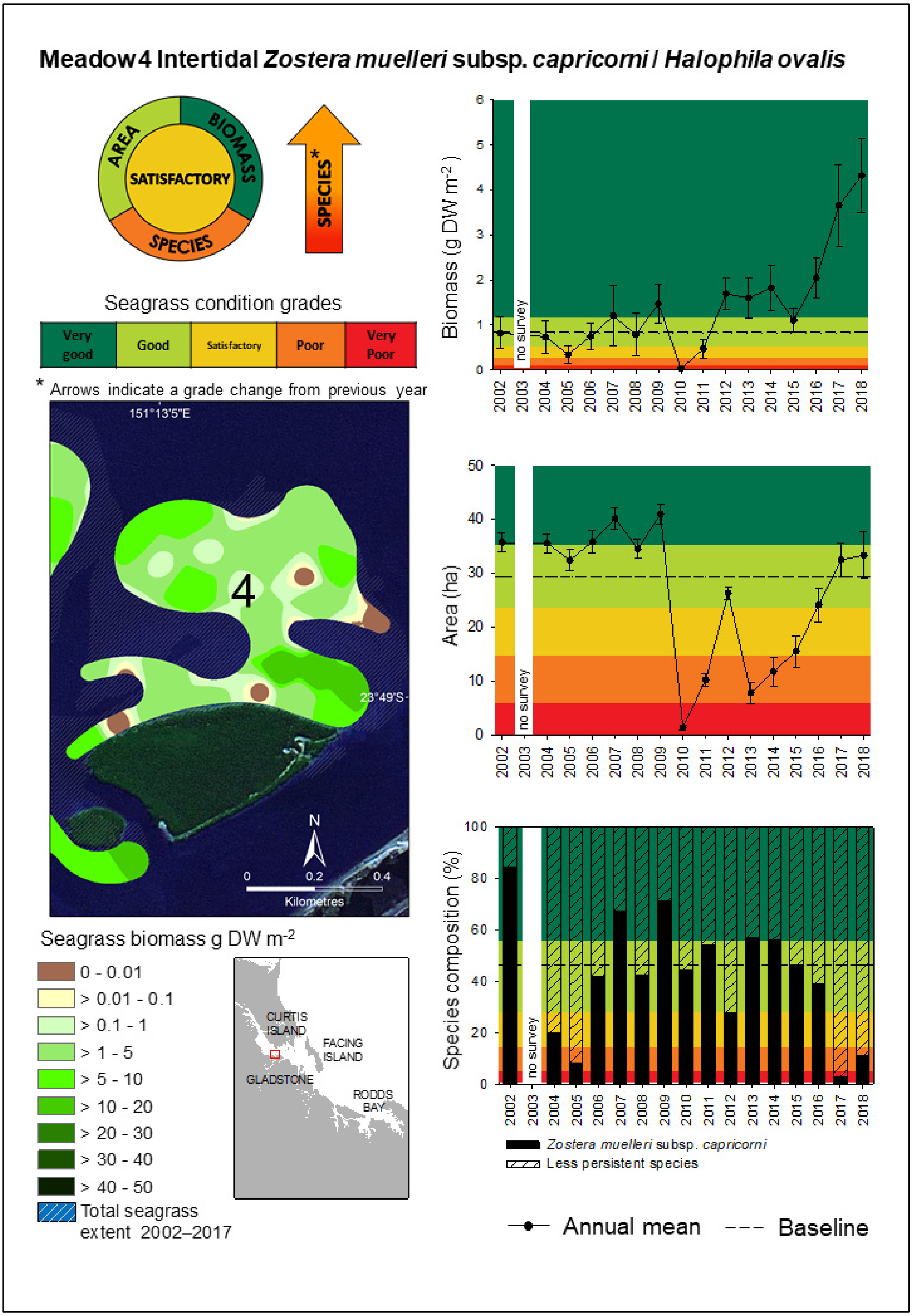


Figure 11. Meadow area, biomass and species composition for seagrass in Meadow 4, Zone 3: Western Basin, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

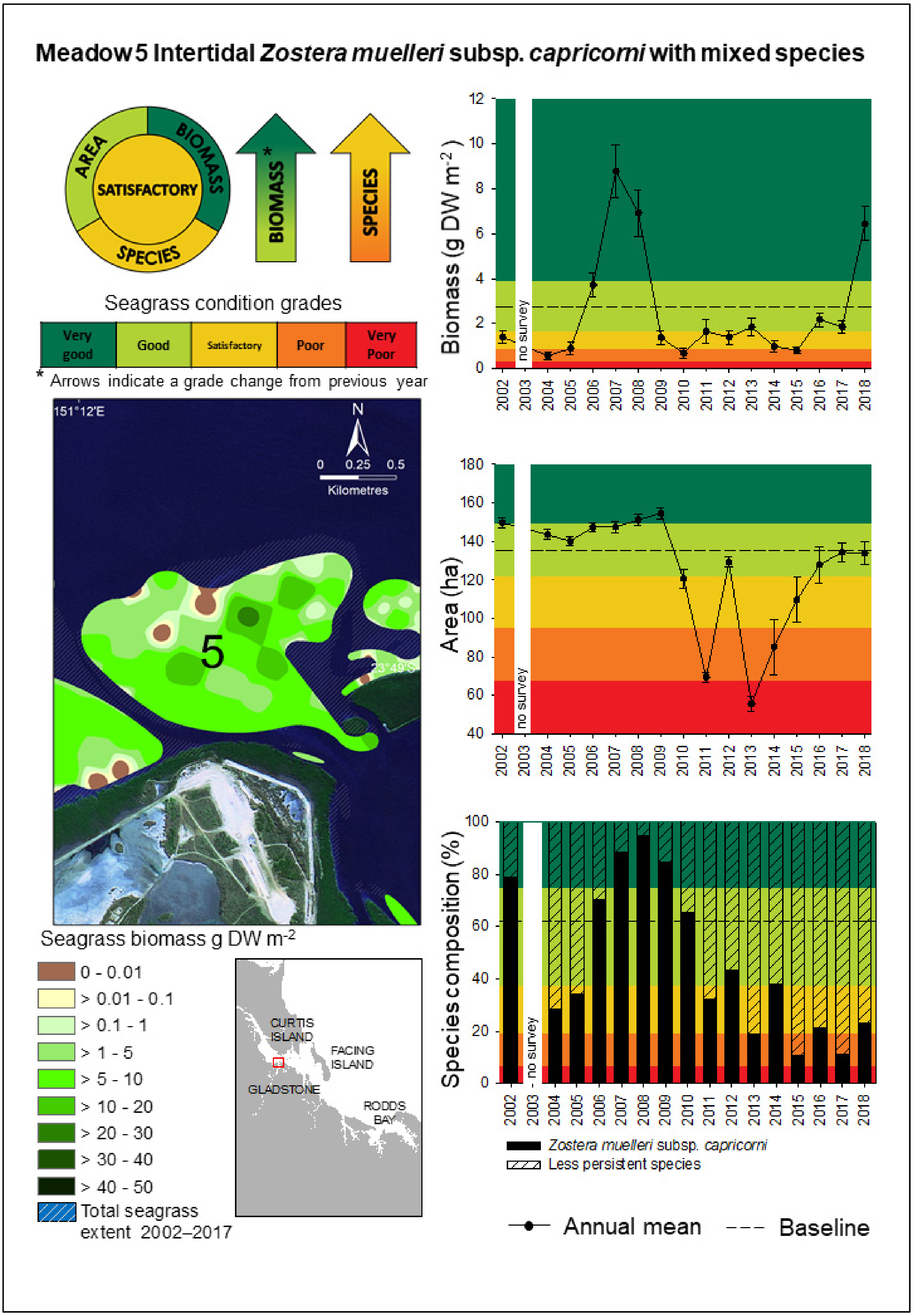


Figure 12. Meadow area, biomass and species composition for seagrass in Meadow 5, Zone 3: Western Basin, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

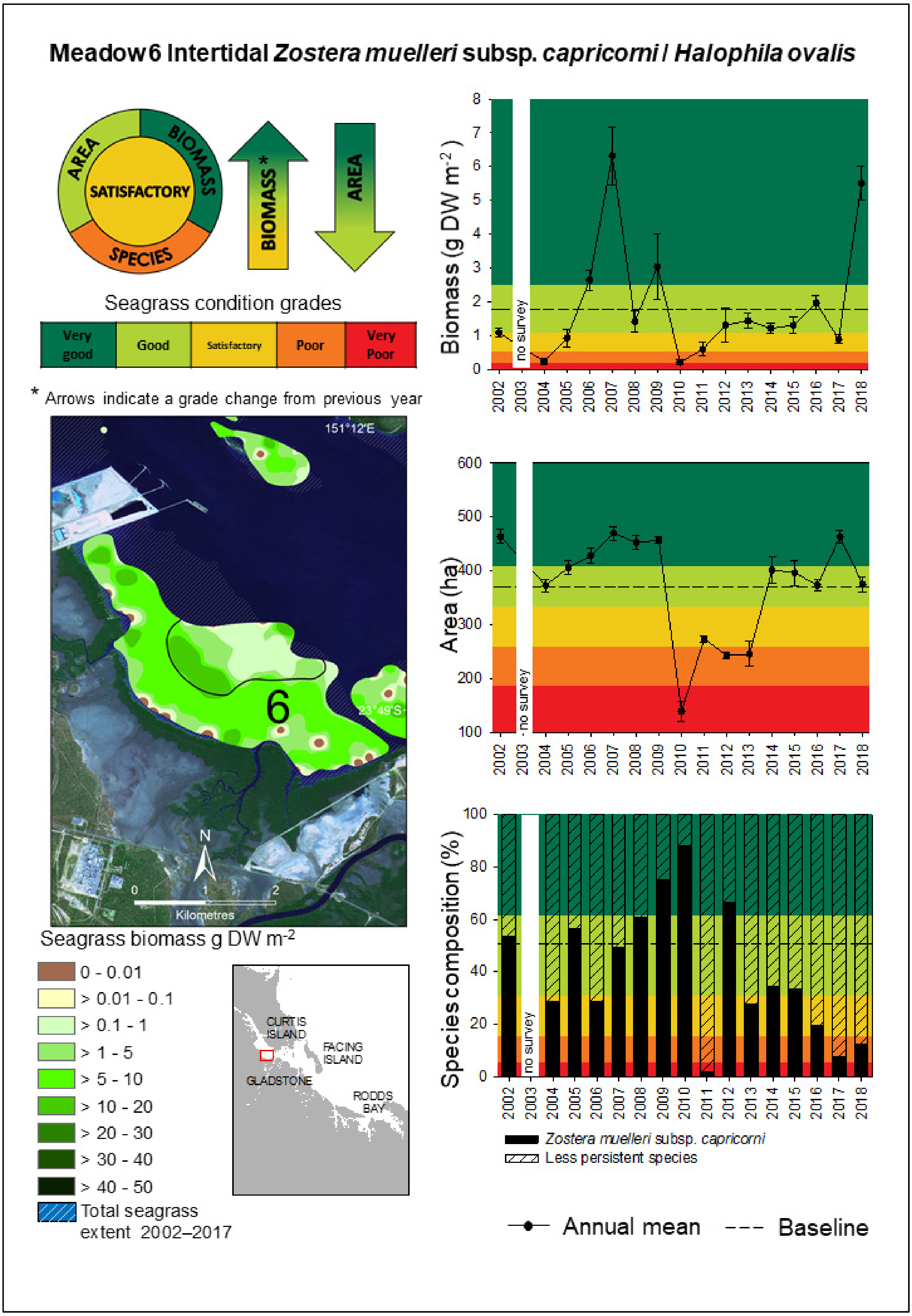


Figure 13. Meadow area, biomass and species composition for seagrass in Meadow 6, Zone 3: Western Basin, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

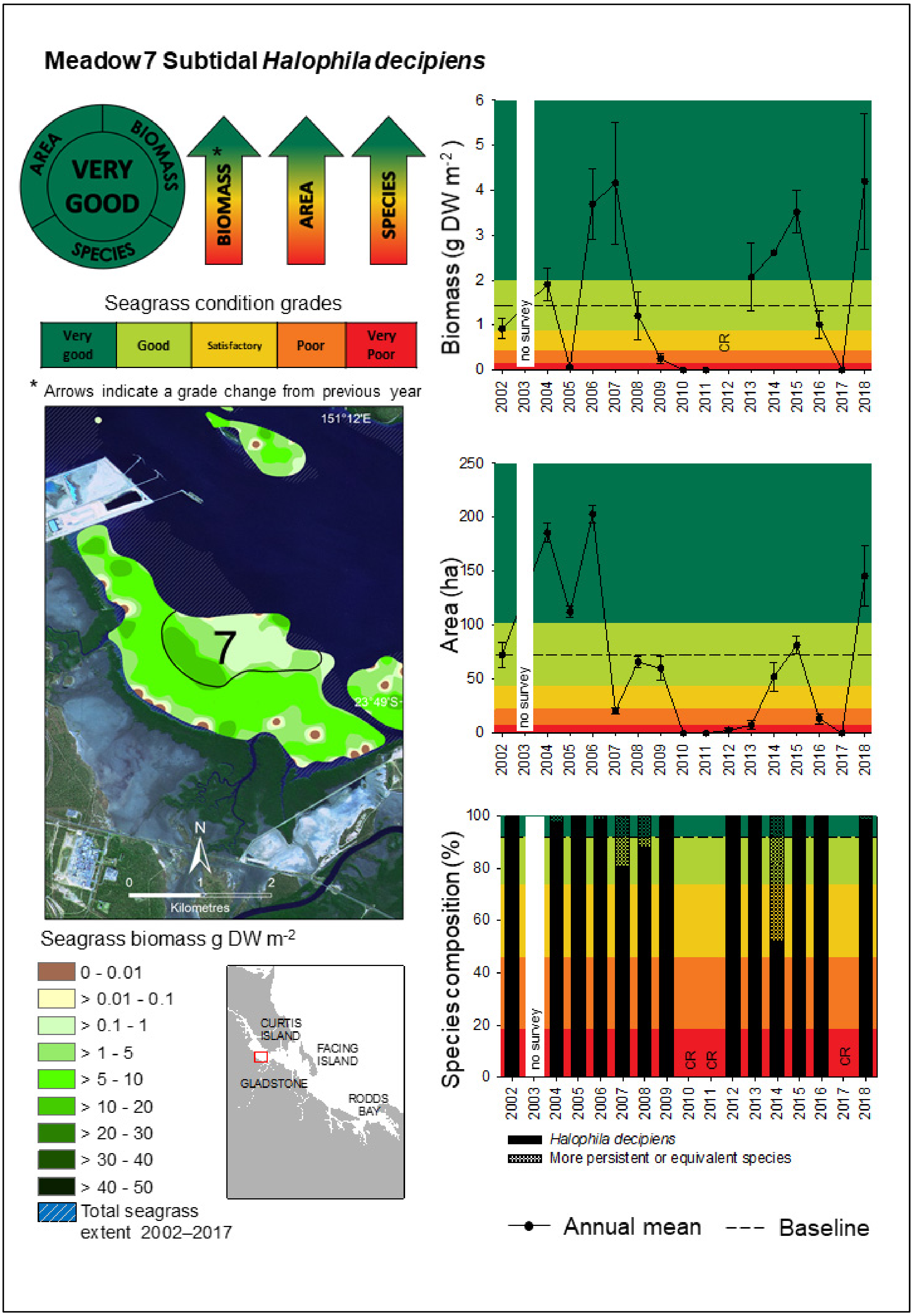


Figure 14. Meadow area, biomass and species composition for seagrass in Meadow 7, Zone 3: Western Basin, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate. CR: calculation restriction (biomass) - a score was not calculated because seagrass was sampled by van Veen grab only (precludes biomass assessment). CR (species composition) - a species composition score was not calculated because seagrass was absent.

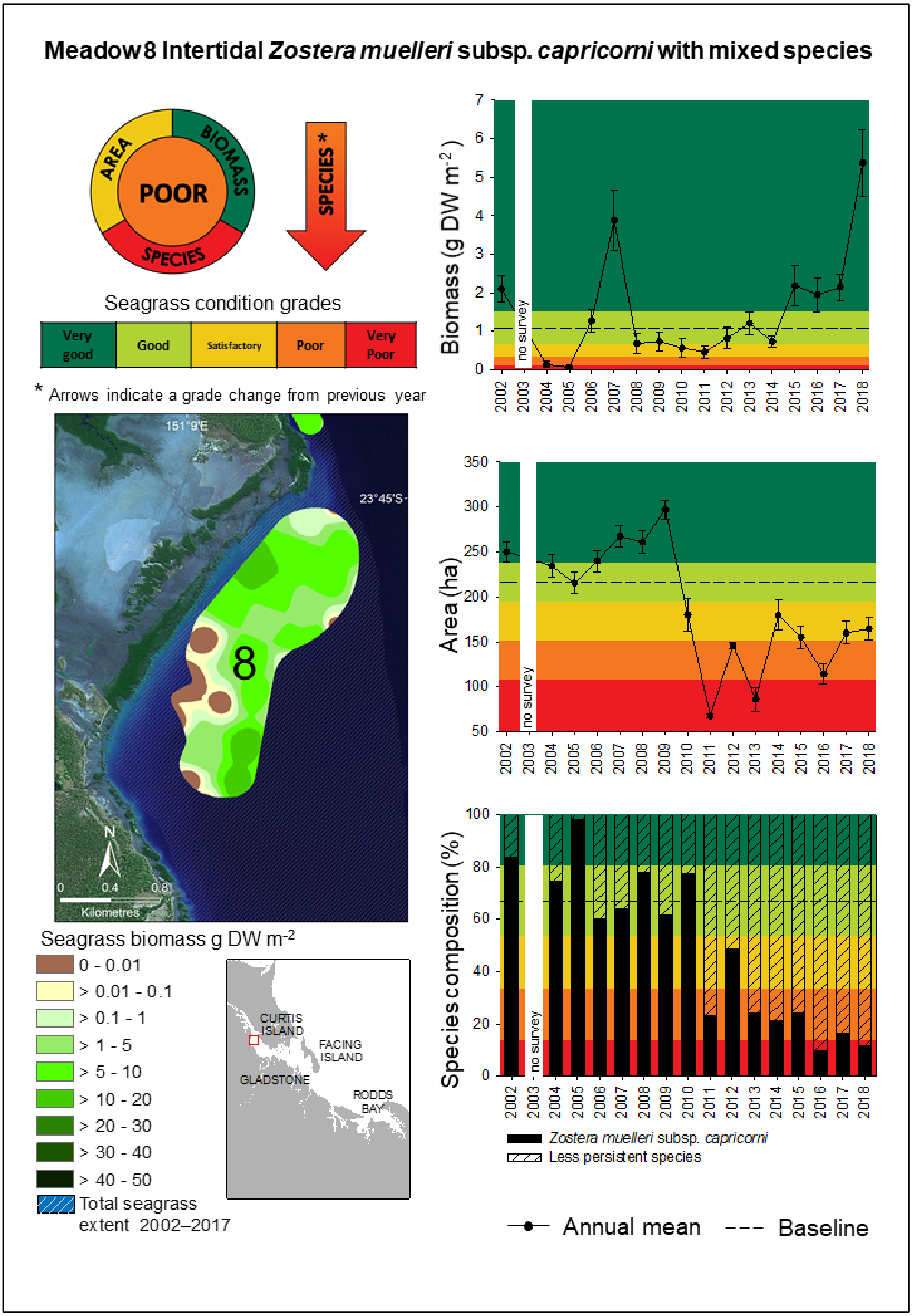


Figure 15. Meadow area, biomass and species composition for seagrass in Meadow 8, Zone 3: Western Basin, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

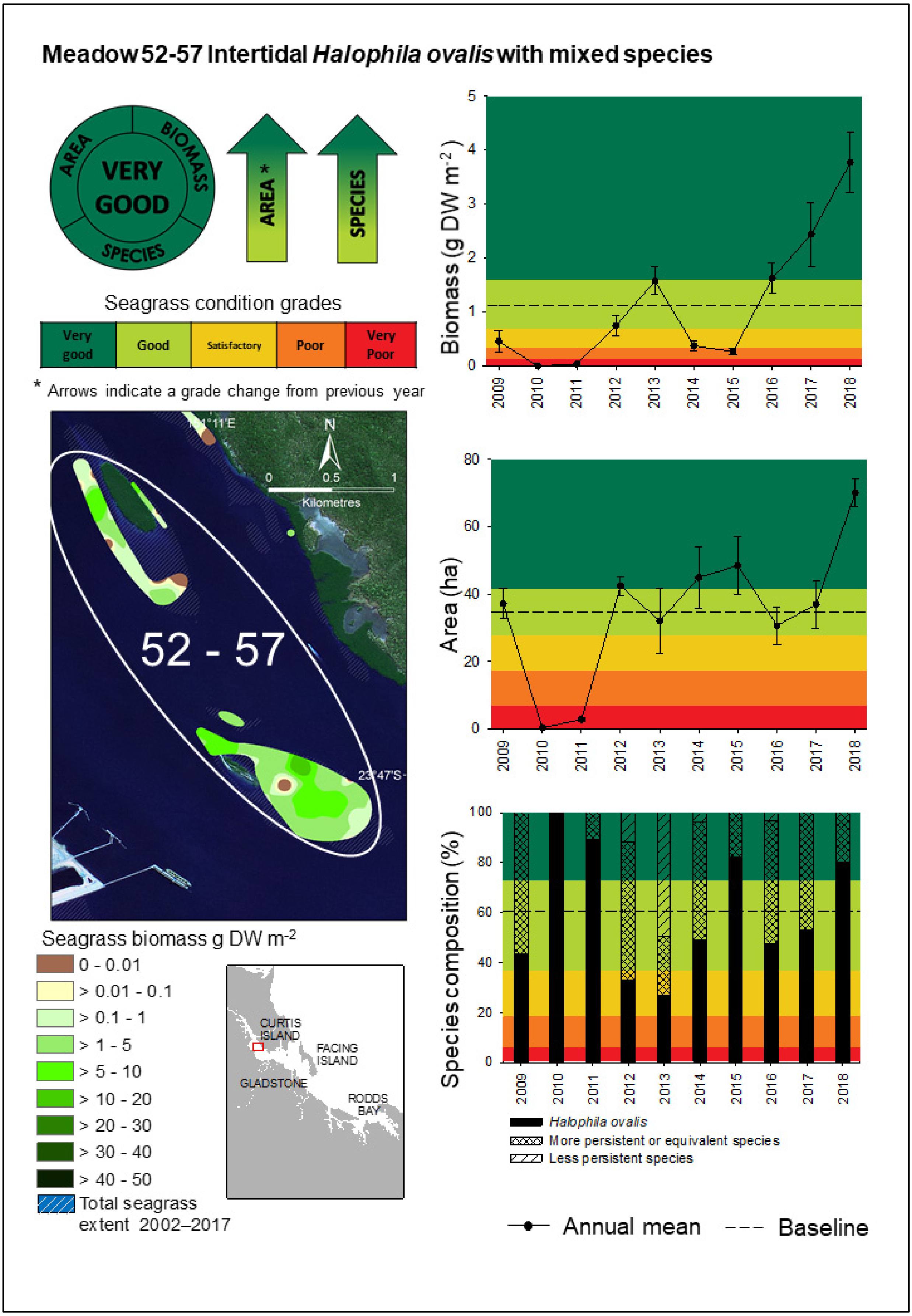


Figure 16. Meadow area, biomass and species composition for seagrass in Meadows 52-57, Zone 3: Western Basin, 2009 – 2018 (2010 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

3.3.3 **Zone 5: Inner Harbour**

Seagrass condition in Zone 5: Inner Harbour remained very poor in 2018 (2019 reporting year; Figure 17). Meadow 58 is the only monitoring meadow in this zone. Extremely low biomass drove the overall meadow condition this year, with mean biomass (0.17 ± 0.06 gDW m^{-2}) well below the 2.1 gDW m^{-2} baseline (Figure 18). Meadow biomass has been mostly poor to very poor since 2010 (2011 reporting year). Meadow area continued to decline from its 2014 (2015 reporting year) peak and was in satisfactory condition. This is the first time since 2011 (2012 reporting year) that area condition has been less than good, with only a thin fragment remaining in the eastern corner of the meadow's historical extent (Figure 18). Species composition condition improved from very poor in 2017 (2018 reporting year) to satisfactory this year. The reappearance of the previously dominant species *Z. muelleri* subsp. *capricorni* is a positive sign, following the absence of this more stable species from the meadow for several years (Figure 18; Appendix 2).

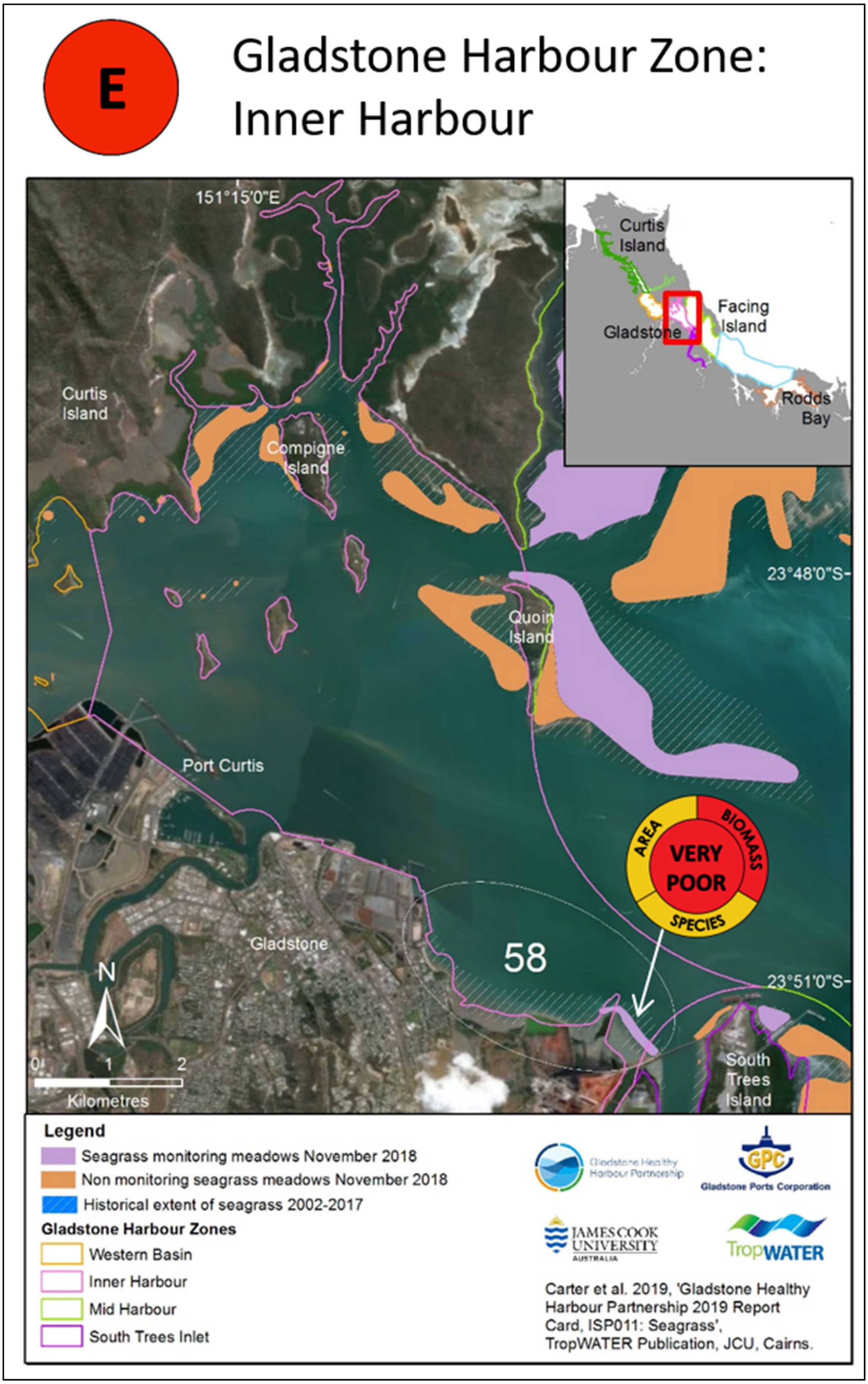


Figure 17. Seagrass condition in Zone 5: Inner Harbour, November 2018 survey (2019 reporting year).

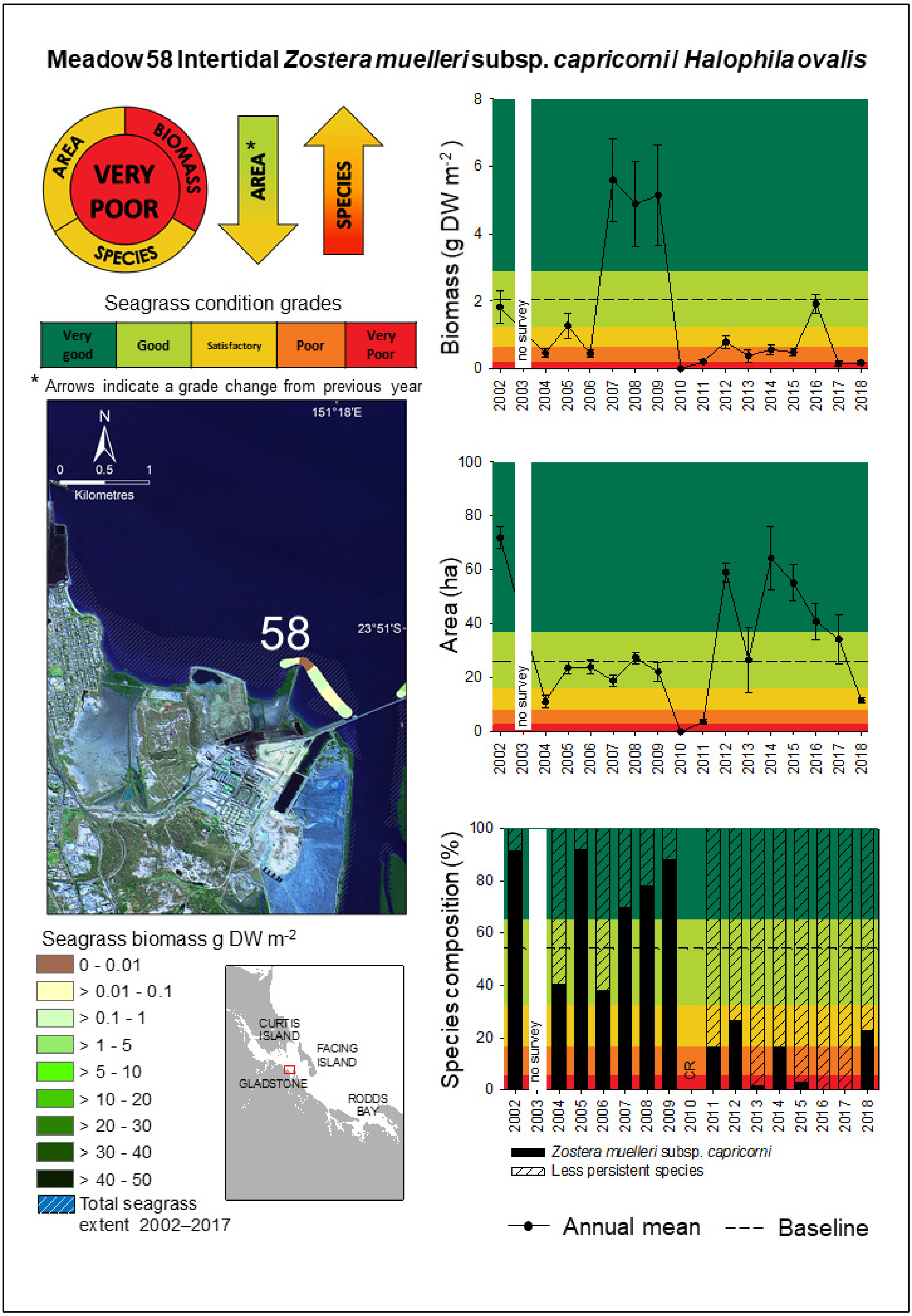


Figure 18. Meadow area, biomass and species composition for seagrass in Meadow 58, Zone 5: Inner Harbour, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate. CR: calculation restriction (species composition) - a species composition score was not calculated because seagrass was absent.

3.3.4 **Zone 8: Mid Harbour**

Seagrass condition in Zone 8: Mid Harbour was satisfactory in the 2019 reporting year, an improvement from poor condition the previous year (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 largest (baseline = 632 ha), most productive (baseline = 19 g DW m^{-2}), and most stable seagrass monitoring meadow in Gladstone Harbour and Rodds Bay. Condition declines in seagrass biomass, area and species composition over the past decade led to very poor meadow condition in 2016 (2017 reporting year), driven primarily by low biomass. Biomass improved substantially the following year (7.67 ± 1.03 g DW m^{-2}), and again this year (8.25 ± 1.08g DW m^{-2}), leading to an overall meadow grade of poor (Figure 20). Meadow area increased from satisfactory condition in 2017 (2018 reporting year) to good condition this year (Figure 20). The reduction in the dominant species *Z. muelleri* subsp. c*apricorni* since 2014 (2015 reporting year) continued, with more than 25% of meadow biomass comprised of the less persistent species *H. uninervis* and *H. ovalis* this year (satisfactory condition; Figure 20; Appendix 2).

Meadow 48

Meadow 48's overall condition was satisfactory this year due to a combination of good area and poor species composition scores (Figure 21). Species composition was poor because the meadow remains dominated by *H. spinulosa* and *H. ovalis* rather than the more persistent baseline species *H. uninervis* (Figure 21; Appendix 2). Meadow area declined from very good condition in 2017 (2018 reporting year) to good condition this year, and at ~240 ha was equal to the baseline. Biomass condition was very good for the first time in a decade (6.4 ± 1.0 gDW m^{-2}), and for only the third time since monitoring began (Figure 21).

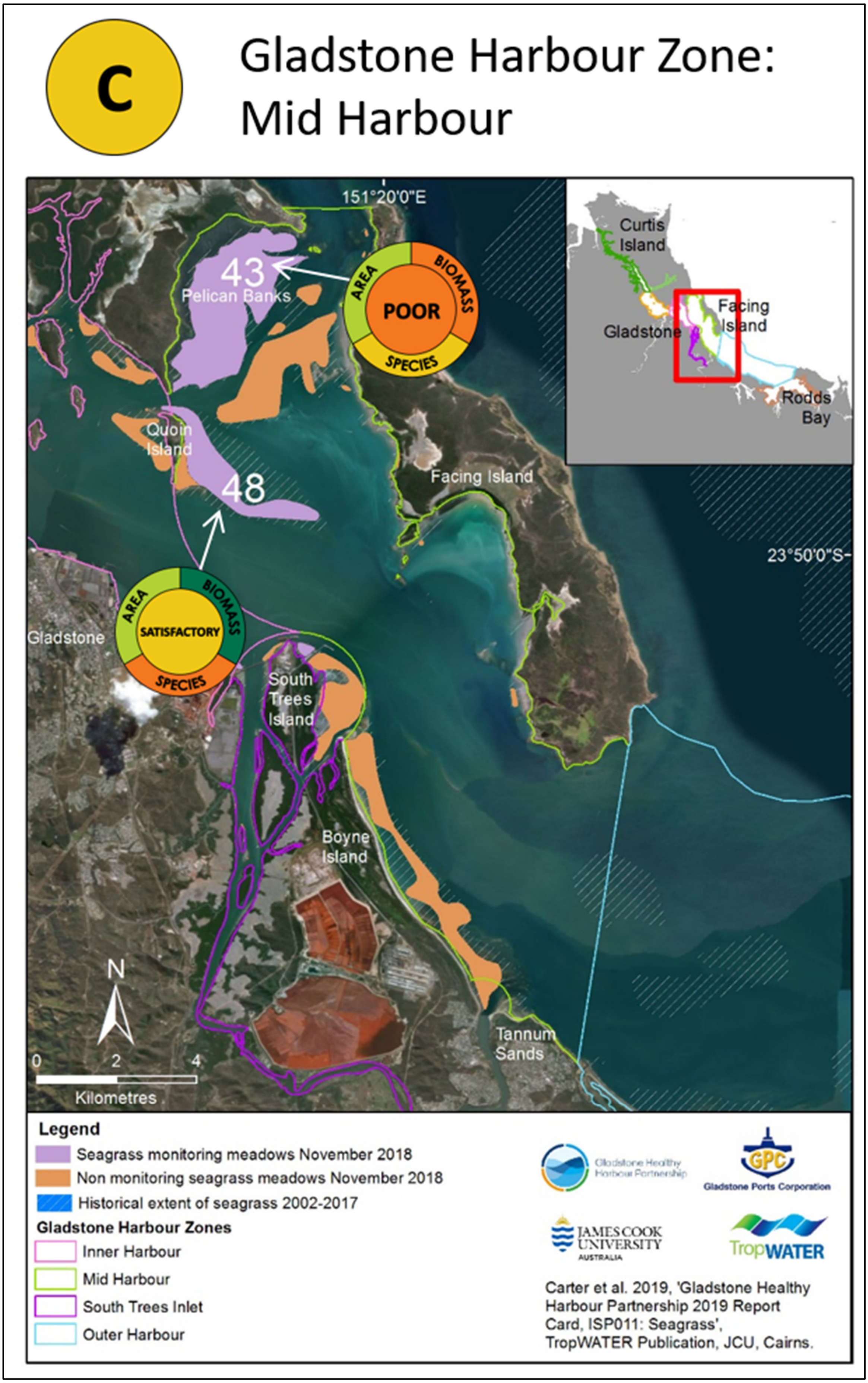


Figure 19. Seagrass condition in Zone 8: Mid Harbour, November 2018 survey (2019 reporting year).

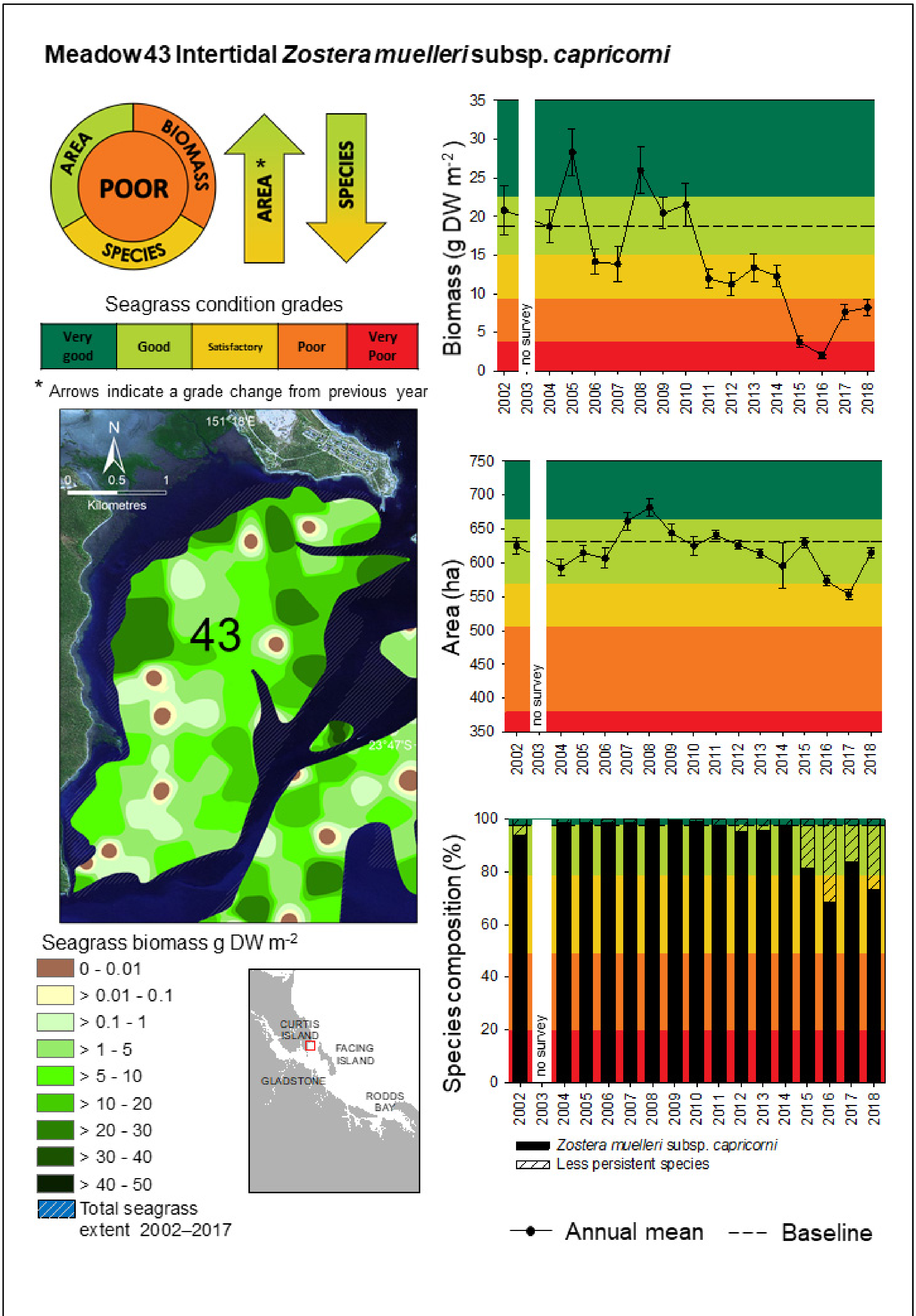


Figure 20. Meadow area, biomass and species composition for seagrass in Meadow 43, Zone 8: Mid Harbour, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

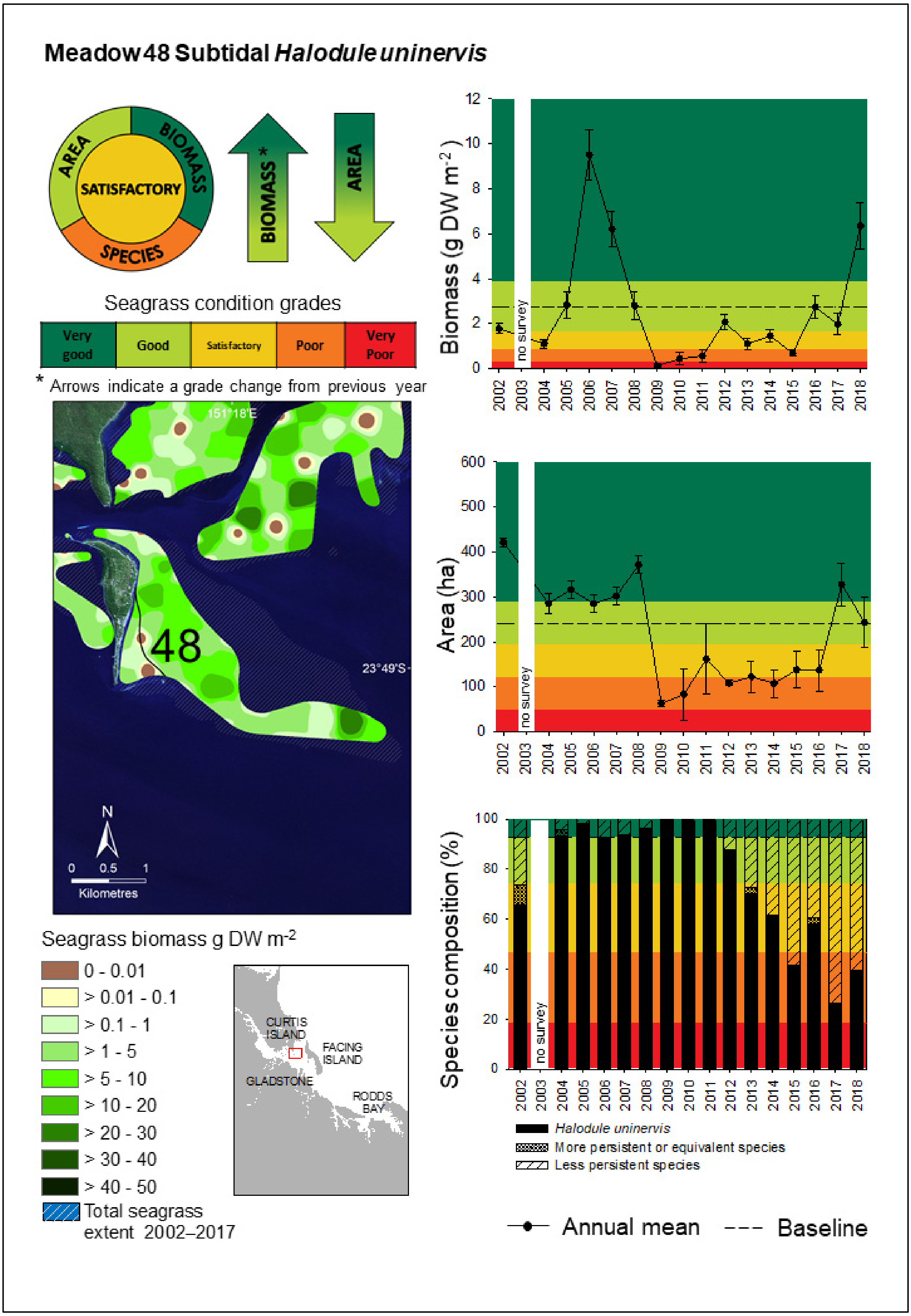


Figure 21. Meadow area, biomass and species composition for seagrass in Meadow 48, Zone 8: Mid Harbour, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

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

Seagrass condition in Zone 9: South Trees Inlet remained very good for the second consecutive year (Figure 22). There is one monitoring meadow in this zone, an intertidal meadow between the two wharves at South Trees Inlet (Meadow 60; Figure 22). This meadow experienced significant condition declines from 2009/2010 (2010/2011 reporting years). Since then, area and species composition recovered to very good condition in 2014 (2015 reporting year), followed by biomass returning to good condition one year later (Figure 23). Species composition was largely the dominant species *Z. muelleri* subsp. *capricorni* (93%) with the remaining fraction *H. ovalis* (Figure 23; Appendix 2).

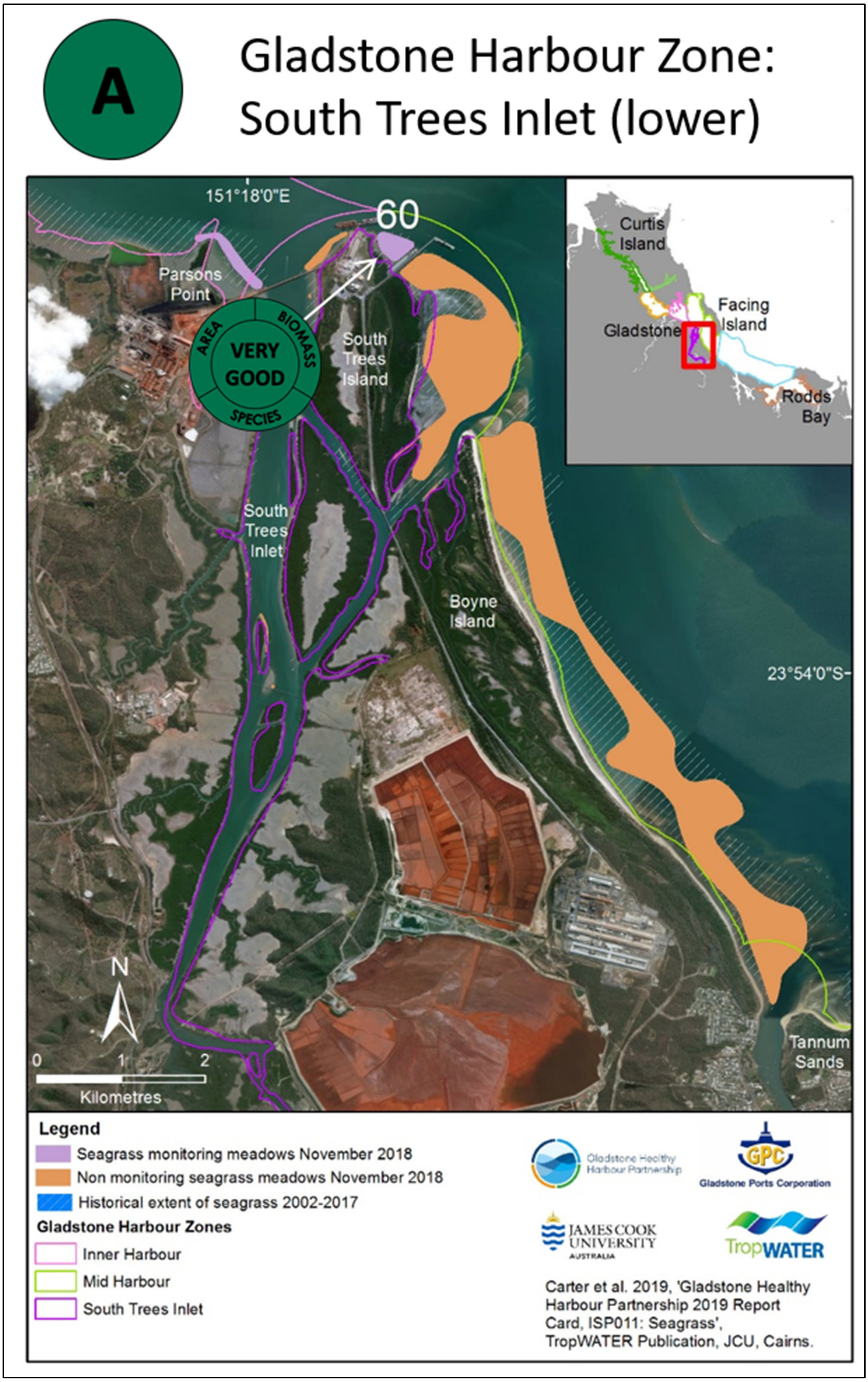


Figure 22. Seagrass condition in Zone 9: South Trees Inlet (lower), November 2018 survey (2019 reporting year).

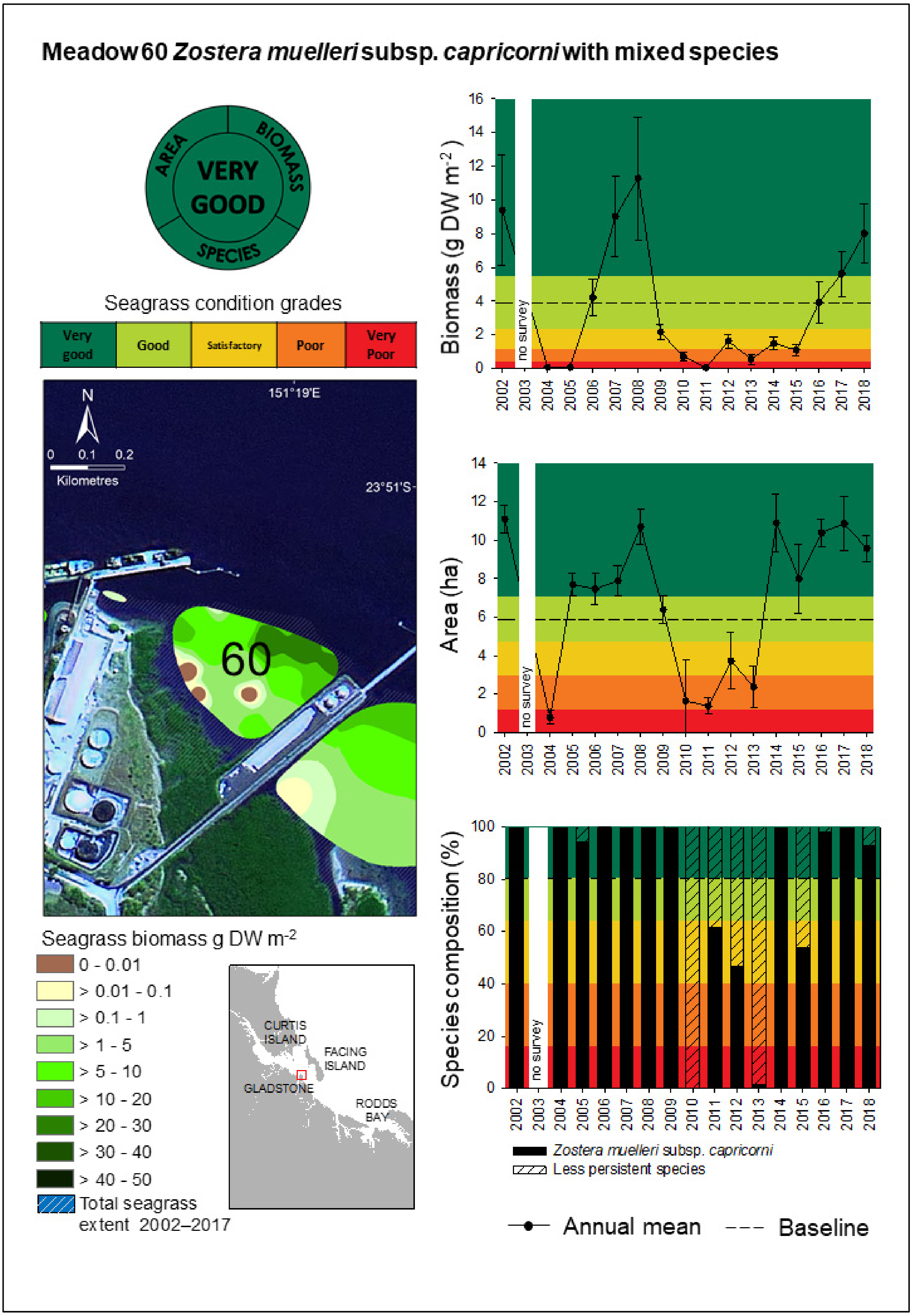


Figure 23. Meadow area, biomass and species composition for seagrass in Meadow 60, Zone 9: South Trees Inlet (lower), 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate.

3.3.6 **Zone 13: Rodds Bay**

Seagrass condition in Zone 13: Rodds Bay improved from very poor in 2017 (2018 reporting year) to poor condition this year (Figure 24). There are three intertidal monitoring meadows in the Rodds Bay Zone – Meadows 94, 96 and 104. Seagrass in Rodds Bay crashed between 2009 and 2011 (2010 and 2012 reporting years) and, apart from a brief recovery in 2014 (2015 reporting year), seagrass condition has remained poor to very poor. This year marked the first time in a decade that the overall condition of a monitoring meadow in this zone was graded as good (Meadow 96). Biomass and area increased in all three monitoring meadows, and species composition improved in two meadows.

Meadow 94

Meadow 94 is the smallest monitoring meadow in Rodds Bay. Meadow condition improved from very poor in 2017 (2018 reporting year) to satisfactory condition this year, with the overall score driven by biomass. This is the first time in a decade the meadow has achieved a grade greater than poor. Meadow area doubled from 2017 (2018 reporting year), but at 2.1 $\pm$ 0.3 ha remains below the 2.7 ha baseline (Figure 25). Biomass (3.29 ± 1.15 gDW m^{-2}) also is at the greatest value recorded since 2008 (2009 reporting year) but remains below the 9.1 gDW m^{-2} baseline. The dominant species *Z. muelleri* subsp. *capricorni* contribution to meadow biomass relative to *H. ovalis* decreased slightly from 2017 (2018 reporting year; Figure 25; Appendix 2).

Meadow 96

Meadow 96's overall condition improved from very poor in 2017 (2018 reporting year) to good this year, driven by species composition and biomass scores (Figure 26). Biomass, area and species composition grades all improved from 2017 (2018 reporting year), and this was the first time in a decade that all indicator grades were good to very good. Meadow biomass was 6.8 ± 1.6 gDW m^{-2}, a dramatic increase from <1 gDW m^{-2} in the previous year. This is the first time since 2009 (2010 reporting year) that biomass has reached a value similar to the baseline. Meadow area was the largest value ever recorded (very good condition; 355 $\pm$ 12 ha), and the contribution of the dominant species *Z. muelleri* subsp. *capricorni* relative to *H. ovalis* increased enough that the species composition score improved from satisfactory in 2017 (2018 reporting year) to good this year (Figure 26; Appendix 2).

Meadow 104

Overall condition of Meadow 104 improved from very poor condition in 2017 (2018 reporting year) to poor condition in 2018 (2019 reporting year), with grade improvements for all three indicators (Figure 27). Overall condition this year was due to poor meadow area, which at 17 $\pm$ 4 ha is approximately half the 34 ha baseline, despite an area increase from the previous year (Figure 27). Biomass condition improved from very poor in 2017 (2018 reporting year) to poor this year; meadow biomass (2.0 + 0.6 gDW m^{-2}) remains well below the 8 gDW m^{-2} baseline. The most dramatic improvement occurred for species composition following four consecutive years of decline and a very poor grade in 2017 (2018 reporting year). Species composition in the 2019 reporting year experienced a 65% increase in the dominant species *Z. muelleri* subsp. *capricorni* relative to *H. ovalis* and was in satisfactory condition (Figure 27; Appendix 2).

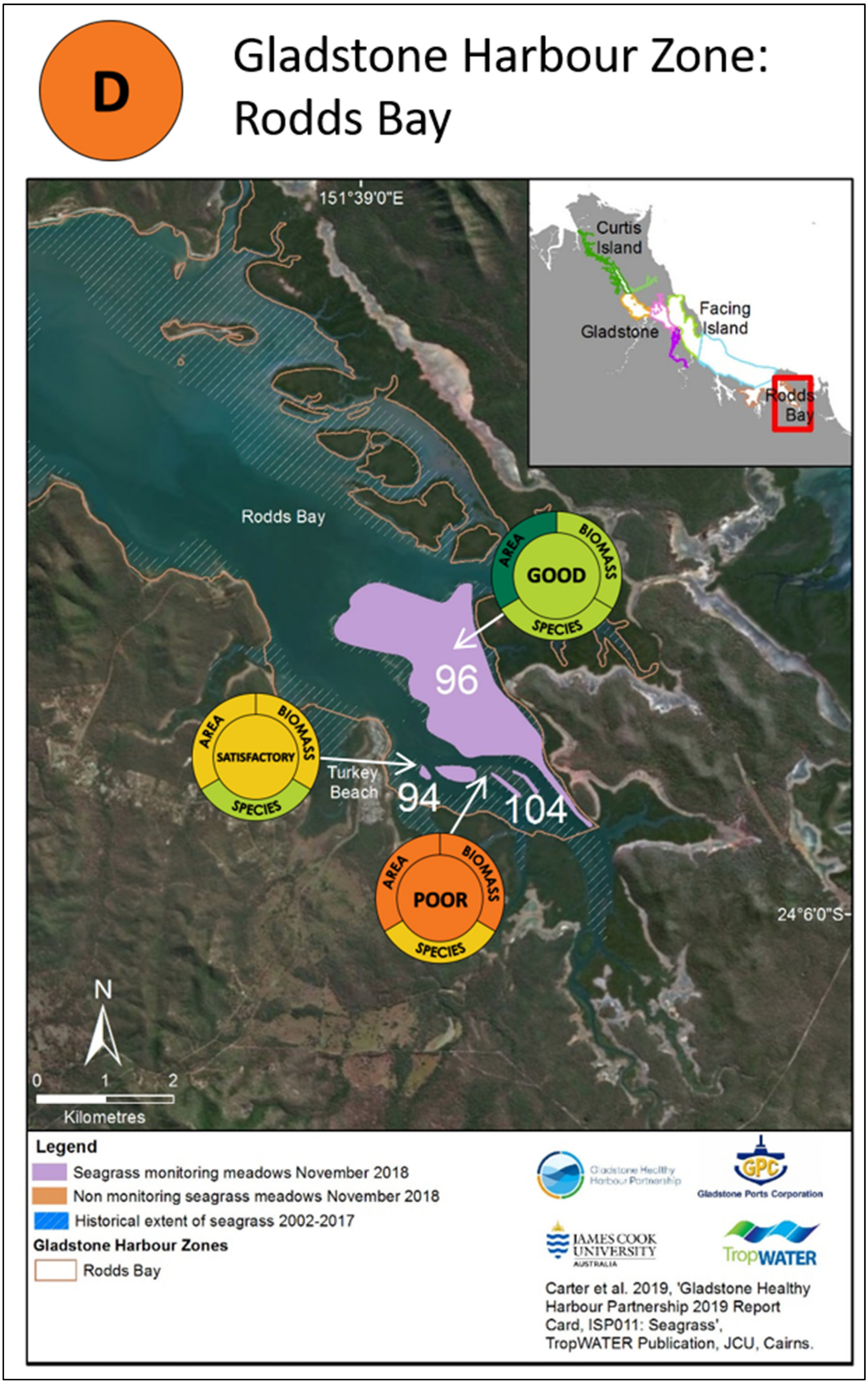


Figure 24. Seagrass condition in Zone 13: Rodds Bay, November 2018 survey (2019 reporting year).

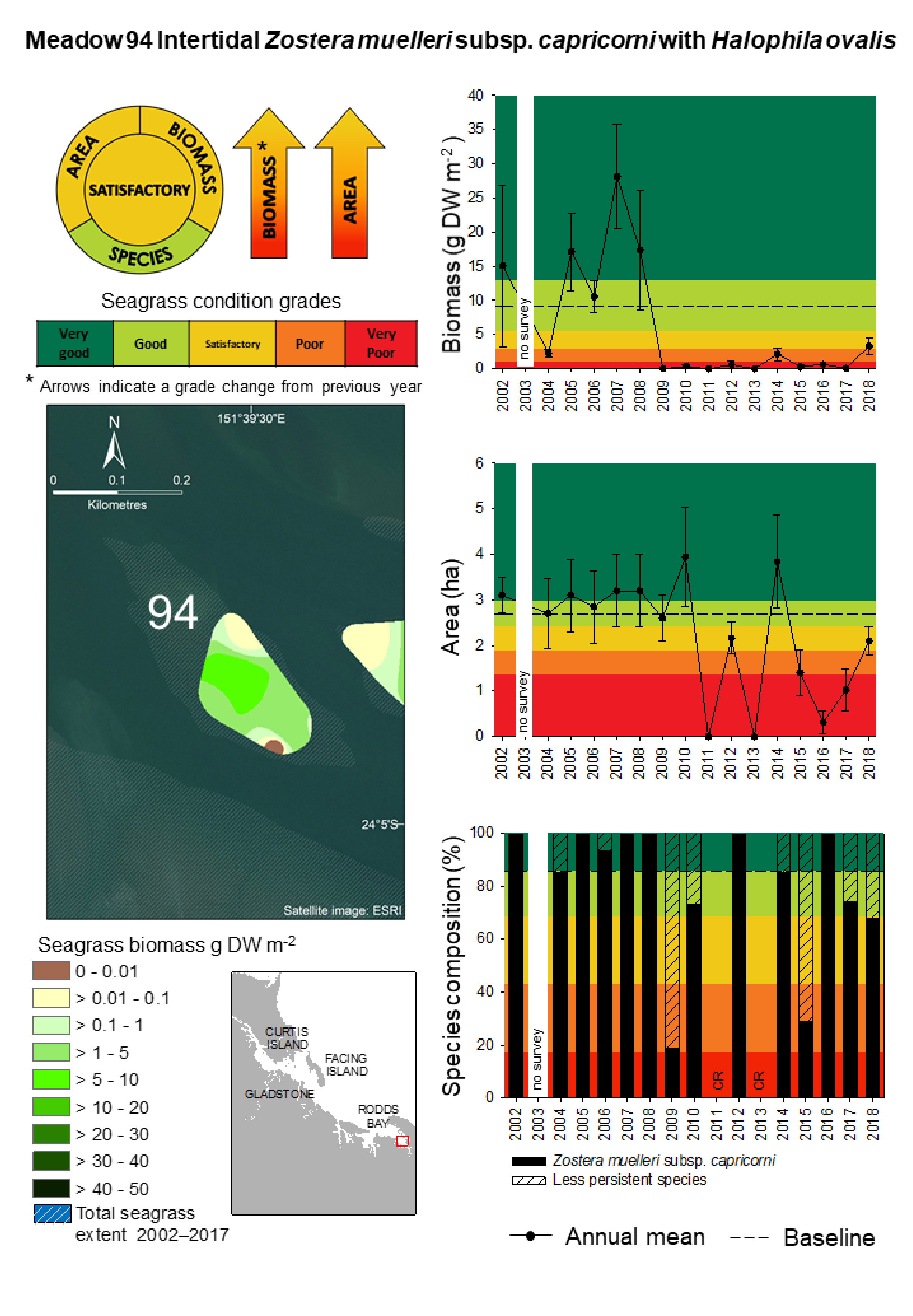


Figure 25. Meadow area, biomass and species composition for seagrass in Meadow 94, Zone 13: Rodds Bay, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate. CR: calculation restriction (species composition) - a species composition score was not calculated because seagrass was absent.

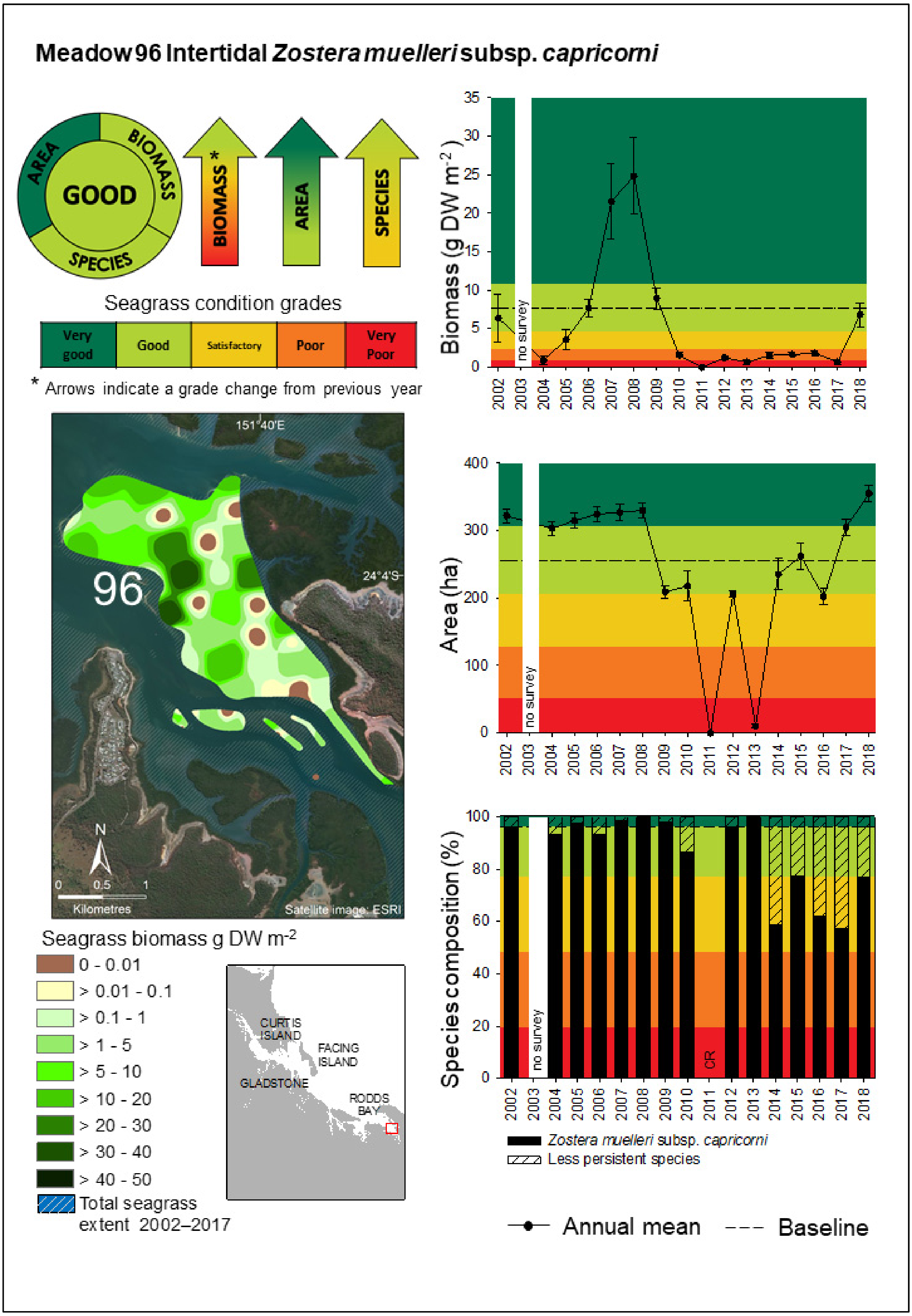


Figure 26. Meadow area, biomass and species composition for seagrass in Meadow 96, Zone 13: Rodds Bay, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate. CR: calculation restriction (species composition) - a species composition score was not calculated because seagrass was absent.

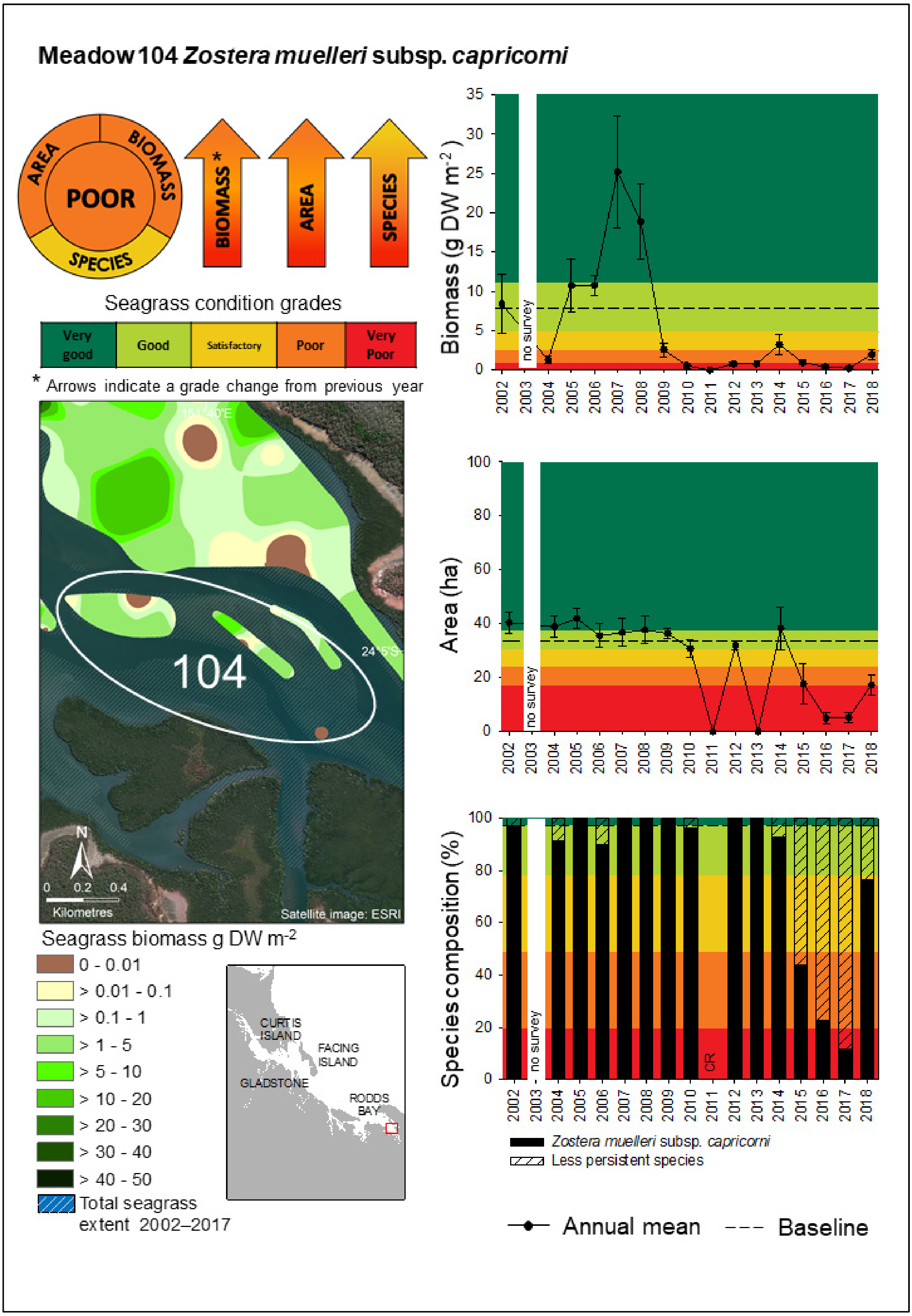


Figure 27. Meadow area, biomass and species composition for seagrass in Meadow 104, Zone 13: Rodds Bay, 2002 – 2018 (2003 – 2019 reporting years). Biomass error bars = SE; area error bars = "R" reliability estimate. CR: calculation restriction (species composition) - a species composition score was not calculated because seagrass was absent.

3.4 Historical Monitoring Data

Gladstone seagrass meadows are influenced by environmental conditions, particularly rainfall and Calliope River discharge (McCormack et al. 2013a). Years where >50% of meadows were assigned an overall meadow condition of poor or very poor either correspond with (2010-2017) or directly follow (2004) years of above average rainfall and river flow in the region (Figures 28, 29; Table 10). Rainfall and Calliope River flow in the 12 months preceding the November 2018 survey were at some of the lowest levels since monitoring began (Figures 28, 29). River flow from the Calliope River was negligible throughout 2018 (Figure 28). The only rainfall events that reached the long-term monthly average occurred in February 2018, a typical wet season event, and in October 2018, just prior to the annual seagrass monitoring survey (Figure 29).

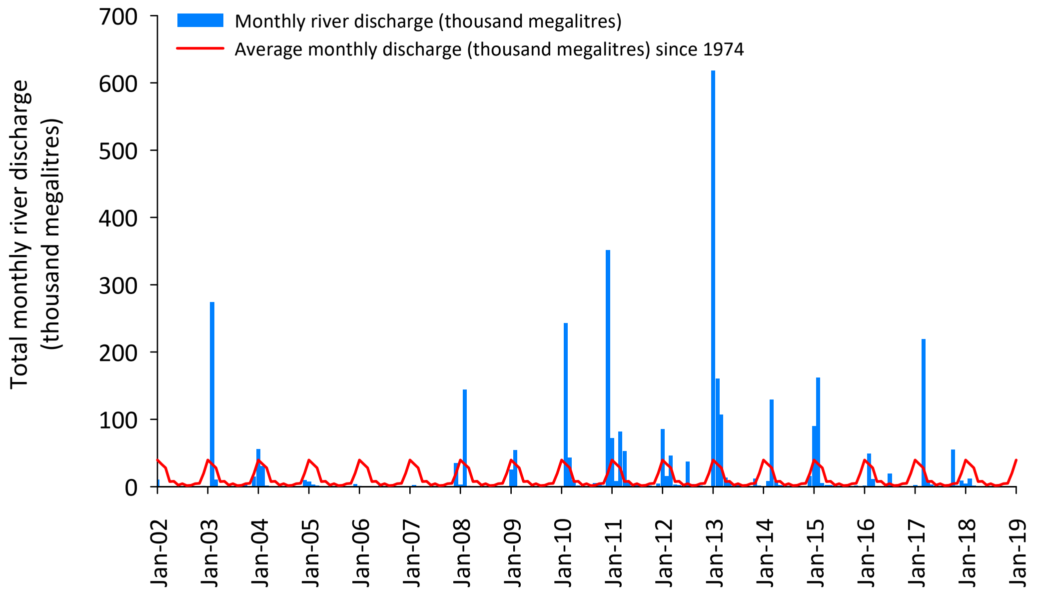


Figure 28. Total monthly river discharge and long-term average monthly discharge (thousand megalitres) for the Calliope River, January 2002-2019. Source: Department of Natural Resources and Mines, station # 132001A; www.water-monitoring.derm.qld.gov.au.

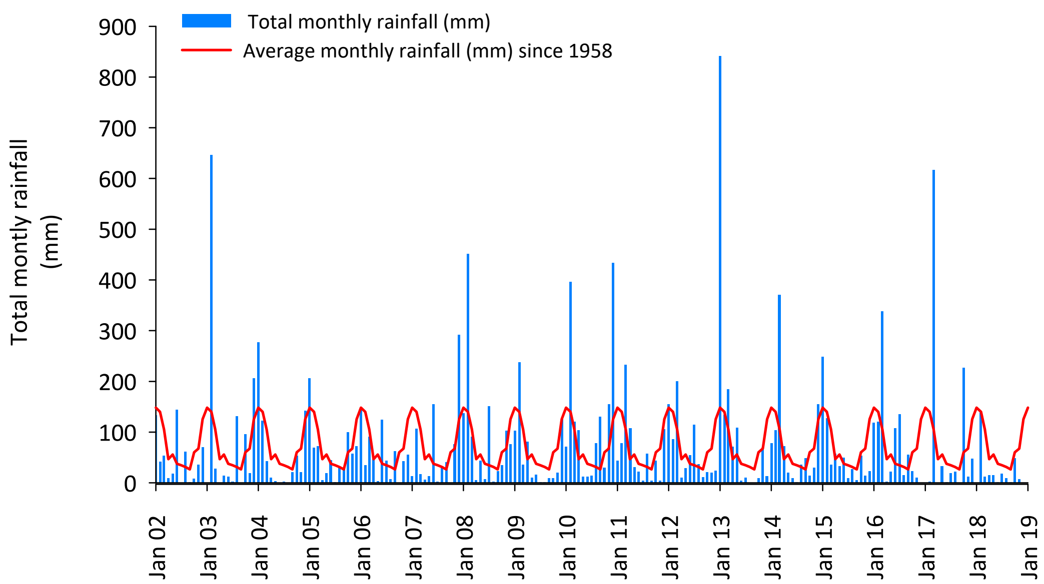


Figure 29. Total monthly rainfall and long-term average monthly rainfall (mm) at Gladstone, January 2002-2019. Source: Australian Bureau of Meteorology, station # 039123; http://www.bom.gov.au/climate/data/.

Seagrass biomass is highly sensitive to environmental conditions. Cycles of deterioration generally follow large rainfall and river flow events, and recovery follows relatively dry and benign years. Biomass condition was good or very good in all but one meadow in 2002 (2003 reporting year), then deteriorated in most meadows in 2004 following above average rainfall and river flow in 2003 (Figures 28, 29; 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 the following year. Biomass condition remained 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 (Figures 28, 29), 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 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 wet seasons that were characterised by above average rainfall and river flow (Bureau of Meteorology 2012). Above average wet season rainfall and river flow continued through to 2017 (Figures 28, 29). Biomass increased in all meadows in 2018 following one of the driest years since monitoring began.

Seagrass biomass was the main influence on overall meadow condition between 2002 and 2015 (2003 and 2016 reporting years) with the exception of the Western Basin meadows, where declines in area and a shift in species composition have had a greater influence than biomass since 2010 (Tables 10 - 13). In 2018 (2019 reporting year), biomass alone was responsible for overall meadow condition in five of the 14 monitoring meadows, and in combination with species composition in two meadows (Tables 9 - 11).

Species composition was the most frequent contributor to overall meadow score in 2018 (2019 reporting year; Table 9). Species composition condition was mostly good or very good for the first eight years of monitoring (Table 13). Exceptions in some years 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 (Figures 28, 29; Table 13). Similar declines in species composition condition occurred across the Gladstone Harbour region from 2011 (2012 reporting year) because the dominant species *Z. muelleri* subsp. *capricorni* or *H. uninervis* (Meadow 48 only) continue to contribute less to meadow biomass compared with the 10-year baseline (Table 13; Appendix 2). In 2017 (2018 reporting year), species composition was in poor or very poor condition in half of the monitoring meadows. This improved in 2018, with only four meadows below satisfactory condition and species composition grades improved (six meadows) or unchanged (six meadows) from the previous year. Condition grades declined over the last year in only two meadows (Meadow 8, Western Basin; Meadow 43, Mid Harbour), a significant improvement from 2016-2017 (2017-2018 reporting years) when species composition grades declined at seven meadows (Table 13).

Meadow area condition was either good or very good for nearly all meadows between 2002 and 2009 (2003 and 2010 reporting years), reflecting stability in area despite fluctuations in biomass condition during this period (Tables 11, 12). Following above average rainfall and river flow in early 2010, meadow area declined to poor-very poor condition in the majority of Western Basin, Inner Harbour and South Trees Inlet meadows by the November 2010 survey. By late 2011, seagrass had disappeared from the three Rodds Bay monitoring meadows (Table 12; Figures 25-27). Area condition improved in many meadows from 2011 to 2012, but reduced again in 2013 (2014 reporting year) following the largest recorded rainfall and river flow since seagrass monitoring began. During the past five years, meadow area has gradually improved to good or very good condition at the majority of monitoring meadows (Table 12). This year, only one meadow (Meadow 104, Rodds Bay) is below satisfactory condition; this is the first time in a decade that so many meadows have been above poor condition (Table 12).

Table 10. Overall scores and grades for individual monitoring meadows, 2002 – 2018 (2003 – 2019 reporting years). No survey conducted in 2003 (2004 reporting year). Grades: Very good, dark green; good, light green; satisfactory, yellow; poor, orange; very poor, red. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. The Narrows	21	NS	NS	NS	NS	NS	NS	0.97	0.72	0.74	0.64	0.22	0.25	0.39	0.59	0.45	0.71
3. Western Basin	4	0.75	0.64	0.45	0.72	0.86	0.74	0.90	0.06	0.38	0.67	0.31	0.42	0.52	0.66	0.48	0.62
	5	0.61	0.39	0.51	0.83	0.84	0.89	0.60	0.44	0.27	0.60	0.21	0.41	0.42	0.61	0.51	0.64
	6	0.65	0.29	0.61	0.74	0.87	0.70	0.87	0.19	0.31	0.44	0.45	0.67	0.68	0.65	0.45	0.59
	7	0.66	0.83	0.11	0.92	0.48	0.71	0.35	0.00	0.00	0.09	0.25	0.68	0.78	0.36	0.00	0.91
	8	0.88	0.29	0.16	0.75	0.82	0.66	0.67	0.60	0.16	0.47	0.20	0.47	0.45	0.23	0.41	0.38
	52-57*	NS	NS	NS	NS	NS	NS	0.55	0.01	0.08	0.66	0.71	0.52	0.42	0.69	0.78	0.97
5. Inner Harbour	58	0.72	0.41	0.65	0.39	0.68	0.76	0.71	0.00	0.25	0.54	0.21	0.47	0.28	0.37	0.09	0.21
8. Mid Harbour	43	0.77	0.70	0.75	0.63	0.62	0.91	0.80	0.77	0.57	0.55	0.61	0.58	0.25	0.14	0.42	0.45
	48	0.65	0.55	0.76	0.84	0.86	0.76	0.12	0.33	0.38	0.46	0.50	0.46	0.44	0.54	0.50	0.60
9. South Trees	60	0.91	0.05	0.06	0.77	0.88	0.94	0.63	0.16	0.03	0.55	0.16	0.54	0.48	0.75	0.85	0.89
13. Rodds Bay	94	0.86	0.44	0.86	0.79	0.87	0.87	0.00	0.09	0.00	0.16	0.00	0.42	0.08	0.06	0.01	0.53
	96	0.71	0.27	0.59	0.75	0.93	0.95	0.66	0.38	0.00	0.33	0.05	0.38	0.40	0.42	0.23	0.69
	104	0.77	0.32	0.84	0.79	0.84	0.86	0.51	0.18	0.00	0.24	0.00	0.55	0.28	0.07	0.07	0.27

* 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.
NS: not surveyed.

Table 11. Biomass scores and grades for individual monitoring meadows, 2002 – 2018 (2003 – 2019 reporting years). No survey conducted in 2003 (2004 reporting year). Grades: Very good, dark green; good, light green; satisfactory, yellow; poor, orange; very poor, red. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. The Narrows	21	NS	NS	NS	NS	NS	NS	0.97	0.87	0.74	0.64	0.48	0.25	0.39	0.64	0.45	0.75
3. Western Basin	4	0.75	0.72	0.56	0.72	0.86	0.74	0.90	0.07	0.63	0.94	0.92	0.96	0.83	1.00	1.00	1.00
	5	0.61	0.39	0.51	0.84	0.97	0.93	0.60	0.44	0.65	0.60	0.67	0.53	0.49	0.70	0.67	0.91
	6	0.65	0.29	0.61	0.85	0.97	0.70	0.87	0.28	0.52	0.68	0.70	0.67	0.68	0.78	0.58	0.95
	7	0.66	0.83	0.11	0.92	0.94	0.71	0.35	0.00	0.00	CR	0.85	0.88	0.91	0.68	0.00	0.94
	8	0.88	0.29	0.16	0.80	0.96	0.66	0.67	0.61	0.57	0.69	0.78	0.67	0.88	0.87	0.87	1.00
	52-57	NS	NS	NS	NS	NS	NS	0.55	0.01	0.08	0.66	0.85	0.52	0.42	0.85	0.90	0.97
5. Inner Harbour	58	0.72	0.41	0.65	0.39	0.95	0.93	0.94	0.00	0.25	0.54	0.36	0.47	0.42	0.73	0.18	0.21
8. Mid Harbour	43	0.81	0.75	0.95	0.63	0.62	0.91	0.80	0.83	0.57	0.55	0.61	0.58	0.25	0.14	0.42	0.45
	48	0.66	0.55	0.76	0.98	0.90	0.76	0.12	0.33	0.38	0.69	0.55	0.62	0.44	0.75	0.68	0.91
9. South Trees	60	0.91	0.05	0.06	0.77	0.91	0.94	0.63	0.36	0.03	0.56	0.31	0.54	0.48	0.75	0.85	0.89
13. Rodds Bay	94	0.86	0.44	0.88	0.79	0.95	0.88	0.00	0.09	0.00	0.16	0.00	0.42	0.08	0.17	0.01	0.53
	96	0.71	0.27	0.59	0.75	0.93	0.96	0.79	0.38	0.00	0.33	0.22	0.38	0.40	0.42	0.23	0.72
	104	0.77	0.32	0.84	0.84	0.95	0.91	0.51	0.18	0.00	0.24	0.24	0.55	0.28	0.13	0.07	0.44

CR: calculation restriction (biomass) - a score was not calculated because seagrass was sampled by van Veen grab only (precludes biomass assessment).
NS: not surveyed.

Table 12. Area scores and grades for individual monitoring meadows, 2002 – 2018 (2003 – 2019 reporting years). No survey conducted in 2003 (2004 reporting year). Grades: Very good, dark green; good, light green; satisfactory, yellow; poor, orange; very poor, red. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. The Narrows	21	NS	NS	NS	NS	NS	NS	0.97	0.72	0.75	0.80	0.22	0.71	0.86	0.59	0.71	0.91
3. Western Basin	4	0.86	0.86	0.80	0.86	0.95	0.84	0.96	0.06	0.38	0.70	0.31	0.42	0.52	0.66	0.80	0.82
	5	0.87	0.81	0.78	0.84	0.84	0.89	0.95	0.64	0.27	0.70	0.21	0.41	0.58	0.69	0.74	0.74
	6	0.96	0.76	0.85	0.89	0.97	0.94	0.95	0.19	0.53	0.44	0.45	0.83	0.82	0.76	0.96	0.76
	7	0.75	0.97	0.86	0.99	0.48	0.73	0.71	0.00	0.00	0.09	0.25	0.68	0.78	0.36	0.00	0.91
	8	0.88	0.83	0.75	0.86	0.91	0.90	0.98	0.60	0.16	0.47	0.20	0.60	0.51	0.29	0.53	0.55
	52-57*	NS	NS	NS	NS	NS	NS	0.79	0.02	0.10	0.85	0.71	0.87	0.88	0.69	0.78	0.98
5. Inner Harbour	58	0.99	0.56	0.73	0.73	0.68	0.76	0.71	0.00	0.30	0.94	0.75	0.96	0.92	0.87	0.83	0.57
8. Mid Harbour	43	0.77	0.70	0.75	0.73	0.85	0.94	0.81	0.77	0.80	0.77	0.74	0.71	0.78	0.66	0.61	0.75
	48	0.99	0.85	0.88	0.84	0.86	0.94	0.30	0.37	0.59	0.46	0.50	0.46	0.54	0.54	0.89	0.76
9. South Trees	60	0.98	0.17	0.87	0.86	0.88	0.97	0.79	0.32	0.28	0.57	0.42	0.97	0.88	0.96	0.97	0.93
13. Rodds Bay	94	0.86	0.76	0.86	0.81	0.87	0.87	0.72	0.92	0.00	0.58	0.00	0.91	0.28	0.06	0.19	0.56
	96	0.92	0.84	0.89	0.93	0.94	0.95	0.66	0.68	0.00	0.65	0.05	0.71	0.76	0.65	0.85	1.00
	104	0.96	0.87	0.90	0.80	0.84	0.86	0.83	0.66	0.00	0.70	0.00	0.86	0.28	0.07	0.08	0.27

NS: not surveyed.

Table 13. Species composition scores and grades for individual monitoring meadows, 2002 – 2018 (2003 – 2019 reporting years). No survey conducted in 2003 (2004 reporting year). Grades: Very good, dark green; good, light green; satisfactory, yellow; poor, orange; very poor, red. See Table 7 for grading scale.

Zone	Meadow	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. The Narrows	21	NS	NS	NS	NS	NS	NS	0.99	0.91	0.86	0.82	0.66	0.66	0.61	0.66	0.68	0.67
3. Western Basin	4	0.95	0.57	0.34	0.75	0.89	0.76	0.90	0.77	0.84	0.65	0.86	0.85	0.78	0.73	0.16	0.43
	5	0.88	0.58	0.62	0.83	0.93	0.97	0.91	0.80	0.61	0.68	0.50	0.65	0.34	0.52	0.35	0.54
	6	0.80	0.63	0.82	0.63	0.77	0.85	0.90	0.95	0.09	0.87	0.62	0.67	0.67	0.54	0.31	0.43
	7	1.00	0.95	1.00	0.97	1.00	1.00	1.00	CR	CR	1.00	1.00	1.00	1.00	1.00	CR	1.00
	8	0.88	0.81	0.98	0.70	0.73	0.83	0.71	0.83	0.37	0.61	0.39	0.35	0.38	0.18	0.29	0.22
	52-57*	NS	NS	NS	NS	NS	NS	1.00	1.00	1.00	0.93	0.73	0.98	1.00	0.98	1.00	1.00
5. Inner Harbour	58	0.96	0.70	0.97	0.68	0.87	0.91	0.95	CR	0.50	0.59	0.07	0.50	0.14	0.00	0.00	0.56
8. Mid Harbour	43	0.81	0.91	0.91	0.89	0.89	0.96	0.98	0.95	0.84	0.82	0.83	0.85	0.68	0.60	0.71	0.62
	48	0.65	0.86	0.96	0.85	0.87	0.92	1.00	1.00	1.00	0.80	0.64	0.58	0.46	0.58	0.32	0.44
9. South Trees	60	1.00	1.00	0.96	1.00	1.00	1.00	1.00	0.00	0.63	0.54	0.02	1.00	0.59	0.98	1.00	0.95
13. Rodds Bay	94	1.00	0.84	1.00	0.93	1.00	1.00	0.27	0.70	CR	1.00	CR	0.85	0.36	1.00	0.71	0.65
	96	0.85	0.82	0.92	0.82	0.95	1.00	0.92	0.75	CR	0.86	1.00	0.56	0.66	0.57	0.55	0.65
	104	0.85	0.79	0.96	0.78	1.00	1.00	0.97	0.84	CR	1.00	1.00	0.80	0.46	0.28	0.15	0.64

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

NS: not surveyed.

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, among Gladstone Harbour zones, and across Gladstone Harbour over time. This is the sixth year we have analysed seagrass condition using a report card approach, and the first year that Gladstone Harbour's overall seagrass condition has improved beyond poor (Bryant et al. 2018; Carter et al. 2017; Carter et al. 2016; Carter et al. 2015b; Bryant et al. 2014). The harbour's satisfactory seagrass condition in the 2019 reporting year therefore marks a noteworthy improvement. This was driven by increased overall condition scores in every monitoring zone. In particular, condition scores in The Narrows and Western Basin zones increased from the poor range in 2017 (2018 reporting year) to the good range this year, and substantial recovery occurred in the Rodds Bay zone for the first time since major seagrass loss a decade ago. Scores increased in the Inner Harbour and South Trees Inlet zones despite overall condition grades remaining unchanged.

In the past decade, Gladstone Harbour has experienced several consecutive years of above average rainfall and river flow, and a series of tropical cyclones (TC) that affected Queensland's east coast from Cairns to Gladstone (see Section 4.1). Seagrass declines have been linked to flood plumes due to a reduction in available light (Campbell and McKenzie 2004), the key environmental driver of seagrass distribution, abundance and species composition (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 found significant negative relationships between Calliope River flow and rainfall with seagrass biomass (McCormack et al. 2013b). Increased seagrass condition scores across all zones in 2018, including at the Rodds Bay out-of-port reference meadows, indicates improved seagrass condition was related to overall environmental conditions rather than anthropogenic activity within the port. Weather-related cycles in seagrass decline and recovery since monitoring began 17 years ago further indicate that lower than average rainfall and river flow throughout 2018, and relatively benign conditions due to the lack of episodic rain events, provided ideal conditions for seagrass growth. Previous light monitoring in the area demonstrates that benthic light increases when significant weather events are reduced, providing conditions favourable for seagrass growth (Chartrand et al. 2017). The return of subtidal Meadow 7 in very good condition this reporting year, following its disappearance only 12 months prior, also suggests recent improvements in benthic light. Below average daytime tidal exposure this reporting year likely provided further protection from extreme desiccation and thermal stress for Gladstone Harbour's intertidal seagrasses (Chartrand et al. 2019; Unsworth et al. 2012).

Despite overall improvements in seagrass condition, the continued dominance of less persistent and colonising species in many monitoring meadows is hindering their full recovery. Species composition was the lowest of the three indicator scores in 50% of the meadows, meaning that overall meadow scores were often in the poor to satisfactory range despite good to very good biomass and area scores (Table 9). This pattern was consistent across the Western Basin's four intertidal *Z. muelleri* subsp. *capricorni* meadows, where the less stable colonising species *H. ovalis* and/or *H. decipiens* have maintained dominance despite improvements in each meadow's biomass and area. This species succession order is a typical indicator of past disturbance and the beginning of seagrass meadow recovery (Rasheed 2004), which in this zone has been particularly slow. This same pattern of species recovery has occurred in Cairns' seagrass meadows following widespread loss in the same period as at Gladstone (Rasheed et al. 2019). The Western Basin is an area with naturally turbid waters and shifting mud banks, which may be restricting the ability of the more persistent *Z. muelleri* subsp. *capricorni* to achieve and maintain a foothold. Dry and benign environmental conditions recorded during 2018 clearly favoured seagrass growth (Section 3.3, 3.4), with small increases in the contribution of *Z. muelleri* subsp. *capricorni* recorded (Table 13). If favourable conditions continue throughout 2019, we expect further increases in the contribution of larger more persistent species to meadow biomass.

Additional stressors such as herbivory and sediment changes may be contributing to suppressed recovery at some meadows. Seagrasses in the region provide a valuable food source for megaherbivores (dugongs and green turtles), including meadows adjacent to port infrastructure and industrial activity. Dugong feeding trails and turtle sightings across all zones where seagrass is present suggests megaherbivore grazing/cropping is an important driver of seagrass condition. Large herbivores have the potential to significantly impact seagrass condition, with major meadow loss recorded in other locations from herbivory (Christianen et al. 2014). A research program is currently underway in Gladstone Harbour to measure the potential effects of dugong and turtle feeding on meadow biomass, structure and condition. Preliminary results show that excluding turtle and dugong from areas does increase seagrass biomass (A. Scott, pers. comm).

Despite condition improvements in many of the seagrass meadows, the largest and historically densest seagrass meadow at Pelican Banks (Meadow 43) maintained relatively low biomass and proportion of the dominant species Z. *muelleri* subsp. *capricorni.* In 2018, this meadow was in poor condition. 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 recent 3-year study of dugong feeding in the region (Rasheed et al. 2017). Green turtles also regularly feed on the meadow (Hamann et al. 2016; TropWATER field staff, pers. comm.). Anecdotal evidence also indicates that sediment movement and accumulation on the southernmost section of Pelican Banks may have led to the reduction in seagrass biomass most apparent at this end of the meadow. However, direct measurements of sediment change have not been made, with only indirect evidence from a 2016 study of seagrass seed banks in which coring in the area indicated a deeper burial of seeds (Bryant et al. 2016). Movement and accumulation of sediments can influence seagrass condition (Cabaço et al. 2008), and sediment dynamics at Pelican Banks should be investigated further if seagrass condition worsens. Given the meadow's historical importance as the most stable meadow in the region, its future recovery remains key to the marine environmental health of Gladstone Harbour.

4.1 Comparisons with State-wide Monitoring Program

The improved seagrass condition observed in Gladstone this year was largely consistent with long-term monitoring locations along Queensland's east coast. Large scale declines in seagrass meadow area, biomass, and the dominant species occurred between 2009 and 2011 at monitoring meadows at Cairns (Reason and Rasheed 2018a), Mourilyan (Reason and Rasheed 2018b), Townsville (Bryant and Rasheed 2018), and Abbot Point (Davey and Rasheed 2018). 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), TC Marcia (February 2015), and TC Debbie (March 2017). 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 Harbour, this corresponded with grade improvements in overall meadow condition for seven of the 14 monitoring meadows, and score improvements (but without a grade change) in a further four meadows (Table 10). High rainfall and flooding associated with TC Debbie in March 2017 coincided with seagrass condition declines at Gladstone and at Abbot Point, which was also affected by this weather event (Davey and Rasheed 2018). Overall dry and benign weather conditions in 2018 coincided with improved seagrass condition scores (but stable grades) at Cairns (Rasheed et al. 2019) and Hay Point's deepwater meadow (York and Rasheed 2019), and continued good condition in Townsville (Bryant et al. 2019).

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. Seagrass recovery will be influenced by local climate conditions including available light, the severity of the initial decline, the available seedbank, and that location's connectivity to similar meadows (Connelly et al. 2018; Grech et al. 2018; O'Brien et al. 2017; Kendrick et al. 2012). 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. 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). However, recovery has differed among locations.

Following widespread seagrass loss along Queensland's east coast from 2009, Townsville's monitoring meadows were the first to recover to good condition in 2016 (Wells and Rasheed 2017). At the other extreme, Mourilyan Harbour seagrass remains in very poor condition and there is little prospect of seagrass recovery without some form of restoration (Reason and Rasheed 2018b). This discrepancy is likely due to Townsville meadows maintaining remnant populations following disturbance and also being part of a highly connected seagrass network (Bryant et al. 2019; Grech et al. 2018). In contrast, Mourilyan Harbour experienced complete loss of the dominant species and its seedbank, and seagrass grows in a relatively closed estuary (Reason and Rasheed 2018b). In this context, meadows in Gladstone have shown reasonable resilience and ability to recover. Sustained seagrass growth during 2019 will likely enhance the replenishment of seed reserves and provide an opportunity for adult plant populations, particulary of the more stable and historically dominant species *Z. muelleri* subsp. *capricorni*, to further increase biomass and improve resilience to future impacts.

Seagrass meadows away from Queensland's east coast generally have fared much better over recent times. Over the last decade, Torres Strait and the Gulf of Carpentaria have experienced a relatively lower frequency and/or severity of extreme weather events, rainfall and flooding, than Queensland's east coast. Seagrass condition at monitoring locations across Torres Strait (Carter et al. 2018; McKenna and Rasheed 2018) and Weipa (McKenna and Rasheed 2019) did not experience the same declines in 2009-2011, and overall seagrass condition was good at both locations in 2018. Karumba also maintained good to very good seagrass condition since 2004; however, condition declined from very good in 2017 to satisfactory in 2018 following significant rainfall and flooding of the Norman River associated with TC Nora, which passed over the region in late March 2018 (van de Wetering et al. 2019).

4.2 Implications for Management

Natural recovery from large declines can take up to five years (Preen et al. 1995) or potentially longer (Birch and Birch 1984). Under favourable environmental conditions in 2018, Gladstone Harbour meadows generally increased their area, biomass, and the dominance of each meadow's key foundation species. Full seagrass recovery following widespread loss in 2009-2011 still has not occurred in many meadows, largely due to the continued prevalence of less persistent pioneering *Halophila* species. The dominance of *Halophila* species in meadows previously dominated by *Z. muelleri* subsp. *capricorni* means these meadows have reduced resilience to future pressures and impacts.

Favourable growing conditions can cause rapid recovery from disturbance (Rasheed 1999). The general improvement in seagrass condition provides a strong foundation for further recovery in the region, assuming favourable conditions remain. Further improvements 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. Activities that could reduce water quality in the region should be avoided or managed to ensure further recovery of seagrass meadows is not hindered. Where such activities are planned, managing water quality and maintaining benthic light at sufficient levels for seagrass growth will be important for the maintenance of seagrasses and the services they provide (Chartrand et al. 2016).

4.3 Limitations of the Study

There remains a large section from South Trees Inlet to Rodds Bay with no monitoring meadows assessed. This is because the 14 monitoring meadows were originally selected for their relevance to monitoring port activities occurring at that time. Coastal seagrasses within this zone are known to be regularly utilised by turtles and dugong with substantial subtidal meadows present. Ideally, an additional two coastal meadows within this zone should be added to the monitoring program to fill this gap in condition reporting.

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

Birch, W. R. and Birch, M. 1984. Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia: a decade of observations. Aquatic Botany, **19**: 343-367

Bryant, C., Carter, A., Chartrand, K., Wells, J. and Rasheed, M. 2018. Gladstone Healthy Harbour Partnership 2018 Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 18/22. James Cook University, Cairns, 67 pp.

Bryant, C., Carter, A., Jarvis, J., Reason, C. and Rasheed, M. 2016. Port Curtis seagrass seed bank density and viability studies - Year 2. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Cairns, 29 pp.

Bryant, C., Jarvis, J. C., York, P. and Rasheed, M. 2014. 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.

Bryant, C., Wells, J. and Rasheed, M. 2019. Port of Townsville Annual Seagrass Monitoring Survey: October 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/01. James Cook University Cairns, 47 pp.

Bryant, C. V. and Rasheed, M. A. 2018. Port of Townsville annual seagrass monitoring: September 2017. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 18/11. James Cook University, Cairns, 49 pp.

Bureau of Meteorology. 2012. Record-breaking La Niña events. Bureau of Meteorology, Melbourne, 24 pp.

Cabaço, S., Santos, R. and Duarte, C. M. 2008. The impact of sediment burial and erosion on seagrasses: A review. Estuarine, Coastal and Shelf Science, **79**: 354-366

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., Bryant, C., Davies, J. and Rasheed, M. 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.

Carter, A., Mellors, J. and Rasheed, M. 2018. Torres Strait Seagrass 2018 Report Card. Centre for Tropical Water & Aquatic Ecosystem Research Publication 18/25, James Cook University, Cairns, 65 pp.

Carter, A., Wells, J. and Rasheed, M. 2017. Gladstone Healthy Harbour Partnership 2017 Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 17/29, James Cook University, Cairns, 66 pp.

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., Bryant, C., Carter, A., Ralph, P. and Rasheed, M. 2016. Light thresholds to prevent dredging impacts on the Great Barrier Reef seagrass, *Zostera muelleri* spp. *capricorni*. Frontiers in Marine Science, **3**: 17

Chartrand, K., Wells, J., Carter, A. and Rasheed, M. 2019. Seagrasses in Port Curtis and Rodds Bay 2018: Annual long-term monitoring. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/02. James Cook University, Cairns, 71 pp.

Chartrand, K., Wells, J. and Rasheed, M. 2017. Seagrass Senstitive Reseptor Site Monitoirng for the Western Basin Dredging Disposal Project in Port Curtis and Rods Bay, 2009 to 2016 - Final Report. Centre for Tropical Water & Aquaculutre Ecosystem Research (TropWATER), Publication 17/03, James Cook University, Cairns, 61 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, Northern Fisheries Centre, 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.

Christiaen, B., Lehrter, J., Goff, J. and Cebrian, J. 2016. Functional implications of changes in seagrass species composition in two shallow coastal lagoons. Marine Ecology Progress Series, **557**: 11

Christianen, M. J. A., Herman, P. M. J., Bouma, T. J., Lamers, L. P. M., van Katwijk, M. M., van der Heide, T., Mumby, P. J., Silliman, B. R., Engelhard, S. L., van de Kerk, M., Kiswara, W. and van de Koppel, J. 2014. Habitat collapse due to overgrazing threatens turtle conservation in marine protected areas. Proceedings of the Royal Society B: Biological Sciences, **281**: 1-7

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.

Connelly, R., Jackson, E., Kendrick, G., Macreadie, P., Maxwell, P. and O'Brien, K. 2018. Seagrass dynamics and resilience. Page 197-212. In A. Larkum, P. Ralph and G. Kendrick (eds), Seagrasses of Australia. Springer, Cham

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

Davey, P. and Rasheed, M. 2018. Port of Abbot Point Long-Term Seagrass Monitoring Program - 2017. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns, 42 pp.

Davies, J., Bryant, C., Carter, A. and Rasheed, M. 2016. Seagrasses in Port Curtis and Rodds Bay 2015: Annual long-term monitoring. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), Publication 16/04, James Cook University, Cairns, 66 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

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.

Grech, A., Coles, R. and Marsh, H. 2011. A broad-scale assessment of the risk to coastal seagrasses from cumulative threats. Marine Policy, **35**: 560-567

Grech, A., Hanert, E., McKenzie, L., Rasheed, M., Thomas, C., Tol, S., Wang, M., Waycott, M., Wolter, J. and Coles, R. 2018. Predicting the cumulative effect of multiple disturbances on seagrass connectivity. Global Change Biology, **24**: 3093-3104

Hamann, M., Limpus, C. J., Shimada, T. and Preston, S. 2016. Annual report on green turtle tracking and habitat use in Port Curtis – Year 2 (2015). Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. Cairns, 19 pp.

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

Hyndes, G. A., Kendrick, A. J., MacArthur, L. D. and Stewart, E. 2003. Differences in the species- and size-composition of fish assemblages in three distinct seagrass habitats with differing plant and meadow structure. Marine Biology, **142**: 12 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

Kendrick, G. A., Waycott, M., Carruthers, T. J. B., Cambridge, M. L., Hovey, R., Krauss, S. L., Lavery, P. S., Les, D. H., Lowe, R. J., Vidal, O. M. I., Ooi, J. L. S., Orth, R. J., Rivers, D. O., Ruiz-Montoya, L., Sinclair, E. A., Statton, J., van Dijk, J. K. and Verduin, J. J. 2012. The central role of dispersal in the maintenance and persistence of seagrass populations. BioScience, **62**: 56-65

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

Lamb, J. B., van de Water, J. A. J. M., Bourne, D. G., Altier, C., Hein, M. Y., Fiorenza, E. A., Abu, N., Jompa, J. and Harvell, C. D. 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science, **355**: 731-733

Lavery, P. S., Mateo, M.-Á., Serrano, O. and Rozaimi, M. 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PLoS ONE, **8**: e73748

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.

McCormack, C., Rasheed, M., Davies, J., Carter, A., Sankey, T. and Tol, S. 2013a. 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.

McCormack, C. V., Rasheed, M. A., Davies, J., Carter, A., Sankey, T. and Tol, S. 2013b. 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 and Aquatic Ecosystem Research (TropWATER), Publication 13/16, 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. and Rasheed, M. 2019. Port of Weipa long-term seagrass monitoring program, 2000 - 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/04. James Cook University, Cairns, 49 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

McKenna, S. A. and Rasheed, M. A. 2018. Long-term Seagrass Monitoring in the Port of Thursday Island: April 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns, 40 pp.

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

Micheli, F., Bishop, M. J., Peterson, C. H. and Rivera, J. 2008. Alteration of seagrass species composition and function over two decades. Ecological Monographs, **78**: 225-244

O'Brien, K. R., Waycott, M., Maxwell, P., Kendrick, G. A., Udy, J. W., Ferguson, A. J., Kilminster, K., Scanes, P., McKenzie, L. J. and McMahon, K. 2017. Seagrass ecosystem trajectory depends on the relative timescales of resistance, recovery and disturbance. Marine Pollution Bulletin,

Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J. and van Belzen, J. 2014. The role of seagrasses in coastal protection in a changing climate. Coastal Engineering, **87**: 11 pp

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

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., O'Grady, D., Scott, E., York, P. and Carter, A. 2017. Dugong Feeding Ecology and Habitat Use on Intertidal Banks of Port Curtis and Rodds Bay – Final Report 2016. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 16/14, James Cook University, Cairns, 65 pp.

Rasheed, M. A. 1999. Recovery of experimentally created gaps within a tropical *Zostera capricorni* (Aschers.) seagrass meadow, Queensland Australia. Journal of Experimental Marine Biology and Ecology, **235**: 183-200

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., McKenna, S. A. and Thomas, R. 2005. Long-term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2004. DPI&F Information Series QI05032. DPI&F, Cairns, 30 pp.

Rasheed, M. A., Reason, C. L. and Wells, J. N. 2019. Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/13. James Cook University, Cairns, 50 pp.

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.

Ray, B. R., Johnson, M. W., Cammarata, K. and Smee, D. L. 2014. Changes in Seagrass Species Composition in Northwestern Gulf of Mexico Estuaries: Effects on Associated Seagrass Fauna. PLoS ONE, **9**: e107751

Reason, C. L. and Rasheed, M. A. 2018a. Seagrass habitat of Cairns Harbour: Annual monitoring report – 2017. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 18/09. James Cook University, Cairns, 45 pp.

Reason, C. L. and Rasheed, M. A. 2018b. Seagrass habitat of Mourilyan Harbour: Annual monitoring report - 2017. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 18/10. James Cook University, Cairns, 49 pp.

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

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

van de Wetering, C., Scott, A. and Rasheed, M. 2019. Port of Karumba Long-term Annual Seagrass Monitoring: November 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/12. James Cook University, Cairns, 28 pp.

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

Wells, J. and Rasheed, M. 2017. Port of Townsville Annual Seagrass Monitoring and Baseline Survey: September - October 2016. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER). Cairns, 54 pp.

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. and Rasheed, M. 2019. Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2018. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 19/18. James Cook University, Cairns, 45 pp.

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 ($A_{satisfactory}$):

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

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_{2016} takes up:

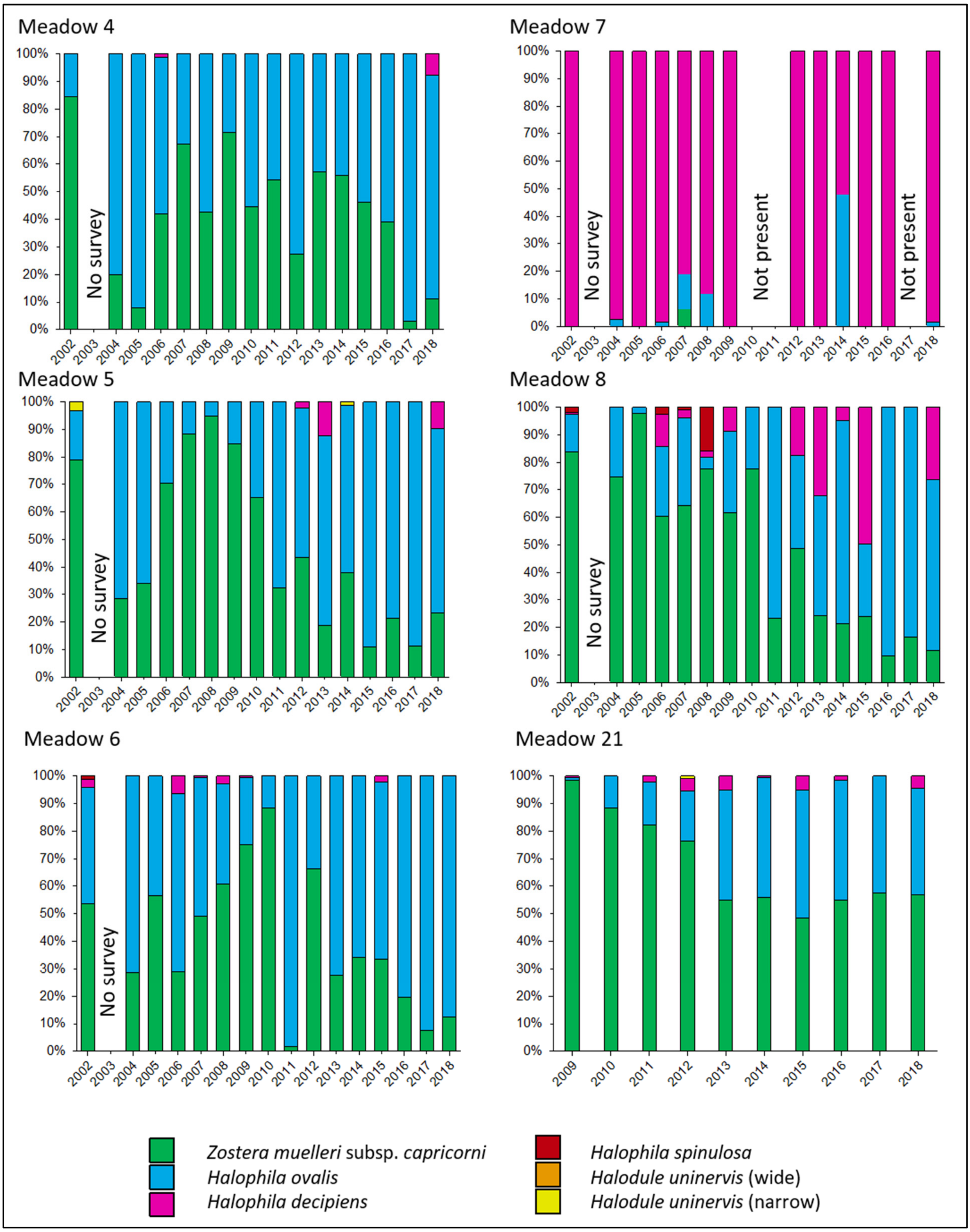
$$\mathrm{A_{prop}} = \frac{\mathrm{A_{diff}}}{\mathrm{A_{range}}}$$

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:

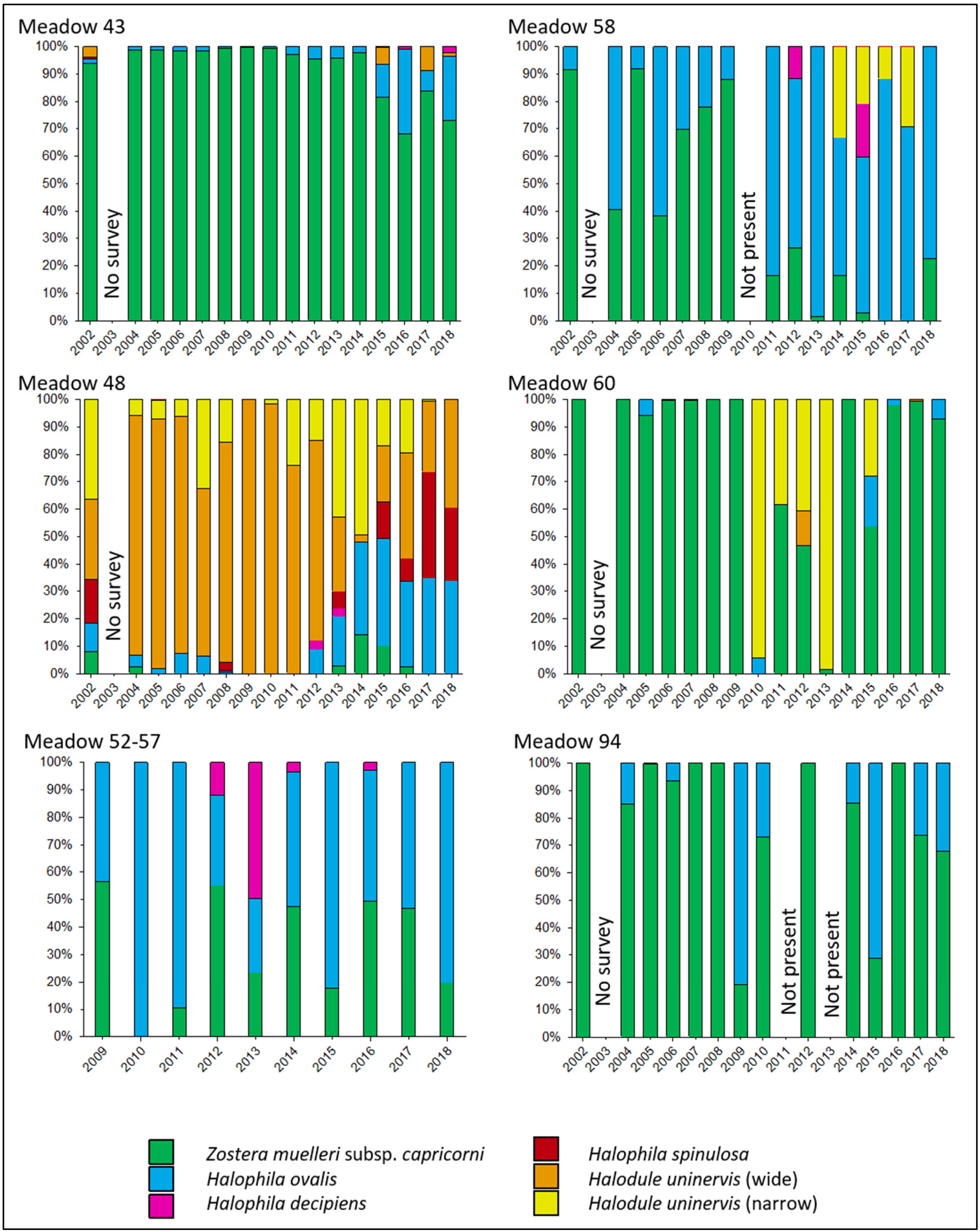
$$\mathrm{Score_{2016}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{A_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

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 (2002-2018) and Meadow 21 (2009- 2018).



Appendix 2. (continued) Species composition for meadows 43, 48, 58, 60 and 94 (2002-2018) and Meadow 52-57 (2009-2018).



Appendix 2. (continued) Species composition for meadows 96 and 104 (2002-2018).