Seagrasses in Port Curtis and Rodds Bay 2023
Annual long-term monitoring

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Annual long-term monitoring survey

A report for Gladstone Ports Corporation

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KEY FINDINGS

Seagrass Condition 2023

GOOD

1. The annual monitoring survey of seagrasses in Port Curtis and Rodds Bay was conducted from 27th – 31st of October 2023.

2. Overall, seagrass was in a good condition, an improvement from satisfactory condition the previous year.

3. Eight of the fourteen annual monitoring meadows were in a good to very good condition and a further four were in satisfactory condition.

4. The Narrows meadows remained in a stable condition across all indicators and was in a very good condition for the third year in a row.

5. Meadows in the Western Basin zone were in a satisfactory to very good condition with changes in species composition, biomass and area all impacting the overall condition grade of these meadows.

6. Seagrass meadows in the Inner Harbour and Mid Harbour were in a similar condition to previous year with meadows ranging from poor to good condition. The meadow at Quoin Island (Meadow 48) decreased to satisfactory condition due to declines in biomass and species composition and meadow 58 improved from very poor to poor.

7. The largest monitoring meadow adjacent to Curtis Island at Pelican Banks (Meadow 43), remained in a poor overall condition due to sustained low biomass however it did undergo improvements in area and species composition.

8. The greatest improvements were seen in the Rodds Bay meadows with all three improving to a good overall condition. All Rodds Bay meadows underwent increases in biomass and area which contributed to condition upgrades.

9. Favourable seagrass growing conditions with below average rainfall and below average river flow likely led to improvements in seagrass condition and contributed to improvements in seagrass biomass and condition in some meadows.

IN BRIEF

Seagrass monitoring in Port Curtis and Rodds Bay commenced in 2002 and has been conducted annually since 2004. Fourteen monitoring meadows are assessed annually, and the condition of the meadows evaluated based on variations in three key seagrass metrics - biomass, area and species composition. The current program has been developed to meet Gladstone Port Corporation's obligations pertaining to the Long-Term Maintenance Dredging Management Plan and includes annual mapping and monitoring of 14 coastal seagrass monitoring meadows and five-yearly mapping of all coastal and deep-water seagrass in Port Curtis and Rodds Bay. Monitoring meadows represent the range of different seagrass community types in Port Curtis and Rodds Bay (Figure 1) and every five years all seagrasses within the greater port limits are reassessed (last done in 2019).

Seagrass condition in 2023 was good overall after being satisfactory the previous year. The main driver behind the overall condition upgrade was improvements in seagrass meadow biomass and area in Rodds Bay in 2023. Eight of the fourteen individual monitoring meadows were rated as being in good or very good condition in 2023 (Figures 2, 3 and section 3 for more details). In the Western Basin and north to the Narrows, seagrass meadows were in satisfactory to very good condition with four of the seven monitoring meadows in these zones in good or very good condition. All three meadows in Rodds Bay were in good condition for the first time since 2019, while the Inner Harbour meadow at South Trees Inlet (Meadow 60) was also in a good condition. The rest of the seagrass meadows at the Inner and Outer Harbour (Meadow 43, 48, 58) were in poor to satisfactory condition although there were improvements in biomass and area in meadows 43 and 58. Rainfall and river flow from the Calliope River in the 12 months prior to the 2023 survey were below average which likely resulted in favourable growing conditions including increases in benthic light allowing seagrass to improve in biomass and build resilience.

The seagrass meadow at Pelican Banks is historically the largest and highest biomass meadow in the Port Curtis and Rodds Bay region. In 2023, the meadow remained in poor condition with biomass remaining below the long-term average. This meadow has had poor or very poor biomass since 2015 and undergone a reduction of the foundation species *Zostera muelleri* over the six years prior to 2022. In this survey there were improvements in the proportion of *Z. muelleri* but biomass has remained low. Ongoing low biomass at Pelican Banks is potentially linked to grazing by megaherbivores (green turtles and dugongs). Turtle and dugongs were commonly sighted during the survey, and Dugong Feeding Trails (DFTs) were common in the Western Basin (Meadow 5, 6, 52-57) and Pelican Banks.

Annual maintenance dredging occurs within the Port of Gladstone each year in channels and facilities adjacent to seagrass meadows. Modelling and impact assessment of maintenance dredging plumes as well as plume field studies have been carried out in the Port of Gladstone (BMT WBM 2017; 2019). These studies have shown dredging plumes can increase turbidity leading to reduced benthic light, but these conditions are short lived relative to ambient conditions (BMT WBM 2017; 2019; Vision Environment 2021). Changes in the benthic light environment, including those associated with dredge plumes, can impact seagrass condition leading to losses in biomass and cover (Chartrand et al. 2018). However, the amount and period of light reduction required to create impacts means that dredging activity can generally be managed in a way that protects seagrasses from light related loss (Chartrand et al. 2018), particularly for shorter duration maintenance programs. Maintenance dredging in 2023 occurred over a short time period (33 days) and benthic light levels throughout the dredging period remained above the growth requirement thresholds for local seagrasses (Vision Environment 2023; Chartrand et al. 2016). Results of this monitoring program show that in 2023 seagrass meadows closest to maintenance dredge activity ranged in condition from poor to very good and most were similar to, or above the long term average. There was no indication of longer term impacts that could be linked to dredging with benthic light maintained above seagrass requirements.

The improved condition of seagrass in Port Curtis and Rodds Bay over the past year is in line with trends in other regions where seagrass is monitored as part of the network of seagrass monitoring in Queensland. In ports such as Cairns and Mackay/Hay Point where local environmental and weather conditions have been favourable, seagrasses have recovered at similar rates to Port Curtis and Rodds Bay. For full details of the Queensland ports seagrass monitoring program see: www.tropwater.com/project/management-of-ports-and-coastal-facilities/

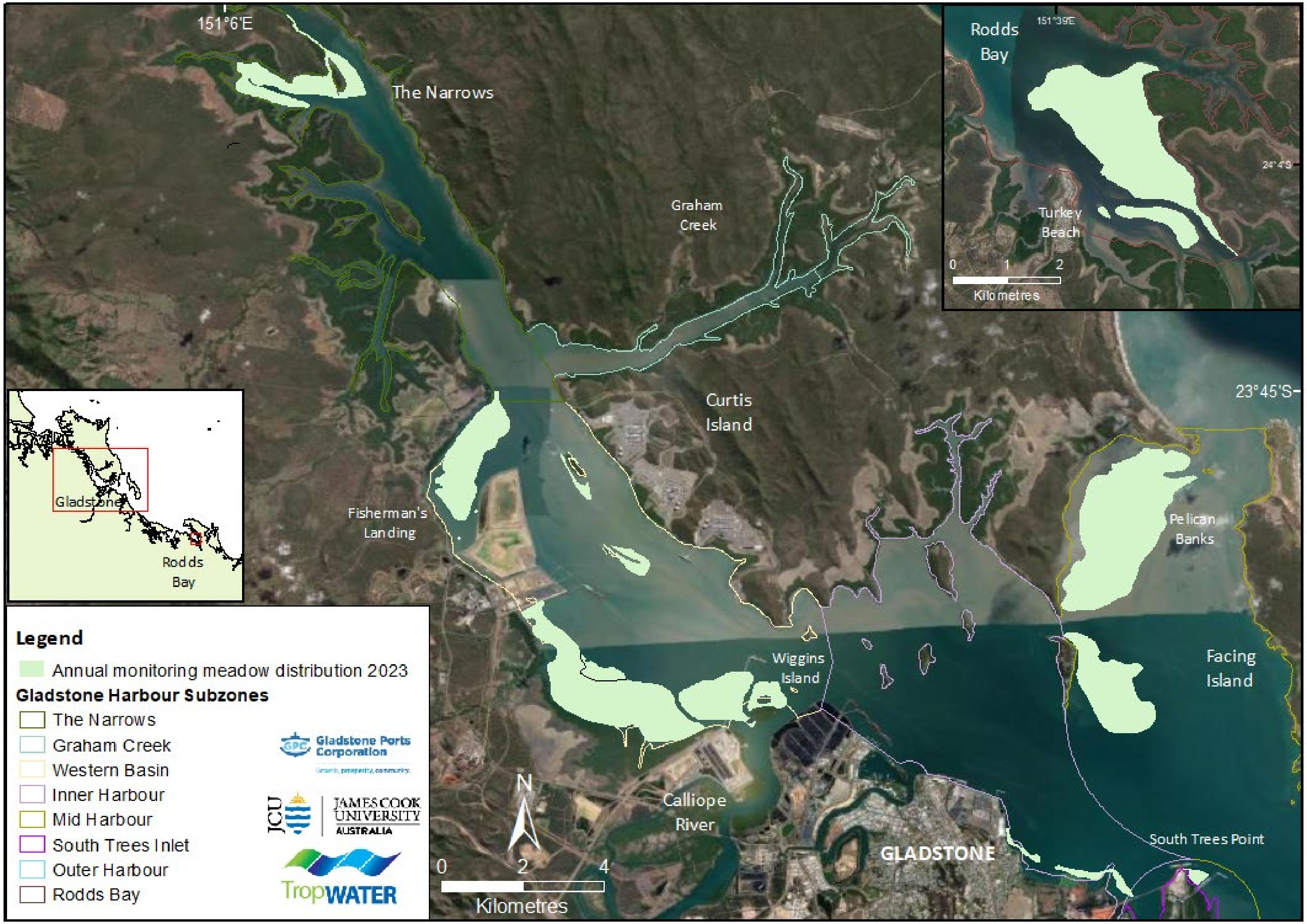

Figure 1. Seagrass distribution in Port Curtis and Rodds Bay monitoring meadows in October 2023.

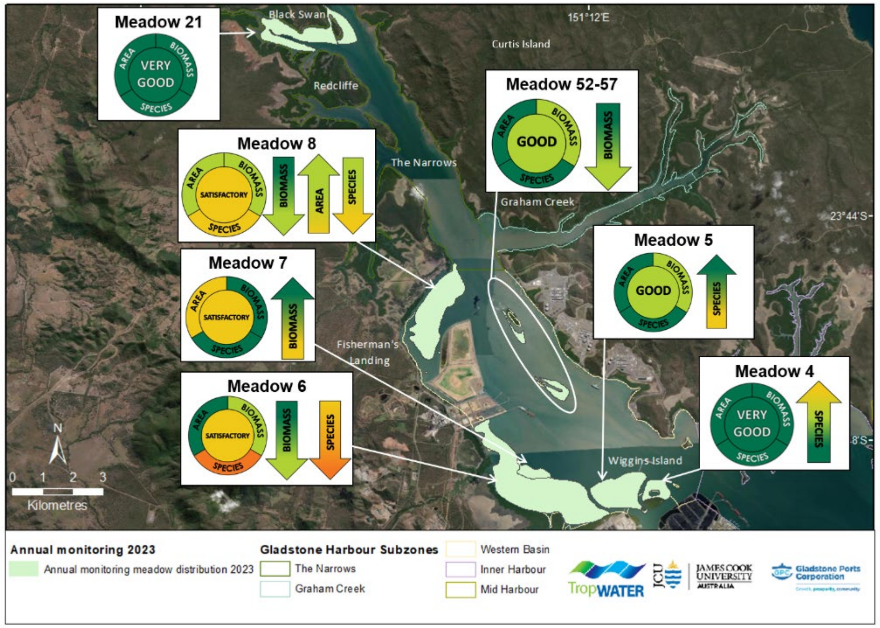

Figure 2. Seagrass distribution and meadow condition in The Narrows and Western Basin zones (Port Curtis), October 2023. Arrows indicate overall grade change from 2022.

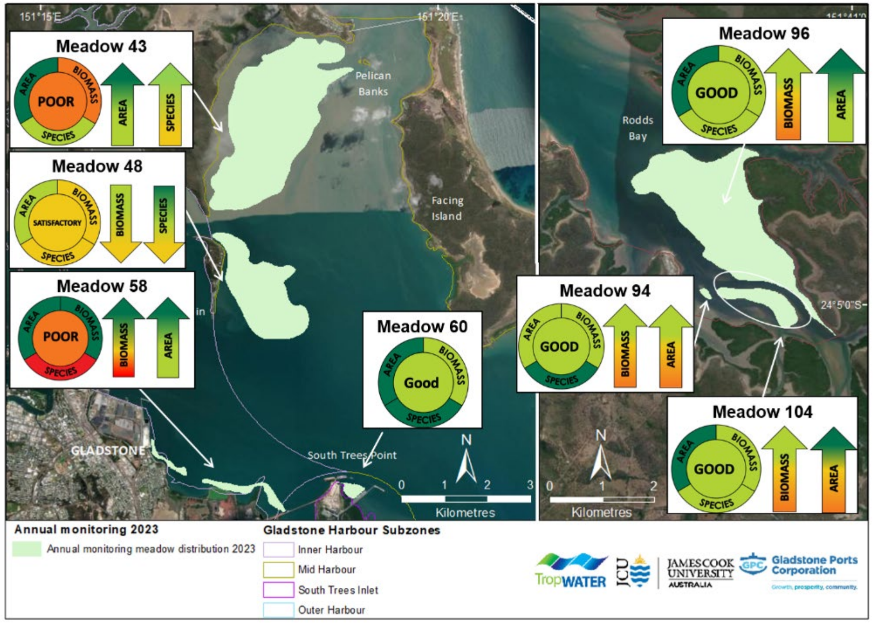

Figure 3. Seagrass distribution and meadow condition in the Inner Harbour, Mid Harbour, and South Trees Inlet zones (Port Curtis), and Rodds Bay, October 2023. Arrows indicate an overall grade change from 2022.

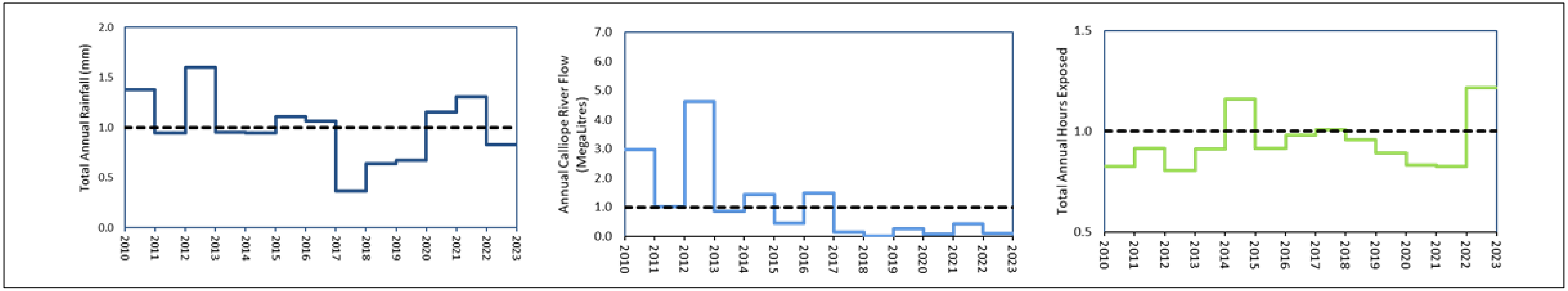

Figure 4. Climate trends in Port Curtis, 2010 to 2023. Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data for the Gladstone region.

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ACRONYMS AND ABBREVIATIONS

dbMSL	Depth below Mean Sea Level
DFTs	Dugong Feeding Trails
DPA	Dugong Protection Area
DW	Dry Weight
GIS	Geographic Information System
GPC	Gladstone Ports Corporation
GPS	Global Positioning System
IDW	Inverse Distance Weighted
JCU	James Cook University
MSQ	Maritime Safety Queensland
PCIMP	Port Curtis Integrated Management Program
R	Reliability estimator of seagrass meadow area
SE	Standard Error
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
WBDDP	Western Basin Dredging and Disposal Project

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, carbon storage, nutrient cycling, and particle trapping (Costanza et al. 2014; Hemminga and Duarte 2000). Seagrass meadows show measurable responses to changes in water quality, making them ideal indicators to monitor 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 was established in the majority of Queensland's commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's (JCU) Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. The aim of the program was to achieve a common method and rationale that established a network of seagrass monitoring locations comparable across the State (Figure 5).

A strategic long-term assessment and monitoring program for seagrass provides port managers and regulators with key information for effective management of seagrass habitat. This information is central to planning and implementing port development and maintenance programs to ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass. The program provides significant advances in the science and knowledge of tropical seagrass ecology. This includes the development of tools, indicators, and thresholds for the protection and management of seagrass, and an understanding of the reasons for seagrass change.

Figure 5. Location of Queensland ports where seagrass monitoring occurs. Red dots: long-term monitoring; blue dots: baseline mapping only.

For more information on the program and reports from other monitoring locations see www.tropwater.com/project/management-of-ports-and-coastal-facilities/

1.2 Port Curtis and Rodds Bay seagrass monitoring program

Diverse and productive seagrass meadows and benthic macro- and mega-fauna flourish in Port Curtis and Rodds Bay (McKenna et al. 2014; Rasheed et al. 2003; Lee Long et al. 1992). Gladstone Ports Corporation (GPC) first commissioned a baseline survey of seagrass resources in Port Curtis, Rodds Bay, and the adjacent offshore area in the Great Barrier Reef Marine Park in 2002 (Rasheed et al. 2003). Over 7000 ha of coastal seagrass was mapped, including an extensive area within the port limits. The majority of Port Curtis and Rodds Bay lies within a Dugong Protection Area (DPA; declared in 1996), an indication of the region's importance as a dugong foraging ground. Port Curtis seagrasses also contribute to the Outstanding Universal Values of the Great Barrier Reef World Heritage Area rated as providing a moderate contribution locally (GPC 2023).

Annual seagrass monitoring commenced in Port Curtis and Rodds Bay in 2004 in response to a whole of port review (SKM 2004) and following recommendations from the Port Curtis Integrated Monitoring Program (PCIMP). Ten meadows representative of the range of seagrass communities within Port Curtis were initially selected for monitoring. These included meadows most likely to be impacted by port activities, intertidal and subtidal meadows, meadows preferred by herbivores such as dugong and turtle, and those likely to support high fisheries productivity. Three monitoring meadows in Rodds Bay were selected as reference sites, i.e. outside port limits, to determine port-related versus regional causes of seagrass change.

The annual monitoring program has been adapted over the years in response to infrastructure developments within the port area including the Western Basin Dredging and Disposal Project (WBDDP) a capital dredging and development project that ran from 2011 to 2013. Adaptations and additions included:

1. Survey expansion to include all intertidal and shallow subtidal seagrass in the Port Curtis monitoring area from 2009-2018.
2. Two monitoring meadows (Meadows 21 and 52-57) added to the program in 2009 due to port developments in the Curtis Island area.
3. One meadow (Meadow 9) removed from the monitoring program in 2011 due to the Western Basin reclamation area's expansion at Fisherman's Landing.
4. All seagrass from The Narrows to Rodds Bay periodically remapped, extending into deep water and to offshore Port Curtis limits, in 2002, 2009, 2013, 2014 and 2019 (Smith et al. 2020; Carter et al. 2015; Bryant et al. 2014b; Thomas et al. 2010).
5. Monitoring of seagrass reproduction and seed banks at Pelican Banks, Rodds Bay and Wiggins Island between 2009 and 2016 (Reason et al. 2017a).

The current program has been developed to meet GPC's obligations pertaining to the Long-Term Maintenance Dredging Management Plan and includes annual mapping and monitoring of 14 coastal seagrass monitoring meadows and five-yearly mapping of all coastal and deep-water seagrass in Port Curtis and Rodds Bay. Additional research and monitoring programs have complemented annual monitoring.
These have included:

- Biannual surveys of Port Curtis and Rodds Bay monitoring areas from 2010-2014 (Carter et al. 2015; Bryant et al. 2014b; Davies et al. 2013; Rasheed et al. 2012; Chartrand et al. 2011; Thomas et al. 2010);
- The establishment of sensitive receptor sites where information on seagrass change was collected monthly to quarterly and linked to water quality monitoring (Bryant et al. 2016; Davies et al. 2015; Bryant et al. 2014a; McCormack et al. 2013);
- Establishment of seagrass light requirements and investigations of sub-lethal indicators of seagrass stress (Schliep et al. 2015; Chartrand et al. 2012; 2016).
- Assessing the importance of herbivores including turtles and dugongs in structuring seagrass meadows (Scott et al. 2021a; 2021b).

Annual monitoring and the additional programs have demonstrated inter- and intra-annual variability in seagrass meadow biomass, area and species composition in the region. Seagrass condition varies according to regional and local climate and weather conditions (Chartrand et al. 2019). Climate induced inter-annual variability is common throughout tropical seagrass meadows of the Indo-Pacific (Agawin et al. 2001). Seagrasses are also highly seasonal. Gladstone seagrass has two broad seasons; the growing season (July – January) when meadows typically increase in biomass and area in response to favourable conditions for growth; and the senescent season (February – June) when meadows typically retract and rely on carbohydrate stores or seeds to persist following wet season conditions such as flooding, poor water quality and light reductions (Chartrand et al. 2016). Annual monitoring is scheduled to coincide with the growing season when seagrass meadows are generally at their peak.

High rainfall, river outflow and tropical cyclones from the 2009/2010 and 2010/2011 La Niña led to significant seagrass losses in Port Curtis and Rodds Bay and more broadly across Northeast Queensland (Chartrand et al. 2019; McKenna et al. 2015; Rasheed et al. 2014). In extreme cases, such as in Rodds Bay, meadows were temporally lost (Rasheed et al. 2012; Carter et al. 2015). Recovery has been slow in many regions and many meadows in Port Curtis and Rodds Bay were in poor or very poor condition from 2011-2014 (Chartrand et al. 2019). Favourable climate conditions such as low rainfall and river outflow saw an improvement in meadow condition over the last 3-5 years, culminating in most meadows returning to near or above long-term average for condition indicators since 2019 (Smith et al. 2022). In this report we update seagrass condition for the 14 established monitoring meadows in 2023.

2 METHODS

2.1 Field surveys

Survey and monitoring methods followed the established techniques for TropWATER's Queensland-wide seagrass monitoring programs. Detailed methods used in Gladstone are in previous reports (Rasheed et al. 2003; Rasheed et al. 2005). Seagrass was surveyed 27th-31st October 2023 during the peak seagrass growth period. Standardising surveys to every October-December allows for appropriate comparisons of seagrass condition among years. This survey involved mapping and assessing the 14 long-term monitoring meadows within Port Curtis and Rodds Bay.

Intertidal meadows were surveyed at low tide using a helicopter. GPS was used to map the position of meadow boundaries and sites were scattered haphazardly within each meadow. Sites were surveyed as the helicopter hovered within one metre above the substrate (Figure 6a). Shallow subtidal meadows were sampled by boat using camera drops and a Van Veen grab (16.5 cm x 17.5 cm, depth 8 cm, Figure 6b, c). Subtidal sites were positioned at ~50-500 m intervals running perpendicular from the shoreline, or where major changes in bottom topography occurred, and extended offshore beyond the edge of each meadow. The appropriate number of sites required to detect seagrass change for each monitoring meadow was informed by power analysis (Rasheed et al. 2003). Where underwater visibility was poor, additional sites using the van Veen grab were used to assist in determining the presence of seagrass for mapping meadow boundaries. The details recorded at each site are listed in Section 2.3.

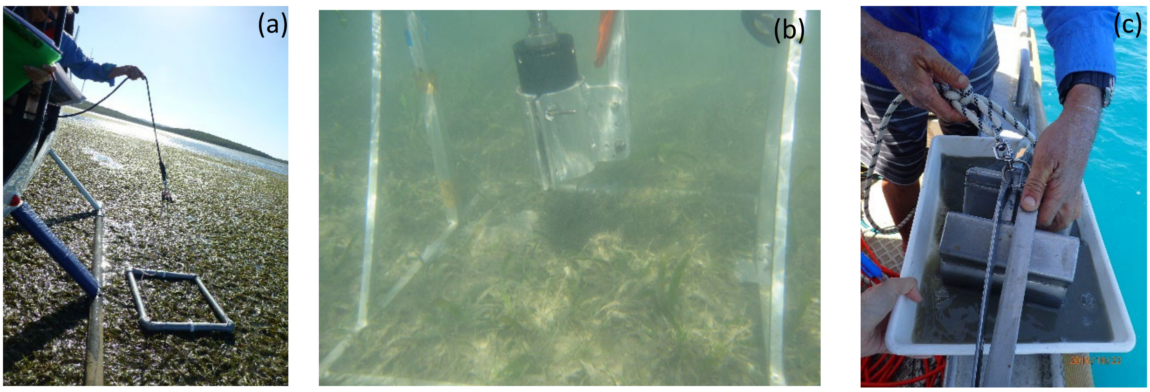


Figure 6. Seagrass monitoring methods in 2023. (a) helicopter survey of intertidal seagrass, (b, c) boat-based camera drops and van Veen grab for subtidal seagrass.

2.2 Seagrass biomass

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (Mellors 1991; Kirkman 1978). At each coastal site, a 0.25 m^2 quadrat was placed haphazardly three times. An observer assigned a biomass rank to each quadrat while referencing a series of quadrat photographs of similar seagrass habitats where the above-ground biomass had previously been measured. Two separate ranges were used - low biomass and high biomass. The percentage contribution of each species to each quadrat's biomass was also was recorded.

At the survey's completion, the observer ranked a series of calibration quadrat photographs representative of the range of seagrass biomass and species composition observed during the survey. These calibration quadrats had previously been harvested and the above-ground biomass weighed in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks recorded in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}) for each of the replicate quadrats at a site. Site biomass, and the biomass of each species, is the mean of the replicates.

2.3 Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.8®. Three GIS layers were created to describe seagrass in the survey area: a site layer, biomass interpolation layer and meadow layer.

2.3.1 Site layer

The site (point) layer contains data collected at each site, including:

- Site number.
- Temporal details – Survey date and time.
- Spatial details – Latitude, longitude, depth below mean sea level (metres) for subtidal sites.
- Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail (DFT) presence/absence.
- Sampling method and any relevant comments.

2.3.2 Interpolation layer

The interpolation (raster) layer describes spatial variation in seagrass biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

2.3.3 Meadow layer

The meadow (polygon) layer provides summary information for all sites within each meadow, including:

- Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass $\pm$ (SE), meadow area (hectares) $\pm$ reliability estimate (R) (Table 1), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 2, 3), meadow landscape category (Figure 7).
- Sampling method and any relevant comments.

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: ESRI), and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcGIS® 10.8. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 1). Mapping precision ranged from ≤5 m for intertidal seagrass meadows with boundaries mapped by helicopter to ±50 m for subtidal meadows with boundaries mapped by distance between sites with and without seagrass. 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.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 2). Community density was based on mean biomass of the dominant species within the meadow (Table 3).

Table 1. Methods used to determine mapping precision estimates for each seagrass meadow.

Mapping precision	Mapping method
<5 m	Meadow boundaries mapped by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide, Relatively high density of mapping and survey sites, Recent aerial photography aided in mapping.
10-20 m	Meadow boundaries determined from helicopter and boat surveys, Intertidal boundaries interpreted from helicopter mapping and survey sites, Recent aerial photography aided in mapping, Subtidal boundaries interpreted from survey sites, Moderately high density of mapping and survey sites.
20-50 m	Meadow boundaries determined from helicopter and boat surveys, Intertidal boundaries interpreted from helicopter mapping and survey sites, Subtidal boundaries interpreted from boat survey sites, Lower density of survey sites for some sections of boundary.
50-200 m	Meadow boundaries determined from boat surveys, Subtidal meadows interpreted from survey sites, Lower density of survey sites for meadow boundary.

Table 2. 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 3. Seagrass meadow density categories based on mean above-ground biomass ranges for the dominant species.

Density	Mean above-ground biomass (g DW m^{-2})				
	Halodule uninervis (thin)	*Halophila ovalis; Halophila decipiens*	*Halodule uninervis* (wide)	*Halophila spinulosa*	*Zostera muelleri*
Light	<1	<1	<5	<15	<20
Moderate	1-4	1-5	5-25	15-35	20-60
Dense	>4	>5	>25	>35	>60

Isolated seagrass patches
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

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

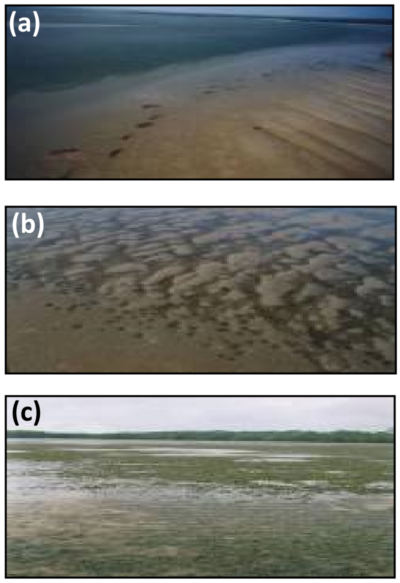


Figure 7. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

2.4 Environmental data

Environmental data were collated for the 12 months preceding each of the monitoring surveys. Tidal data was provided by Maritime Safety Queensland (© The State of Queensland (Department of Environment and Science) 2022/23, Tidal Data) for Gladstone at South Trees. Total daily rainfall (mm) was obtained for the nearest weather station from the Australian Bureau of Meteorology (Gladstone Radar station #039123; http://www.bom.gov.au/climate/data/). Calliope River water flow data (total monthly megalitres) was obtained from the Department of Regional Development, Manufacturing and Water (station #132001A; https://water-monitoring.information.qld.gov.au/).

2.5 Seagrass condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a ten year baseline (see Carter et al. 2023 for full details). Seagrass condition for each indicator in each meadow was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50% (Carter et al. 2023).

3 RESULTS

3.1 Seagrass presence and species in Port Curtis and Rodds Bay

In 2023, a total of 921 sites were assessed across the 14 seagrass monitoring meadows (Figure 9). Five seagrass species from three families were observed during the survey (Figure 10). Total seagrass area was 2,575.27 ± 68 ha across the 14 monitoring meadows. In the Western Basin meadows, seagrass covered 960 ± 23 ha, a slightly larger area than the previous year which recorded 880 ± 21 ha. Rodds Bay seagrass area was 444 ± 17 ha in 2023, also a larger footprint than in 2022 (325 ± 14 ha). There was evidence of DFTs in monitoring meadows within all the zones in Port Curtis and Rodds Bay, from The Narrows, Western Basin, Inner and Mid Harbour, South Trees and Rodds Bay.

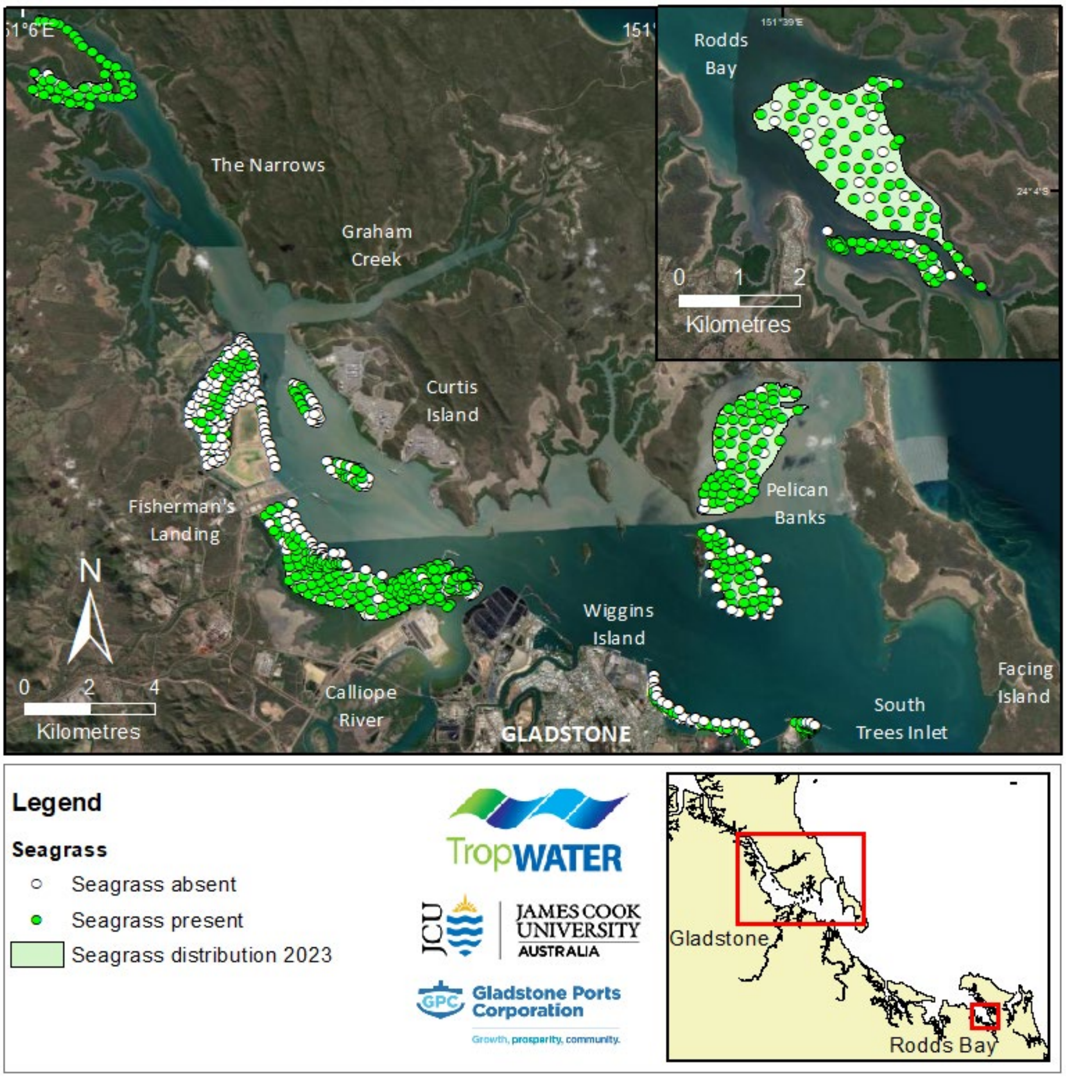


Figure 9. Seagrass presence/absence at seagrass assessment sites within Port Curtis and Rodds Bay in 2023.

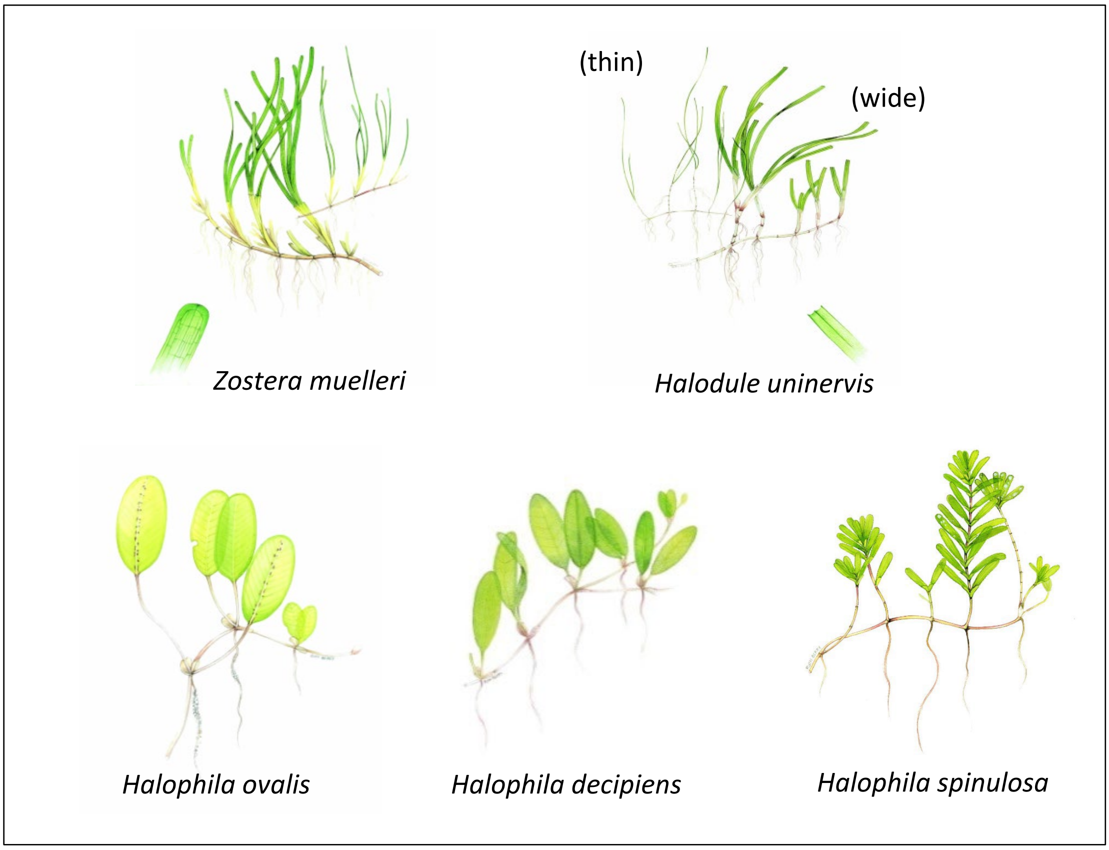


Figure 10. Seagrass species present in Port Curtis and Rodds Bay, 2023.

Figure 11. DFTs on seagrass patches in Meadow 6.

3.2 Seagrass condition in Port Curtis and Rodds Bay

In 2023, seagrasses in the Port Curtis and Rodds Bay port region improved to an overall good condition (Table 4). Eight of the 14 monitoring meadows were in a good or very good condition. The Narrows meadow was in a very good condition for the third year in a row. Seagrass meadows in the Western Basin were in a satisfactory condition or better. A reduction in area and species composition were the drivers behind declines in seagrass condition in the Western Basin zone. The Inner Harbour meadow (Meadow 58) improved to be in in poor condition as biomass and area increased. The Mid Harbour meadows saw a general decline in seagrass biomass and species composition resulting in overall meadow condition being graded poor and satisfactory. The Pelican Banks meadow (Meadow 43) returned to poor condition due to low biomass, however area and species composition was in a very good and good condition. The meadow at South Trees Inlet remained in good condition with biomass and area remaining stable over the past two years. All three Rodds Bay meadows were in a good condition including meadow (Meadow 94) that upgraded from poor after improvements in species composition.

Port Curtis and Rodds Bay has been partitioned into zones (see Figure 1) for the purposes of assessing water quality and for developing a regional report card (GHHP 2022). We present the results for the 2023 seagrass monitoring for monitoring meadows in each of the zones.

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for Port Curtis and Rodds Bay seagrass monitoring meadows, 2023. = very good condition, = good condition, = satisfactory condition, = poor condition, = very poor condition.

Zone	Monitoring meadow	Biomass score	Area score	Species composition score	Overall meadow score
The Narrows	21	0.89	0.96	0.97	0.89
Western Basin	4	0.88	0.97	0.86	0.87
	5	0.84	0.91	0.87	0.84
	6	0.74	0.94	0.32	0.53
	7	0.85	0.58	1.00	0.58
	8	0.69	0.84	0.54	0.62
	52–57	0.73	0.87	1.00	0.73
Inner Harbour	58	0.87	0.87	0.00	0.43
Mid Harbour	43	0.45	0.86	0.83	0.45
	48	0.54	0.79	0.65	0.54
South Trees Inlet	60	0.81	1.00	0.99	0.81
Rodds Bay	94	0.85	0.74	0.98	0.74
	96	0.78	1.00	0.85	0.78
	104	0.71	0.93	0.84	0.71
Overall score for Gladstone seagrass monitoring meadows					0.68

*Meadow 52-57 consists of several small meadows surrounding the Passage Islands that are grouped for reporting purposes (Figure 1).

3.2.1 The Narrows long-term monitoring meadows

The Narrows has one long-term monitoring meadow at Black Swan Island and was in a very good condition for the third year in a row (Meadow 21; Figure 12). While mean biomass declined slightly in 2023 (12.38 ± 1.95 g DW m^{-2}), it remains well above the long-term average (5.07 g DW m^{-2}). Seagrass meadow area covered 193.31 ± 8.35 ha and has also remained consistently above the long average over the last six years. Species composition remained in very good condition in 2023 and was dominated by *Zostera muelleri* (Figure 12; Appendix 4).

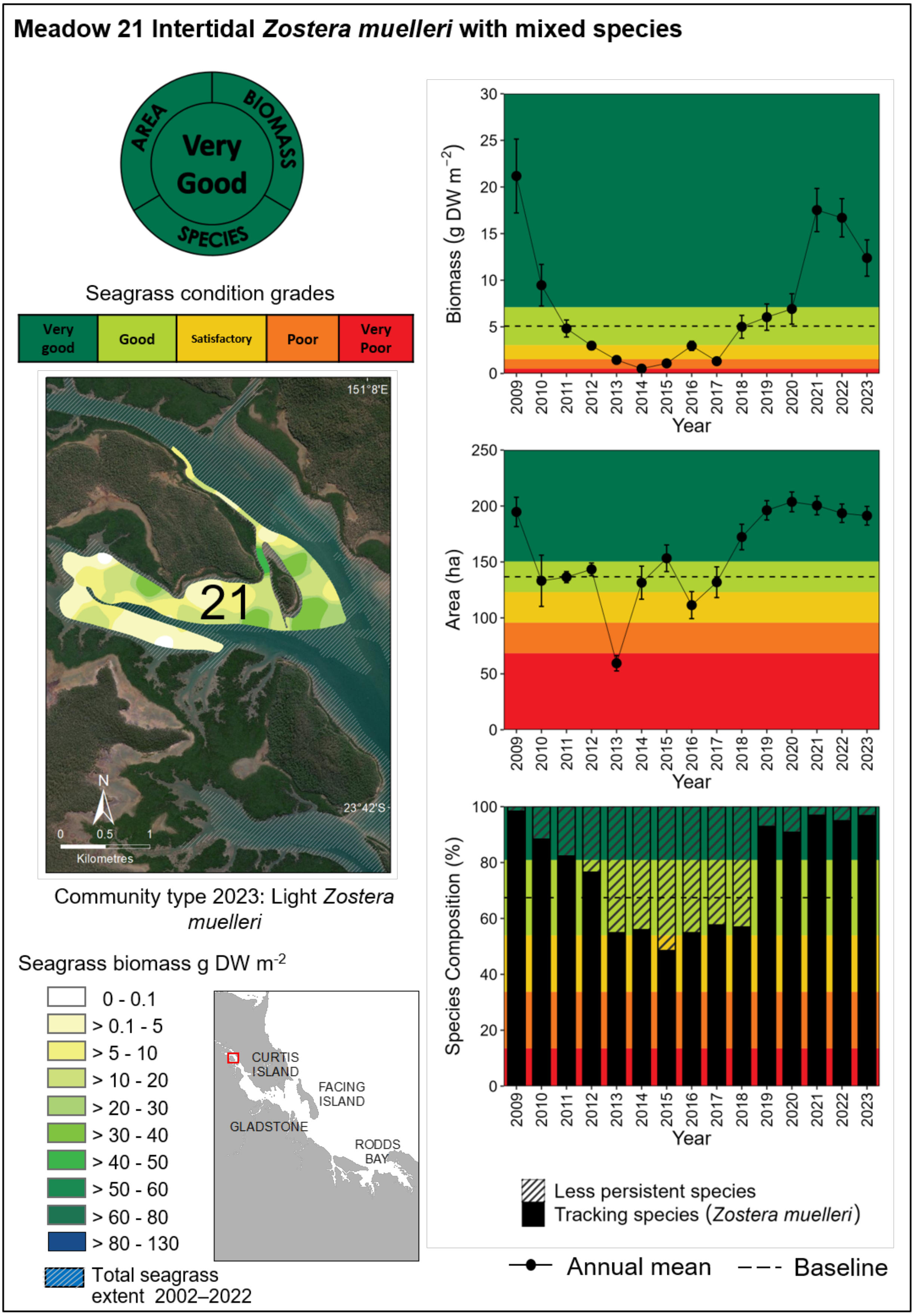


Figure 12. Changes in meadow area, biomass and species composition at Meadow 21, Black Swan (The Narrows Zone), 2009-2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.2 Western Basin long-term monitoring meadows

All six long-term monitoring meadows in the Western Basin Zone were in a satisfactory or better condition in 2023 (Figures 1-2).

Meadow 4:

The Wiggins Island, Meadow 4, returned to a very good condition after previously being in a good condition the year before (Figure 13). Despite a decline in 2023, meadow biomass continues to be in very good condition (1.31 ± 0.28 g DW m^{-2}) and above the long-term average (0.83 g DW m^{-2}). Meadow area (41.32 ± 1.85 ha) is also above average (29.38 ha) and in a very good condition for the fifth year in a row. Improvements were observed with seagrass species composition returning to a very good condition with a greater presence of *Z. muelleri* in the meadow (Figure 13; Appendix 2).

Meadow 5:

The meadow west of Wiggins Island remained in a good condition in 2023 (Figure 14). Biomass improved slightly (3.76 ± 0.45 g DW m^{-2}) and remained in a good condition and above the long term average (2.74 g DW m^{-2}) (Figure 14). Meadow area remained in very good condition for the third consecutive year. The species composition of this intertidal meadow improved to a very good condition with an increase in the proportion of *Z. muelleri* (Figure 14; Appendix 2).

Meadow 6:

The largest meadow in the Western Basin, Meadow 6, at South Fisherman's Landing was in an overall satisfactory condition in 2023, a decline from a good condition in the previous year (Figure 15). Biomass declined from very good to good condition 1.72 ± 0.19 g DW m^{-2} and was close to the long term average (1.78 g DW m^{-2}). Meadow area is in a very good condition for the fifth year in a row and increased slightly to 451.29 ± 6.64 ha. The main driver behind the condition downgrade for this meadow was the decrease in the proportion of *Z. muelleri* in the meadow with the meadow being dominated by less persistent species (*Halophila* spp.) which represented >90% of the biomass (Figure 15; Appendix 2).

Meadow 7:

The only subtidal monitoring meadow in the Western Basin, Meadow 7, was in satisfactory condition in 2023 (Figure 16). Biomass improved from a satisfactory condition to a very good condition with increases to 2.02 ± 0.29 g DW m^{-2}, the highest recorded in five years. Meadow area has remained stable over the past two years and is in a satisfactory condition. This meadow has been highly variable in both biomass and area over the years, a typical trend of subtidal *Halophila* meadows. Species composition was in very good condition as only *H. decipiens* and more persistent species *H. ovalis* were recorded.

Meadow 8:

In 2023, Meadow 8 at North Fisherman's Landing was in satisfactory condition for the second year in a row. Meadow biomass decreased to a good condition 0.82 ± 0.15 g DW m^{-2} and just below the long term average (1.08 g DW m^{-2}) (Figure 17). Meadow area (235.22 ± 4.36 ha), improved to be in good condition and above the long-term average for first time in three years (Figure 17). Species composition shifted to being dominated by less persistent species *H. ovalis* and was in a satisfactory condition in 2023. Notable, was the addition of a small patch of *Halophila spinulosa*, not previously recorded in this meadow (Figure 17).

Meadows 52-57:

Meadows 52-57, are a group of predominantly intertidal meadows surrounding the Passage Islands. The overall condition of these meadows declined to good in 2023 due to a reduction in biomass, however it remains close to the long term average and is in a good condition (1.06 ± 0.19 g DW m^{-2}). Meadow area remains in a very good condition despite a small decline in 2023. Species composition of this meadow remains in a very good condition made up of a 50:50 balance of more persistent *Z. muelleri* and the representative species of the meadow *H. ovalis* (Figure 18).

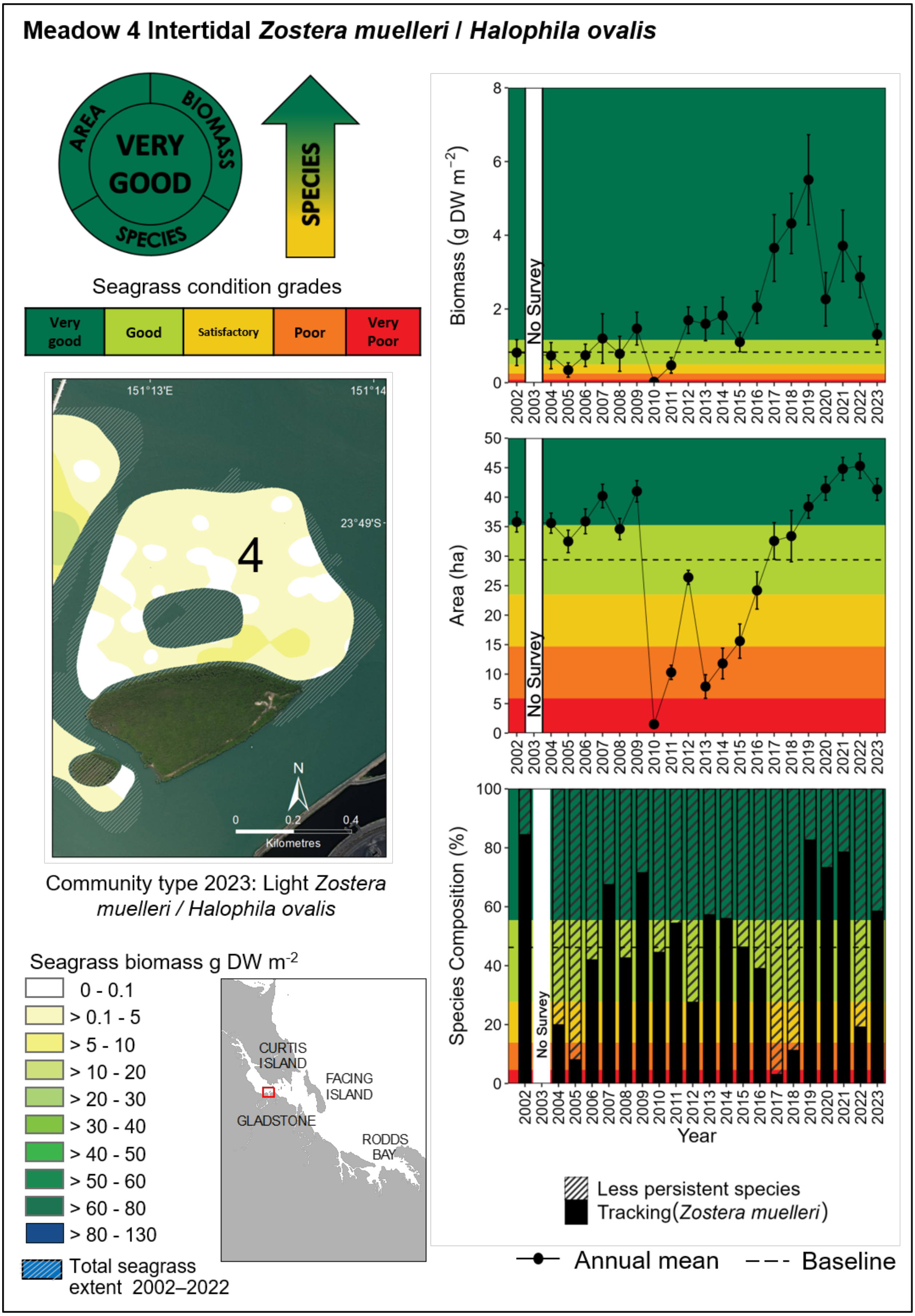


Figure 13. Changes in meadow area, biomass and species composition for Meadow 4, Wiggins Island (Western Basin Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

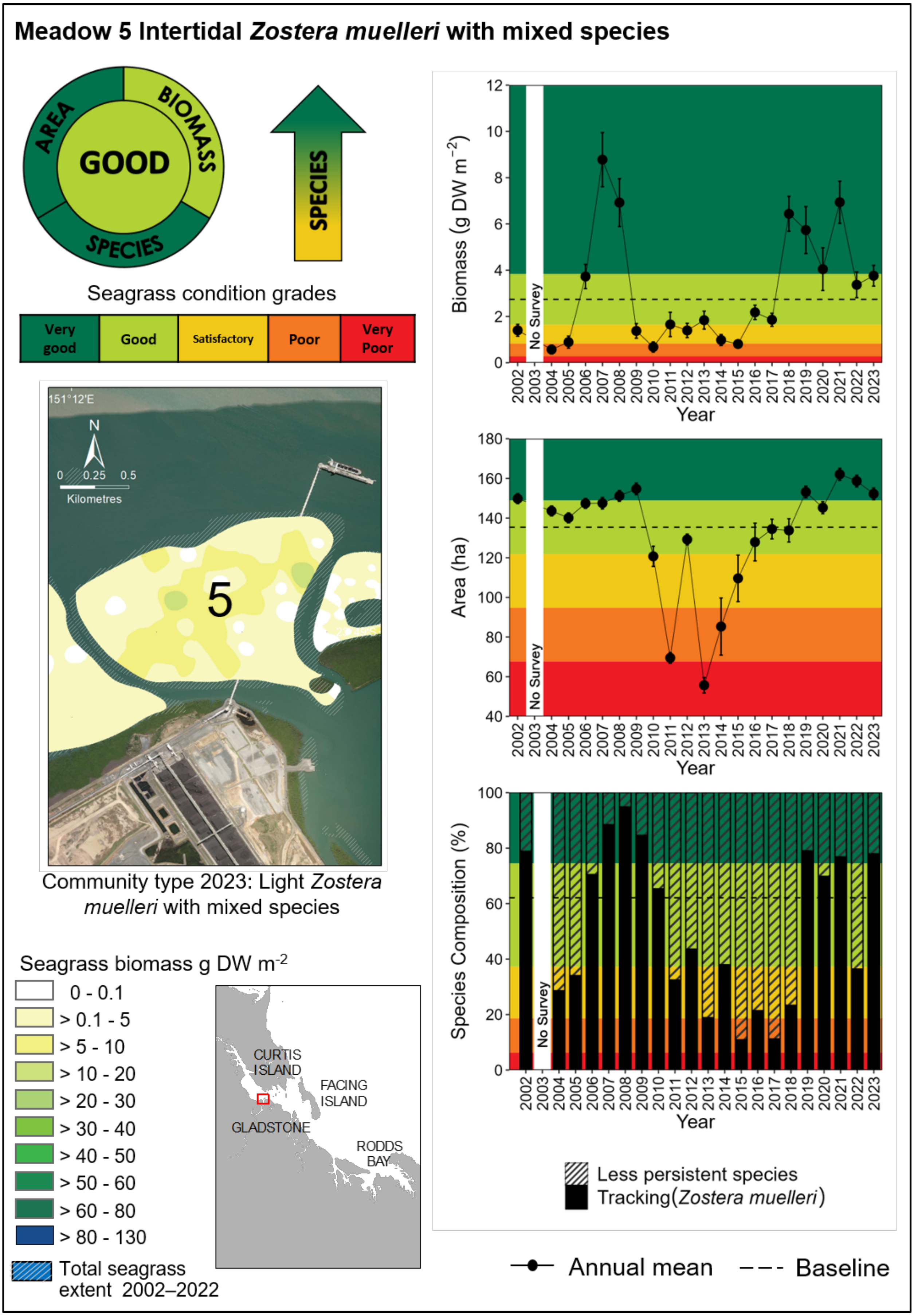


Figure 14. Changes in meadow area, biomass and species composition for Meadow 5, Wiggins Island (Western Basin Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

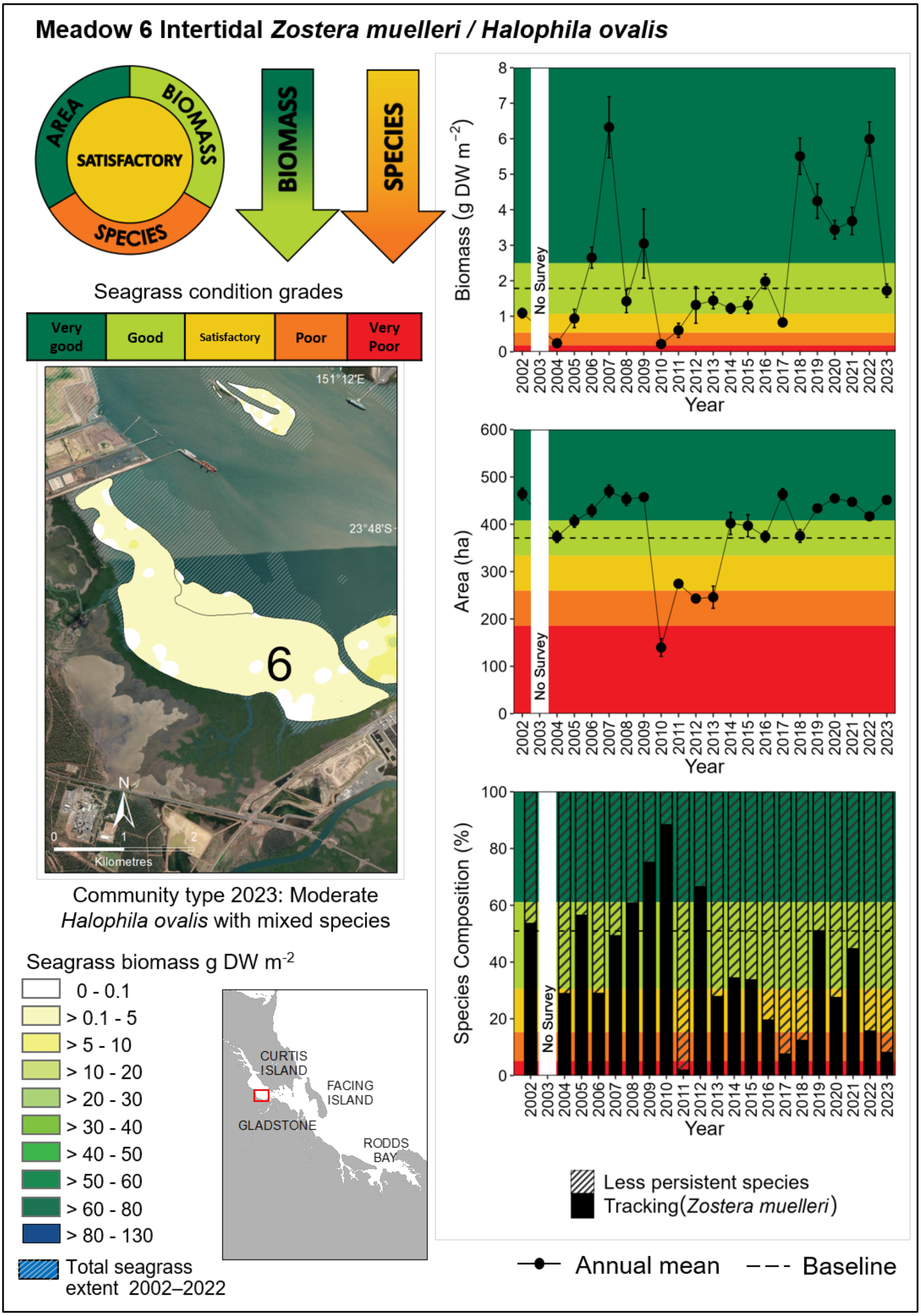


Figure 15. Changes in meadow area, biomass and species composition for Meadow 6, South Fisherman's Landing (Western Basin Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

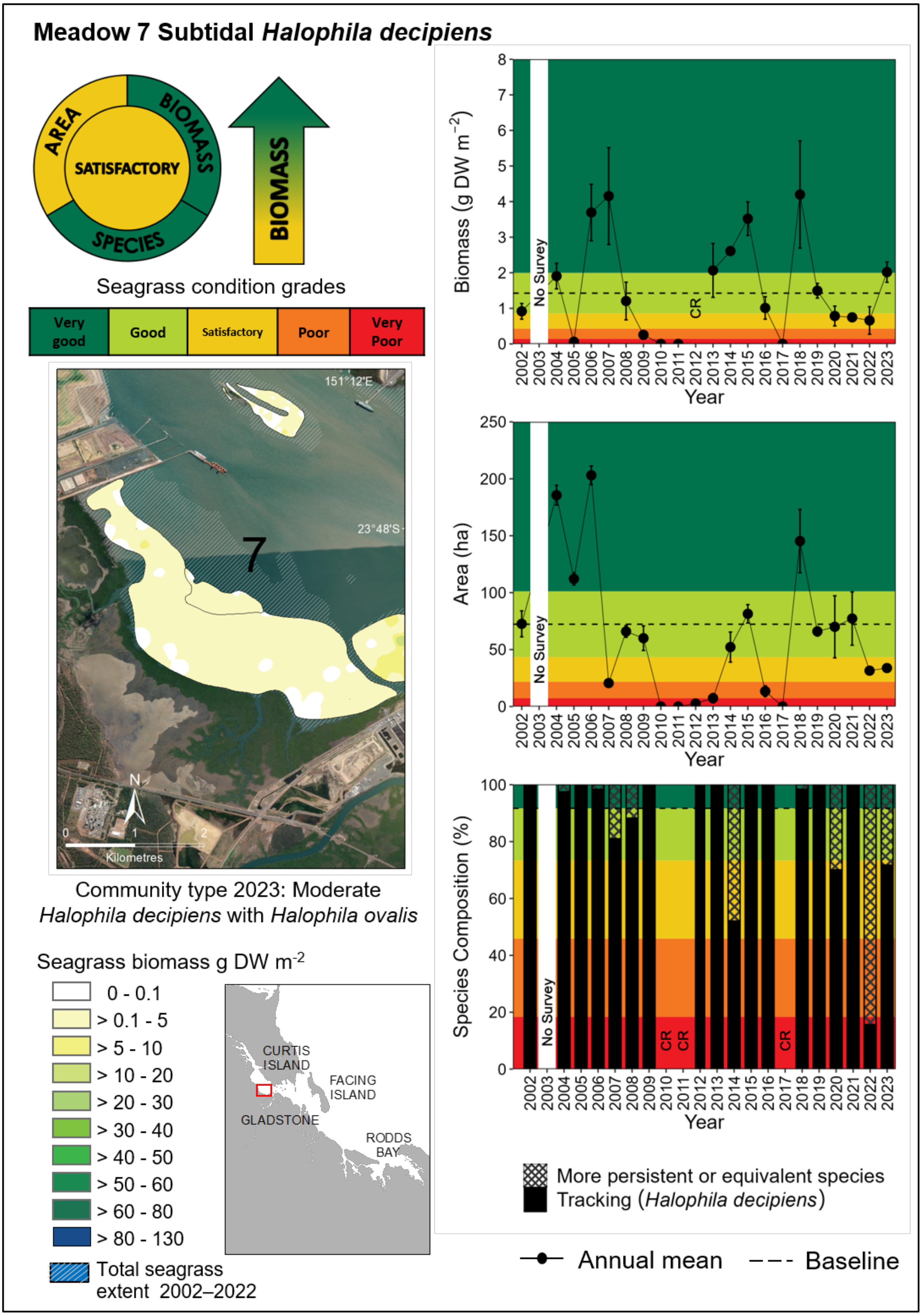


Figure 16. Changes in meadow area, biomass and species composition for Meadow 7, South Fisherman's Landing (Western Basin Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate). CR = calculation restriction due to the absence of seagrass (species composition) or biomass observations.

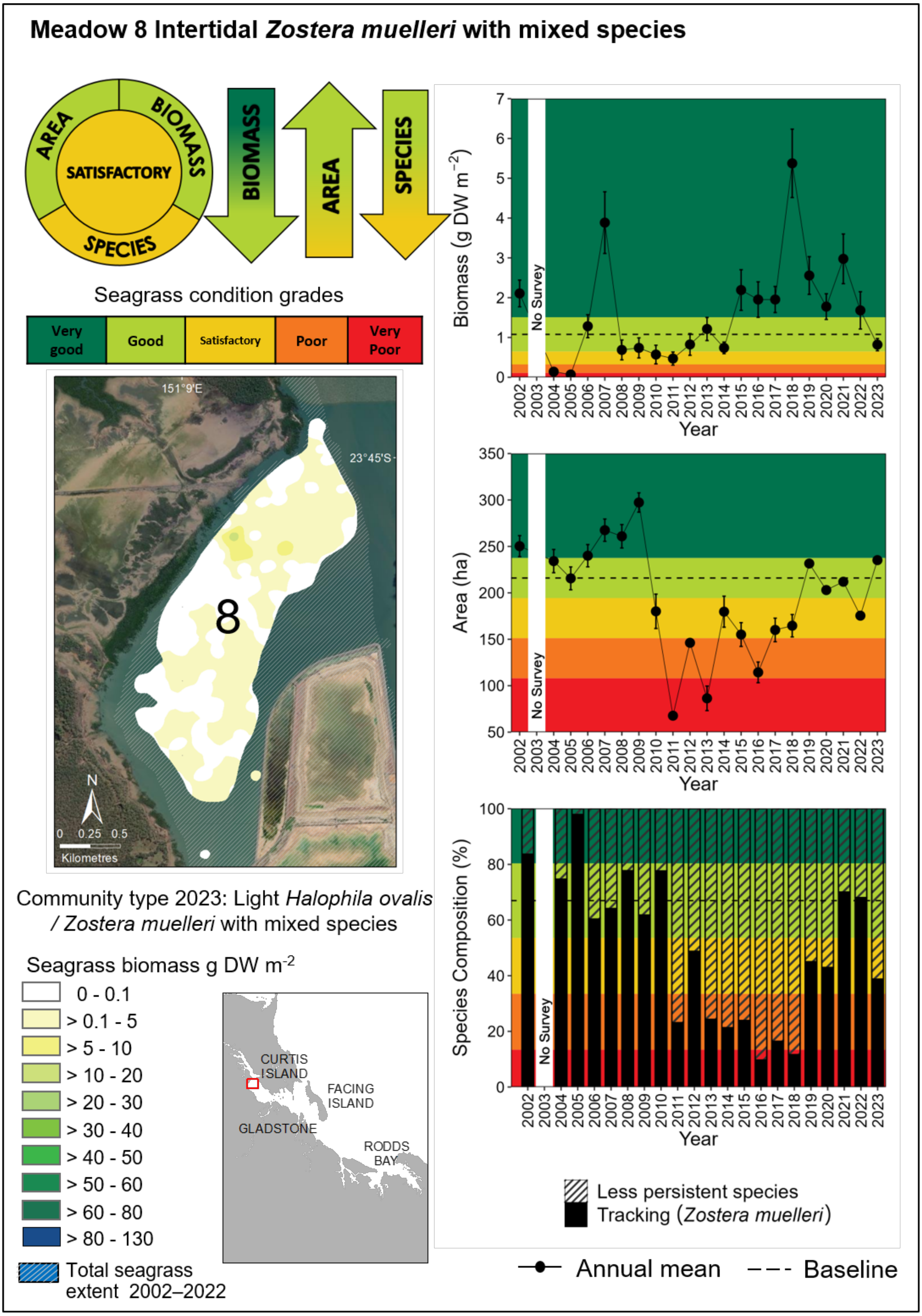


Figure 17. Changes in meadow area, biomass and species composition for Meadow 8, North Fisherman's Landing (Western Basin Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 52-57 Intertidal *Halophila ovalis* with mixed species

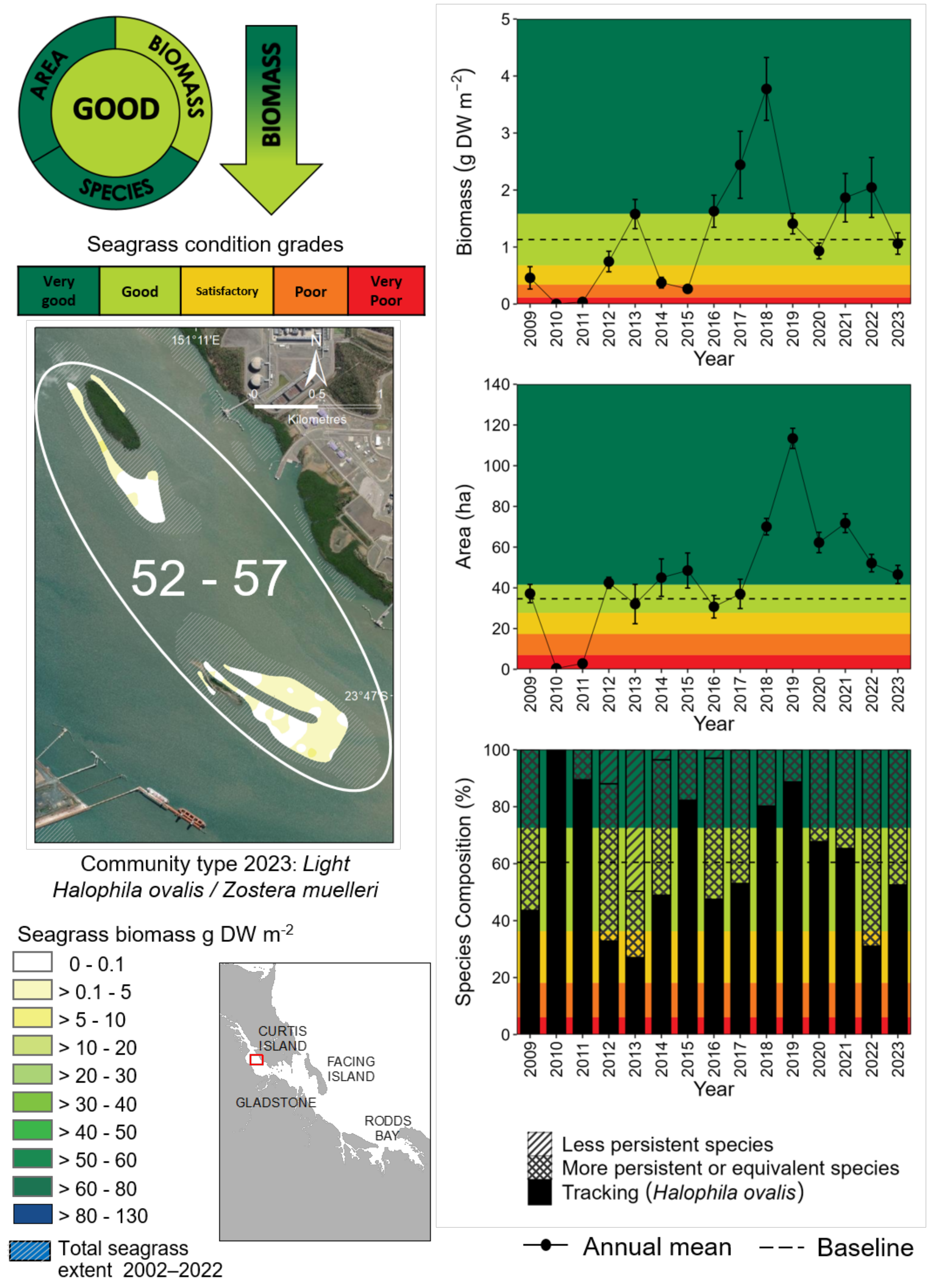


Figure 18. Changes in meadow area, biomass and species composition for Meadows 52-57, Passage Islands (Western Basin Zone), 2009–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.3 Inner Harbour long-term monitoring meadows

There is a single monitoring meadow at the Inner Harbour that stretches along the intertidal bank west from the mouth of the Calliope River as a narrow strip (Meadow 58; Figure 19).

Meadow 58

Overall seagrass meadow condition was poor due to absence of tracking species *Z. muelleri*. Both biomass and area improved to very good condition, however the absence of tracking species *Z. muelleri* meant the overall condition was poor. Biomass has improved to a very good condition from a very poor condition to 3.44 ± 0.46 g DW m^{-2}, and was well above the long term average. Meadow area also improved to above the long-term baseline and is in a very good condition covering 41.52 ± 3.68 ha. Species composition of this meadow was dominated by *H. uninervis* and *H. ovalis* which are less persistent than the tracking species *Z. muelleri* which has been absent for the past three years (Figure 20). Historically, species composition within meadow 58 fluctuates and has not been in a good condition since 2019 (Figure 20; Appendix 2).

3.2.4 Mid Harbour long-term monitoring meadows

There are two monitoring meadows in the Mid Harbour Zone, a large intertidal meadow on Pelican Banks (Meadow 43; Figure 21), and a subtidal meadow along the eastern side of Quoin Island (Meadow 48; Figure 22).

Meadow 43:

Meadow 43 is the largest seagrass meadow in Port Curtis and was in an overall poor condition in 2023 (Figure 21). Seagrass biomass was in a poor condition and was well below the long-term average, however it was similar to last year at 8.15 ± 0.66 g DW m^{-2}. Meadow area improved to a very good condition and is the highest in the past three years covering 666.50 ± 6.71 ha. The species composition of this meadow was in a good condition with a light cover of tracking species *Z. muelleri* (Figure 21; Appendix 2).

Meadow 48:

Meadow 48 is a predominantly subtidal meadow on the eastern side of Quoin Island. Overall meadow condition was in a satisfactory condition in 2023 (Figure 22). Meadow biomass declined to a satisfactory condition, while meadow area was in a good condition and showed little variation from 2022. Species composition also declined to a satisfactory condition with a greater proportion of less persistent species *Halophila spp.* and lower proportion of the tracking species *H. uninervis*.

3.2.5 South Trees Inlet long-term monitoring meadows

The South Trees Inlet zone has one monitoring meadow, Meadow 60, which is located between the two wharves (Figure 23). The intertidal meadow traditionally consists of continuous *Z. muelleri*.

Meadow 60

This meadow has been stable over the past two years and is in a good overall condition (Figure 23). Biomass remains relatively unchanged at 4.87 ± 0.73 g DW m^{-2} in 2023 compared to 4.73 ± 0.69 g DW m^{-2} in 2022. Likewise, the footprint of this meadow remains relatively unchanged and is in a very good condition for the 10th year in a row. The meadow was comprised nearly entirely of the persistent *Z. muelleri*, with a small amount of *H. ovalis,* therefore species composition was very good for the eighth year in a row (Figure 23).

Figure 19. Seagrass cover at Meadow 60 in 2023 (left) and 2021 (right) when biomass was the highest recorded across all monitoring years.

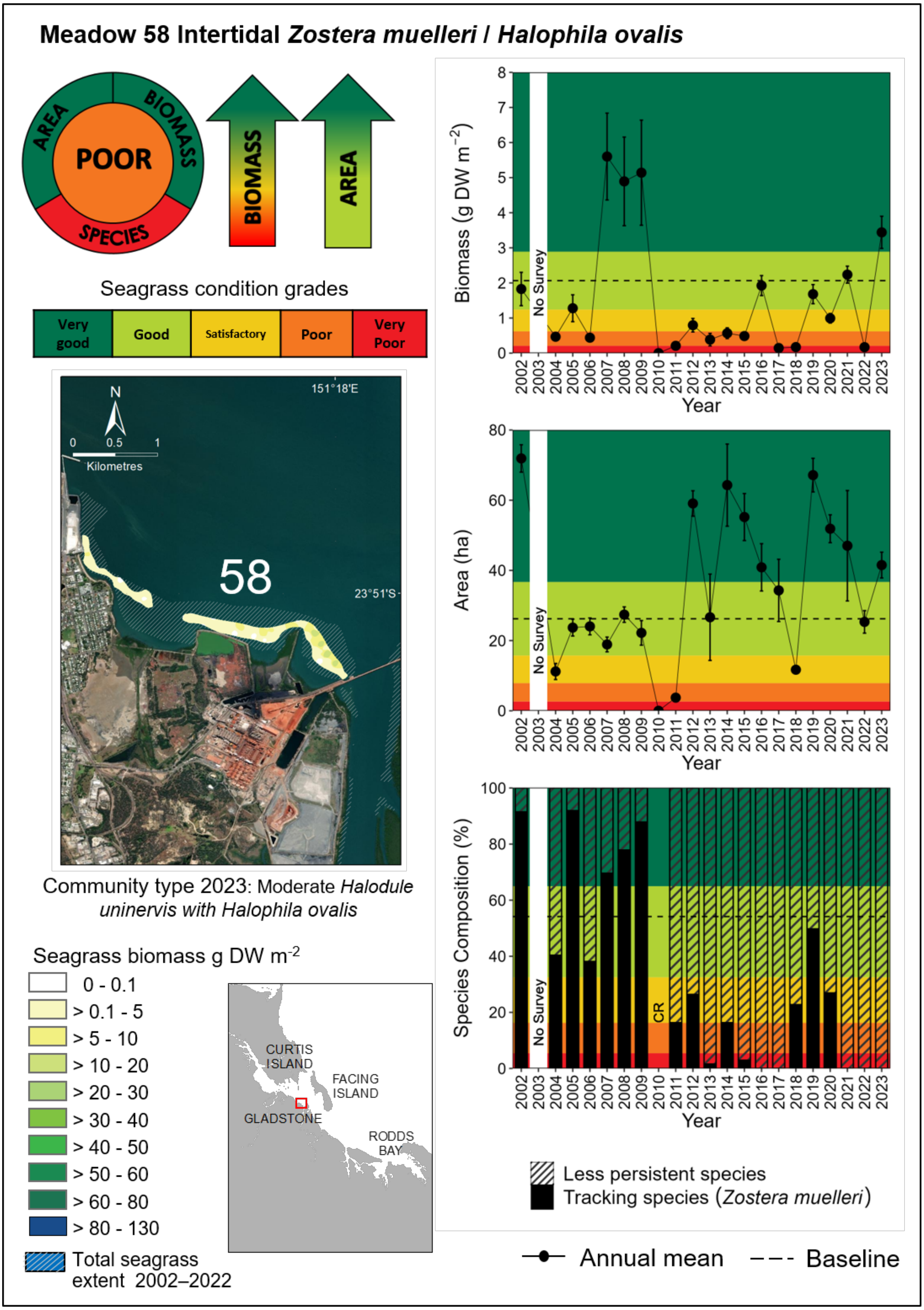


Figure 20. Changes in meadow area, biomass and species composition for Meadow 58, (Inner Harbour Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate). CR = calculation restriction due to the absence of seagrass.

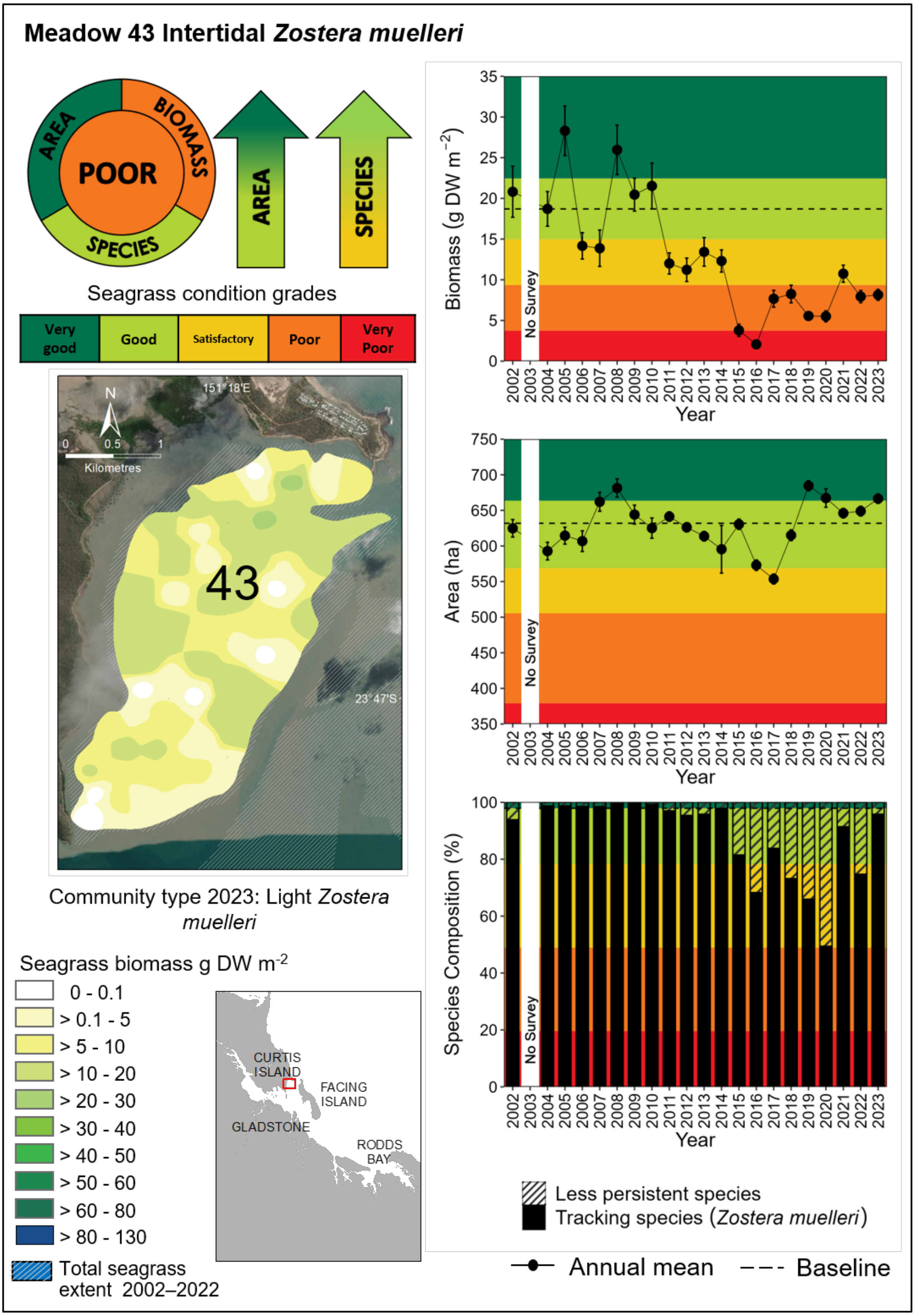


Figure 21. Changes in meadow area, biomass and species composition Meadow 43, Pelican Banks (Mid Harbour Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

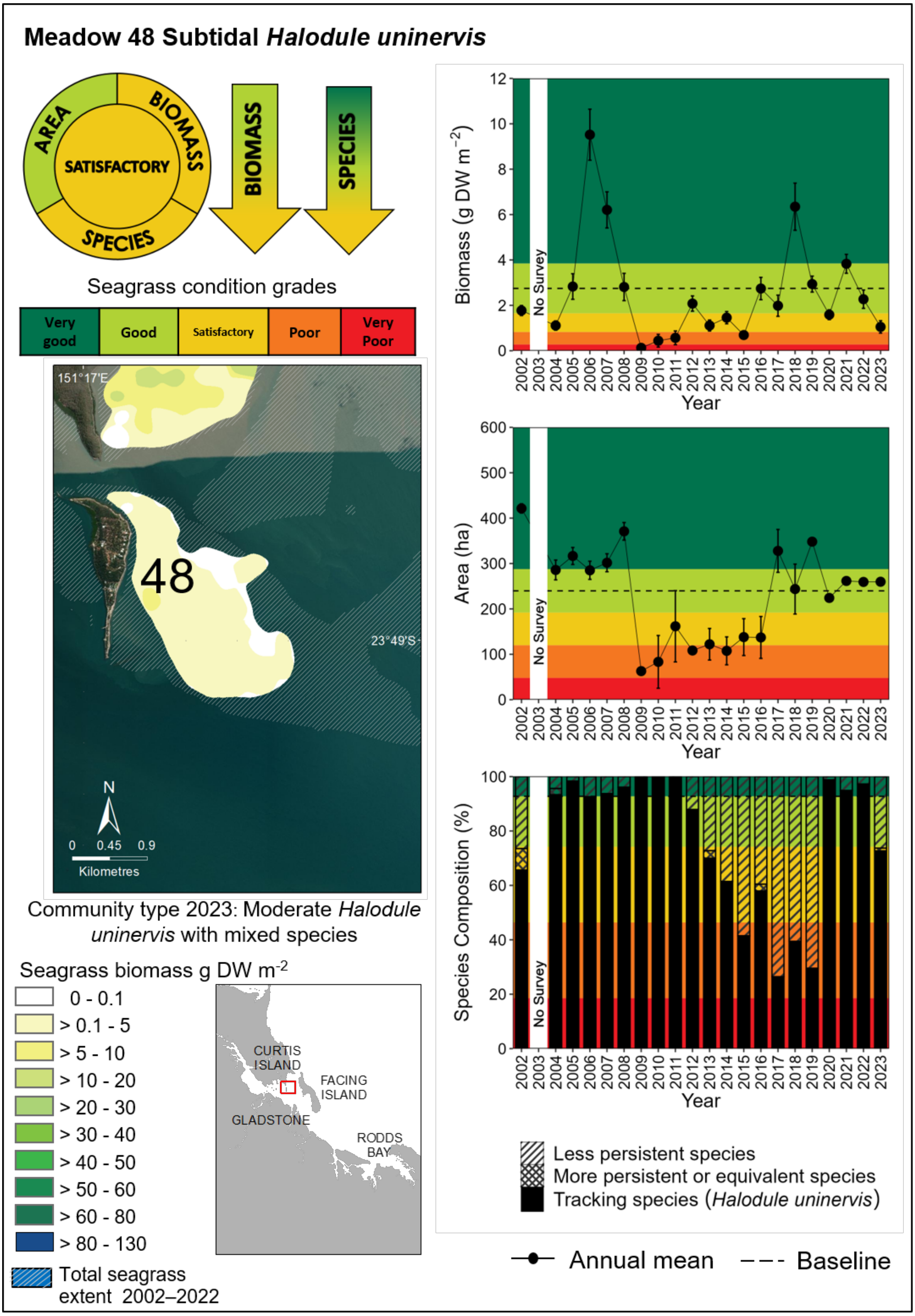


Figure 22. Changes in meadow area, biomass and species composition Meadow 48, Quoin Island (Mid Harbour Zone), 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

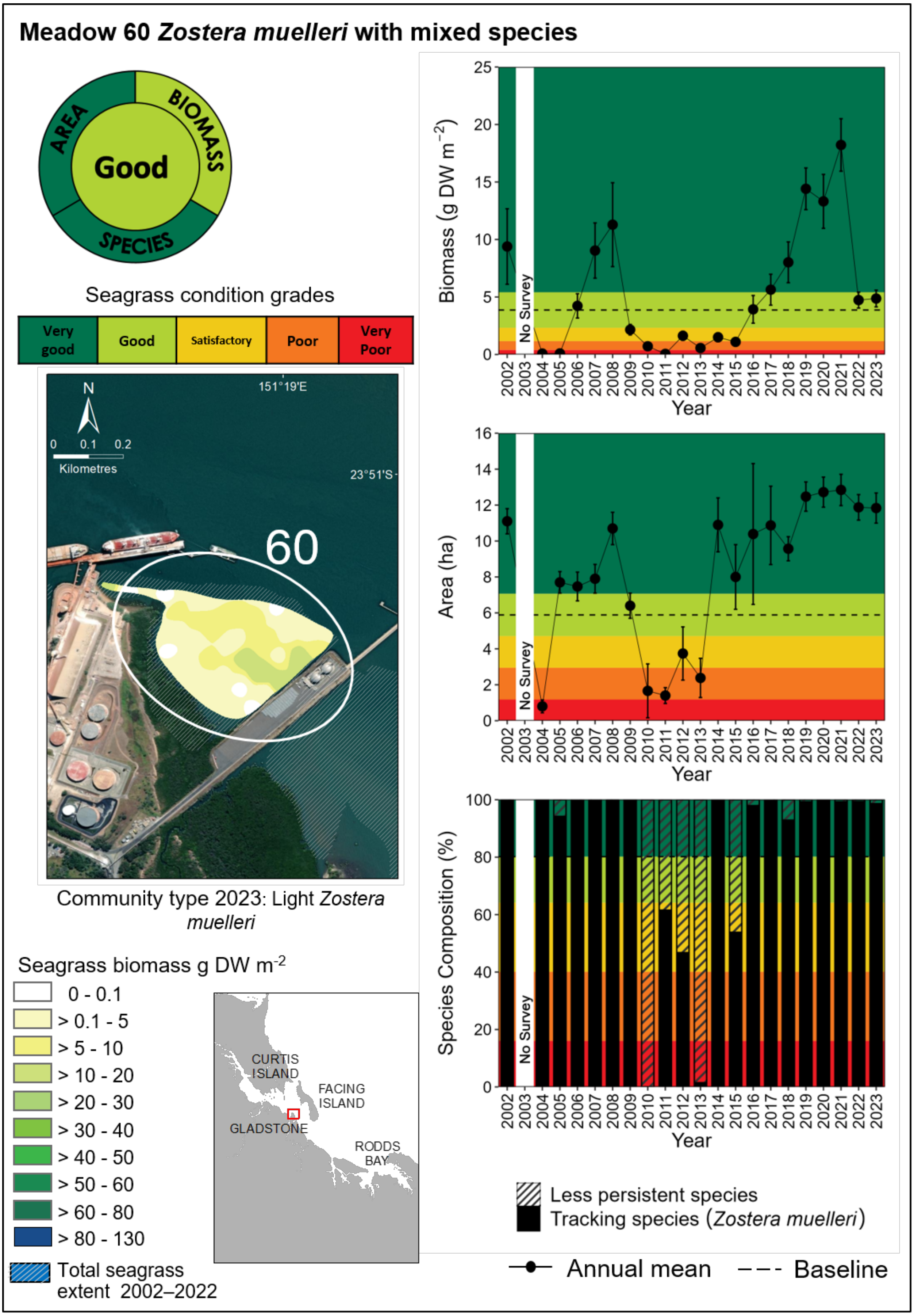


Figure 23. Changes in meadow area, biomass and species composition for Meadow 60, South Trees Inlet Zone, 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.6 Rodds Bay long-term monitoring meadows

Since the inception of the monitoring program, three meadows in Rodds Bay have been monitored as reference areas to compare to meadows within the port and to provide an opportunity to measure seagrass health in an area that is not exposed to port activities (Figures 22-24).

Meadow 94:

The smallest monitoring meadow in Rodds Bay was in an overall good condition in 2023, an improvement from poor condition the previous year. Both biomass and area improved and were above the long-term baselines. Biomass in this meadow was the highest recorded in two years at 12.62 ± 2.55 g DW m^{-2}, and was above the long term average of 9.13 g DW m^{-2}. The area of the meadow also increased to 2.65 ± 0.70 ha in 2023, resulting in the condition grade improving from poor to good. Seagrass species *Z. muelleri* dominated the species composition and was in a very good condition (Figure 22).

Meadow 96:

The largest meadow in Rodds Bay, Meadow 96, was also in an overall good condition with improvements in biomass and area (Figure 23). Biomass improved to just above the long-term average and was the highest in three years with 8.71 ± 1.28 g DW m^{-2}. The footprint of this meadow was one of the highest recorded since monitoring began covering an area of 396.62 ± 12.54 ha. This meadow is dominated by *Z. muelleri* with a small proportion of *H.ovalis* and species composition was in a good condition.

Meadow 104:

Meadow 104 was in a good condition, an improvement from poor in 2022 (Figure 24). Biomass improved from poor to good with 6.57 ± 2.03 g DW m^{-2} in 2023, an increase from 1.89 ± 0.98 g DW m^{-2} in 2022. Area increased to one of the highest since monitoring began covering 44.61 ± 3.75 ha resulting in a very good condition for the first time in two years. Species composition was also in a good condition with *Z. muelleri* persisting in this meadow (Figure 24).

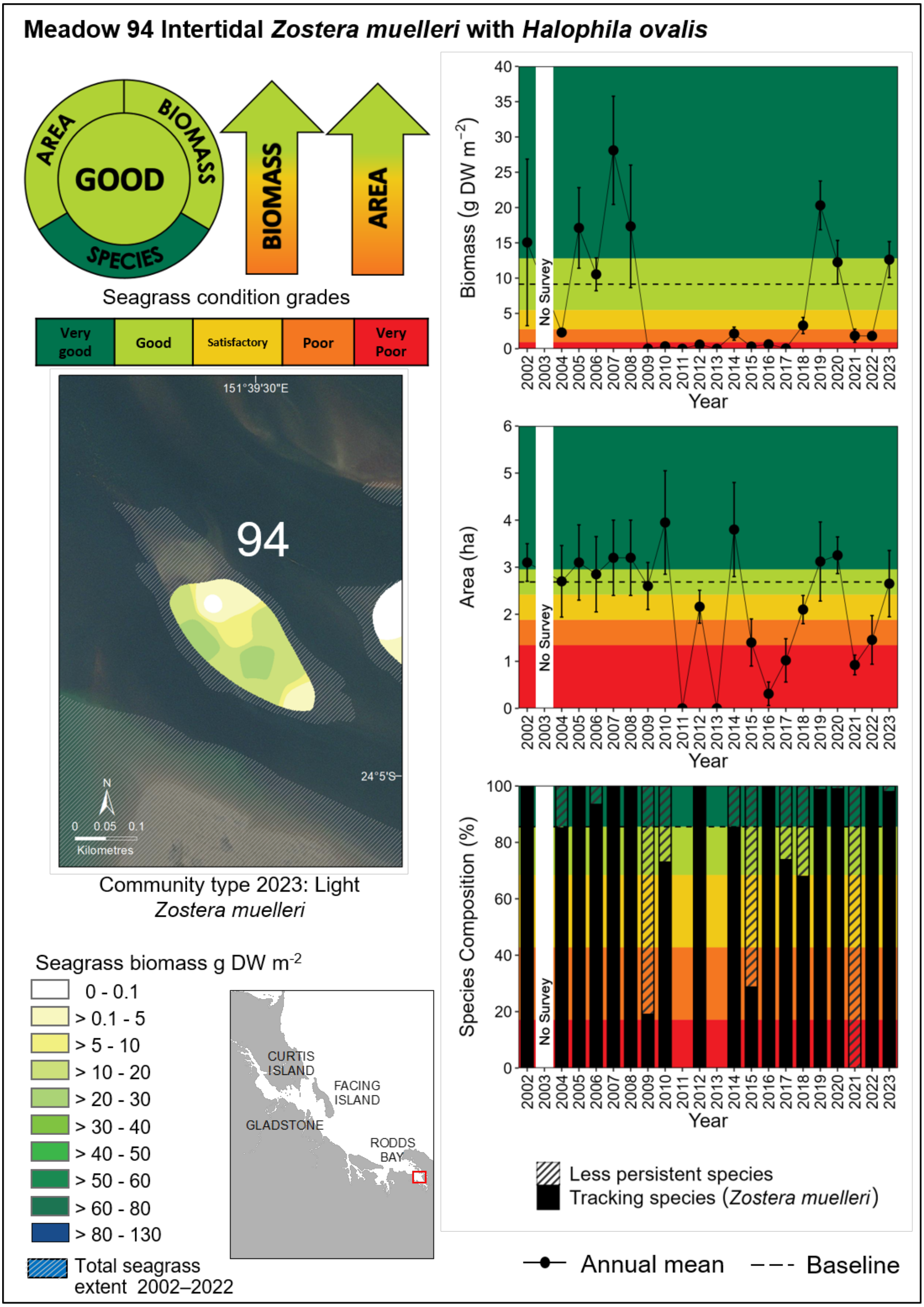


Figure 22. Changes in meadow area, biomass and species composition for Meadow 94, Rodds Bay Zone, 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

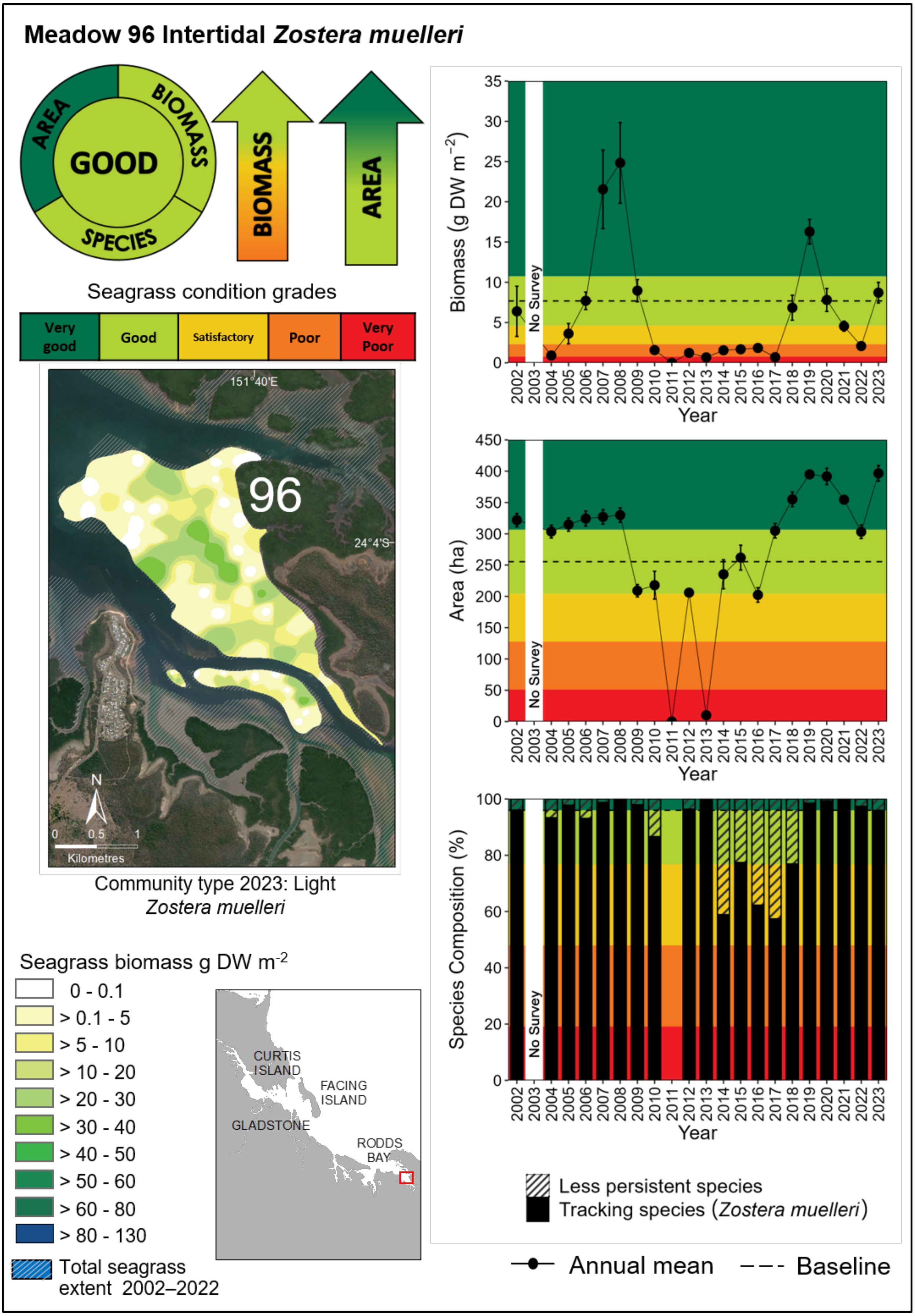


Figure 23. Changes in meadow area, biomass and species composition for Meadow 96, Rodds Bay Zone, 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

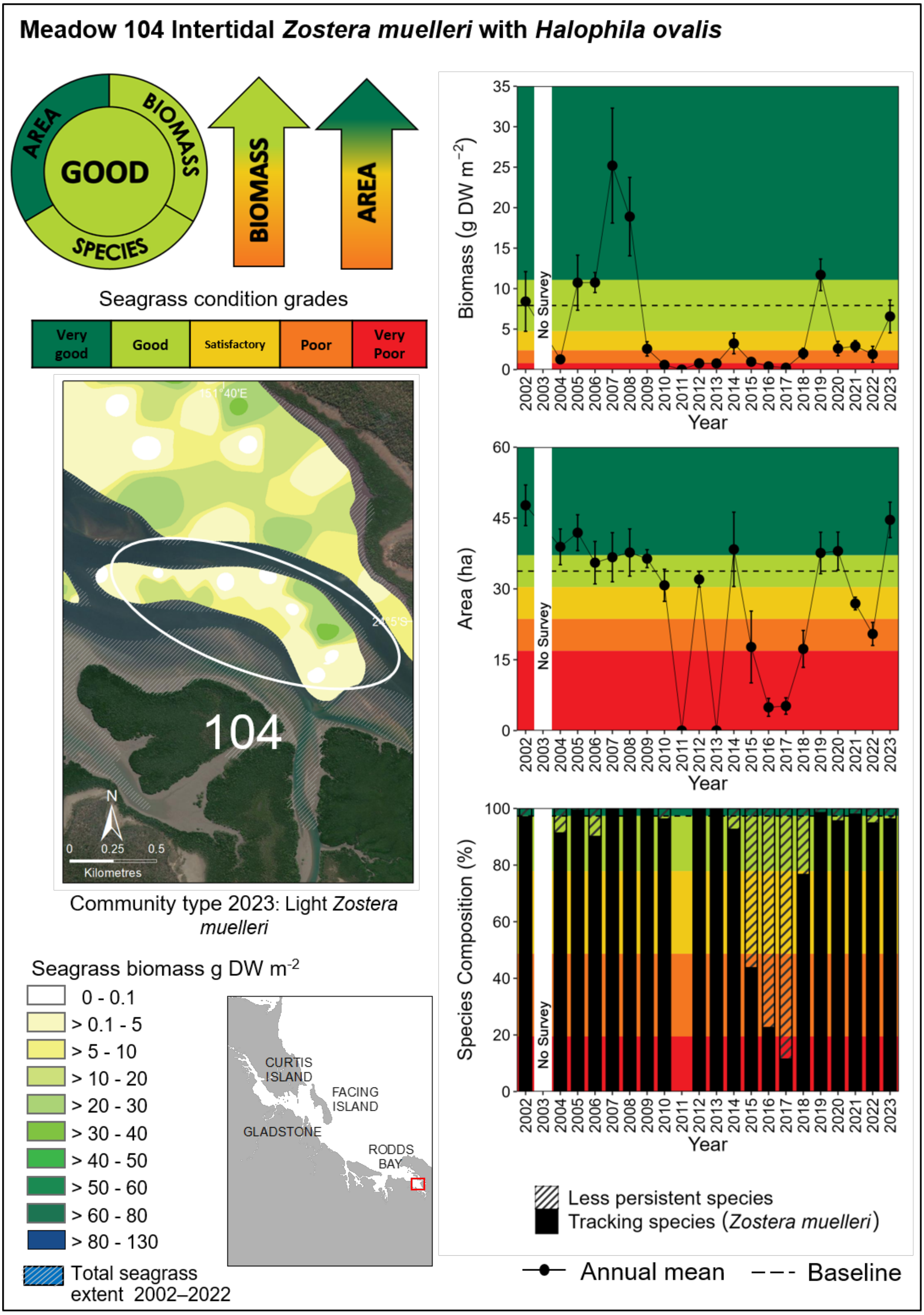
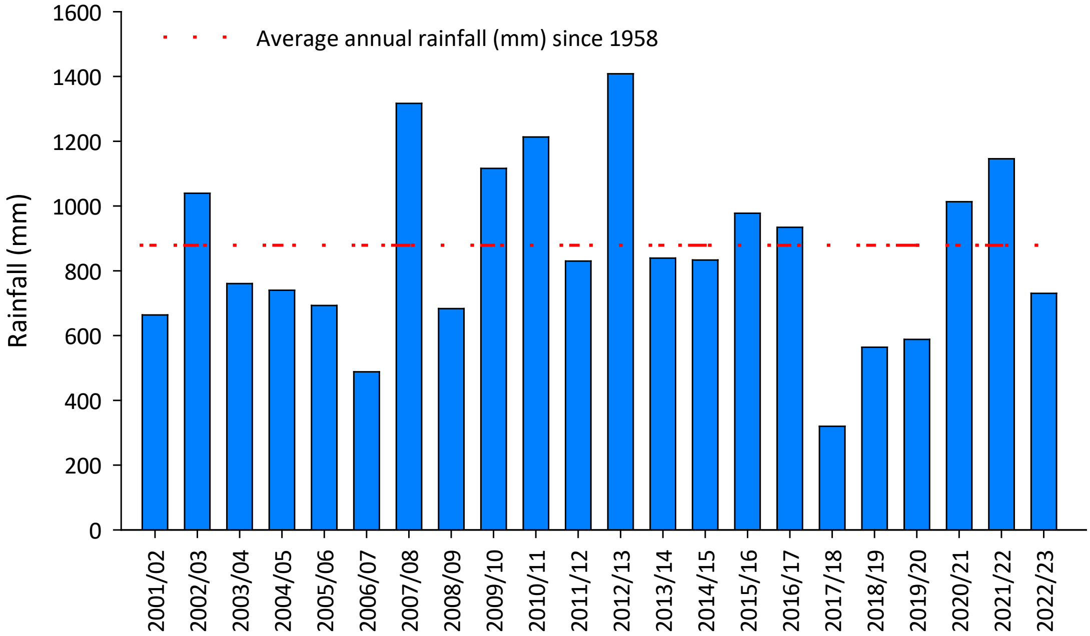


Figure 24. Changes in meadow area, biomass and species composition for Meadow 104, Rodds Bay Zone, November 2002–2023 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3 Gladstone environmental conditions

In the 12 months preceding the October 2023 survey, total annual rainfall was 730 mm and below the long-term average (879.9 mm) (Figure 25a). March was the only month that had monthly rainfall above average with the rest of the year experiencing below average monthly falls (Figure 25b). The Calliope River flow was also below average which is in line with the low rainfall recorded around the Gladstone region (Figure 26). The annual total daytime exposure of intertidal seagrass meadows was above average for the first time in four years and one of the highest on record (Figure 27).

a)



b)

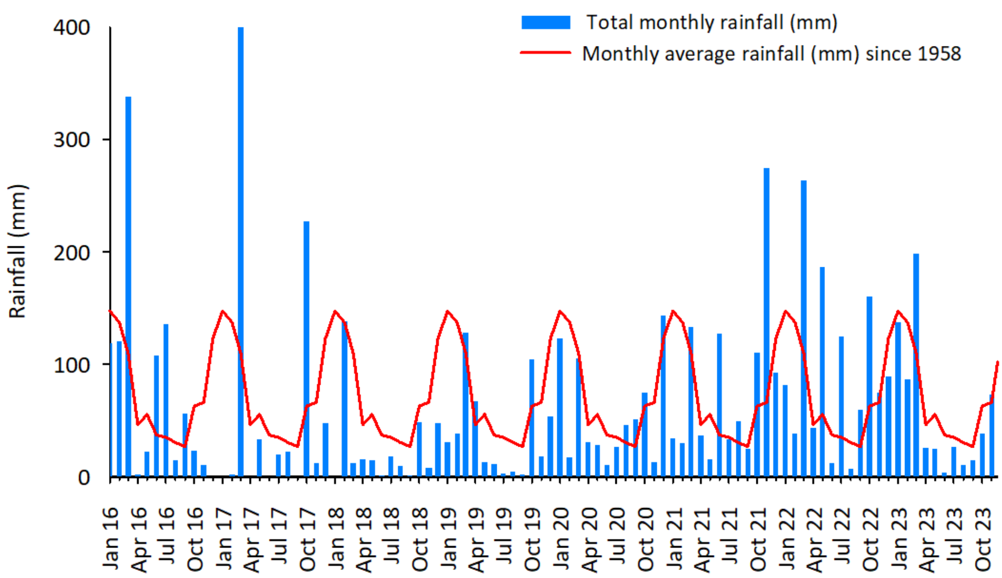


Figure 25. a) Gladstone annual rainfall (mm) and b) monthly rainfall (mm) totals; January 2016–November 2023.

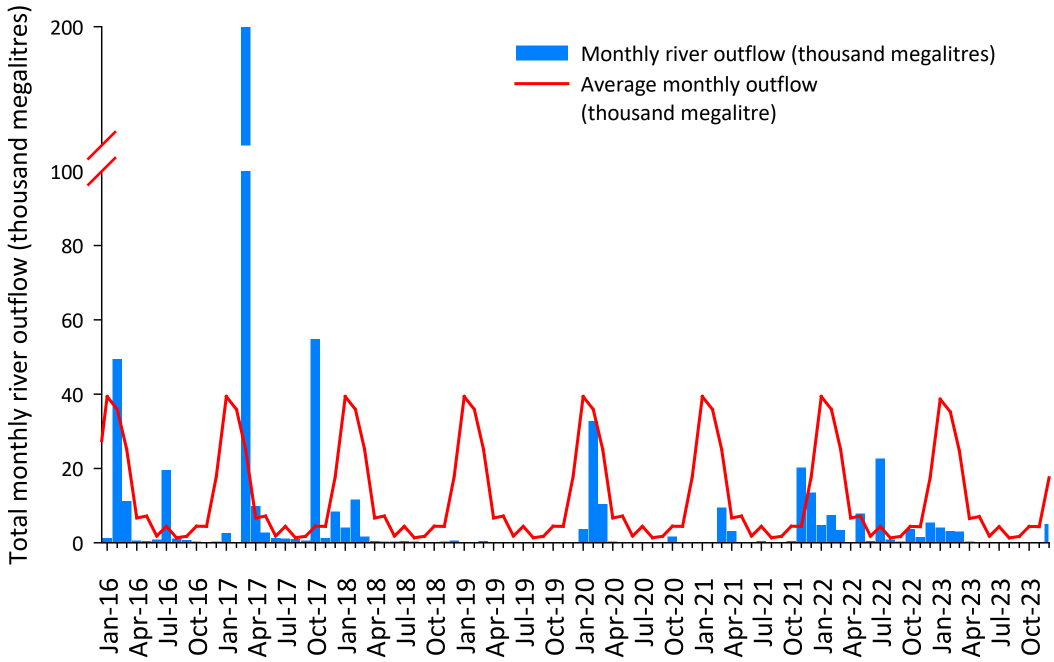


Figure 26. Monthly total river outflow for the Calliope River (thousand megalitres); January 2016–November 2023.

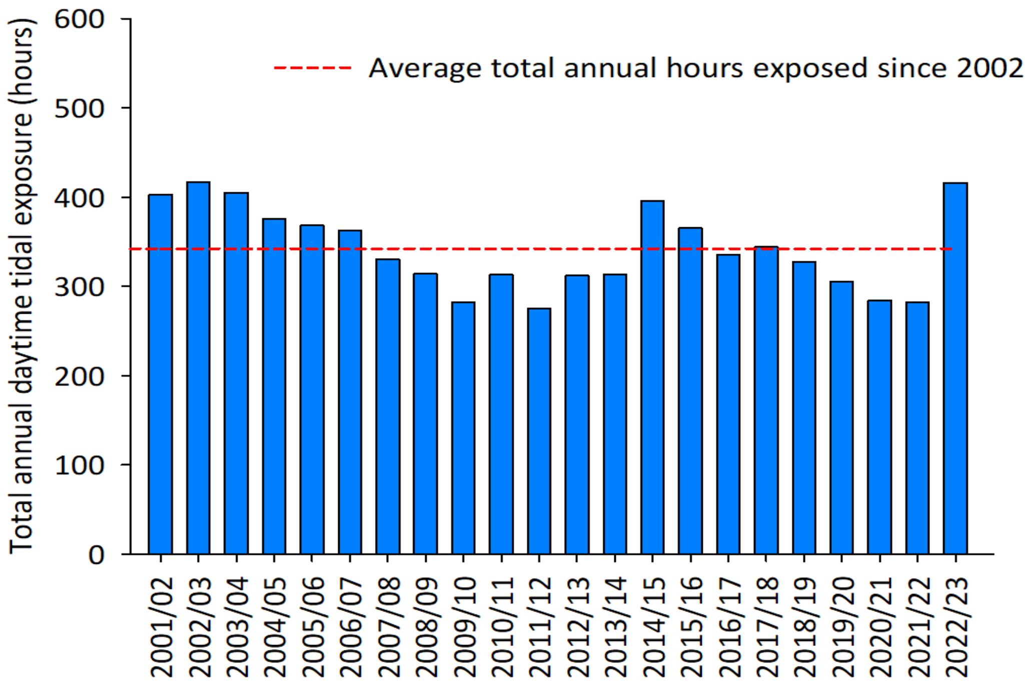


Figure 27. Total annual daytime hours seagrass meadows exposed to air 2001/02 - 2022/23 (daytime hours used 0600 – 1800; <1.0 m below mean sea level).

4 DISCUSSION

4.1 Gladstone seagrass

In 2023, seagrasses in Port Curtis and Rodds Bay underwent improvements in condition and were classed as being in an overall good condition, an improvement from a satisfactory condition the previous year. This improvement is due to eight of the 14 monitoring meadows being in a good to very good condition with the majority of these meadows found in The Narrows, South Trees Inlet, Rodds Bay and the Western Basin zones. Three of the Western Basin meadows were in a satisfactory condition. The Inner Harbour and Mid Harbour meadows were in a poor to satisfactory condition with lower scores principally due to low biomass and a reduction in species composition.

In 2023, below average rainfall and river flow were likely to have led to favourable seagrass growing conditions. These conditions generally lead to improved benthic light a principal controlling factor in seagrass growth. Local environmental conditions are a key factor in determining seagrass distribution, biomass and health in the Gladstone region. Long-term trends in seagrass condition over the past 20 years of annual monitoring reveal a strong relationship with river flow and rainfall in the region. The Calliope River outflow was well below average in 2023 with no flow in the months leading up to the survey, a trend not seen since 2020. Annual rainfall was also below average for the majority of the year with March the only month with a significant above average rainfall event. Seagrass has specific light requirements for photosynthesis and growth (Chartrand et al. 2016; 2018). Turbidity associated with rainfall and river outflow reduces benthic light conditions inhibiting seagrass growth and can ultimately lead to plant death. In 2023 below average rainfall and river flow in the six months preceding the 2023 survey have likely led to adequate benthic light, and therefore favourable seagrass growing conditions. If favourable conditions continue, seagrass biomass and condition may continue to increase and improve in building resilience to potential future disturbances.

Maintenance dredging in Gladstone occurs annually and is carefully managed to ensure minimal reductions in benthic light and subsequent impacts to seagrass meadows (GPC 2023). The methodology, timing, frequency and duration of dredging operations play a major role in determining what impact, if any, they have on seagrass meadows and careful management of dredging operations can limit these (Chartrand et al. 2016; Wu et al. 2018). Maintenance dredging strategies such as ensuring dredging occurs over relatively short timeframes that restrict the extent of the dredge plumes, and ensuring maintenance activity occurs within the period where local seagrasses tend to have high resilience to light impacts. Meadows in proximity to the maintenance dredging activity in the Western Basin, the Inner Harbour and South Trees Inlet ranged in condition from poor to very good condition in 2023. The variation in condition and the overall condition improvement indicates that the maintenance dredging did not have any long-term impact on these meadows in 2023.

Meadow 58 in the Inner Harbour has been in poor or very poor condition for the past three years. In 2023, this meadow improved in biomass and footprint to be in very good condition for both of these indicators however the species composition has failed to return to tracking species *Z. muelleri*. Prior to 2010, Meadow 58 had higher biomass (5-6 g DW m^{-2}) before it underwent severe decline after high rainfall and river flow. During this time, *Z. muelleri* contributed 40-90% of the meadow biomass. Since the meadow was lost in 2010, it has transformed to be predominantly *H. uninervis*/*H. ovalis,* and the ongoing low contributions of *Z. muelleri* to the meadow suggest that it has not been able to re-establish and persist. This is the third year in a row that a total absence of the foundation species *Z. muelleri* has been recorded in the meadow, which has been replaced with less persistent *H. uninervis* and *H. ovalis*. The absence of *Z. muelleri* not only results in a very poor species composition score, but also leads to lower meadow biomass as *Z. muelleri* generally has greater biomass than *H. uninervis* and *H. ovalis*.

Historically, the Pelican Banks meadow is the largest, high-biomass seagrass meadow in Port Curtis, and up until 2014 was in a good to satisfactory condition. In 2023, the Pelican Banks meadow (Meadow 43) was in poor condition for the second year in a row. The main drivers behind the condition downgrade over the previous years has been the reduction in biomass as a result of changes in species composition from the foundation species *Z. muelleri* to less persistent *H. uninervis* and *H. ovalis.* In 2021, the contribution of *Z. muelleri* to the meadow biomass improved to 90% resulting in increased meadow biomass, however in 2022 and 2023, the meadow returned to poor condition as *Z. muelleri* biomass decreased across the meadow. *Zostera muelleri* has much greater biomass than the other species in the meadow (e.g. *H. uninervis*, *H. ovalis*) and biomass should increase if the contribution of *Z. muelleri* improves. The Pelican Banks meadow typically experiences the best water quality conditions for seagrass meadows in the region based on historical monitoring of benthic light (Chartrand et al. 2016) and therefore meadow condition would be expected to be more consistent or better than those elsewhere in Port Curtis. Megaherbivore (green turtles and dugong) grazing has been suggested as a possible cause of these declines. The Pelican Banks meadow has high levels of herbivory from dugong and turtle with dugong feeding trails regularly observed within the meadow (Rasheed et al. 2017) and direct observations of green turtles also feeding on the meadow (direct observations and Pillans et al. 2021; Hamann et al. 2016; Limpus et al. 2017). Research using herbivore exclusion cages has found the impact of herbivores on both seagrass biomass and canopy height were greater at Pelican Banks than other meadows within Port Curtis and Rodds Bay (Scott et al. 2021a). It has been suggested that megaherbivores target areas of high biomass which may explain high levels of herbivory in the past (Smith et al. 2022, Rasheed et al. 2017) and major meadow losses have occurred in other locations around the world as a direct result of turtle herbivory (Christianen et al. 2014).

The three monitoring meadows in the out of port reference area in Rodds Bay all had improvements in biomass and area signalling a return to or above baseline levels. Large declines were observed in the Rodds Bay meadows from 2009 to 2010 with a complete loss of seagrass in the monitoring meadows in 2011 to 2013. Biomass and area in the Rodds Bay meadows peaked in 2019-2020 and were considered very good after nine to 10 years of being in satisfactory to poor condition. These meadows have been variable in condition over the past few years with declines occurring again in biomass and area. The improvement in all meadows across all condition indicators is a positive sign that climate conditions have been favourable for these meadows to build on their resilience for another season and are able to continue to re-establish.

4.2 Comparisons with Queensland-wide monitoring program

Other monitoring locations along Queensland's east coast between Cairns and Port Curtis had similar seagrass conditions to the seagrass meadows in Port Curtis and Rodds Bay. In 2023 seagrass in Cairns and Townsville to the north were in a satisfactory to good condition in 2023 with generally favourable local weather conditions providing optimal growing conditions (Reason et al. 2024; McKenna et al. 2024). Seagrass surveys further south at Hervey Bay and the Great Sandy Straits recorded very low seagrass biomass and area following major flooding of the Mary River during 2022, with observations of recovery of the intertidal seagrasses in 2023 attributed to favourable local weather conditions (York et al. 2022; Bryant et al. 2024). There has been a trend of recovery in seagrass meadows over recent years in response to widespread climate associated losses in 2009/2010, with localised climate events having a major impact on seagrass outcomes around the state since then. Severe localised flooding that occurred in the Townsville and Kurumba region in 2019, led to a decline in seagrass meadows in that year but have since been recovering with no extreme weather events in recent years (McKenna et al. 2024; Scott et al. 2024). However, Mourilyan Harbour has shown little recovery after complete meadow loss in 2010/2011 and seagrass remains in very poor condition with little prospect of seagrass recovery without some form of restoration (Reason et al. 2023).

4.3 Implications for port management

The good condition of seagrasses in 2023 indicates a healthy marine environment for Port Curtis and Rodds Bay. The seagrass dynamics observed in Port Curtis and Rodds Bay over the past year are consistent with the major climate drivers of seagrass change seen elsewhere in North Queensland and the continued use of the meadows by dugongs and green turtles are signs of a healthy functioning seagrass ecosystem. The improvements in biomass and area and the maintenance of foundation species over the previous sampling years in most Port Curtis and Rodds Bay meadows likely provided some resilience to the less favourable conditions that occurred in 2022. Sustained periods of high biomass can lead to increased reproductive effort and replenish seed banks in the region, particularly for *Z. muelleri.* Larger seed banks further increase seagrass meadow resilience to impacts by increasing their capacity for recovery (Reason et al. 2017b).

In Port Curtis, substantial work has been done to develop relevant light requirement thresholds for the local seagrasses and these are implemented by GPC as part of routine management requirements during port activities to protect seagrasses (Chartrand et al. 2012; 2016). Maintaining light environments that are sufficient for seagrass growth is one of the key drivers of seagrass condition in Port Curtis and Rodds Bay, and elsewhere in Queensland. Activities that could reduce water quality in Port Curtis and Rodds Bay should be managed in such a way as to ensure water quality and particularly benthic light is sufficient for seagrass growth. Over the past decade, seagrass meadows in Port Curtis and Rodds Bay have undergone repeated disturbances from climate, floods, cyclones and anthropogenic activities but have maintained their historical extent and have recovered biomass and species composition to pre disturbance levels following these events. While improvements in biomass and the return of more persistent species to meadows has increased seagrasses resilience to weather events in 2023, future pressures or impacts have the potential to further erode this resilience and increase the susceptibility to further declines.

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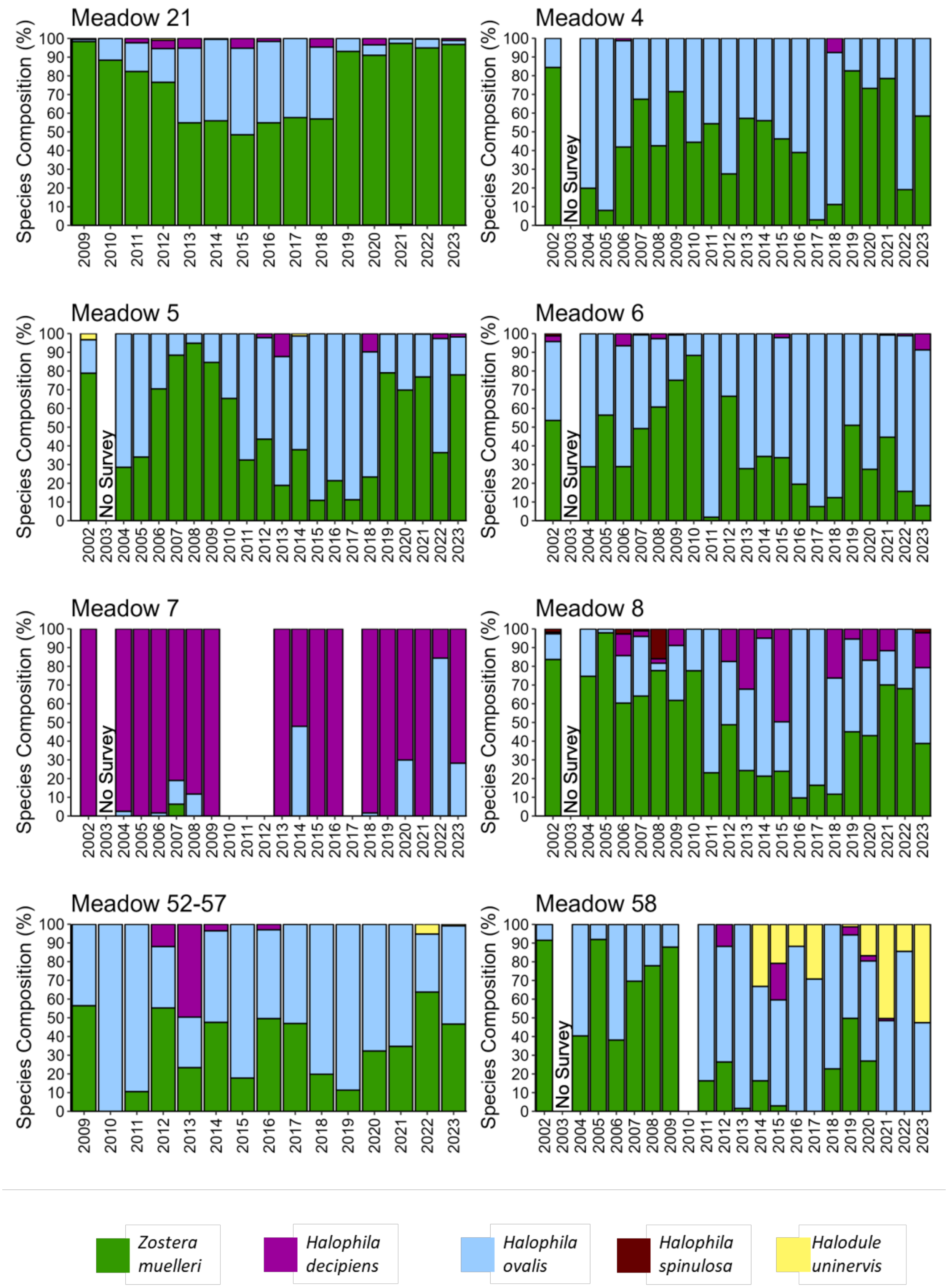
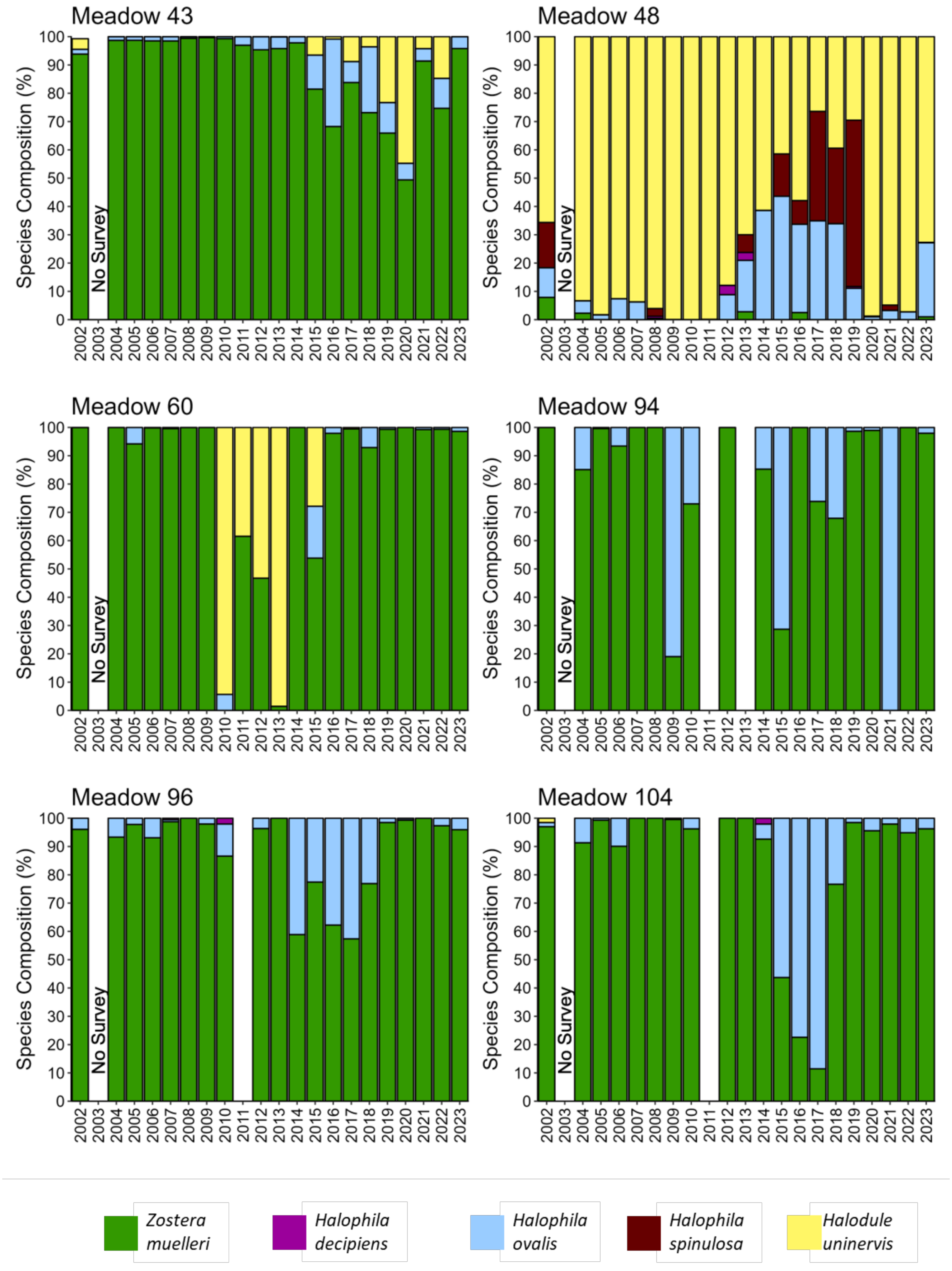
APPENDICES

Appendix 1. Meadow area and above-ground biomass of Port Curtis and Rodds Bay seagrass meadows 2023

Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present	Zone
21	12.38 ± 1.95	191.31 ± 8.35	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis, H. decipiens, H. spinulosa*	The Narrows
4	1.31 ± 0.28	41.32 ± 1.85	Light *Z. muelleri/H. ovalis*	Aggregated patches	*Z. muelleri, H. ovalis*	Western Basin
5	3.76 ± 0.45	152.23 ± 2.95	Light *Z. muelleri* with mixed species	Aggregated patches	*Z. muelleri, H. ovalis, H. uninervis*	Western Basin
6	1.72 ± 0.19	451.29 ± 6.64	Moderate *H. ovalis* with mixed species	Aggregated patches	*H. ovalis, H. decipiens, Z. muelleri*	Western Basin
7	2.02 ± 0.29	33.79 ± 3.13	Moderate *H. decipiens* with *H. ovalis*	Continuous cover	*H. decipiens, H. ovalis*	Western Basin
8	0.82 ± 0.15	235.22 ± 4.36	Light *H. ovalis/Z. muelleri* with mixed species	Aggregated patches	*H. ovalis, Z. muelleri, H. decipiens, H. spinulosa*	Western Basin
52-57	1.06 ± 0.19	46.56 ± 4.48	Light *H. ovalis/Z. muelleri*	Isolated patches	*Z. muelleri, H. ovalis, H. uninervis*	Western Basin
43	8.15 ± 0.66	666.50 ± 6.71	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis*	Mid Harbour
48	1.05 ± 0.27	259.82 ± 8.15	Moderate *H. uninervis* (thin) with mixed species	Continuous cover	*H. uninervis* (thin), *H. ovalis, Z. muelleri, H. spinulosa*	Mid Harbour
58	3.44 ± 0.46	41.52 ± 3.68	Moderate *H. uninervis (thin)/H. ovalis*	Aggregated patches	*H. uninervis* (thin), *H. ovalis*	Inner Harbour
60	4.87 ± 0.73	11.84 ± 0.84	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis*	South Trees
94	12.62 ± 2.55	2.65 ± 0.70	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis*	Rodds Bay
96	8.71 ± 1.28	396.62 ± 12.54	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis*	Rodds Bay
104	6.57 ± 2.03	44.61 ± 3.75	Light *Z. muelleri*	Aggregated patches	*Z. muelleri, H. ovalis*	Rodds Bay

Appendix 2. Detailed species composition for long term monitoring meadows 2023




Meadow 43
Meadow 48
Meadow 60
Meadow 94
Meadow 96
Meadow 104
Species Composition (%)
0 10 20 30 40 50 60 70 80 90 100
No Survey
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
Zostera muelleri
Halophila decipiens
Halophila ovalis
Halophila spinulosa
Halodule uninervis