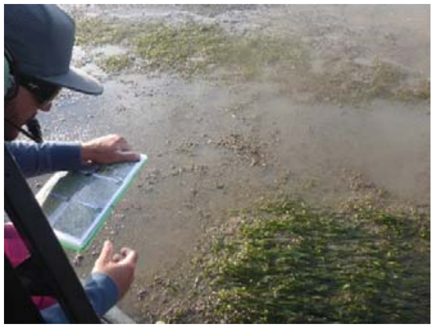


Seagrasses in Port Curtis and Rodds Bay 2017 Annual long-term monitoring

Chartrand KM, Rasheed MA, and Carter AB

Report No. 18/14
April 2018

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Annual long-term monitoring

A Report for Gladstone Ports Corporation

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KEY FINDINGS

Seagrass Condition 2017

Poor

1. In 2017, seagrasses in Port Curtis and Rodds Bay remained in an overall poor condition. While the spatial footprint of seagrass meadows was above average, the majority of seagrass meadows had a low biomass and high proportion of colonising species, leading to the overall poor condition score.

2. All seagrass species historically present during annual monitoring surveys remained present in 2017 and seagrass meadows also generally occurred throughout their historical distribution .

3. The results for individual meadows and regions vary, however in 2017, there were few overall improvements to monitoring meadows from 2016 surveys.

4. In 2016, the biggest concern was the condition of Pelican Banks seagrass, the largest and historically most stable seagrass meadow in Port Curtis. In 2017 there were improvements in both biomass and species composition which resulted in this meadow improving from very poor to poor condition.

5. There was no clear relationship between distance from anthropogenic activities and seagrass condition with some of the poorest condition meadows occurring in the out of port reference areas in Rodds Bay.

6. Two large rainfall and river flow events in March and October 2017 were likely to have contributed to conditions that prevented any substantial seagrass recovery during 2017.

7. Meadows can be classified as being in poor condition if any one of the three key indicators (biomass; area; species composition) were poor, even if the other two indicators had improved. For some meadows this was the case in 2017, especially those that had started to recover from recent declines with the key species yet to return.

8. Resilience of seagrasses in Port Curtis to further natural or anthropogenic impacts is likely to be low. While seagrass was maintained across most of the historical extent of seagrass distribution, the proportion of more resistant and stable species within meadows were at historically low levels.

IN BRIEF

Seagrass monitoring in Port Curtis and Rodds Bay commenced in 2002 and has been conducted annually since 2004. In November each year, 14 monitoring meadows are assessed for changes in three seagrass metrics; biomass, area and species composition (Figures 3 and 4). These monitoring meadows represent the range of different seagrass community types in Port Curtis and Rodds Bay. Changes in the seagrass metrics are used to develop a seagrass condition index. Since 2009, all seagrasses within the annual monitoring area, from the Narrows to the southern tip of Facing Island, have also been mapped (see Figure 2).

In 2017, the overall condition of seagrass in Port Curtis and Rodds Bay remained poor for a third consecutive year. The total area of seagrass mapped in the monitoring area was above the long-term average, slightly up from 2016 (Figure 1). Overall, only four meadows were in very good or satisfactory condition while the remaining ten meadows were deemed poor or in a very poor state (Figure 3 & 4). Changes from 2016 were mixed with improved, unchanged, and declines in meadows found across the survey area. Meadow condition appeared to be independent of zone or proximity to anthropogenic or port activity (Figure 3 & 4).

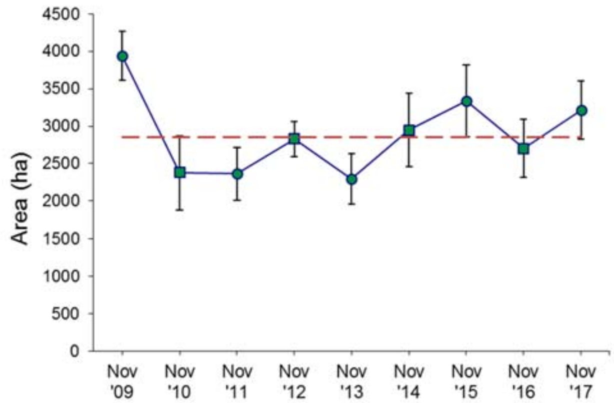


Figure 1. Annual changes in total seagrass area in Port Curtis, excluding Rodds Bay, 2009–2017. Red dashed line represents the long-term average of meadow area mapped 2009–2016.

In 2016, serious concerns were raised regarding the largest and densest area of seagrass in Port Curtis at Pelican Banks with significant biomass loss and an increased proportion of less persistent seagrass species in the meadow. In 2017, this trend was reversed with biomass and species composition improving, resulting in the meadow shifting from very poor to poor condition. The lightest portion of the meadow continues to be in the southern sector where seagrass biomass is extremely low. While the improvements are a positive sign, the meadow is still a long way from regaining its full biomass and area. Given its' historical importance as the most stable seagrass meadow in the region, a continued trajectory of recovery in the future remains a key to marine environmental health in Port Curtis.

Meadows at a greater distance from port, urban and industrial activity at Rodds Bay had further declines and remained in a very poor state in 2017 (Figure 4). These meadows have been in a poor state since substantial declines occurred between 2008 and 2009.

It is unclear what has led to the lack of improvement in overall seagrass condition in Port Curtis and Rodds Bay over the past three years. Generally, the annually averaged environmental conditions were close to long term averages and therefore within expected ranges for favourable seagrass growth in 2017 (Figure 5). However, large rainfall events, leading to well above average flows of local rivers including the Calliope occurred in March and October which may have created conditions preventing substantial seagrass recovery (see Section 5.3 for details). High river flows in particular, could have had negative effects on seagrass meadows closest to the river mouth at Wiggins Island and the subtidal South Fisherman's Landing meadow which was absent in 2017 (Figure 3). Previous monitoring of benthic light in Port Curtis has shown similar high rainfall and episodic river flow events result in a lower benthic light environment over seagrass meadows, although no direct benthic light monitoring was conducted in 2017.

There are a range of other potential contributors to the decline of seagrasses at Pelican Banks and other meadows such as South Fisherman's Landing and Wiggins Island in recent years. These meadows have a higher frequency of turtle observations and dugong feeding activity than many other meadows in Port Curtis, however it is unclear if this has substantially increased from previous years. Research is currently underway in Port Curtis to measure the potential effects of herbivory on seagrass and how this may alter meadow structure and condition. The changes observed may also be the result of an accumulation of pressures and impacts over multiple years. The large declines in biomass initially observed in 2015 were hypothesised to be linked to high temperatures and air exposure. Repeated natural impacts from local flooding and cyclones since 2010 are also well described. Local rivers and the Calliope River, in particular, had substantial floods well above long-term averages in 2014 and again in 2015 and the greatest single flow event in March 2017 since major flooding in January 2013. These repeated pressures may have left little respite for seagrasses to recover in condition.

Resilience of seagrasses in Port Curtis to further natural or anthropogenic impacts was likely to be low at the time of the survey in 2017. Further losses of seagrass would impact the critical services seagrasses provide, including as food for turtles and dugong. The future trajectory of recovery will be highly dependent on the maintenance of climate and weather conditions that are favourable for seagrass growth. Should these occur during 2018 we would expect seagrass meadows to improve given that seagrass presence has been maintained, albeit at lower biomass, across the majority of the historical footprint.

Seagrasses at other locations along the east coast of Queensland were similarly impacted by a number of climate events between 2010 and 2017, including flooding and cyclones. The trajectory for recovery since then has varied; the condition of some meadows has improved substantially but in other locations remains poor. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

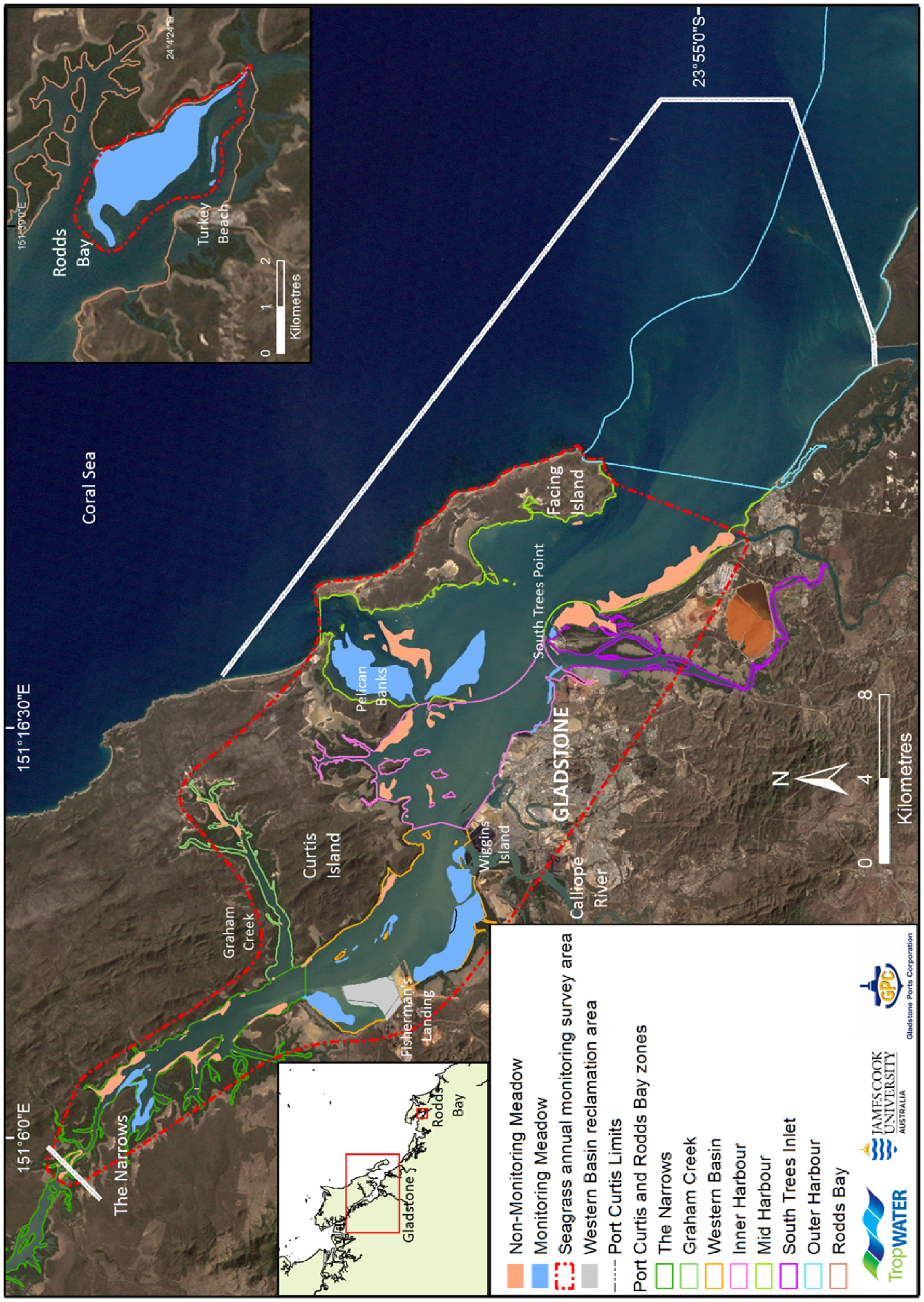


Figure 2. Seagrass distribution in Port Curtis and Rodds Bay, November 2017.

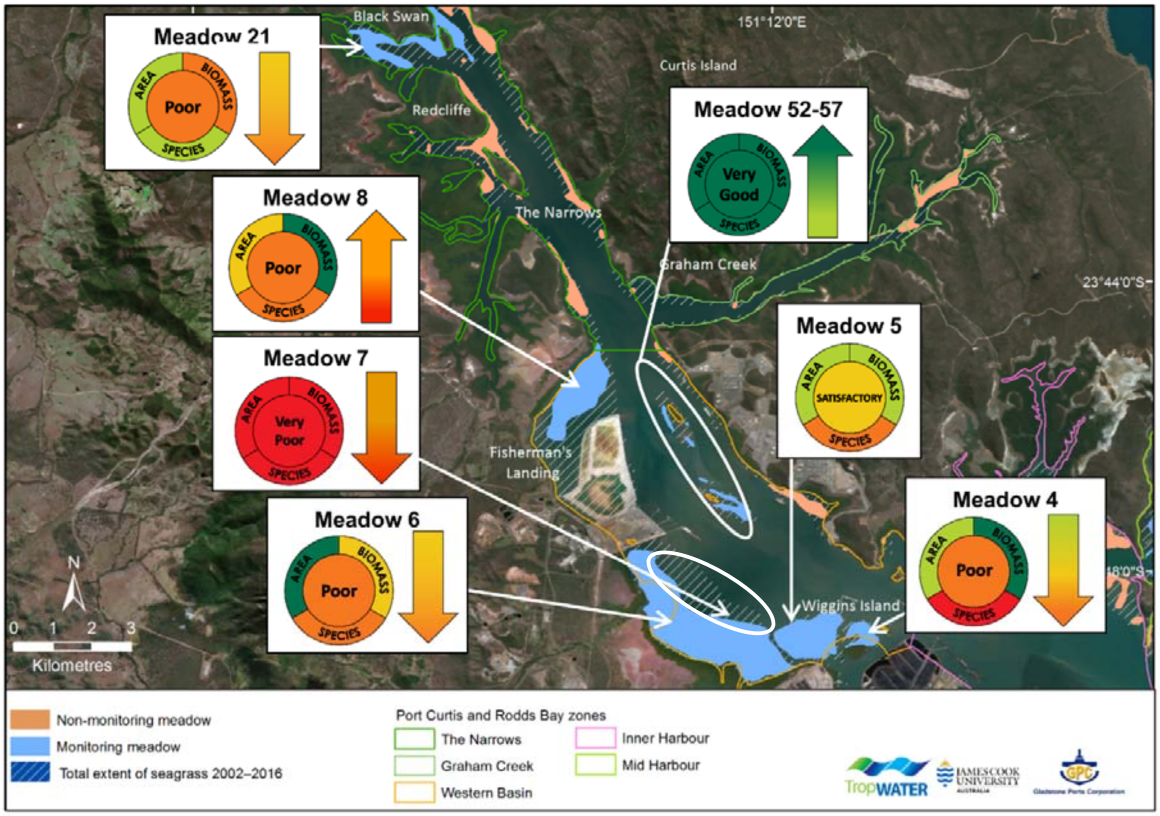


Figure 3. Seagrass distribution and meadow condition in The Narrows and Western Basin zones of Port Curtis, November 2017. Arrows represent an overall score change from 2016.

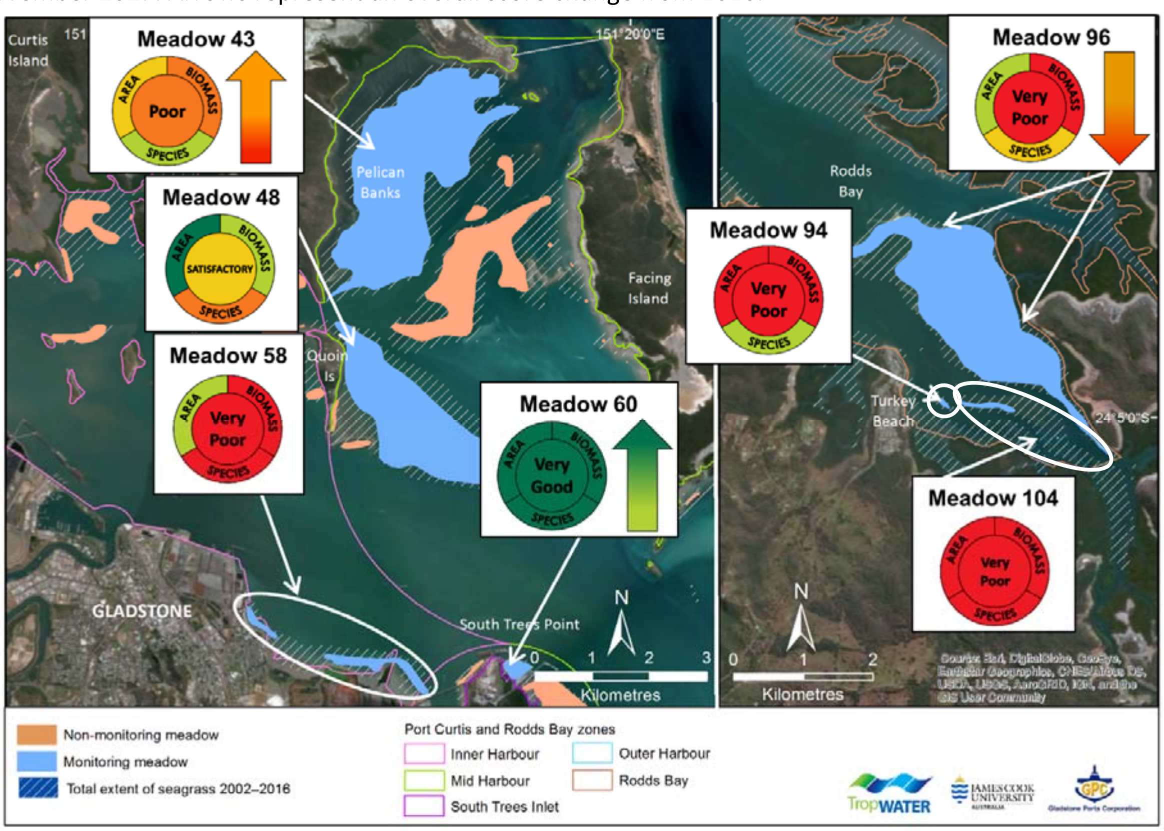


Figure 4. Seagrass distribution and meadow condition in the Inner Harbour, Mid Harbour and South Trees zones of Port Curtis, and at Rodds Bay, November 2017. Arrows represent an overall score change from 2016.

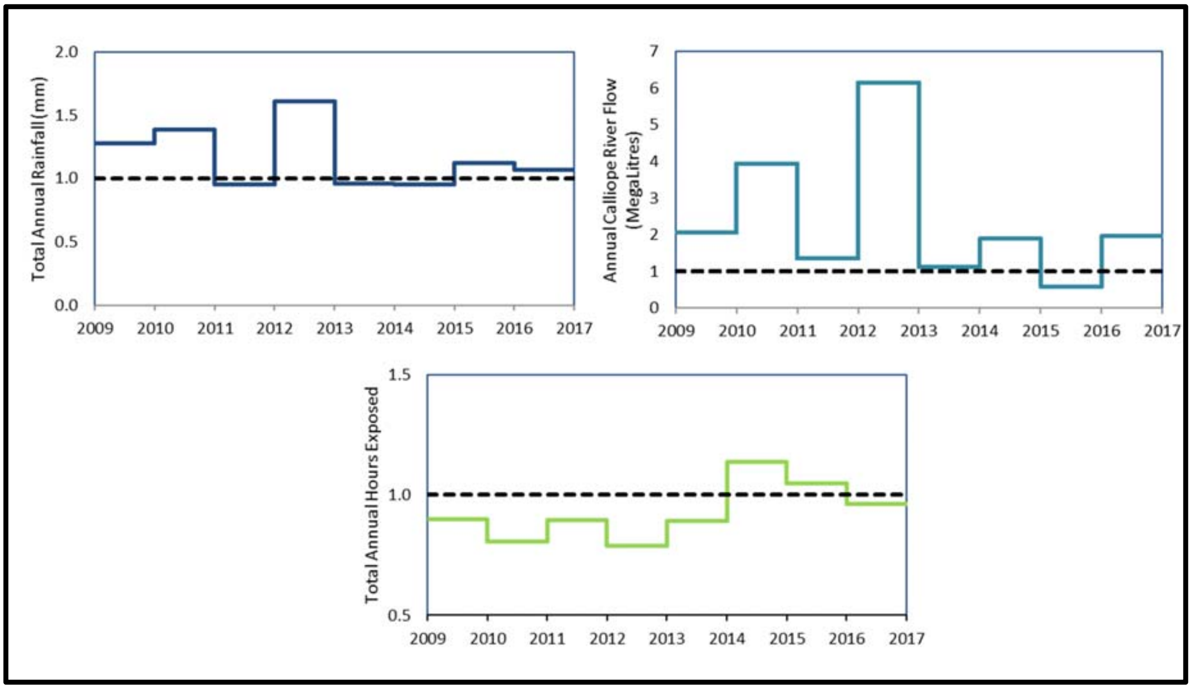


Figure 5. Climate trends in Gladstone, 2009 to 2017. Annual average (solid coloured line) expressed as a relative change compared to the long-term average (dashed line - rainfall since 1958, river flow since 1974, exposed hours since 2002). Y axis is scaled to 1.0 being equivalent to the long term average. See

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
DPA	Dugong Protection Area
GPC	Gladstone Ports Corporation
PCIMP	Port Curtis Integrated Monitoring Program
WBDDP	Western Basin Dredging and Disposal Project
GIS	Geographic Information System
dbMSL	Depth below Mean Sea Level
MSQ	Maritime Safety Queensland
DFTs	Dugong Feeding Trails

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, 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 is established in the majority of Queensland 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 the various Queensland port authorities. Each location is funded separately, but the common methodology and rationale provides a network of seagrass monitoring locations throughout Queensland (Figure 6).

Figure 6. Location of Queensland port seagrass assessment sites. (Red – long-term monitoring; blue – baseline mapping only)

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

The program delivers key information for the management of port activities to minimise impacts on seagrasses and 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 an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld.

1.2 Gladstone seagrass monitoring program

Seagrass surveys in the Gladstone region from The Narrows to Rodds Bay (referred throughout this report as Port Curtis and Rodds Bay - Figure 2) show that the 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 Port Curtis & Rodds Bay region have been recognised for their importance to dugong by the declaration of the Rodds Bay Dugong Protection Area (DPA) in 1996. Gladstone Ports Corporation (GPC) recognised that seagrasses are an important and sensitive component of the marine habitats within the port limits and are committed to maintaining the health of these habitats. In 2002, GPC commissioned a fine-scale baseline survey of seagrass resources in Port Curtis and Rodds Bay and the adjacent offshore area in the Great Barrier

Reef Marine Park (Rasheed et al. 2003). The 2002 baseline survey recorded 7,246 ± 421 ha of coastal seagrass habitat including large areas of seagrass within the port limits.

The annual seagrass monitoring program commenced in 2004 in response to a whole of port review (SKM 2004) and following recommendations from the Port Curtis Integrated Monitoring Program (PCIMP). Initially 10 seagrass meadows representative of the range of seagrass communities within the port were selected for monitoring. These included meadows considered most likely to be impacted by port developments and facilities. Monitoring locations included intertidal and subtidal seagrass meadows, meadows preferred by dugong, and those likely to support high fisheries productivity. Three meadows in Rodds Bay (outside port limits) were also selected as reference sites for monitoring. These sites provide information on seagrasses unlikely to be impacted by port activity, and assist in identifying port-related versus regional causes of seagrass change. From 2009, an additional two monitoring meadows were added to the long-term monitoring program to reflect the shift in new port activity to the Curtis Island area as part of the Western Basin Dredging and Disposal Project (WBDDP). These meadows complement the existing suite of monitoring meadows to include those most likely to be impacted by the WBDDP (Meadows 21 and 52-57). Due to the expansion of the Western Basin reclamation area adjacent to Fisherman's Landing, Meadow 9 is no longer monitored as part of this program.

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

1.3 Additions to the annual seagrass monitoring program

In 2009 proposed infrastructure developments within the port area, including a number of reclamation and dredging projects, required an expansion of the established long-term seagrass monitoring program. Additions to the monitoring program included:

- Re-mapping of all seagrass meadows within Port Curtis and Rodds Bay in 2009, 2013 and 2014 (Carter et al. 2015a; Bryant et al. 2014c; Thomas et al. 2010);
- Establishment of a network of sensitive receptor seagrass sites where information on seagrass change was collected at least quarterly (and monthly during dredging) and linked to water quality monitoring and assessments of seagrass resilience (Bryant et al. 2016; Davies et al. 2015; Bryant et al. 2014a; McCormack et al. 2013);
- A research program to establish the light requirements of Gladstone seagrasses and investigate sub-lethal indicators of seagrass stress (Schliep et al. 2014; Chartrand et al. 2012; Bostrom et al. 2006);
- Biannual (2009 – 2014) and annual (2015 – 2018) mapping and assessment of all seagrasses within the seagrass annual monitoring survey area reported here and previously (Carter et al. 2015a; Bryant et al. 2014c; Davies et al. 2013; Rasheed et al. 2012; Chartrand et al. 2011; Thomas et al. 2010).

Biannual surveys (2009 – 2014) were conducted at the peak of each growing (November) and senescent season (June) and surveyed all seagrass habitat in the seagrass annual monitoring survey area including the previously established PCIMP annual long-term monitoring meadows (see Figure 2). These surveys documented the spatial extent and biomass of intertidal and shallow subtidal seagrass meadows from The Narrows to the mouth of the Boyne River as well as the three monitoring meadows in Rodds Bay and assessed seasonal dynamics prior to, during, and after capital dredging associated with the WBDDP.

The annual (November) long-term seagrass monitoring (reported here) also includes Rodds Bay which is not directly affected by port activities. These surveys record changes in the distribution, biomass and species composition of seagrass monitoring meadows within Port Curtis and Rodds Bay.

All seagrasses within the greater Port Curtis and Rodds Bay area, as well as the adjacent offshore areas, were resurveyed in 2009. The survey recorded the greatest seagrass area since surveys began in 2002, with 7,150 ± 509 ha of coastal seagrass mapped. In 2013, new development proposals including the proposed Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project, led to the requirement for an updated baseline (Bryant et al. 2014c). The survey mapped 3,027 ha of coastal seagrass including intertidal and shallow subtidal areas from The Narrows to Rodds Bay, as well as approximately 1300 ha of deepwater seagrass habitat (>6 m) within Port Curtis and Rodds Bay and adjacent offshore areas. These areas were surveyed again in 2014 to build a more comprehensive understanding of these habitats leading up to any proposed works (Carter et al. 2015a). The 2014 survey found the total seagrass area including offshore meadows had expanded by over 8,300 ha, mostly due to the natural expansion of the offshore deepwater meadows which expanded to over 7400 ha (Carter et al. 2015a).

2 METHODS

2.1 Sampling approach and methods

Survey and monitoring methods followed the established techniques for the TropWATER Queensland-wide ports seagrass monitoring program. Detailed methods for its application in Gladstone can be found in the 2002 baseline and 2004 monitoring program reports (Rasheed et al. 2005; Rasheed et al. 2003).

The annual seagrass survey was conducted from 2nd – 9th November 2017. The survey involved mapping and assessing:

- All intertidal and shallow subtidal seagrasses within the Western Basin annual monitoring survey area of Port Curtis;
- Established long-term seagrass monitoring meadows within Port Curtis and at Rodds Bay (annual long-term monitoring survey).

The survey was conducted during November as seagrasses in the region are likely to be at their maximum biomass and distribution in late spring. This allows appropriate comparisons with baseline (2009, 2013, 2014) and annual monitoring surveys conducted every October/November since 2004.

At each survey site, seagrass characteristics including seagrass above-ground biomass, species composition, percent algal cover, depth below mean sea level (MSL; metres) for subtidal meadows, sediment type, time, and position (latitude and longitude) were recorded.

Two sampling techniques were used (Figure 7):

1. Intertidal areas: helicopter survey;
2. Shallow subtidal areas: boat-based free diving/grab survey.

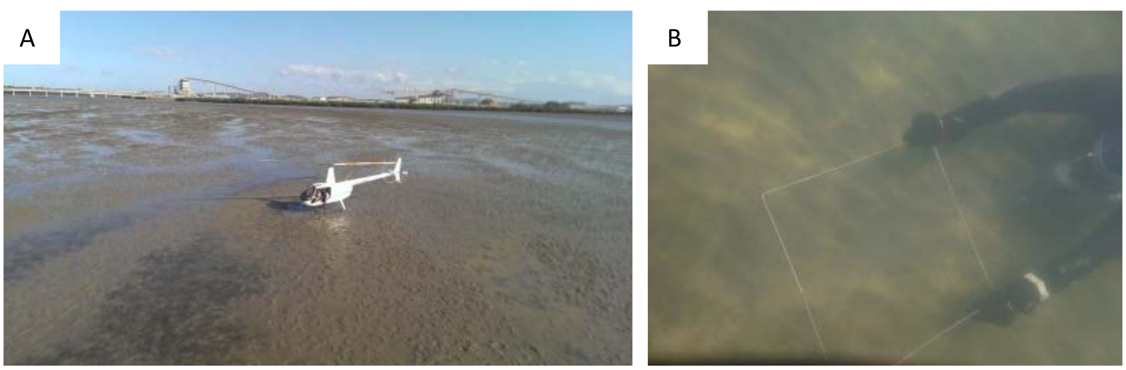


Figure 7. Seagrass monitoring methods; (A) helicopter aerial surveillance and (B) boat-based free diving.

2.1.1 Intertidal and shallow subtidal areas

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

Shallow subtidal meadows were sampled from a small boat using free divers. Seagrass characteristics were recorded at sites located along transects perpendicular to the shoreline at ~100 - 500 m intervals, or where major changes in bottom topography occurred. Transects extended to the offshore edge of seagrass meadows with random sites used to measure continuity of habitat between transects.

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (see Mellors 1991; Kirkman 1978). A 0.25 m^2 quadrat was placed randomly three times at each site. For each quadrat, an observer assigned a biomass rank made in reference to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass had previously been measured. Two separate ranges were used - low biomass and high biomass. The relative proportion of the above-ground biomass (i.e. percentage) of each seagrass species within each quadrat was also recorded. At the completion of ranking, the observer also ranked a series of photographs of calibration quadrats that represented the range of seagrass observed during the survey. These calibration quadrats had previously been harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks given in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}). Seagrass biomass could not be determined from sites sampled by Van Veen grab, but seagrass presence/absence and species composition was recorded.

2.2 Seagrass meadow mapping and Geographic Information System

Seagrass presence/absence site data was used to construct the meadow (polygon) layer. Seagrass meadows were assigned a meadow identification number used to compare individual meadows between annual monitoring surveys. Monitoring meadows are referred to by these identification numbers throughout this report. The total area of monitoring meadows was determined in ArcGIS® using the GPS position of meadow boundary and sampling sites. Three seagrass GIS layers were created in ArcGIS® - site information, seagrass meadow characteristics and seagrass landscape category:

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

2. **Seagrass meadow characteristics** - Area data for individual seagrass meadows. Seagrass meadows were assigned a meadow identification number which was used to compare individual meadows between annual monitoring surveys. Monitoring meadows are referred to by these identification numbers throughout this report. Seagrass community types were determined according to overall species composition (the mean species composition of all sites within the meadow boundary) from nomenclature developed for seagrass meadows of Queensland (Table 1). Density categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 2);

3. **Seagrass meadow landscape category** - Area data showing the seagrass landscape category determined for each meadow (Figure 8).

Table 1. Nomenclature for community types in Port Curtis and Rodds Bay.

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 2. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in Port Curtis and Rodds Bay.

Density	Mean above-ground biomass (gDW m^{-2})				
	Halodule uninervis (thin)	*Halophila ovalis; Halophila decipiens*	*Halodule uninervis* (wide)	*Halophila spinulosa*	*Zostera 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

Meadows were also assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 3). The mapping precision for coastal seagrass meadows ranged from <5 m for isolated seagrass patches to ±150 m for larger subtidal meadows. The mapping precision estimate was used to calculate a range around each meadow area estimate and is expressed as a meadow reliability estimate (R) in hectares.

Isolated seagrass patches
The majority of area within the meadows consisted of un-vegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of un-vegetated sediment within the meadow boundaries

Continuous seagrass cover
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of un-vegetated sediment.

Figure 8. Landscape categories for seagrass meadows in Queensland.

Table 3. Methods used to determine mapping precision estimates for each seagrass meadow.

Mapping precision	Mapping method
≤5 m	Meadow boundaries mapped in detail by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide, Relatively high density of mapping and survey sites, Recent aerial photography aided in mapping.
10-20 m	Meadow boundaries determined from helicopter and diver/grab surveys, Intertidal boundaries interpreted from helicopter sites, Subtidal boundaries interpreted from survey sites and aerial photography, Moderately high density of mapping and survey sites.
20-50 m	Meadow boundaries determined from helicopter and diver/grab surveys, Intertidal boundaries interpreted from helicopter sites, Subtidal boundaries interpreted from diver/grab survey sites, Lower density of survey sites for some sections of boundary.
50-100+ m	Subtidal meadow boundaries interpreted from survey sites

2.3 Environmental data

Environmental data were collated for the 12 months preceding each November survey. Tidal data was provided by Maritime Safety Queensland (© The State of Queensland (Department of Transport and Main Roads) 2017, Tidal Data) for Gladstone at Auckland Point (MSQ station # 052027A; www.msq.qld.gov.au). Total daily rainfall (mm) was obtained for the nearest weather station from the Australian Bureau of Meteorology (Gladstone Airport station # 039123; http://www.bom.gov.au/climate/data/). Calliope River water flow data (total monthly megalitres (ML)) was obtained from the Department of Natural Resources and Mines (station # 132001A; www.watermonitoring.derm.qld.gov.au).

2.4 Seagrass condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in Gladstone Harbour was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 9 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.

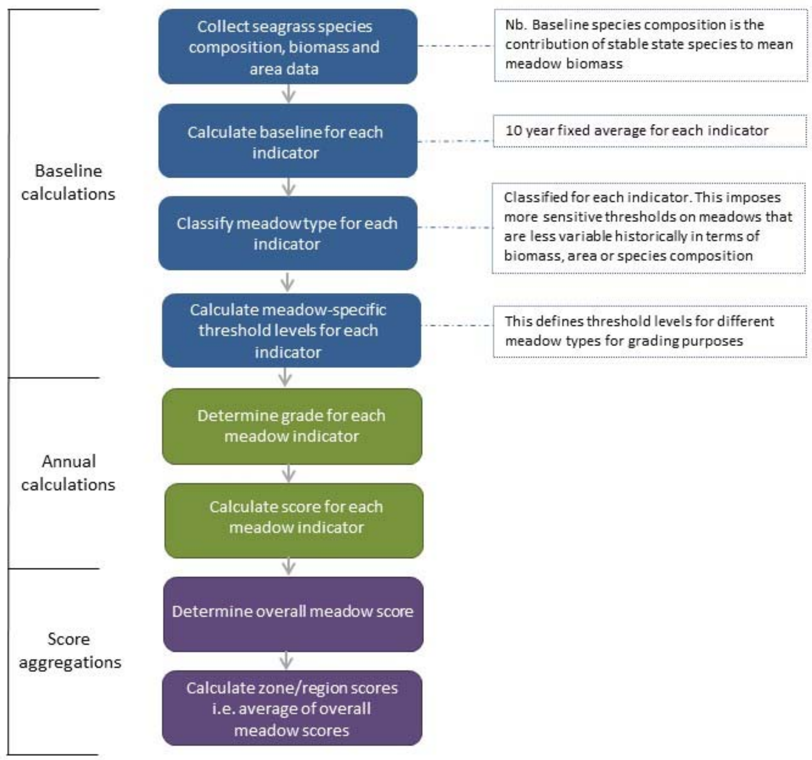


Figure 9. Flow chart used to determine monitoring meadow condition.

A review in 2017 of how meadow scores were aggregated led to a slight modification from previous years' reports. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change 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. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged (see Appendix 1 for further details).

3 RESULTS

3.1 Seagrasses in Port Curtis and Rodds Bay

A total of 1,739 sites were surveyed in the Port Curtis and Rodds Bay seagrass annual monitoring survey area in November 2017 (Figure 10).

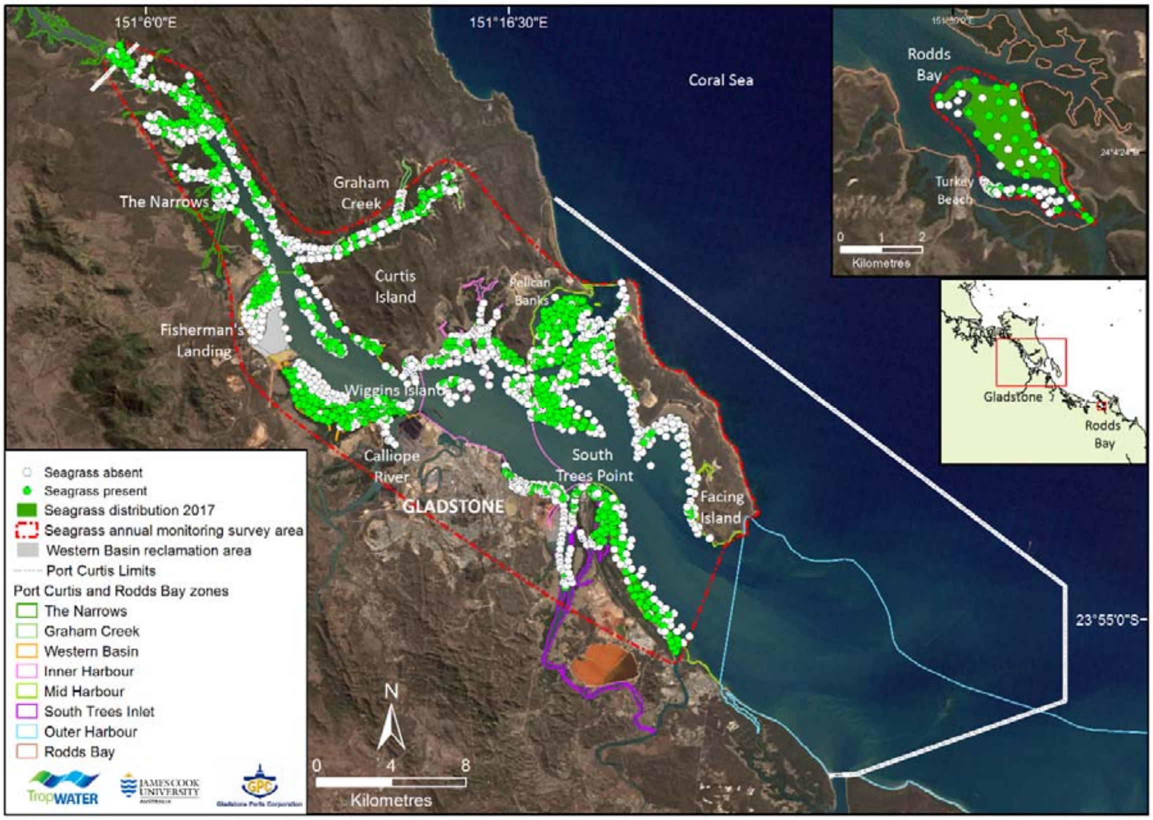


Figure 10. Sites surveyed in Port Curtis and Rodds Bay, November 2017.

Five seagrass species (from three families) were observed during the survey (Figure 11). For a full list of species found in the area the full baseline surveys examining all seagrass meadows should be consulted (see Rasheed et al 2003; Thomas et al. 2010; Carter et al. 2015a; Bryant et al. 2014c).

A total of 3,218 ± 391 ha of seagrasses was mapped in the annual monitoring survey area limits for Port Curtis (see Figure 1) in 2017, a return to above-average distribution as mapped in 2015. In Rodds Bay the area of seagrasses within the annual monitoring survey limits was 311 ± 14 ha, a similar increase from 2016 seagrass area coverage.

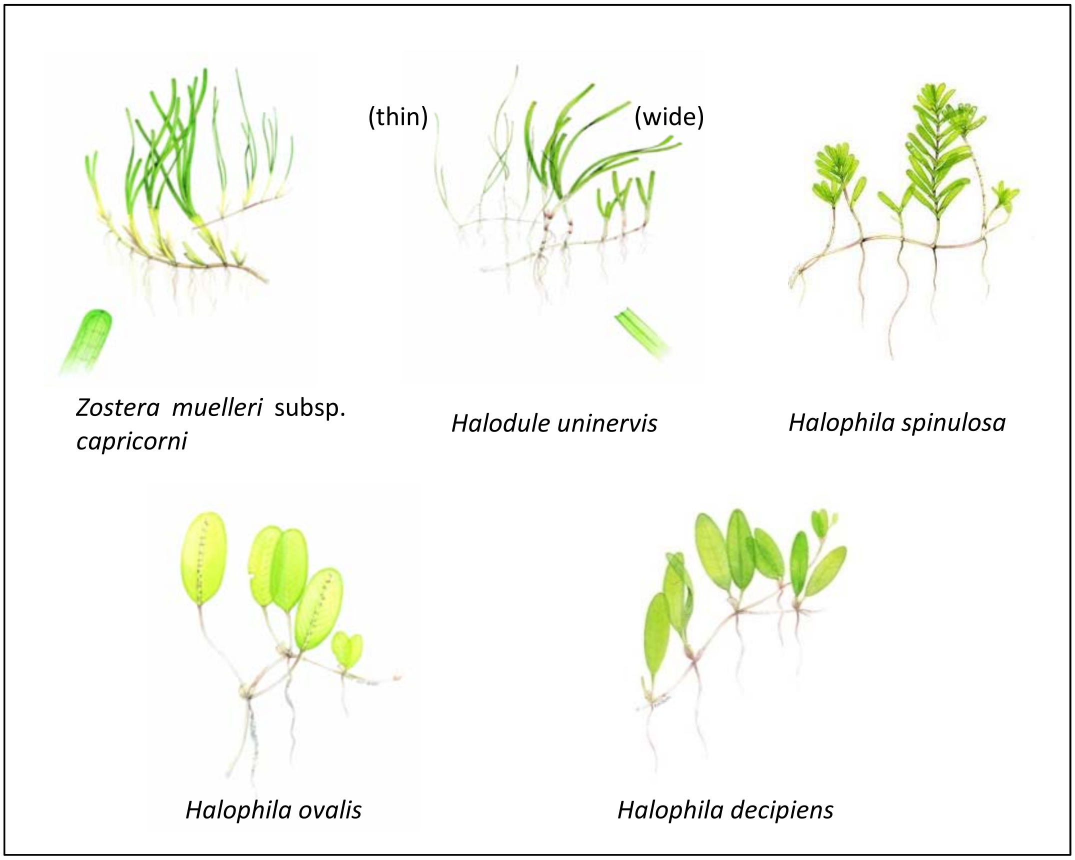


Figure 11. Seagrass species present in Port Curtis and Rodds Bay, November 2017.

Dugong feeding trails (DFTs) were found in 12 of the 15 meadows in which they were previously recorded in 2016; from the Western Basin, Mid Harbour, South Trees Inlet, and Rodds Bay zones. The highest number of sites with recorded DFTs was found at Pelican Banks (Meadow 43) and Wiggins Island (Meadow 5). Overall, DFT presence suggests a similar level of herbivory from dugongs as recorded in previous annual surveys (Rasheed et al. 2017).

3.2 Seagrass condition for individual meadows and zones

While the overall condition score for seagrasses in Port Curtis and Rodds Bay was poor, some meadows improved in condition from 2016 surveys. Meadows 8 and 52-57 in the Western Basin and Meadows 43 and 60 from the Mid Harbour and South Trees Inlet zones respectively all increased in their lowest indicator condition, which in turn brought the meadow scores up. While there is substantial variation in condition between individual meadows, poor species composition was the dominant indicator driving overall meadow condition for Port Curtis meadow scores. In the three Rodds Bay meadows, biomass was consistently the lowest out of the three indicators (biomass; area; species composition) and therefore ultimately responsible for the overall meadow score (Table 4).

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for Port Curtis and Rodds Bay seagrass monitoring meadows. Overall meadow score is the lowest of the biomass or area scores, or where species composition is the lowest score it makes up 50% of the score with the other 50% from the next lowest indicator (see Appendix 1 and Table A3 for a full description of scores and grades).

Monitoring meadow	Biomass score	Area score	Species composition score	Overall meadow score
4	1.00	0.80	0.16	0.48†
5	0.67	0.74	0.35	0.51†
6	0.58	0.96	0.31	0.45†
7	0.00	0.00	NA	0.00
8	0.87	0.53	0.29	0.41†
21#	0.42	0.74	0.66	0.42
43	0.43	0.61	0.71	0.43
48	0.68	0.89	0.32	0.50†
52-57*#	1.00	0.86	1.00	0.86
58	0.18	0.83	0.00	0.09†
60	0.85	0.97	1.00	0.85
94	0.01	0.19	0.71	0.01
96	0.23	0.84	0.55	0.23
104	0.07	0.08	0.15	0.07
Overall score for Gladstone seagrass monitoring meadows				0.38

* 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.

\# Indicates meadows where <10 years of data were available to calculate baseline values. Results for these meadows should be interpreted with caution until long-term data are available.

† Indicates meadows where the lowest indicator was species composition and the new methodology applied a weighting of 50% species composition and 50% to the next lowest indicator score to come up with an overall meadow score. (Appendix 1; Bryant et al. 2014c).

The Port Curtis and Rodds Bay region has been partitioned into zones (see Figure 2) for the purposes of assessing water quality and for developing a regional report card. In the below sections we have presented the results for the 2017 seagrass monitoring for each of the zones where we have seagrass information.

3.2.1 The Narrows

The Narrows zone consisted of 10 seagrass meadows covering 401 ± 68 ha, similar to areal cover recorded in 2016. The area of individual meadows ranged from small isolated patches (<0.5 ha) to larger ~100 ha expanses of seagrass on the exposed banks of both sides of the estuary (Figure 12 and Appendix 3). *Z. muelleri* subsp. *capricorni*, *H. ovalis*, *H. spinulosa* and *H. decipiens* were present in the zone. Meadow biomass ranged from an isolated patch of 0.06 g DW m^{-2} of *H. decipiens* (Meadow 13) to 14.38 ± 3.81 g DW m^{-2} for the aggregated patches of *Z. muelleri* subsp. *capricorni* covering the exposed banks at the top of The Narrows survey boundary (Meadow 10 & 17) (Figure 12; Appendix 3).

The seagrass meadows were comprised of a mixture of isolated patches and aggregated patches. Meadow biomass and species composition resulted in eight out of ten meadows being classified as light in cover, similar to 2016 surveys. Seagrasses north of Black Swan Island were dominated by *Z. muelleri* subsp. *capricorni* while those to the south primarily dominated by *Halophila* species (Figure 12 and Appendix 3).

Long-Term Monitoring Meadows

There is one long-term monitoring meadow in The Narrows zone at Black Swan Island (Meadow 21; Figure 13). The intertidal meadow was in poor condition in 2017, a return to its' 2015 classification. Area and species composition were classified as good condition, while biomass drove the poor overall score (Figure 13; Appendix 3). Biomass declined to 1.31 ± 0.35 gDW m^{-2} in 2017 from a brief increase in 2016 to 3.0 gDW m^{-2} (satisfactory condition), following a steady decline from 2009 to minimal remaining above-ground biomass. Meadow area condition improved from satisfactory to good condition from 2016 to 2017 following a return of ~30 ha that was absent in 2016. Species composition also shifted from satisfactory to good condition due to a slight increase in the dominant species *Z. muelleri* subsp. *capricorni*. The species composition score had not reached a good classification since 2012 when *Z. muelleri* subsp. *capricorni* accounted for over 70% of the seagrass biomass in the meadow (Figure 13; Appendix 4).

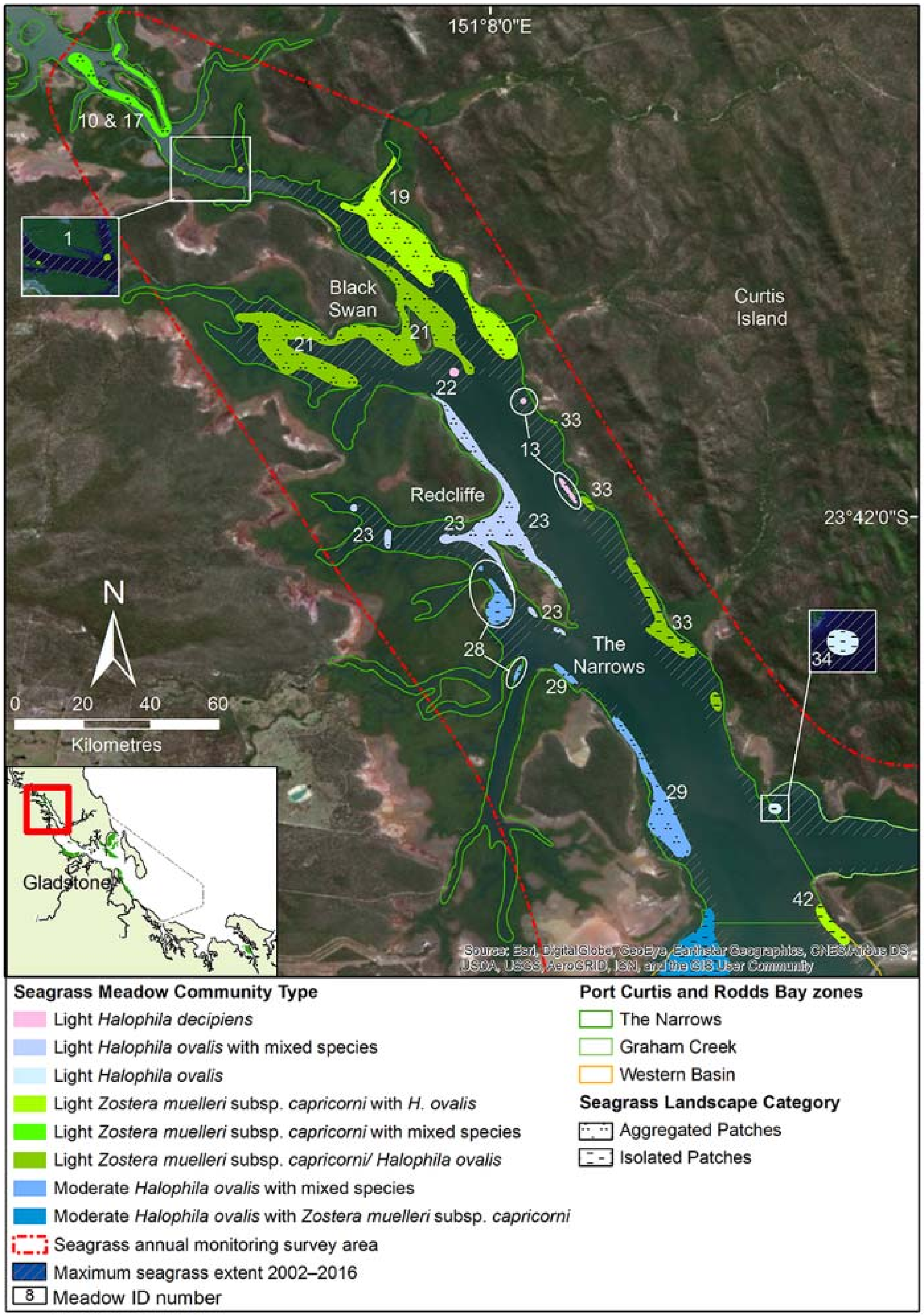


Figure 12. Seagrass distribution and community types in The Narrows, November 2017.

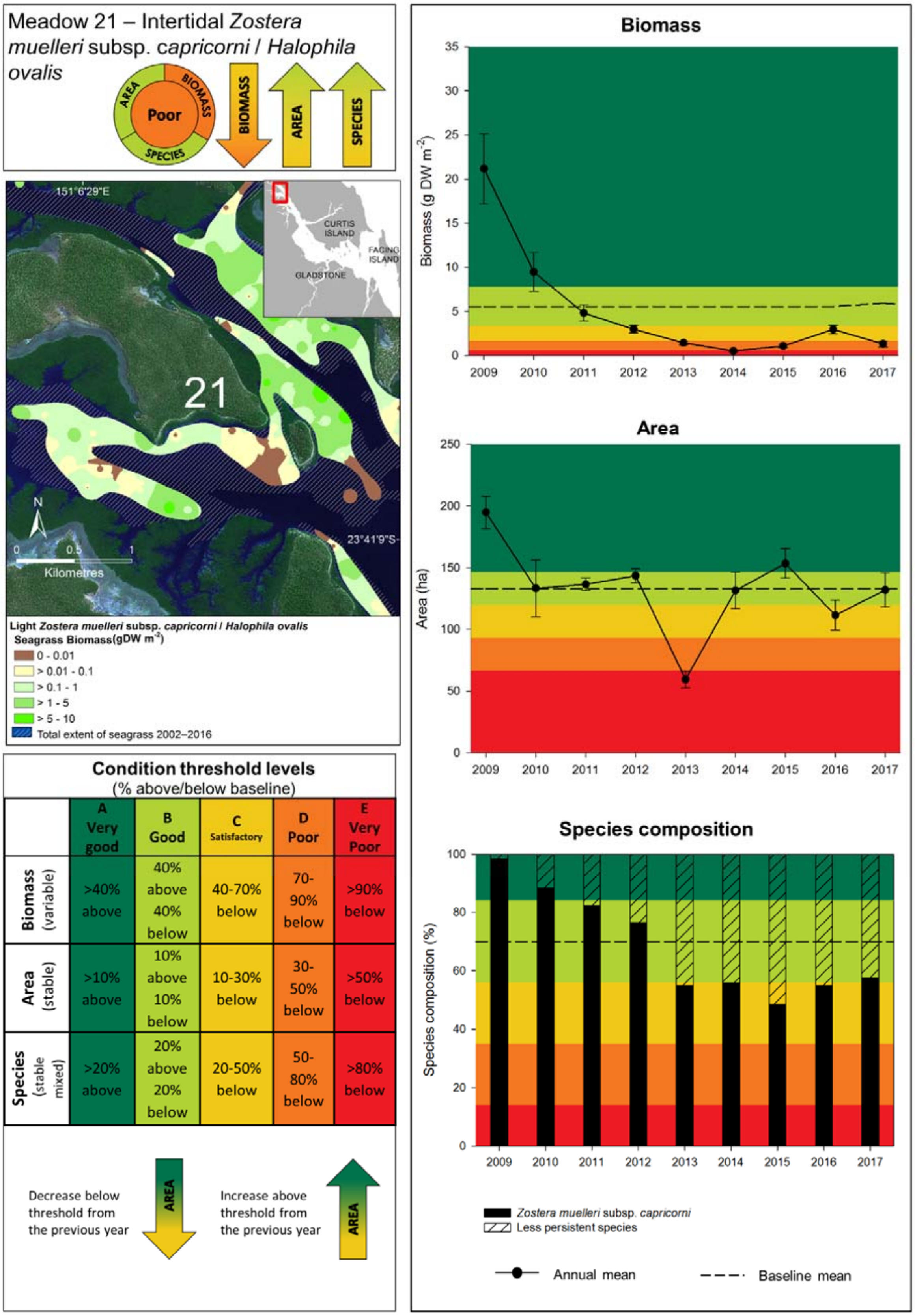


Figure 13. Changes in meadow area, biomass and species composition for seagrass at Meadow 21, Black Swan (The Narrows zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.2 Graham Creek (Upper and Lower)

Seagrasses in the Graham Creek (Upper and Lower) zone formed 11 individual meadows covering 61 ± 10 ha, a gain of 36 ha from 2016 levels yet still substantially less than the 2015 area. Meadows ranged from small isolated patches (~0.09 ha) of light *H. ovalis* to a larger meadow at the top of the creek (38 ha) (Meadows 41; Figure 14 and Appendix 3). The majority of meadows were comprised of isolated patches of seagrass with *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens* present. Meadow biomass was relatively low in this zone with a maximum of 1.98 g DW m^{-2} for an isolated yet moderate *H. ovalis* meadow at the opening of Graham Creek to The Narrows (Meadow 2; Figure 14; Appendix 3).

Similar to the decline in dominance by *Z. muelleri* subsp. *capricorni* in 2016, all but three meadows were dominated by *Halophila* spp. (Figure 14 and Appendix 3). The presence of *H. decipiens* in the Graham Creek meadows continued to decline with only a single patch recorded in subtidal areas in 2017 (Meadow 37; Figure 14; Appendix 3). Graham Creek has no long-term monitoring meadows.

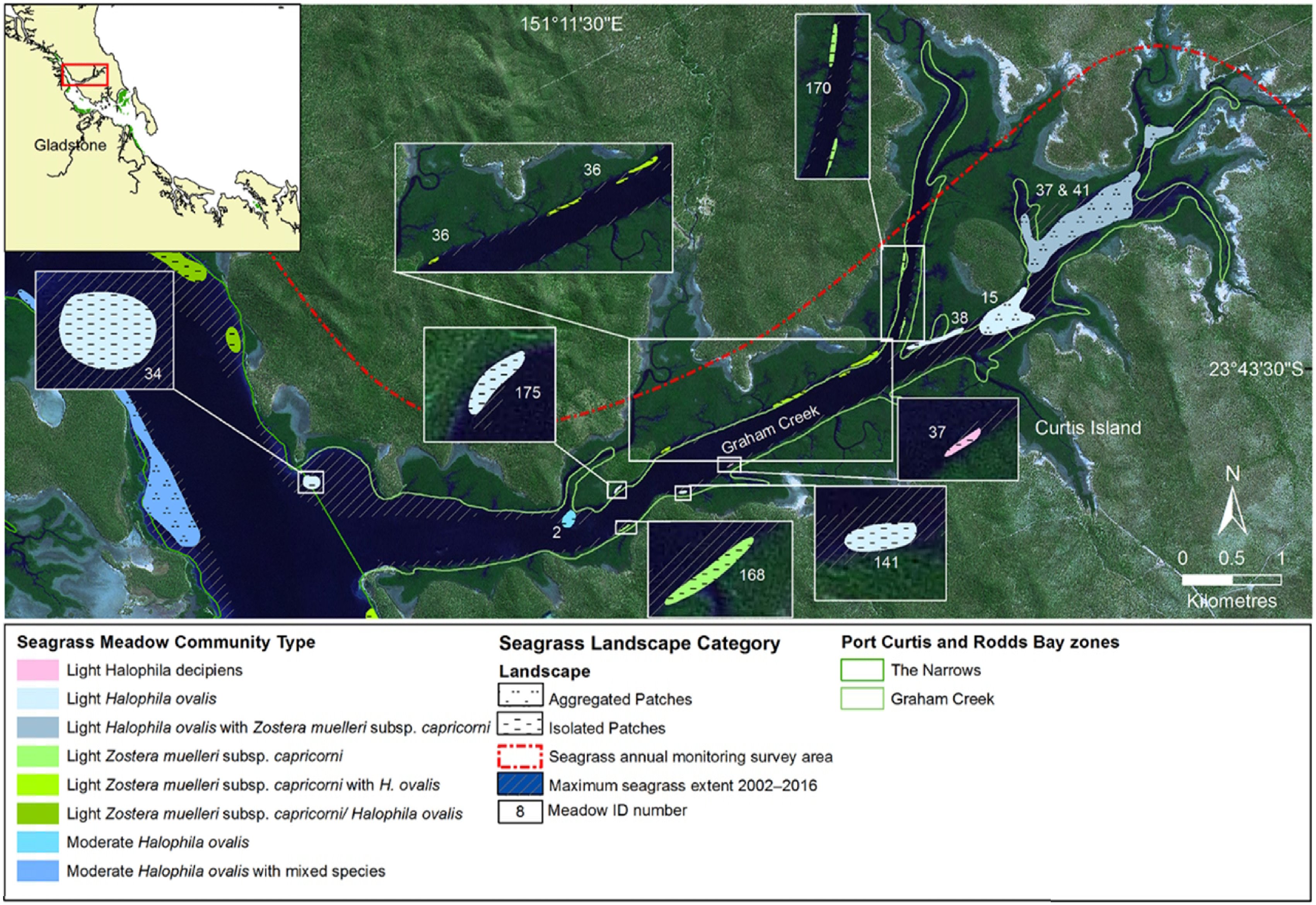


Figure 14. Seagrass distribution and community types in Graham Creek zone, November 2017.

3.2.3 Western Basin

Seagrasses in the Western Basin zone gained over 170 ha from 2016 to cover an area of 869 ± 46 ha, a total zone area similar to 2015. Overall, meadows were dominated by light to moderate *Halophila ovalis* with a smaller composition of *Z. muelleri* subsp. c*apricorni*, a more stable species. Small isolated patches of intertidal seagrass remained along the developed Curtis Island shoreline consisting of primarily *H. ovalis* and *Z. muelleri* subsp. *capricorni* (Figure 15; Appendix 3). A single isolated patch of subtidal *H. decipiens* was located to the east of Wiggins Island (Figure 15; Appendix 3) while all other seagrass meadows were predominantly intertidal with edges in the marginal subtidal zone. In total area, the most substantial meadow was South Fisherman's Landing (Meadow 6) with 463 ha (Figure 15; Appendix 3). *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens* continued to be the only species present in the zone. Meadow biomass ranged from a diminutive isolated *H. ovalis* patch (Meadow 51) to 4.91 ± 2.45 gDW m^{-2} for a *Z. muelleri* subsp. *capricorni* dominated meadow at the northern end of the Curtis Island intertidal banks (Meadow 42; Figure 15).

Long-Term Monitoring Meadows

There are six long-term monitoring meadows in the Western Basin Zone, including five intertidal and one subtidal meadow.

Meadow 4:

Meadow 4 at Wiggins Island was in an overall poor condition (Figure 16; Appendix 3). The significant decline in this variable mixed species meadow was driven by the shift in species composition. There was a loss of *Z. muelleri* subsp. *capricorni* biomass and overall presence in the meadow (only observed at 4 out of 20 sites) compared to all previous survey years (Figure 16; Appendix 3). In contrast, biomass was in very good condition (3.65 ± 0.91 gDW m^{-2}) due to the further increase of moderate *H. ovalis* making it the highest recorded meadow biomass since monitoring began. Area was also slightly up and in good condition after steady improvements from a near complete absence of seagrass in 2010 (Figure 16; Appendix 3).

Meadow 5:

Meadow 5, west of Wiggins Island, remained in a satisfactory condition despite good biomass and area scores. The score was driven by the very poor species composition, which diminished the overall meadow score (Figure 17; Appendix 3). Meadow 5 is an intertidal, variable mixed species meadow that fluctuates between *Z. muelleri* subsp. *capricorni* and *H. ovalis*. In 2017 the composition of *Z. muelleri* subsp. *capricorni* declined from 21% of the meadow in 2016 to 11% in 2017, well below the 62% baseline (Figure 17; Appendix 4). Meadow biomass remained in a good condition with similar levels to 2016. Meadow area was also unchanged from the good condition score in 2016 and was close to the 10 year long-term average (Figure 17).

Meadow 6:

At South Fisherman's Landing, Meadow 6, overall condition declined for a second year in a row from satisfactory to poor condition in 2017, due to additional declines in species composition (Figure 18; Appendix 3). Meadow 6 is an intertidal, variable mixed species meadow where the dominant species *Z. muelleri* subsp. *capricorni* has declined relative to *H. ovalis* since 2010. In 2017, *H. ovalis* comprised over 90% of the biomass (Figure 18; Appendix 3). Biomass was down from good to satisfactory condition which is likely due to the loss of the larger *Z. muelleri* subsp. *capricorni* in the meadow. In contrast, meadow area condition improved to very good with total area (463 ha) equal to the maximum total area recorded in previous monitoring years (Figure 18).

Meadow 7:

This subtidal *H. decipiens* meadow was absent in 2017 so received a very poor score (Figure 19; Appendix 3). The last time this meadow was absent during surveys was in 2011. The monospecific meadow is extremely variable due to the marginal light environment and high sensitivity of the species type occurring in this subtidal habitat.

Meadow 8:

The intertidal Meadow 8 at North Fisherman's Landing, had improved from very poor to poor condition between 2016 and 2017. This improvement was principally due to an improved species composition score combined with a gain in meadow area (Figure 20; Appendix 3). The meadow was historically dominated by *Z. muelleri* subsp. *capricorni*, relative to *H. ovalis,* however *Z. muelleri* subsp. *capricorni* has remained well-below the baseline level of 67% since 2011 (Figure 20; Appendix 4). Meadow area increased from 114 ha to 160 ha in 2017 while biomass remained in very good condition for a third year in a row (Figure 20).

Meadows 52-57:

The Passage Island meadows 52-57 are a group of predominantly intertidal meadows. In 2017 overall condition for these meadows was very good with meadow area increasing such that all three indicators were in the top score category (Figure 21; Appendix 3). The meadow is dominated by *H. ovalis* which results in a relatively low biomass even when the meadow is considered to be in very good condition. Biomass in 2017 was highly variable but also the highest level recorded for the meadow since monitoring began in 2009 (Figure 21; Appendix 3). The high overall biomass is partly due to a near equal proportion of persistent *Z. muelleri* subsp. *capricorni* as *H. ovalis* (Figure 21; Appendix 4).

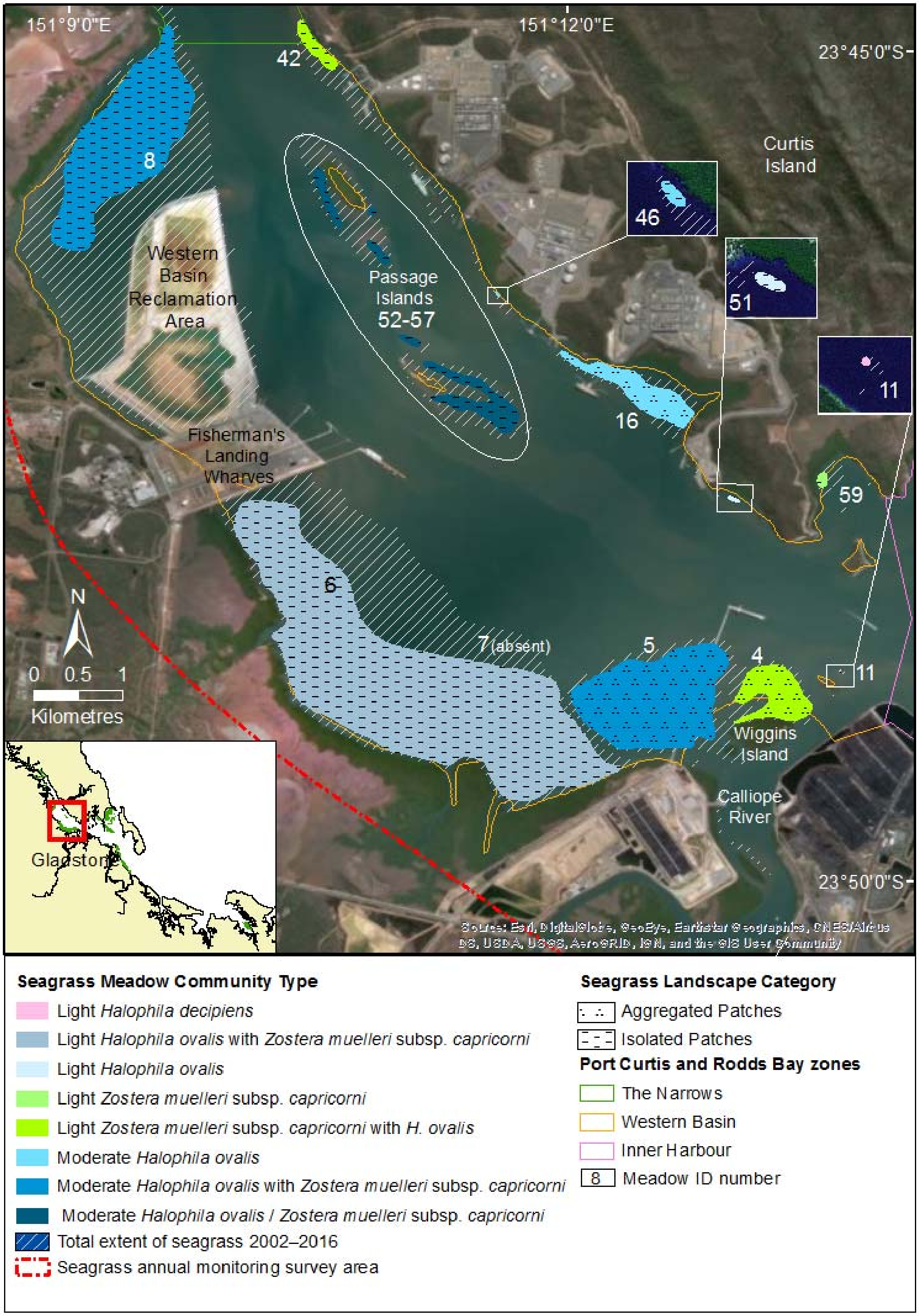


Figure 15. Seagrass distribution and community types in the Western Basin zone, November 2017.

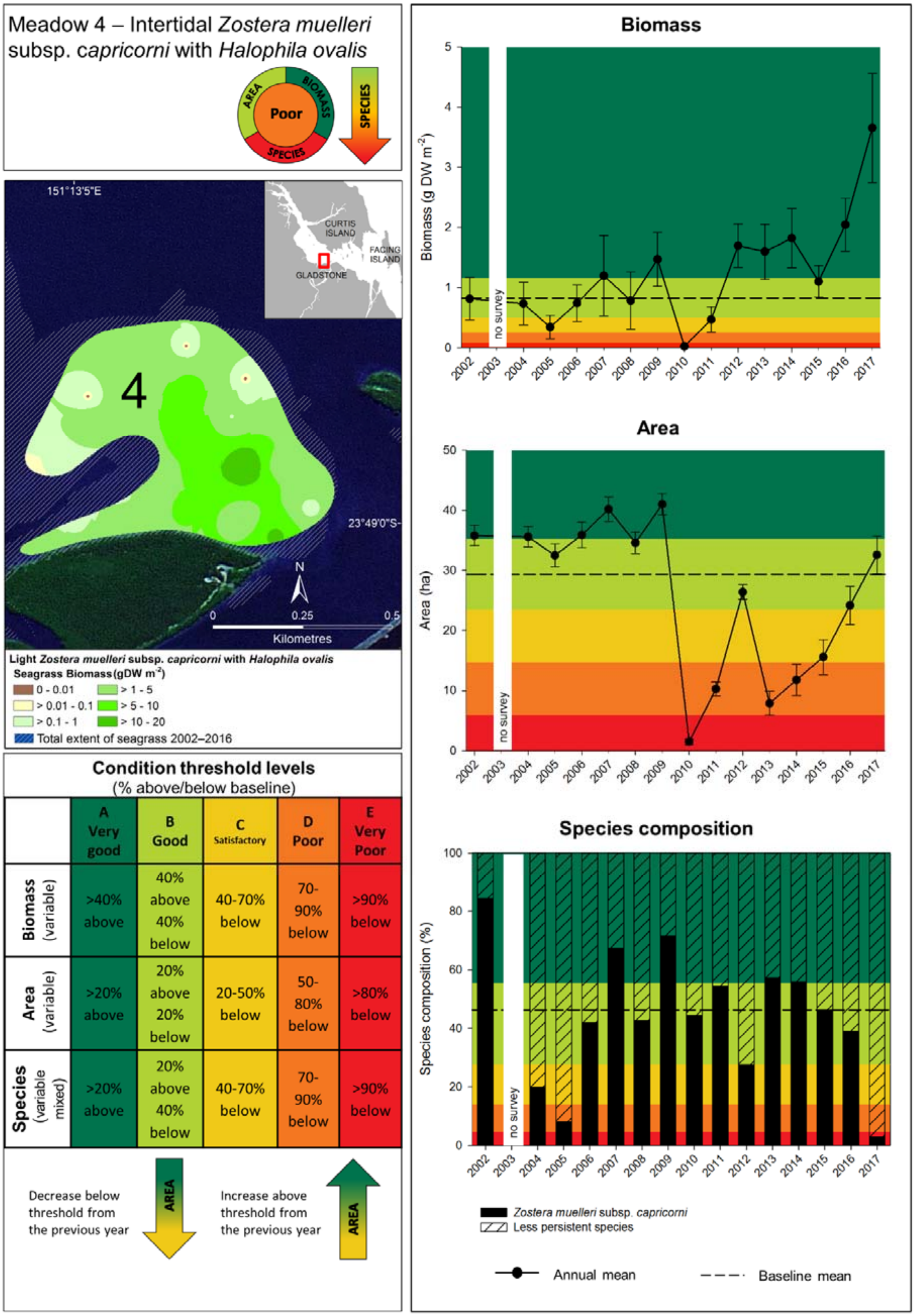
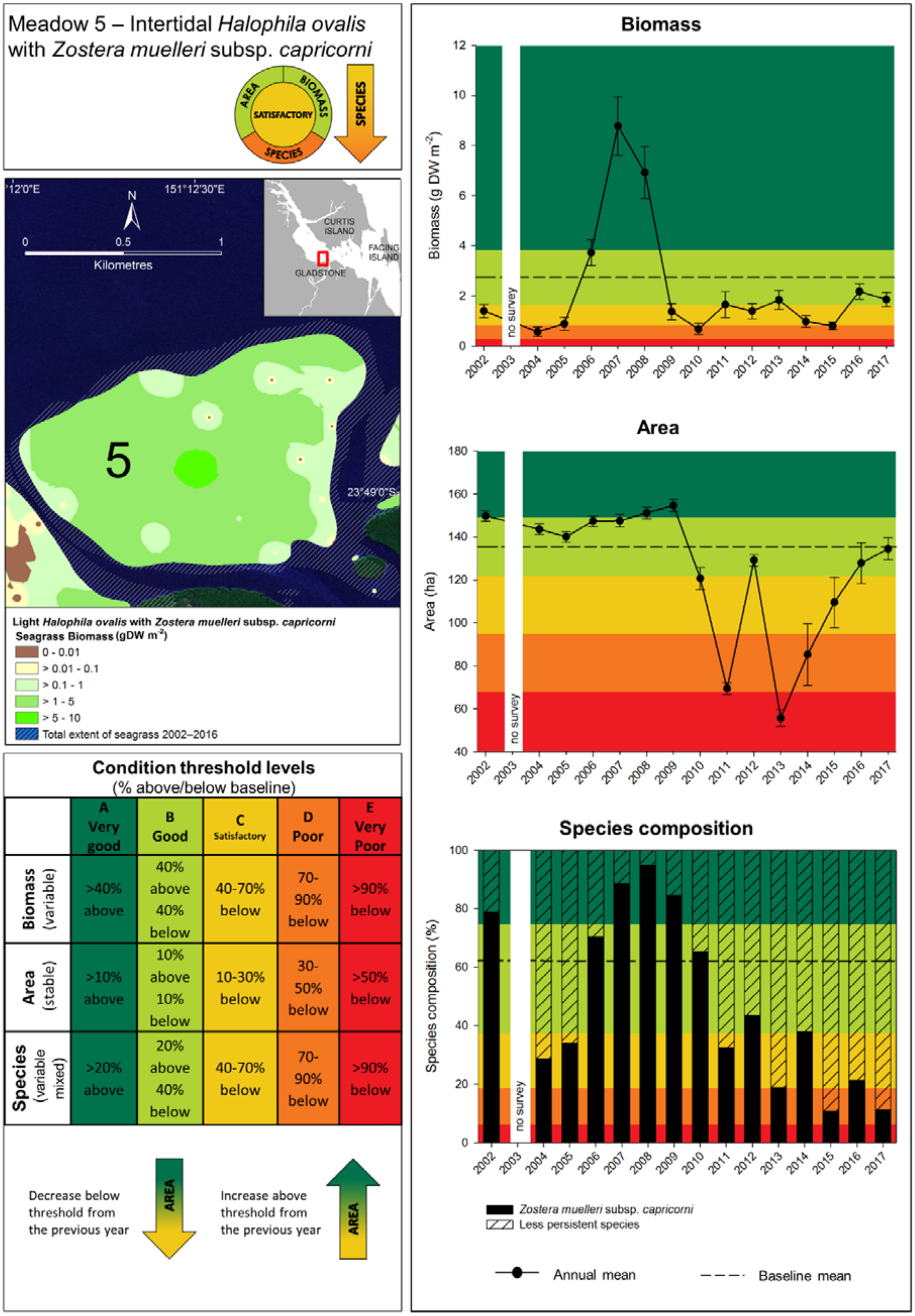


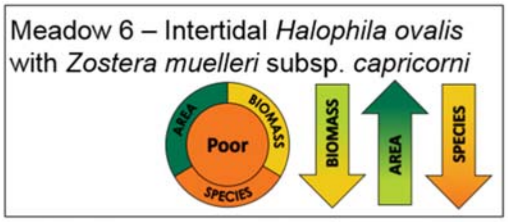
Figure 16. Changes in meadow area, biomass and species composition for seagrass at Meadow 4, Wiggins Island (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

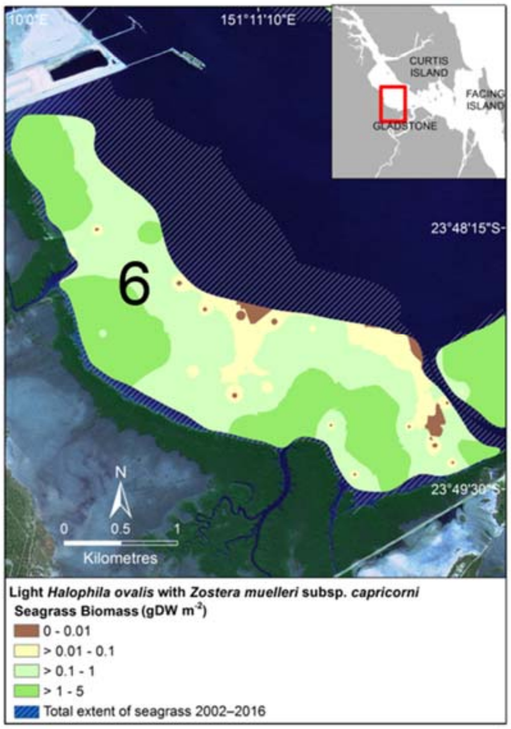


Condition threshold levels
(% above/below baseline)

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

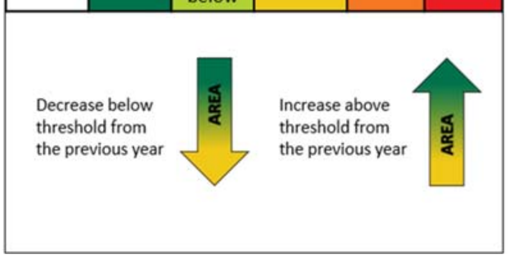
Figure 17. Changes in meadow area, biomass and species composition for seagrass at Meadow 5, Wiggins Island (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).





Condition threshold levels (% above/below baseline)

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



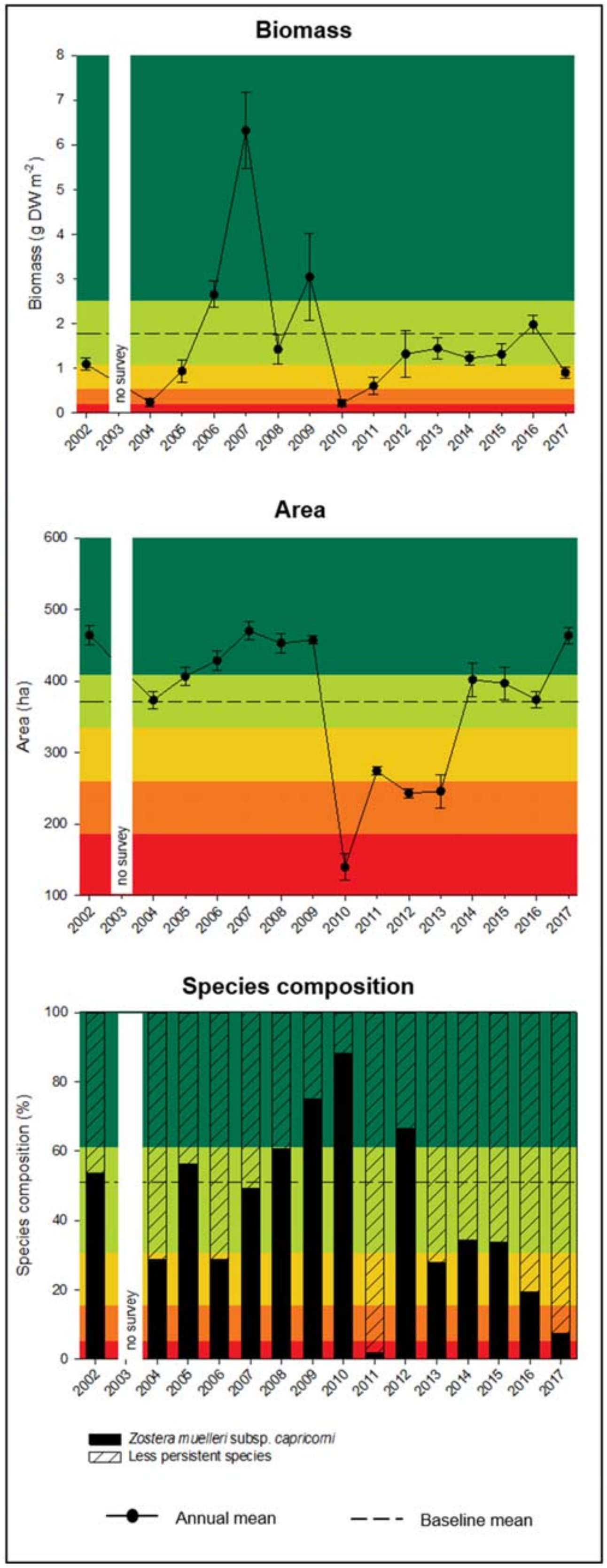
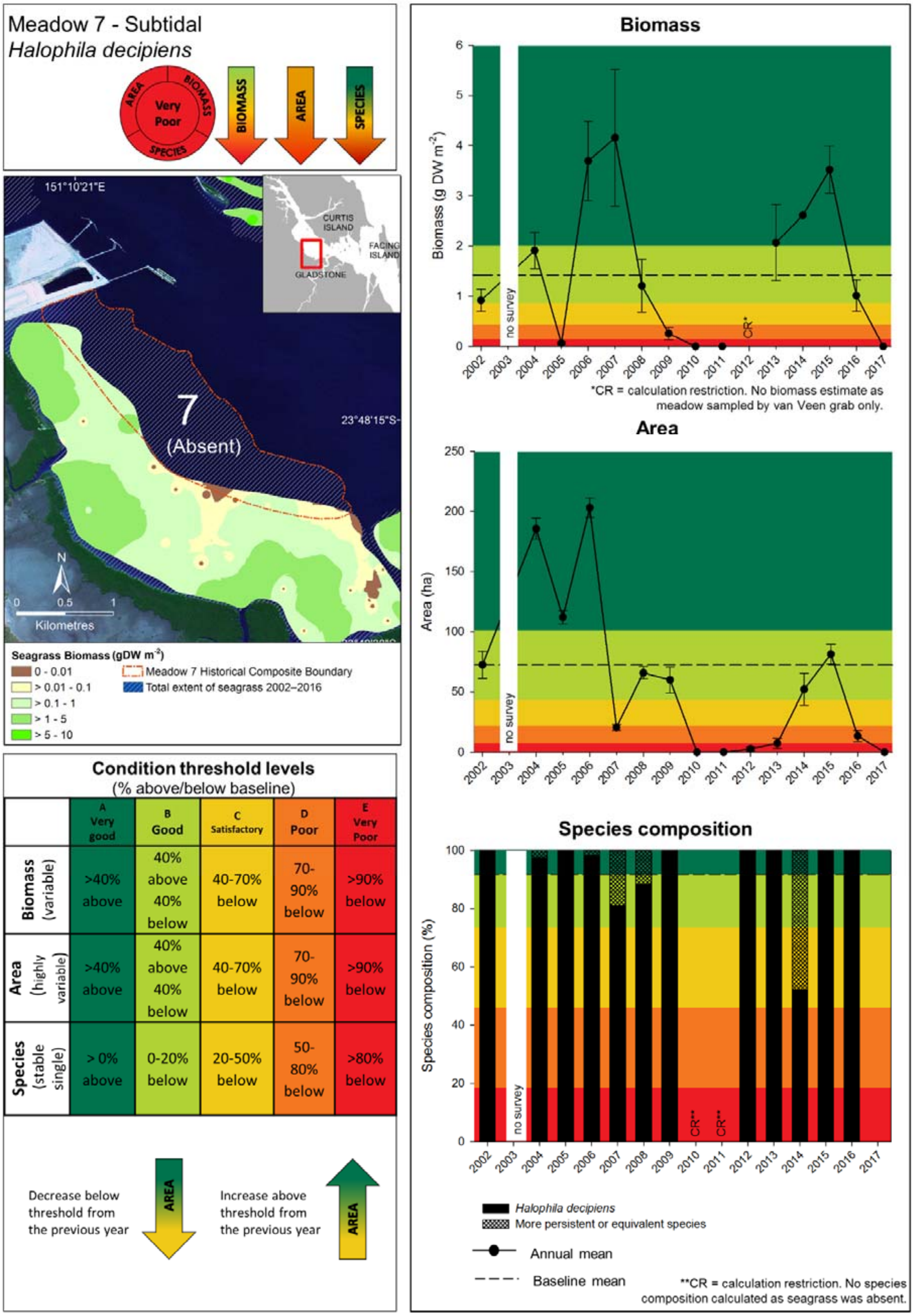


Figure 18. Changes in meadow area, biomass and species composition for seagrass at Meadow 6, South Fisherman's Landing (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).



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

Figure 19. Changes in meadow area, biomass and species composition for seagrass at Meadow 7, South Fisherman's Landing (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

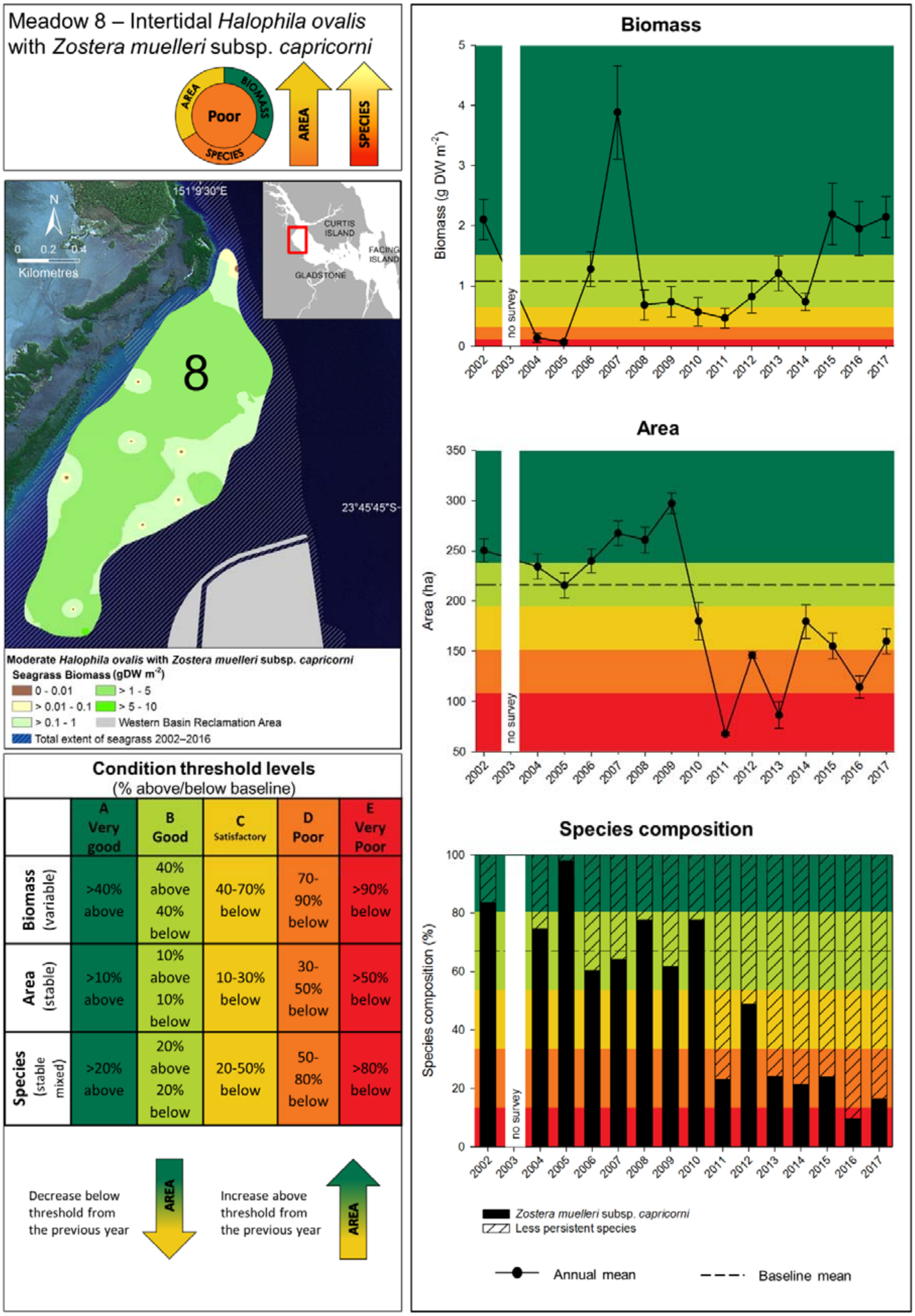


Figure 20. Changes in meadow area, biomass and species composition for seagrass at Meadow 8, North Fisherman's Landing (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

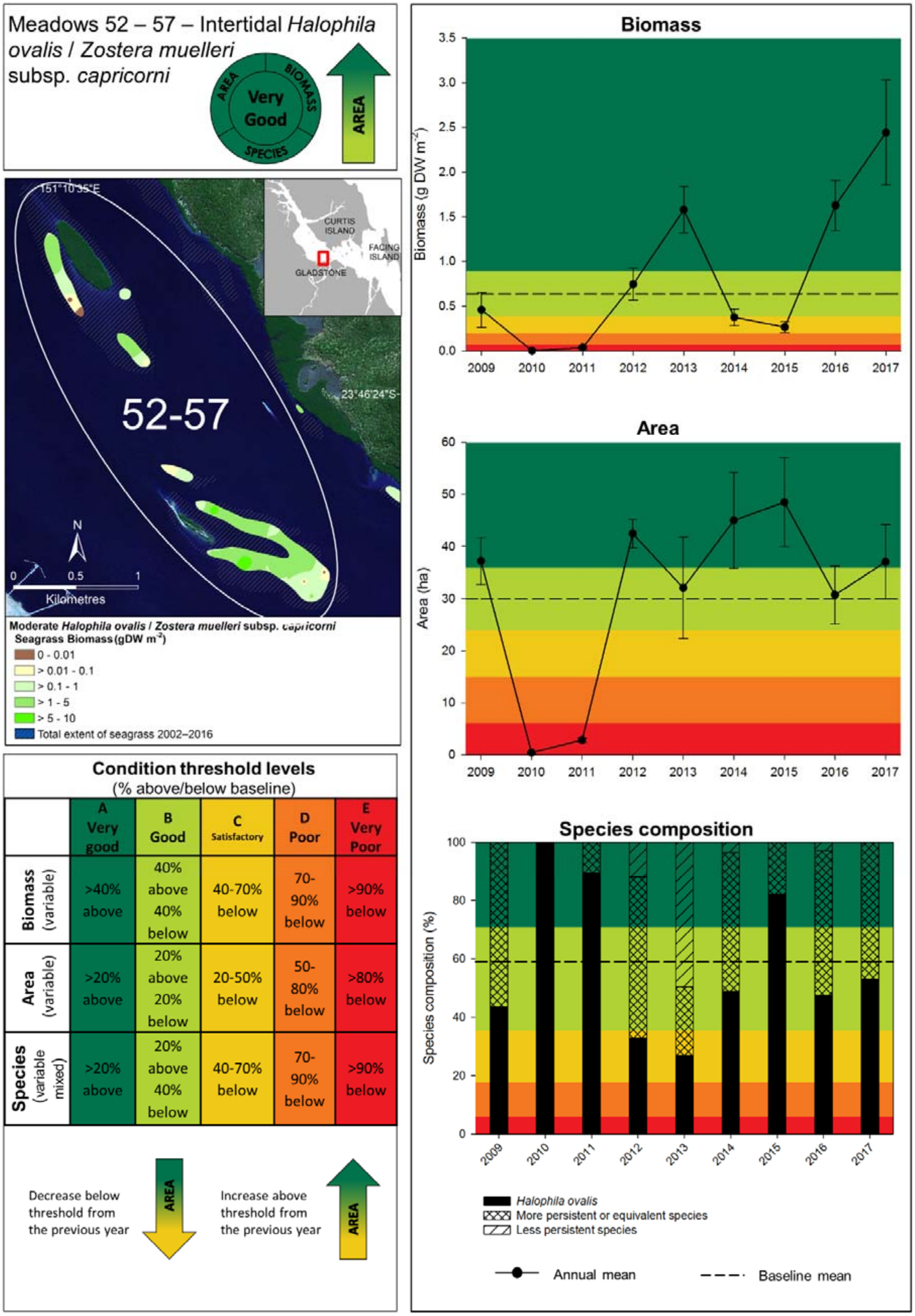


Figure 21. Changes in meadow area, biomass and species composition for seagrass at Meadows 52-57, Passage Islands (Western Basin zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.4 Inner Harbour

Seagrasses in the Inner Harbour zone covered an area of 227 ± 43 ha, a doubling of area from 2016. Meadows ranged from small isolated patches to broad expanses of seagrass (~100 ha) (Meadows 85; Figure 22; Appendix 3). *Z. muelleri* subsp. *capricorni*, *H. uninervis* (narrow) and *H. ovalis* were present in the zone. Average biomass ranged from 0.01 gDW m^{-2} for an isolated patch of *H. ovalis* (Meadow 81; Figure 22; Appendix 3), to a small *Z. muelleri* subsp. c*apricorni* meadow near Curtis Island 6.49 ± 6.49 gDW m^{-2} (Meadow 61; Figure 22; Appendix 3). All meadows except one *H. ovalis* meadow to the west of Quoin Island (Meadow 50) were light in cover. The dominant species in meadows was a mix of *H. ovalis* and *Z. muelleri* subsp. *capricorni* (Figure 22; Appendix 4).

Long-Term Monitoring Meadows

The single monitoring meadow in the Inner Harbour zone on the western side of South Trees Point remained in very poor condition for a third consistent year in 2017 (Meadow 58; Figure 23; Appendix 3). The score was driven by species composition following a complete loss of the previously dominant *Z. muelleri* subsp. *capricorni* and replacement by the colonising species *H. ovalis* with a minor component of *H. uninervis* (thin) (Figure 23, Appendix 4). The shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis* followed the meadow's 2010 disappearance and 2011 re-establishment (Figure 23). Meadow biomass had improved from poor to good in 2016, however, it dropped off to negligible levels in 2017 (very poor) with less of both *H. ovalis* and *H. uninervis* (thin) biomass. Meadow area declined from very good to good in this light and patchy meadow (Figure 23).

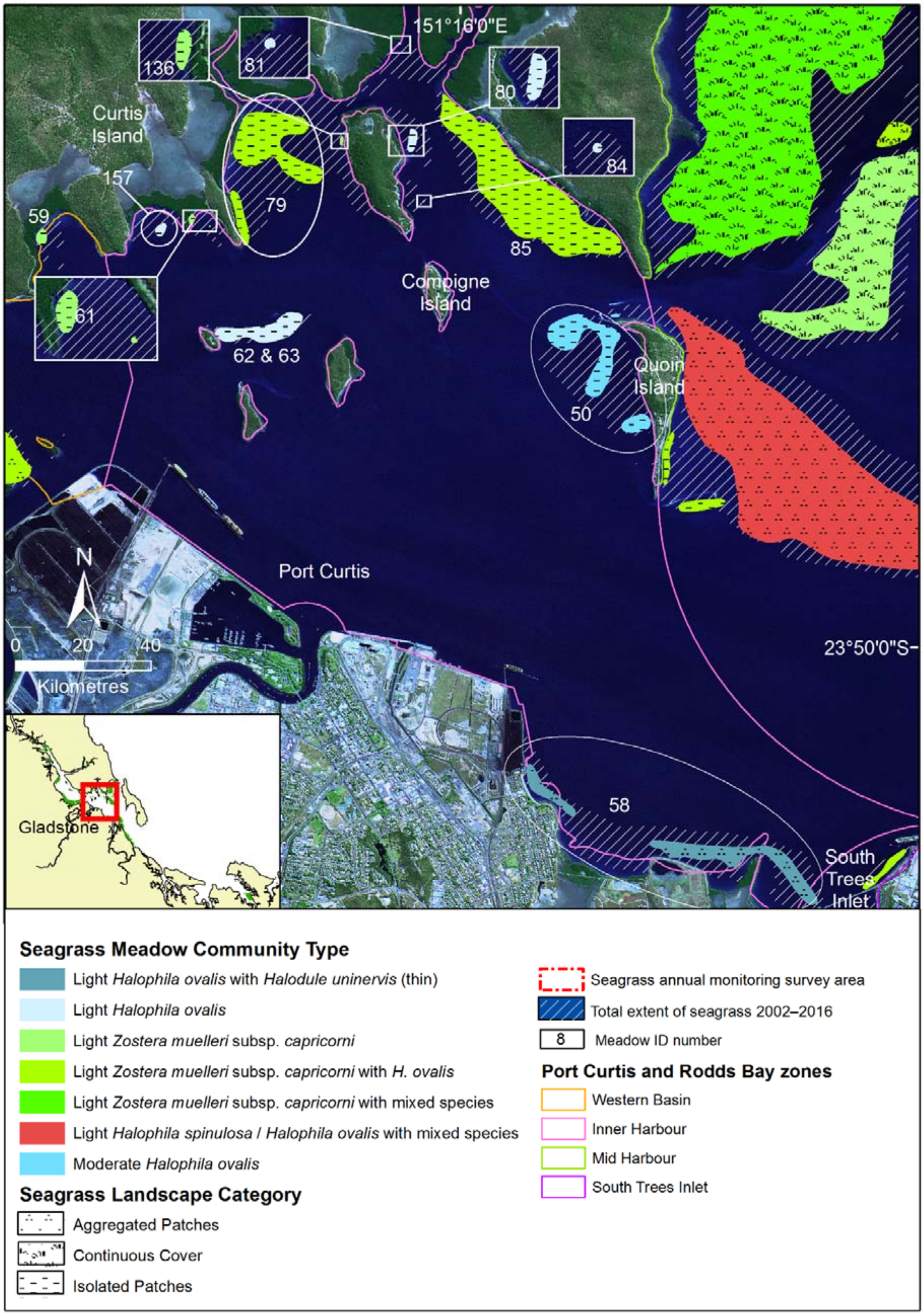
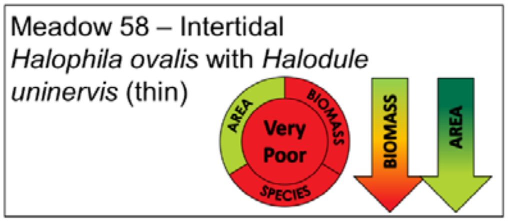
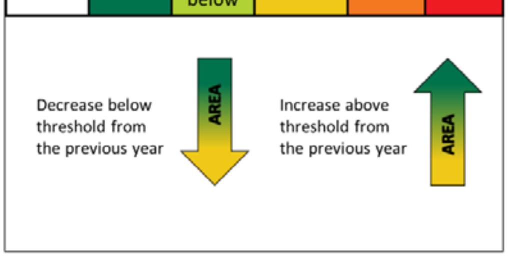


Figure 22. Seagrass distribution and community types in the Inner Harbour zone, November 2017.



Condition threshold levels
(% above/below baseline)

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



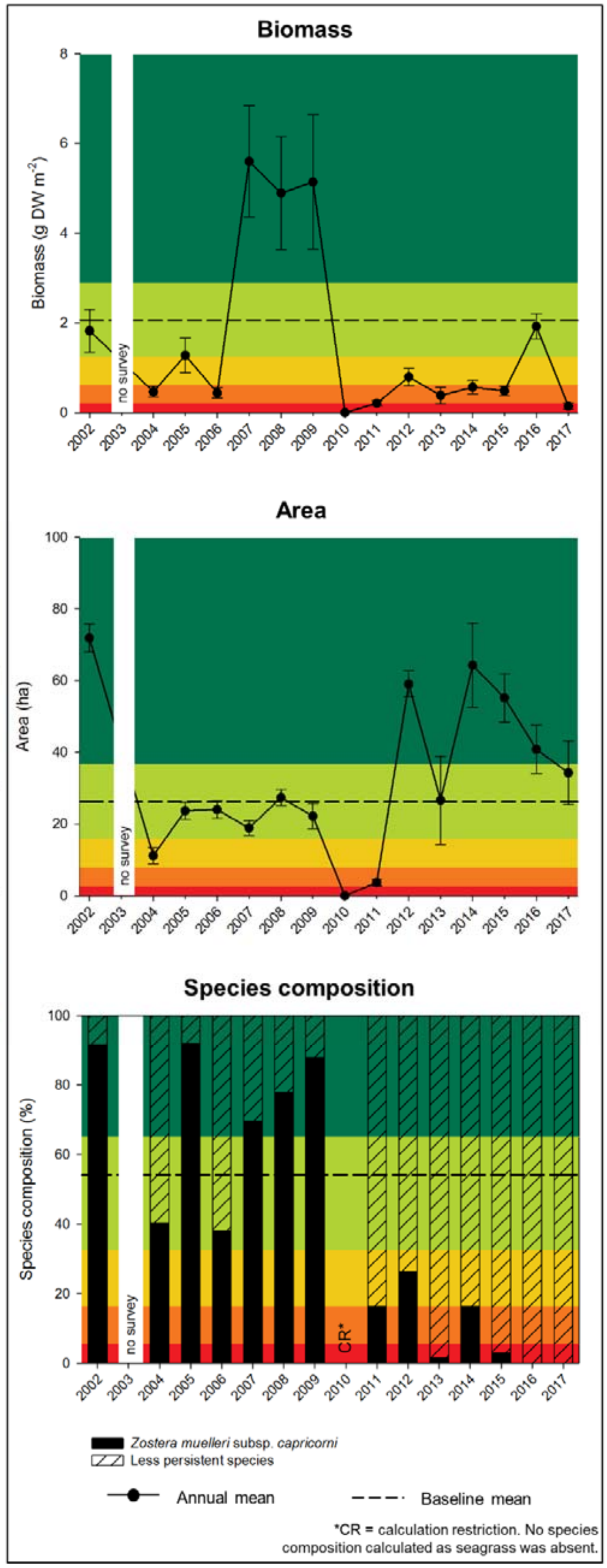


Figure 23. Changes in meadow area, biomass and species composition for seagrass at Meadow 58, South Trees Inlet zone, November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.5 Mid Harbour

Seagrasses in the Mid Harbour zone formed 14 individual meadows and covered an area of 1470 ± 207 ha. The area of individual meadows ranged from small isolated patches (~0.07 ha) along Facing Island to the largest seagrass meadow surveyed (~554 ha) on the intertidal mudflats at Pelican Banks (Meadows 65 and 43 respectively; Figure 24; Appendix 3). *Z. muelleri* subsp. *capricorni*, *H. uninervis, H. spinulosa* and *H. ovalis* were all present. Average biomass ranged from 0.02 g DW m^{-2} for a small patch of light *H. ovalis* off Facing Island (Meadow 69) to 9.44 ± 1.12 g DW m^{-2} for a meadow with light, continuous cover of *Z. muelleri* subsp. *capricorni* adjacent to the large Pelican Banks meadow (Meadow 137) (Figure 24 and Appendix 3). There are three large meadows (Meadows 43, 48, and 66) besides numerous small isolated patches scattered across the zone (Figure 24). Meadows were a mixture of Z. *muelleri* subsp. *capricorni, H. ovalis* and *H. uninervis* dominated meadows (Figure 24; Appendix 3).

Long-Term Monitoring Meadows

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 meadow in Port Curtis & Rodds Bay. A culmination of declines in seagrass over the past few years, led to a drop to very poor condition, driven by low biomass, in 2016. In 2017, a substantial improvement in biomass (7.67 ± 1.03 g DW m^{-2}) led to an improved meadow score from very poor to poor (Figure 25; Appendix 3). The biggest loss of seagrass biomass in 2016 was in the central-south region of the meadow, which remained the lowest biomass section of the meadow in 2017 (Figure 25). Meadow area was similar to 2016 but with a downgrade to satisfactory condition (Figure 25). Species composition improved with *Z. muelleri* subsp. c*apricorni* returning to over 80% of the species biomass in 2017. *H. uninervis* and *H. ovalis* comprised the remaining ~15% of the meadow (Figure 25; Appendix 4).

Meadow 48:

Meadow 48 is a subtidal meadow on the eastern side of Quoin Island. Overall meadow condition was scored as satisfactory due to a combination of good biomass and poor species composition (Figure 26). The meadow was dominated by *H. spinulosa* and *H. ovalis* in place of the more persistent and baseline condition species *H. uninervis* (Figure 26; Appendix 4). Meadow area significantly increased to over 300 ha, well above the baseline of 240 ha, and a jump in two score levels to a very good condition (Figure 26). Biomass remained at a similar level to 2016 and was again classified in good condition.

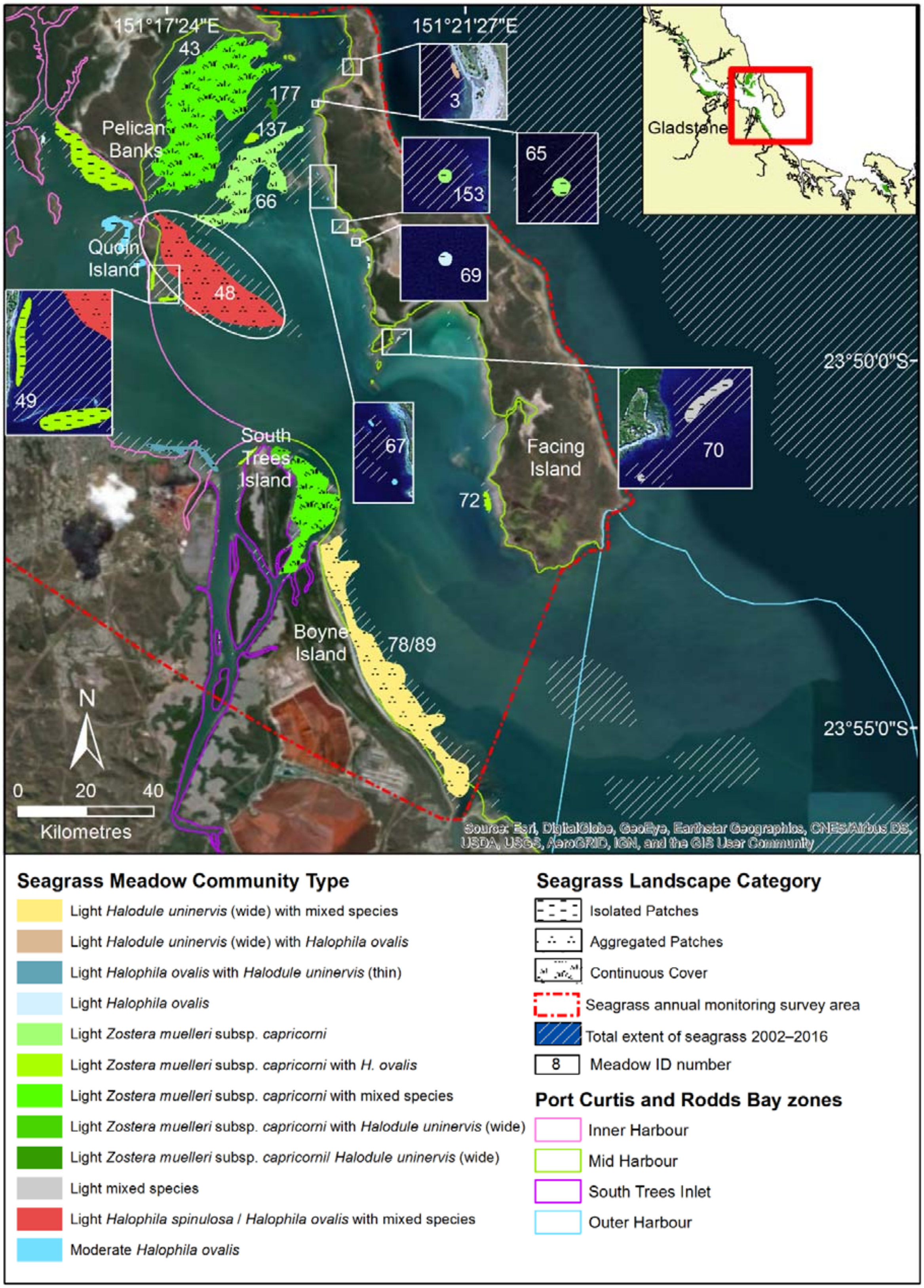


Figure 24. Seagrass distribution and community types in the Mid Harbour zone, November 2017.

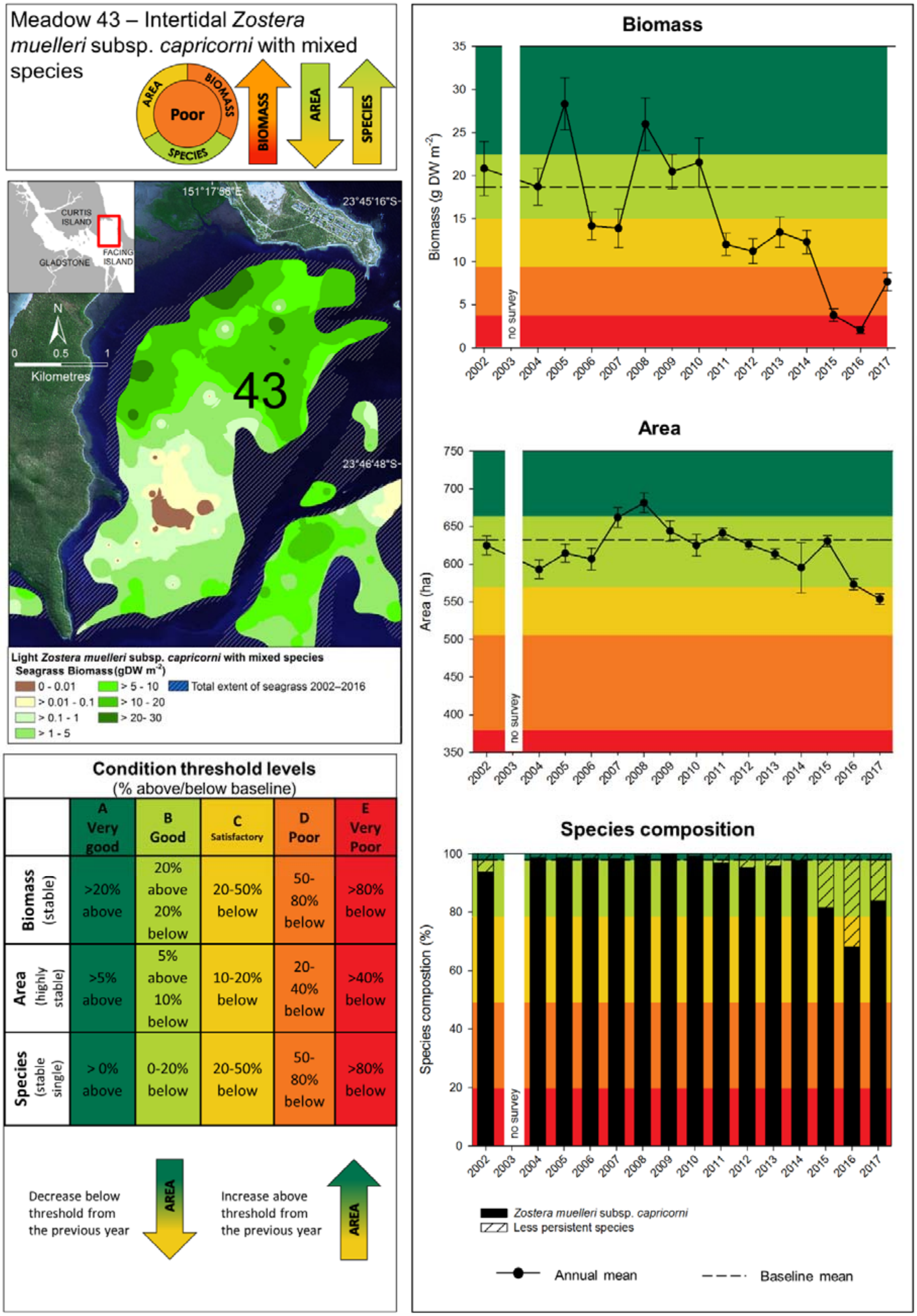
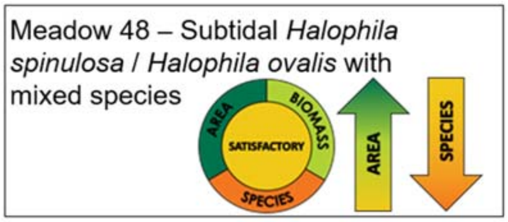
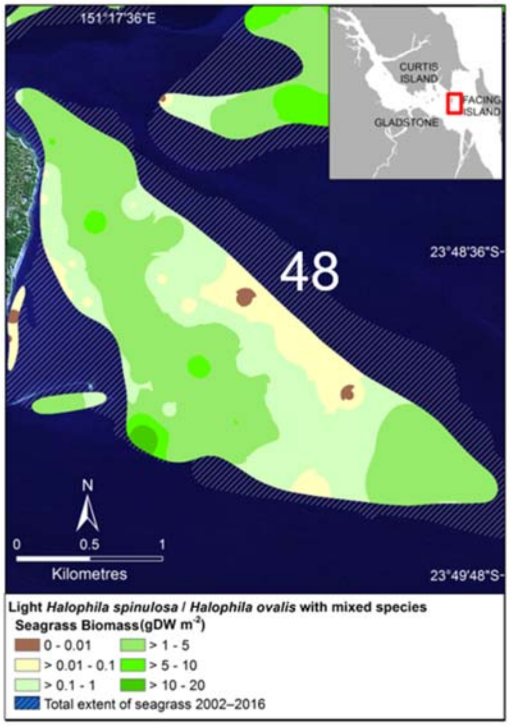


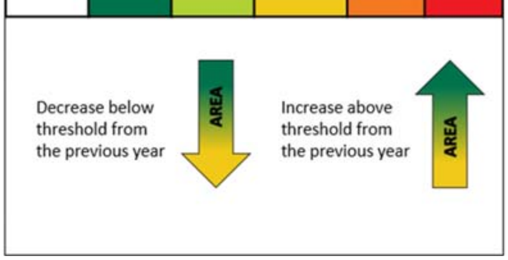
Figure 25. Changes in meadow area, biomass and species composition for seagrass at Meadow 43, Pelican Banks (Mid Harbour zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).





Condition threshold levels
(% above/below baseline)

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



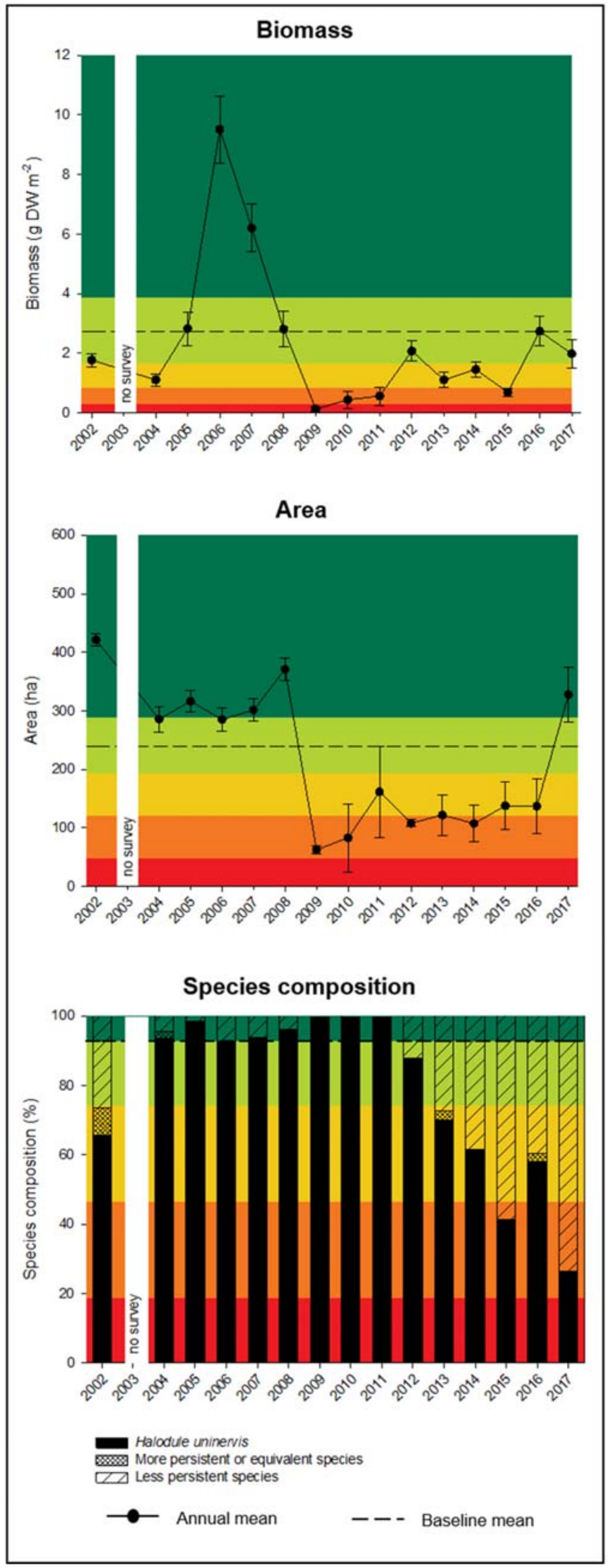


Figure 26. Changes in meadow area, biomass and species composition for seagrass at Meadow 48, Quoin Island (Mid Harbour zone), November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.6 South Trees Inlet (lower)

Surveys of the South Trees Inlet (lower) zone found five meadows and covered an area of approximately 190 ± 17 ha, similar to the previous three years. The area of individual meadows ranged from small isolated patches (~0.11 ha) to a larger intertidal meadow (~174 ha) to the south of the wharf (Meadows 172 and 76-77 respectively; Figure 27; Appendix 3). *Z. muelleri* subsp. *capricorni*, *H. uninervis,* and *H. ovalis* were present in the zone. Average biomass ranged from 0.01 gDW m^{-2} for isolated patches of *Z. muelleri* subsp. *capricorni* along the intertidal bank in South Trees Inlet (Meadow 172; Figure 27; Appendix 3) to 15.93 ± 1.89 gDW m^{-2} for continuous cover of Z. *muelleri* subsp. *capricorni* (Meadow 76-77; Figure 27; Appendix 3). Meadows were a mix of intertidal seagrasses ranging from isolated patches through to continuous cover (Appendix 3). The larger meadows on the exposed banks surrounding the wharves were dominated by *Z. muelleri* subsp. *capricorni* and had dugong feeding trails present in all three meadows (Figure 27; Appendix 3).

Long-Term Monitoring Meadows

There is one monitoring meadow in this zone, an intertidal meadow between the two wharves at South Trees Inlet (Meadow 60; Figure 28). Condition improved to very good in 2017 from good in 2016 (Figure 28; Appendix 3). An increase in biomass led to all three indicators being well above the baseline (Figure 28). The last time biomass was at this level was in 2008 when biomass peaked above 11 gDW m^{-2}. Meadow area remained in very good condition for the third consecutive year (>20% above the baseline). Species makeup was almost entirely the dominant *Z. muelleri* subsp. *capricorni* subsp. *capricorni* (99%) with the remaining fraction being *H. uninervis* (Figure 28; Appendix 4).

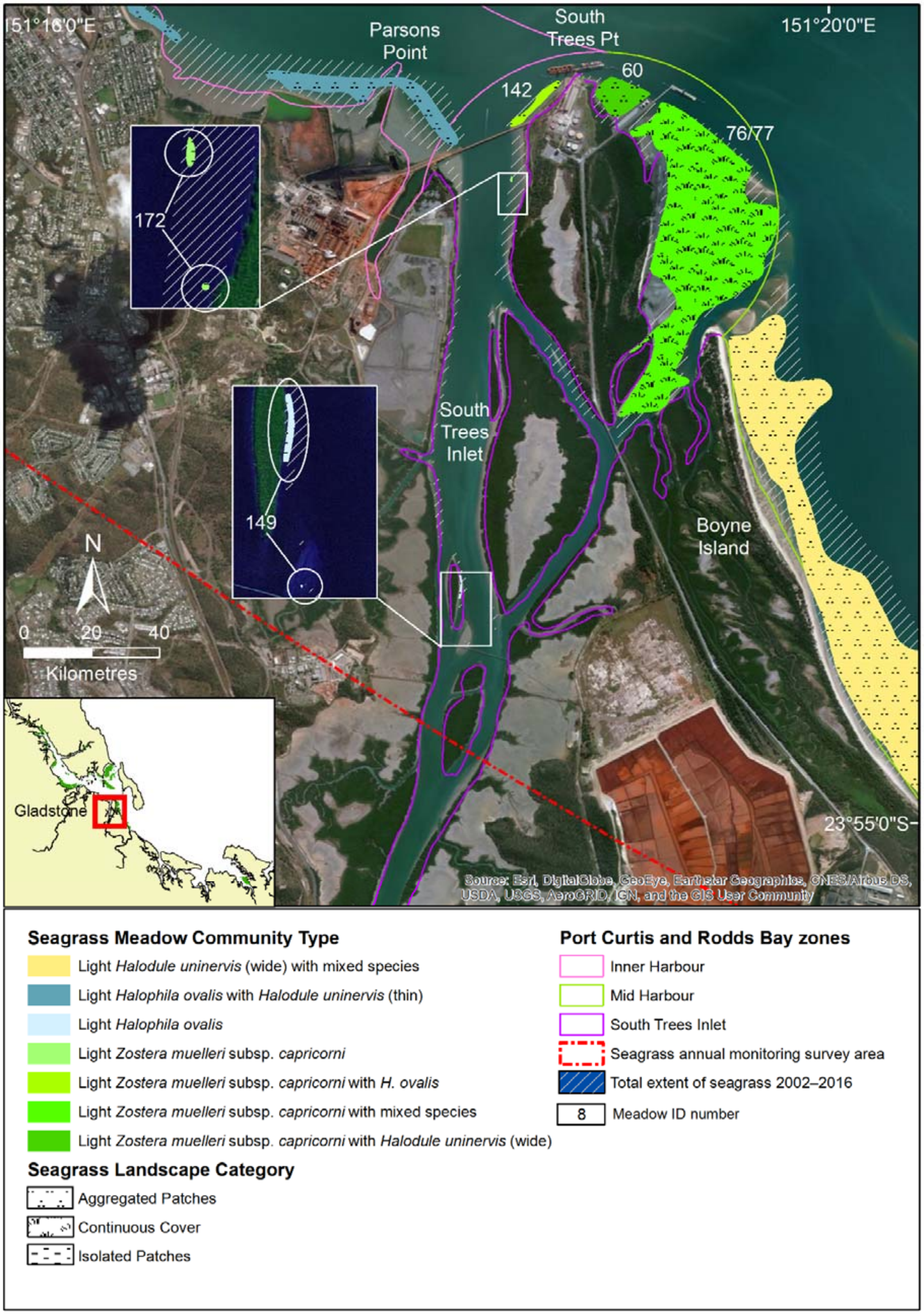
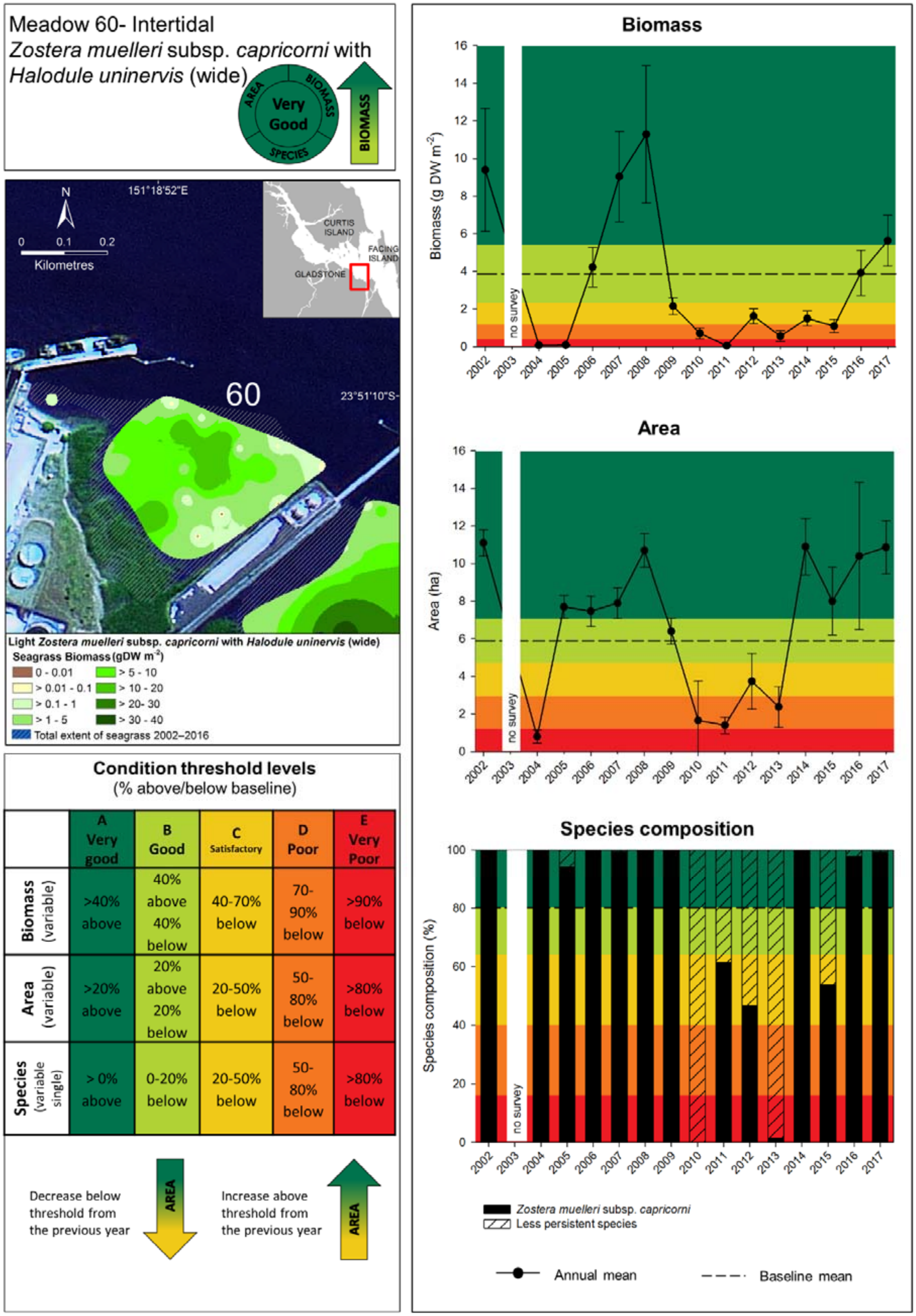


Figure 27. Seagrass distribution and community types at South Trees Inlet zone, November 2017.



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

Figure 28. Changes in meadow area, biomass and species composition for seagrass at Meadow 60, South Trees Inlet zone, November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2.7 Rodds Bay

Seagrasses assessed within the Rodds Bay survey area formed three individual meadows and covered an area of approximately 311 ± 14 ha, similar to 2015 coverage following a loss of nearly a third of meadow area in 2016. The area of individual meadows ranged from isolated patches (~1 ha) to the larger meadow (~305 ha) on the exposed banks in the middle of the bay (Meadows 94 and 96 respectively; Figure 29; Appendix 3). *Z. muelleri* subsp. *capricorni* and *H. ovalis* were present in the zone. Average biomass ranged from 0.04 ± 0.01 gDW m^{-2} (Meadow 94; Figure 29; Appendix 3) to 0.70 ± 0.29 gDW m^{-2} for the aggregated patches of Z. *muelleri* subsp. *capricorni* on the largest meadow (Meadow 96; Figure 32; Appendix 3). Two of the three meadows were comprised of isolated patches of seagrass and all meadows were classified as light in cover. Not all areas of the Rodds Bay zone are assessed in the annual monitoring survey and large areas of seagrass also occur outside of the monitoring region.

Long-Term Monitoring Meadows

There are three intertidal monitoring meadows in the Rodds Bay Zone – Meadows 94, 96 and 104. Prior to 2010, these meadows have consisted of continuous seagrass cover; however declines over the course of monitoring have left only aggregated patches in the largest meadow 96, and isolated patches in Meadows 94 and 104 (Figures 30-32).

Meadow 94:

Meadow 94 is the smallest monitoring meadow in Rodds Bay and remained in overall very poor condition due to extremely reduced meadow area – 1 ha in 2017 compared to >3 ha in previous years (Figure 30; Appendix 3). Biomass has remained extremely low (<2 gDW m^{-2}) for the past nine years following substantial declines between 2007 and 2009, and in 2017 biomass remained in very poor condition. Species dropped down to good from very good condition in 2017, with the dominant species *Z. muelleri* subsp. *capricorni* accounting for ~74% of mean meadow biomass (Figure 30; Appendix 4).

Meadow 96:

Overall condition of meadow 96 was very poor in 2017 due to biomass condition (Figure 31; Appendix 3). Biomass has remained below 2 gDW m^{-2} since 2010, following dramatic biomass declines from peaks of over 20 gDW m^{-2} in 2007 and 2008. Area did improve from 2016 to above baseline levels at 305 ha but without a change in score from good condition. Species composition was maintained at a satisfactory level with continued historical lows in the dominant species *Z. muelleri* subsp. *capricorni,* relative to *H. ovalis* (Figure 31; Appendix 4).

Meadow 104:

Overall condition of meadow 104 remained at very poor condition in 2017 with all three indicators at record lows. While biomass and area did not shift from 2016 levels, species composition dropped from poor to very poor with the increase in *H. ovalis* to 88% of meadow biomass over *Z. muelleri* subsp. *capricorni* (Figure 32; Appendix 3). This decline in *Z. muelleri* subsp. *capricorni* began in 2011 and has dropped significantly each year since (Figure 32; Appendix 4).

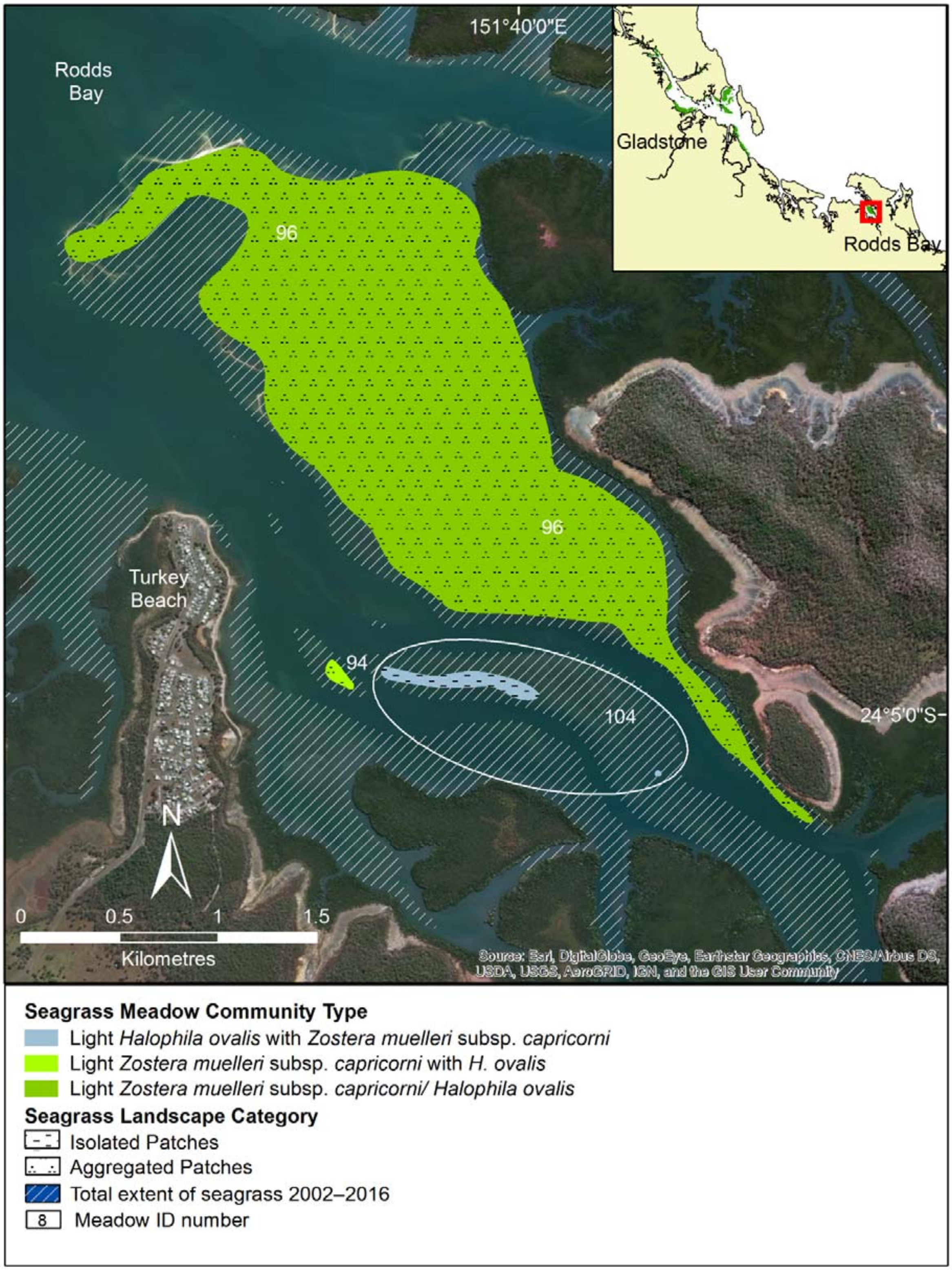


Figure 29. Seagrass distribution and community types in the Rodds Bay zone, November 2017.

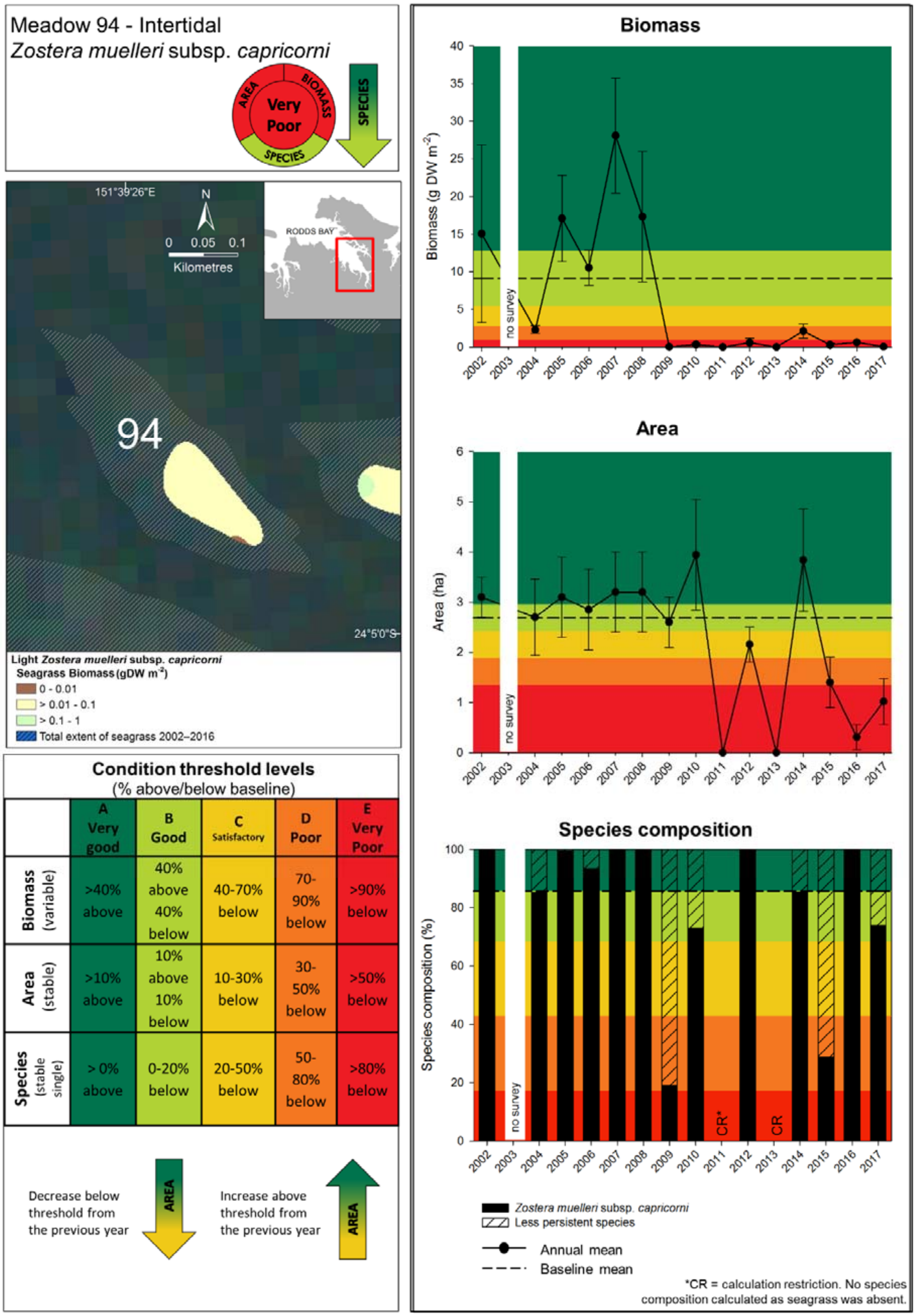


Figure 30. Changes in meadow area, biomass and species composition for seagrass at Meadow 94, Rodds Bay zone, November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

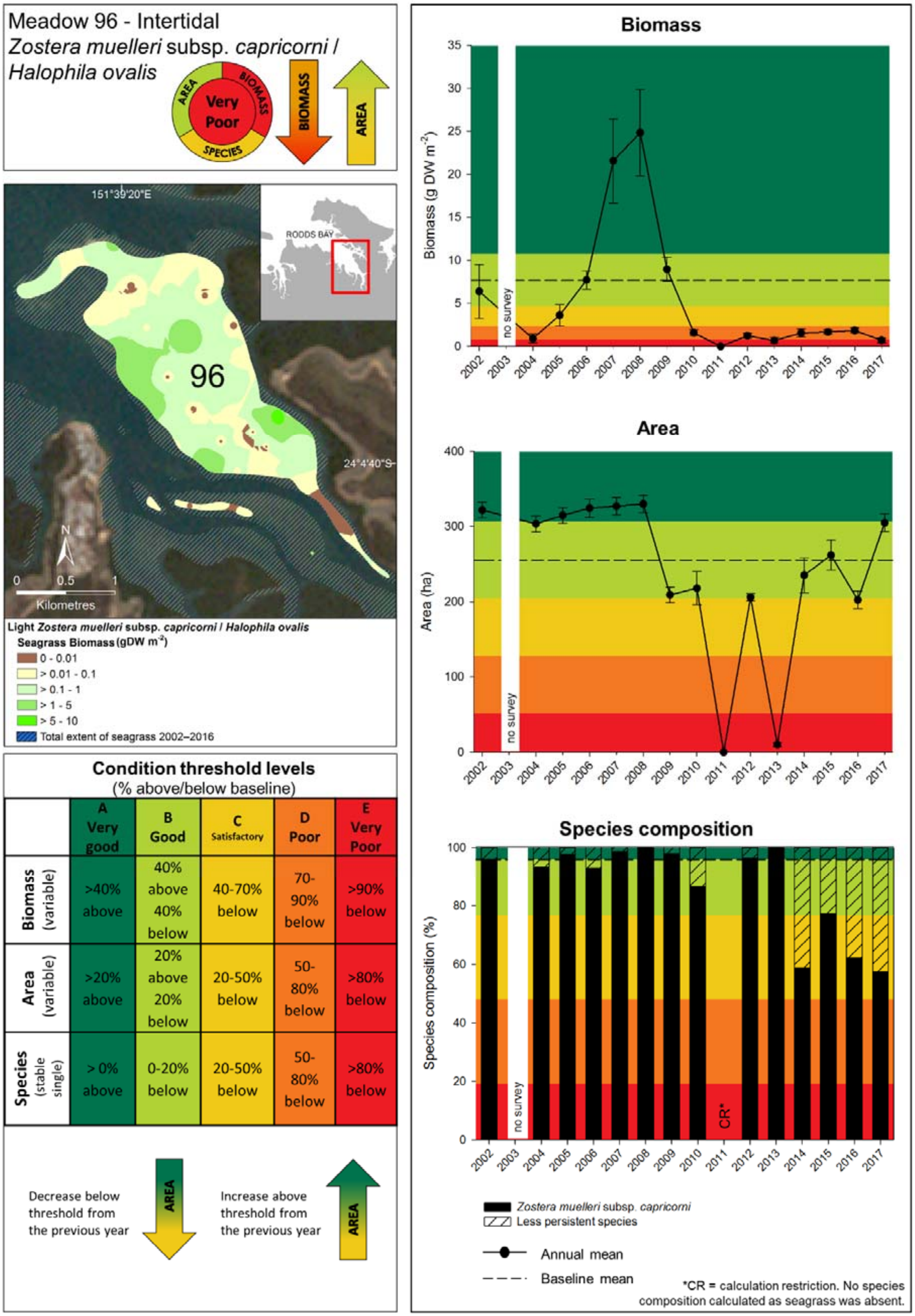
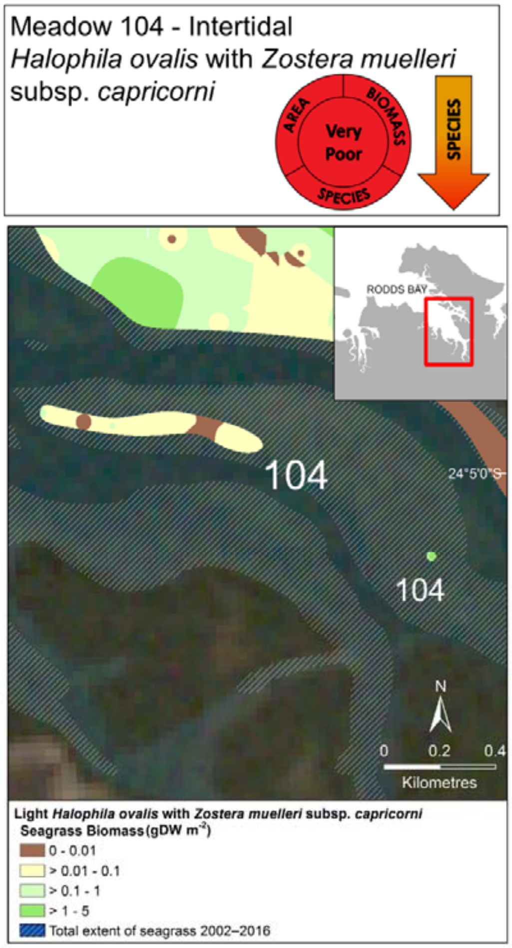
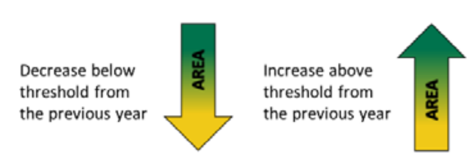


Figure 31. Changes in meadow area, biomass and species composition for seagrass at Meadow 96, Rodds Bay zone, November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).



Condition threshold levels
(% above/below baseline)

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



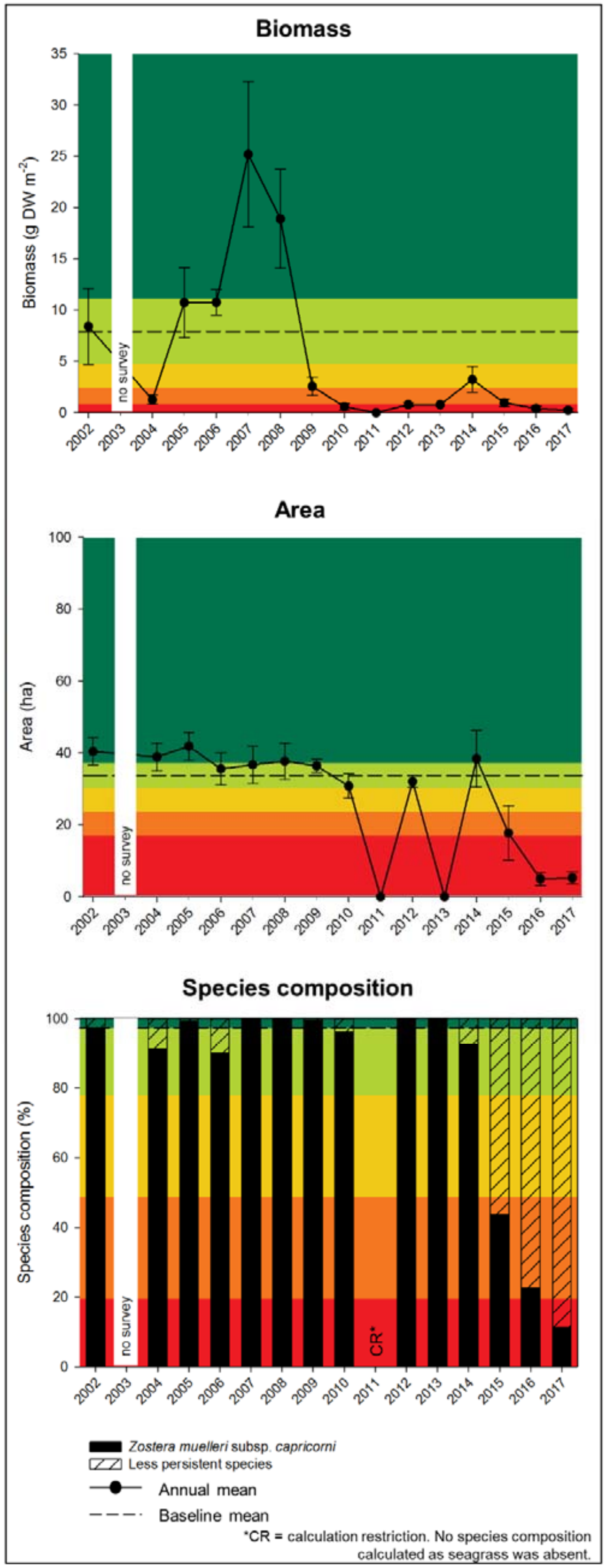


Figure 32. Changes in meadow area, biomass and species composition for seagrass at Meadow 104, Rodds Bay zone, November 2002–2017 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3 Gladstone environmental conditions

3.3.1 Rainfall and riverflow

Total annual rainfall in the 12 months preceding the November 2017 survey was slightly above the long-term average annual rainfall (since 1958) (Figure 33A). Total monthly rainfall was well above the long-term monthly average in March and more strikingly in October 2017, a typically drier time of year (Figure 33B). River flow from the Calliope River peaked well above the long-term average (since 1970) in March and October 2017 in parallel with the monthly rainfall data (Figure 34). All other months were relatively dry and with little river flow.

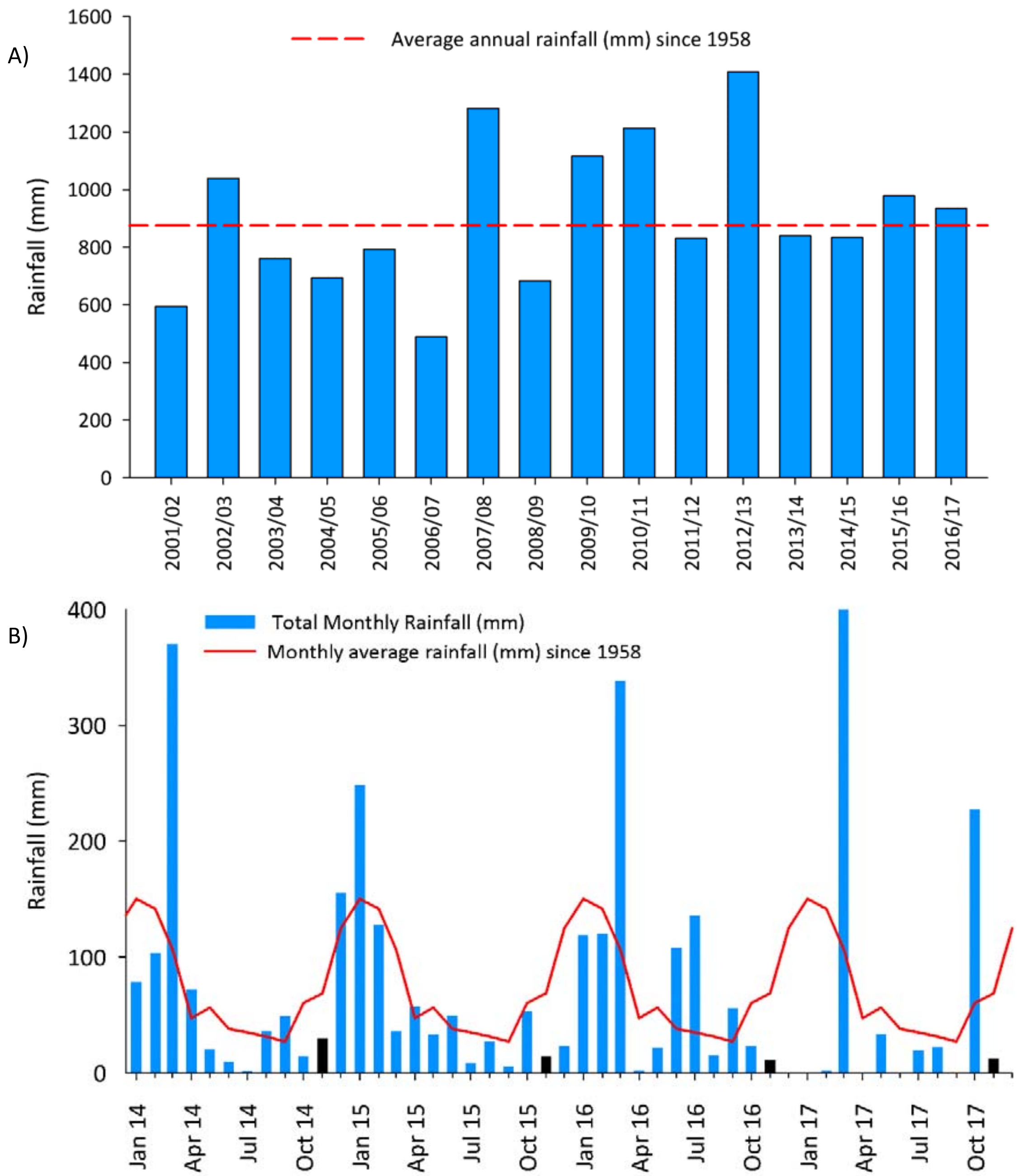


Figure 33. A) Total annual rainfall (mm) at Gladstone and B) total monthly rainfall (mm), January 2014–November 2017. Black bars indicate October/November rainfall when seagrass was sampled (spring peak growth period).

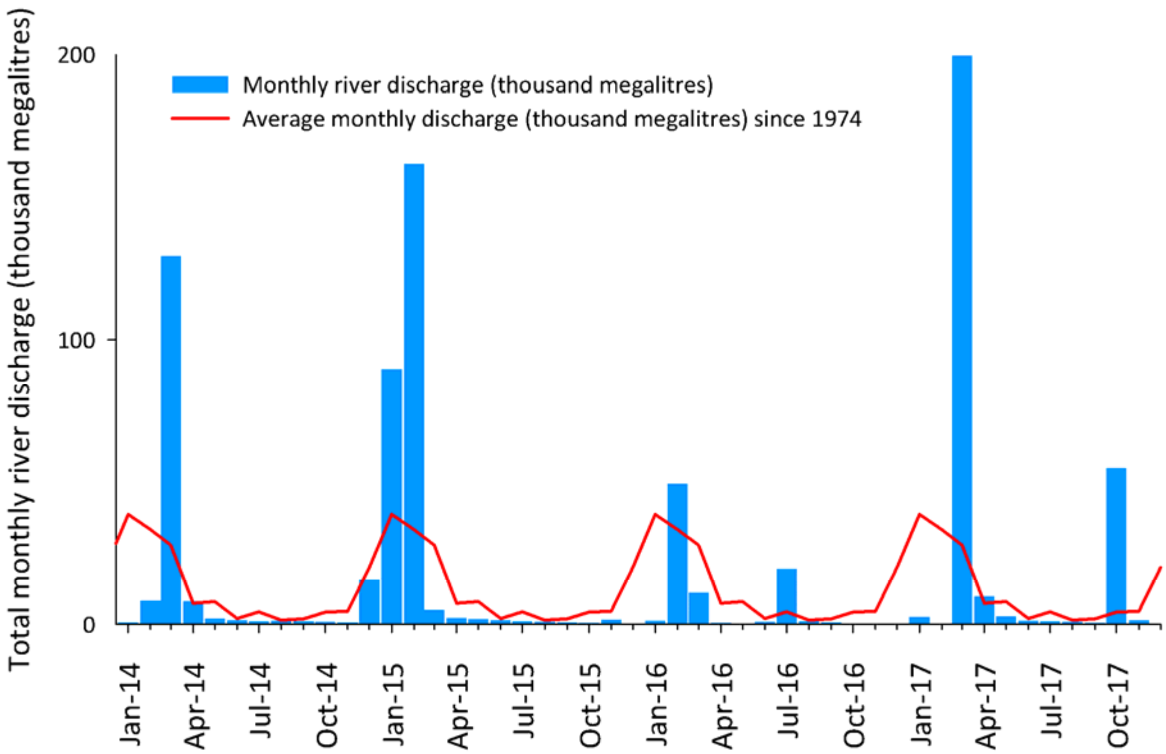
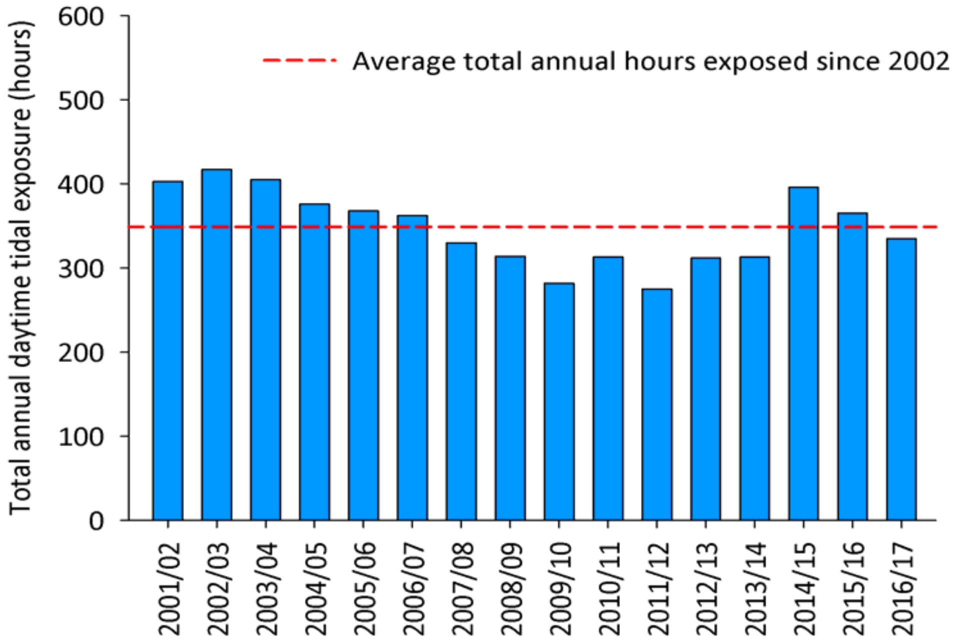


Figure 34. Monthly total river flow for the Calliope River (thousand megalitres), January 2014–November 2017.

3.3.2 Tidal exposure

Tidal exposure of seagrass meadows is naturally variable and is dependant on the tidal regime of any given year. Annual total daytime exposure of seagrass meadows was just below average and in line with a natural decline in exposure hours with expected decadal cycles (Figure 35A). Total monthly daytime exposure leading up to the November 2017 survey in October was below the average since seagrass monitoring began in 2002 (Figure 35B), and similar lower than average exposure hours occurred up to five months prior to the survey (Figure 35B). Water temperature monitored *in situ* at Pelican Banks shows the majority of incidences where elevated water temperature takes place following the November surveys; in January – April when seagrasses begin to senesce rather than prior to and leading up to the annual survey period.

A)



B)

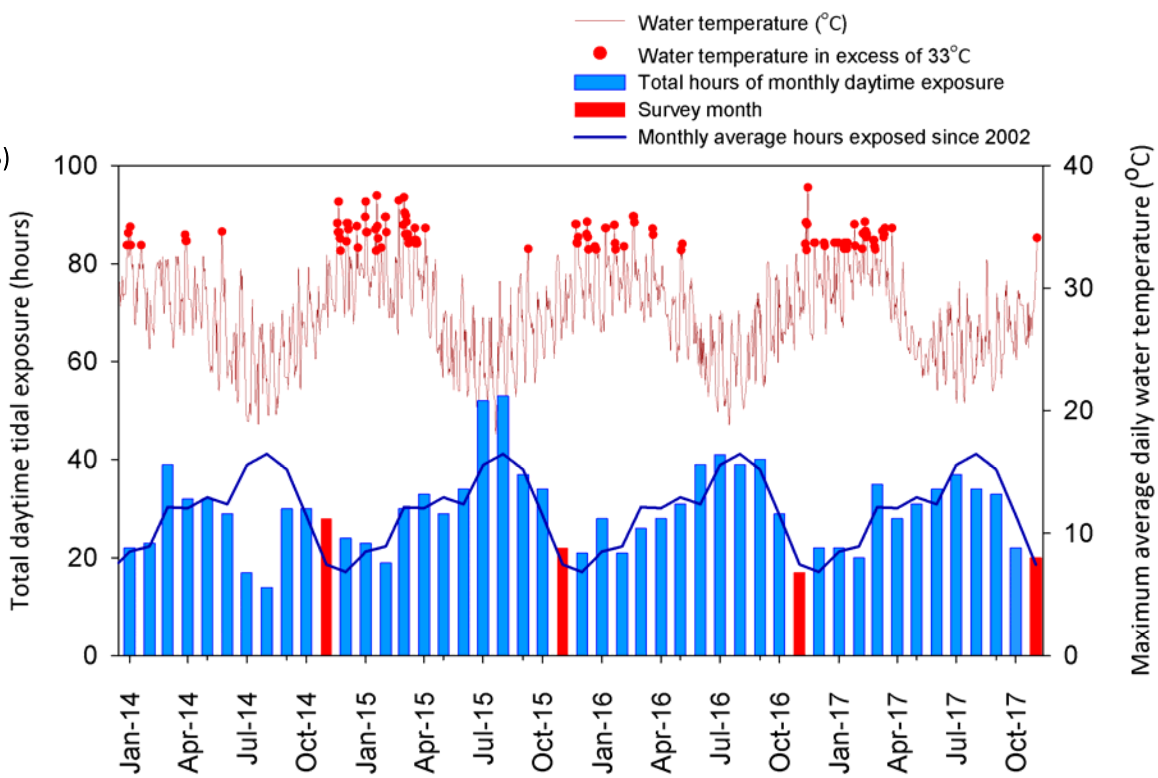


Figure 35. A) Total annual daytime hours exposed 2001/02 to 2016/17 and B) monthly total daytime tidal exposure and maximum daily water temperature (taken from Pelican Banks), 2014-2017, (0600 – 1800; <1.0 m below mean sea level).

4 DISCUSSION

In 2017 seagrasses in Port Curtis and Rodds Bay remained in an overall poor condition. Results for individual meadows were mixed but there were few overall improvements. One exception was the large seagrass meadow at Pelican Banks, that had regained some of its lost biomass and increased its composition of the larger more stable species. This resulted in reversing some of the declines in recent years with the meadow improving from very poor to poor condition. In general it was lower than average biomass and a high prevalance of less stable colonising species that led to low meadow condition scores, with area of most seagrass meadows in average or better condition. There was no relationship between proximity of port and anthropogenic activities and meadow condition with meadows most removed from port activities in Rodds Bay decling and remaining in a very poor state in 2017. Port Curtis and Rodds Bay seagrasses have generally failed to return to pre-disturbance levels following the major declines that occurred between 2009 and 2010. This is likely due to a range of repeated disturbances from climate, floods, cyclones and anthropogenic activities over the last seven years. While seagrass generally remained within the majority of its historical extent, the decline in overall biomass and greater prevalence of less stable seagrass species in many meadows, indicate seagrasses are likely vulnerable and less resilient to future pressures or impacts.

A prevalence of less stable colonising species was a key driver of condition for a number of meadows in Port Curtis. For some this resulted in a lower overall score despite achieving above average condition for biomass and area. For example, Meadow 4 at Wiggins Island was scored as overall satisfactory despite good for area and very good for biomass due to the high proportion of *Halophila ovalis* in the meadow. The Quoin Island meadow (Meadow 48) was also affected in a similar way. It increased significantly in area to be classified as very good and had a good overall biomass score, yet it again was dominated by less persistent *Halophila* spp. and *Halodule uninervis.* The presence of these more variable species is an indicator of past disturbance and the beginning of seagrass meadow recovery (Rasheed 2004). Should favourable conditions for seagrass growth occur during 2018 we would expect to see a return to a higher proportion of the dominant more stable species, especially as most meadows retained some presence of these species albeit at reduced density in 2017.

In 2015 and 2016, serious concerns were raised regarding the largest and densest area of seagrass in Port Curtis at Pelican Banks with significant loss of biomass and the increased proportion of less persistent seagrass species in the meadow. In 2017, this trend was reversed with biomass and species composition improving resulting in the meadow shifting from very poor to poor condition. While the improvements are a positive sign, the meadow is still a long way from regaining its full biomass and area. Given its' historical importance as the most stable seagrass meadow in the region, a continued trajectory of recovery in the future remains a key to marine environmental health in Port Curtis.

There doesn't appear to be an obvious or discrete single driver of the lack of seagrasses recovery in Port Curtis and Rodds Bay over the past three years. Generally annually averaged environmental conditions were close to long-term averages and therefore within expected ranges for favorable seagrass growth in 2017. Lower than average number of tidal exposure hours in 2017 likely protected seagrasses from the effects of desiccation and thermal stress (Unsworth et al. 2012) and annual rainfall, and temperature, were below long term averages. However, while annual average conditions seemed relatively benign it is often shorter term episodic events that lead to major environmental impacts. During 2017 in Port Curtis there were at least two of these with the potential to impact on seagrasses. Tropical Cyclone Debbie (Cat 4) crossed the Queensland coast in March 2017 near the Whitsundays and followed a path inland, skirting around Gladstone before heading off the southeast coast of Queensland. While the cyclone path did not directly cross the Port Curtis area, rainfall and river flow from the event impacted the Port Curtis region with high turbidity and freshwater flows from the Calliope River and also the Fitzroy River down into the Narrows. This event along with and additional uncharacteristic above average rainfall and river flow event in October 2017, just prior to seagrass surveys, was likely to have impacted seagrasses, particularly the meadows close to the mouth of the Calliope River. It is unclear to what degree these weather events affected the seagrass' benthic light environment and associated growing conditions since light monitoring in the port ceased in 2016. However, previous monitoring in the area has shown that benthic light is generally reduced by these types of river flow events. General climatic conditions collated and discussed in this report provide a good indication of likely trends in water quality and benthic light, but as there are many complex interactions they are no substitute for actual *in situ* water quality monitoring in the seagrass meadows.

There are a range of other potential contributors to the lack of seagrass recovery in 2017 and the declines of recent years. For many of the meadows most affected a high frequency of turtles and presence of dugong feeding activity has been observed. The Pelican Banks meadow has a high level of herbivory from dugong and turtle, with dugong feeding trails (DFTs) observed within the meadow during every seagrass monitoring survey and during a detailed study of dugong feeding over the previous two years (Rasheed et al. 2017). Green turtles also regularly feed on the meadow (direct observations and Hamann et al. (2016)). Both of these large herbivore species have the potential to significantly impact the state of seagrasses, with examples of major meadow losses recorded in other locations as a direct result of herbivory (Christianen et al. 2014). While anecdotal observations from field surveys in November indicated a large number of green turtles, it is unclear if this had substantially increased from previous years. Research is currently underway in Port Curtis to measure the potential effects of herbivory on seagrass meadow biomass and how this may alter meadow structure and condition. Early indications from this research found excluding megaherbivores (turtles and dugong) from areas increased seagrass biomass at Pelican Banks and at South Trees Inlet (Meadow 76-77). In depth analysis and additional herbivory studies will help to clarify the extent to which this cropping and grazing on Port Curtis seagrasses is affecting overall meadow condition and seagrass dynamics. Widespread use of Port Curtis and Rodds Bay seagrass meadows for dugong feeding indicate seagrasses in the region continue to provide a valuable food source to megaherbivore populations, including adjacent to port infrastructure and industrial activity. Furthermore, the prevalence of DFTs and turtle sightings indicate megaherbivores may in fact be an important component of the overarching drivers of seagrass condition.

Movement and accumulation of sediments can also influence seagrass condition (Cabaco et al. 2008). There is some anecdotal evidence that sediment movement and accumulation may have occurred in recent times on the southern most section of Pelican Banks where the greatest reduction in seagrass biomass for the meadow has occurred. However, direct measurements have not been made of sediment change 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).

The changes observed in 2016 and lack of recovery in 2017 are most likely the result of an accumulation of multiple pressures and impacts occurring over multiple years. The initial declines recorded during 2015 were hypothesised to be linked to extended periods of relatively high water temperatures. However, in 2016 and 2017, there were few instances of temperatures occurring above 33°C for extended periods (see Section 5.3.3), with local species able to cope with temperatures well in excess of this (Collier and Waycott 2014; Massa et al. 2009; Campbell et al. 2006). Repeated natural impacts from local flooding and cyclones to Port Curtis seagrasses since 2010 are also well described in previous reports. The Calliope River, in particular, had substantial flows and floods well above long-term averages in 2014 and again in 2015 and the greatest single flow event in March 2017 since the major flooding that occurred in January 2013.

Repeated and above average river flow of the Calliope River in seven out of the last nine years may have left little respite for recovery from these potential stress events on seagrasses. Repeated impacts may lead to a legacy of reduced meadow resilience. For instance, a study in 2016 found significant declines in reproductive shoots containing seeds (spathes) and signs of a decreasing seed bank density over the years; an indication reproductive capacity of the meadows was reduced (Bryant et al. 2016).

While the continued poor condition of seagrasses within Port Curtis in 2017 is concerning, it is worth noting that seagrasses were in a similarly poor state in the meadows most distant to port activities in Rodds Bay. Rodds Bay has had poor seagrass coverage and biomass since major declines occurred in 2008 and 2009.

Port Curtis seagrass meadows maintained an above-average areal footprint despite a likely reduction in resilience of some core areas of seagrass. It is unclear how seagrasses will fair in 2018 with recovery dependent on a range of favourable weather and climate conditions including how rainfall, river flow, and other drivers of water quality impact the light environment and possible sediment movements on intertidal banks as well as how herbivory continues to influence meadow condition. In 2017 the key species remained within the majority of meadows, so the foundation for potential recovery of meadows remained, should favourable conditions prevail.

4.1 Comparisons with Queensland-wide monitoring program and seagrass resilience

Reduced seagrass meadow condition in 2010-2017 observed in Port Curtis and Rodds Bay was generally consistent with seagrass trends along Queensland's east coast between Cairns and Port Curtis. Large scale declines in seagrass meadow area and biomass occurred in 2009 and 2010 at Cairns (York et al. 2016), Mourilyan (Reason et al. 2017), Townsville (Wells and Rasheed 2017), and Bowen/Abbot Point (McKenna et al. 2017). These declines coincided with above average rainfall and river flow (McKenna et al. 2017) often associated with tropical cyclones (TC) and extended La Niña weather patterns 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 this corresponded with improvements in overall meadow condition for 9 of the 14 monitoring meadows (and no declines in overall meadow condition in any of the meadows). High rainfall and flooding associated with TC Debbie (March 2017) coincided with similar trends in seagrass condition across the ports affected by this weather event: Hay Point, Abbot Point, and Port Curtis (JCU in prep).

Tropical seagrasses in Queensland have demonstrated an ability to recover from previous impacts (York et al. 2015; Rasheed et al. 2014; Rasheed 2004; Birch and Birch 1984). In Queensland, recovery has differed by location and is likely influenced by local climate as well as the severity of the initial decline. In 2017, Townsville's seagrass meadows continued to improve following good recovery in 2016 (Bryant and Rasheed 2018). Cairns seagrass condition also continued to improve from poor in 2016 to satisfactory in 2017 for the coastal meadows (Reason and Rasheed 2018a).

Reductions in meadow area, biomass, and stable/persistent species during years of extreme weather events reduce both the adult plant population and limit the resources available for that meadow to initiate recovery. When limited or no adult plants remain, recovery will depend upon seed banks in the sediment or sexual propagules sourced from nearby locations (Jarvis and Moore 2010; Duarte and Sand-Jensen 1990; Phillips and Lewis 1983). Under these circumstances the rate of recovery is likely to be much slower, particularly where no local or nearby sources of propagules exist. For example in Mourilyan Harbour there was complete meadow loss and seagrass remains in very poor condition in 2017 with little prospect of seagrass recovery without some form of restoration (Reason and Rasheed 2018b). In this context, meadows in Port Curtis have shown reasonable resilience and ability to recover. Seagrass growth during 2018 is critical to ensure replenishment of seed reserves and an opportunity for the adult populations to increase in biomass to re-establish resilience buffers.

Seagrass meadows away from Queensland's east coast have fared much better over recent times. These regions generally experienced a lower frequency or severity of extreme weather events, rainfall and flooding, than along Queensland's east coast south of Cooktown. Seagrass condition at monitoring locations in Thursday Island (Torres Strait) (Sozou et al. 2017), Weipa (Sozou and Rasheed 2018) and Karumba (Shepherd et al. 2018) did not experience the same declines in 2010-2016. Seagrass condition at Thursday Island and Karumba was good in 2017 (Shepherd et al. 2018; Sozou et al. 2017). Weipa seagrass condition improved to good from 2016 to 2017, a recovery in part from localised declines related to acute pressures which have eased (Sozou and Rasheed 2018).

4.2 Implications for port management

The current condition of seagrasses in Port Curtis has management implications particularly regarding activities that could potentially reduce water quality in the region. Resilience of seagrasses in Port Curtis to further natural or anthropogenic impacts is likely to be low. Despite their reduced biomass most meadows maintained their spatial footprint and at least some presence of the key foundation species. Under these circumstances where favourable conditions for growth are maintained recovery can be rapid, potentially occuring within a single growing season (Rasheed 1999). Should these conditions prevail then we would expect to see improvements in seagrass condition for Port Curtis during 2018. However, natural recovery from large declines where entire meadows or key species are lost can take up to five years (Preen et al. 1995) or potentially longer to recover (Birch and Birch 1984). As such, it is critical that seagrass condition in Port Curtis is maintained to avoid meadow scale losses that are likely to be very slow to recover. An improvement in meadow condition may be delayed if anthropogenic activities in the region cause additional stressors to seagrass meadows such as high turbidity, poor water quality or low light levels, particularly if natural weather and climate conditions are unfavorable. Where these activities are planned, managing water quality and particularly benthic light to be sufficient for seagrass growth (Chartrand et al. 2016) will be important for maintenance of seagrasses and the services they provide.

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APPENDICES

Appendix 1.

Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2002–2012; nb. no survey conducted in 2003). This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014b). The 2002–2012 period incorporates a range of conditions present in Gladstone Harbour, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events (Carter et al. 2015a). In some cases less than 10 years of data were available, e.g. meadows 21 and 52–57 which have only been surveyed since 2009, or species composition data were unavailable for years where no seagrass was present. In this instance the baseline was calculated over the longest available time period excluding the year of interest (i.e. November 2015 data). Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments. This will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Grade and Score Calculations section and Figure A1).

Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass and species composition were classified as either stable or variable (Table A1). Meadow area was classified as either highly stable, stable, variable, or highly variable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table A1. Coefficient of variation (CV) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

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

Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).

Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

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

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, Port Curtis Harbour Zones, and for the Port Curtis region (Table A3; see Carter et al. 2016; 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 (see Baseline Calculations section), allocating a grade for each indicator by comparing 2017 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period. For meadows 21 and 52-57 this upper limit will be recalculated each year until the 10 year baseline period is complete.

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 2.

Table A3. 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

Where species composition was determined to be anything less than in "perfect" condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure A1). If this was the case then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *Cymodocea rotundata* and *Cymodocea 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 *Syringodium isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found in Port Curtis, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure A1).

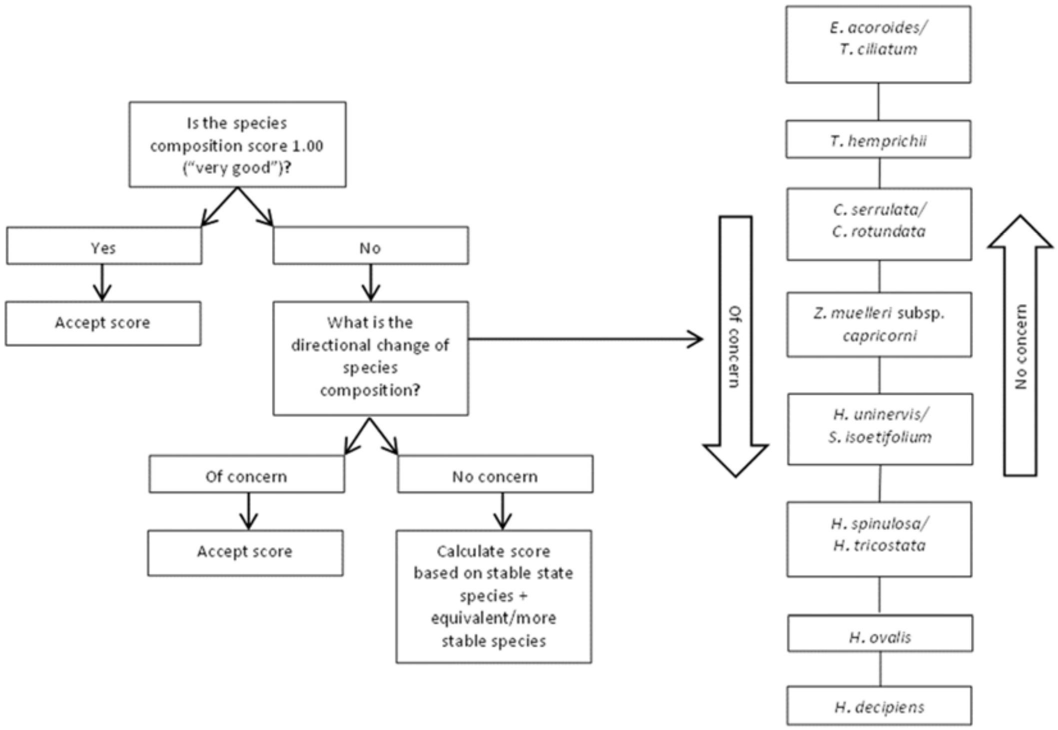


Figure 10. (a) Decision tree and (b) directional change assessment for grading and scoring seagrass species composition.

Score Aggregation

A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years' annual report. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change 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. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014b).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such a food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a "0" score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lowest of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in Port Curtis as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Abbot Point, Mackay, Hay Point, Mourilyan Harbour, Torres Strait, Weipa and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across Gladstone (and the other locations), where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Overall Port Curtis grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Port grades are therefore more sensitive to changes in stable than variable meadows.

Appendix 2.

An example of calculating a meadow score for biomass in satisfactory condition in 2016.

1. Determine the grade for the 2017 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2017 area value (A_{2017}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{2017} - A_{satisfactory}$$

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

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

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

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

4. Calculate the proportion of the satisfactory grade (A_{prop}) that A_{2017} takes up:

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

5. Determine the area score for 2017 ($Score_{2016}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

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

Appendix 3. Meadow area and above-ground biomass

Mean above-ground biomass (g DW m^{-2}) + standard error and area (ha) ± reliability estimate (R) for seagrass meadows in Port Curtis and Rodds Bay, 2017.

Meadow ID	Biomass ± SE (g DW m-2)	Area ± R (ha)	Community Type	Landscape Category	Species Present
THE NARROWS REGION					
1	4.28 ± 0.37	0.60± 0.44	Light Zostera muelleri subsp. capricorni/ Halophila ovalis	Isolated patches	*Zostera muelleri* subsp. *capricorni. Halophila ovalis*
10 & 17	14.38 ± 3.81	27.38 ± 7.16	Light *Zostera muelleri* subsp. *capricorni* with mixed species	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis, Halophila decipiens*
13	n.a.	2.83 ± 2.51	Light *Halophila decipiens*	Isolated patches	*Halophila decipiens*
19	1.18 ± 0.35	92.06 ± 12.29	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
21	1.31 ± 0.35	131.88 ± 13.72	Light *Zostera muelleri* subsp. *capricorni/ Halophila ovalis*	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
22	n.a.	1.15 ± 2.69	Light *Halophila decipiens*	Aggregated patches	*Halophila decipiens*
23	0.31 ± 0.12	66.10 ± 11.07	Light *Halophila ovalis* with mixed species	Aggregated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni, Halophila decipiens*
28	1.52 ± 0.66	12.96 ± 2.37	Moderate *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni, Halophila decipiens*
29	1.23 ± 0.49	38.85 ± 5.38	Moderate *Halophila decipiens* with mixed species	Aggregated patches	*Halophila decipiens, Zostera muelleri* subsp. *capricorni, Halophila ovalis*
33	1.17 ± 0.50	27.34 ± 9.97	Light *Zostera muelleri* subsp. *capricorni/ Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*

n.a. less than three biomass sites present

Meadow ID	Biomass ± SE (g DW m-2)	Area ± R (ha)	Community Type	Landscape Category	Species Present
GRAHAMS CREEK REGION					
2	n.a.	1.66 ± 0.51	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
15	0.26 ± 0.23	12.11 ± 1.68	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
34	n.a.	1.89 ± 0.52	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
36	0.68 ± 0.66	2.32 ± 0.95	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
37	n.a.	0.09 ± 0.20	Light *Halophila decipiens*	Isolated patches	*Halophila decipiens*
38	0.12 ± 0.10	2.56 ± 0.61	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
41	0.57 ± 0.20	38.89 ± 4.77	Light *Halophila ovalis* with *Zostera muelleri* subsp. *capricorni*	Aggregated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
141	n.a.	0.21 ± 0.22	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
168	n.a.	0.23 ± 0.33	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
170	0.90 ± 0.47	0. 96 ± 0.51	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
175	0.41 ± 0.11	0.24 ± 0.13	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
WESTERN BASIN REGION					
4	3.65 ± 0.91	32.58 ± 3.10	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
5	1.86 ± 0.28	134.46 ± 4.98	Moderate *Halophila ovalis* with *Zostera muelleri* subsp. *capricorni*	Aggregated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
6	0.90 ± 0.13	463.40 ± 11.85	Light *Halophila ovalis* with *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
7	0.00	0.00	Meadow Absent	-	-
8	2.15 ± 0.34	160.05 ± 12.69	Moderate *Halophila ovalis* with *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
11	n.a.	0.06 ± 0.12	Light *Halophila decipiens*	Isolated patches	*Halophila decipiens*
16	2.02 ± 0.42	31.53 ± 3.45	Moderate *Halophila ovalis*	Aggregated patches	*Halophila ovalis*
42	4.91 ± 2.45	7.81 ± 1.49	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
46	2.35	0.21 ± 0.22	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
51	n.a.	0.58 ± 0.16	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
52 - 57	2.44 ± 0.58	37.03 ± 7.18	Moderate *Halophila ovalis/ Zostera muelleri* subsp. *capricorni*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
59	n.a.	1.54 ± 0.49	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*

n.a. less than three biomass sites present

Meadow ID	Biomass ± SE (g DW m-2)	Area ± R (ha)	Community Type	Landscape Category	Species Present
INNER HARBOUR REGION					
50	1.08 ± 0.2	16.09 ± 5.17	Light *Halophila ovalis/ Zostera muelleri* subsp. *capricorni*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*
58	1.92 ± 0.28	40.87 ± 6.74	Moderate *Halophila ovalis/ Halodule uninervis* (narrow)	Aggregated patches	*Halophila ovalis, Halodule uninervis* (narrow)
61	n.a.	0.55 ± 0.40	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
62 & 63	0.05 ± 0.01	14.76 ± 2.10	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
79	3.48 ± 1.50	43.01 ± 9.43	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
80	0.53 ± 0.25	0.85 ± 0.5	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
81	n.a.	0.08 ± 0.13	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
84	n.a.	0.03 ± 0.09	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
85	4.05 ± 1.76	100.22 ± 11.27	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
136	6.40	0.30 ± 0.27	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
157	0.24	1.21 ± 0.68	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*

n.a. less than three biomass sites present

Meadow ID	Biomass ± SE (g DW m-2)	Area ± R (ha)	Community Type	Landscape Category	Species Present
MID HARBOUR REGION					
3	n.a.	0.19 ± 0.23	Light *Halodule uninervis* (wide) with *Halophila ovalis*	Isolated patches	*Halodule uninervis* (wide), *Halophila ovalis*
43	7.67 ± 1.03	553.62 ± 6.99	Light *Zostera muelleri* subsp. *capricorni* with mixed species	Continuous cover	*Zostera muelleri* subsp. *capricorni, Halodule uninervis* (wide), *Halophila ovalis*
48	1.98 ± 0.47	327.82 ± 47.27	Light *Halophila spinulosa / Halophila ovalis* with mixed species	Aggregated patches	*Halophila spinulosa, Halophila ovalis, Halodule uninervis* (wide & narrow
49	0.84 ± 0.60	8.10 ± 1.15	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
65	n.a.	0.08 ± 0.13	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
66	5.46 ± 0.91	192.73 ± 55.95	Light *Zostera muelleri* subsp. *capricorni*	Continuous cover	*Zostera muelleri* subsp. *capricorni*
67	2.28 ± 0.11	0.54 ± 0.1.05	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
69	0.02 ± 0.02	1.83 ± 1.86	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
70	n.a.	1.66 ± 0.87	Light mixed species	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halodule uninervis* (narrow), *Halophila ovalis,*
72	n.a.	6.34 ± 2.39	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
78 & 89	4.46 ± 0.80	361.39 ± 85.23	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Zostera muelleri* subsp. *capricorni, Halophila ovalis*
137	9.44 ± 1.12	6.41 ± 1.01	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Continuous cover	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
153	n.a.	0.16 ± 0.08	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
177	3.34 ± 1.56	8.90 ± 2.84	Light *Zostera muelleri* subsp. *capricorni / Halodule uninervis* (wide)	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halodule uninervis* (wide)

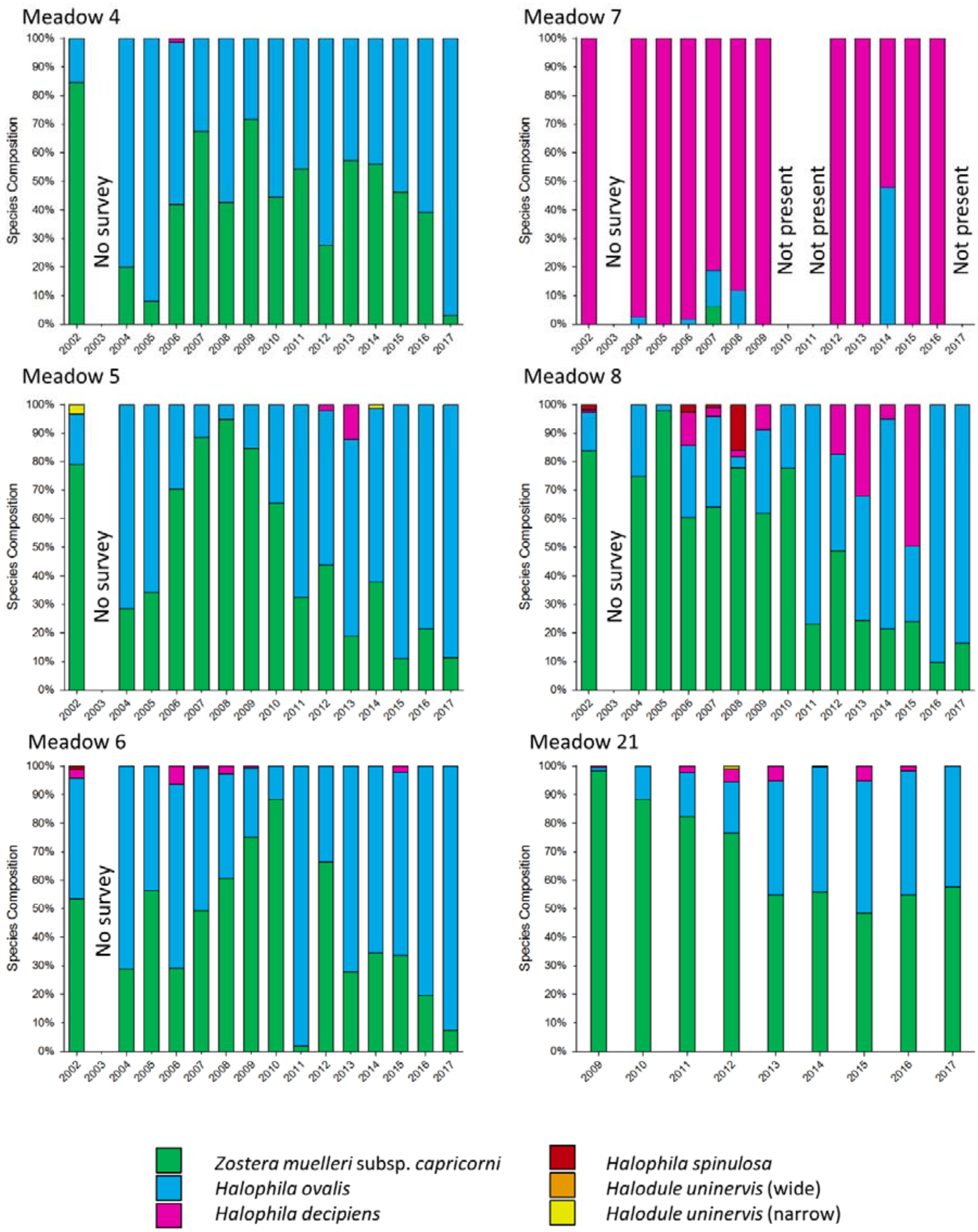
n.a. less than three biomass sites present

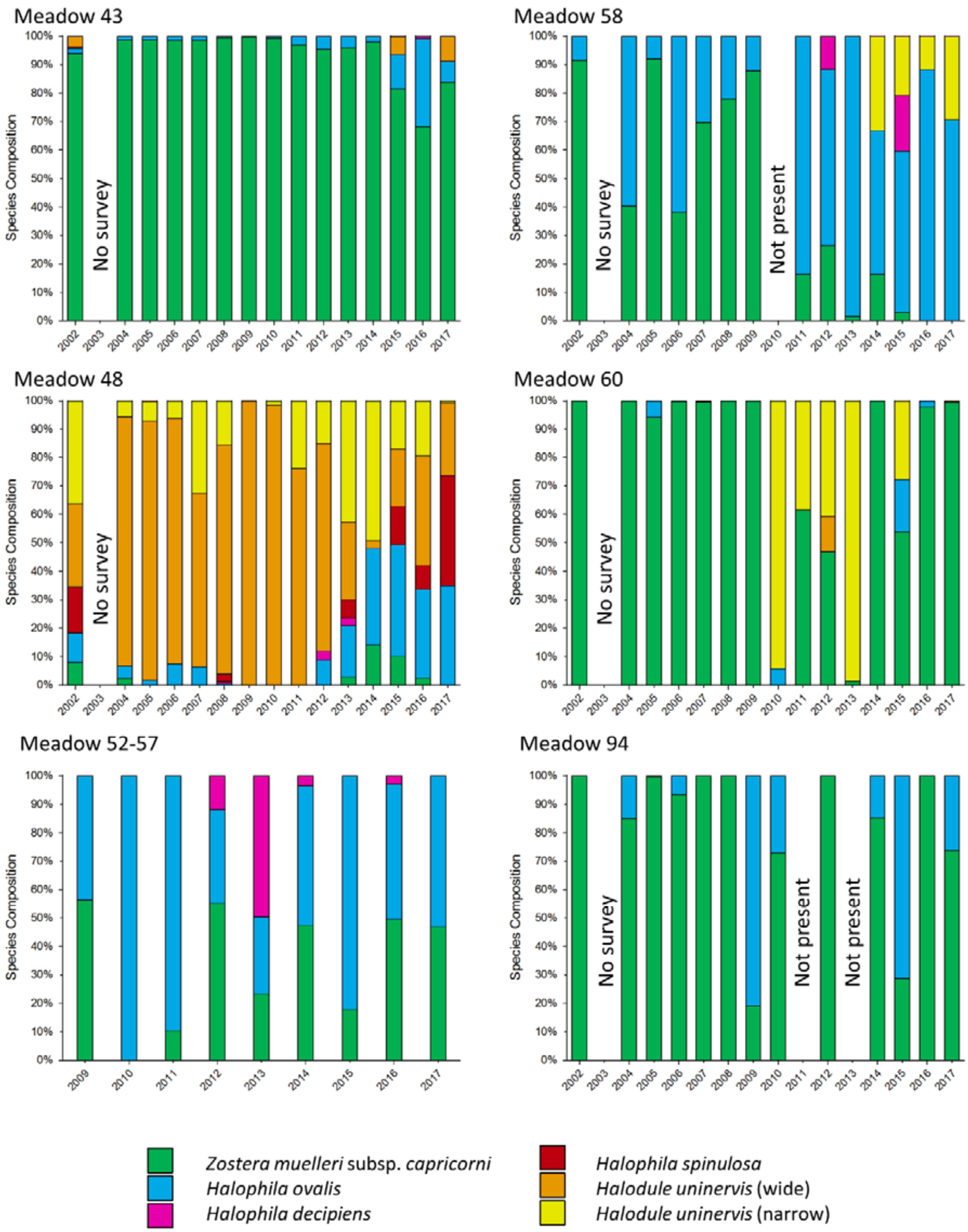
Meadow ID	Biomass ± SE (g DW m-2)	Area ± R (ha)	Community Type	Landscape Category	Species Present

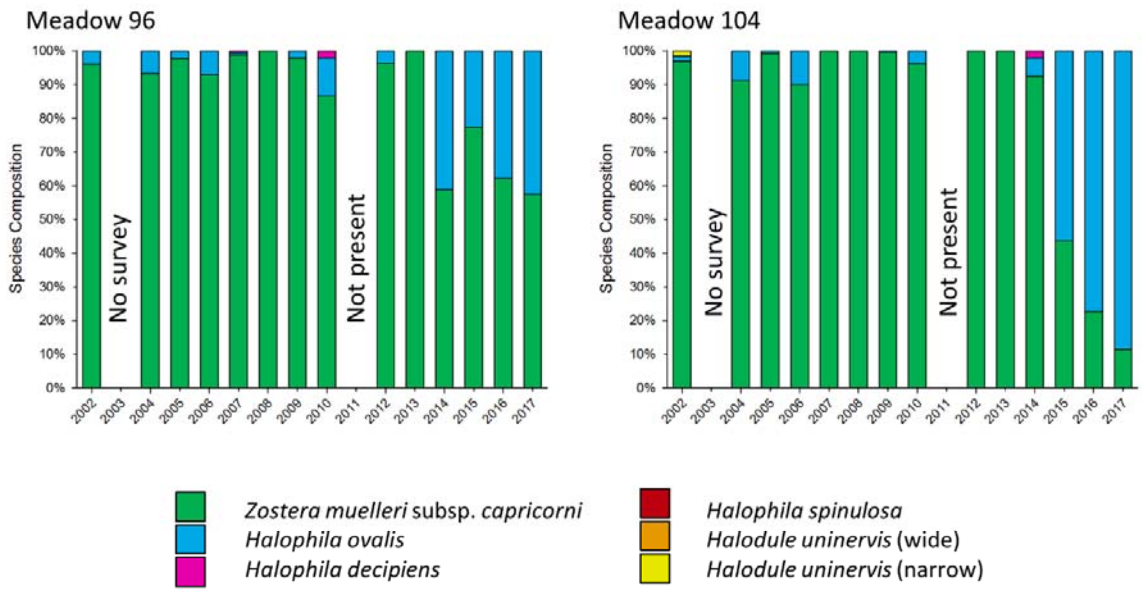
SOUTH TREES INLET REGION					
60	5.63 ± 1.34	10.86 ± 1.42	Light *Zostera muelleri* subsp. *capricorni* with *Halodule uninervis* (wide)	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halodule uninervis* (wide)
76 & 77	15.93 ± 1.89	174.74 ± 12.83	Light *Zostera muelleri* subsp. *capricorni* with mixed species	Continuous cover	*Zostera muelleri* subsp. *capricorni, Halodule uninervis* (wide & narrow), *Halophila ovalis*
142	0.07 ± 0.01	3.74 ± 1.30	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
149	n.a.	0.45 ± 0.57	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
172	n.a.	0.11 ± 0.25	Light *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Zostera muelleri* subsp. *capricorni*
RODDS BAY REGION					
94	0.04 ± 0.01	1.02± 0.46	Light *Zostera muelleri* subsp. *capricorni* with *Halophila ovalis*	Isolated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
96	0.70 ± 0.29	304.87 ± 11.64	Light *Zostera muelleri* subsp. *capricorni* / *Halophila ovalis*	Aggregated patches	*Zostera muelleri* subsp. *capricorni, Halophila ovalis*
104	0.23 ± 0.18	5.20 ± 1.74	Light *Halophila ovalis* with *Zostera muelleri* subsp. *capricorni*	Isolated patches	*Halophila ovalis, Zostera muelleri* subsp. *capricorni*

n.a. less than three biomass sites present

Appendix 4. Detailed species composition, November 2002–2017




Meadow 43
Species Composition
No survey
Meadow 58
Species Composition
No survey
Not present
Meadow 48
Species Composition
No survey
Meadow 60
Species Composition
No survey
Meadow 52-57
Species Composition
Meadow 94
Species Composition
No survey
Not present
Not present
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Zostera muelleri subsp. *capricorni*
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide)
Halodule uninervis (narrow)


Meadow 96
Species Composition
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No survey
Not present
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Meadow 104
No survey
Not present
Zostera muelleri subsp. capricorni
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide)
Halodule uninervis (narrow)