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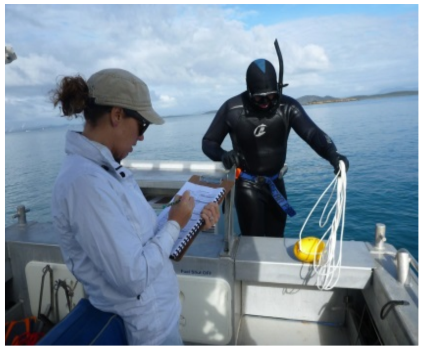


Seagrasses in Port Curtis and Rodds Bay 2015

Annual long-term monitoring

Davies JD, Bryant CV, Carter AB and Rasheed MA

Report No. 16/02

May 2016

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A Report for Gladstone Ports Corporation

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Davies JD, Bryant CV, Carter AB and Rasheed MA

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
Townsville
Phone : (07) 4781 4262
Email: TropWATER@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

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

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KEY FINDINGS

Seagrass Condition 2015

Poor

1. In November 2015 the overall condition of seagrasses in Port Curtis and Rodds Bay was poor.

2. Average meadow biomass remained below the long-term average in all but three monitoring meadows following significant declines in 2009/10. Biomass was the main reason meadows received poor scores.

3. Despite biomass declines meadow area increased in the majority of monitoring meadows, particularly in The Narrows and Western Basin zones. The total area of seagrass mapped from The Narrows to the Boyne River was the second highest total area since November 2009.

4. Low biomass condition likely resulted from a combination of sustained high temperatures during the 2014 growing season and exposure-related stress caused by high total daytime tidal exposure at the beginning of the 2015 growing season.

5. Other environmental conditions were generally favourable in the twelve months preceding the survey. Light levels were well above the established threshold for maintenance and growth of seagrass, suggesting that light was not a limiting factor during the 2015 growing season.

6. Extensive dugong feeding activity was recorded from The Narrows to South Trees Inlet and also in Rodds Bay.

7. Substantial declines in meadow condition from 2009/2010 and again in 2013 after some recovery in 2012 have likely reduced seagrass meadow resilience and influenced their capacity for recovery. While condition improved in several meadows in 2015, full recovery may take several years of favourable growing conditions.

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 (Figure 1). 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 (see Sections 2.5 and 3.6). This report presents results from the November 2015 monitoring survey.

The overall condition of seagrasses in Port Curtis and Rodds Bay was assessed as 'Poor' mostly due to low seagrass biomass. Average biomass declined at more than half of the monitoring meadows and remained below the long-term average. Following the large declines for most meadows in 2009/10 there had been some recovery recorded in 2012 but declines for most meadows were recorded again in 2013 (Figures 2 and 3). At many meadows there has also been a shift from the once dominant *Z. muelleri* subsp. *capricorni* to the colonising *Halophila* species. Biomass and/or species composition has generally deteriorated at monitoring meadows from the Inner Harbour to Rodds Bay since 2014 and overall meadow condition in these zones is currently poor to very poor (Figure 3).

Despite the declines in biomass and shifts in species composition, seagrass area has continued to increase with half of the monitoring meadows recording an increase in area in 2015. The total distribution of coastal seagrasses from The Narrows to the Boyne River increased by over 1000ha following reductions in 2013, and covered the greatest area since November 2009 (Figure 4). Many new or substantially expanded meadows were mapped in The Narrows and Grahams Creek zones. There were also increases in area at the intertidal/shallow subtidal *Halodule uninervis* meadow off Boyne Island and in the Inner and Mid Harbour zones where several small patches of *Z. muelleri* subsp. *capricorni* and *H. ovalis* emerged.

Seagrass condition was best in the Narrows and Western Basin zones where substantial increases in area were recorded and average biomass also generally increased or remained well above the long-term average. Some meadows in The Narrows and Western Basin (e.g. Meadow 8 and Meadow 21) have also experienced shifts to less persistent species; however the majority were classed as being in an overall condition of satisfactory or better (Figure 2).

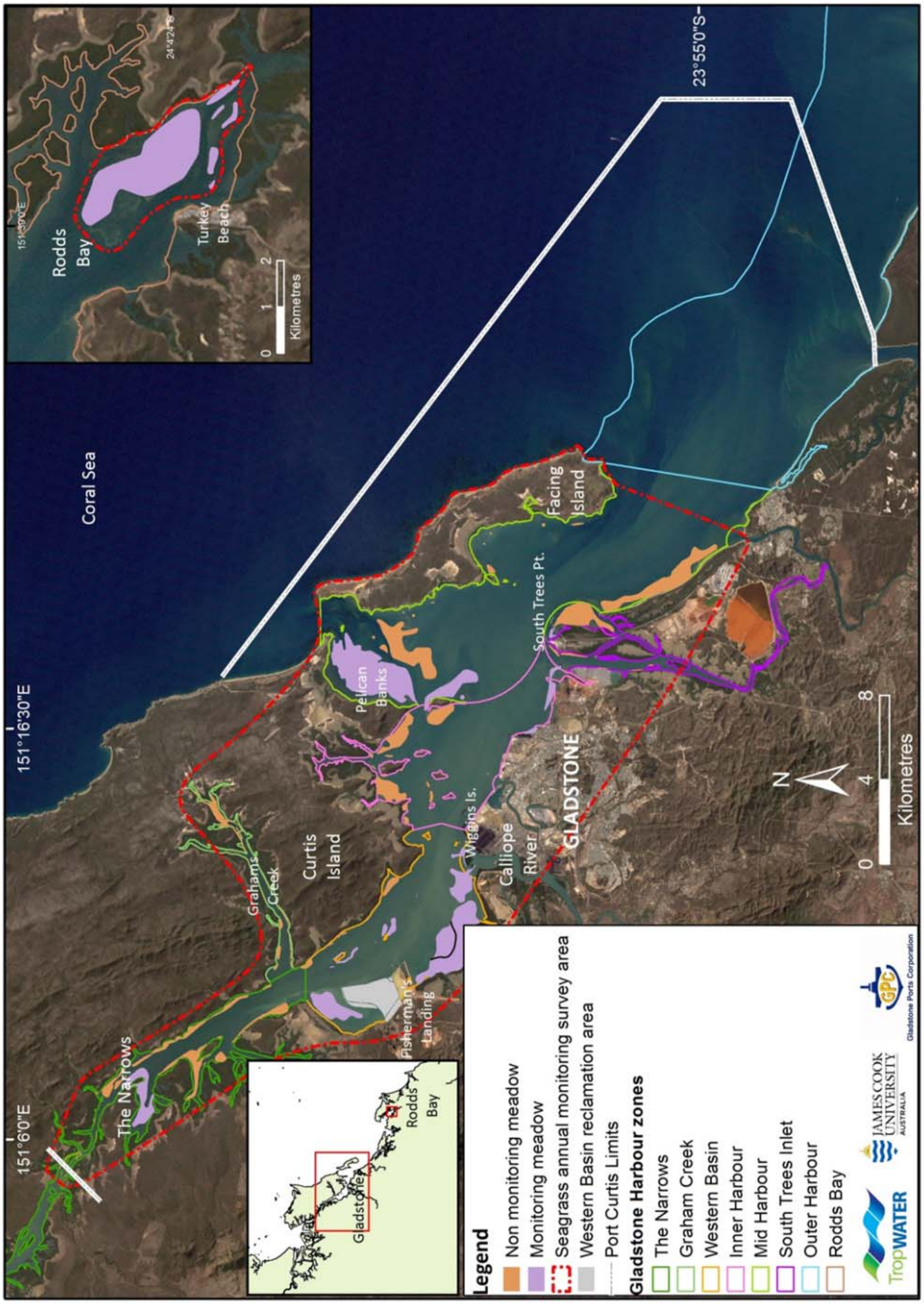

Figure 1. Seagrass distribution in Port Curtis and Rodds Bay, November 2015.

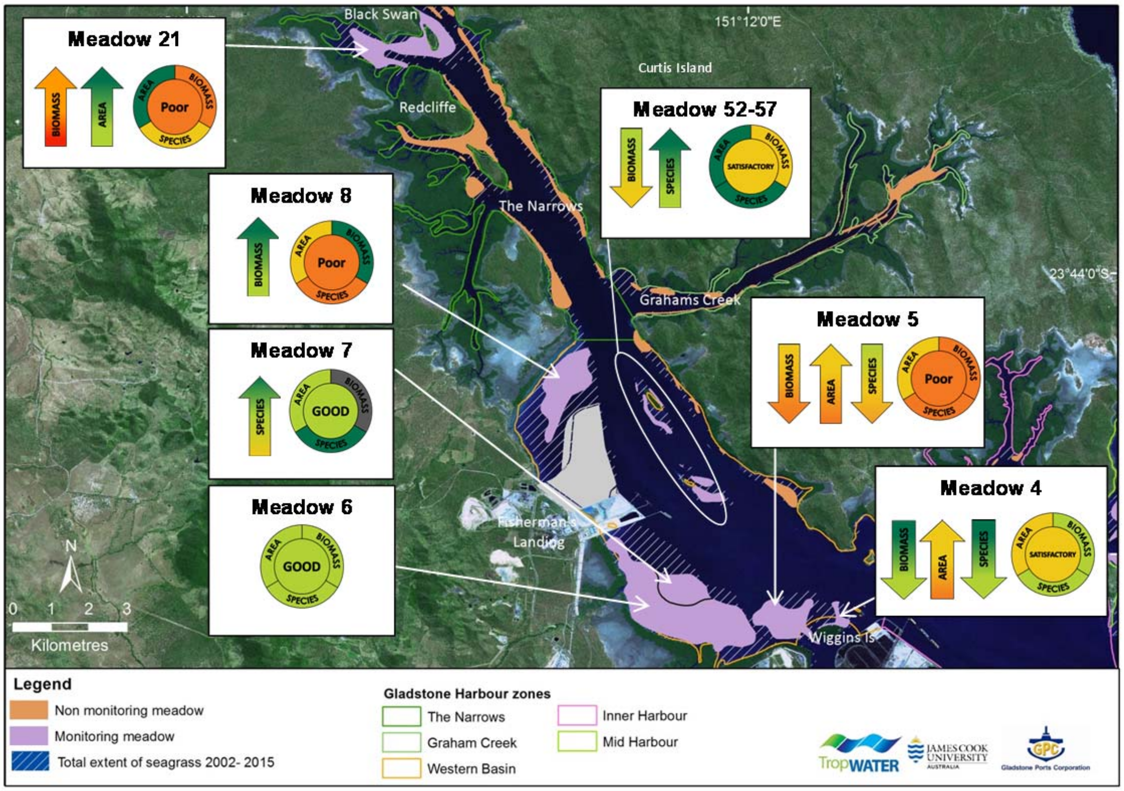

Figure 2. Seagrass distribution and meadow condition in The Narrows and Western Basin zones of Port Curtis, November 2015.

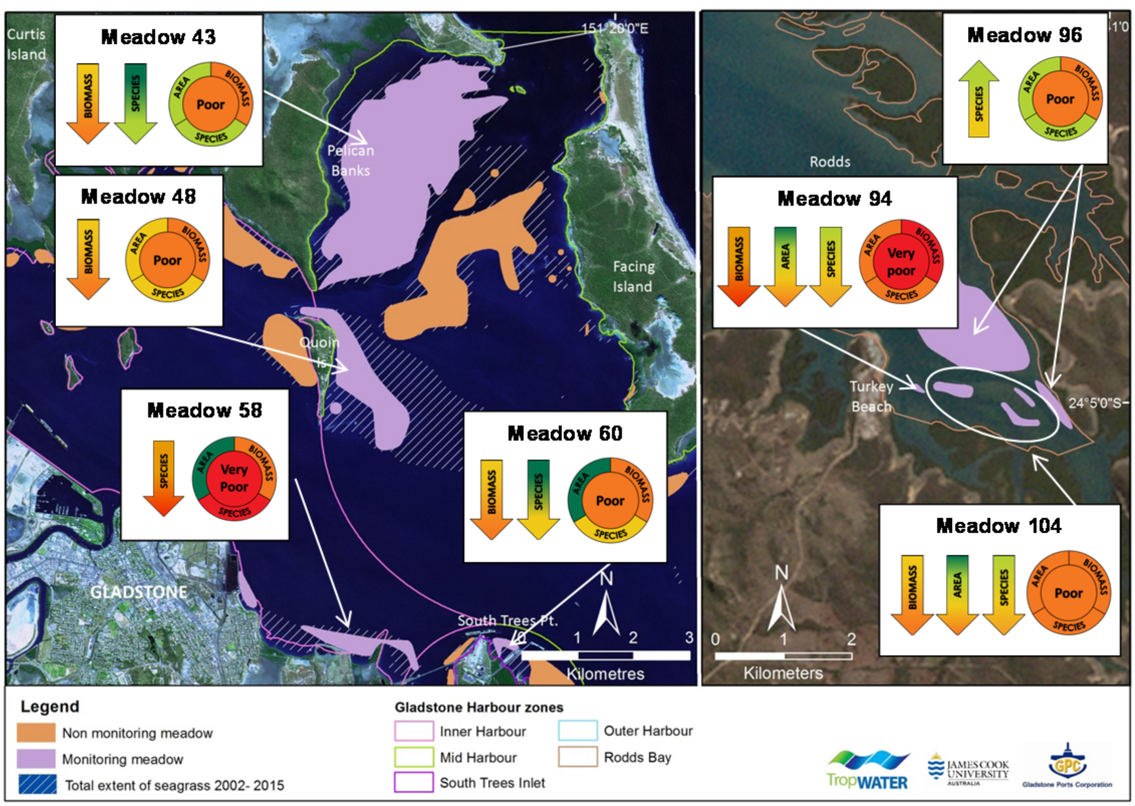

Figure 3. Seagrass distribution and meadow condition in the Inner Harbour, Mid Harbour and South Trees zones of Port Curtis, and at Rodds Bay, November 2015.

Environmental conditions were generally favourable for seagrass growth in 2015, with below average rainfall and relatively low river flow compared with recent years (Figure 5). Light remained well above the locally derived levels required for seagrass maintenance or growth and does not appear to be a limiting factor for seagrass recovery. This is evident by the increases in meadow area particularly in deeper sections of the meadows. The generally lower seagrass biomass in 2015 was likely the result of long periods of daytime tidal exposure and associated stresses occurring at the beginning of the growing season (Figure 5).

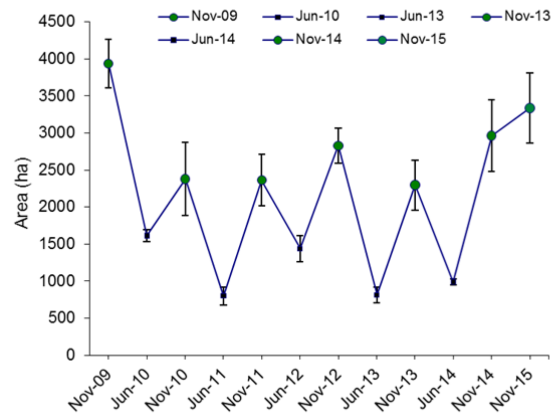

Figure 4. Seasonal changes in total seagrass meadow area in Port Curtis, excluding Rodds Bay, 2009 - 2015.

Although we detected an improvement in meadow condition at some meadows in 2015, declines from 2009/2010 and again in 2013 (after some recovery in 2012) have likely left seagrass meadows with a reduced level of resilience. These declines mean full recovery of seagrass meadows may take several years of favourable growing conditions. Port Curtis and Rodds Bay seagrass monitoring forms part of James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) seagrass assessment and research program that examines seagrass condition in the majority of Queensland commercial ports. Seagrasses at other locations along the east coast of Queensland were similarly impacted by a number of climate events between 2010 and 2013, including flooding and cyclones. The trajectory for recovery since then has varied; the condition of some meadows has improved substantially but in many locations remains poor. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

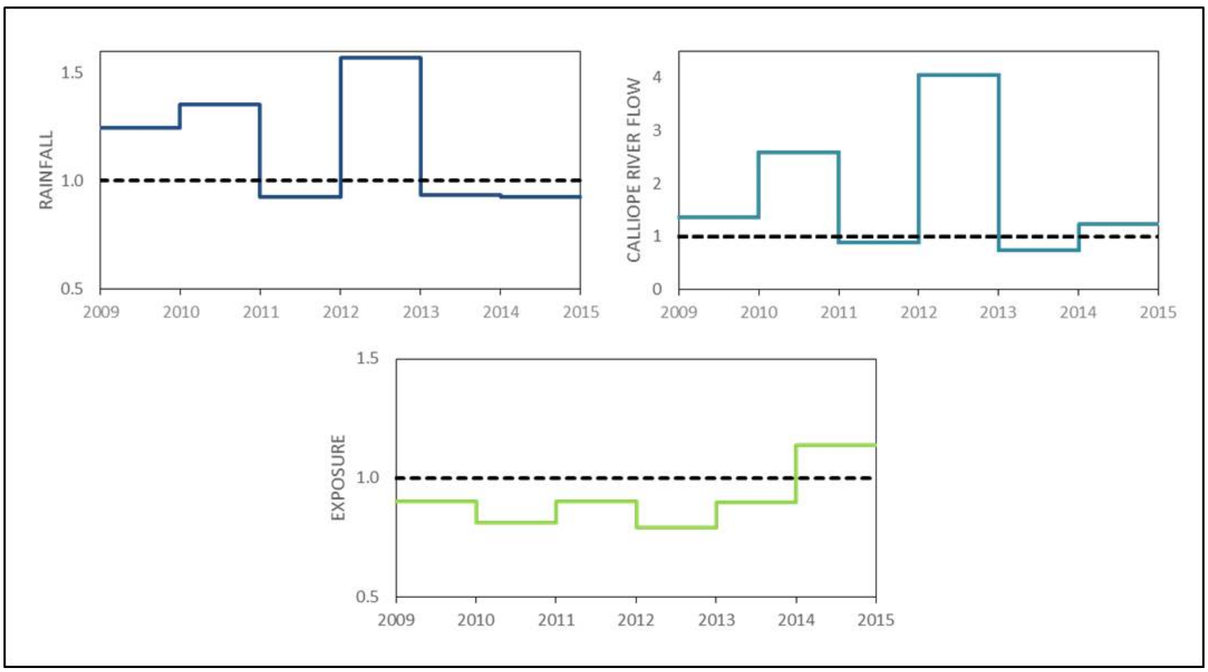

Figure 5. Recent climate trends in Gladstone. Annual average (solid coloured line) compared to the long term average scaled to 1.0 (dashed line). See Section 3.7 for detailed climate data.

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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 show that the harbour contains diverse and productive seagrass meadows and macro-benthic fauna (McKenna et al. 2014; Rasheed et al. 2003; Lee Long et al. 1992). Seagrasses in the Gladstone region are of particular value as a food source to dugong, recognised by the declaration of the Rodds Bay Dugong Protection Area (DPA). 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 DEEDI to conduct a fine-scale baseline survey of seagrass resources from The Narrows to 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 include intertidal and subtidal seagrass meadows, meadows preferred by dugong, and those likely to support high fisheries productivity. Three meadows in Rodds Bay (outside port limits) were also selected as reference sites for monitoring. 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 reclamation area at 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 is most likely a response to regional and local climatic 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. 2012b). The peak of the growing season occurs between October - 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:

1. Re-mapping of all seagrass meadows within Port Curtis and Rodds Bay in 2009, 2013 and 2014 (Carter et al. 2015; Bryant et al. 2014c; Thomas et al. 2010);
2. Establishment of a network of sensitive receptor seagrass sites where information on seagrass change is collected at least quarterly (and monthly during dredging) and linked to water quality monitoring and assessments of seagrass resilience (Bryant et al. In prep; Davies et al. 2015a; Bryant et al. 2014a; McCormack et al. 2013);
3. 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. 2012b; Bostrom et al. 2006).
4. Biannual (2009 – 2014) and annual (2015 – 2017) mapping and assessment of all seagrasses within the seagrass annual monitoring survey area reported here and previously (Carter et al. 2015; 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 1). 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 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 region from The Narrows to Rodds Bay 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 ± 547 ha of coastal seagrass including intertidal and shallow subtidal areas from The Narrows to Rodds Bay as well as deepwater areas (>6 m) within Port Curtis and the Rodds Bay DPA 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. 2015). 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 (Carter et al. 2015).

Results from the 2015 annual seagrass survey are discussed in relation to light and temperature data recorded in the seagrass meadows as part of the sensitive receptor seagrass transect monitoring program established for the WWBDP. These are discussed in more detail in the report for that monitoring program (Bryant et al. In prep).

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 (see Unsworth et al. 2012; Rasheed and Unsworth 2011; Taylor and Rasheed 2011; Lee Long et al. 1996). 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 23rd – 28th November 2015. The survey involved mapping and assessing:

- All intertidal and shallow subtidal seagrasses within the seagrass annual monitoring survey area of Port Curtis and Rodds Bay;
- Established PCIMP 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 and 2013) and PCIMP 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.

Three sampling techniques were used (Figure 7):

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

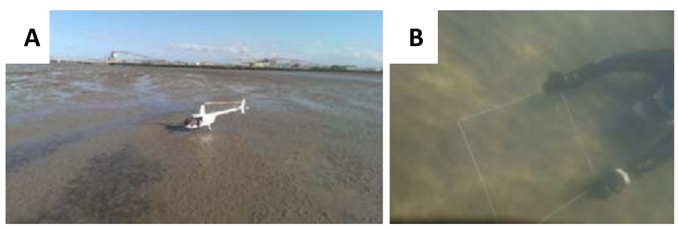


Figure 7. Seagrass monitoring methods. (A) helicopter aerial surveillance and (B) boat based free divers.

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}).

2.2 Habitat mapping and Geographic Information System

Spatial data from the 2015 survey were entered into the Port Curtis Geographic Information System (GIS). 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.

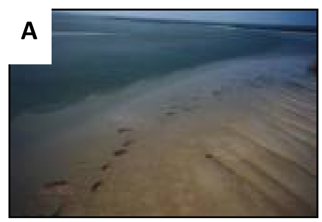
Community type	Species composition
Species A	Species A is >90-100% of composition
Species A with Species B (2 species present) Species A with mixed species (>2 species)	Species A is >60-90% of composition
Species A/Species B	Species A is 40-60% of composition

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 (g DW m^{-2})				
	H. uninervis **(thin)**	***H. ovalis H. decipiens***	***H. uninervis*** **(wide)**	***H. spinulosa***	***Z. muelleri*** **subsp.** ***capricorni***
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

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 ±750 m for offshore deepwater 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 unvegetated sediment interspersed with isolated patches of seagrass



Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated 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 unvegetated sediment

Figure 8. Seagrass meadow landscape categories: (A) Isolated seagrass patches, (B) Aggregated seagrass patches, (C) Continuous seagrass cover.

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

Light and water temperature data was collected by Vision Environment Queensland throughout Gladstone Harbour as part of the Western Basin water quality monitoring program until December 2013. Light and water temperature data for 2014 – 2015 was collected as part of seagrass monitoring at the sensitive receptor sites (Bryant et al. In prep).

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) 2015, 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 Gladstone seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline, and expanded on the previous index that was applied in the 2014 Gladstone report (Carter et al. 2015; Davies et al. 2015b). Seagrass condition for each indicator 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) by comparing the current condition against the baseline conditions (Figure 9).

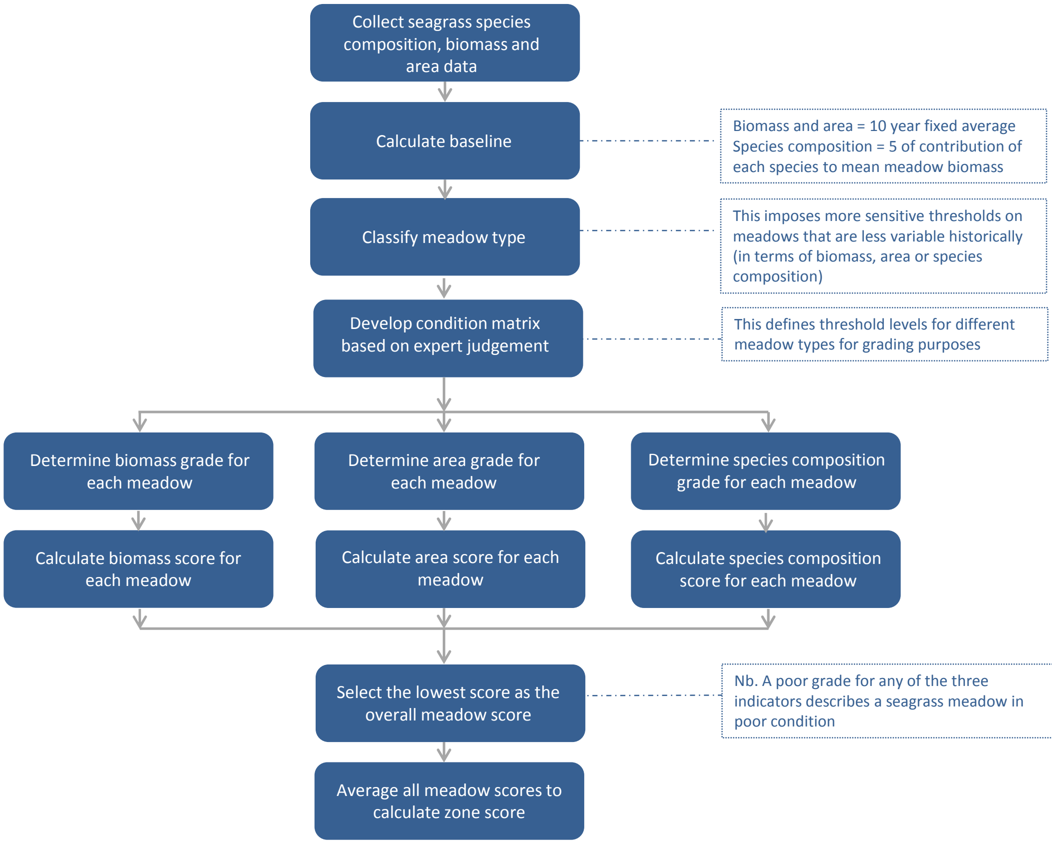


Figure 9. Flow chart used to determine monitoring meadow condition.

2.4.1 Baseline Conditions

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2002, 2004-2012). This baseline was set based on results of the 2014 pilot report card (Bryant et al. 2014). The first ten years of monitoring were used as a baseline as this period incorporated a range of environmental conditions present in Port Curtis, including El Niño (e.g. 2002-2003) and La Niña (e.g. 2010-2012) periods (http://www.bom.gov.au/climate/enso/index.shtml), multiple extreme rainfall and river flow events, large scale capital dredging (WBDDP) and annual maintenance dredging. In some cases less than 10 years of data were available, e.g. meadows 21 and 52-57 which have only been surveyed since 2009, or species composition data were unavailable for years where no seagrass was present. In this instance the baseline was calculated over the longest available time period excluding the year of interest (i.e. 2015). Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to the mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species composition), 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 Section 2.4.4 and Figure 10 for further description). As with biomass and area, the species composition baseline was calculated from a fixed 10 year mean (2002, 2004-2012).

2.4.2 Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass, area and species composition was classified as either stable or variable (Table 4). Two further classifications for meadow area were used: highly stable and highly variable, in recognition that some meadows are very stable while others have a naturally extreme level of variation (Table 4). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each of condition indicator. Classifications were then used to define which set of threshold levels were appropriate to apply around the monitoring meadow for biomass, area and species composition baseline.

Table 4. 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%	-

2.4.3 Threshold Levels for Grading Indicators

Seagrass condition for each indicator was assigned one of five grades (very good, good, satisfactory, poor, very poor). Threshold levels for each grade were set relative to the baseline and were selected 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 5).

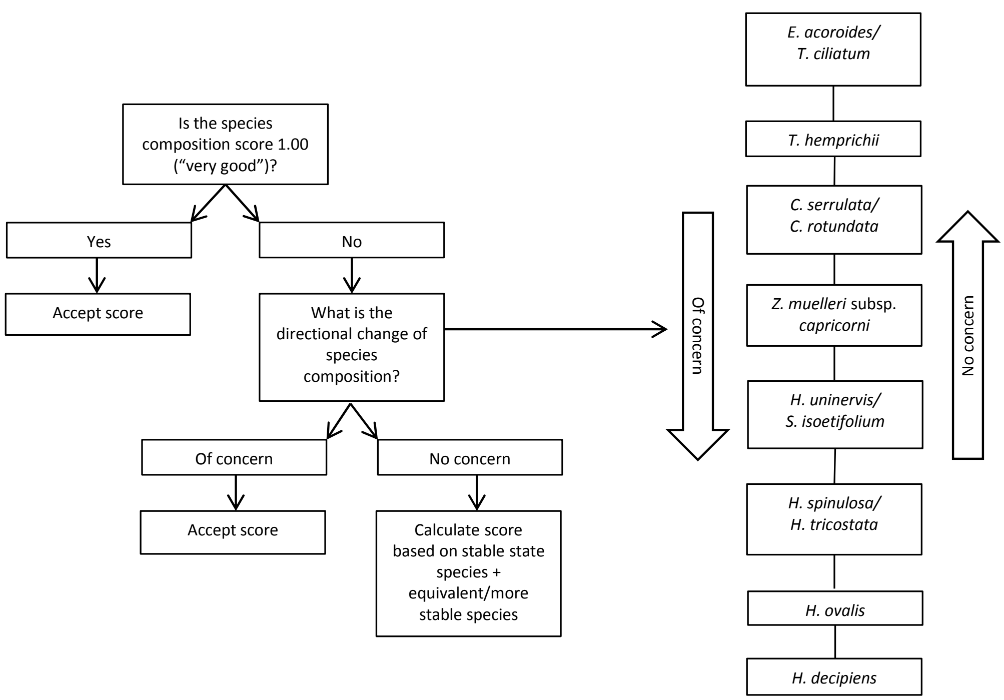


Figure 10. Decision tree and directional change assessment for grading and scoring seagrass species composition.

Table 5. 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%	>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		

2.4.4 Grades and Scores

A score system (0-1) was developed for each grade to enable comparisons of seagrass condition among meadows within a port, and among all the ports monitored by TropWATER (Table 6; see Carter et al. 2016 for a detailed description).

Calculating the score for each condition indicator required determining the 2015 grade for each indicator, then scaling the 2015 value for biomass, area or species composition against the prescribed score range for that grade. Scaling was required because the score range in each grade was not equal (Table 6). This involved several steps. An example of calculating a meadow score for biomass in good condition is provided in Appendix 1.

Table 6. The score range for each grade used for TropWATER seagrass report cards.

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

Each overall meadow grade and score was determined by the lowest grade and score of the three condition indicators (biomass, area, species composition) within that meadow. The lowest score, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these three fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method enables the most conservative estimate of meadow condition to be made (Bryant et al. 2014b).

Where species composition was determined to be anything less than in "perfect" condition (i.e. a score of 1.00), a decision tree was used to determine whether equivalent and/or more persistent species (based on Kilminster et al. 2015) were driving this grade/score (Figure 10). 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 10). This would occur when the stable state species is replaced by species considered to be earlier colonisers (Kilminster et al. 2015). Such a shift indicates a decline in meadow stability (e.g. a shift from *H. uninervis* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species).

3 RESULTS

3.1 Seagrasses in Port Curtis and Rodds Bay

At total of 1,748 sites were surveyed in the Port Curtis and Rodds Bay seagrass annual monitoring survey area in November 2015 (Figure 11).

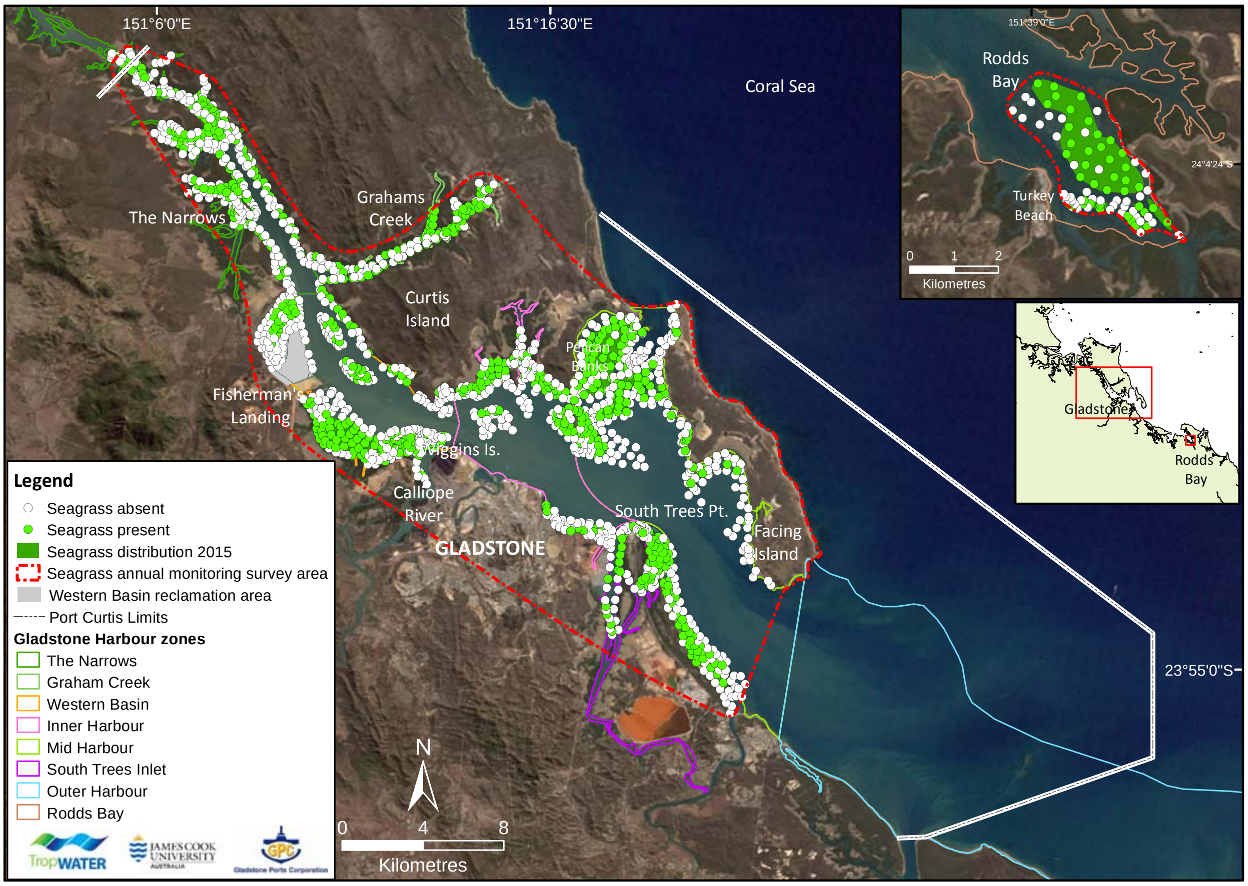


Figure 11. Sites surveyed in Port Curtis and Rodds Bay, November 2015.

Dugong feeding trails (DFTs) have historically been recorded throughout The Narrows (Meadow 23; Figure 14), Fisherman's Landing (Meadow 6; Figure 17), Wiggins Island (Meadows 4 and 5; Figure 17), Pelican Banks (Meadow 43; Figure 26), Facing Island (Meadow 66; Figure 26) South Trees (Meadow 60 and 76; Figure 29) and Rodds Bay (Meadow 119; Figure 31). In November 2015, DFTs were observed in Rodds Bay on the large *Z. muelleri* subsp. *capricorni* meadow*,* at South Trees, South Fisherman's Landing, the Passage Islands, and throughout the Mid Harbour and Narrows zones (Figure 12). The greatest density of feeding trails were observed across a large portion of the exposed bank at the Wiggins Island monitoring meadow (Meadow 5) and multiple dugongs were sighted while conducting boat work off nearby South Fisherman's Landing (over the subtidal Meadow 7).

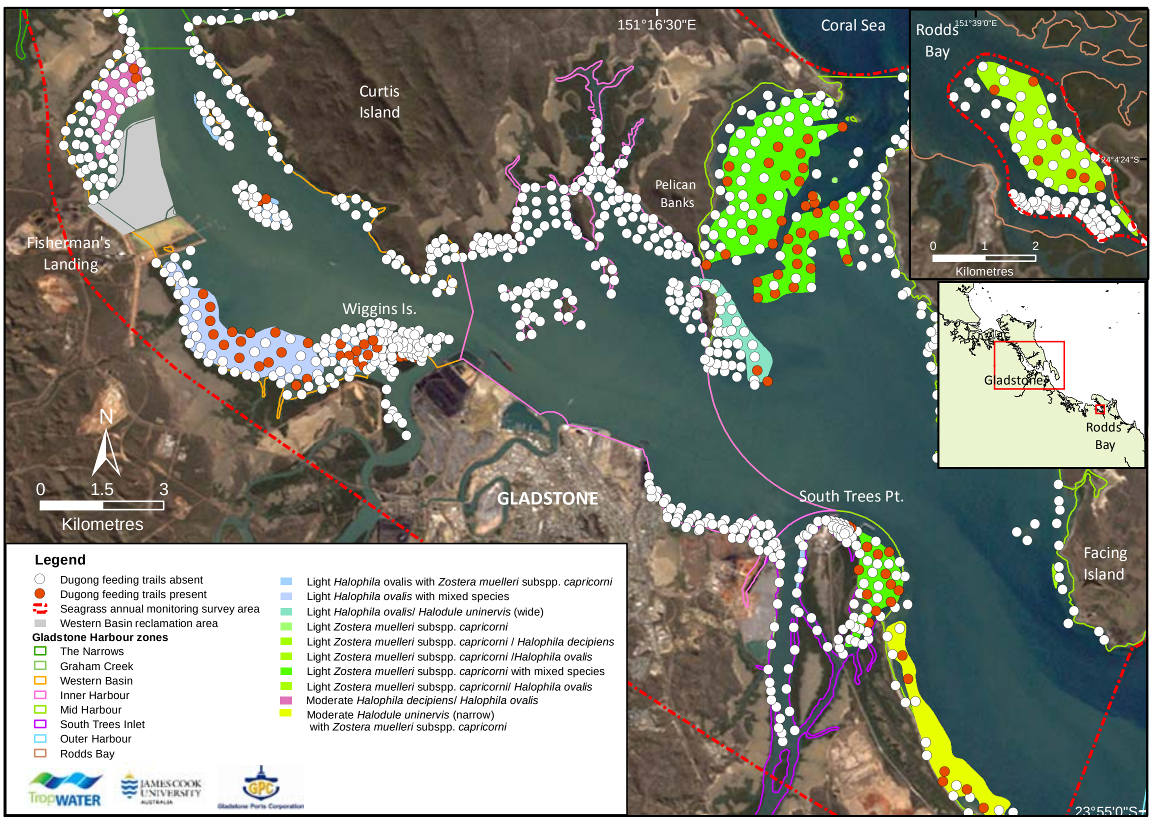


Figure 12. Helicopter sites with dugong feeding trails (DFTs) surveyed in Port Curtis and Rodds Bay, November 2015. DFTs not pictured include The Narrows zone.

Five seagrass species (from three families) were observed during the survey (Figure 13). 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).

Family HYDROCHARITACEAE Jussieu:
Halophila decipiens
Halophila ovalis
Halophila spinulosa

Family ZOSTERACEAE Drummortier:
Zostera muelleri subsp. *capricorni*

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

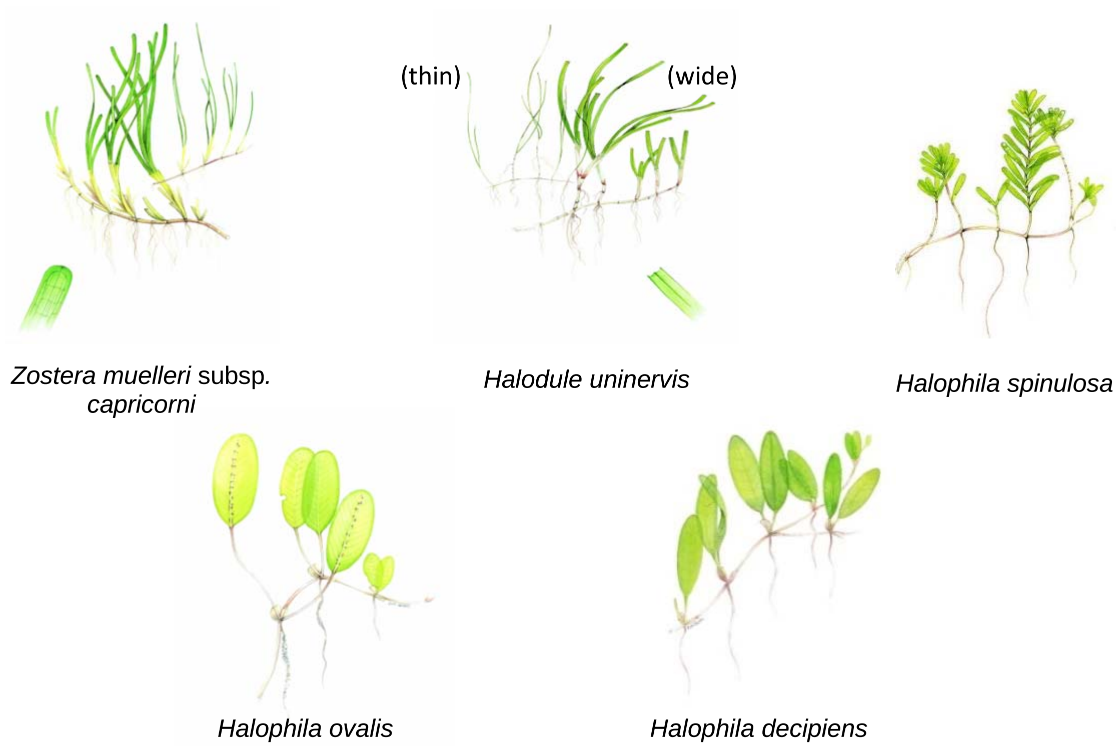


Figure 13. Seagrass species present in Port Curtis and Rodds Bay, November 2015.

Coastal seagrasses

3.1.1 The Narrows

Seagrasses in The Narrows zone formed 12 individual meadows and covered an area of approximately 530 ± 78 ha. The area of individual meadows ranged from small isolated patches (<0.01 ha) to larger expanses of seagrass (~153 ha) on the exposed banks on the mainland side of the estuary (Meadows 21 and 23; Figure 14 and Appendix 2). *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens* were present in the zone. Average biomass ranged from 0.09 ± 0.04 gDW m^{-2} for a small subtidal *H. decipiens* meadow (Meadow 25; Figure 14 and Appendix 2) to 2.60 ± 1.31 gDW m^{-2} for a dense isolated patch of Z. *muelleri* subsp. *capricorni* (Meadow 25; Figure 14 and Appendix 2). The majority of meadows were comprised of aggregated patches or continuous cover of seagrass and all meadows were classified as light in cover. Intertidal seagrasses on the mainland side of the estuary were dominated by *Z. muelleri* subsp. *capricorni*, while those on the Curtis Island side were dominated by *H. ovalis* (Figure 14 and Appendix 2). *H. decipiens* was mainly present in the subtidal portions of meadows on both sides of the estuary.

Long Term Monitoring Meadows

At the monitoring meadow at Black Swan (Meadow 21; Figure 15) average biomass and area both increased in 2015, raising the condition index from very poor to poor for biomass; and from good to very good for area. Species composition continued to shift from *Z. muelleri* subsp. *capricorni* dominated communities with gradual increases in the proportion of less persistent *Halophila* species (Appendix 3). Species composition was classified as being in a satisfactory condition, accounting for the variability in the historical data. Although some gains were made towards recovery at Meadow 21, biomass remains well below the long term average and the overall condition of the meadow was classified as poor (Table 7). The baselines used to calculate index classifications will be reviewed when ten years of data are available for this meadow.

Table 7. Grades and scores for seagrass indicators (biomass, area and species composition) for Port Curtis and Rodds Bay seagrass monitoring meadows.

Monitoring meadow	Biomass score	Area score	Species composition score	Overall meadow score
4	0.83	0.52	0.78	0.52
5	0.49	0.58	0.34	0.34
6	0.68	0.82	0.67	0.67
7	CR*	0.78	1.00	0.78
8	0.88	0.51	0.38	0.38
21	0.33	0.87	0.57	0.33
43	0.25	0.78	0.68	0.25
48	0.46	0.54	0.51	0.46
52-57**	0.60***	0.96	1.00	0.60
58	0.42	0.92	0.14	0.14
60	0.48	0.88	0.59	0.48
94	0.08	0.28	0.36	0.08
96	0.40	0.76	0.66	0.40
104	0.28	0.28	0.46	0.28
Overall score for Gladstone seagrass monitoring meadows				0.41

* CR = calculation restriction - a biomass score could not be calculated for 2015 due to small sample size.
**Meadow 52-57 consists of a number of small meadows surrounding the Passage Islands in the Western Basin Zone (see Figure 1). These meadows are grouped for reporting purposes.
***Cells with white diagonal lines indicate meadows where <10 years of data were available to calculate baseline values. Results for these meadows should be interpreted with caution until long-term data are available.

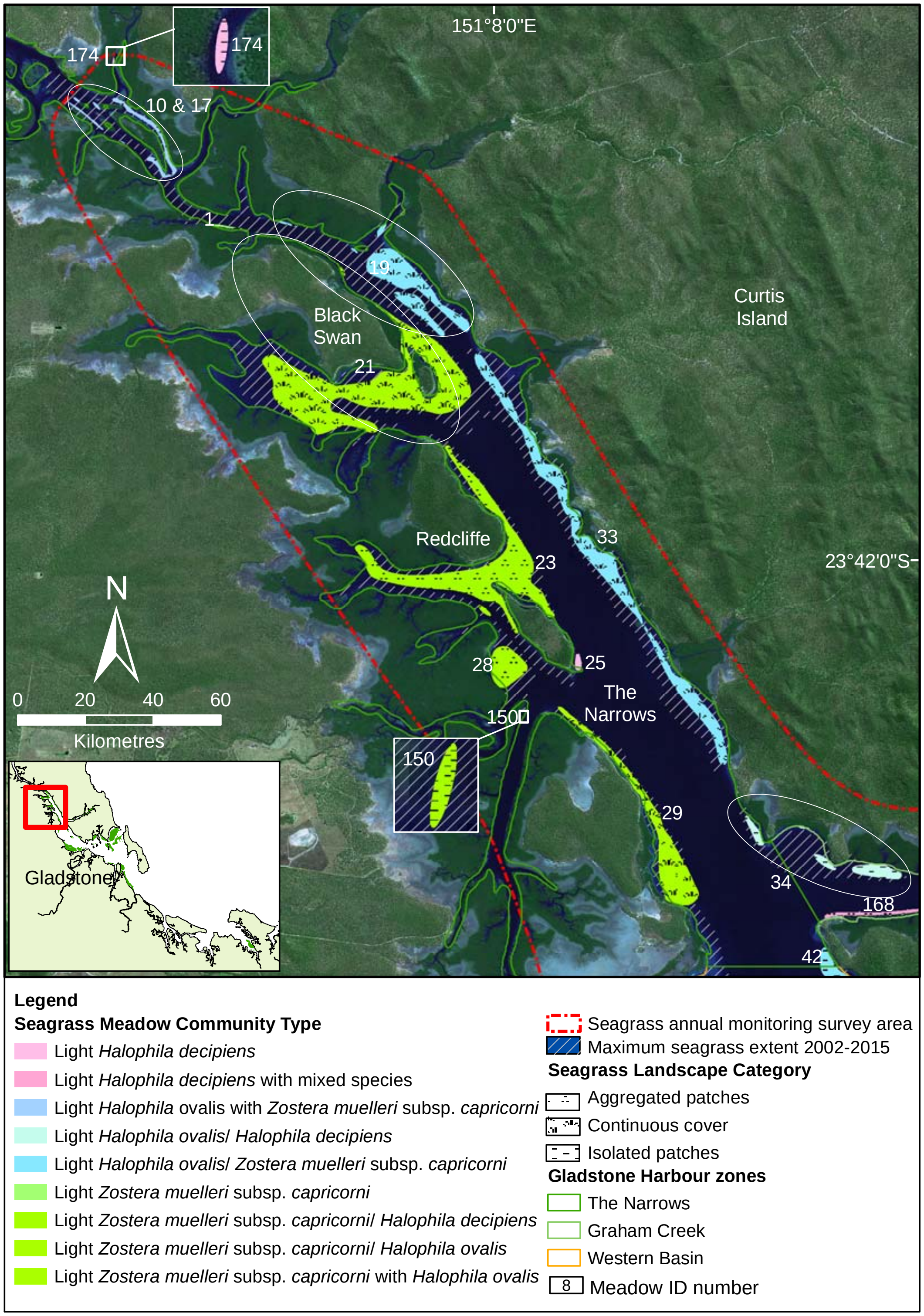


Figure 14. Seagrass distribution and community types in The Narrows, November 2015.

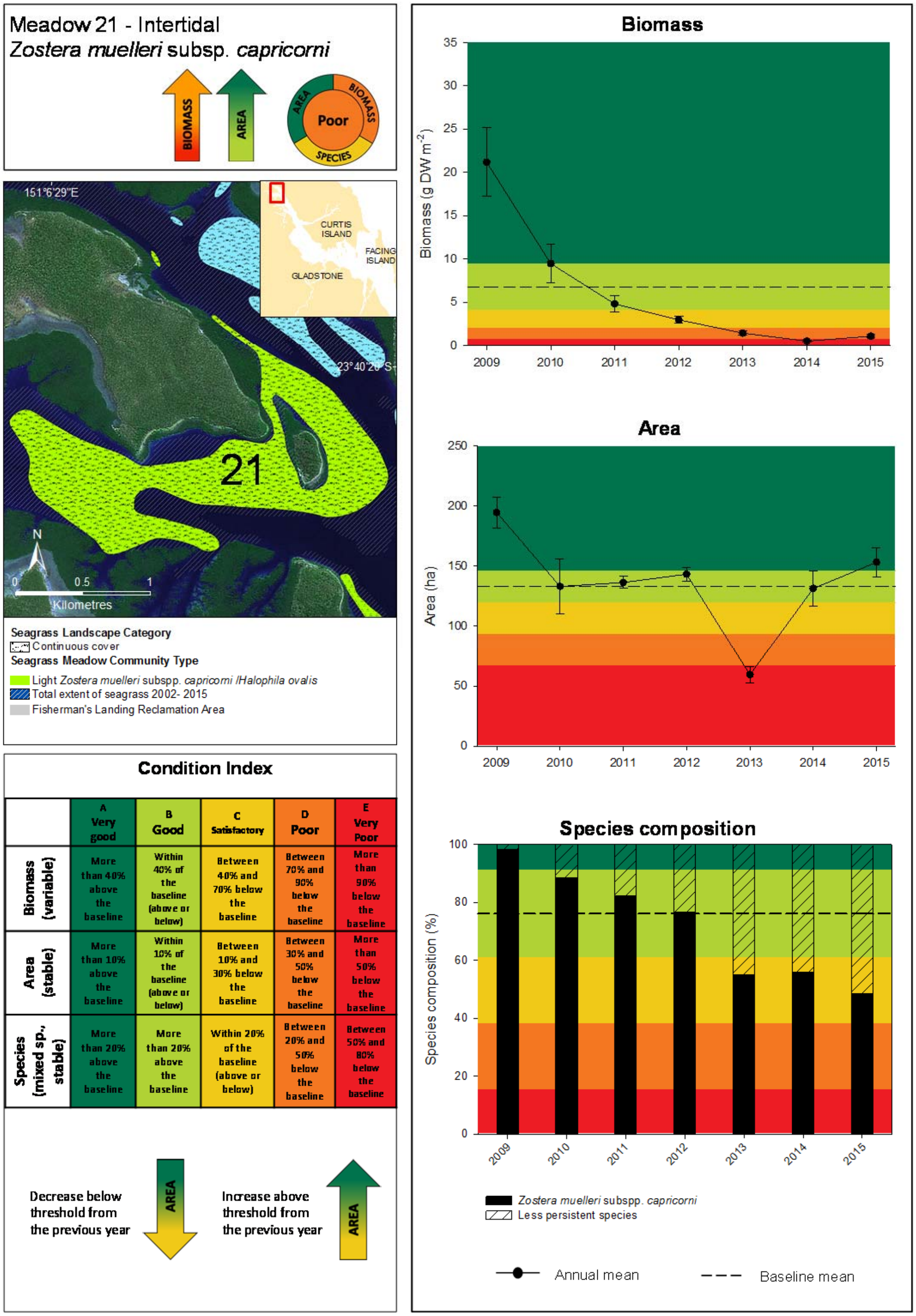


Figure 15. Changes in meadow area, biomass and species composition for seagrass at Meadow 21, Black Swan (The Narrows zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.1.2 Grahams Creek (Upper and Lower)

Seagrasses in the Grahams Creek (Upper and Lower) zone formed 9 individual meadows and covered an area of approximately 114 ± 50 ha. The area of individual meadows ranged from small isolated patches (~0.9 ha) of light Z. *muelleri* subsp. *capricorni* to the meadow at the top of the creek (68 ha) which stretches from one side of the creek to the other (Meadows 141 and 37 & 41; Figure 16 and Appendix 2). *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens* were present in the zone. Average biomass ranged from 0.34 ± 0.15 gDW m^{-2} for an intertidal *Z. muelleri* subsp. *capricorni* meadow up one of the arms of the creek (Meadow 170; Figure 16 and Appendix 2) to 0.88 ± 0.38 gDW m^{-2} for a dense isolated patch of *H. ovalis* and *H. decipiens* at the opening of Grahams Creek to The Narrows (Meadow 34; Figure 16 and Appendix 2). The majority of meadows were comprised of isolated patches of seagrass and all meadows were classified as light in cover. Intertidal meadows were dominated by *Z. muelleri* subsp. *capricorni*, while those towards the middle of the creek were dominated by *H. ovalis* (Figure 16 and Appendix 2). *H. decipiens* was present in all but one meadow, and was dominant in the intertidal meadow at the opening of the creek to The Narrows (Meadow 168, Figure 16 and Appendix 2). Grahams Creek has no long term monitoring meadows.

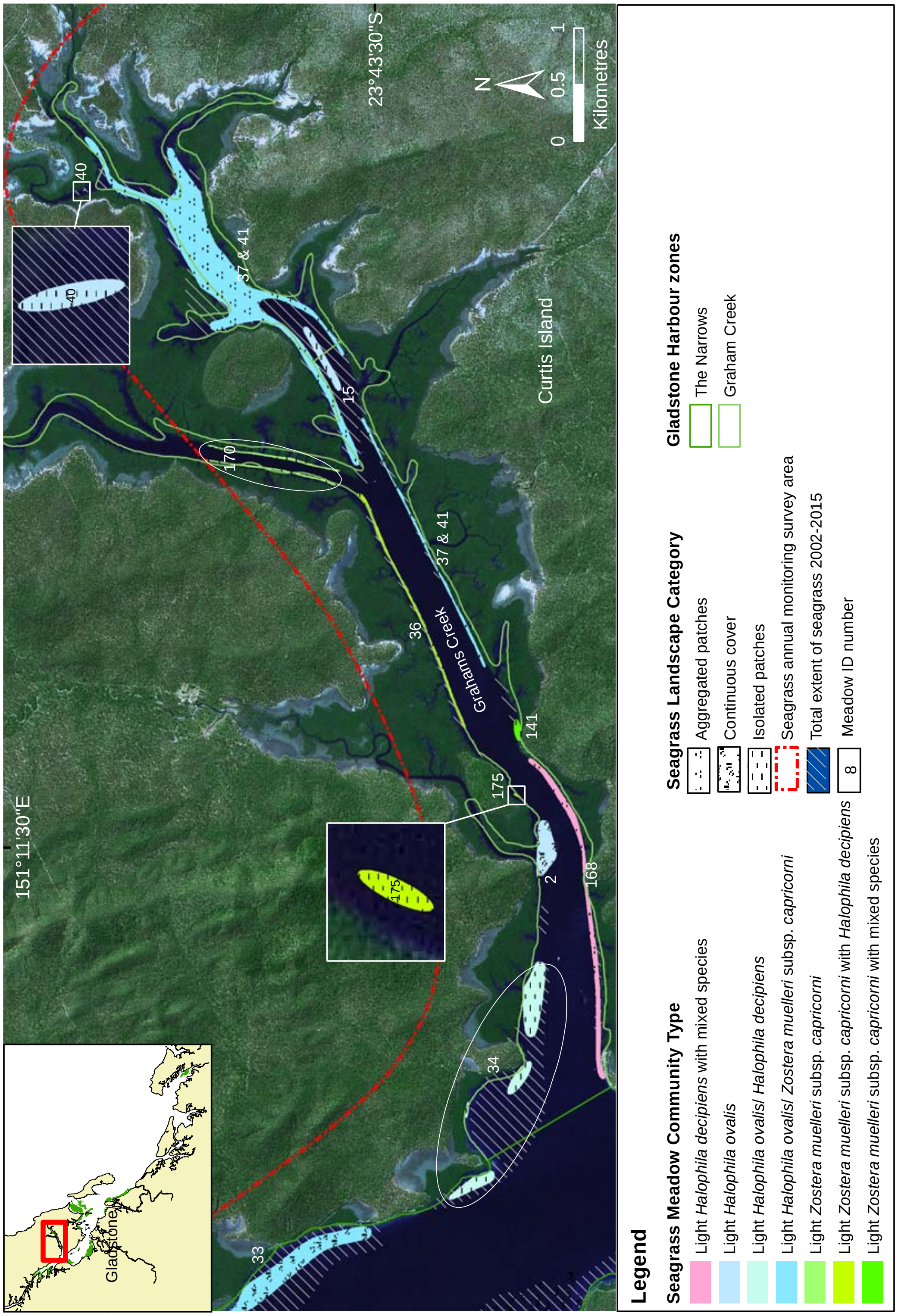


Figure 16. Seagrass distribution and community types in Grahams Creek zone, November 2015.

3.1.3 Western Basin

Seagrasses in the Western Basin zone formed 12 individual meadows and covered an area of approximately 853 ± 79 ha. The area of individual meadows ranged from small isolated patches (~0.3 ha) to the East of Wiggins Island to the substantial South Fisherman's meadow (~397 ha) (Meadows 11 and 6; Figure 17 and Appendix 2). *Z. muelleri* subsp. *capricorni*, *H. ovalis* and *H. decipiens* were present in the zone. Average biomass ranged from 0.27 ± 0.22 gDW m^{-2} for the cluster of meadows surrounding the Passage Islands in the middle of the zone (Meadow 52- 57; Figure 17 and Appendix 2) to 2.19 ± 0.34 gDW m^{-2} for the only meadow in the zone with a moderate cover of *H. decipiens* (Meadow 8; Figure 17 and Appendix 2). The majority of meadows were comprised of isolated or aggregated patches of seagrass and were classified as light in cover. Most meadows were dominated by *H. ovalis*, with only two meadows each dominated by *Z. muelleri* subsp. *capricorni* or *H. decipiens* (Figure 17 and Appendix 2).

Long Term Monitoring Meadows

Average biomass and species composition at the intertidal Wiggins Island Meadow were in good condition, with biomass well above the long-term average (Meadow 4; Figure 18 and Appendix 2-3). Meadow area had increased for the second consecutive year. Despite this increase area remains below the long-term average and the meadow was classed as satisfactory.

The adjacent meadow (Meadow 5; Figure 19 and Appendix 2) was classified as being in poor condition as biomass had yet to recover from the declines recorded in 2009 and species composition had shifted from the dominant species (*Z. muelleri* subsp. *capricorni*) to less persistent species. Despite poor biomass and species composition, the area of this meadow had expanded in 2015 with the area score improving from poor to satisfactory. (Appendix 3).

The large intertidal *Z. muelleri* subsp. *capricorni* meadow nearby remained in similar condition to November 2014 following steady improvements since declines in 2010, and was classed as being in a good condition for all three indicators (Meadow 6; Figure 20 and Appendix 2). The aerial survey found a large portion of the intertidal bank covered in dugong feeding trails. The adjacent subtidal *Halophila decipiens* meadow was completely absent from 2010 – 2011 following declines in biomass and area since 2007 and 2006, respectively (Meadow 7; Figure 21 and Appendix 2)). This meadow has continued to expand since returning in 2012, and was assessed as being in very good condition for both biomass and species composition indicators (Appendix 3). During the November 2015 survey, several dugongs were sighted over both of these meadows.

North of the Fisherman's Landing Reclamation Area (FLRA), seagrass biomass had increased and observers noted dense patches of *Halophila* spp. spanning the intertidal bank (Meadow 8; Figure 22 and Appendix 2). This meadow was dominated by *Z. muelleri* subsp. *capricorni* up until 2010 when meadow area sharply declined, and the proportion of *Z. muelleri* subsp. *capricorni* has remained at a lower level since 2011 resulting in the species composition for this meadow being classified as poor (Appendix 3). In 2015 *H. decipiens* became the dominant species for the first time since monitoring began.

The *Halophila ovalis* monitoring meadow in the Passage Islands adjacent to the FLRA has been monitored since 2009 (Meadow 52-57; Figure 23 and Appendix 2). This meadow consists of several small areas of aggregated patches surrounding the islands. In 2010 this meadow was reduced to just two sites with seagrass, but meadow biomass and area have generally been in either a good or very good condition since 2012. As with many meadows in 2015, a decline in biomass from good to satisfactory drove the overall meadow score of satisfactory. The baselines used to calculate index classifications for this meadow will be reviewed when ten years of data are available.

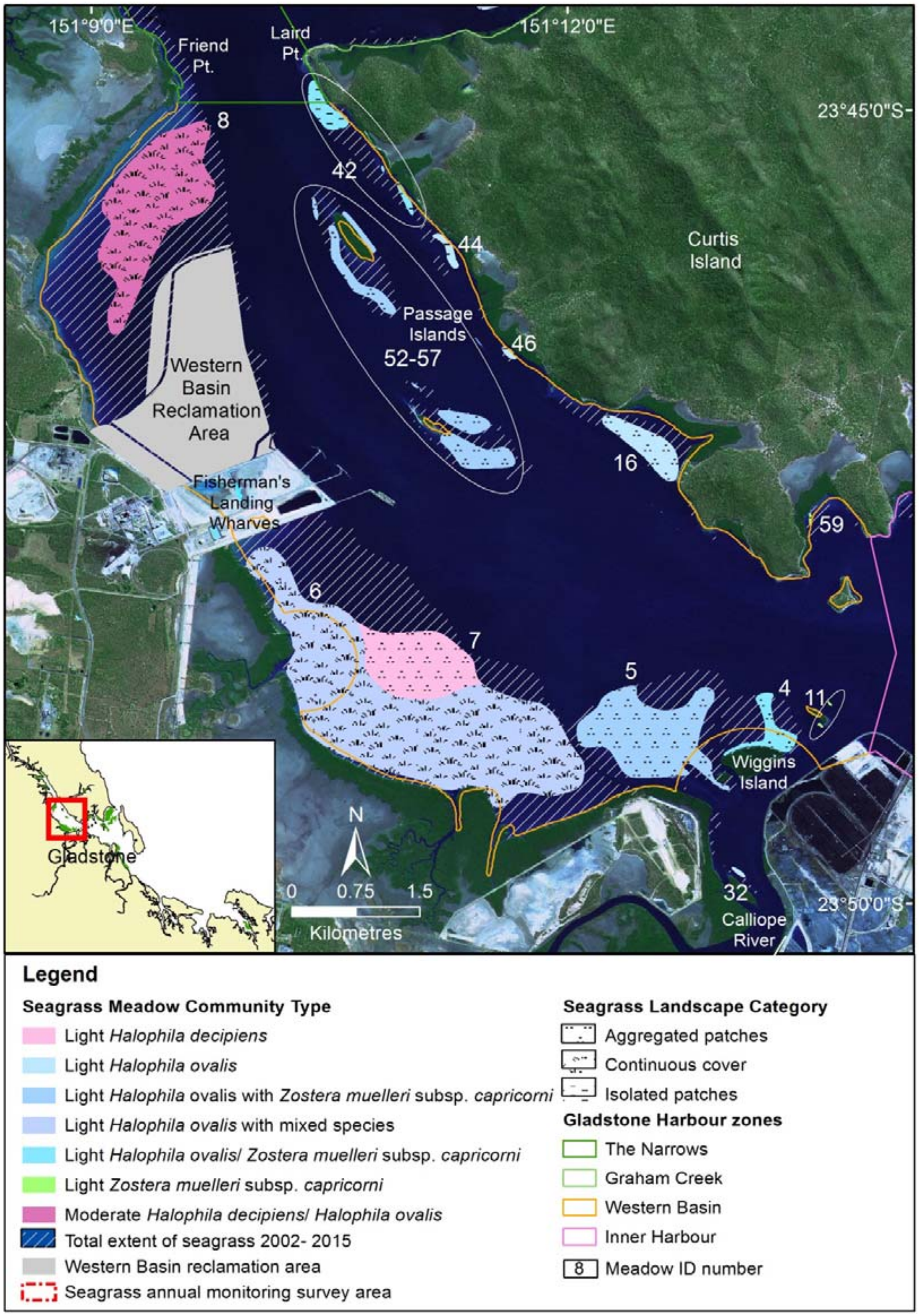


Figure 17. Seagrass distribution and community types in the Western Basin zone, November 2015.

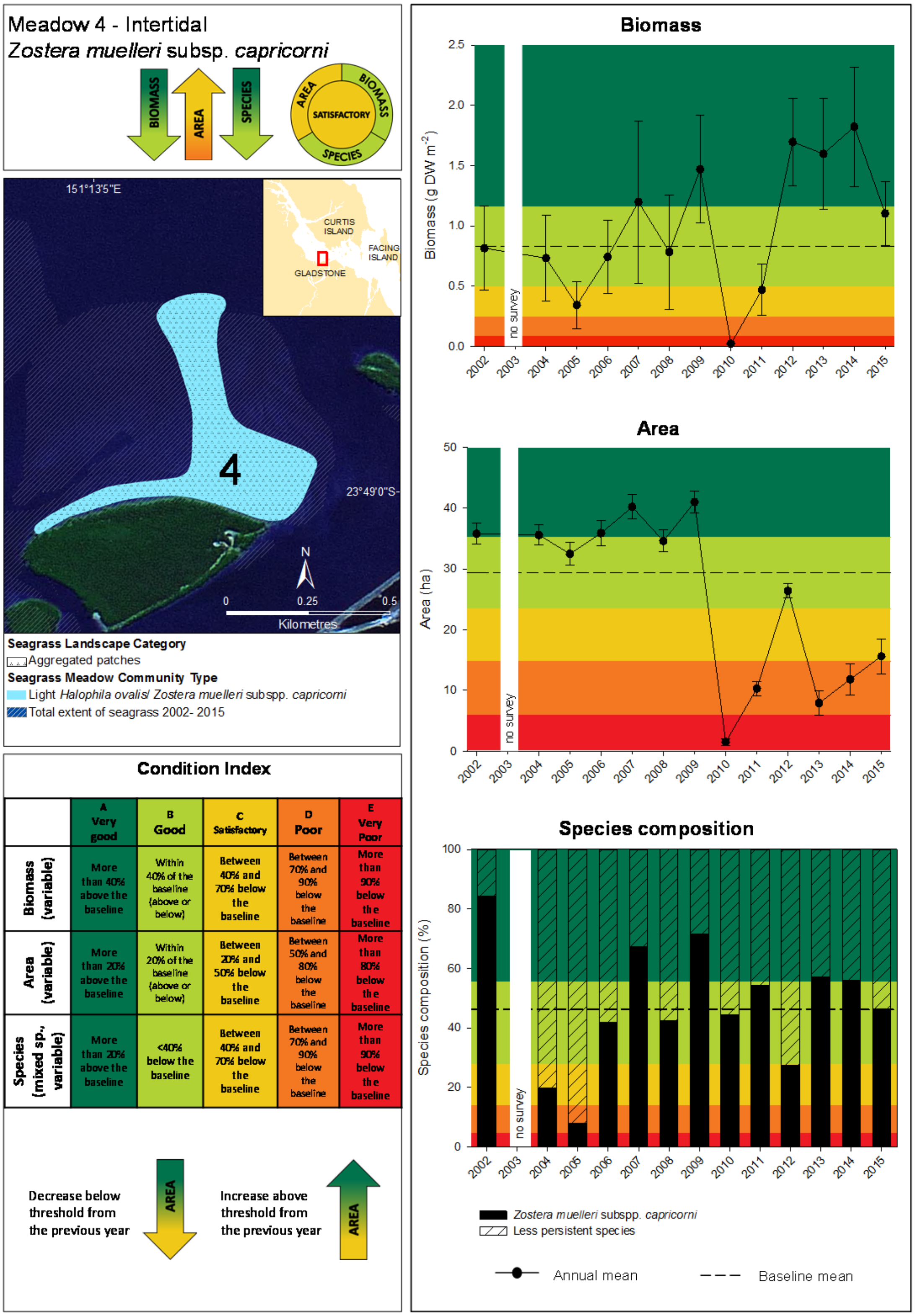


Figure 18. Changes in meadow area, biomass and species composition for seagrass at Meadow 4, Wiggins Island (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

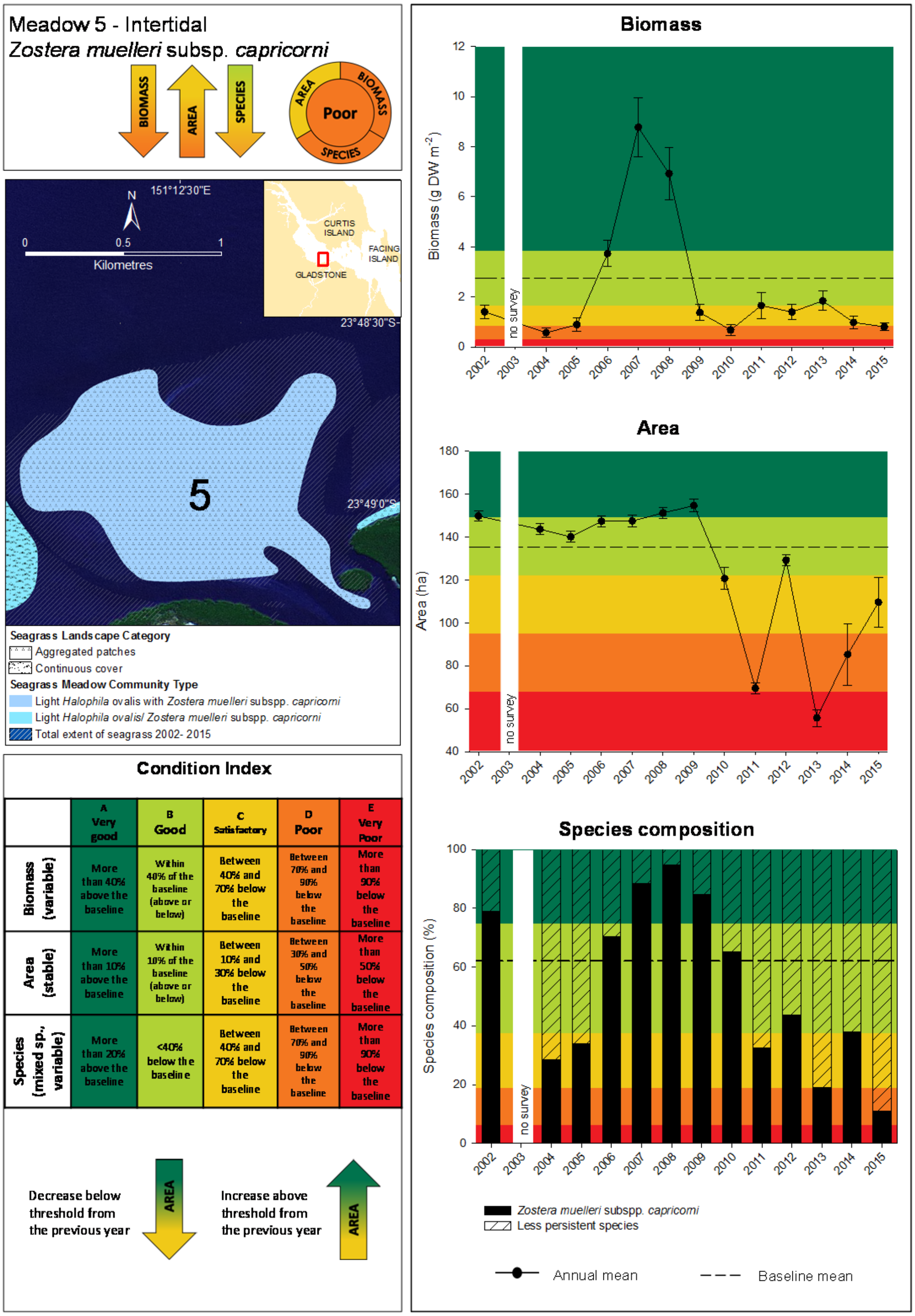


Figure 19. Changes in meadow area, biomass and species composition for seagrass at Meadow 5, Wiggins Island (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

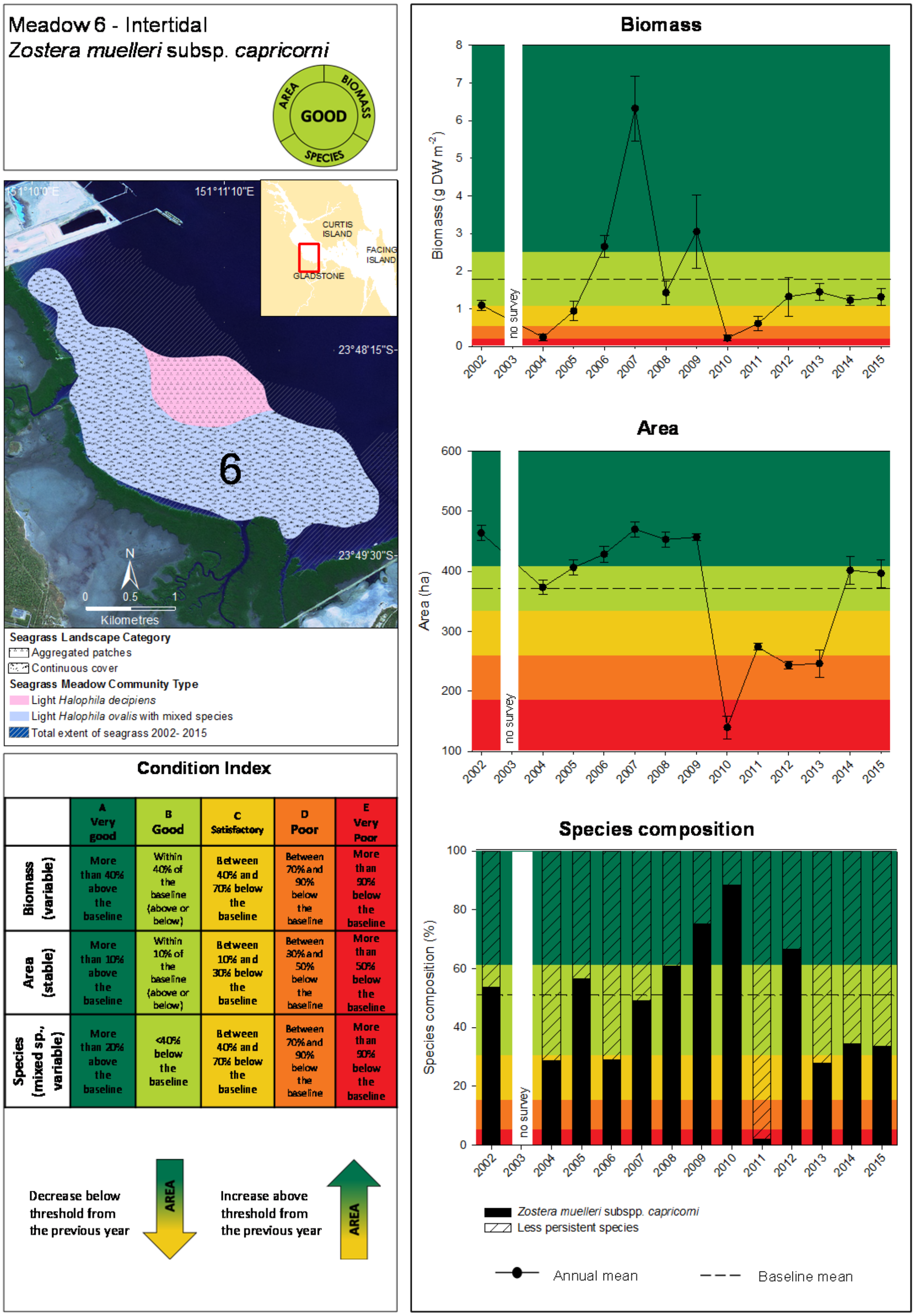


Figure 20. Changes in meadow area, biomass and species composition for seagrass at Meadow 6, South Fisherman's Landing (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

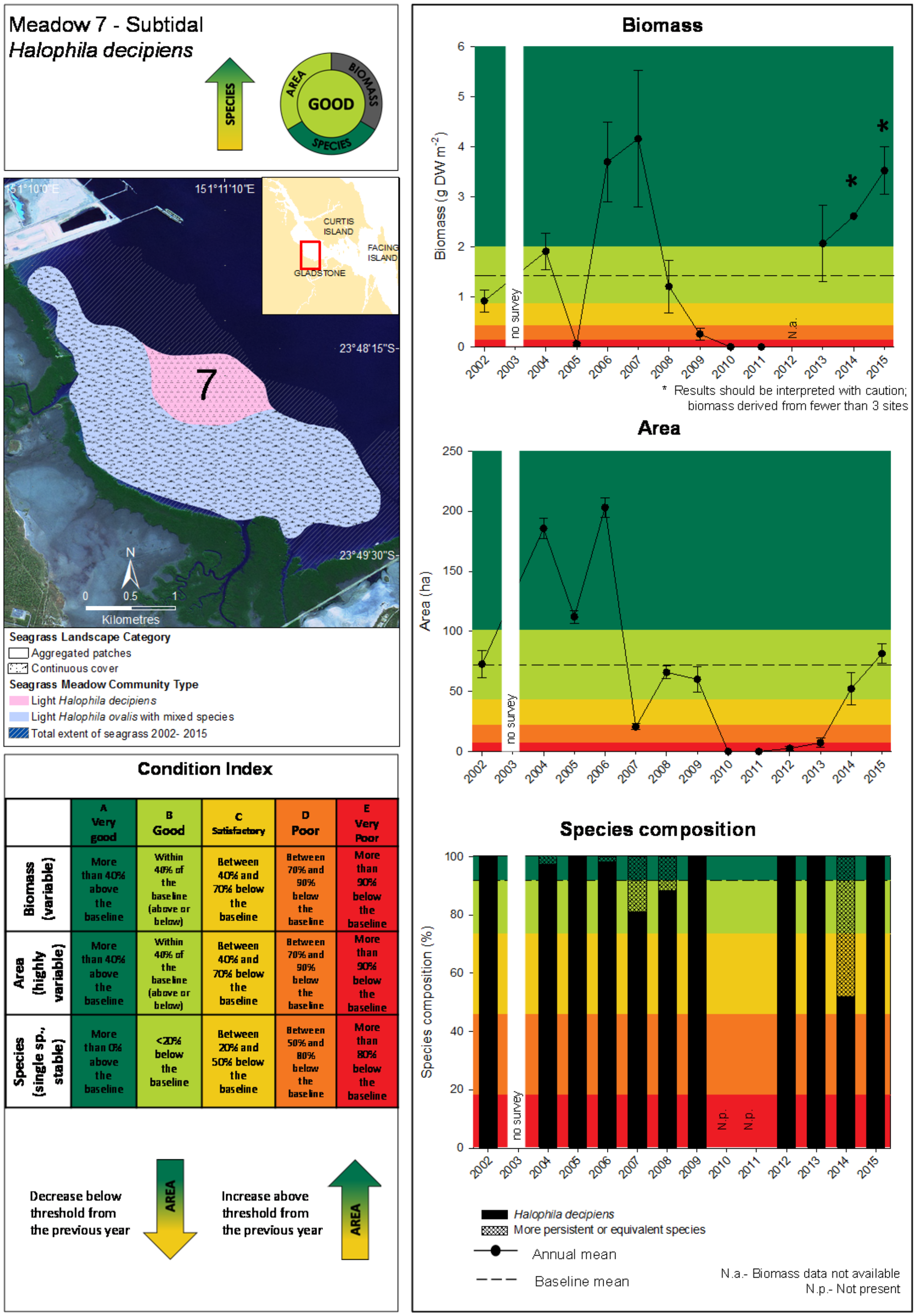


Figure 21. Changes in meadow area, biomass and species composition for seagrass at Meadow 7, South Fisherman's Landing (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

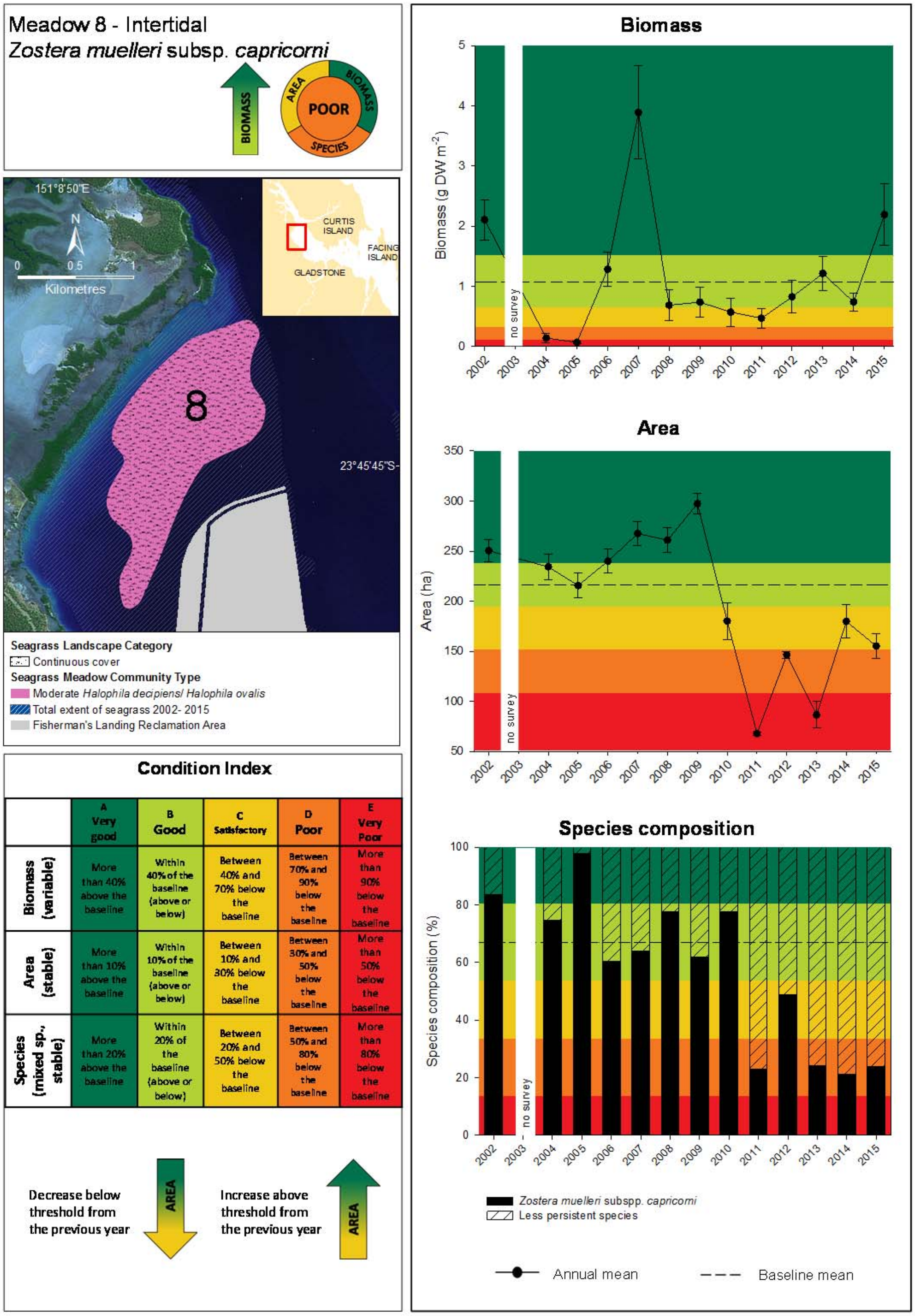


Figure 22. Changes in meadow area, biomass and species composition for seagrass at Meadow 8, North Fisherman's Landing (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

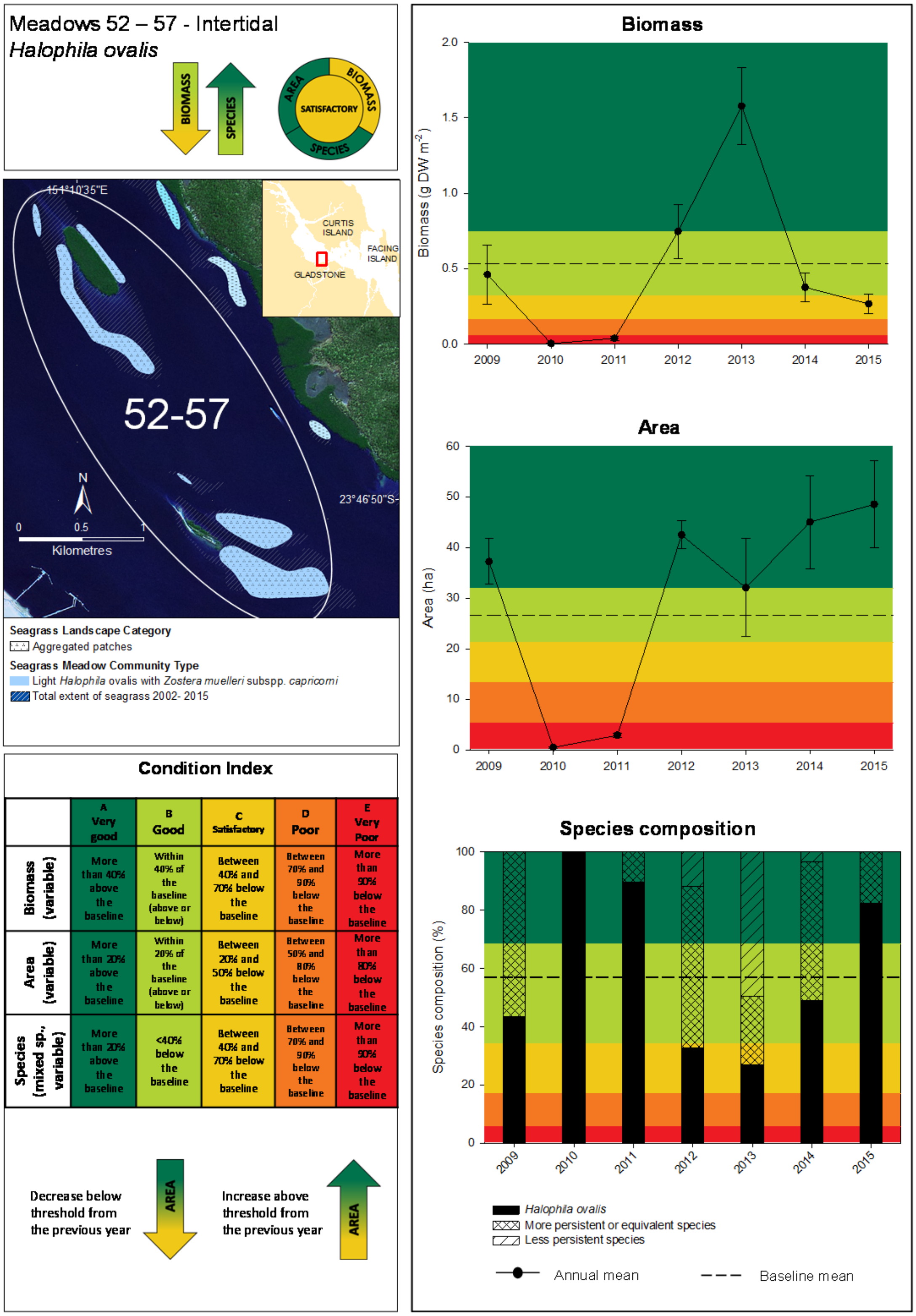


Figure 23. Changes in meadow area, biomass and species composition for seagrass at Meadows 52-57, Passage Islands (Western Basin zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.1.4 Inner Harbour

Seagrasses in the Inner Harbour zone formed 14 individual meadows and covered an area of approximately 348 ± 49 ha. The area of individual meadows ranged from small isolated patches (<0.003 ha) to broader expanses of seagrass (~99 ha) (Meadows 81 and 85; Figure 24 and Appendix 2). *Z. muelleri* subsp. *capricorni*, *H. uninervis* (narrow), *H. ovalis* and *H. decipiens* were present in the zone. Average biomass ranged from 0.23 ± 0.23 gDW m^{-2} for the meadow of isolated patches of *Z. muelleri* subsp. *capricorni* in the western-most bay on the Curtis Island side (Meadow 157; Figure 24 and Appendix 2), to 1.07 ± 1.07 gDW m^{-2} for a group of isolated patches on the western side of Compigne Island (Meadow 136; Figure 24 and Appendix 2). The majority of meadows were comprised of isolated or aggregated patches of seagrass and all meadows were classified as light in cover. Meadows were equally dominated by *H. ovalis* and *Z. muelleri* subsp. *capricorni* (Figure 24 and Appendix 2).

Long Term Monitoring Meadows

The single monitoring meadow in the Inner Harbour zone is on the western side of South Trees Point (Meadow 58; Figure 25 and Appendix 2). Biomass in the South Trees Inlet *H. ovalis*/*H. uninervis* dominated meadow remains at a low but stable level since 2011 following the complete disappearance of the meadow in 2010 and was classified as poor. When the meadow re-established in 2011, most of the previously dominant *Z. muelleri* subsp. *capricorni* was lost and accounted for only 3% of the seagrass biomass in the meadow during the 2015 survey, resulting in a decline from poor to very poor for the species composition indicator (Appendix 3). Meadow area made substantial gains since recovery in 2011 and has generally remained well above the long-term average, achieving a score of very good for the past two years. Similar to 2014, below average biomass and the shift in species composition to pioneering species has resulted in the overall very poor condition of this meadow, despite meadow area expansion.

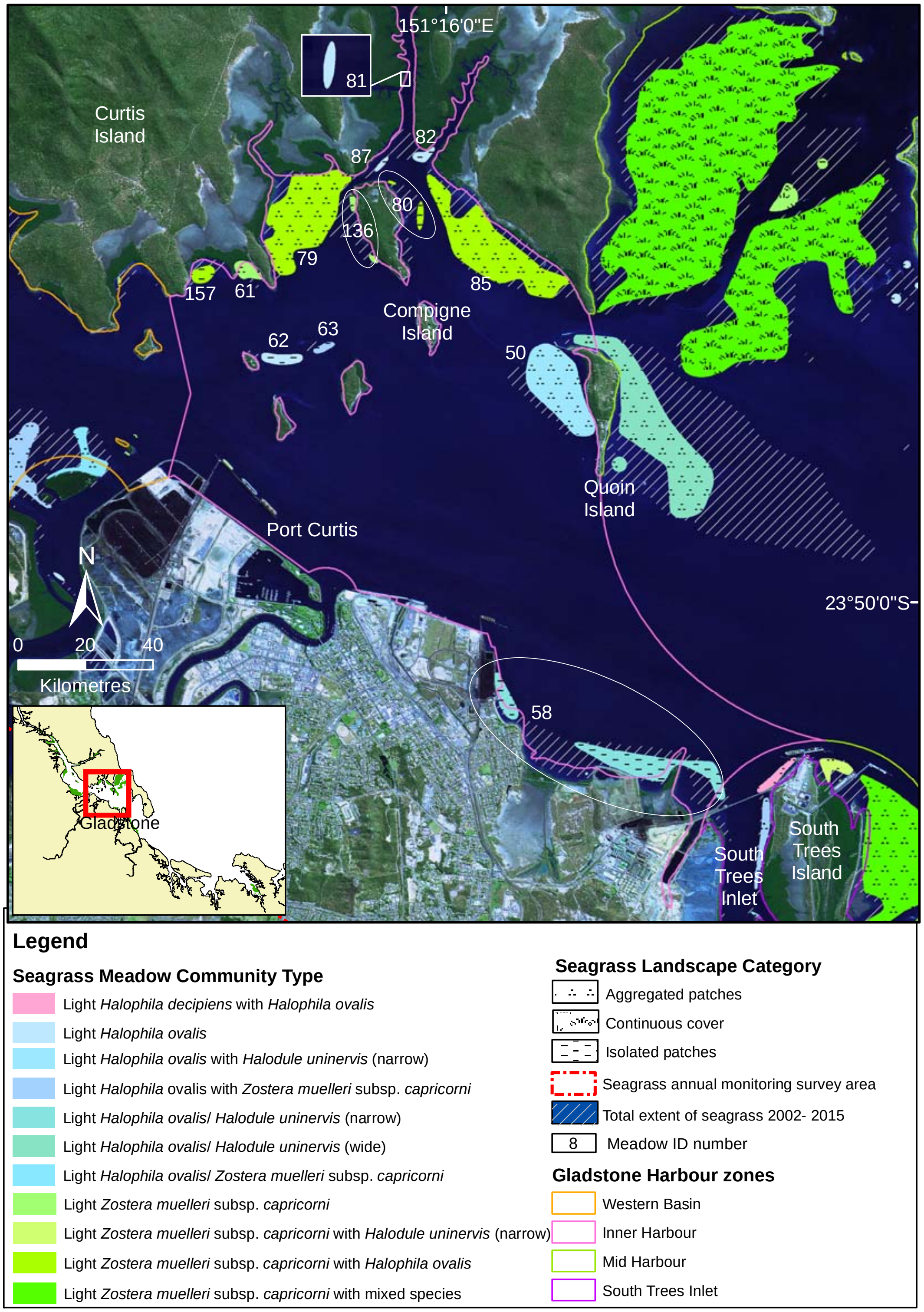


Figure 24. Seagrass distribution and community types in the Inner Harbour zone, November 2015.

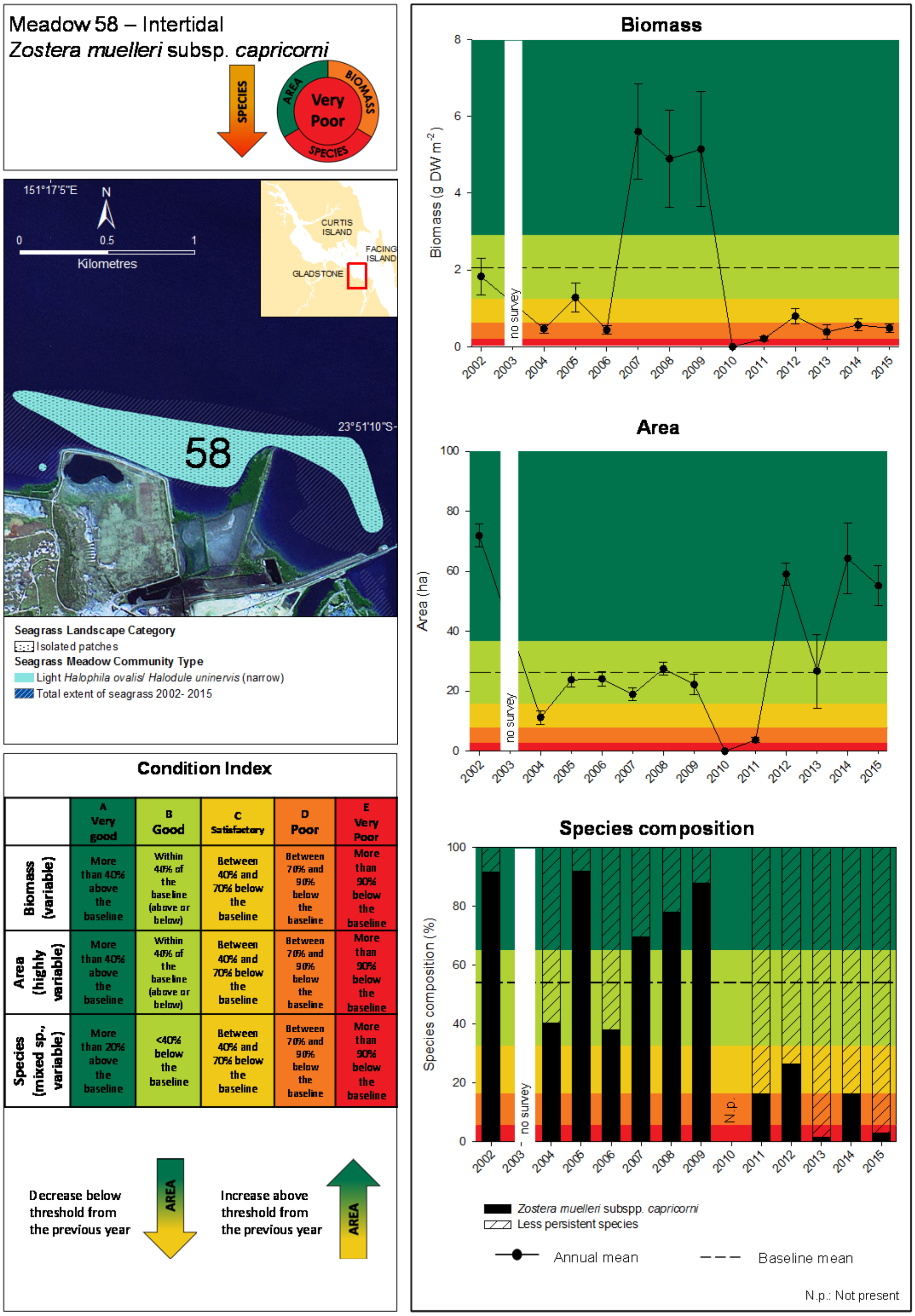


Figure 25. Changes in meadow area, biomass and species composition for seagrass at Meadow 58, South Trees Inlet zone, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.1.5 Mid Harbour

Seagrasses in the Mid Harbour zone formed 17 individual meadows and covered an area of approximately 1534 ± 202 ha. The area of individual meadows ranged from small isolated patches (~0.2 ha) to the largest seagrass meadow surveyed (~630 ha) on the intertidal mudflats at Pelican Banks (Meadows 158 and 43; Figure 26 and Appendix 2). The zone was the most diverse in species, with *Z. muelleri* subsp. *capricorni*, *H. uninervis, H. spinulosa, H. ovalis* and *H. decipiens* all present. Average biomass ranged from 0.33 ± 0.23 gDW m^{-2} for a small intertidal Z. *muelleri* subsp. *capricorni* meadow off Facing Island (Meadow 25; Figure 26 and Appendix 2) to 14.54 ± 0.44 gDW m^{-2} for a meadow with continuous cover of Z. *muelleri* subsp. *capricorni* adjacent to the large Pelican Banks meadow (Meadow 25; Figure 26 and Appendix 2). The majority of meadows were comprised of isolated patches of seagrass and all meadows but one (a *H. uninervis* meadow along Boyne Island) were classified as light in cover. Seagrass meadows were primarily dominated by Z. *muelleri* subsp. *capricorni* with the exception of the Boyne Island *H. uninervis* meadow, and *H. ovalis* meadows on the eastern side of Quoin Island and along Facing Island (Figure 26 and Appendix 2).

Long Term Monitoring Meadows

The large intertidal *Z. muelleri* subsp. *capricorni* dominated meadow at Pelican Banks is typically characterised by consistent cover of seagrass and both area and species composition were in good condition in 2015, though the meadow had become patchier. Biomass had been relatively stable leading up to 2014, but a decline to nearly 80% below the long-term average brought the biomass indicator from a satisfactory to poor condition, and drove the overall score of poor (Meadow 43; Figure 27 and Appendix 3).

At the Quoin Island subtidal *H. uninervis* dominated meadow, biomass has fluctuated around the threshold between the satisfactory and poor conditions since 2009 and was in poor condition in 2015 (Meadow 48; Figure 28). Meadow area had been relatively stable in a satisfactory condition since 2011 following dramatic reductions in 2009. Changes in species composition did not appear until 2012 when the dominant species began to decline as less persistent *Halophila* spp. increased, resulting in a satisfactory condition in 2015 (Appendix 3). The overall condition of the meadow was classified as poor.

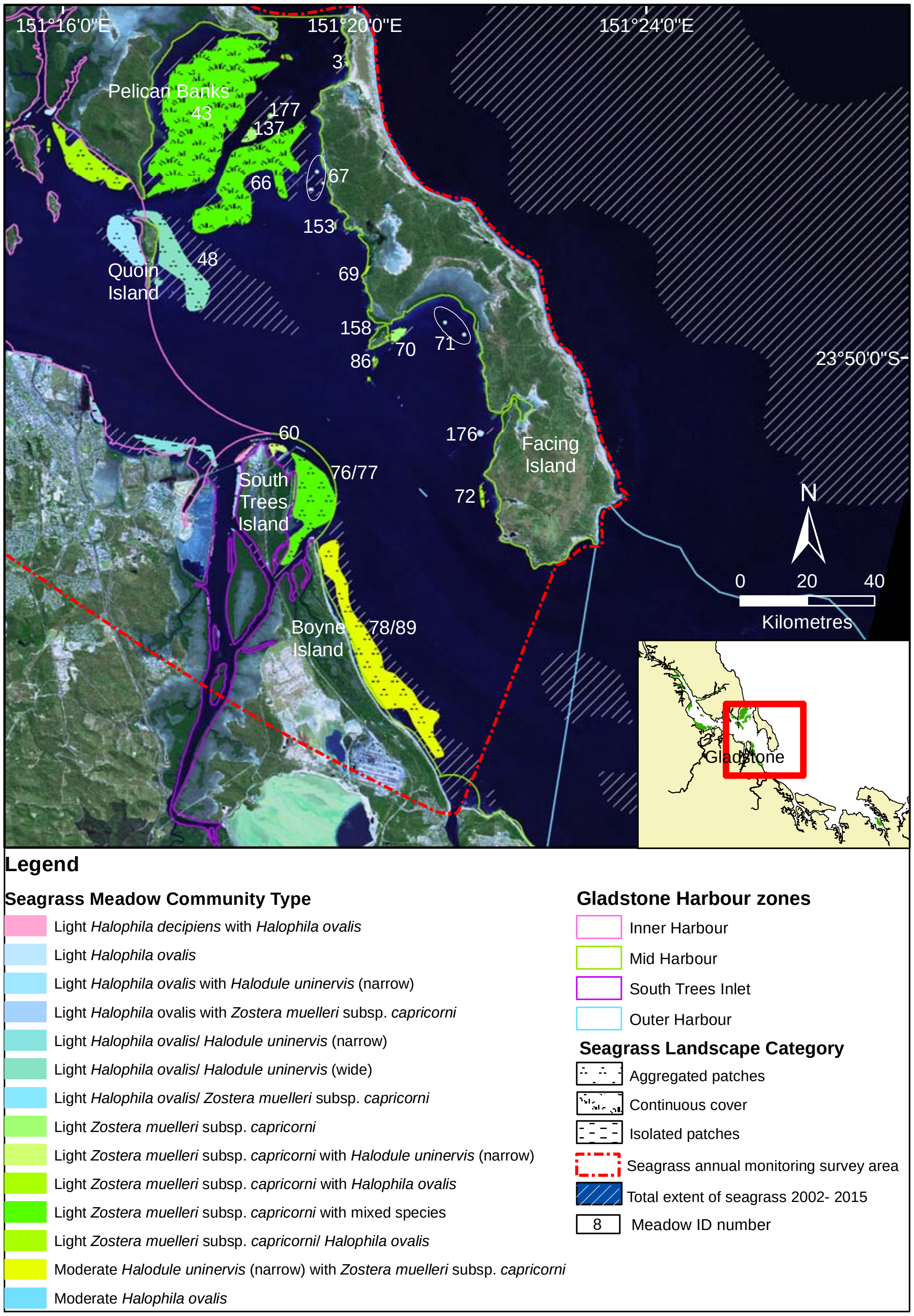


Figure 26. Seagrass distribution and community types in the Mid Harbour zone, November 2015.

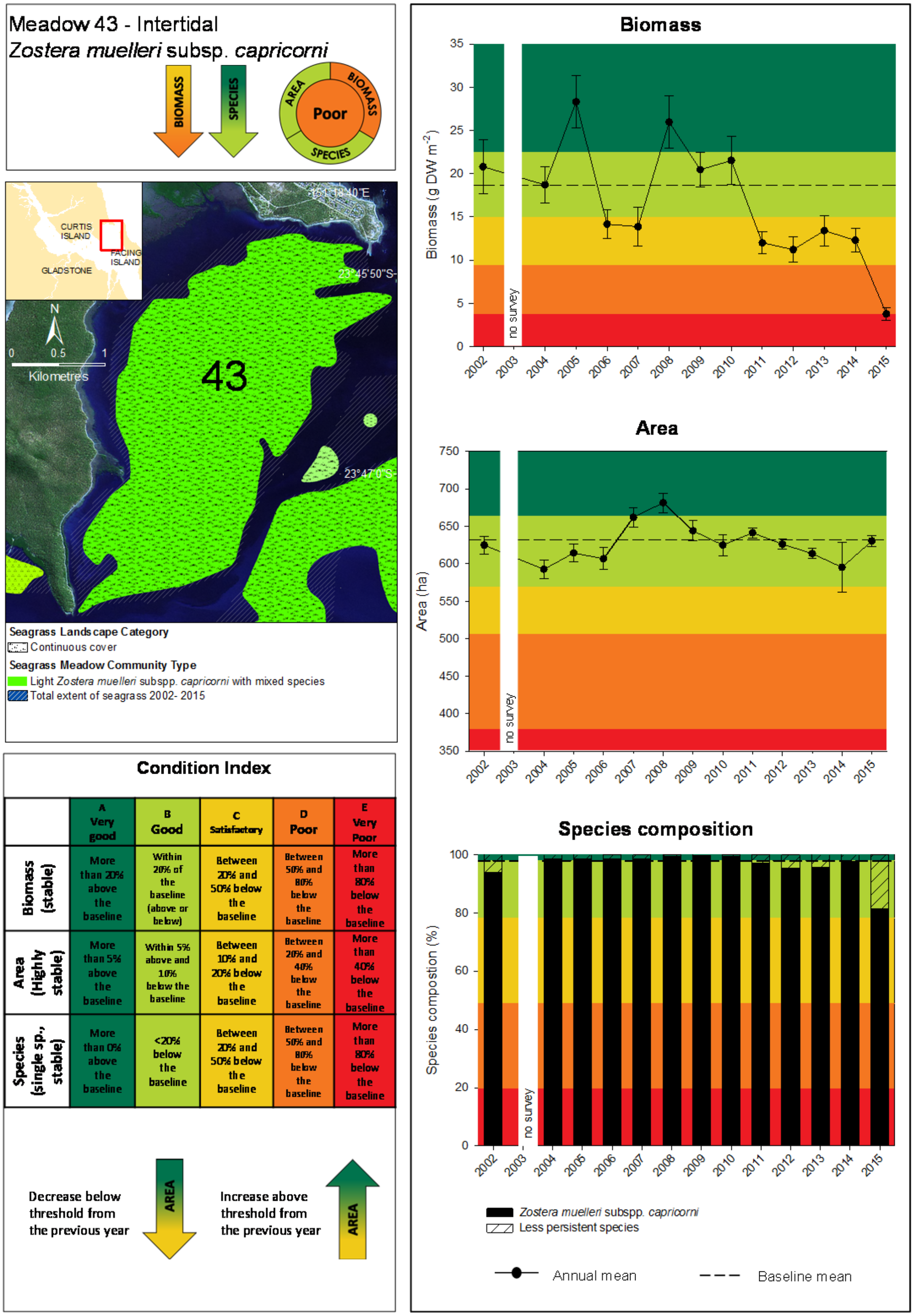


Figure 27. Changes in meadow area, biomass and species composition for seagrass at Meadow 43, Pelican Banks (Mid Harbour zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

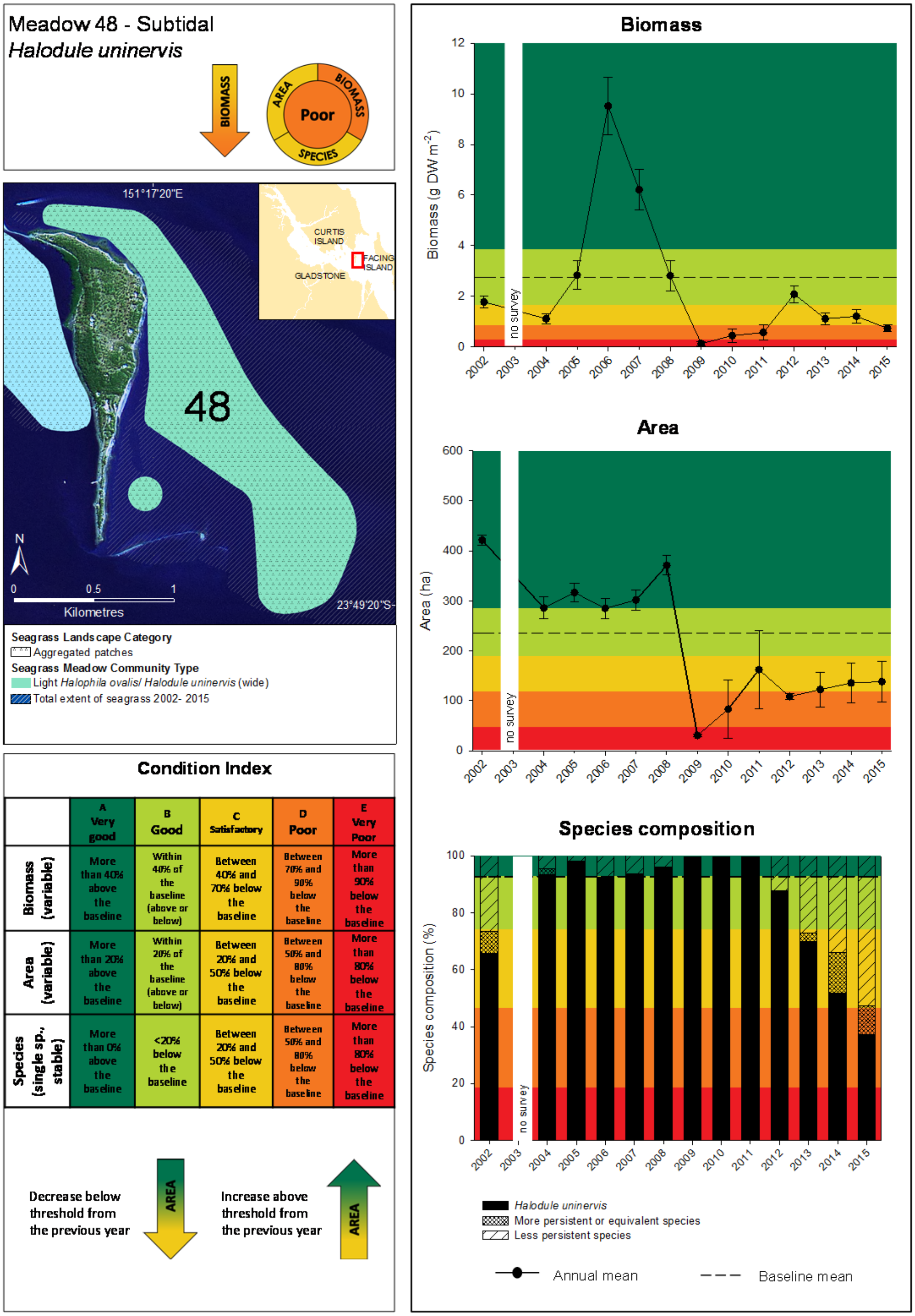


Figure 28. Changes in meadow area, biomass and species composition for seagrass at Meadow 48, Quoin Island (Mid Harbour zone), November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.1.6 South Trees Inlet (lower)

Seagrasses in the South Trees Inlet (lower) zone formed 9 individual meadows and covered an area of approximately 197 ± 17 ha. The area of individual meadows ranged from small isolated patches (~0.6 ha) to a larger intertidal meadow (~166 ha) to the south of the wharf (Meadows 155 and 76/77; Figure 29 and Appendix 2). *Z. muelleri* subsp. *capricorni*, *H. uninervis, H. ovalis* and *H. decipiens* were present in the zone. Average biomass ranged from 0.91 ± 0.32 gDW m^{-2} for a *H. decipiens* meadow west of South Trees Point (Meadow 142; Figure 29 and Appendix 2) to 3.65 ± 0.81 gDW m^{-2} for aggregated patches of Z. *muelleri* subsp. *capricorni* (Meadow 76/77; Figure 29 and Appendix 2). The majority of meadows were comprised of isolated or aggregated patches of seagrass and all meadows were classified as light in cover except a single *H. ovalis* meadow further up the inlet. The majority of seagrass meadows were dominated by *H. ovalis* with the larger meadows on the exposed banks surrounding the jetty dominated by *Z. muelleri* subsp. *capricorni* (Figure 29 and Appendix 2). *H. decipiens* was mainly present in the subtidal portions and dominated the meadow on the eastern side of the mouth of the inlet.

Long Term Monitoring Meadows

At the monitoring meadow at South Trees Point, average biomass had fluctuated around the threshold separating the satisfactory and poor conditions since 2010 and was in poor condition in 2015 (Meadow 60; Figure 30 and Appendix 2). Meadow area was at reduced levels between 2010 and 2013 but had been classified as being in very good condition since 2014. The spike in meadow area in 2014 also marked the return of the dominant species *Z. muelleri* subsp. *capricorni* following its near disappearance and the species composition was classified as satisfactory (Appendix 3). As with many other monitoring meadows, biomass remains well below the long term average and the overall condition of the meadow was classified as poor.

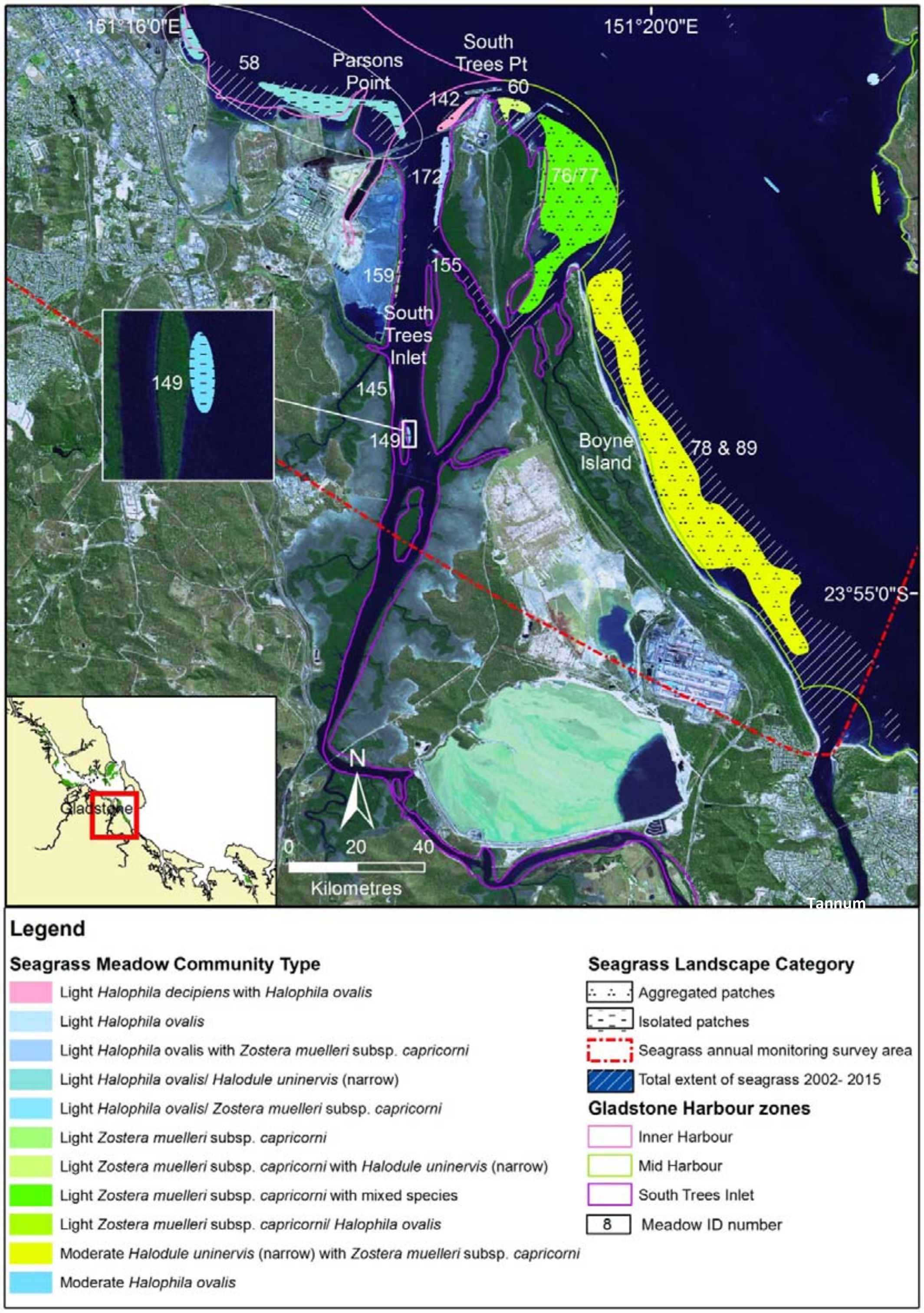
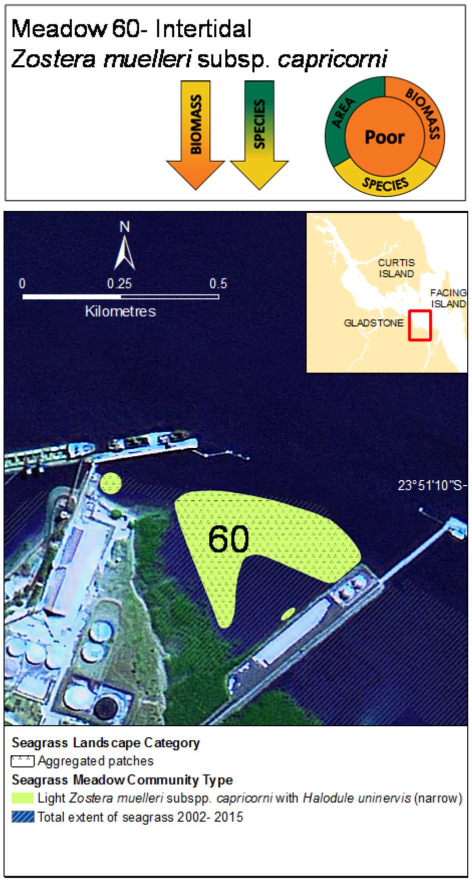
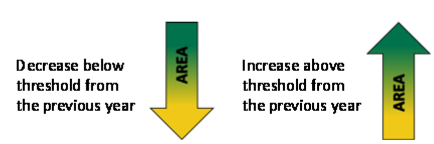


Figure 29. Seagrass distribution and community types at South Trees Inlet zone, November 2015.



Condition Index

	A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Area (variable)	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
Species (single sp., stable)	More than 0% above the baseline	<20% below the baseline	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline



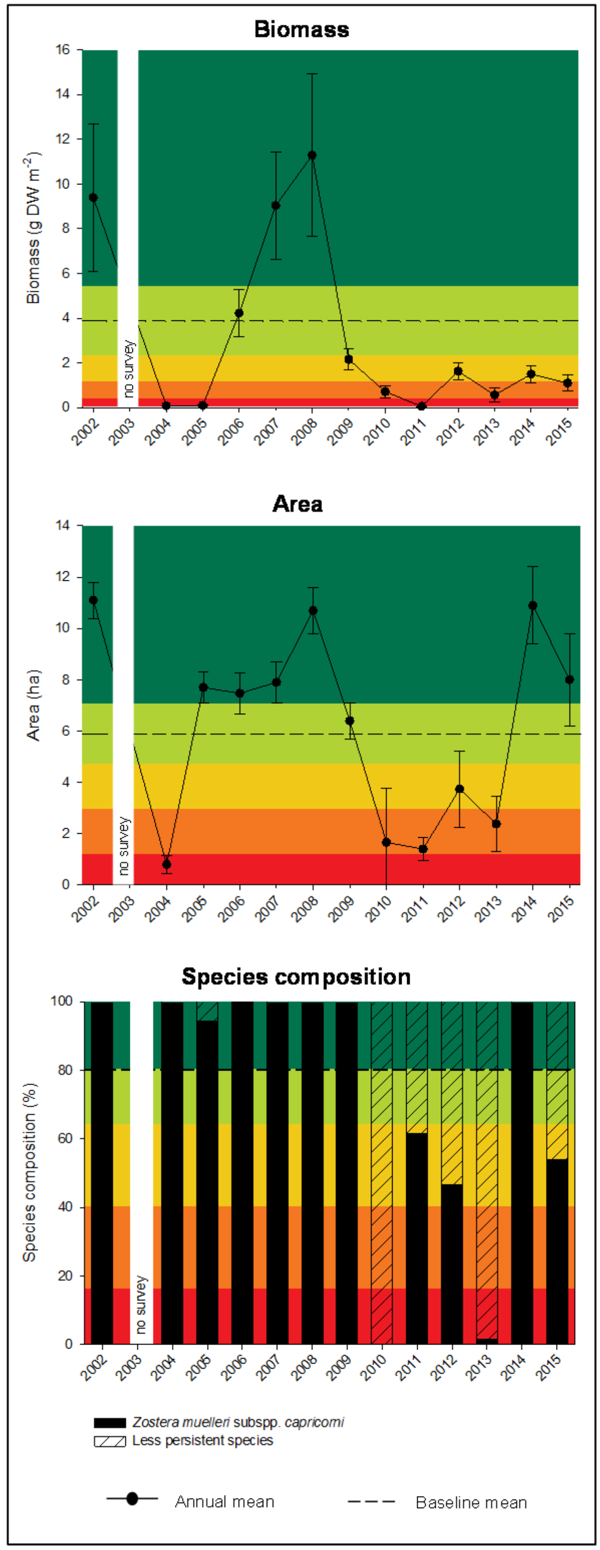


Figure 30. Changes in meadow area, biomass and species composition for seagrass at Meadow 60, South Trees Inlet zone, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.1.7 Rodds Bay

Seagrasses assessed within the Rodds Bay zone formed 3 individual meadows and covered an area of approximately 280 ± 28 ha. The area of individual meadows ranged from isolated patches (~1ha) to the broader meadow (~262 ha) on the exposed banks in the middle of the bay (Meadows 94 and 96; Figure 31 and Appendix 2). *Z. muelleri* subsp. *capricorni* and *H. ovalis* were present in the zone. Average biomass ranged from 0.3 ± 0.3 gDW m^{-2} for the smallest meadow of *H. ovalis* (Meadow 94; Figure 31 and Appendix 2) to 1.68 ± 0.75 gDW m^{-2} for the aggregated patches of Z. *muelleri* subsp. *capricorni* on the largest meadow (Meadow 96; Figure 31 and Appendix 2). Two of the three meadows were comprised of isolated patches of seagrass and all meadows were classified as light in cover. The smaller meadows to the south were dominated by *H. ovalis,* while the large meadow in the middle of the bay was dominated by *Z. muelleri* subsp. *capricorni* (Figure 31 and Appendix 2). Not all areas of the Rodds Bay zone are assessed in the annual monitoring survey and large areas of seagrass also occur outside of monitoring region.

Long Term Monitoring Meadows

The large intertidal *Z. muelleri* subsp. *capricorni* meadow increased in area and was classified as being in good condition (Meadow 96; Figure 32 and Appendix 2). Biomass has been very low but stable since declines observed in 2008 and 2009, and remains in poor condition. Species composition had remained relatively stable and was in good condition (Appendix 3), however biomass remains well below the long term average and the overall condition of the meadow was poor.

The adjacent *Z. muelleri* subsp. *capricorni* monitoring meadow was comprised of three sections in 2015 and had declined in area from a very good to poor condition (Meadow 104; Figure 33). Biomass and species composition had also declined (Appendix 3), and were classified as being in poor condition, leading to an overall meadow condition of poor.

The smallest monitoring meadow due east of Meadow 104 had declined in all three indicators, with area and species composition classified as poor and biomass classified as very poor (Meadow 94; Figure 34). Biomass has remained at a reduced level since dramatic declines in 2009, and since that time the proportion of the dominant species *Z. muelleri* subsp. *capricorni* had also fluctuated (Appendix 3). The overall condition of this meadow was classed as very poor.

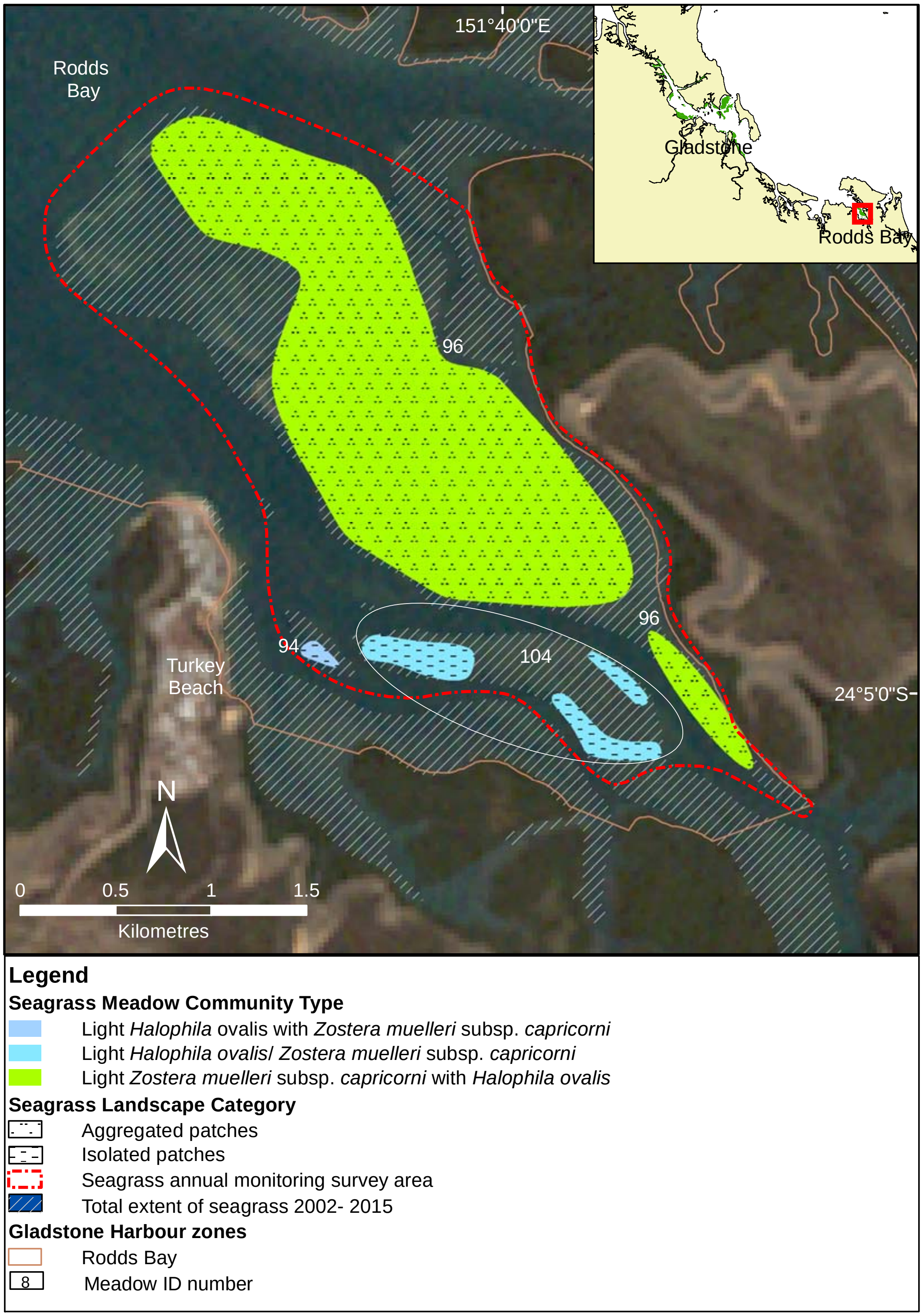


Figure 31. Seagrass distribution and community types in the Rodds Bay zone, November 2015.

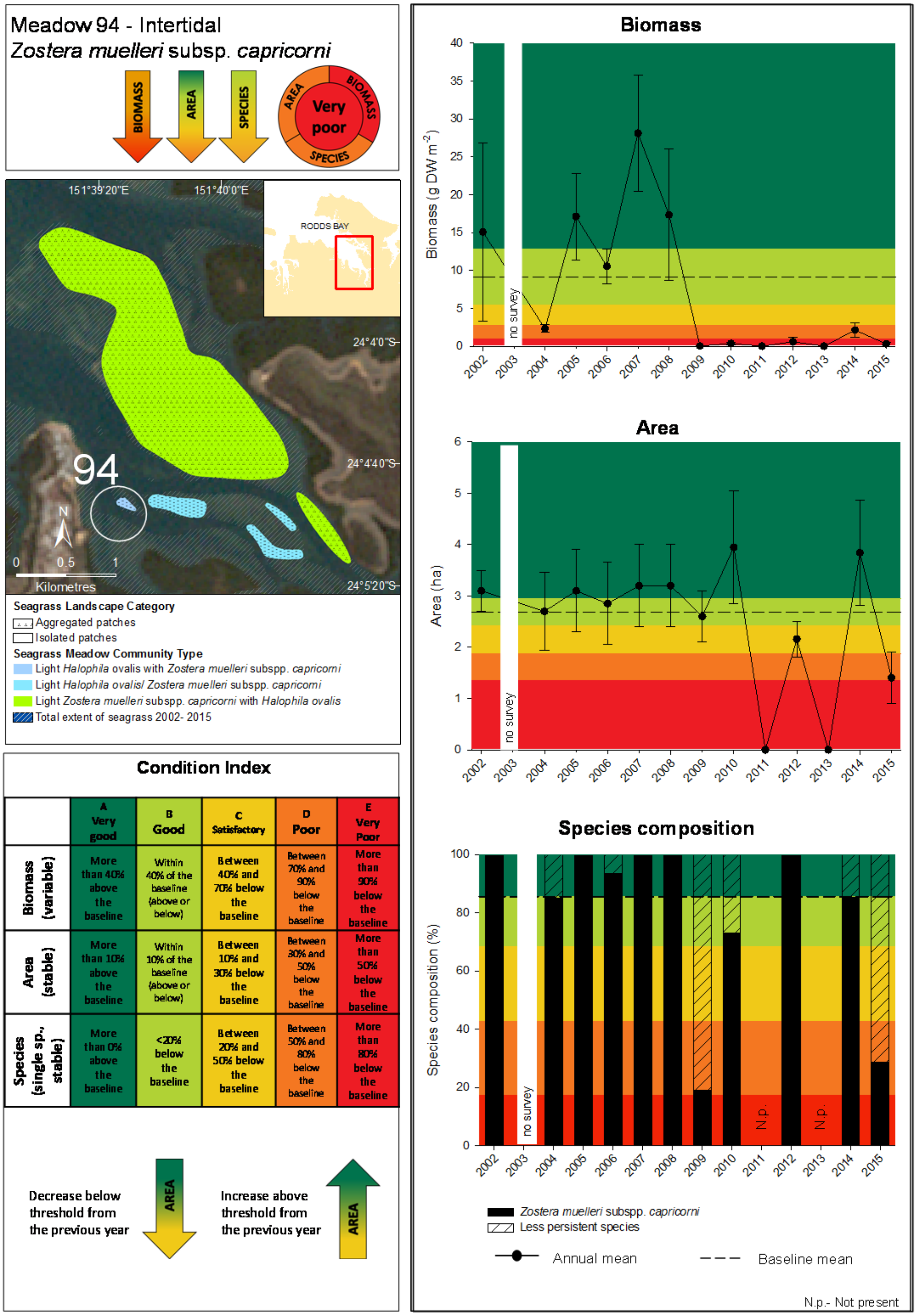


Figure 32. Changes in meadow area, biomass and species composition for seagrass at Meadow 94, Rodds Bay zone, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

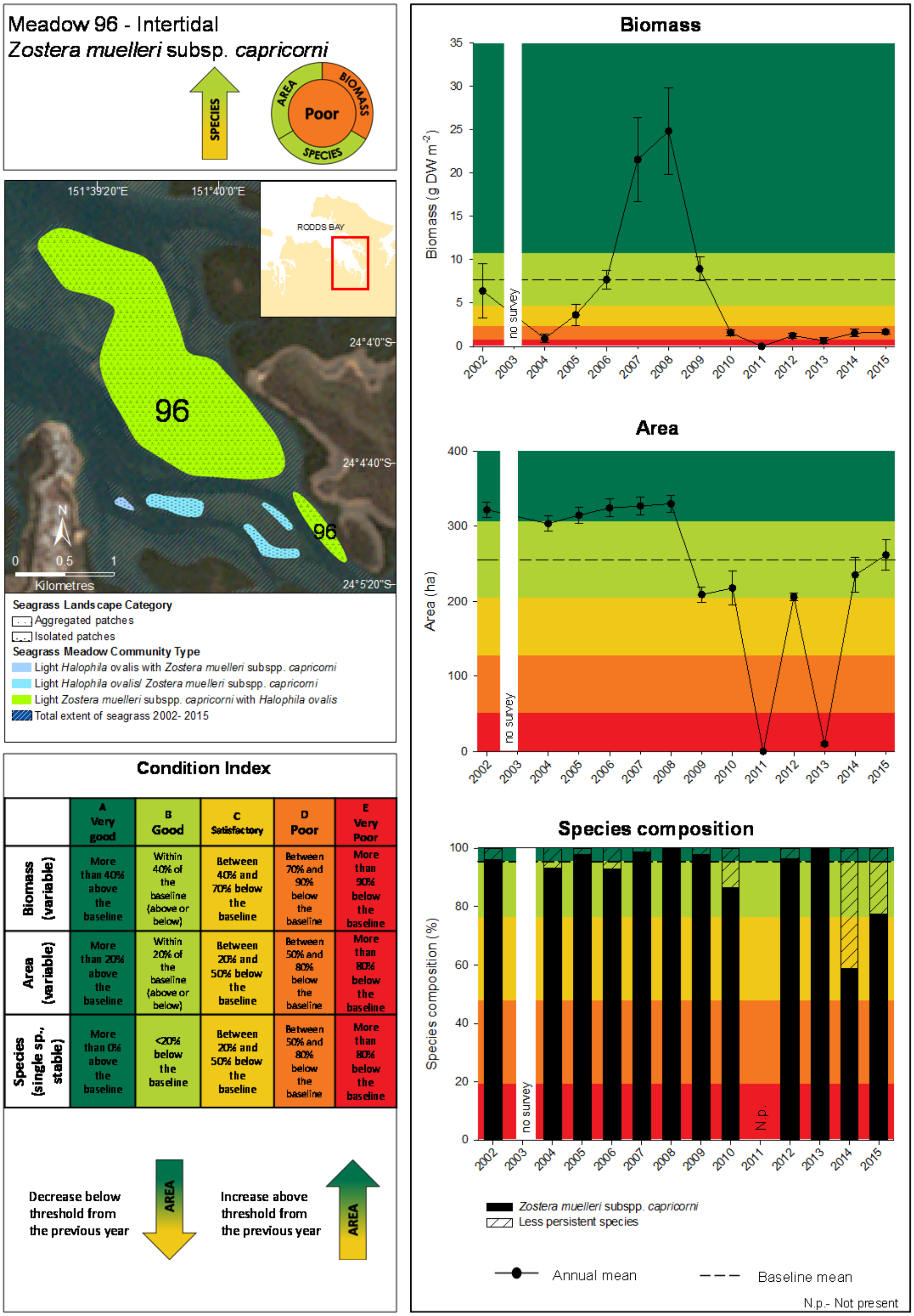


Figure 33. Changes in meadow area, biomass and species composition for seagrass at Meadow 96, Rodds Bay zone, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

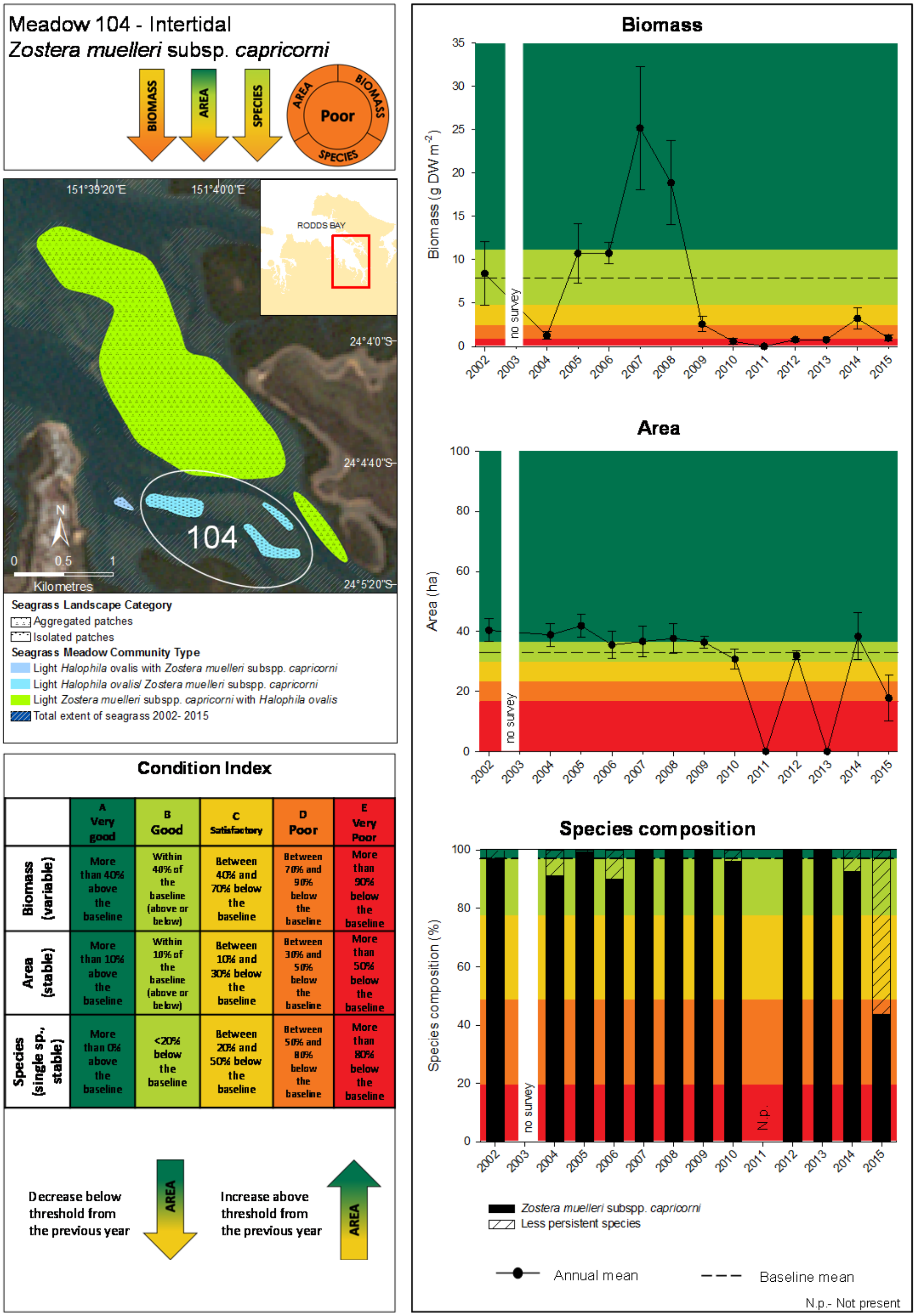


Figure 34. Changes in meadow area, biomass and species composition for seagrass at Meadow 104, Rodds Bay zone, November 2002 - 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2 Gladstone environmental conditions

Environmental conditions experienced by Gladstone seagrass meadows in 2015 were characterised by above average daytime tidal exposure, below average rainfall, and relatively low river flow compared with recent years. Water temperature followed seasonal trends and seagrasses were growing in an adequate light environment.

Tidal exposure of seagrass meadows is naturally variable and is dependant on the tidal regime of any given year. Total daytime tidal exposure in the months preceding the annual survey (September through November) was similar to the previous five years, however July and August 2015 at the beginning of the growing season had extremely high total daytime exposure (Figure 35).
Total annual rainfall in the 12 months preceding the November 2015 survey was below average and similar to 2014, following the highest recorded rainfall over the course of the monitoring program in 2013 (Figure 36). In the 12 months preceding the 2015 survey, total monthly rainfall was above the long-term average (since 1958) in three months (December 2014, January and June 2015), and below average in five months (November 2014, March, May, July and September 2015) (Figure 36). River flow from the Calliope River peaked in January and February 2015 above the long-term average (since 1970) then remained below, or close to the long-term average leading up to the November 2015 survey (Figure 37).

Light and water temperature data collected *in situ* at monitoring meadows in 2015 generally followed established seasonal trends; water temperature generally peaked in summer and light generally peaked in spring (Figures 38 and 39). Water temperatures in excess of 33 ^{o}C have been shown to negatively impact seagrass growth rates in as little as a few days (Collier et al. 2011). Water temperature exceeded 33 ^{o} in the days immediately preceding the 2015 survey at several monitoring sites (Figure 38 - 39). A threshold of an average of six mol m^{-2} day^{-1} over a two week period had been successfully used as a management threshold in Gladstone Harbour (Chartrand et al. 2012b). At this level there is sufficient light to maintain growth of *Z. muelleri* subsp. *capricorni*. Light levels in 2015 were generally lower than 2012 and 2013 but remained well above the threshold of light required for maintenance and growth of seagrass (Figures 38 – 39).

Light levels in the Western Basin zone at Fisherman's Landing (Meadow 8) and Wiggins Island (Meadow 5) often fell below six mol m^{-2} day^{-1} between late 2009 and early 2011, but have remained above this threshold since that time (Figure 38). At Fisherman's Landing light levels steadily increased over the 2015 growing season and mean above-ground biomass measured in November 2015 was the highest detected since 2010 (Figure 38). Wiggins Island experienced the same increase in light levels across the 2015 growing season, but no increase in mean above-ground biomass was detected during the November 2015 survey. (Figure 38).

In the Mid Harbour Pelican Banks meadow (Meadow 43) light levels dropped below six mol m^{-2} day^{-1} briefly during the latter part of February 2015. Light levels increased steadily during the 2015 growing season; however peak levels were the lowest recorded since monitoring began in 2009 (Figure 39). Despite this, light levels remained well above the threshold of an average of six mol m^{-2} day^{-1} over a two week period. Mean above-ground biomass during the November 2015 survey was also the lowest measured since monitoring began.

At the out of port reference site at Rodds Bay (Meadow 104) light levels remained above six mol m^{-2} day^{-1} over the duration of 2015. Light increased steadily over the first part of the 2015 growing season but declined over the three weeks leading up to the November 2015 survey (Figure 39). Average above-ground biomass at the meadow measured during the survey was lower than the previous year but similar to 2012 and 2013.

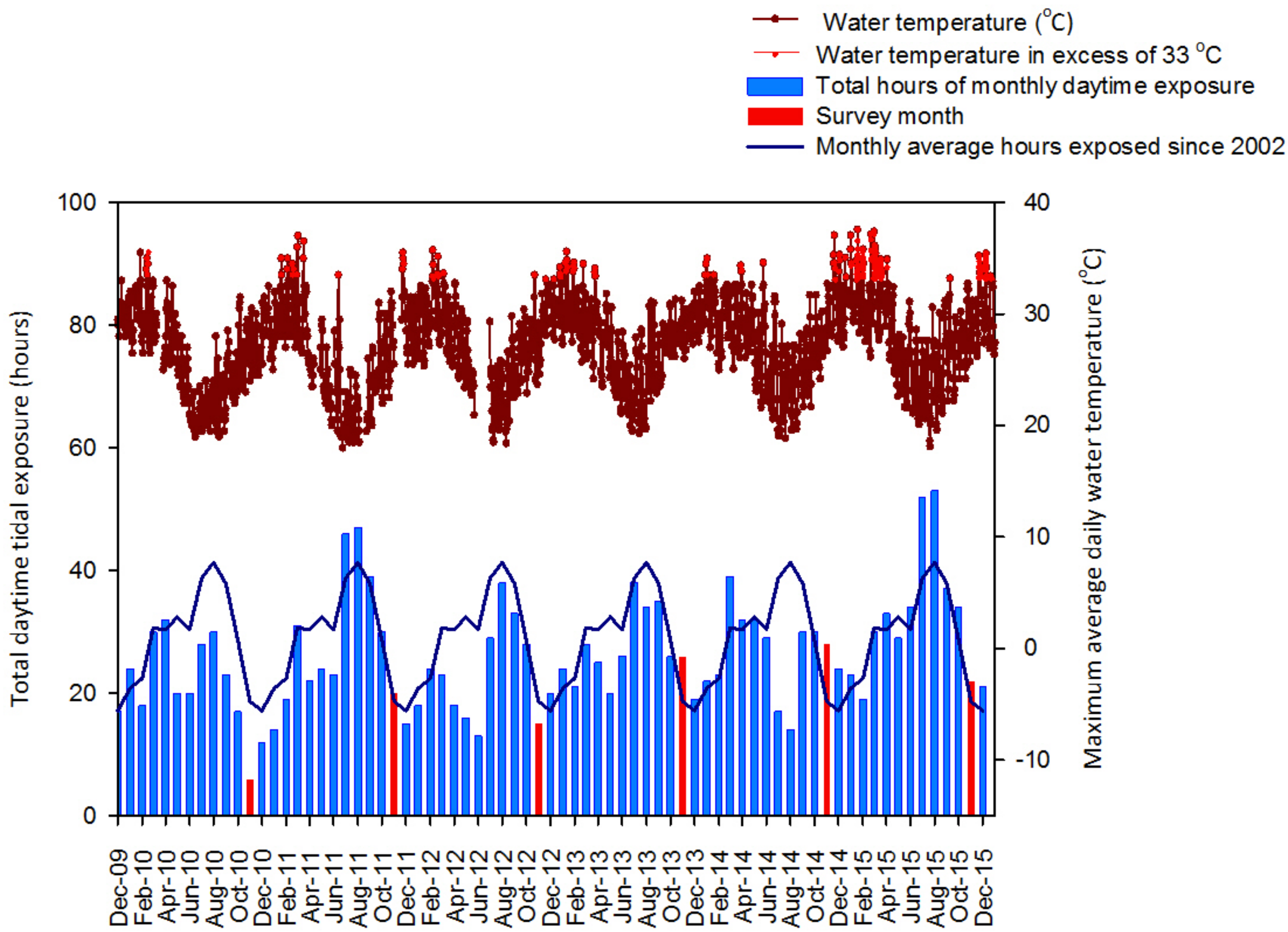
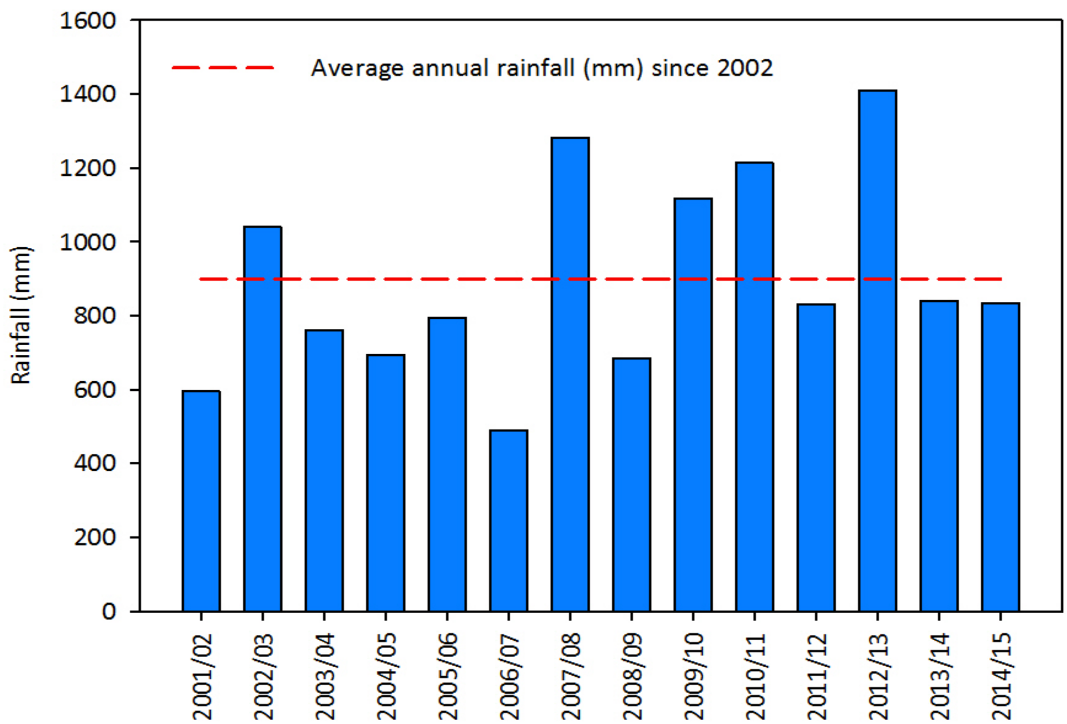


Figure 35. Total monthly daytime exposure (0600 – 1800; <1.0 m below mean sea level) and water temperature (taken from Pelican Banks) at Gladstone Harbour, 2010 – 2015.

A)



B)

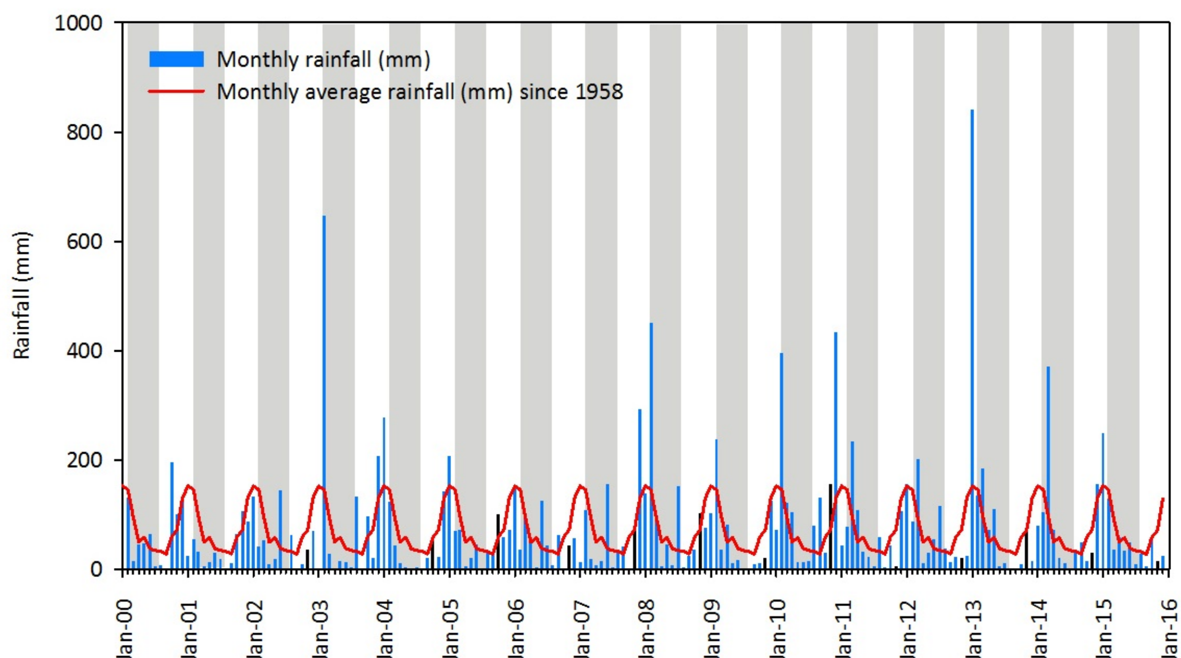


Figure 36. A) Total annual rainfall (mm) at Gladstone Harbour and B) total monthly rainfall (mm), January 2000 – January 2016. Black bars indicate October/November rainfall when seagrass was sampled (spring peak growth period). Shaded areas represent the seagrass senescent season.

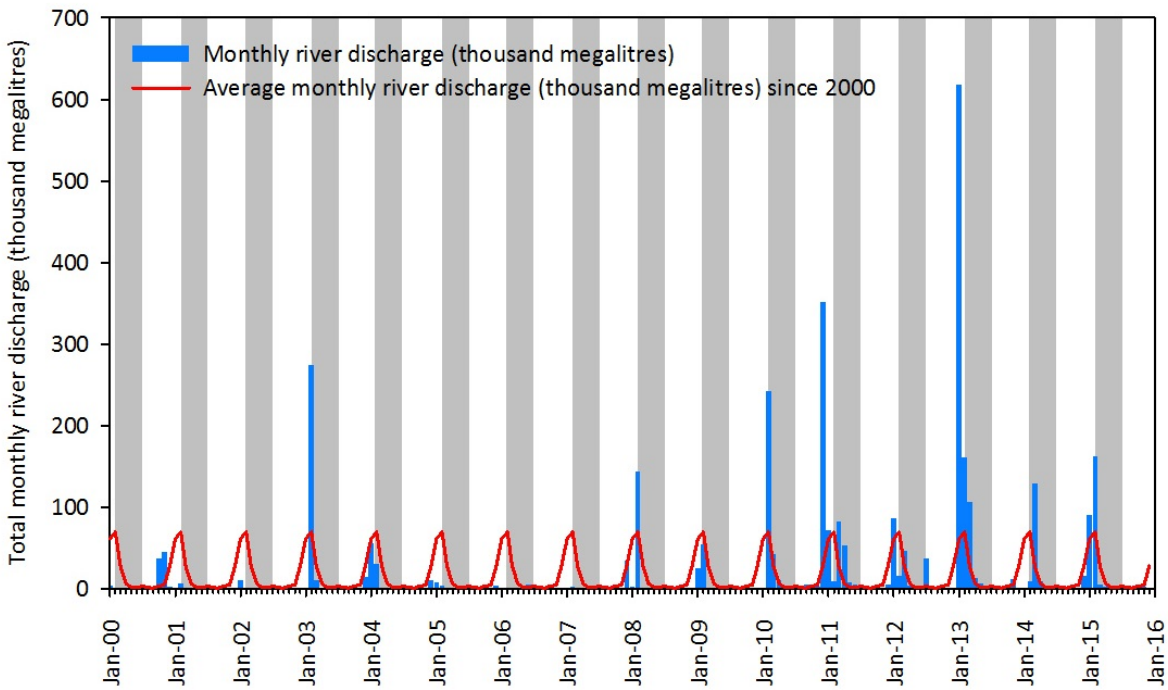


Figure 37. Monthly total river flow for the Calliope River (thousand megalitres), January 2000 – January 2016. Shaded areas represent the seagrass senescent season.

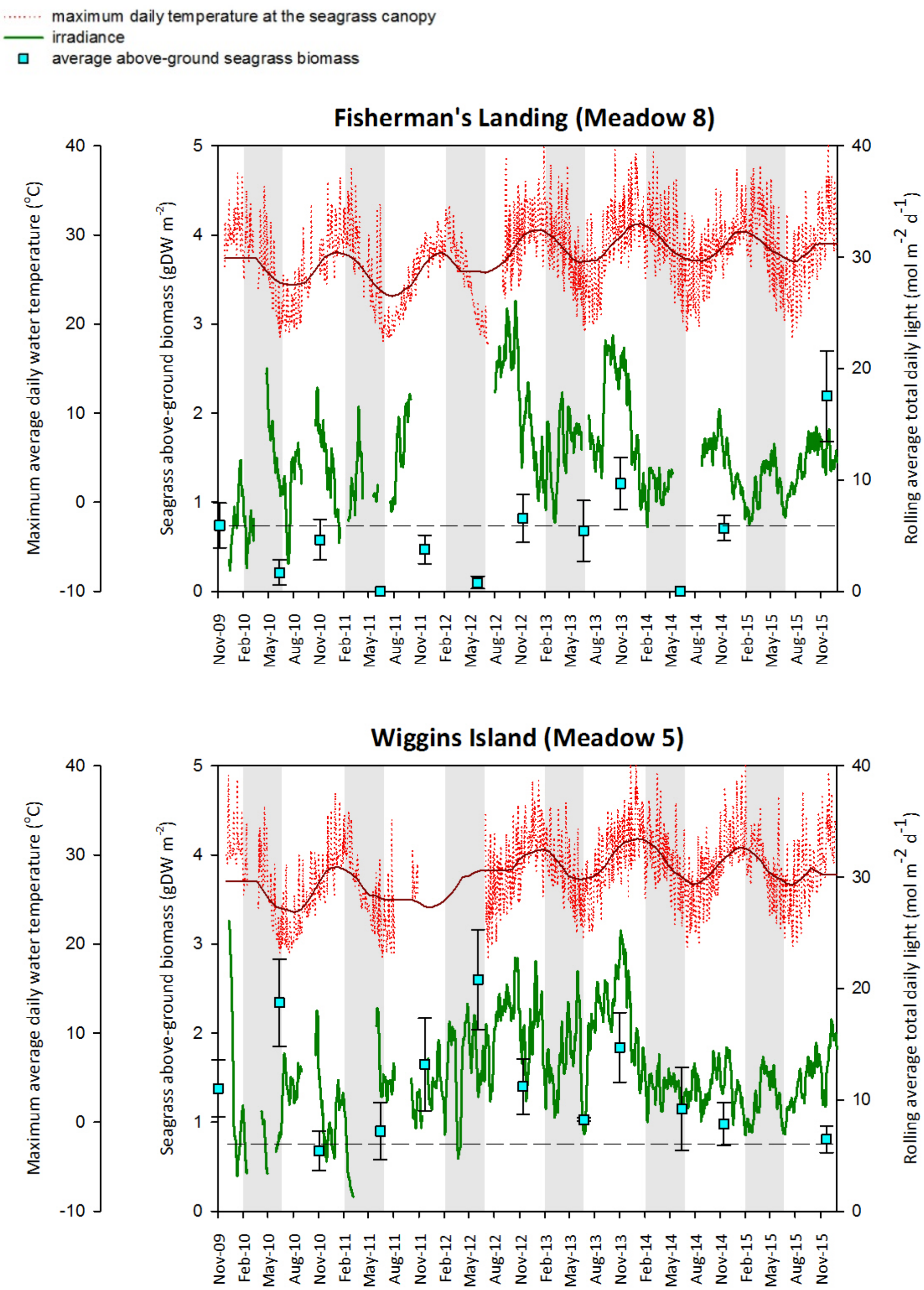


Figure 38. Mean (+ standard error seagrass) above-ground biomass (blue squares) at (A) Fisherman's Landing (Meadow 8) and (B) Wiggins Island (Meadow 5), Western Basin zone, plotted against the fortnightly rolling average total daily *in situ* light (mol m^{-2} day^{-1}) and maximum average daily water temperature (°C). The black dashed line indicates 6 mol m^{-2} day^{-1} which was the management trigger value for monitoring light during Western Basin dredging operations (Chartrand et al. 2012).

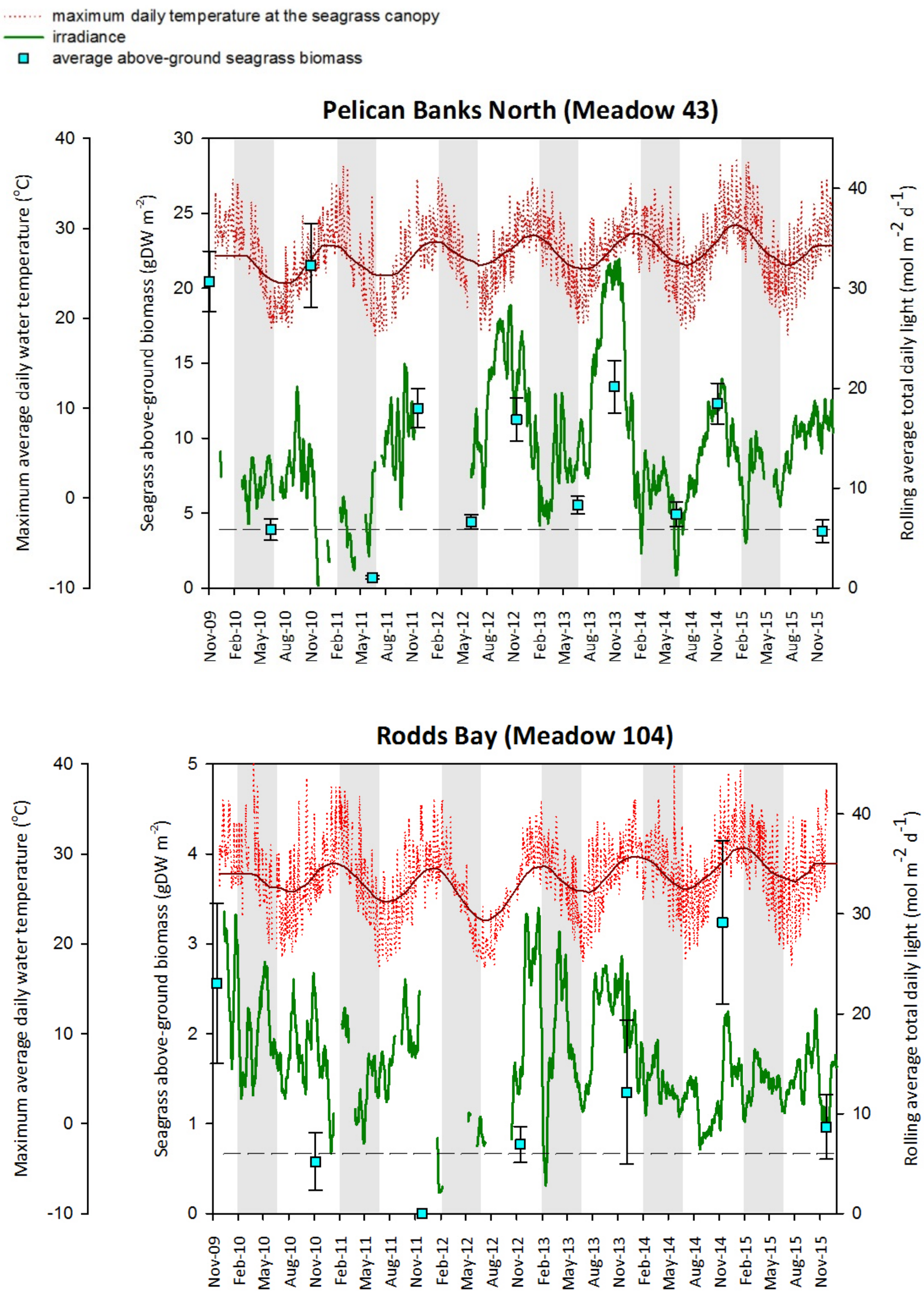


Figure 39. Mean (+ standard error seagrass) above-ground biomass (blue squares) at Pelican Banks (Meadow 34, Mid Harbour zone) and Rodds Bay (Meadow 104), plotted against the fortnightly rolling average total daily *in situ* light (mol m^{-2} day^{-1}) and maximum average daily water temperature (°C). The black dashed line indicates 6 mol m^{-2} day^{-1} which was the management trigger value for monitoring light during Western Basin dredging operations (Chartrand et al. 2012).

4 DISCUSSION

In November 2015 the overall condition of seagrass in Port Curtis and Rodds Bay was classified as poor based on assessment of the long-term monitoring meadows. However there were differences within the region with some zones having seagrass in better condition. Additionally there were differences between indicators, with area of seagrasses and species composition generally in a good condition but lower biomass leading to overall poor scores. The total area of seagrasses surveyed continued to increase from 2014 to 2015, with expansions in area mostly concentrated to these zones where major seagrass declines had occurred in proximity to the source of recent episodic flooding (2010-2013) and Western Basin dredging operations. The continuing expansion of meadows in these regions shows seagrasses have the capacity to recover from the episodic impacts experienced in recent years, should favourable conditions for seagrass growth continue.

Seagrass monitoring meadows in The Narrows and Western Basin zones improved between 2014 and 2015 with increases in area and/or biomass at the majority of meadows, and most meadows assigned an overall condition of satisfactory or good. In other zones, from the Inner Harbour to Rodds Bay, meadow condition had not shown the same improvement. The condition of many monitoring meadows declined in 2015 and all monitoring meadows in these zones were assessed as being in a poor or very poor condition. Low biomass drove the majority of scores regardless of zone, with average biomass remaining below the long-term average for all but three monitoring meadows. The most significant decline in biomass occurred at the large intertidal *Z. muelleri* subsp. *capricorni* meadow at Pelican Banks in the Mid Harbour region that generally has had the highest density of seagrasses found in the Port Curtis region.

Seagrasses growing on the intertidal banks in Gladstone experience highly variable environmental conditions, in part dictated by tidal regimes. Exposure-related stress caused by high total daytime tidal exposure at the beginning of the growing season in 2015 may have led to the observed seagrass biomass declines. When seagrasses are exposed to air at low tide for extended periods of time, they are subjected to extremes in temperature and light which have the potential to cause thermal stress, desiccation, elevated pH and photosynthetic damage (Petrou et al. 2013; Beer et al. 2006; Erftemeijer and Herman 1994). Stress to seagrass plants at the beginning of the growing season may have impacted the trajectory of recovery from the senescent season, inhibiting growth and proliferation despite favourable climate conditions. Sampling for sexual reproductive structures at Pelican Banks in November 2015 revealed the lowest density of spathes over the course of the monitoring program (Bryant et al. in prep).

The quality and quantity of light reaching seagrasses on the seabed is one of the primary environmental factors determining the distribution, abundance and species composition of seagrass communities (Ralph et al. 2007; Dennison 1987). Light was unlikely to be a limiting factor leading to biomass declines in 2015. During the twelve months preceding the November 2015 survey, relatively low rainfall and river flow from the Calliope River likely contributed to a favourable light environment for seagrasses. Light levels remained well above the locally derived light threshold for *Z. muelleri* subsp. *caprcorni* (Chartrand et al. 2012a) and does not appear to have driven biomass declines.

Many intertidal monitoring meadows had undergone a gradual shift in species composition over the course of monitoring with the proportion of the more persistent *Z. muelleri* subsp. *capricorni* decreasing and the proportion of less persistent *Halophila* species increasing. The most pronounced shifts have occurred at intertidal *Z. muelleri* subsp. *capricorni* dominated meadows along the mainland coast from The Narrows to the Inner Harbour, where much of the standing crop of seagrass was lost following severe flooding in 2010. In 2015, the proportion of *Z. muelleri* subsp. *capricorni* decreased at almost every monitoring meadow regardless of zone, and may be in part influenced by tidal regimes and exposure-related stresses (see above). Smaller bodied plants such as *Halophila* species may be able to lie flat during prolonged exposure to remain damp, whereas larger bodied species such as *Z. muelleri* subsp. *capricorni* are likely less protected (Bjork et al. 1999).

However the longer term trends in species composition likely reflect the lasting impacts of episodic climate and/or anthropogenic events. The proliferation of *Halophila* species in recent years is an expected pattern of colonising seagrass species, which have short periods for shoot turnover and sexual reproduction, and are able to respond quickly following disturbance (Kilminster et al. 2015). In low light conditions *Halophila* spp. show rapid declines (Durako et al. 2003; Kenworthy et al. 1989), but may respond quickly with fast growth and recovery when conditions improve following a disturbance such as the flooding events in Gladstone (Rasheed et al. 2014a; Hammerstrom et al. 2006). More persistent species, such as *Z. muelleri* subsp. *capricorni,* may require longer periods of time for growth and reproduction, leading to a longer period of time necessary for recovery.

The expansion in meadow area from the Narrows to the Western Basin was largely due to the colonisation by pioneering *Halophila* species. Most meadows in these regions were dominated by *Halophila* species in 2015 and overall showed large increases in area. In contrast *Z. muelleri* subsp. *capricorni* meadows in the Inner and Mid harbour regions were in poor condition with reductions in area at some meadows. Monitoring of species composition at these meadows is an important tool for tracking their recovery and may prove an important indicator of their ongoing resilience and the ecosystem services provided.

TropWATER is currently undertaking a study of the feeding ecology and habitat use by dugong in Port Curtis. Preliminary findings from the study (Rasheed et al 2016) suggest that during the seagrass growing season, dugong feeding trails are unlikely to persist for longer than three months. This suggests that the extensive network of trails observed at Wiggins Island and elsewhere during the November 2015 mapping and monitoring survey were recent (within the previous three months) and highlights the importance of these banks for dugong in the region. It is possible that the heavy grazing pressure observed during the survey has contributed to declines in biomass and/or changes in species composition in some areas such as Wiggins Island; however this contribution is difficult to determine.

In subtropical areas with large dugong and turtle populations it has been hypothesised that constant grazing pressure can favour rapidly growing colonising species such as *Halophila ovalis* over slower growing foundation species such as *Zostera muelleri* (Preen 1995); and simulated grazing in tropical Queensland meadows found changes in biomass, productivity, and species composition, with recovery taking months to years depending on the grazing intensity (Aragones and Marsh 2000). The onset of declines at Wiggins Island are consistent with flood related impacts but grazing pressure may contribute to species specific trends in recovery at the meadow. When high grazing intensity is combined with other stressors that reduce light availability the rate of seagrass recovery may be further reduced (Eklof et al. 2009). Spatial and temporal changes in dugong feeding activity in the Port Curtis region will become more apparent as the study progresses.

Comparisons with Queensland-wide monitoring program and seagrass resilience

Large scale declines in seagrass distribution and meadow biomass occurred in 2009/2010 throughout the north-eastern coast of Queensland, including in Cairns (Jarvis et al. 2014), Mourilyan (York et al. 2014), Townsville (Davies et al. 2014), and Abbot Point (McKenna and Rasheed 2014; Rasheed et al. 2014b). These declines coincided with above average rainfall and river flow (McKenna et al. 2015b) often associated with tropical cyclones (TC) that have impacted the Cairns to Gladstone region. The region endured five tropical cyclones in five years including TC Hamish (March 2009), TC Ului (March 2010), TC Anthony (January 2011), TC Yasi (March 2011) and TC Oswald (January 2013). There was a reprieve from cyclones in the region in 2012, with below-average rainfall and river flow across the region however the effects of several consecutive severe weather events likely left seagrasses with a reduced level of resilience.

Trends in seagrass meadow density and distribution observed in Gladstone are similar to changes noted in other long-term monitoring locations surveyed in 2015 on the east coast of Queensland between Cairns and Gladstone. Townsville seagrass monitoring meadows showed similar patterns of continued increasing meadow area, particularly in the subtidal meadows, coupled with declines in biomass in intertidal areas (Davies and Rasheed 2016). Persistent species had also begun to return where large scale declines had caused shifts in the species composition in Townsville (Davies et al. 2016), Abbot Point (McKenna et al. 2015a) and Cairns (York et al. 2016).

The trajectory of recovery since the declines has varied somewhat between locations, likely as a response to local differences in climate, as well as the severity of the initial declines. For some sites the loss of seagrass meadows was total (e.g. Mourilyan) but in others such as Townsville remnant populations of adult plants remained. Reductions in meadow area and biomass during years of extreme weather events reduce not only the adult plant population but also limit the resources available for that meadow to initiate recovery. With limited or no adult plants remaining, 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.

On the Northern Cape York, Torres Strait and Gulf of Carpentaria, seagrasses have fared much better those on the East Coast. Seagrass meadows at monitoring locations on Thursday Island (Carter et al. 2014), Weipa (McKenna et al. 2016) and Karumba (Sozou et al. 2016) were in a "good" condition in 2015, with meadows remaining relatively stable in biomass and meadow area. These regions have generally experienced fewer extreme weather events in recent years compared with the east coast south of Cooktown.

Implications for port management

Gains in meadow area during 2015 indicate seagrasses in Port Curtis and Rodds Bay have been a capacity to recover from recent impacts, however natural recovery from large declines can take up to five years (Preen et al. 1995) or potentially longer, with recovery delayed if additional stressors such as high turbidity, poor water quality high temperatures or low light levels are present. In Port Curtis seagrasses have had to deal with multiple impact events since the initial declines in 2009/2010, with the biggest flood event of the Calliope river recorded in 2013 leading to further seagrass declines after initial recovery in 2012.

Continued increases in seagrass meadow area and biomass within Port Curtis and Rodds Bay over the next twelve months are likely in the absence of another severe weather event. Seagrasses in Gladstone have shown a capacity to recover from impacts and substantial seed banks detected at several sites are a good indication of continued resilience at some sites. However, as in other Queensland locations, multiple years of high rainfall, river flow and cyclone activity in the region may have reduced resilience and capacity for recovery (Rasheed et al. 2014b; Pollard and Greenway 2013).

The seagrass management tools and thresholds established through major research programs in Gladstone (Schliep et al. 2014; Chartrand et al. 2012a) provide a good basis to assist in management to protect seagrasses. Additional work funded through the Ecosystem Research and Monitoring Program to look in more detail at seed banks and their viability and assessments of dugong habitat use will also assist in assessing the ongoing capacity of Gladstone's seagrass to recover and remain resilient. These measures combined with the extensive seagrass monitoring efforts means port managers and regulators are ideally placed to understand the natural ecological processes occurring and identify measures that may be introduced to reduce the chances of exacerbating natural impacts with human activities.

APPENDICES

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix 2. Area and mean above-ground biomass at monitoring meadows.

Mean above-ground biomass (g DW m^{-2}) + standard error and area (ha) ± reliability estimate for seagrass meadows in Port Curtis and Rodds Bay, 2015.

Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present
THE NARROWS REGION					
1	0.39 ± 0.23	1 ± 1	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*
10 & 17	1.32 ± 0.35	10 ± 6	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Aggregated patches	*H. ovalis* , *Z. muelleri* subsp. *capricorni*
19	1.20 ± 0.34	46 ± 7	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Continuous cover	*Z. muelleri* subsp. *capricorni, H. ovalis*
21	1.08 ± 0.31	153 ± 12	Light *Z. muelleri* subsp. *capricorni* / *H. ovalis*	Continuous cover	*Z. muelleri subsp. capricorni, H. ovalis, H. decipiens*
23	0.57 ± 0.21	95 ± 23	Light *Z. muelleri* subsp. *capricorni* / *H. decipiens*	Aggregated patches	*Z. muelleri subsp. capricorni, H. ovalis, H. spinulosa, H. decipiens*
25	0.09 ± 0.04	2 ± 1	Light *H. decipiens*	Aggregated patches	*H. decipiens*
28	0.47 ± 0.46	18 ± 2	Light *Z. muelleri* subsp. *capricorni* / *H. ovalis*	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
29	0.69 ± 0.18	48 ± 7	Light *Z. muelleri* subsp. *capricorni* / *H. ovalis*	Continuous cover	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
33	0.31 ± 0.09	83 ± 27	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Continuous cover	*Z. muelleri subsp. capricorni, H. ovalis, H. decipiens*
34	0.88 ± 0.38	16 ± 4	Light *H. ovalis* / *H. decipiens*	Continuous cover	*H. ovalis, H. decipiens*
150	2.60 ± 1.31	0.009 ± 0.006	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
174	2.60 ± 1.31	0.3 ± 0.1	Light *H. decipiens*	Isolated patches	*H. decipiens*

Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present
GRAHAMS CREEK REGION					
2	0.82 ± 0.21	6 ± 1	Light *H. ovalis*	Continuous cover	*H. ovalis, H. decipiens*
15	0.74 ± 0.12	4 ± 3	*Light H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
36	0.48 ± 0.32	4 ± 2	Light *Z. muelleri* subsp. *capricorni* with *H. decipiens*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. decipiens*
37 & 41	0.69 ± 0.02	68 ± 32	Light H. ovalis/ *Z. muelleri* subsp. capricorni	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
40	0.71 ± 0.39	0.2 ± 0.1	Light *H. ovalis*	Isolated patches	*H. ovalis*
141	0.97 ± 0.38	0.9 ± 0.4	Light *Z. muelleri* subsp. *capricorni* with mixed species	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
168	0.40 ± 0.13	12 ± 6	Light *H. decipiens* with mixed species	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
170	0.34 ± 0.15	4 ± 2	Light *Z. muelleri* subsp. capricorni	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. decipiens*
175	1.62 ± 1.03	0.1 ± 0.09	Light *Z. muelleri* subsp. *capricorni* with *H. decipiens*	Isolated patches	*Z. muelleri subsp. capricorni, H. decipiens*
WESTERN BASIN REGION					
4	1.10 ± 0.16	16 ± 3	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Aggregated patches	*Z. muelleri, H. ovalis*
5	0.81 ± 0.21	110 ± 12	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
6	1.31 ± 0.32	397 ± 23	Light *H. ovalis* with mixed species	Continuous cover	*Z. muelleri* subsp. *capricorni, H. ovalis, H. decipiens*
7	n.a.	81 ± 8	Light *H. decipiens*	Aggregated patches	*H. decipiens*
8	2.19 ± 0.34	155 ± 13	Moderate *H. decipiens* / *H. ovalis*	Continuous cover	*Z. muelleri* subsp. *capricorni* , *H. ovalis, H. decipiens*
11	0.15 ± 0.15	0.3 ± 0.2	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*
16	0.65 ± 0.45	26 ± 5	Light *H. ovalis*	Aggregated patches	*H. ovalis*
32	n.a.	0.8 ± 0.4	Light *H. ovalis*	Isolated patches	*H. ovalis*
42	1.31 ± 0.44	15 ± 3	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Isolated patches	*H. ovalis, Z. muelleri* subsp. *capricorni* , *H. decipiens*
44	0.79 ± 0.24	4 ± 3	*Light H. ovalis*	Isolated patches	*H. ovalis*
46	n.a.	1 ± 1	*Light H. ovalis*	Isolated patches	*H. ovalis*
52-57	0.27 ± 0.22	48 ± 9	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
59	2.77 ± 0.16	0.4 ± 0.4	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*

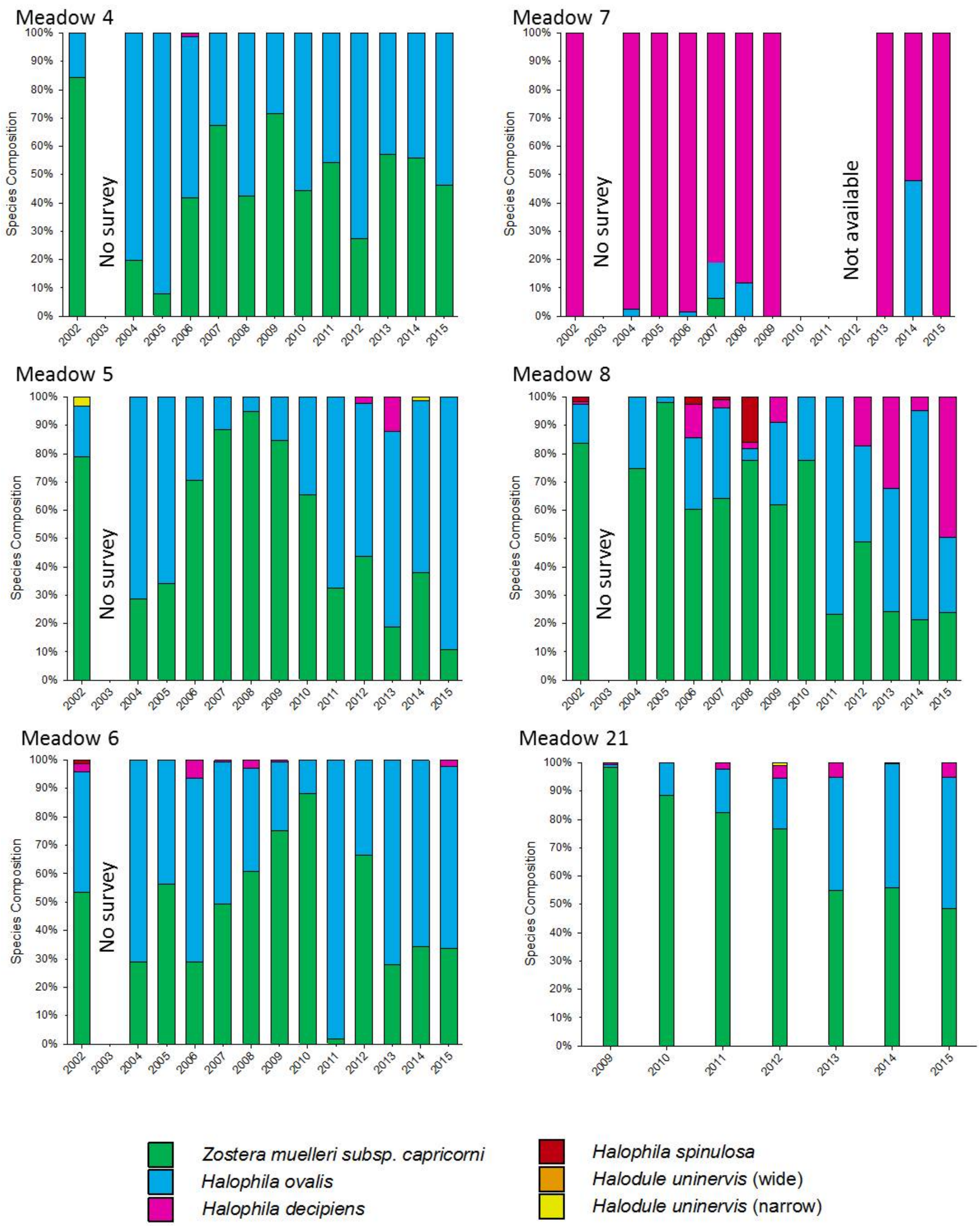
Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present
INNER HARBOUR REGION					
50	0.41 ± 0.32	68 ± 7	Light *H. ovalis* with *Halodule uninervis* (narrow)	Aggregated patches	*H. ovalis, H. uninervis* (narrow)
58	0.49 ± 0.40	55 ± 7	Light *H. ovalis* / *Halodule uninervis* (narrow)	Isolated patches	*Z. muelleri* subsp. *capricorni, H. uninervis (narrow)* *H. ovalis, H. decipiens*
61	0.53 ± 0.50	6 ± 1	Light *Z. muelleri* subsp. *capricorni*	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
62	0.27 ± 0.27	7 ± 1	Light *H. ovalis*	Isolated patches	*H. ovalis*
63	0.57 ± 0.41	3 ± 2	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
79	0.28 ± 0.21	93 ± 9	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Aggregated patches	*Z. muelleri, H. ovalis*
80	0.55 ± 0.55	3 ± 3	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Isolated patches	*H. ovalis, Z. muelleri* subsp. *capricorni*
81	0.51	0.002 ± 0.001	*Light H. ovalis*	Isolated patches	*H. ovalis*
82	0.25 ± 0.19	3 ± 2	*Light H. ovalis*	Isolated patches	*H. ovalis*
85	0.25 ± 0.19	99 ± 12	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Aggregated patches	*Z. muelleri* subsp. *capricorni* , *H. ovalis*
87	0.07 ± 0.03	1 ± 1	Light *H. ovalis*	Isolated patches	*H. ovalis*
136	1.07 ± 1.07	3 ± 2	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri subsp. capricorni*
157	0.23 ± 0.23	6 ± 2	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni* , *H. ovalis*

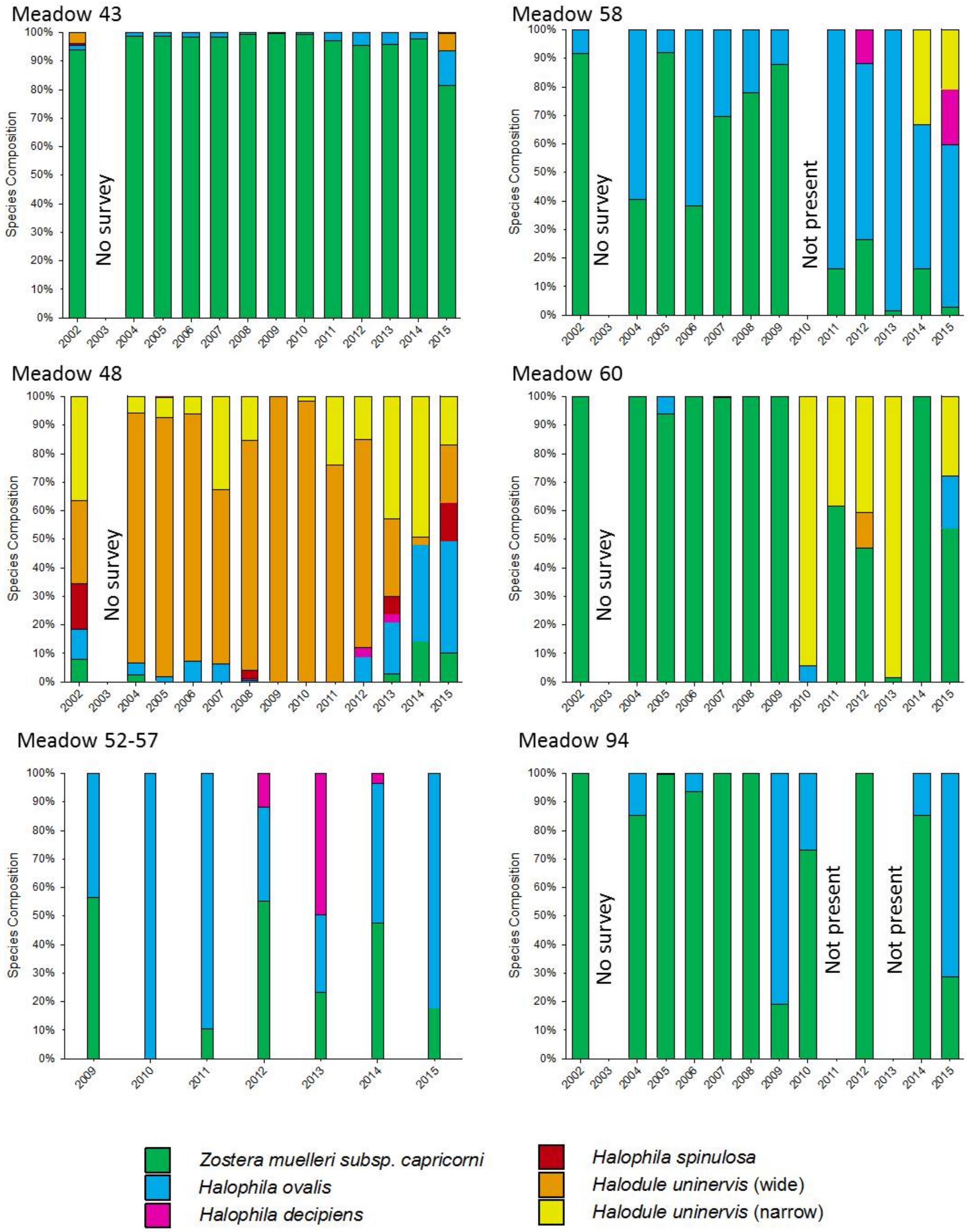
Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present
MID HARBOUR REGION					
3	1.09 ± 0.58	1 ± 0.6	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*, *H. ovalis*
43	3.78 ± 0.49	630 ± 7	Light *Z. muelleri* subsp. *capricorni* with mixed species	Continuous cover	*Z. muelleri* subsp. *capricorni*, *H. uninervis* (wide & narrow), *H. ovalis*
48	0.73 ± 0.39	138± 41	Light *H. ovalis* with *Halodule uninervis* (wide)	Aggregated patches	*Z. muelleri* subsp. *capricorni*, *H. uninervis* (wide & narrow), *H. ovalis*, *H. spinulosa*
66	3.58 ± 0.54	278 ± 58	Light *Z. muelleri* subsp. *capricorni* with mixed species	Continuous cover	*Z. muelleri* subsp. *capricorni*, *H. uninervis* (wide & narrow), *H. ovalis*, *H. spinulosa*
67	0.62 ± 0.33	3 ± 2	Light *H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni* , *H. ovalis*
69	2.69 ± 2.49	2 ± 1	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni* , *H. ovalis*
70	0.33 ± 0.23	10 ± 3	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*, *H. ovalis*
71	0.03 ± 0.03	1.6 ± 1.5	Light *H. ovalis*	Isolated patches	*H. ovalis*
72	n.a.	5 ± 3	Light *Z. muelleri* subsp. *capricorni* / *H. ovalis*	Isolated patches	*Z. muelleri* subsp. *capricorni*, *H. ovalis*
78 & 89	2.71 ± 0.43	283 ± 70	Moderate *Halodule uninervis* (narrow) with *Z. muelleri* subsp. *capricorni*	Aggregated patches	*Z. muelleri* subsp. *capricorni*, *H. uninervis* (narrow)
86	0.43 ± 0.43	0.7 ± 0.6	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri subsp. capricorni*
137	11.48 ± 0.39	9 ± 3	Light *Z. muelleri* subsp. *capricorni*	Continuous cover	*Z. muelleri* subsp. *capricorni*, *H. ovalis*
153	n.a.	1 ± 0.7	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri subsp. capricorni*
158	n.a.	0.2 ± 0.1	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*
176	n.a.	2 ± 1	Light *H. ovalis*	Isolated patches	*H. ovalis*
SOUTH TREES INLET REGION					
60	1.10 ± 0.47	8 ± 2	Light *Z. muelleri* subsp. *capricorni* with *Halodule uninervis* (narrow)	Aggregated patches	*Z. muelleri* subsp. *capricorni*, *H. uninervis (narrow)*, *H. ovalis*
76/77	3.65 ± 0.81	167 ± 9	Light *Z. muelleri* subsp. *capricorni* with mixed species	Aggregated patches	*Z. muelleri* subsp. *capricorni*, *H. uninervis* (narrow), *H. ovalis*, *H. decipiens*
142	0.91 ± 0.32	6 ± 2	Light *H. decipiens* with *H. ovalis*	Aggregated patches	*H. decipiens*, *Z. muelleri* subsp. *capricorni*, *H. ovalis*
145	0.54 ± 0.51	2 ± 0.7	Light *H. ovalis*	Isolated patches	*H. ovalis*
149	2.12 ± 0.44	1.4 ± 0.3	Moderate *H. ovalis*	Isolated patches	*H. ovalis*
155	0.11 ± 0.06	0.6 ± 0.4	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Isolated patches	*H. ovalis*, *Z. muelleri* subsp. *capricorni*
177	n.a.	2 ± 1	Light *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni*
172	1.00 ± 0.45	10 ± 3	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Aggregated patches	*H. ovalis*, *Z. muelleri* subsp. *capricorni*

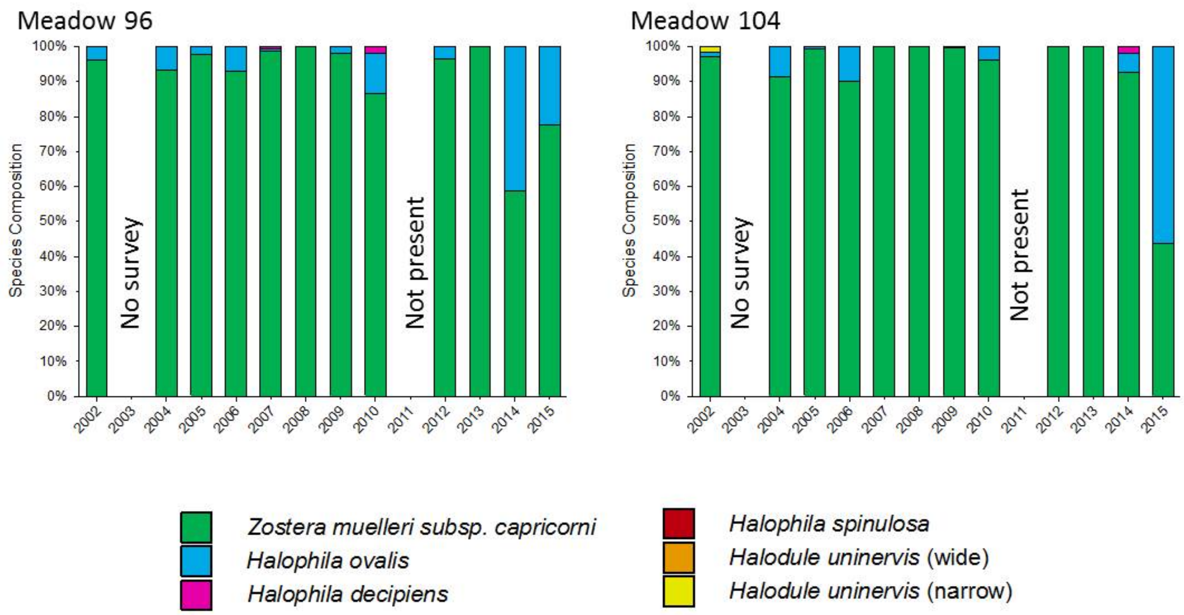
Meadow ID	Biomass ± SE (g DW m^{-2})	Area ± R (ha)	Community Type	Landscape Category	Species Present
RODDS BAY REGION					
94	0.30 ± 0.30	1 ± 0.5	Light *H. ovalis* with *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
96	1.68 ± 0.75	261 ± 20	Light *Z. muelleri* subsp. *capricorni* with *H. ovalis*	Aggregated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*
104	0.96 ± 0.50	18 ± 8	Light *H. ovalis* / *Z. muelleri* subsp. *capricorni*	Isolated patches	*Z. muelleri* subsp. *capricorni, H. ovalis*

n.p.; no seagrass present during the survey
n.a.; less than three biomass sites present

Appendix 3. Species composition of all species present, November 2002 - 2015.




Meadow 43
Species Composition
No survey
Meadow 58
No survey
Not present
Meadow 48
No survey
Meadow 60
No survey
Meadow 52-57
Meadow 94
No survey
Not present
Not present
Zostera muelleri subsp. capricorni
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide)
Halodule uninervis (narrow)


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

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