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PORT OF TOWNSVILLE
ANNUAL MONITORING

OCTOBER 2014

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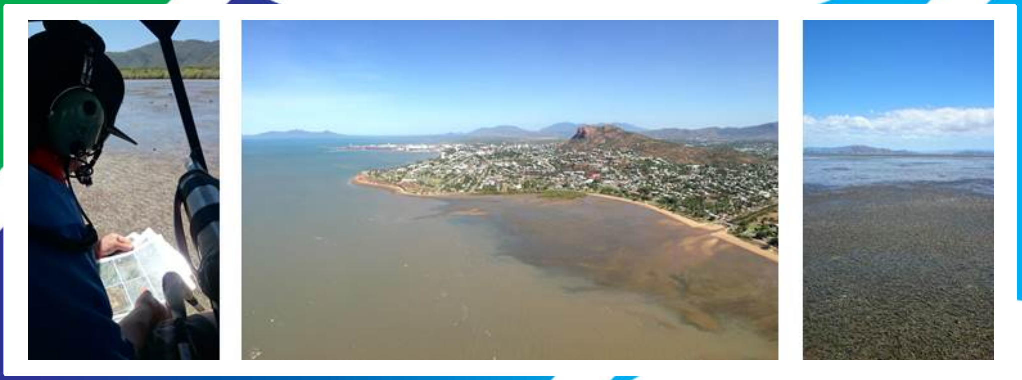
Report No. 15/01

February 2015



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A Report for the Port of Townsville Limited

Report No. 15/01

February 2015

Prepared by Jaclyn Davies, Samantha Tol and Michael Rasheed

Centre for Tropical Water & Aquatic Ecosystem Research
(TropWATER)
James Cook University
PO Box 6811
Cairns Qld 4870
Phone : (07) 4781 4262
Email: TropWATER@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

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For further information contact:
Jaclyn Davies
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 2014

Good

1. In 2014 seagrasses in Townsville had continued to recover for a third year, with the overall condition of seagrasses classified as “good”.

2. The average above-ground biomass and the distribution for the seagrass meadows in 2014 surpassed the long-term average in eight of the ten seagrass monitoring meadows.

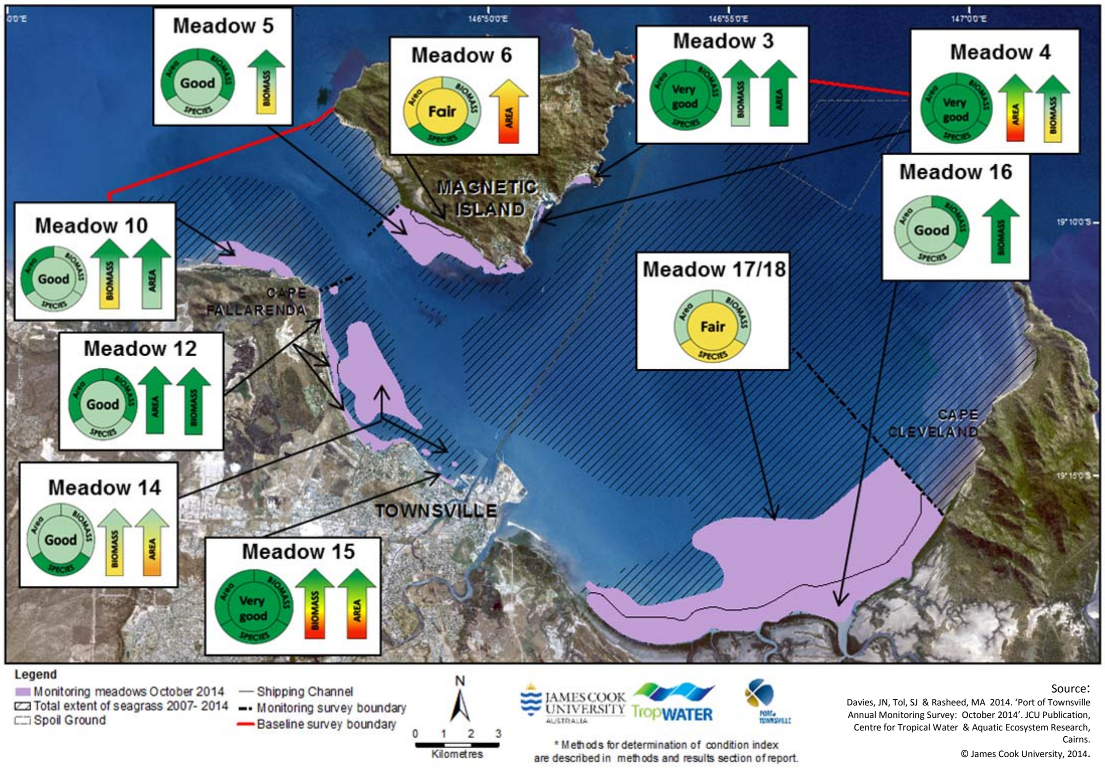
3. The species composition of the majority of monitoring meadows continued to shift towards larger “foundation” species such as Halodule, Zostera and Cymodocea and away from colonising species, however species composition for some meadows remained altered from baseline conditions between 2008-2011.

4. Dugong feeding trails were observed in high concentrations throughout Cockle Bay, Cape Cleveland, Cape Pallarenda and Shelly Beach survey areas.

IN BRIEF

Seagrasses have been monitored annually in the Port of Townsville since 2007. Each year seagrass monitoring meadows representing the range of different seagrass community types found in Townsville are mapped and assessed for changes in area, biomass and species composition. These metrics are then used to develop a seagrass condition index (see section 2.3 of this report for further details). In 2014 seagrass meadows in Townsville continued to recover from declines in area and biomass that occurred in the region leading up to 2011 (Figure 1). Eight of the ten monitoring meadows were classified as in “good” or “very good” condition when compared to their long-term averages (Map 1). With the remaining two classified as “fair” (Map 1).

Map 1. Seagrass condition index for Townsville seagrass monitoring meadows in 2014.



* Methods for determination of condition index are described in methods and results section of report.

Source:
Davies, JN, Tol, SJ & Rasheed, MA 2014. ‘Port of Townsville Annual Monitoring Survey: October 2014’. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

Seagrass Indicators/Scores		Very Good	Good	Fair	Poor	Very Poor
Biomass	Stable	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
	Highly 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	Stable	More than 10% above the baseline	Within 10% of the baseline (above or below)	Between 10% and 30% below the baseline	Between 30% and 50% below the baseline	More than 50% below the baseline
	Highly variable, intertidal	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
	Highly variable, subtidal	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
Species composition		Composition remains stable	Some loss of climax species	Shift towards colonising species	Colonising species dominant	Complete loss of climax species
Trend Indicators		⇧ BIOMASS	Substantial increase from previous year		⇩ BIOMASS	Substantial decrease from previous year

Townsville seagrasses were impacted prior to 2012 by regional-scale climate events that resulted in declines to seagrasses in other areas of tropical eastern Queensland including Cairns, Mourilyan, Bowen/Abbot Point and Gladstone. A third consecutive year of increasing seagrass abundance and meadow expansion in 2014 has seen the majority of these losses recovered for Townsville.

In 2014 both the above-ground biomass and area of seagrass surpassed the long-term average in eight of the ten seagrass monitoring meadows. The Cape Pallarenda *Halodule uninervis* meadow which had completely disappeared following several years of extremely limited distribution and abundance re-established in 2014 at its highest meadow distribution and mean biomass since monitoring began in 2007.

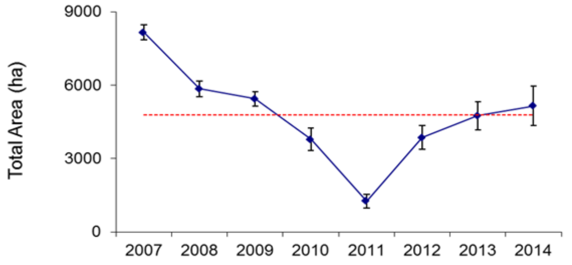
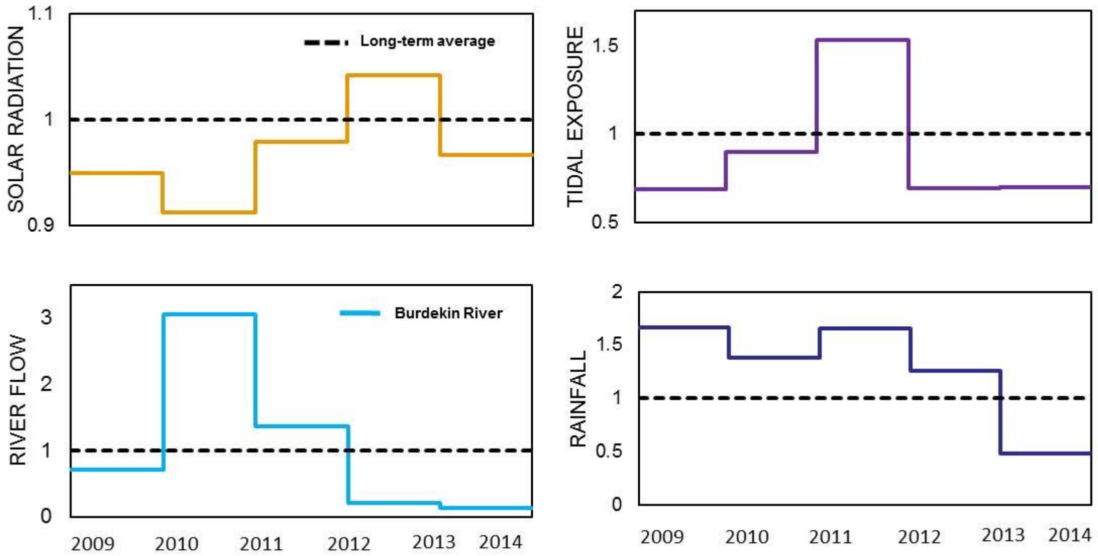


Figure 1. Total area of seagrass within the Townsville monitoring meadows from 2007 to 2014 (error bars = "R" reliability estimate). Red dashed line indicates 8-year mean of total meadow area.

Seagrasses were likely to have recovered some of their resilience following the multiple years of climate related impacts from 2007-2011. Recent climate trends have returned to being favourable for seagrass growth with higher light resulting from lower rainfall & river flow as well as a reduction in tidal exposure related stresses in 2014. Quantifying the relationships between seagrass change and these drivers would benefit from light and temperature assessments within the seagrass meadows which would yield detailed information about the requirements for healthy seagrass and assist in the management of human activities and impacts.

Recent climate trends in Townsville: Change in climate variables as a proportion of the long-term average



See Section 3.3 for detailed climate data

The Townsville seagrass monitoring program forms part of a broader Queensland program that examines condition of seagrasses in the majority of Queensland commercial ports and is a component of James Cook University's (JCU) broader seagrass assessment and research program. Other locations along the east coast of Queensland monitored as part of this program such as coastal seagrasses in Abbot Point and Gladstone have shown signs of recovery in 2013/2014 following severe climate events. Seagrasses in Western Cape York, the Torres Strait and the Gulf of Carpentaria were also generally in a good condition. However some other locations such as Mourilyan Harbour and Cairns have yet to recover and remain in a vulnerable condition. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

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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 (Hemminga and Duarte 2000; Costanza et al. 1997). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long term 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 has been 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. While each location is funded separately, a common methodology and rationale is used providing a network of seagrass monitoring locations throughout Queensland (Map 2).

A strategic long term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure that seagrasses and anthropogenic activities can co-exist. Ports use the information collected by this program to support planning and implementing sustainable port operations and development. The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses but has also 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 Port of Townsville Seagrass Monitoring Program

The Townsville port environment is managed by Port of Townsville Limited (PoTL). In 2007 PoTL commissioned the TropWATER Seagrass Group to undertake a seagrass monitoring program. The goal of the monitoring program is to understand the health of seagrass communities in Cleveland Bay. POTL uses this information to assist in the management of port activities and developments. Beyond the port-specific applications, the monitoring forms part of JCU's broader state wide assessment of seagrass condition and an overall measure of the marine environmental health of Townsville and Cleveland Bay.

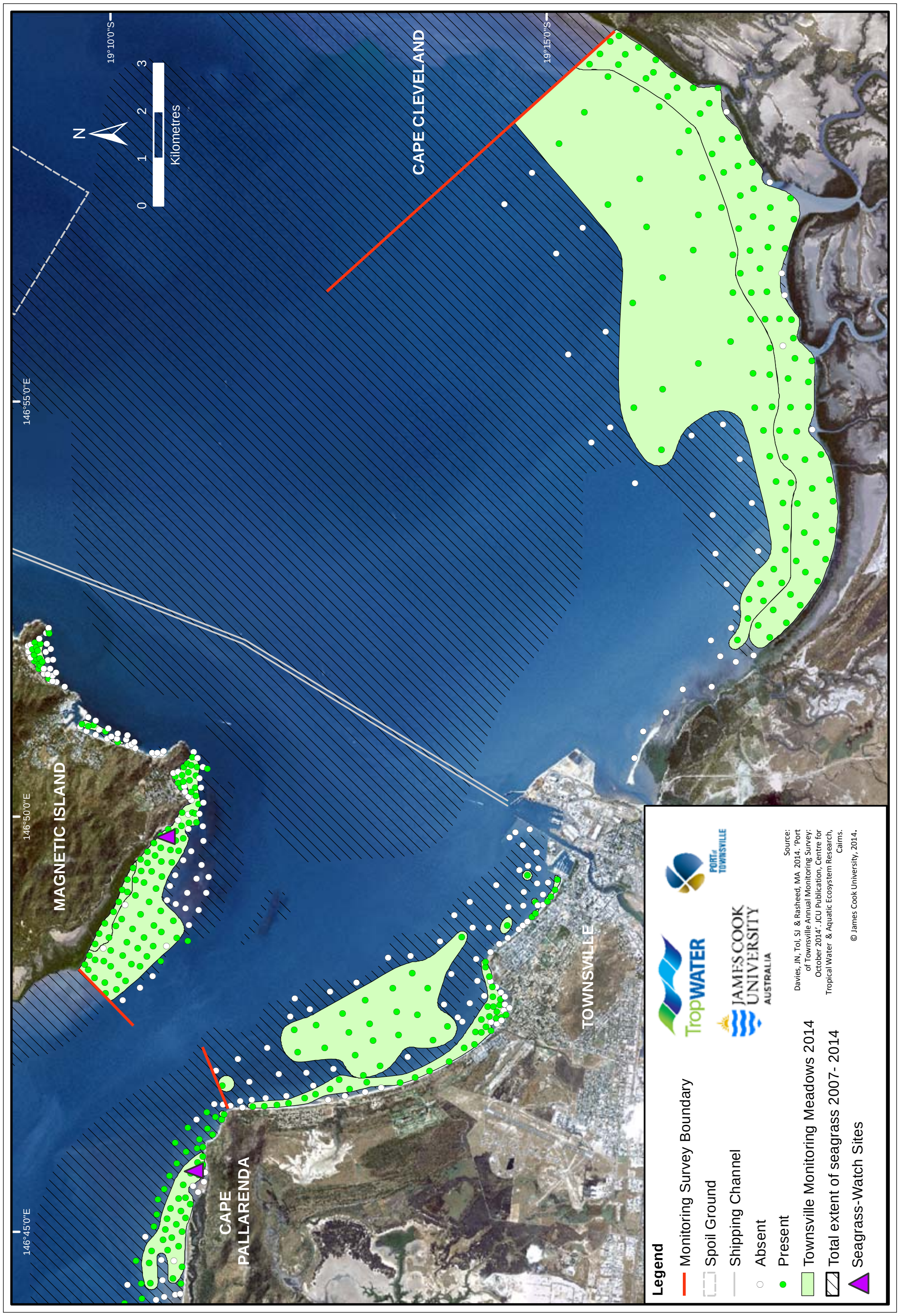
Detailed baseline surveys were conducted in summer 2007/2008 and winter 2008 to provide important information on the distribution, abundance and seasonality of seagrasses within the broader port limits (Rasheed and Taylor 2008). From these baseline surveys, eleven seagrass meadows were identified as representative of the range of seagrass species and habitat types (intertidal and subtidal) found within the Townsville port limits. The meadows also included habitat areas most likely to be impacted from anthropogenic activities. Since 2009 there have been ten meadows surveyed as two of the monitoring meadows at Cape Cleveland merged based on species composition. An updated baseline survey was conducted in 2013. Monitoring has been conducted annually since October 2008 (Map 3).

This report presents the results of the long term seagrass monitoring conducted in October 2014. The objectives of the 2014 long term monitoring survey were to:

1. Survey seagrass monitoring meadows within the Cleveland Bay to determine seagrass distribution, species composition and abundance;
2. Assess the changes in seagrass distribution, species composition and abundance;
3. Incorporate results into the Geographic Information System (GIS) database for the Cleveland Bay.

In addition to the larger spatial scale surveys in this monitoring program, the Reef Rescue Marine Monitoring Program (Reef Rescue MMP) also conduct intensive small-scale seagrass monitoring using the Seagrass-Watch protocol. Seagrass-watch monitoring occurs at two locations within the boundaries of the current survey (Map 3). The results of the current survey are considered with respect to these additional seagrass monitoring sites.

Map 3 Extent of October 2014 seagrass monitoring meadows and habitat characterisation sites in Cleveland Bay.



Source:
Davies, JN, Tol, SJ & Rasheed, MA 2014. 'Port of Townsville Annual Monitoring Survey: October 2014'. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

2 METHODS

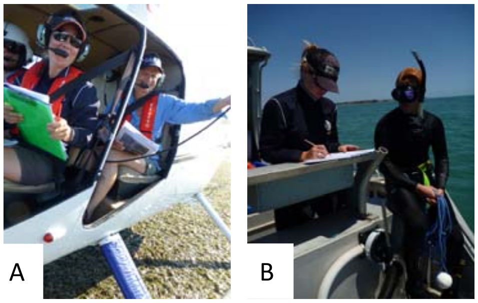
2.1 Sampling Approach and Methods

The 2014 seagrass monitoring survey was conducted on the 4th-10th October 2014. Sampling at this time of year allows for direct comparison with baseline surveys and subsequent monitoring surveys between 2007 - 2013. It also coincides with the seasonal peak abundance for tropical seagrass communities.

The 2014 survey sampled the ten annual monitoring meadows. This survey included representative intertidal and subtidal areas extending from the Bohle River to Cape Cleveland and the south and east coasts of Magnetic Island (Map 3).

Two sampling techniques were used:

1. Intertidal areas: helicopter survey
2. Shallow subtidal areas: boat based free diving survey



Seagrass monitoring utilising (A) helicopter aerial surveillance and (B) boat based free divers

Intertidal meadows were sampled at low tide using a helicopter. GPS was used to fix and record the position of meadow boundaries. Seagrass meadow characteristics were then recorded at sites scattered within the seagrass meadow as the helicopter hovered within two metres 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 changes (Rasheed et al., 2003).

Subtidal meadows were sampled from a small boat using free divers. Seagrass meadow characteristics were recorded at sites located along transects perpendicular to the shoreline. Sites were located at approximately 100m intervals along each transect 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.

At each sampling site seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (see Kirkman, 1978; Mellors, 1991). A 0.25m2 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 photos 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}).

Data collected and recorded at each site included:

1. *Seagrass species composition* - Seagrass identification in the field according to Kuo and McComb (1989).
2. *Seagrass biomass* - Estimates of seagrass biomass using a calibrated visual estimates technique
3. *Algae* - Presence/absence, algae type and per cent cover (identified according to Cribb 1996).
4. *Site location* - by GPS and weather conditions recorded at the time of sampling.

Habitat mapping and Geographic Information System

Spatial data from the 2014 survey were entered into the Port of Townsville Geographic Information System (GIS). Three seagrass GIS layers were created in ArcGIS® - site information, seagrass meadow characteristics and seagrass landscape category.

- ***Site information***- data containing seagrass per cent cover and above-ground biomass (for each species), depth below mean sea level (dbMSL), sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.

- ***Seagrass meadow characteristics***- area data for seagrass meadows with summary information on meadow characteristics. Seagrass meadows were assigned a meadow identification number which was used to compare individual meadows among annual monitoring surveys. Identification numbers for core monitoring meadows were also used to reference meadows throughout the results section. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). Abundance categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 2).

Table 1 Nomenclature for community types, 2014.

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	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, 2014.

Density	Mean above-ground biomass (g DW m^{-2})				
	***H. uninervis* (narrow)**	***H. ovalis* *H. decipiens***	***H. uninervis* (wide) *C. serrulata***	***H. spinulosa***	***Z. capricorni***
Light	< 1	< 1	< 5	<15	< 20
Moderate	1 - 4	1 - 5	5 – 25	15-35	20 - 60
Dense	> 4	> 5	> 25	>35	> 60

- ***Seagrass landscape category***- area data showing the seagrass landscape category determined for each meadow.

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.

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping method used for that meadow (Table 2). The mapping precision estimate was used to calculate a range of meadow area for each meadow and was expressed as a meadow reliability estimate (R) in hectares (Table 3). The reliability estimate for subtidal habitat is based on the distance between sites with and without seagrass when determining the habitat boundary. Additional sources of mapping error were embedded within the meadow reliability estimates.

2.2 Statistical analysis

Seagrass above-ground biomass was compared among years using a one-way analysis of variance (ANOVA). Each meadow's data was examined for normality and homogeneous variance and data transformations applied to meet ANOVA assumptions ($\log_{(x+1)}$-transformed or square root-transformed). Tukey's post hoc analysis (equal variances) or a Behrens Fisher test (unequal variance) was used to test for significant differences in biomass between years. All statistical analysis was performed using R (R Development Core Team 2009).

Table 3 Mapping precision and methodology for seagrass meadows in Townsville, 2014.

Mapping precision	Mapping methodology
10m	Meadow boundaries determined from helicopter and free diver; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent aerial photography aided in mapping.
15-20m	Meadow boundaries determined from helicopter and free diver; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and aerial photography; Relatively high density of mapping and survey sites.
50m	Meadow boundary interpreted from free diving surveys; All meadows partially subtidal; Relatively high density of survey sites; Recent aerial photography aided in mapping.
150m	Subtidal meadow boundaries determined from free diving/grab surveys only; All meadows subtidal; Moderate density of survey sites; Recent aerial photography aided in mapping.

2.3 Seagrass meadow condition index

This is the second year of applying and testing the seagrass meadow condition index. This index was developed for the monitoring meadows and is based on the mean above ground biomass, total meadow area and species composition of each seagrass meadow. We have modified the classifications of the initial index that was rolled out and tested across ports in 2013/2014 by expanding the number of categories from three to five. The previous classifications of seagrass meadow condition: “good”, “moderate” or “poor has been expanded to five classifications: “very good”, “good”, “fair”, “poor” and “very poor” to more closely match other report card programs in Queensland that apply condition indices (i.e. Reef Rescue Marine Monitoring Program, Gladstone Healthy Harbour Program). The index provides a means of comparing current meadow condition and likely resilience to impacts with the known long-term average.

Two different threshold ranges for biomass and three different threshold ranges for area were developed to recognise that some seagrass meadows are historically more stable and others are expected to fluctuate substantially from year to year (highly variable). These differences reflect growth characteristics of species that comprise different meadows, as well as the meadow setting. There are also regional differences within a meadow that reflect the natural growing conditions. This resulted in four classes of monitoring meadow for reporting purposes.

- **Class 1 Meadows –** stable biomass, stable distribution
- **Class 2 Meadows –** variable biomass, stable distribution
- **Class 3 Meadows –** variable biomass, variable distribution (intertidal)
- **Class 4 Meadows –** variable biomass, variable distribution (subtidal)
- **Class 5 Meadows –** stable biomass, variable distribution (intertidal)

For biomass and area the current value for each meadow was compared with the meadow’s long-term average and categorised into a range that corresponded to the five index categories (Table 4). Ranges for each level of the condition index were selected based on the historical variability of the monitoring meadow representing seagrass condition. For the Townsville monitoring meadows, the long-term average of biomass is determined as an average incorporating all data since monitoring began (currently 8 years) and updated each year. In other locations where we have a longer term dataset the average has been fixed based on the first 10 years of monitoring. We will review the appropriateness of fixing the average for Townsville once the program has collected 10 years of data.

Species composition was assessed qualitatively as “very good” when the species composition remained stable; “good” when there had been minor loss of the climax species; “fair” when there had been a substantial shift in species toward colonising species indicating disturbance or stress; “poor” when the meadow had shifted to become clearly dominated by colonising species; and “very poor” where there was a complete loss of the climax species. Species shifts are relative and determined on a meadow by meadow basis taking into account both the current years’ species composition and historical trends.

It is important to note that tropical seagrass communities vary in condition naturally due to a number of factors including climate. Some monitoring meadows being classified as “poor” condition can be part of the natural range of expected conditions and not necessarily a result of anthropogenic impacts. The index provides a means of comparing current meadow condition and likely resilience to impacts with the known long term average.

The final condition of each monitoring meadow was determined by looking at all three factors (biomass, area and species composition), with the lowest of any of the three factors determining the overall condition index. Where additional information was available, such as seagrass seed-bank status, light and temperature stress or other measures of resilience such as flowering and fruiting and carbohydrate stores may be used to modify the overall condition score if they indicate the meadow may be under increased stress. The average condition for all of the monitoring meadows combined was used to determine the overall seagrass condition for the study area.

A trend indicator was also added where there has been a substantial increase or decrease in any of the three criteria (biomass, area, species composition) from the previous year. In the condition index this is represented as either an upwards or downwards arrow for the criteria where the change has occurred (Table 4).

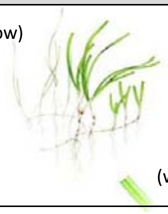
Table 4. Determination of seagrass condition index for Townsville seagrass monitoring meadows.

Seagrass Indicators/Scores		**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**
Biomass	Stable	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
	Highly 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	Stable	More than 10% above the baseline	Within 10% of the baseline (above or below)	Between 10% and 30% below the baseline	Between 30% and 50% below the baseline	More than 50% below the baseline
	Highly variable, intertidal	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
	Highly variable, subtidal	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
Species composition		Composition remains stable	Some loss of climax species	Shift towards colonising species	Colonising species dominant	Complete loss of climax species
Trend Indicators		↑ BIOMASS	Substantial increase from previous year	↓ BIOMASS	Substantial decrease from previous year	

3 RESULTS

3.1 Seagrass distribution and abundance in the Annual Monitoring Meadows

A total of 550 helicopter and underwater diver site assessments were made in Townsville in 2014, 62% of these had seagrass present (Map 3). Seven seagrass species (from 3 families) were identified within the monitoring meadows. For a complete species list and seagrass distribution, refer to the 2007 baseline survey report (Rasheed & Taylor 2008).

Family	**Species**			
CYMODOCEACEAE Taylor	*Cymodocea serrulata* (R.Br.) Aschers and Magnus		*Halodule uninervis* (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier	
ZOSTERACEAE Drummortier	*Zostera capricorni* Aschers.		* Note *Zostera capricorni* has been re-classified as a sub-species of *Zostera mulleri* however for consistency purposes we will continue to name the seagrass as *Z. capricorni*	
HYDROCHARITACEAE Jussieu	*Halophila decipiens* Ostenfield		*Halophila ovalis* (R. Br.) Hook. F.	
	Thalassia hemprichii (Ehrenb.) Aschers. in Petermann		*Halophila spinulosa* (R. Br.) Aschers. In Neumayer	

The ten monitoring meadows had a combined total area of 5155.75 ± 815.27 hectares of seagrass. This was the third consecutive year of increase in meadow area following declines from 2007 to 2011 (Map 4; Appendix 2). Total meadow area exceeded the 8-year average of 4786.09 ± 444.29 ha but remained well below the 2007 peak in area (Figure 1). Individual meadow area ranged from 6.6 ha in the inshore monitoring meadow at the southern end of Cape Pallarenda (Meadow 15), to 2,533.3 ha in the Cape Cleveland meadow (Meadow 17).

Mean above-ground biomass of monitoring meadows ranged from 2.86 ± 0.36 g DW m^{-2} in the shallow subtidal *H. spinulosa* meadow (Meadow 14; Figure 8) to 43.27 ± 4.58 g DW m^{-2} in the Cape Cleveland *Z. capricorni* meadow (Meadow 16; Figure 10). Of the ten monitoring meadows, five had the second highest mean meadow biomass recorded since monitoring began, and two meadows (meadows 12 and 15) had the highest biomass observed in eight years of monitoring (Appendix 2).

The intertidal *Z. capricorni* meadows on Magnetic Island and Cape Cleveland (Meadows 6 & 16) increased in landscape cover from aggregated patches to continuous cover (Figures 5 and 10). Seagrass monitoring meadows had a light or moderate density of seagrass cover, with the exception of Meadows 12 and 17. These meadows had dense cover of *H. uninervis* with mixed species (Figures 7 and 11).

Dugong feeding trails were observed in high concentrations in Cockle Bay, Cape Cleveland, Cape Pallarenda and Shelly Beach (Map 3). Seagrass meadows at these sites were dominated by *H. uninervis* or *Z. capricorni*.

3.1.1 Comparison with previous monitoring surveys

Seagrasses in Townsville continued to recover in 2014, with the overall condition of seagrasses in Townsville classified as "good". The average above-ground biomass and distribution for the monitoring meadows in 2014 surpassed the long-term average in nearly every seagrass meadow, with the two exceptions of area in the Magnetic Island inshore meadow (Meadow 6) and both biomass and area in the Cape Pallarenda subtidal *Halophila* meadow (Meadow 14) (Figures 5 and 8; Appendix 2). Though species composition in the Townsville monitoring meadows has not returned to the baseline conditions from 2008-2011, composition in 2014 for the majority of meadows was stable or shifting towards climax species and representation by colonising species was decreasing (Figures 2-11).

Above-ground biomass increased in all ten monitoring meadows. Seagrass area continued to increase for a third year following the partial recovery of seagrass meadows in 2012, with an increase in total meadow area of over 3,888 ha since 2011 (Map 4; Figures 2-11; Appendix 2). Several monitoring meadows approached the peaks in above-ground biomass and distribution observed during the first few years of monitoring, with a few meadows exceeding these peaks to have the highest area or biomass reported since monitoring began in 2007 (Figures 2-11).

The species composition of many seagrass monitoring meadows continued to shift towards the larger climax species at the expense of the colonising species responsible for initial recovery (Figures 2-11). The large Magnetic Island *H. uninervis* meadow (Meadow 5) had a substantial increase in average above-ground biomass from 6.0 ± 0.7 to 26.37 ± 3.22 g DW m^{-2} in 2014, and a considerable increase in the proportion of the large species *C. serrulata* with a corresponding decrease in the smaller colonising *H. decipiens*, resulting in a species composition more similar to the baseline 2007-2009 composition (Figure 4). Similarly the meadow at Shelly Beach in Cape Pallarenda had a reduction in the colonising species *H. ovalis* with an increase in *Z. capricorni*, contributing to an increase in biomass to the second highest recorded since monitoring began (Figure 6; Appendix 2).

Since 2009 the Cape Cleveland *H. uninervis* dominated meadow (Meadow 17/18) has been merged following the disappearance of *C. serrulata* (Figure 11). A four-year decline in meadow area from 2007-2011 left the meadow severely fragmented into four remnant patches of extremely low biomass (Figure 11; Appendix 2). During this time the species composition shifted from a *C. serrulata* dominated meadow to a *H. uninervis* (thin) meadow with higher proportions of *Halophila spp.* (Figure 11). Since 2012, meadow area had increased by over 784 ha, primarily along the deeper margins as well as the western end to just south of Alligator Creek. Biomass showed signs of recovery and in 2013 *C. serrulata* returned as a small proportion. However the density of *C. serrulata* remains too low to separate out the original two meadows. Should the density continue to increase, these meadows may be separated as originally described in the baseline surveys.

The large inshore *Z. capricorni* meadow (Meadow 16) in Cape Cleveland had the second highest biomass and meadow area recorded since 2007 (Appendix 2; Figure 10). This meadow fragmented into two sections following severe declines in area in 2010-2011 and had increased in both mean biomass and meadow extent for the last three years (Appendix 1). The species composition since 2010 had remained relatively stable, with declines in the dominance of *H. uninervis* (thin) since 2012. *C. serrulata* returned in very small patches and remains a very small component of the species composition.

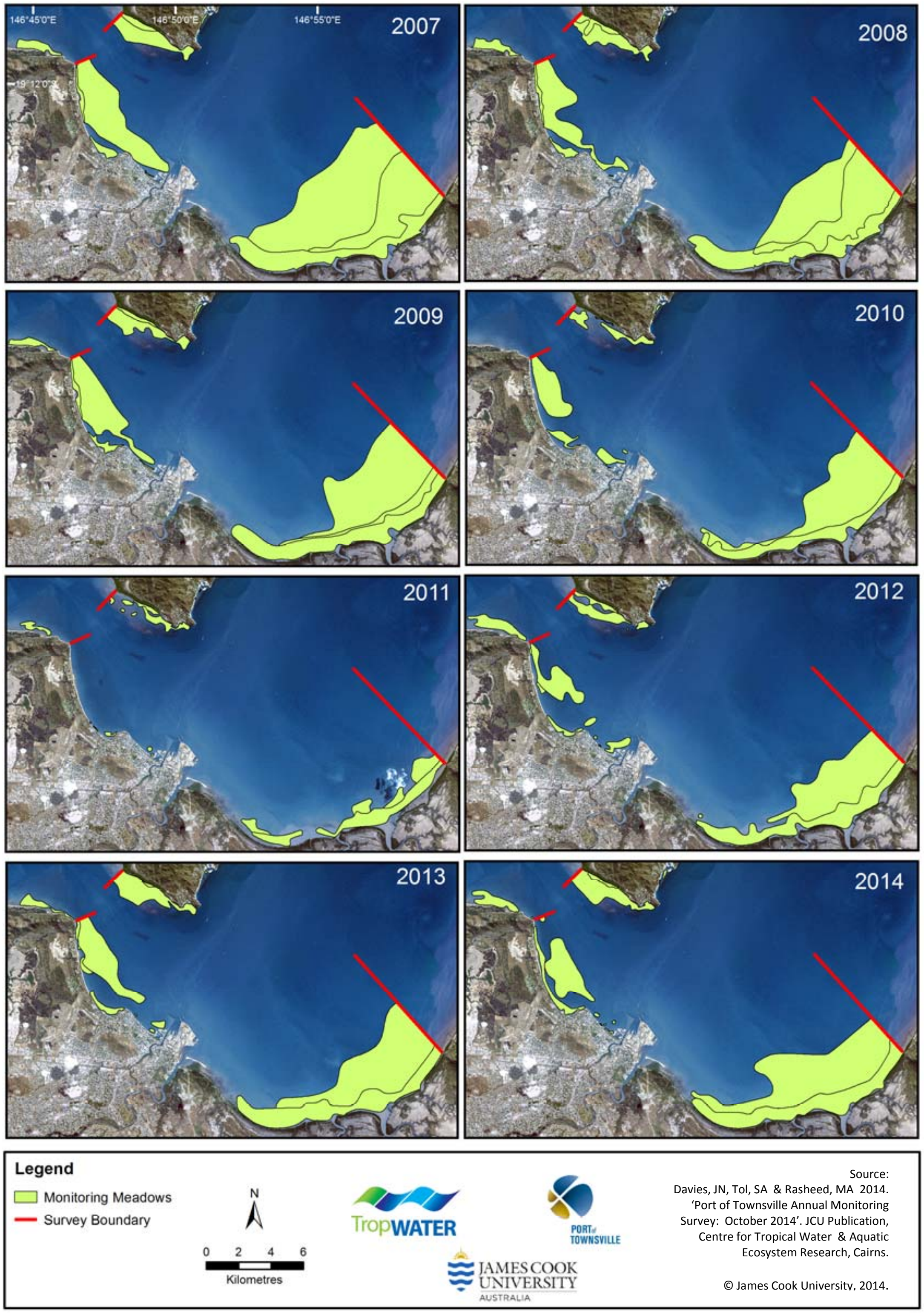
The intertidal *H. uninervis* meadow at Rowes Bay (Meadow 12) had been fragmented and patchily distributed for the past several years but had expanded to form one continuous meadow in 2014. Both biomass and area were well above the long term averages (Figure 7; Appendix 2). The intertidal/subtidal *H. uninervis* meadow along the Strand (Meadow 15) has historically been extremely patchy and highly variable, disappearing completely in 2013 following declines in area in 2012. In 2014 this meadow re-established and had the second highest area and highest average above-ground biomass observed since monitoring began (Figure 9; Appendix 2).

The subtidal Rowes Bay meadow (Meadow 14) has historically been variable in distribution, particularly at the southern extent of the meadow. In 2010 the meadow fragmented into three areas, decreased in biomass and underwent a species shift from a *H. spinulosa* dominated meadow to a *H. decipiens* meadow (Appendix 2; Figure 8). By 2013 the meadow had expanded from Cape Pallarenda further south toward the Strand as well as along the deeper margin, connecting two patches and exceeding the long-term average. However in 2014 meadow area declined while biomass continued to increase (Figure 8). The species composition in 2014 remains similar to the 2007-2009 composition, with *H. spinulosa* returning as the dominant species and *H. decipiens* decreasing to a small component (Figure 8).

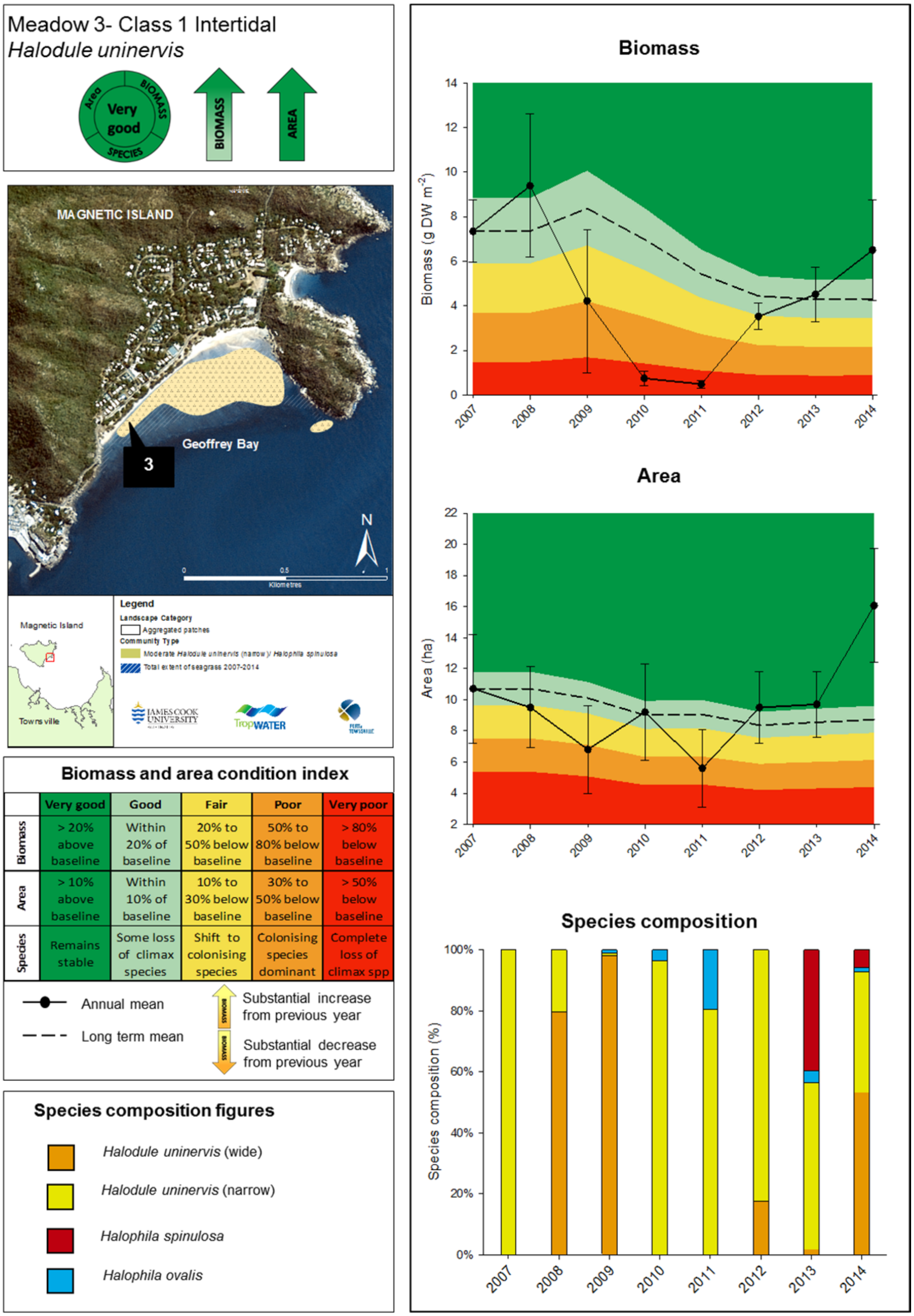
All of the four monitoring meadows on Magnetic Island (Meadows 3-6) increased in biomass, with all but Meadow 5 increasing in area (Appendix 2; Figures 2-5). The area of the intertidal *Z. capricorni* meadow in Cockle Bay (Meadow 6) has recovered by expanding both along shore and offshore following a sharp decline in 2013, resulting in the meadow area falling well below the long term average (Appendix 2; Figure 5). This expansion corresponded to an increase in mean biomass as well as an increased dominance of *Z. capricorni* at the expense of the colonising species *H. decipiens*. Meadow 5 was one of only two meadows to decline in meadow area in 2014, though meadow biomass had substantially increased as noted above (Figure 4; Map 4).

The monitoring meadows in Geoffrey and Nelly Bays (Meadows 3 and 4) have had a stable species composition for the last few surveys and remain dominated by *H. uninervis* (Figures 2 and 3). The *H. spinulosa* in Meadow 3, which appeared for the first time in 2013, had decreased in dominance in 2014 (Figure 2). Meadow 3 had increased in area to the largest extent yet observed, and Meadow 4 recovered substantially in area to exceed the long-term average in 2014 (Figure 3).

Map 4 Seagrass monitoring meadow location and spatial extent from October 2007-2014.



Source:
Davies, JN, Tol, SA & Rasheed, MA 2014.
'Port of Townsville Annual Monitoring Survey: October 2014'. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.



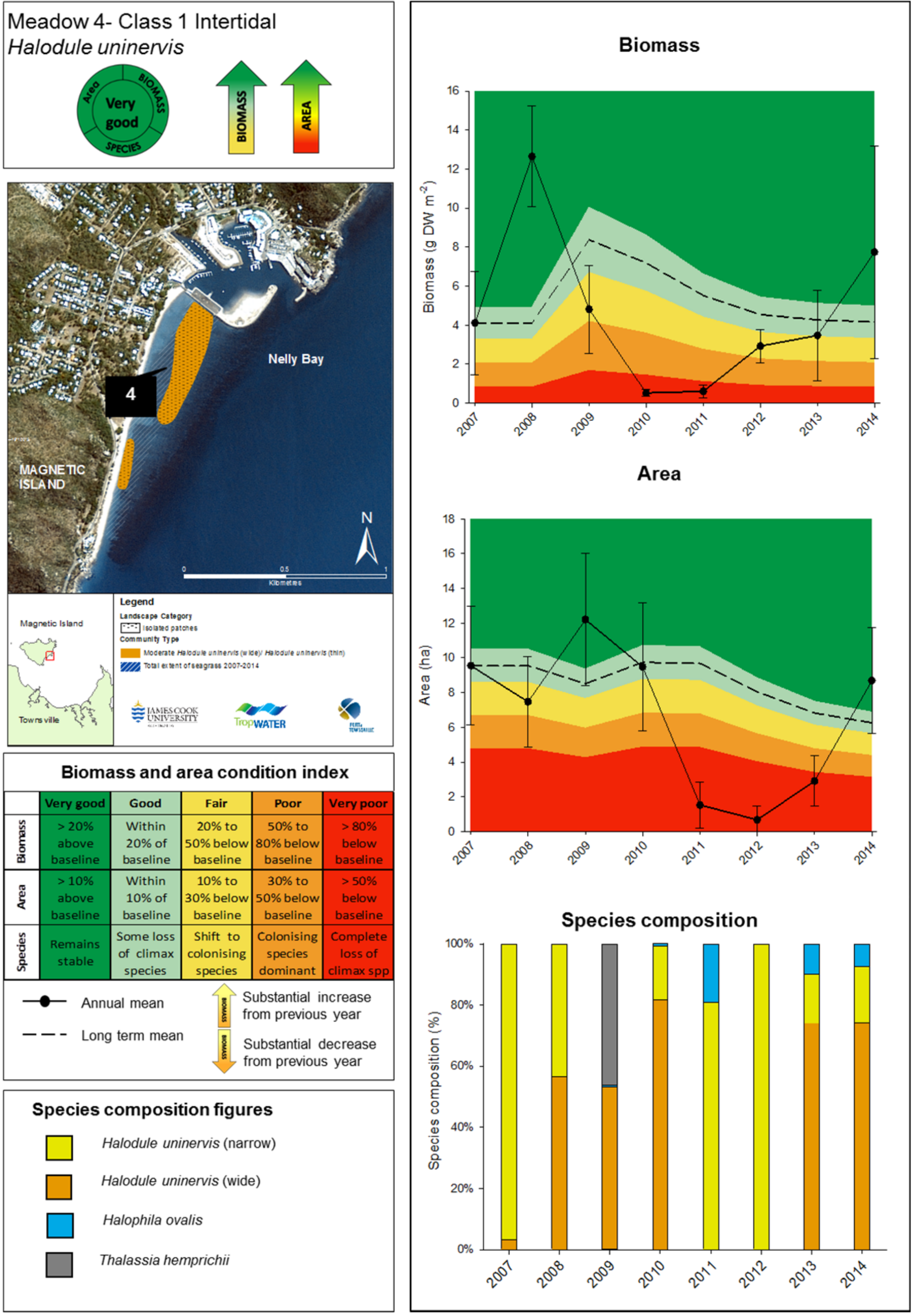
Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Species composition figures

🟧	*Halodule uninervis* (wide)
🟨	*Halodule uninervis* (narrow)
🟥	*Halophila spinulosa*
🟦	*Halophila ovalis*

Figure 2 Changes in meadow area, biomass and species composition for seagrass Meadow 3 at Magnetic Island, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).



Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

●— Annual mean

– – Long term mean

BIOMASS Substantial increase from previous year

BIOMASS Substantial decrease from previous year

Species composition figures

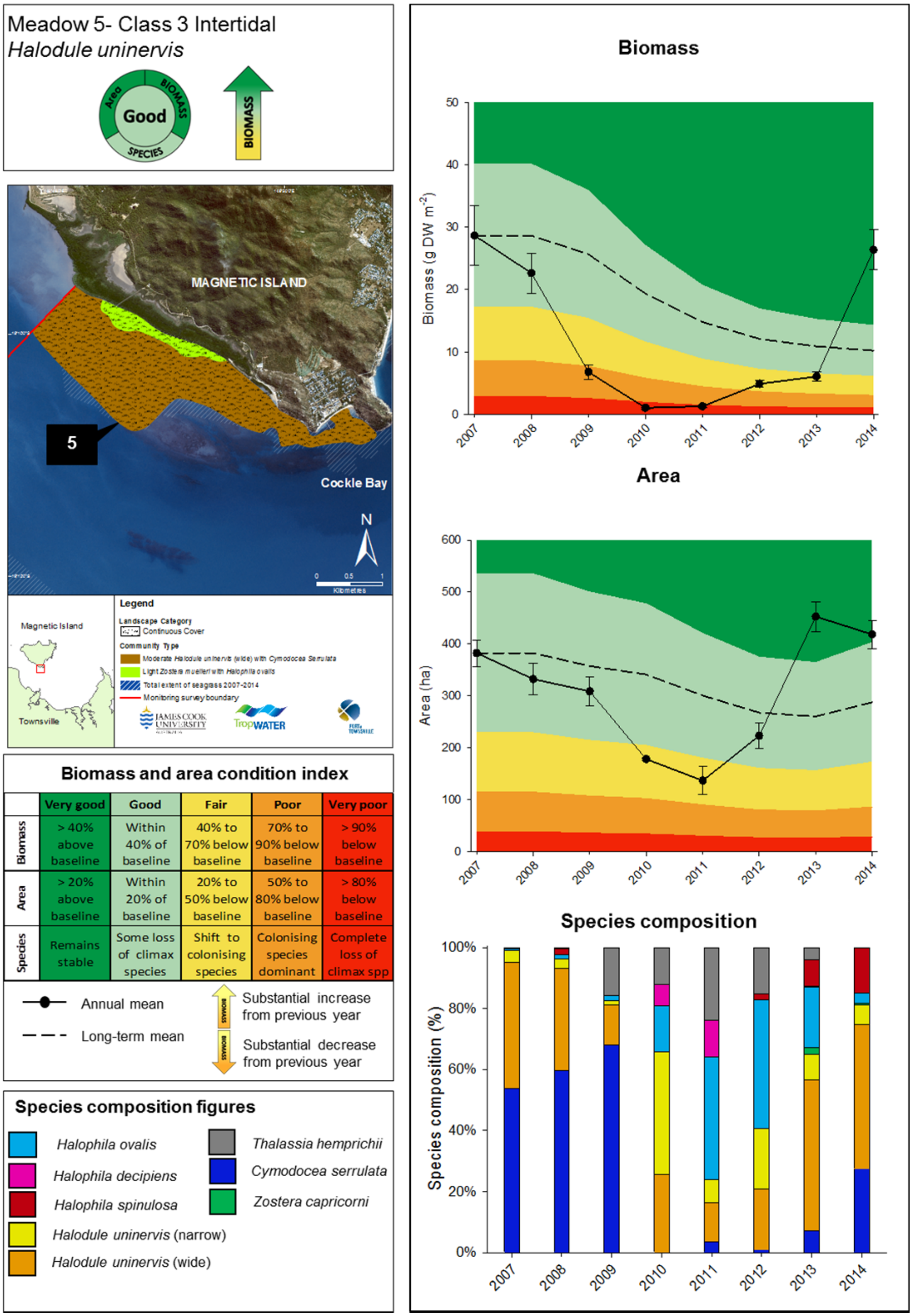
🟨 *Halodule uninervis* (narrow)

🟧 *Halodule uninervis* (wide)

🟦 *Halophila ovalis*

⬜ *Thalassia hemprichii*

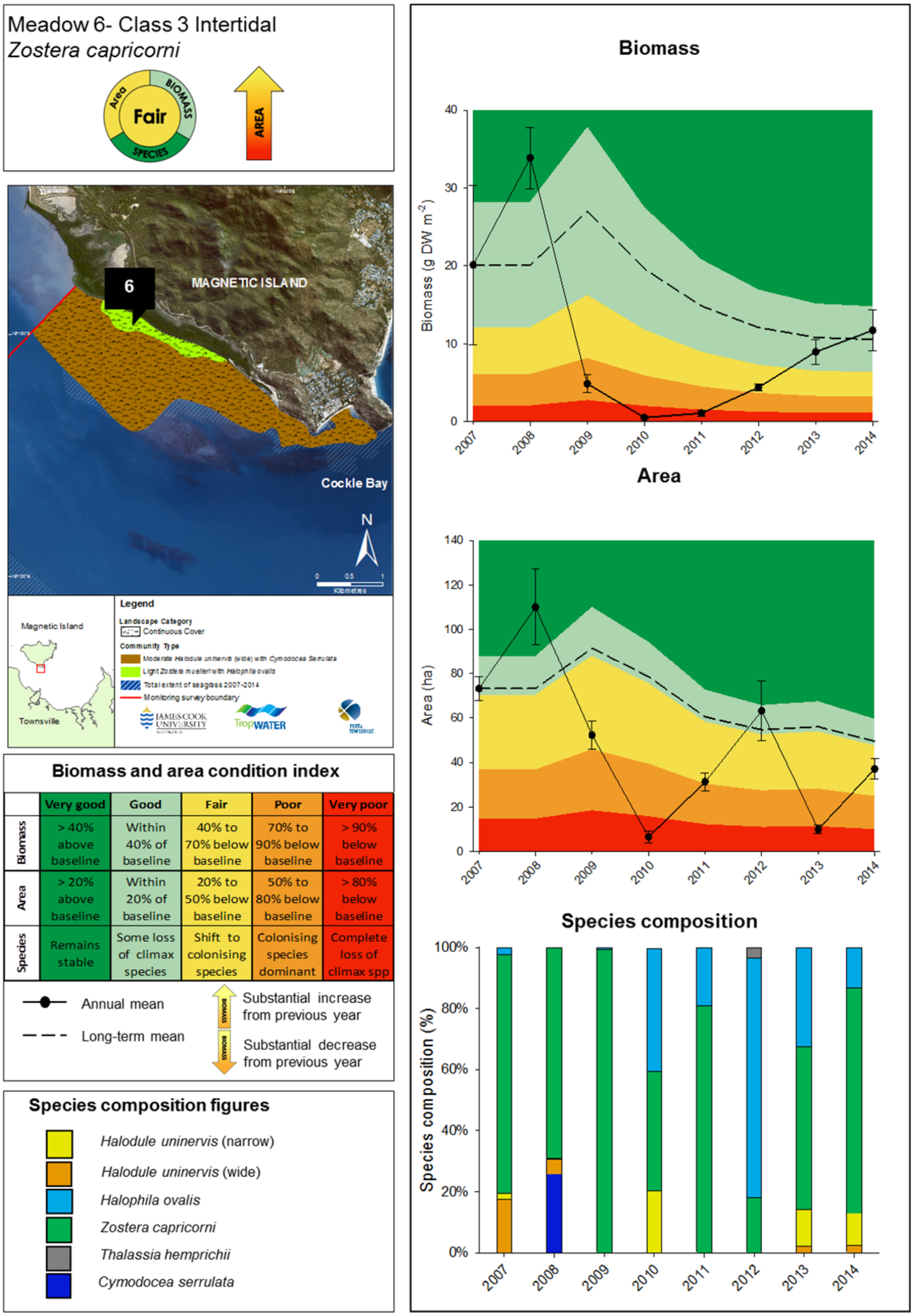
Figure 3 Changes in meadow area, biomass and species composition for seagrass Meadow 4 at Magnetic Island, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).



Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Figure 4 Changes in meadow area, biomass and species composition for seagrass Meadow 5 at Magnetic Island, October 2007- 2014. (biomass error bars = SE; area error bars = “R” reliability estimate).



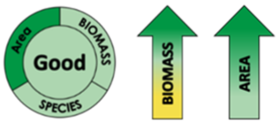
Biomass and area condition index

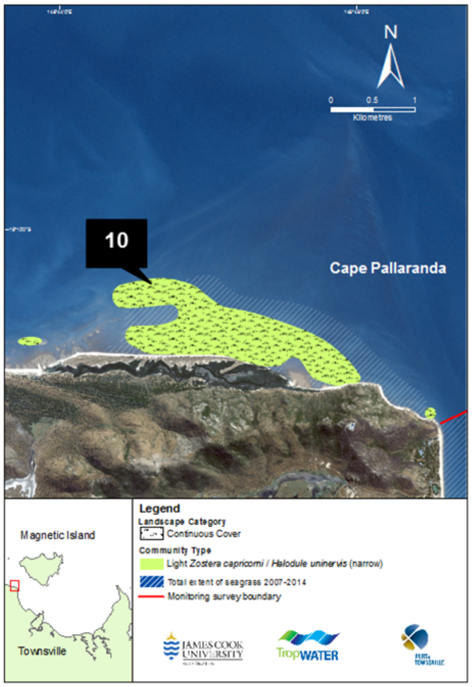
	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Figure 5 Changes in meadow area, biomass and species composition for seagrass Meadow 6 at Magnetic Island, October 2007- 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 10- Class 3 Intertidal

Zostera capricorni





Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

●— Annual mean

– – Long-term mean

⇧ Substantial increase from previous year

⇩ Substantial decrease from previous year

Species composition figures

- 🟨 *Halodule uninervis* (narrow)
- 🟧 *Halodule uninervis* (wide)
- 🟦 *Halophila ovalis*
- 🟩 *Zostera capricorni*
- 🟦 *Cymodocea serrulata*

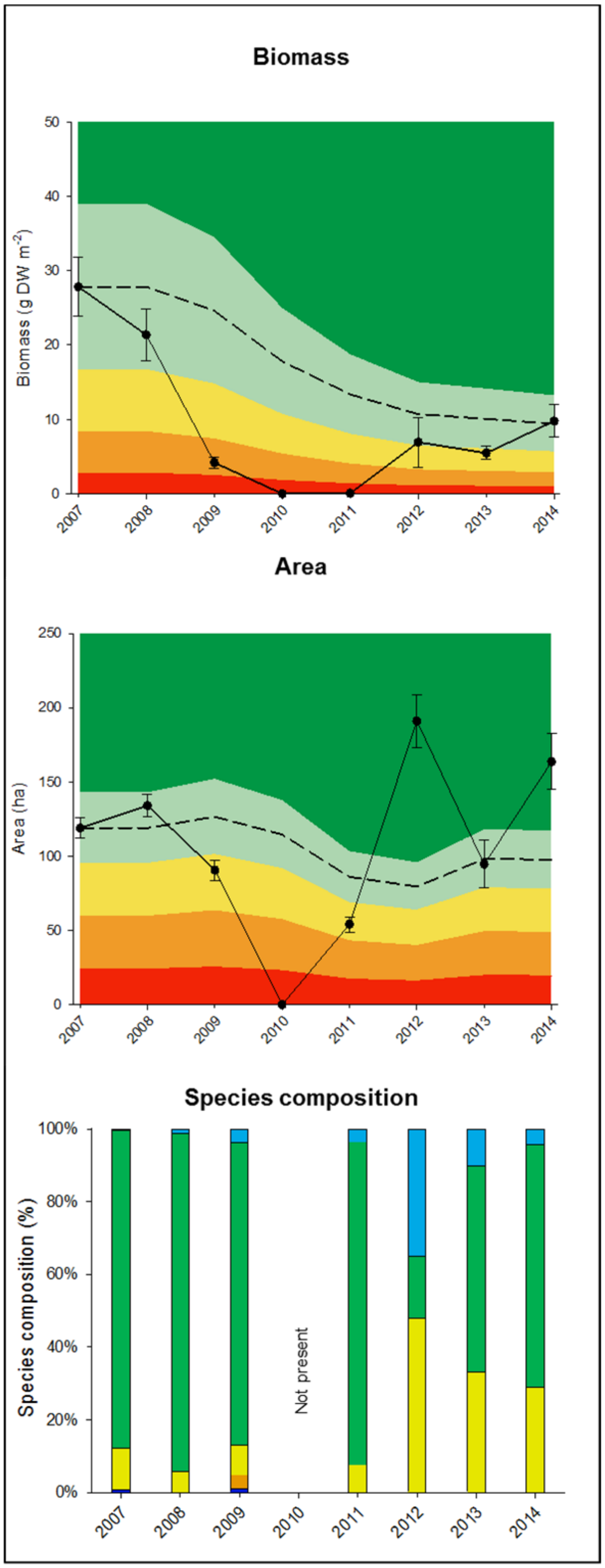
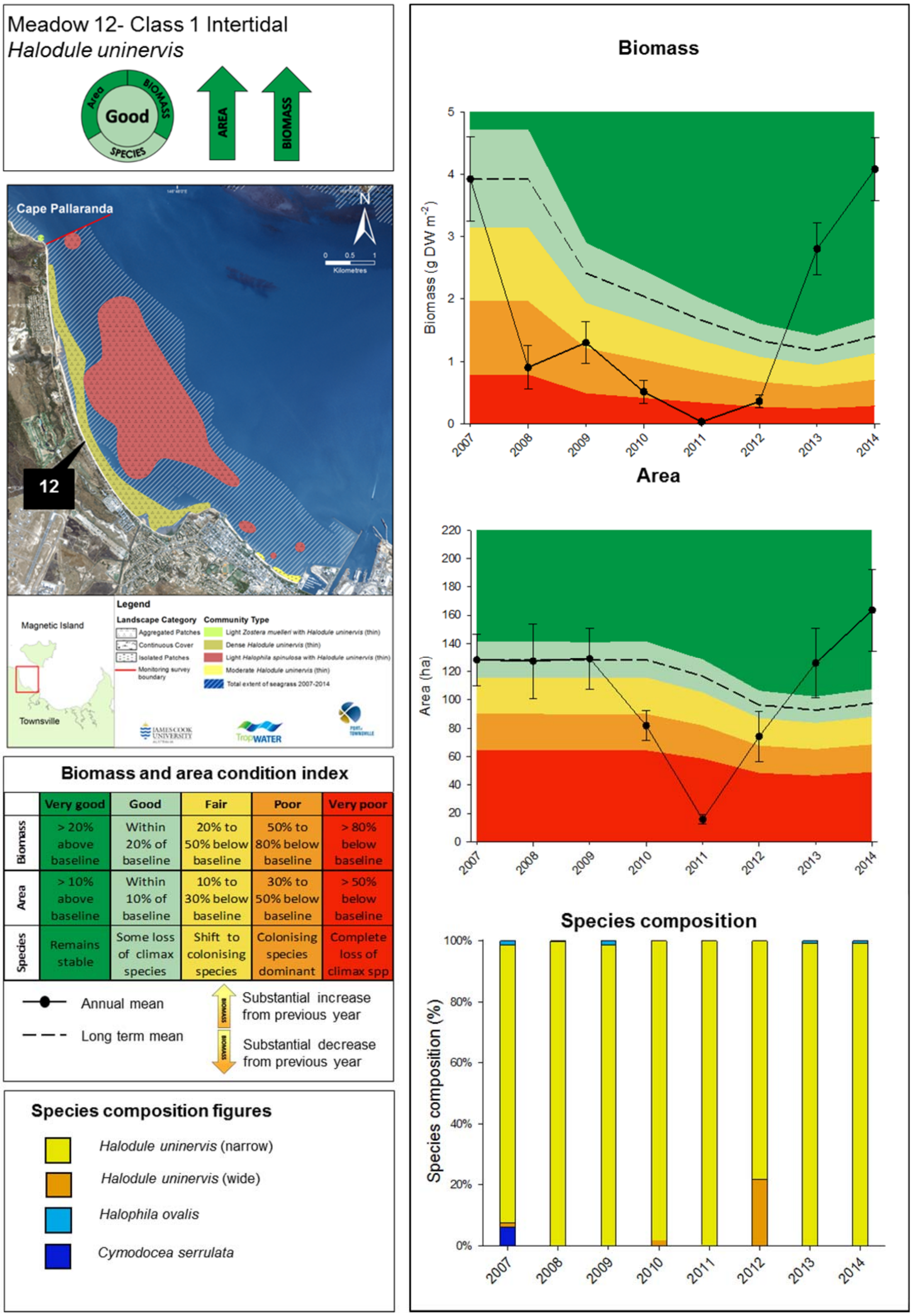


Figure 6 Changes in meadow area, biomass & species composition for seagrass Meadow 10 in Cape Pallarenda, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

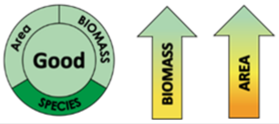


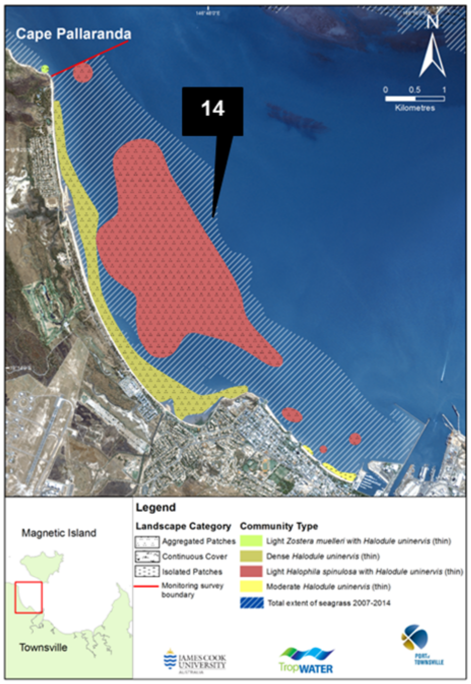
Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Figure 7 Changes in meadow area, biomass & species composition for seagrass Meadow 12 in Cape Pallarenda, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 14- Class 5 Subtidal
Halophila spinulosa





Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

● Annual mean
– – – Long term mean
Substantial increase from previous year
Substantial decrease from previous year

Species composition figures

🟨 *Halodule uninervis* (narrow)
🟧 *Halodule uninervis* (wide)
🟦 *Halophila ovalis*
🟪 *Halophila decipiens*
🟥 *Halophila spinulosa*
🟦 *Cymodocea serrulata*

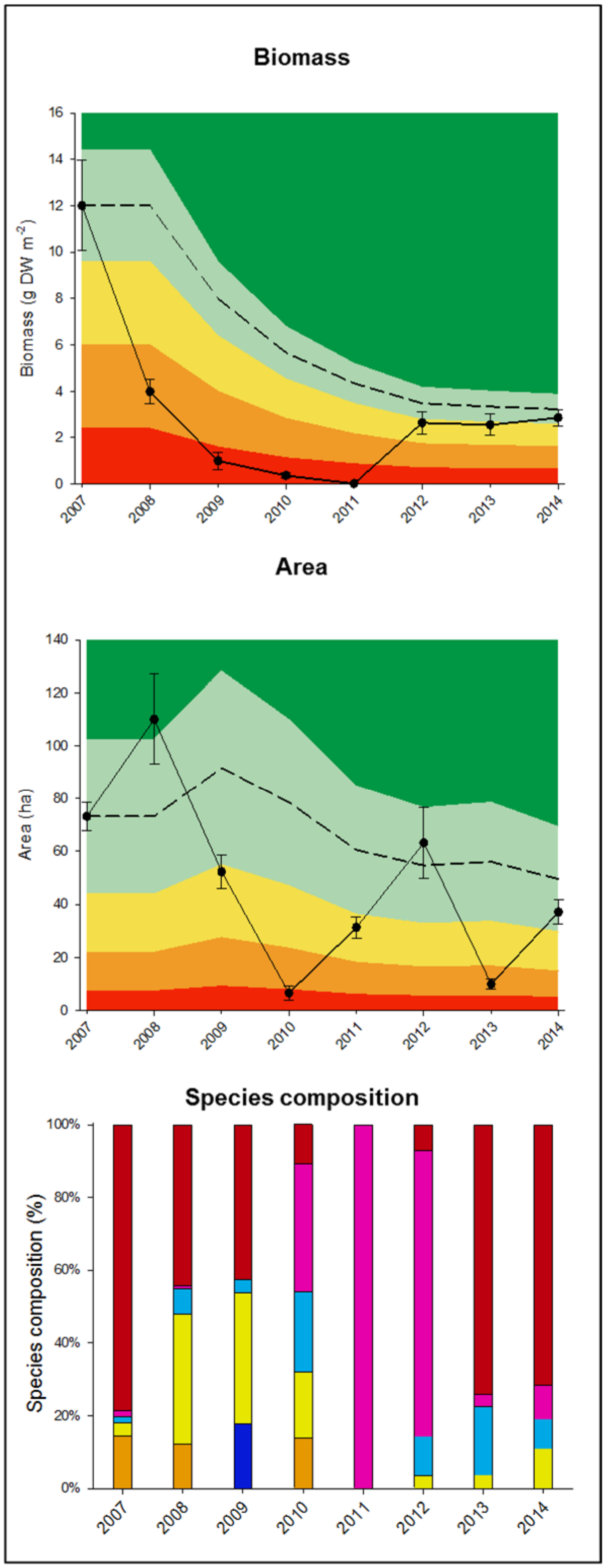
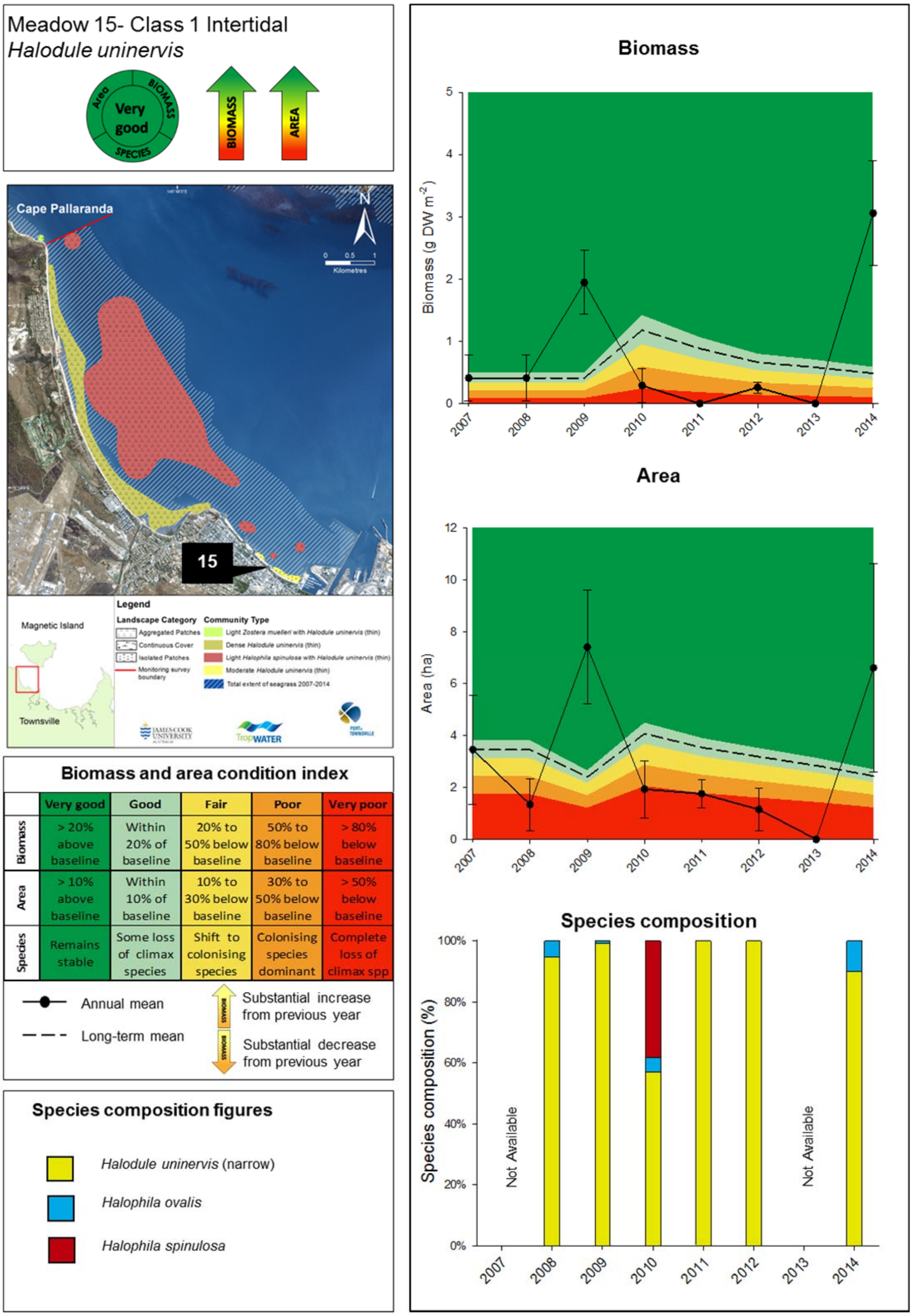


Figure 8 Changes in meadow area, biomass & species composition for seagrass Meadow 14 in Cape Pallarenda, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).



Biomass and area condition index

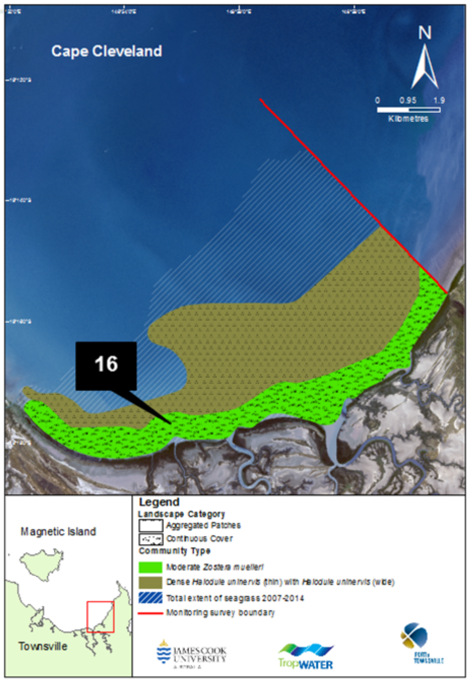
	Very good	Good	Fair	Poor	Very poor
Biomass	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Area	> 10% above baseline	Within 10% of baseline	10% to 30% below baseline	30% to 50% below baseline	> 50% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

Figure 9 Changes in meadow area, biomass & species composition for seagrass Meadow 15 in Cape Pallarenda, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadow 16- Class 3 Intertidal
Zostera capricorni

Good
Area
BIOMASS
SPECIES

BIOMASS



Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 20% above baseline	Within 20% of baseline	20% to 50% below baseline	50% to 80% below baseline	> 80% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

—●— Annual mean

– – – Long-term mean

Substantial increase from previous year

Substantial decrease from previous year

Species composition figures

- 🟨 *Halodule uninervis* (narrow)
- 🟧 *Halodule uninervis* (wide)
- 🟦 *Halophila ovalis*
- 🟩 *Zostera capricorni*
- 🟦 *Cymodocea serrulata*

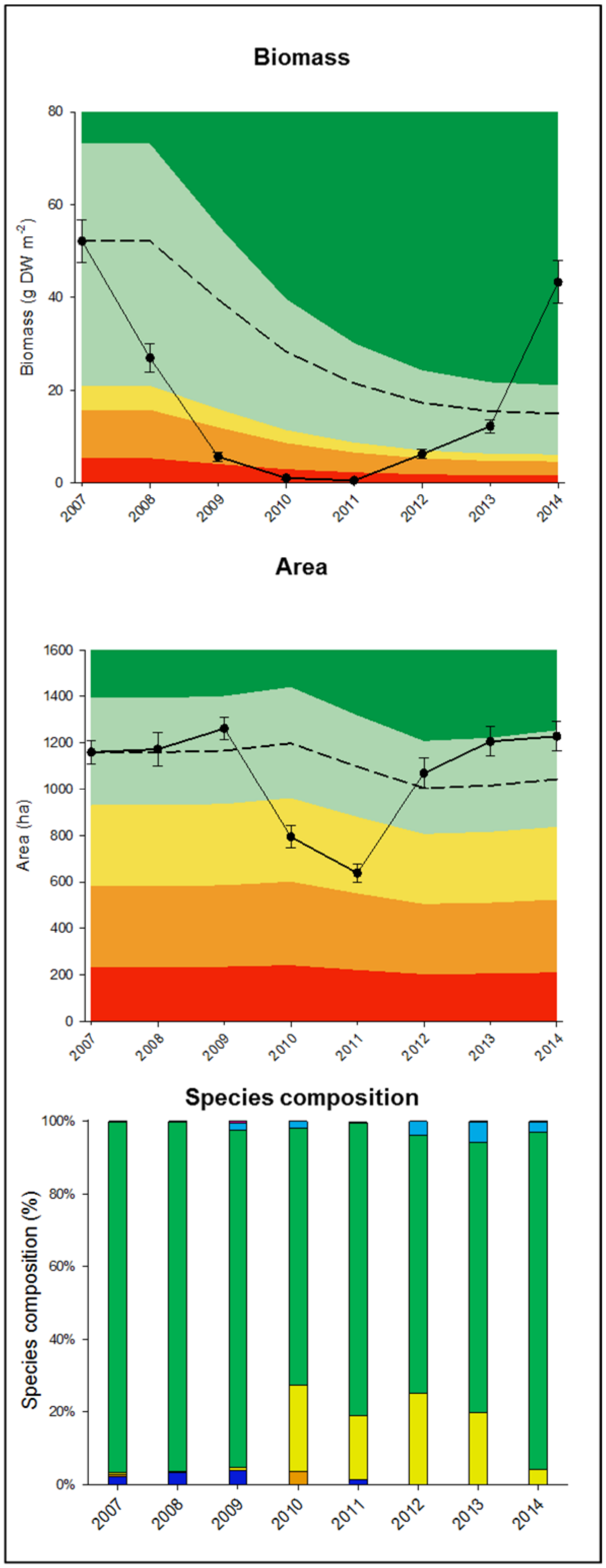
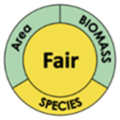
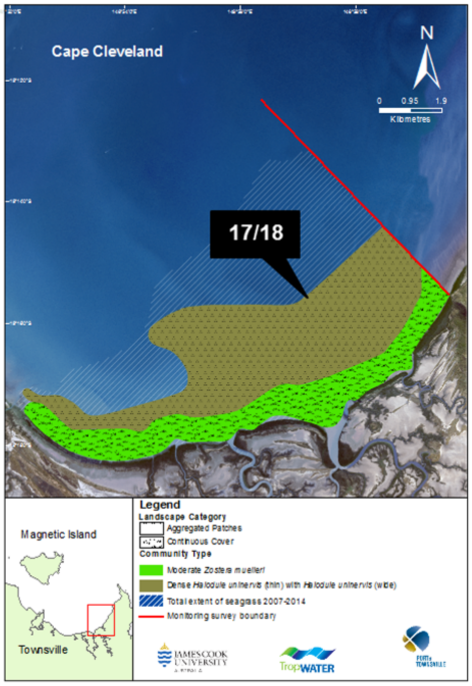


Figure 10 Changes in meadow area, biomass & species composition for seagrass Meadow 16 in Cape Pallarenda, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

Meadows 17/18- Class 4 Subtidal
Halodule uninervis





Biomass and area condition index

	Very good	Good	Fair	Poor	Very poor
Biomass	> 40% above baseline	Within 40 % of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Area	> 40% above baseline	Within 40% of baseline	40% to 70% below baseline	70% to 90% below baseline	> 90% below baseline
Species	Remains stable	Some loss of climax species	Shift to colonising species	Colonising species dominant	Complete loss of climax spp

●— Annual mean

– – – Long-term mean

⇧ Substantial increase from previous year

⇩ Substantial decrease from previous year

Species composition figures

🟨 *Halodule uninervis* (narrow)

🟧 *Halodule uninervis* (wide)

🟦 *Halophila ovalis*

🟩 *Zostera capricorni*

🟦 *Cymodocea serrulata*

🟪 *Halophila decipiens*

🟥 *Halophila spinulosa*

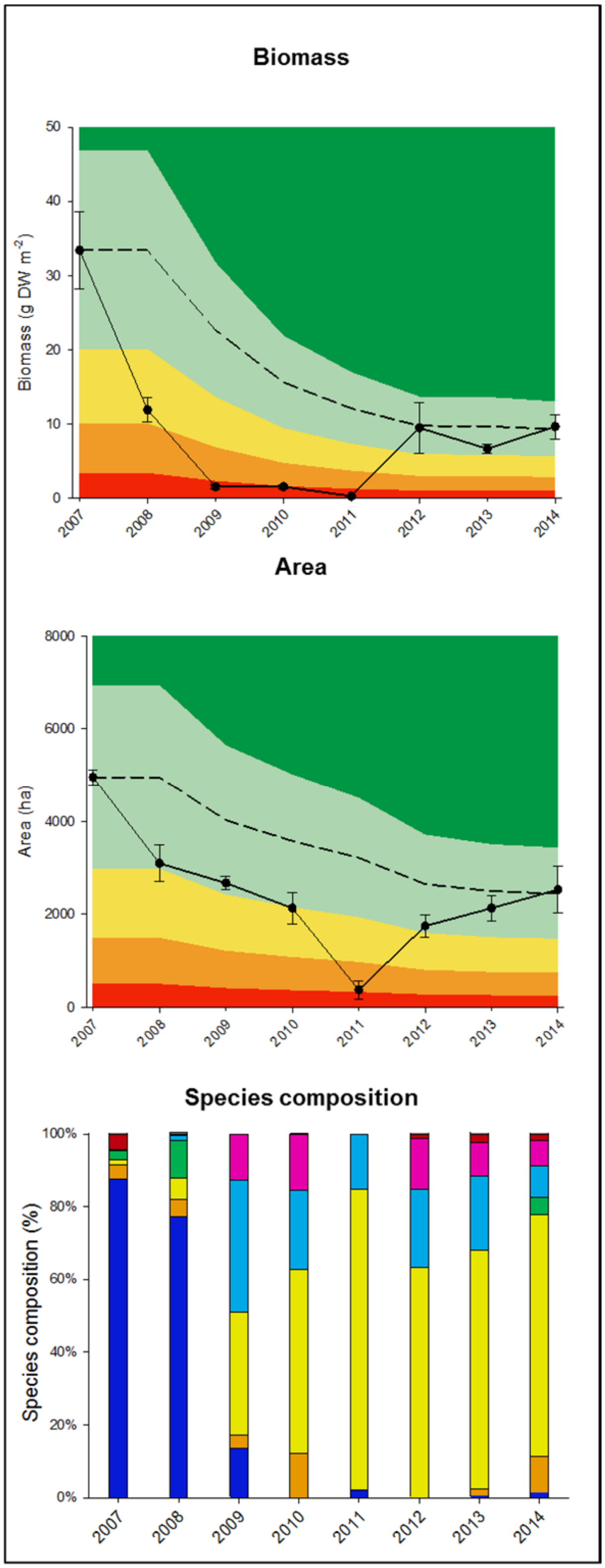


Figure 11 Changes in meadow area, biomass and species composition for seagrass Meadows 17/18 in Cleveland Bay, October 2007 – 2014. (biomass error bars = SE; area error bars = "R" reliability estimate).

3.2 Townsville Climate Data

Rainfall and River flow

Total annual rainfall in the 12 months preceding the annual survey increased from 2012/13 to just under the average total annual rainfall since 2002. (Figure 13b). Rainfall in Townsville is highly seasonal with the majority of rainfall typically occurring from December to March/April (Figure 13a). Winter months in 2014 were much wetter than in 2013, particularly in the four months prior to the annual monitoring surveys (Figure 13a). River flow in the Bohle and Black Rivers increased substantially in 2014 after a low in 2013, whereas the Burdekin River output continues to decline and remains well below the monthly 12-year average (2002 – 2014) (Figure 14a, b).

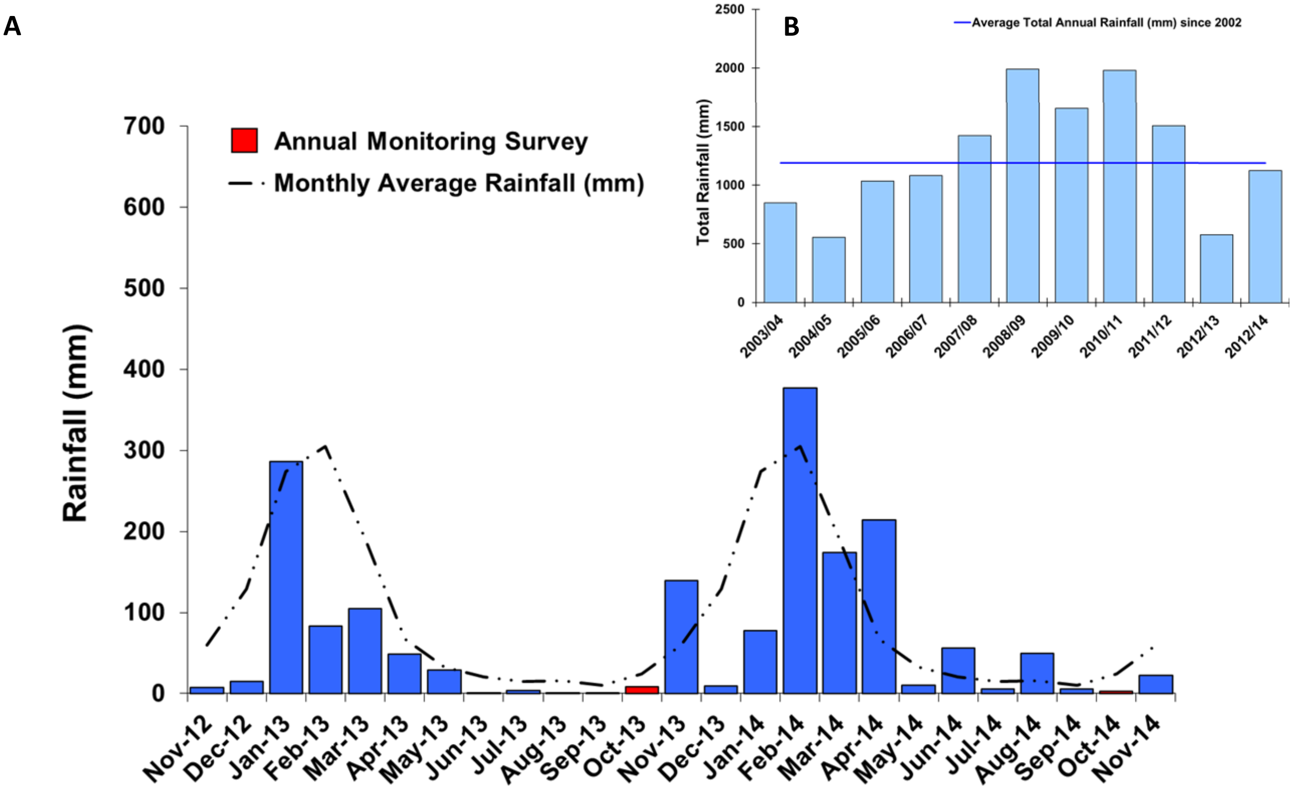
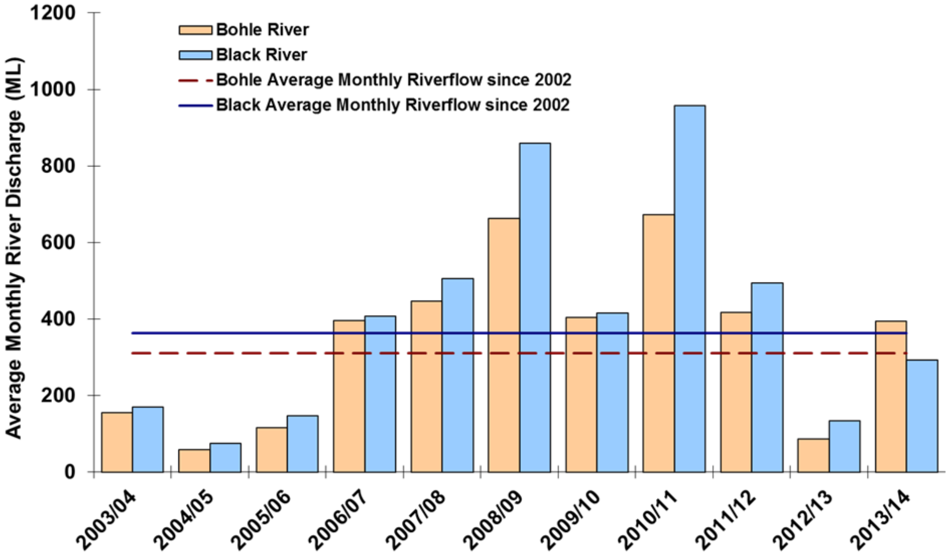


Figure 13 (A) Total annual rainfall and (B) total monthly rainfall recorded at Townsville airport (station 032040) (Data from the Bureau of Meteorology, http://www.bom.gov.au).

A



B

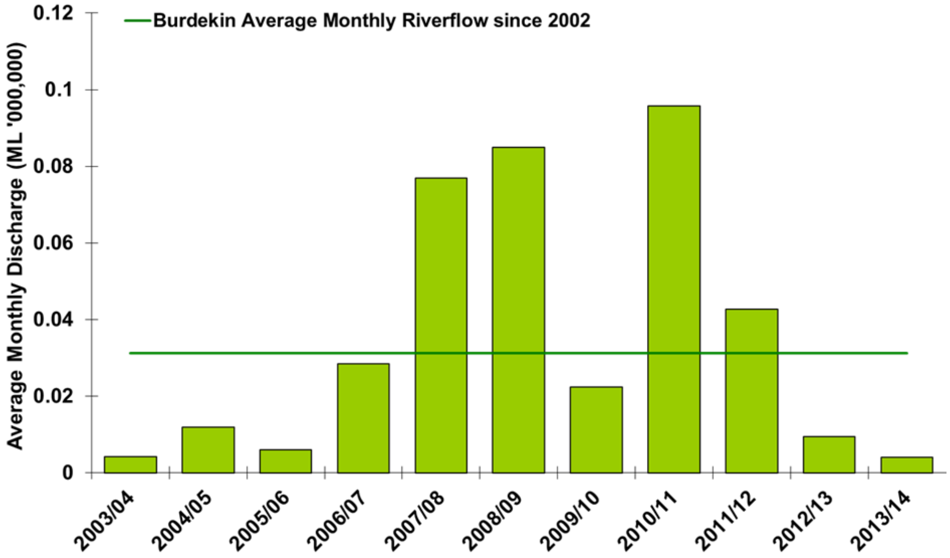


Figure 14 (A) Average annual flow of the Black and Bohle Rivers and (B) average annual flow of the Burdekin River from 2002/2003 to 2013/2014 (Department of Environment and Resource Management, http://watermonitoring.derm.qld.gov.au).

Daily Global Solar Exposure

Solar radiation fell below the long-term average in 2013/14 following the highest recorded year in 2012/13 since monitoring began (Figure 15).

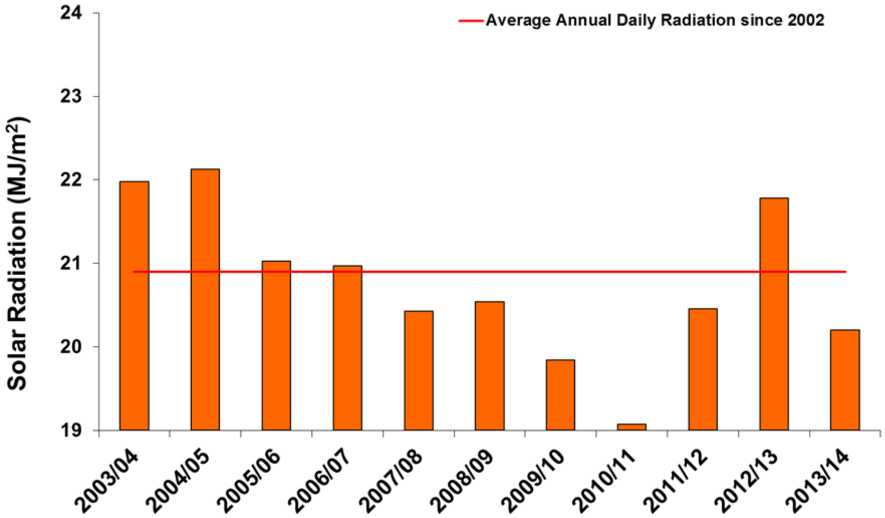


Figure 15 Mean annual daily total solar radiation recorded at Townsville airport (station 032040) 2002/2003 to 2012/2014 and average annual daily radiation (2002-2014) (Data from the Bureau of Meteorology, http://www.bom.gov.au).

Tidal Exposure of Seagrass Meadows

Total daytime exposure to air of intertidal seagrasses in Townsville is generally higher during the winter months, three to four months prior to annual monitoring surveys, and lower over summer. Total hours of tidal exposure in the one and three months prior to the monitoring survey decreased slightly from 2013 (Figure 16).

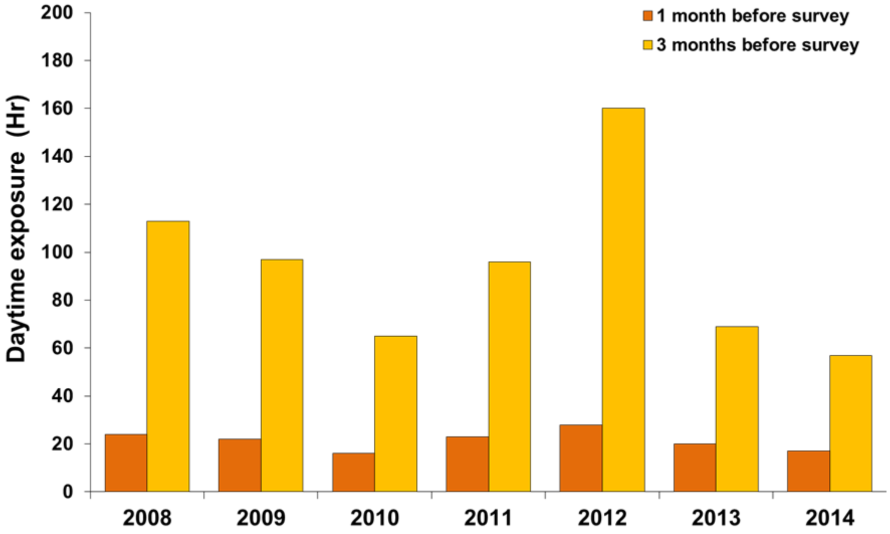


Figure 16 Total daytime intertidal exposure (<0.8m tidal height) one month and three months prior to monitoring in Townsville (Maritime Safety Queensland, www.msq.qld.gov.au).

4 DISCUSSION

In 2014 seagrass meadows in Townsville continued to recover for a third consecutive year from losses which occurred leading up to 2011. Seagrass meadows increased in both mean biomass and distribution for eight of the ten monitoring meadows. Larger "foundation" seagrass species increased in dominance in several meadows throughout the region, shifting towards the baseline conditions reported in the first few years of monitoring. The overall seagrass condition in the region was classified as "good".

Dynamics of seagrass productivity, abundance and propagation in coastal areas are heavily driven by the local environmental conditions. Declines in seagrass abundance and distribution that occurred from 2009 to 2011 in Townsville, as well as in many wet and dry tropics regions around the state, were linked to severe weather events such as flooding, storms and cyclones associated with La Nina climate patterns (Rasheed et al. 2014; Petus et al. 2014). In particular, declines in Townsville were highly correlated with turbid water conditions associated with flood plumes (Petus et al. 2014). Since 2011 Townsville climate conditions have been relatively mild, creating more favourable conditions for seagrass growth. For the past two years average annual rainfall had been below the long-term average with two of the three rivers monitored here yielding below-average monthly river discharge for the same period. Solar radiation had also fallen below the long-term average for the twelve months preceding the 2014 survey.

These milder climate conditions combined with reduced time of exposure to air at low tide may have reduced the tidal exposure-related stresses to seagrasses, and allowed for increased seagrass productivity and meadow expansion. In 2014 solar exposure measured in Townsville was well below the long-term average with the lowest total time meadows were exposed since monitoring began. Seagrasses growing in intertidal meadows are greatly influenced by low tides and the conditions the plants are exposed to during this time (Unsworth et al 2014). Length of tidal exposure, solar radiation and air temperature can combine to adversely affect shallow water communities at low tide (Petrou et al 2013) (Unsworth et al. 2012). Thermal stress can affect photosynthesis of tropical seagrasses, and if sustained for successive days has been shown to interfere with seagrass growth and increase mortality (Collier and Waycott 2014). Seagrass meadows in Townsville experienced fewer total hours of exposure to air in the three months prior to the 2014 survey than in previous years where declines have been observed (2010-2011). These conditions may have reduced the impact of exposure-related stressors to meadows.

In 2014 the species composition of many meadows continued to shift, with "foundation" species increasing in both prevalence and dominance in monitoring meadows. The availability of light is an established primary driver of seagrass community dynamics (Chartrand et al. 2012; Collier et al. 2012; Bjork et al. 1999). Larger "foundation" species such as *Cymodocea serrulata* and *Zostera capricorni* require more light (around 40% surface light intensity) than pioneering species such as *Halophila* and *Halodule* that typically require around 10-30% of the surface light (Collier et al. 2009; Freeman et al. 2008; Bach et al. 1998; Grice et al. 1996). These pioneering species were largely responsible for the initial recovery observed in 2012. Monitoring meadows have shifted towards the dominance of the foundation species as the light conditions have likely continued to become more favourable for seagrass growth. Plants species requiring increased light levels which re-appeared in 2013 have continued to grow in density and distribution, indicating growing conditions continue to remain favourable in Townsville in 2014.

Townsville is one of the few locations in the wet and dry tropics where there has been early and substantial recovery of coastal seagrasses; however other locations are beginning to show signs of recovery. Coastal seagrass meadows in monitoring locations such as Abbot Point (Rasheed et al. 2014) and Gladstone (Davies et al. 2015, in preparation) show some signs of recovery following the 2010 floods with the return of foundation species in Abbot Point and expansion of meadow area in Gladstone. Other monitoring locations such as Cairns (Jarvis et al. 2014) and Mourilyan (York et al. 2014) had not shown recovery of similar meadows during 2014, although recent information from 2015 suggests recovery may have begun in Cairns (Jarvis et al. 2015, in preparation).

The differential recovery of seagrass meadows following wide-scale declines emphasises the importance of understanding the drivers of local resilience and recovery of seagrasses in Townsville. Despite the declines in seagrass meadows throughout Townsville, in most areas there remained patches of seagrass providing a source for re-colonisation and expansion as climate conditions improved. However, entire meadows were lost in other locations in the state where large-scale declines had been observed. Without a significant source population from which to recover, these meadows were reliant upon seed stores or other sources of sexual propagules (Duarte and Sand-Jensen 1990; Phillips et al. 1983). Their slower recovery, if at all, indicates that either local environmental conditions have yet to allow germination and growth, stored seeds are no longer viable, or that there is a lack of seeds stored in the sediment, as has been described for some coastal seagrasses in nearby Abbot Point (Rasheed et al 2014). It is difficult to determine the source of recovery (adult propagules or seed stores) in Townsville without regular assessments of local seedbanks and seed viability.

While local weather patterns can be correlated with seagrass condition, a lack of environmental data at the meadow scale makes interpretation of observed changes difficult. Light and temperature are two of the major factors linked to meadow-scale changes in seagrass and their inclusion as part of monitoring would greatly enhance the ability of the program to assess the causes of seagrass change. Apart from establishing the drivers of change, light information collected at Townsville's seagrass meadows would also help establish locally relevant light triggers to manage seagrasses during dredging programs. In addition, expanding monitoring to include more widespread seed bank assessments in Townsville would allow for a better assessment of meadow resilience and capacity for recovery as part of seagrass management strategies.

The multiple years of climate related impacts to seagrasses from 2007-2011 are likely to leave a legacy of reduced resilience of seagrasses to impacts, although the most recent survey would indicate that at least some of this resilience had been restored. Additions to the monitoring program to include assessments of light and temperature would yield detailed information about the requirements for healthy seagrass meadows within the port. This will assist in the management of human activities and impacts on seagrass habitat.

In summary, key outcomes of the 2014 seagrass monitoring are:

1. Seagrasses continued to recover from losses that occurred leading up to 2011. The majority of the monitoring meadows have reached or exceeded long-term averages in mean biomass and meadow area.
2. The overall condition of seagrasses in Townsville is classified as "good".
3. Townsville, along with Gladstone and coastal seagrasses in Abbot Point, remains one of the few coastal areas in the Wet and Dry Tropics regions where seagrasses have shown recovery in 2014 following wide-scale declines.
4. The increase in coastal seagrass meadow biomass and area corresponds with the continued recovery of the larger "foundation" species such as *Halodule*, *Zostera* and *Cymodocea*; although some meadows were still dominated by colonising species such as *Halophila*.
5. The addition of temperature and light (PAR) monitoring to the seagrass program would greatly enhance the ability to determine the causes of seagrass change and provide information to determine critical thresholds of light for management of anthropogenic activities.

5 REFERENCES

Abal, E. and Dennison, W. 1996. Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research, **47**: 763-771

Bach, S. S., Borum, J., Fortes, M. D. and Duarte, C. M. 1998. Species composition and plant performance of mixed seagrass beds along a siltation gradient at Cape Bolinao, The Philippines. Marine Ecology-Progress Series, **174**: 247-256

Bjork, M., Uka, J., Weil, A. and Beer, S. 1999. Photosynthetic tolerances to desiccation of tropical intertidal seagrasses. Marine Ecology Progress Series, **191**: 121-126

Chartrand, K. M., Ralph, P. J., Petrou, K. and Rasheed, M. A. 2012. Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program. Page 126. DAFF Publication, Fisheries Queensland, Cairns.

Collier, C. and Waycott, M. 2014. Temperature extremes reduce seagrass growth and induce mortality. Marine pollution bulletin, **83**: 483-490

Collier, C. J., Lavery, P. S., Ralph, P. J. and Masini, R. J. 2009. Shade-induced response and recovery of the seagrass *Posidonia sinuosa*. Journal of Experimental Marine Biology and Ecology, **370**: 89-103

Collier, C. J., Waycott, M. and McKenzie, L. J. 2012. Light thresholds derived from seagrass loss in the coastal zone of the northern Great Barrier Reef, Australia. Ecological Indicators, **23**: 211-219

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neil, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van der Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature, **387**: 253-260

Cribb, A. B. 1996. Seaweeds of Queensland: A naturalist's guide. Queensland Naturalists' Club, Queensland, Australia

Dennison, W. C., Orth, R. J., Moore, K. A., Stevenson, J. C., Carter, V., Kollar, S., Bergstrom, P. W. and Batiuk, R. A. 1993. Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. BioScience, **43**: 86-94

Duarte, C. M. and Sand-Jensen, K. 1990. Seagrass colonization: Patch formation and patch growth in *Cymodocea nodosa*. Marine Ecology Progress Series, **65**: 193-200

Freeman, A. S., Short, F. T., Isnain, I., Razak, F. A. and Coles, R. G. 2008. Seagrass on the edge: Land-use practices threaten coastal seagrass communities in Sabah, Malaysia. Biological Conservation, **141**: 2993-3005

Grice, A., Loneragan, N. and Dennison, W. 1996. Light intensity and the interactions between physiology, morphology and stable isotope ratios in five species of seagrass. Journal of Experimental Marine Biology and Ecology, **195**: 91-110

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

Jarvis, J. C., Rasheed, M. A., McKenna, S. A. and Sankey, T. 2014. Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual and Quarterly Monitoring Report, Cairns, 51 pp.

Jarvis, J. C., Rasheed, M. A., McKenna, S. A. and Sankey, T. 2015. Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual and Quarterly Monitoring Report. In Preparation.

Kuo, J. and McComb, A. J. 1989. Seagrass taxonomy, structure and development. Page 6-73. In A. W. D. Larkum, A. J. McComb and S. A. Shepherd (eds), Biology of seagrasses: a treatise on the biology of seagrasses with special reference to the Australian Region. Elsevier, New York

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M. and Williams, S. L. 2006. A global crisis for seagrass ecosystems. BioScience, **56**: 987-996

Petus, C., Collier, C., Devlin, M., Rasheed, M. and McKenna, S. 2014. Using MODIS data for understanding changes in seagrass meadow health: A case study in the Great Barrier Reef (Australia). Marine Environmental Research, **98**: 68-85

Phillips, R. C., Stewart Grant, W. and Peter McRoy, C. 1983. Reproductive strategies of eelgrass (*Zostera marina* L.). Aquatic Botany, **16**: 1-20

R Development Core Team. 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria: .

Rasheed, M. A., McKenna, S. A., Carter, A. B. and Coles, R. G. 2014. Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia. Marine pollution bulletin,

Rasheed, M. A. and Taylor, H. A. 2008. Port of Townsville seagrass baseline survey report. Department of Primary Industries Information Series PR08-4014, Northern Fisheries Centre, Cairns, Australia, 45 pp.

Unsworth, R. K. F., Collier, C. J., Henderson, G. M. and McKenzie, L. J. 2012. Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. Environmental Research Letters, **7**: 024026

York, P. H., Davies, J. N. and Rasheed, M. A. 2014. Long-term seagrass monitoring in the Port of Mourilyan – 2013. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 35 pp., pp.

York PH, & Rasheed MA 2015, 'Long-term seagrass monitoring in the Port of Mourilyan – 2014', JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research. In Preparation.

6 APPENDICES

Appendix 1 Statistical Analysis

(a) Summary of statistical results for mean above-ground biomass for each year of monitoring in the Port of Townsville (2007 – 2014). Normality was assumed for all meadows therefore a parametric test One-Way ANOVA was used. Pairwise comparisons for ANOVA were conducted using either a Tukey's (equal variances) or a Behrens Fisher Test (unequal variances). . *** indicates means are significantly different at $p < 0.000$; ** indicates means are significantly different at $p < 0.001$. The data was log(x+1) transformed (^) or square root transformed (~).

Meadow 3^	DF	SS	MS	F	Pr(>F)
Year	7	35.23	5.033	11.59	***
Residuals	79	34.31	0.434		

Meadow 4^	DF	SS	MS	F	Pr(>F)
Year	7	23.58	3.369	3.425	**
Residuals	45	44.26	0.984		

Meadow 5^	DF	SS	MS	F	Pr(>F)
Year	7	288.0	41.15	32.14	***
Residuals	484	619.7	1.28		

Meadow 6~	DF	SS	MS	F	Pr(>F)
Year	7	122.5	17.494	17.13	***
Residuals	138	141	1.022		

Meadow 10^	DF	SS	MS	F	Pr(>F)
Year	7	238	34.00	73.14	***
Residuals	226	105	0.46		

Meadow 12~	DF	SS	MS	F	Pr(>F)
Year	7	72.99	10.427	14.66	***
Residuals	228	162.16	0.711		

Meadow 14~	DF	SS	MS	F	Pr(>F)
Year	7	56.16	8.024	11.69	***
Residuals	217	148.89	0.686		

Meadow 16~	DF	SS	MS	F	Pr(>F)
Year	7	2271	324.4	51.38	***
Residuals	478	3018	6.3		

Meadows 17 & 18~	DF	SS	MS	F	Pr(>F)
Year	7	525.3	75.05	19.84	***
Residuals	352	1331.2	3.78		

(b) Results of Tukey post hoc comparison comparing mean above-ground seagrass biomass in the monitoring meadows 3, 4, 5, 6, 10, 12, 14, 15, 16 and 17/18 in Townsville. Cells marked with a “Yes” indicates a significant difference in meadow biomass (p < 0.01) between comparison years and cells marked “No” indicates no significant difference in meadow biomass between years.

Meadow 3

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	YES	NO						
2010	YES	YES	NO					
2011	YES	YES	NO	NO				
2012	NO	NO	NO	YES	YES			
2013	NO	NO	NO	YES	YES	NO		
2014	NO	NO	YES	YES	YES	NO	NO	

Meadow 4

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	NO	NO						
2010	NO	YES	NO					
2011	NO	NO	NO	NO				
2012	NO	NO	NO	NO	NO			
2013	NO	NO	NO	NO	NO	NO		
2014	NO	NO	NO	NO	NO	NO	NO	

Meadow 5

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	YES	YES						
2010	YES	YES	YES					
2011	YES	YES	YES	NO				
2012	YES	YES	NO	YES	YES			
2013	YES	YES	NO	YES	YES	YES		
2014	NO	NO	YES	YES	YES	NO	NO	

Meadow 6

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	NO	YES						
2010	NO	YES	YES					
2011	NO	YES	YES	NO				
2012	NO	YES	NO	YES	YES			
2013	NO	YES	NO	YES	YES	NO		
2014	NO	YES	NO	YES	YES	NO	NO	

Meadow 10

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	YES	YES						
2010	YES	YES	YES					
2011	YES	YES	YES	YES				
2012	YES	YES	NO	YES	YES			
2013	YES	YES	NO	YES	YES	NO		
2014	YES	YES	NO	YES	YES	NO	NO	

Meadow 12

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	YES							
2009	YES	NO						
2010	YES	NO	NO					
2011	YES	YES	YES	NO				
2012	YES	NO	YES	NO	YES			
2013	NO	NO	YES	YES	YES	YES		
2014	NO	YES	YES	YES	YES	YES	NO	

Meadow 14

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	YES							
2009	YES	YES						
2010	YES	YES	YES					
2011	N.a	N.a	N.a	N.a				
2012	YES	NO	YES	YES	N.a.			
2013	YES	NO	NO	YES	N.a.	NO		
2014	YES	NO	YES	YES	N.a.	NO	NO	

Meadow 15

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	NO							
2009	NO	NO						
2010	NO	NO	NO					
2011	NO	NO	NO	NO				
2012	NO	NO	NO	NO	NO			
2013	NO	NO	NO	NO	NO	NO		
2014	NO	NO	NO	YES	NO	NO	YES	

Meadow 16

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	YES							
2009	YES	YES						
2010	YES	YES	YES					
2011	YES	YES	YES	NO				
2012	YES	YES	NO	YES	YES			
2013	YES	YES	YES	YES	YES	NO		
2014	NO	YES	YES	YES	YES	YES	YES	

Meadow 17 & 18

YEAR	2007	2008	2009	2010	2011	2012	2013	2014
2007								
2008	YES							
2009	YES	YES						
2010	YES	YES	NO					
2011	YES	YES	YES	YES				
2012	YES	NO	YES	YES	YES			
2013	YES	NO	YES	YES	YES	YES		
2014	YES	NO	YES	YES	YES	YES	YES	

Appendix 2 Mean above-ground biomass within the Port of Townsville, 2007-2014. (SE= Standard error, n= number of sampling sites, R= reliability estimate)

	Monitoring Meadow (ID number)	**Meadow Cover**	**Mean Biomass ± SE in g DW m^2** **no. of sites**								**Total Meadow Area ± R in hectares**							
			2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Magnetic Island	**Geoffrey Bay (3)** Intertidal/subtidal *Halodule* dominated	Aggregated patches	7.3 ± 3.0 5	9.4 ± 3.2 13	1.0 ± 0.8 7	0.7 ± 0.1 14	0.4 ± 0.1 9	3.5 ± 0.6 9	4.5 ± 1.2 9	6.50 ± 2.20 16	10.7 ± 3.5	9.5 ± 2.6	6.8 ± 2.8	9.2 ± 3.1	5.6 ± 2.5	9.5 ± 2.3	9.7 ± 2.4	16.07 ± 3.67
	Nelly Bay (4) Intertidal/subtidal *Halodule* dominated	Isolated patches	4.1 ± 1.8 4	12.6 ± 2.6 9	4.8 ± 1.0 11	0.5 ± 0.1 15	0.6 ± 0.3 3	NA 9	3.4 ± 2.3 9	7.74 ± 5.45 6	9.5 ± 3.4	7.5 ± 2.6	12.2 ± 3.8	9.5 ± 3.7	1.5 ± 1.3	0.6 ± 0.7	2.9 ± 1.4	8.69 ± 3.04
	Cockle Bay Reef (5) Intertidal Halodule dominated	Continuous cover	28.7 ± 4.9 33	22.6 ± 3.1 47	6.8 ± 1.2 82	1.0 ± 0.3 31	1.3 ± 0.2 50	4.8 ± 0.5 9	6.0 ± 0.7 9	26.37 ± 3.22 82	382.4 ± 25.5	332.3 ± 30.3	308.8 ± 27.2	178.3 ± 2.9	136.7 ± 26.8	223.3 ± 24.3	452.9 ± 28.7	418.44 ± 27.15
	Cockle Bay Reef (6) Intertidal *Zostera* dominated	Continuous cover	20.1 ± 8.2 5	33.9 ± 3.9 24	4.9 ± 1.5 42	0.5 ± 0.4 9	1.0 ± 0.3 23	4.3 ± 0.4 9	8.9 ± 1.5 9	11.71 ± 2.61 10	73.2 ± 5.3	110.0 ± 17.1	52.3 ± 6.4	6.6 ± 2.7	31.3 ± 3.9	63.2 ± 13.2	9.9 ± 1.8	37.11 ± 4.49
Bohle River to Ross Creek	**Shelly Beach (10)** Intertidal *Zostera* dominated	Continuous cover	27.8 ± 7.2 14	21.4 ± 3.5 17	4.1 ± 0.6 22	Not present	0.1 ± 0.0 25	3.7 ± 0.5 9	5.4 ± 0.8 9	9.77 ± 2.18 28	118.9 ± 6.7	134.0 ± 7.6	90.6 ± 6.9	Not present	54.1 ± 5.1	191.0 ± 17.7	94.5 ± 16.0	163.6 ± 18.79
	Rowes Bay (12) Intertidal/Subtidal *Halodule* dominated	Aggregated patches	3.9 ± 0.7 16	1.5 ± 0.4 35	1.3 ± 0.2 49	0.5 ± 0.2 17	0.03 ± 0.0 16	0.3 ± 0.1 9	2.8 ± 0.4 9	4.08 ± 0.5 36	128.3 ± 18.2	127.4 ± 26.3	129.1 ± 21.5	81.1 ± 10.6	15.8 ± 3.3	74.2 ± 17.7	126.02± 24.6	163.57 ± 28.79
	Pallarenda (14) Subtidal *Halophila* dominated	Aggregated patches	12.0 ± 1.8 43	4.0 ± 0.5 36	1.2 ± 0.3 40	0.3 ± 0.1 29	0.02 ± 0 1	2.6 ± 0.4 9	2.5 ± 0.4 9	2.86 ± 0.36 25	1321.3 ± 40.3	866.1 ± 244.8	900.9 ± 38.6	572.5 ± 31.7	6.6 ± 5.4	484.5 ± 106.4	714.6 ± 155.9	579.78 ± 162.76
	Strand (15) Intertidal/Subtidal *Halodule* dominated	Isolated patches	Not available	0.4 ± 0.4 2	2.0 ± 1.0 7	0.2 ± 0.1 4	Not available	Not available	Not present	3.06 ± 0.84 6	3.4 ± 2.1	1.3 ± 1.0	7.4 ± 2.2	1.9 ± 1.1	1.8 ± 0.5	1.1 ± 0.8	Not present	6.59 ± 4.02
Cleveland Bay	**Cleveland (16)** Intertidal *Zostera* dominated	Continuous cover	52.1 ± 5.4 93	27.0 ± 3.0 60	5.9 ± 1.7 99	1.0 ± 0.2 37	0.5 ± 0.1 51	6.2 ± 0.9 9	12.2 ± 1.3 9	43.27 ± 4.58 72	1160.1 ± 51.1	1173.1 ± 70.7	1262.0 ± 49.4	793.7 ± 47.8	638.1 ± 40.7	1069.8 ± 66.7	1206.5 ± 63.5	1228.56 ± 64.7
	Cleveland (17&18) Subtidal *Halodule* dominated	Aggregated patches	33.4 ± 5.2 51	9.5 ± 1.4 60	1.5 ± 0.3 52	1.5 ± 0.2 49	0.3 ± 0.1 15	9.5 ± 3.4 9	6.6 ± 0.5 9	9.64 ± 1.64 43	4952.9± 61.2	3097 ± 400.7	2673.4 ± 44.2	2132.0 ± 41.1	376.2 ± 193	1749.2± 42.2	2133.3 ± 71.8	2533.34 ± 497.85
Total of Monitoring Meadows (avg biomass, sum area)			**18.9 ± 3.8**	**14.2 ± 2.2**	**3.3 ± 0.9**	**0.7 ± 0.2**	**0.5 ± 0.2**	**3.9 ± 0.5**	**5.8 ± 1.0**	**12.71 ± 2.4**	**8160.9 ± 310.4**	**5858.4 ± 317.3**	**5443.1 ± 303.0**	**3785.6 ± 466.7**	**1267.7 ± 282.7**	**3866.7 ± 492.4**	**4750.5 ± 566.5**	**5155.75 ± 815.27**

Not Available – biomass values not available due to insufficient biomass samples