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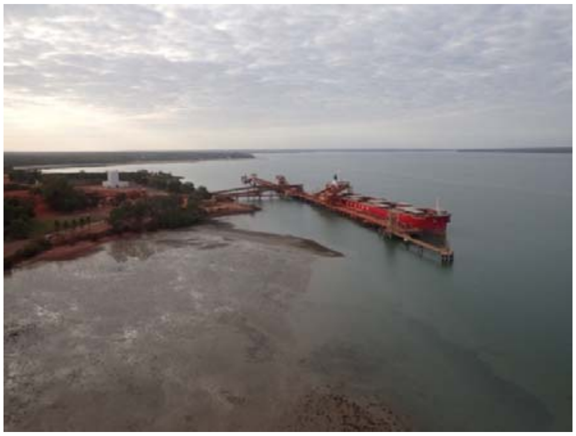

PORT OF WEIPA LONG-TERM SEAGRASS MONITORING: 2000 - 2015

McKenna SA, Sozou, AM, Carter AB, Scott EL Rasheed MA

Report No. 16/16

March 2016

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KEY FINDINGS

Seagrass Condition 2015

Good

1. Seagrasses in the Port of Weipa were in a good condition with biomass and area near or above the long-term average and species composition stable.

2. The good condition of seagrass meadows indicates meadows should continue to be resilient to planned maintenance dredging activities in 2016, without the requirement for additional mitigation measures.

3. While remaining in a good condition, total seagrass meadow area decreased between 2014 and 2015, and biomass decreased at some meadows. Species composition however, remained stable.

4. Results from light monitoring (photosynthetically active radiation(PAR)) indicates that the light environment remained favourable for seagrass growth during the majority of 2014-2015, but fell below the likely minimum light requirements for significant periods of time during the wet season.

5. Water temperature within the meadows reached peaks of over 40°C for consecutive days, coinciding with tidal air exposure between May and September 2015. These high temperatures likely explain declines observed between 2014 and 2015.

6. Locally relevant light requirements for *Enhalus acoroides* suitable for management application are being developed through the expanded light and seagrass change monitoring that commenced during 2015.

7. Dugong feeding trails were seen throughout the *Halodule uninervis* dominated A5 meadow.

IN BRIEF

Seagrasses have been monitored annually in the Port of Weipa since 2000. Each year all seagrasses within the Intensive Monitoring Area (IMA) around the major areas of port activity are mapped and five core seagrass meadows representing the range of different seagrass community types found in Weipa are assessed for changes in biomass, area and species composition. Changes to biomass, area and species composition are then used to develop a seagrass condition index (see sections 2.3 of this report for further details). Every 3 years all seagrasses within the port limits are remapped (conducted in 2014).

Seagrasses in the Port of Weipa were in a good condition in 2015, with biomass, area and species composition of monitoring meadows close to or above the long-term average. The total area of all seagrasses within the IMA has been relatively stable over the past decade (Figure 1). Between 2014 and 2015 seagrass distribution in the IMA declined but was similar to the long-term average (Figure 1). Three of the five monitoring meadows were classed as being in "satisfactory" condition, which included both *Halodule uninervis* monitoring meadows (A3 and A5), and the A7 *Enhalus acoroides* meadow at Evans Landing (Figure 3). Declines in area of these three meadows led to their condition being classified as satisfactory despite biomass and species composition remaining in "very good" or "good" condition (Figure 3).

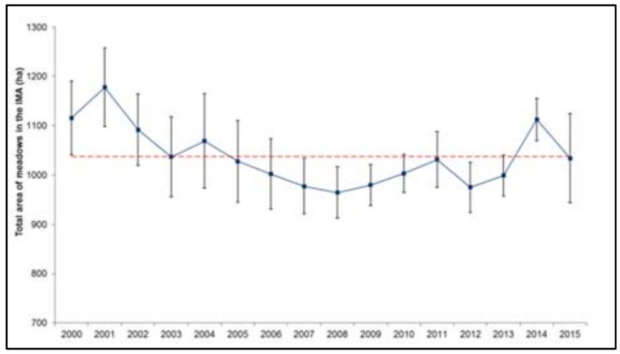

Figure 1. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2015. (error bars = "R" reliability estimate). Red dashed line indicates 16-year mean of total meadow area.

Seagrass biomass and distribution in coastal areas are strongly influenced by local environmental conditions. In 2015 many of these environmental factors were at levels considered to be favourable for seagrass growth and survival; below average tidal exposure, below average rainfall and average solar exposure. However extreme peaks in water temperature occurred at the seabed in Weipa in the latter half of the year at levels known to cause thermal stress and declines in tropical seagrasses. Water temperature peaked at over 40°C on eighteen occasions at the intertidal A2 site, and at over 35°C sixteen times in the subtidal/intertidal A7 site between May and September 2015. These peaks in temperature usually coincided with periods of tidal exposure. In addition while the amount of air exposure during the day for intertidal meadows was below the long term average, it was the highest it has been since 2008 potentially leading to an increase in exposure related stresses to these meadows.

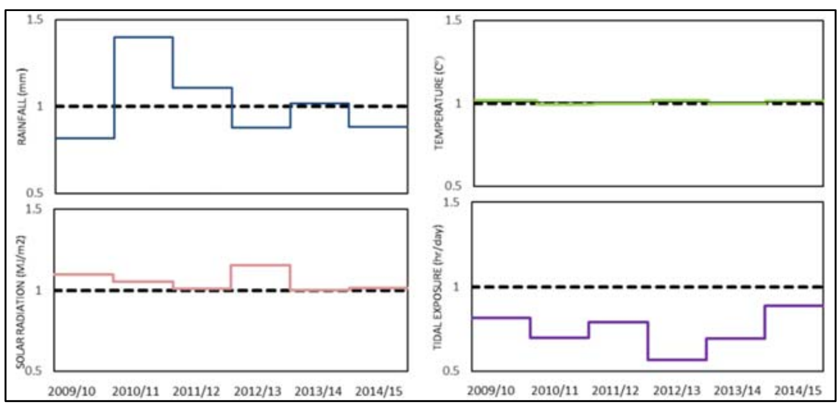

Figure 2. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average from 2009/10 to 2014/15. (See section 3.5 for detailed climate data).

Monitoring of light available to seagrasses in Weipa during 2015 indicates that light availability was likely to be favourable for seagrass growth during most of the year. During the wet season however, light levels were recorded well below likely seagrass minimum requirements for a duration which has been shown to cause deleterious effects on some seagrass species (Collier et al. 2016).

In order to determine the specific light requirements for local seagrass species, the quarterly PAR program was expanded in 2015 to include assessments of seagrass biomass and species composition at permanent transect sites alongside the PAR logging stations. Over time these assessments will lead to biologically relevant light requirement values that can be used as a management tool for future port activities. To date, three quarterly seagrass assessments have been conducted (June, September & December 2015).

The good condition of seagrasses in 2015 means they should continue to be resilient to planned maintenance dredging activities in 2016 without the requirement for additional mitigation measures, provided the duration of dredging remains relatively short and there are no major losses associated with climate or other impacts leading up to maintenance dredging in 2016.

The Weipa seagrass monitoring program forms part of James Cook University's seagrass assessment and research program that examines condition of seagrasses in the majority of Queensland commercial ports. At the closest monitoring location to Weipa (Karumba, in the southern Gulf of Carpentaria) seagrasses were also in a good condition but with similar declines in biomass to Weipa during 2015. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

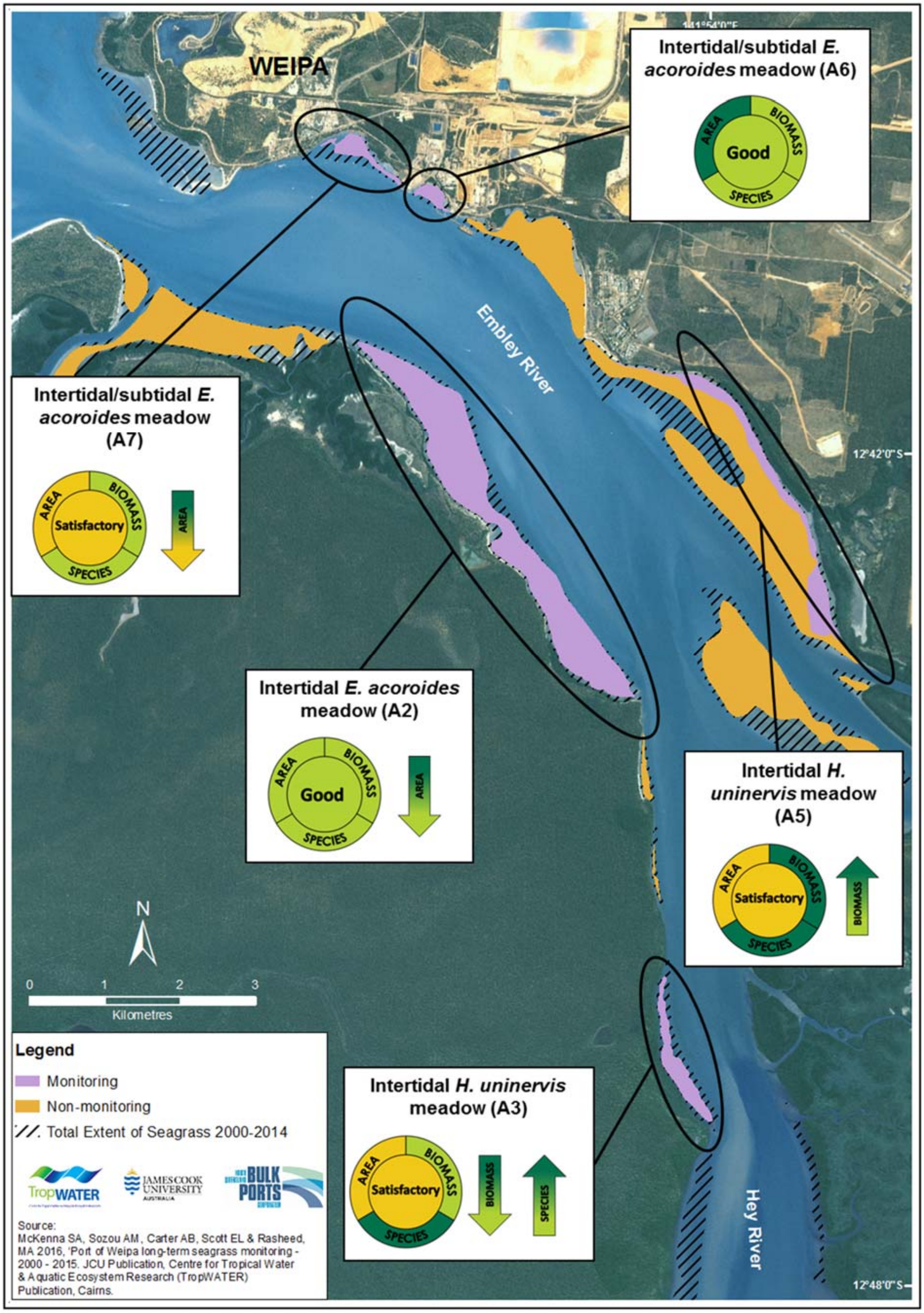

Figure 3. Seagrass meadow condition in the port of Weipa 2015.

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1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem functions and services including nutrient cycling and particle trapping that improves water quality, coastal protection, support of fisheries production and the capture and storage of carbon (Hemminga and Duarte 2000; Orth et al. 2006; Barbier et al. 2011; Costanza et al. 2014). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Dennison et al. 1993; Abal and Dennison 1996; Orth et al. 2006).

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 (Figure 4).

Figure 4. Location of Queensland Port seagrass assessment sites.

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure that seagrasses and ports can co-exist. It is useful information for planning and implementing port development and maintenance programs so they have a minimal impact on seagrass. 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 Weipa Seagrass Monitoring Program

North Queensland Bulk Ports (NQBP) Corporation is responsible for managing and monitoring Weipa's port environment. NQBP has recognised that seagrasses form a key ecological habitat in the Weipa region and commissioned TropWATER to establish a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al. 2001; 2003; 2005). The goals of the program are to minimise impacts of port activities on seagrass habitats and to periodically assess the health of Weipa's port environment. Results from seagrass monitoring surveys are used by NQBP to assess the health of the port marine environment, and help identify any possible detrimental effects of port operations (e.g. dredging) on seagrass meadows. In 2015 the annual maintenance dredge campaign commenced on June 23 and was completed in 23 days, with 339,105m^3 of dredge material relocated to the approved spoil ground. This volume was slightly less than the 2014 campaign (368,384m^3). Seagrass monitoring surveys satisfy environmental monitoring requirements as part of the port's Long-Term Dredge Management Plan and are used by management agencies to assess the status and condition of seagrass resources in the region.

The first three years (2000 to 2002) of the seagrass monitoring program provided important information on the distribution, abundance and seasonality of seagrasses within the greater port limits. Due to the large area of the port, the approach for long term monitoring has been to focus monitoring efforts on seagrass meadows located near the port and shipping infrastructure and activities. This area is known as the Intensive Monitoring Area (IMA; Figure 5). Each August/September all seagrass meadows within the IMA are surveyed and mapped. Five core monitoring meadows within the IMA are also assessed for biomass and seagrass species composition. These meadows represent the range of seagrass meadow communities identified in the region. Every three years (i.e., 2000, 2002, 2005, 2008, 2011, 2014), seagrass monitoring surveys are extended to cover all meadows in the greater port limits, with a focus on mapping seagrass meadow distribution, meadow cover type and species composition (Figure 5).

As part of the seagrass monitoring program in Weipa, irradiance (Photosynthetically Active Radiation (PAR)) and temperature conditions within the seagrass meadows have been assessed quarterly since September 2010. Three PAR and temperature logging stations are located at a northern and southern site within the intertidal A2 *Enhalus acoroides* meadow and at one site in the intertidal/subtidal A7 *E. acoroides* meadow (Figure 12). New to the monitoring program in 2015 was the expansion of the established PAR and temperature logger program to incorporate quarterly seagrass assessments at permanent transects sites alongside the logging stations. The aim of conducting seagrass assessments coupled with collecting light and temperature data is to produce biologically relevant light requirement values for the dominant seagrass species in the Weipa area that can be used as a management tool for future port activities. To date, three quarterly seagrass assessments have been conducted (June, September & December 2015). Preliminary results will not be presented in this report while data is still being collected, but will be presented in the 2016 report.

This report presents the results of the long-term seagrass monitoring assessments conducted in September 2015. The objectives were:

1. Map seagrass distribution and determine biomass and meadow area in core monitoring meadows;
2. Map seagrass distribution and species composition of seagrass meadows within the IMA;
3. Assess changes in seagrass meadows with previous monitoring surveys;
4. Assess light and temperature conditions within seagrass meadows;
5. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

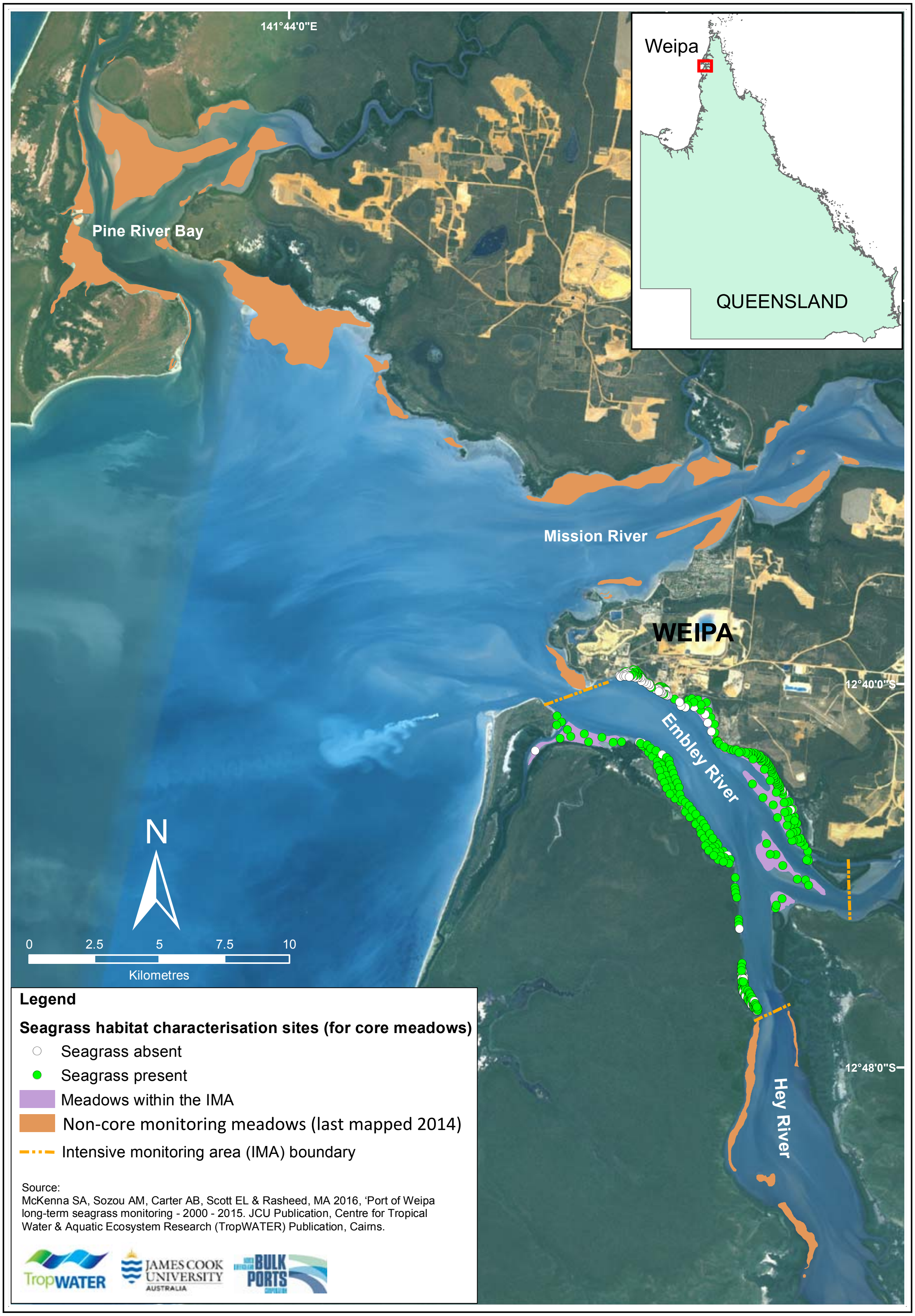

Figure 5. Location of 2015 seagrass monitoring sites and seagrass meadows in the Port of Weipa.

2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area

Annual seagrass monitoring within the Port of Weipa was conducted September 7th – 10th 2015. Annual monitoring over the past 16 years has focused on five core monitoring meadows selected from baseline surveys within the Intensive Monitoring Area (IMA) (Figure 5) (Roelofs et al. 2001). These meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in the baseline survey, and because they were located in areas likely to be vulnerable to impacts from port operations and developments.

Two levels of sampling were used in the September 2015 survey:

1. Assess and map seagrass distribution, species composition and biomass in the five core monitoring meadows (A2, A3, A5, A6, and A7; Figure 13).
2. Map seagrass distribution and species composition in non-core monitoring meadows within the IMA (Figure 5).

Seagrass meadows were surveyed using a combination of helicopter aerial assessments and boat-based camera surveys (Figure 6). At each site surveyed seagrass meadow characteristics were recorded including seagrass species composition, above-ground biomass, percent algal cover, sediment type, time, position fixes (GPS; ±5m), and depth below mean sea level (dbMSL) for subtidal meadows. A detailed outline of these methods can be found in Roelofs et al. (2001).

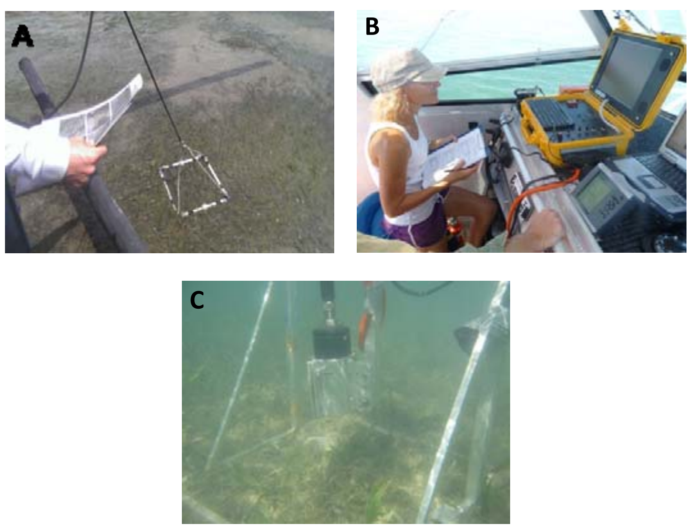

Figure 6. Seagrass methods using (A) helicopter aerial surveillance, and (B, C) boat-based CCTV surveillance.

Results from previous baseline surveys suggested the analysis of biomass for meadows where the large growing species *E. acoroides* was present but not dominant required a different method compared to meadows where *E. acoroides* was dominant (Roelofs et al. 2003). The dry weight biomass for *E. acoroides* is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Historically therefore, isolated *E. acoroides* plants occurring within the *Halodule*/*Halophila* dominated meadows A3 and A5 were excluded from all biomass and species composition analyses in order to track the dynamics of the morphologically distinct *Halodule*/*Halophila* species within the IMA.

2.2 Habitat mapping and Geographic Information System

Spatial data from the 2015 survey were entered into the Port of Weipa 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 percent cover and above-ground biomass (for each species), depth below mean sea level (dbMSL), sediment type, latitude and longitude, sampling method and 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).
- ***Seagrass landscape category***- area data showing the seagrass landscape category determined for each meadow (Figure 7).

Table 1. Nomenclature for Queensland seagrass community types.

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 with Species B/Species C	Species A is 50% 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 type in Weipa.

Density	Mean above ground biomass (g DW m^{-2})				
	***H. uninervis* (narrow)**	***H. ovalis H. decipiens***	***H. uninervis* (wide) *S. isoetifolium***	***T. hemprichii***	***E. acoroides***
Light	< 1	< 1	< 5	< 15	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	40 - 100
Dense	> 4	> 5	> 25	> 35	> 100

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

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

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

Figure 7. Landscape categories for seagrass meadows in Queensland

Seagrass meadow boundaries were determined from a combination of techniques. Exposed inshore boundaries were mapped directly from helicopter and guided by recent satellite imagery of the region (Source: ESRI; Google Earth). Subtidal boundaries were interpreted from a combination of subtidal survey sites and the distance between sites, field notes, depth contours and recent satellite imagery.

Each seagrass meadow was assigned a mapping precision estimate (±m) based on the mapping method used for that meadow (Table 3). Mapping precision estimates ranged from 5m for intertidal seagrass meadows to 10 - 50m for intertidal to subtidal meadows. 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. 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 associated with digitising imagery and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 3. Mapping precision and methods for seagrass meadows in the Port of Weipa 2015.

Mapping precision	Mapping method
5m	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.
10-50m	Meadow boundaries determined from helicopter and camera/grab surveys; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and aerial photography; Relatively high density of mapping and survey sites.

2.3 Seagrass meadow condition index

A condition index was developed for the Weipa seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition, and expanded on the previous index that was applied in the 2014 Weipa report (see Taylor et al. 2015). Meadow condition was divided into one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor) by comparing the condition of the current meadow against the baseline conditions.

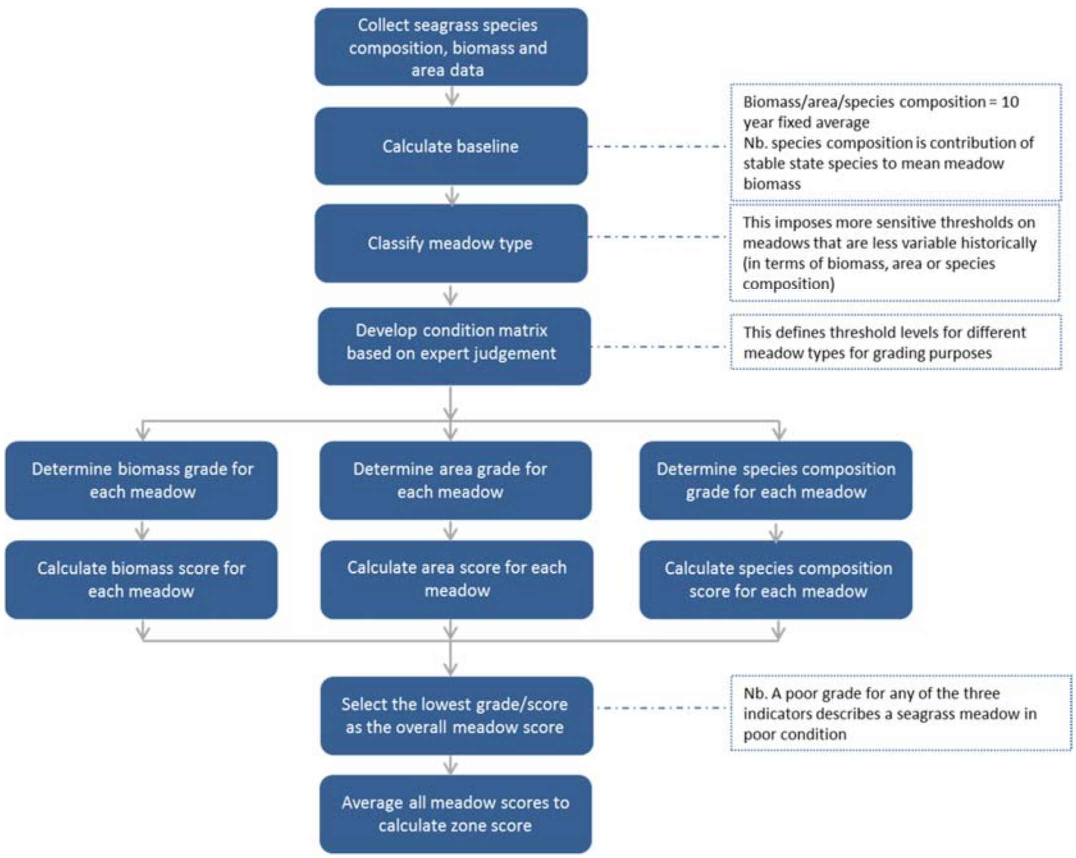

Figure 8. Flow chart to develop the TropWATER seagrass monitoring meadow condition index.

2.3.1 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 (2000 - 2009) following the methods of Carter et al. (2015). Where possible, a long-term average of 10 years is a more accurate representation of the baseline conditions, as a 10 year period incorporates a range of environmental conditions present including El Niño and La Niña periods.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise ≤80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40-60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Section 2.3.4 and Figure 9 for further description).

2.3.2 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.

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 $\geq$ 40%	-
Area	< 10%	CV $\geq$ 10, < 40%	CV $\geq$ 40, <80%	CV $\geq$ 80%
Species composition	-	CV < 40%	CV $\geq$ 40%	-

2.3.3 Threshold Levels for Grading Indicators

Seagrass condition 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).

Table 5. Threshold levels for grading seagrass indicators for various meadow classes. 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	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
	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	Highly stable	More than 5% above the baseline	Within 5% above and 10% below the baseline	Between 10% and 20% below the baseline	Between 20% and 40% below the baseline	More than 40% below the baseline
	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
	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
	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
Species composition	Stable; Single species dominated	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
	Stable; Mixed species	More than 20% above the baseline	<40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
	Variable; Single species dominated	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
	Variable; Mixed species	More than 20% above the baseline	<40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline

Increase above threshold from the previous year

Decrease below threshold from the previous year

2.3.4 Grades and Scores

A score system (0-1) was developed for each grade to enable comparisons of seagrass condition among meadows within a location, and among all the locations monitored by TropWATER (Table 6; see Carter et al. 2015 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 area in satisfactory 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. 2014).

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 9). 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 9). 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).

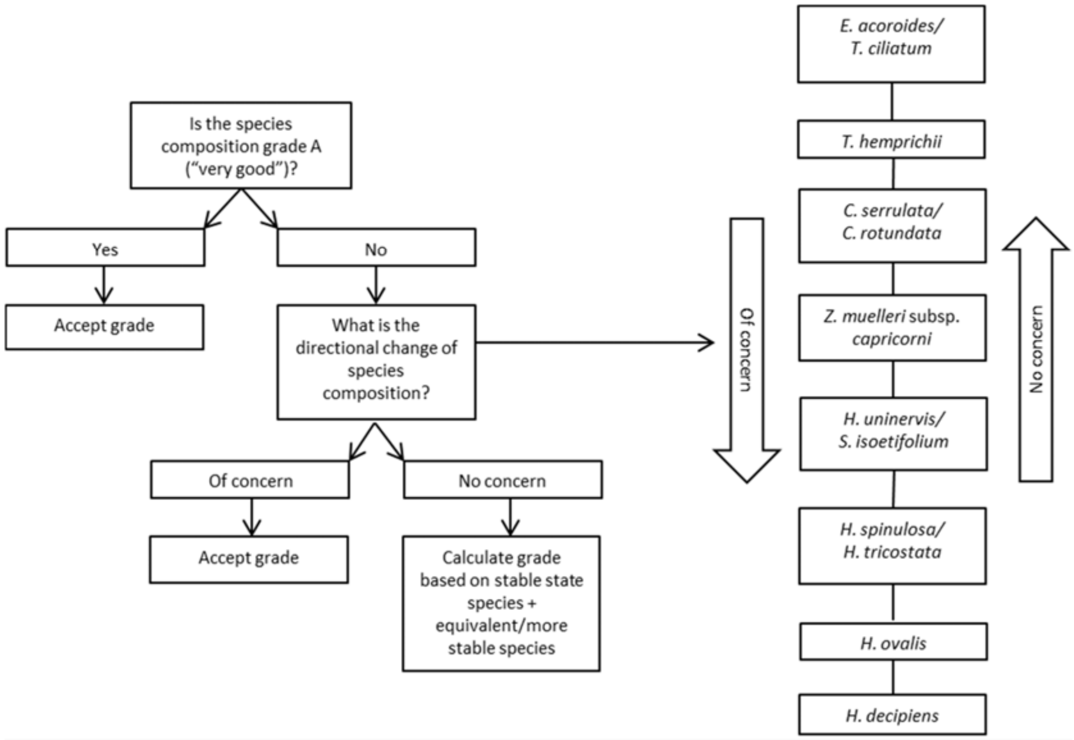

Figure 9. Decision tree and directional change assessment for grading and scoring seagrass species composition.

2.4 Environmental data

Irradiance (Photosynthetically Active Radiation (PAR) mol photons m^{-2} day^{-1}) conditions within the seagrass meadows at Weipa have been assessed at a northern and southern site with the intertidal A2 meadow and at one site in the subtidal/intertidal A7 meadow (Figure 13) since September 2010 using custom built benthic data logging stations (Figure 10). Each independent logging station consists of 2π cosine-corrected irradiance loggers (Submersible Odyssey Photosynthetic Irradiance Recording System, Dataflow Systems Pty. Ltd., New Zealand) with supporting electronic wiper units. Irradiance loggers were calibrated using a cosine corrected Li-Cor underwater quantum sensor (LI-190SA; Li-Cor Inc., Lincoln, Nebraska USA) and corrected for immersion effect using a factor of 1.33 (Kirk 1994). Readings were made at 15 minute intervals and used to estimate total daily irradiance (PAR) reaching seagrasses. The electronic wiper unit fitted to each irradiance logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling.

Environmental data was obtained from the Australian Bureau of Meteorology (www.bom.gov.au) and the Department of Environment and Heritage Protection (www.ehp.qld.gov.au).

PAR loggers in cradles

Deployed PAR loggers in cradles on intertidal seagrass meadow

Figure 10. Logging station consisting of a stainless steel frame, PAR loggers, electronic wiper unit and temperature loggers.

3 RESULTS

3.1 Seagrass species in the Port of Weipa

A total of 417 seagrass habitat characterisation sites were surveyed in the Weipa IMA area in September 2015, with seagrass present in 81% of sites (Figure 5). Four seagrass species (from two families) were identified. A full list of species present in the broader Weipa area is available in previous reports.

Table 7. Seagrass species present in the Port of Weipa 2015.

CYMODOCEACEAE Taylor		***Halodule uninervis*** (narrow & wide leaf morphology) (Forsk.) Aschers • Narrow leaf blades 0.25-5mm wide • Trident leaf tip ending in three points • 1 central longitudinal vein which does not usually split into two at the tip • Usually pale ivory rhizome, with clean black leaf scars along the stem
HYDROCHARITACEAE Jussieu		***Enhalus acoroides*** *(*L.*f.*) Royle • Very distinctive seagrass • Very long, ribbon-like leaves (30-150cm long, 1.25 - 1.75cm wide) • Thick leaves with many parallel veins • Very thick rhizome (at least 1cm) with black, fibrous bristles
		***Halophila ovalis*** (Br.) D.J. Hook. • Small oval shaped leaves (0.5 - 2cm long) • 8 or more cross-veins on leaf • No hairs on leaf surface • Dugong preferred food
		***Thalassia hemprichii (Ehrenb.) Aschers. in Petermann*** • Long, ribbon-like leaves 10-40cm long • 10-17 longitudinal leaf veins • Short black bars of tannin cells on leaf blade • Leaf sheaths 3-7cm long • Thick rhizome (up to 5mm) with conspicuous scars between shoots

3.2 Seagrass in the Intensive Monitoring Area

Fourteen seagrass meadows were mapped in September 2015 within the Intensive Monitoring Area (IMA) (Figure 13). The total combined seagrass meadow area was 1034 ± 90 ha, a 7% decrease in area from 2014 (Figure 11). Seagrass area in 2015 was similar to the long-term average of 1037 ha (Figure 11). Individual meadow area within the IMA ranged from 2 ha to 248 ha.

The dominant seagrass species in each of the core monitoring meadows remained unchanged from 2013 and 2014 (Figures 14-18; Appendix 2). *E. acoroides* dominated seagrass communities in twelve of the fourteen meadows within the IMA, including the core monitoring meadows A2, A6 and A7 (Figure 13; Appendix 2). *Halodule uninervis* was the dominant species in monitoring meadow A5 on the eastern side of the Embley River, and meadow A3 on the western bank of the Hey River. In 2014 *Thalassia hemprichii* was the dominant species in two meadows within the IMA (A1 and the small meadow closest to A1) (Taylor et al 2015). This changed in 2015 whereby *E. acoroides* made up more of the species composition in these meadows, re-categorising these meadows to *E. acoroides/T. hemprichii* meadows.

The condition known as burning, i.e. the browning and subsequent death of seagrass blades (Figure 12), was observed at 16% of sites surveyed within the IMA in 2015; a decrease from 2014 which recorded 24% of sites with burning.

Dugong feeding trails were observed in two areas on the bank where the A5 meadow is located. Prior to 2014, dugong feeding trails had not been observed between 2011 - 2013 in the IMA.

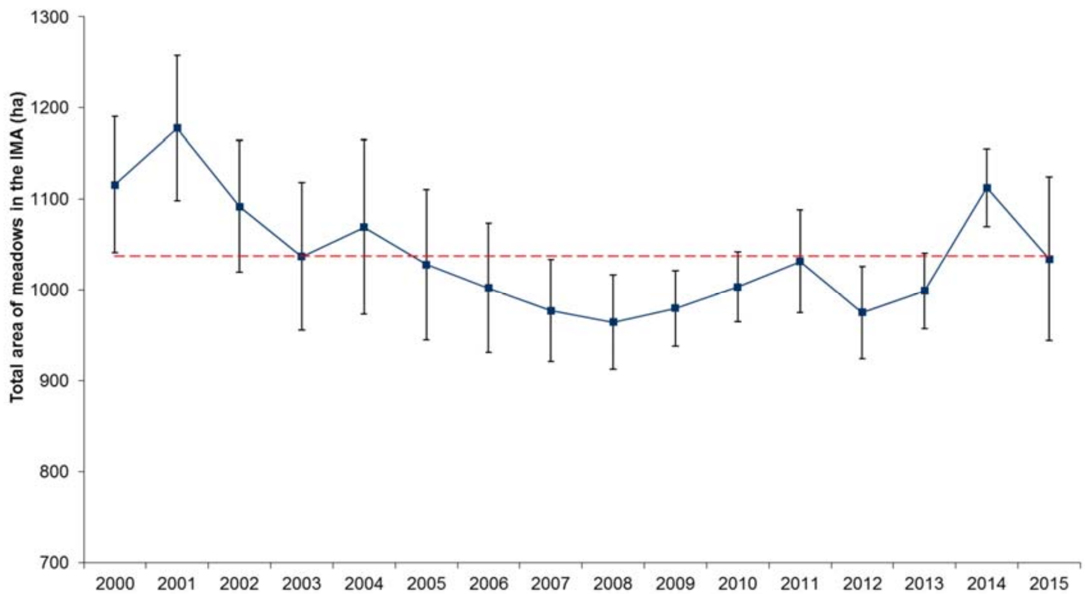

Figure 11. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2015 (error bars = "R" reliability estimate). Red dashed line indicates 15-year mean of total meadow area.

Figure 12. Examples of burning of *Enhalus acoroides* in Weipa meadows and dugong feeding trails in the A5 Weipa monitoring meadow..

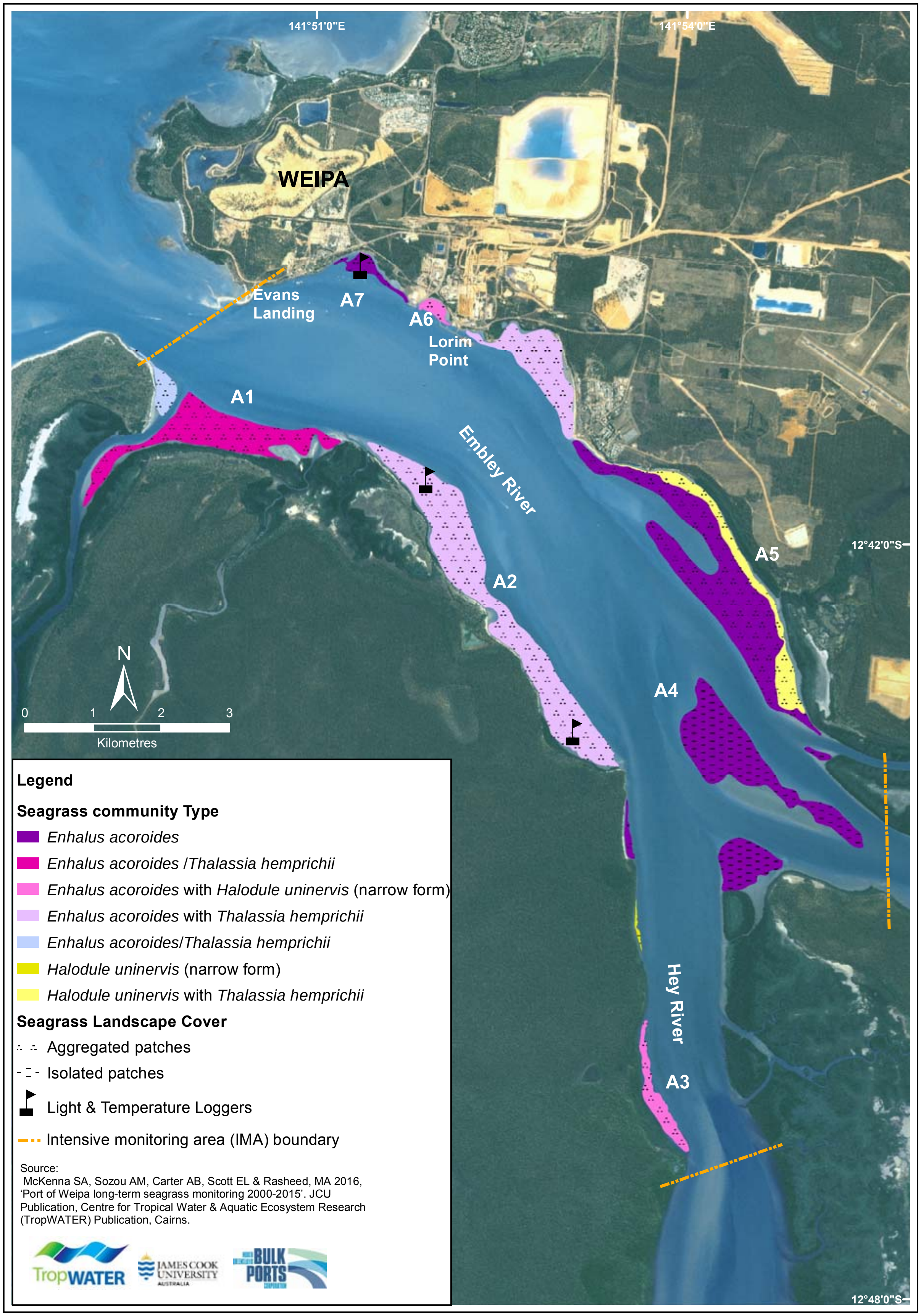

Figure 13. Meadow type and landscape cover for seagrass within the Intensive Monitoring Area 2015.

3.3 Seagrass condition in the core annual monitoring meadows

The overall condition of seagrasses in Weipa in 2015 was classed as good (Table 8). The biomass and species composition indicators for all monitoring meadows were classed as either very good or good (Figures 14-18). It was the lower area indicator scores that drove the overall meadow scores. Two meadows were classed as good overall (A2 and A6), while the other three monitoring meadows (A3, A5 and A7) were classed as satisfactory as a result of lower area indicator scores (Table 8; Figures 14-18).

Seagrass biomass was near to or above the long-term average for all monitoring meadows, while meadow area was below the long-term average for three meadows including both monitoring meadows dominated by *H. uninervis*. There was no evidence of substantial shifts in species composition towards colonising species that would cause concern in meadow condition in any of the monitoring meadows (Figures 14-18).

Two of the three monitoring meadows dominated by *E. acoroides* (A2 and A6), the largest growing species found in Weipa, were in good condition in 2015, while the third *E. acoroides* dominated monitoring meadow, A7 at Evan's Landing was classified as satisfactory (Figures 14-18). The down-grading of the A7 meadow from good for the past couple of years to satisfactory in 2015 was a result of the decrease in the area of the meadow to 15ha in 2015. This is the lowest area recorded for the subtidal/intertidal *E. acoroides* meadow since 2009. Most of the decline in area has occurred at the deeper edges of the meadow. Mean above-ground biomass in the three *E. acoroides* monitoring meadows ranged from 6.4 ± 1.03 g DW m^{-2} (A6) to 14.37 ± 0.66 g DW m^{-2} (A2) (Figures 14-18).

Concerns have previously been raised regarding the resilience of meadow A2 on the opposite side of the port facilities and Napranum due to declining biomass between 2000 and 2009 (Figure 14 and 19). Biomass of this meadow appears to have stabilised over the past four years. An analysis of biomass density across the meadow over time indicates that biomass was more evenly distributed in the past two years (2014-2015) with less obvious areas of low biomass, as well as fewer dense hotspots compared with previous years (Figure 19). Mean above-ground biomass in this meadow has ranged from 4.65 ± 0.63 g DW m^{-2} (2008) to 33.63 ± 5.82 g DW m^{-2} (2000) (Figure 14; Appendix 3). Area of this meadow remained relatively stable, with meadow area in 2015 similar to the long-term average.

Biomass in the intertidal *H. uninervis* dominated meadows (A3 and A5) has been in the 'very good' or 'good' seagrass grade since 2009/2010, but has fluctuated above and below the long-term average throughout these years (Figures 15 and 16). Both these meadows were graded as being in satisfactory condition in 2015 due to meadow area declines (Figures 15 and 16; Appendix 3). This was the fourth consecutive year there was a decline in area in the A5 meadow.

The majority of seagrass monitoring meadows in Weipa had a light density of seagrass cover, with only one of the meadows; meadow A5 consisting of a dense cover of *H. uninervis* with *T. hemprichii*, similar to 2014. The landscape cover for this meadow increased from isolated patches in 2014 to aggregated patches indicating a more consistent spread of *H. uninervis* throughout the meadow. No meadows in 2015 were classified as having a continuous cover of seagrass.

Table 8. Grades and scores for seagrass indicators (biomass, area and species composition) for the Port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.747	0.779	0.706	0.706
A3	0.704	0.612	0.918	0.612
A5	0.853	0.527	0.988	0.527
A6	0.786	0.884	0.776	0.776
A7	0.717	0.632	0.848	0.632
Overall Score for the Port of Weipa				**0.651**

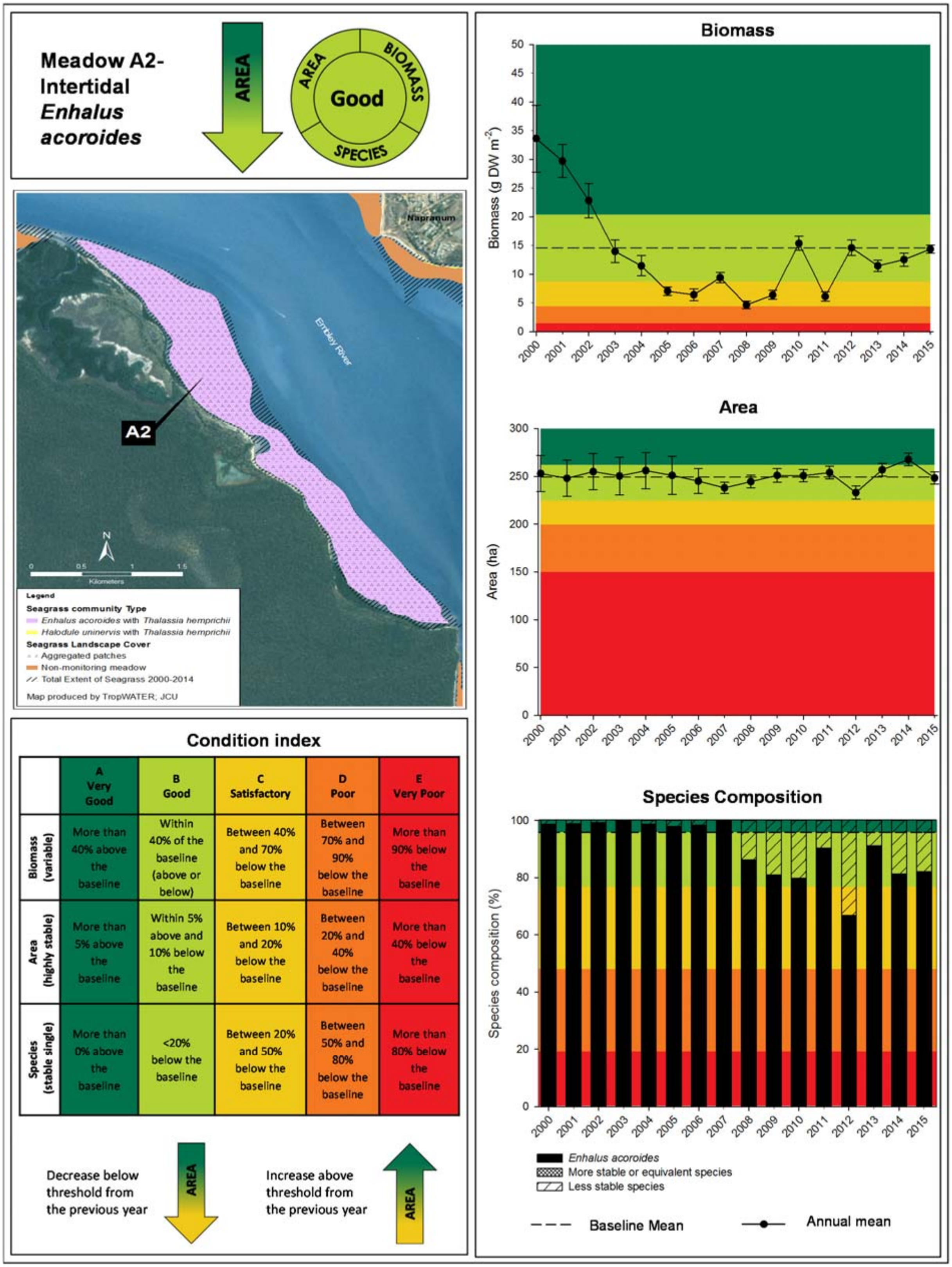

Figure 14. Changes in biomass, area and species composition for the Enhalus acoroides dominated core monitoring meadow A2 in Weipa from 2000 to 2015 (biomass error bars = SE; area error bars = "R").

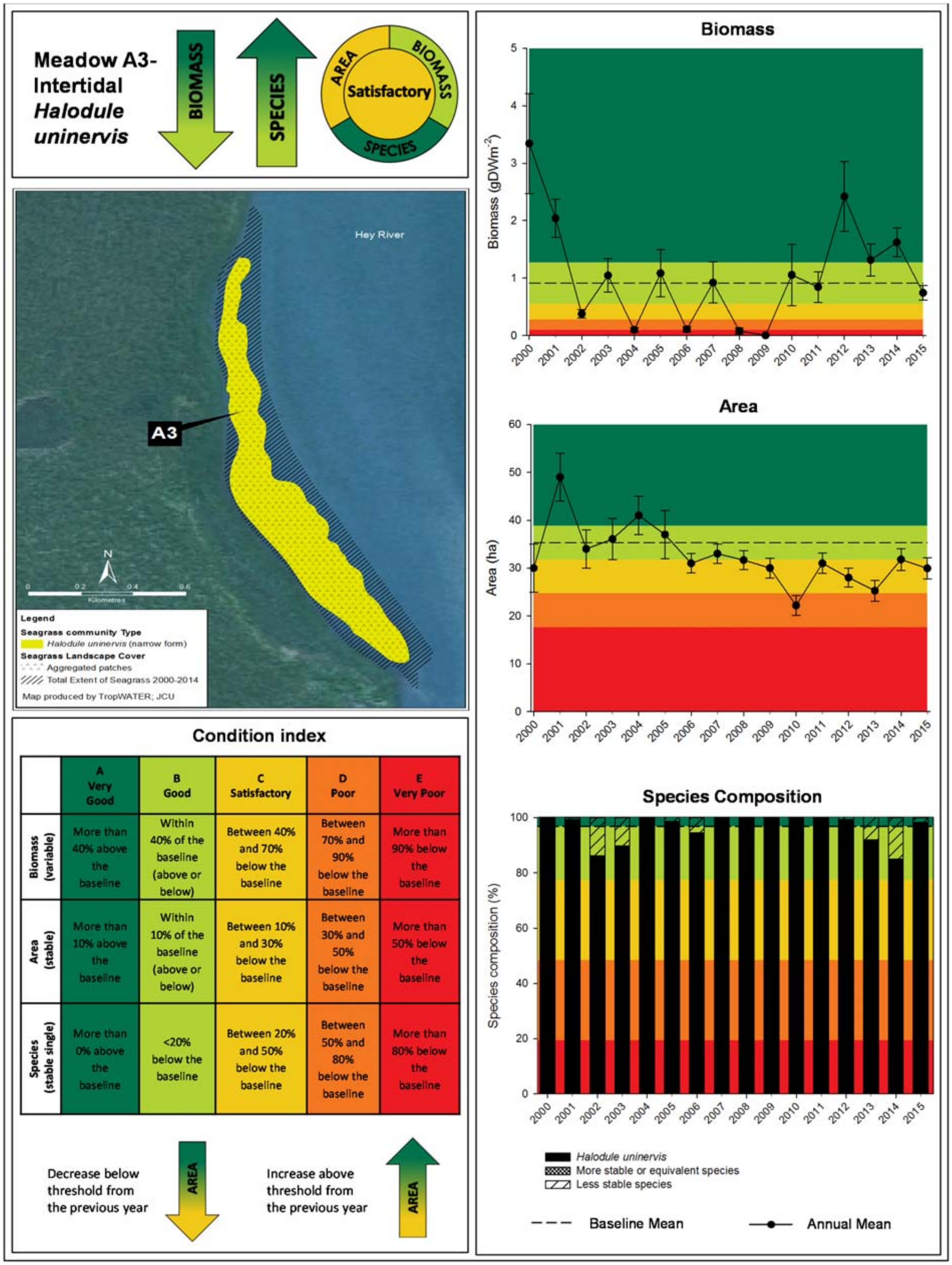

Figure 15. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A3 in Weipa from 2000 to 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

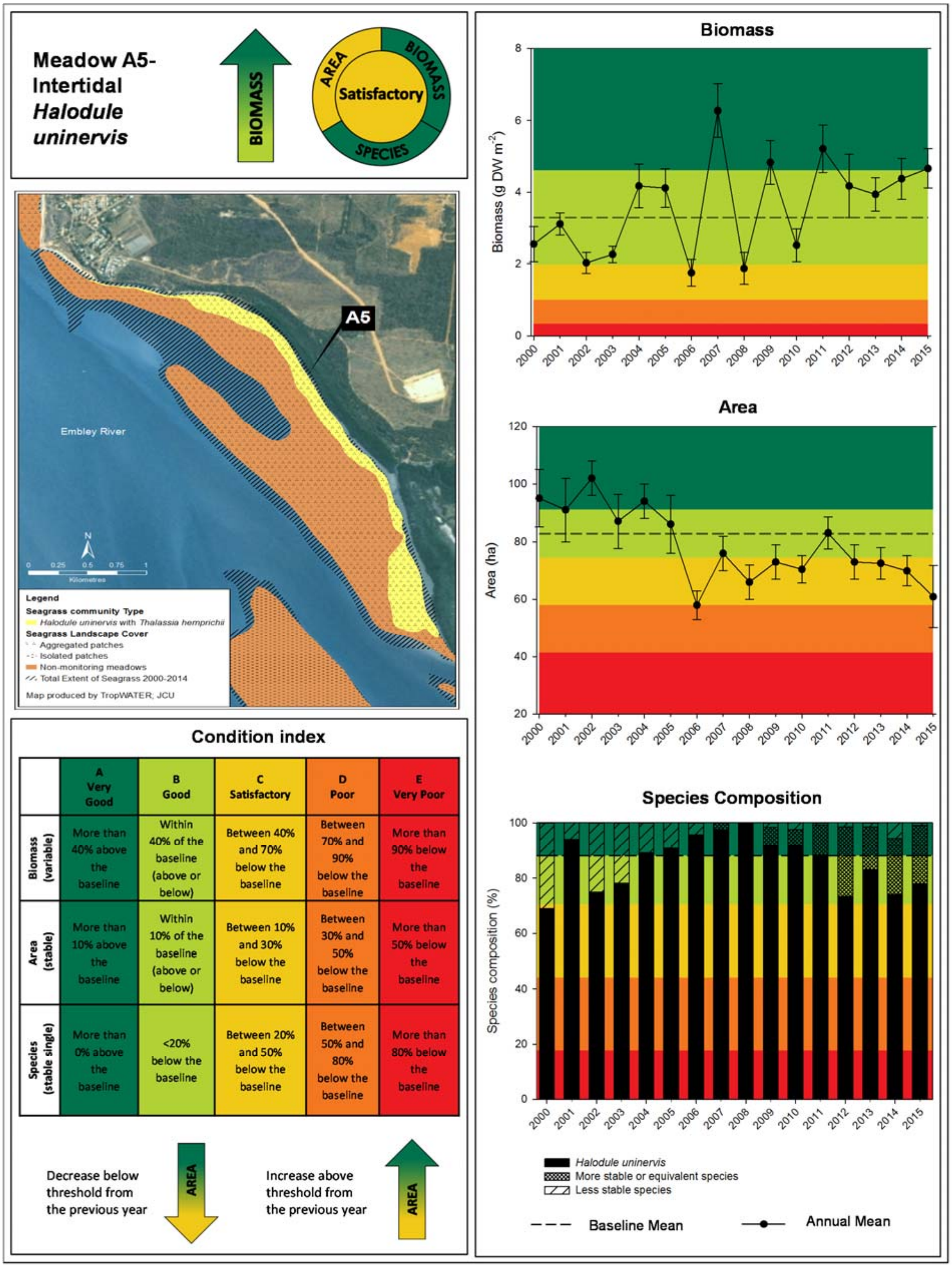

Figure 16. Changes in biomass, area and species composition for the *Halodule uninervis* dominated core monitoring meadow A5 in Weipa from 2000 to 2015 (biomass error bars = SE; area error bars = “R” reliability estimate).

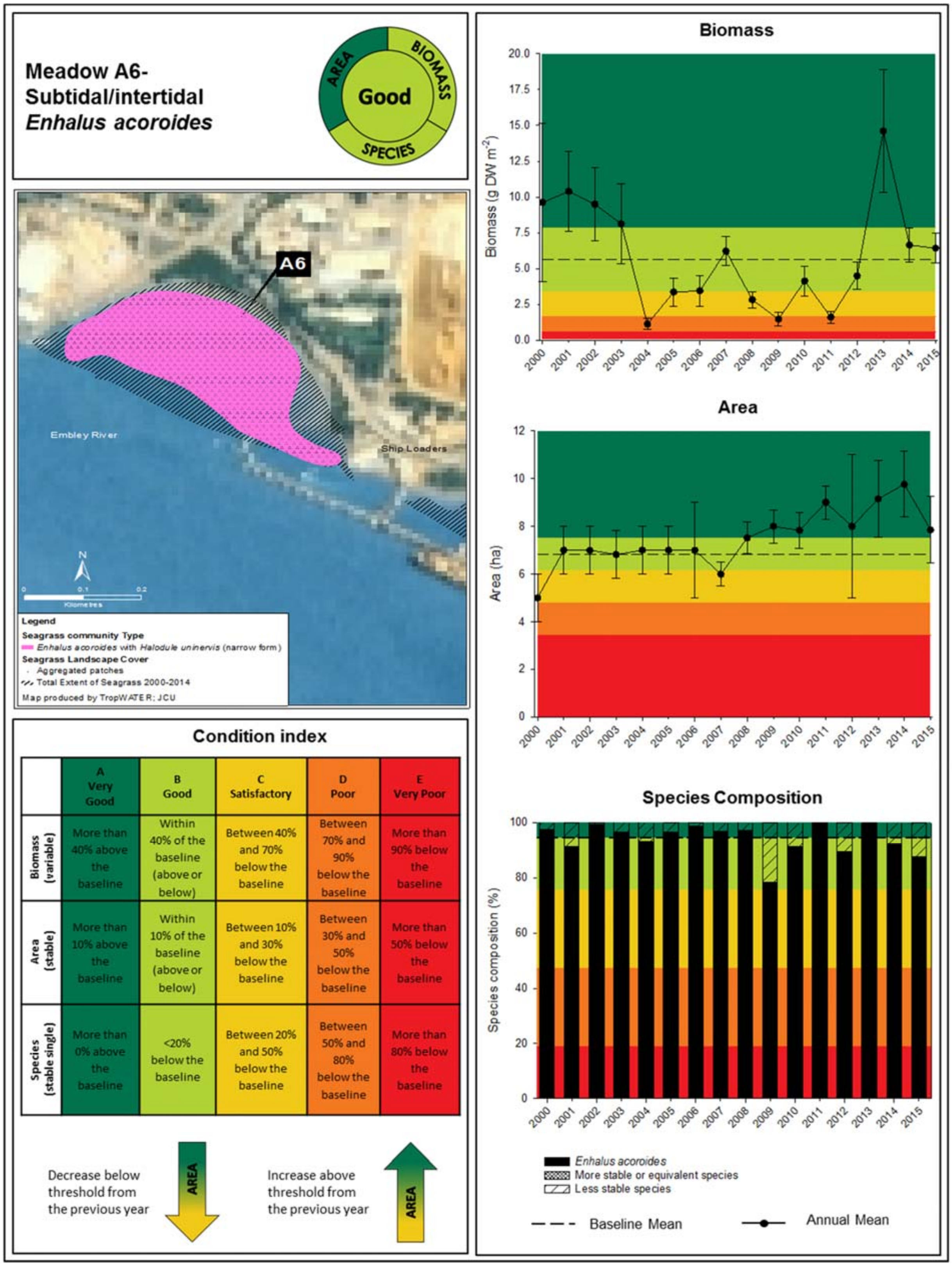

Figure 17. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A6 in Weipa from 2000 to 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

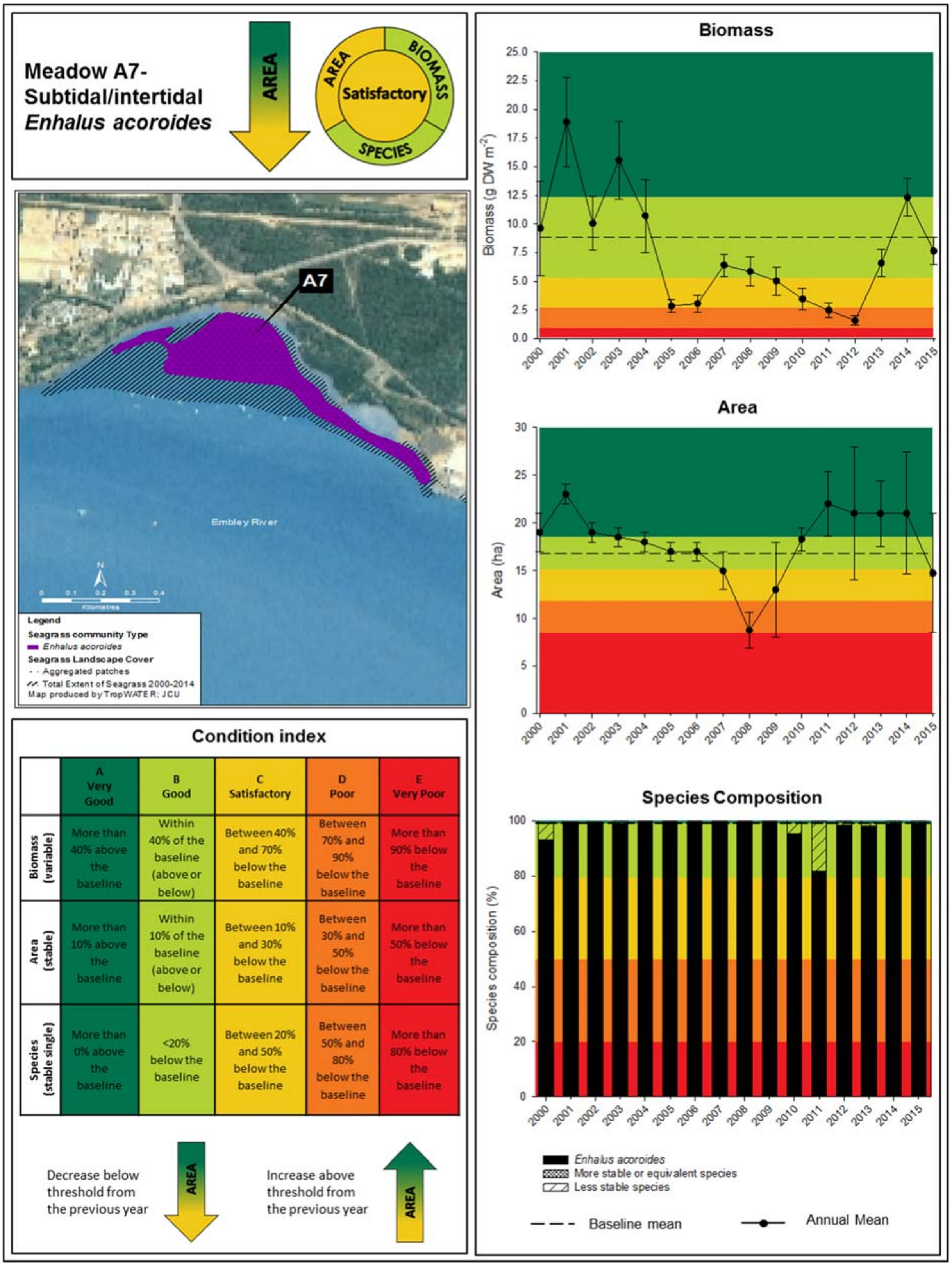

Figure 18. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated core monitoring meadow A7 in Weipa from 2000 to 2015 (biomass error bars = SE; area error bars = "R" reliability estimate).

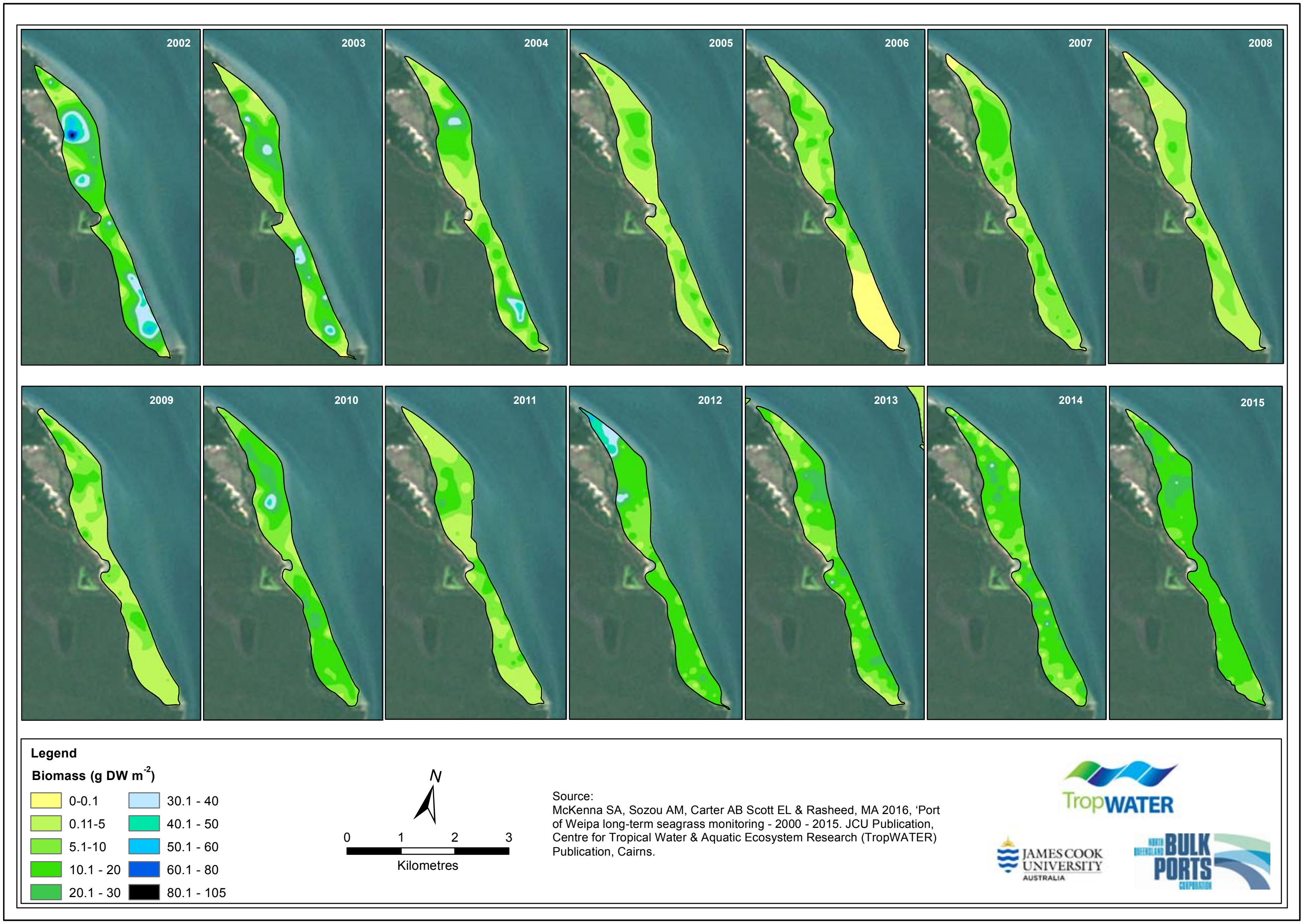

Figure 19. Seagrass biomass changes in the A2 monitoring meadow from 2002-2015

3.4 Weipa climate data and seagrass change

3.4.1 Rainfall

Total annual rainfall in Weipa in the 12 months preceding the 2015 survey (September) was below the long-term average of 1732 mm and below what fell in 2014 (Figure20). Only 3.6 mm of rain was recorded between May 2015 and the survey month (Figure 20 and 21). Rainfall was highly variable between months and showed a typical tropical wet and dry season pattern (Figure 20 and 21).

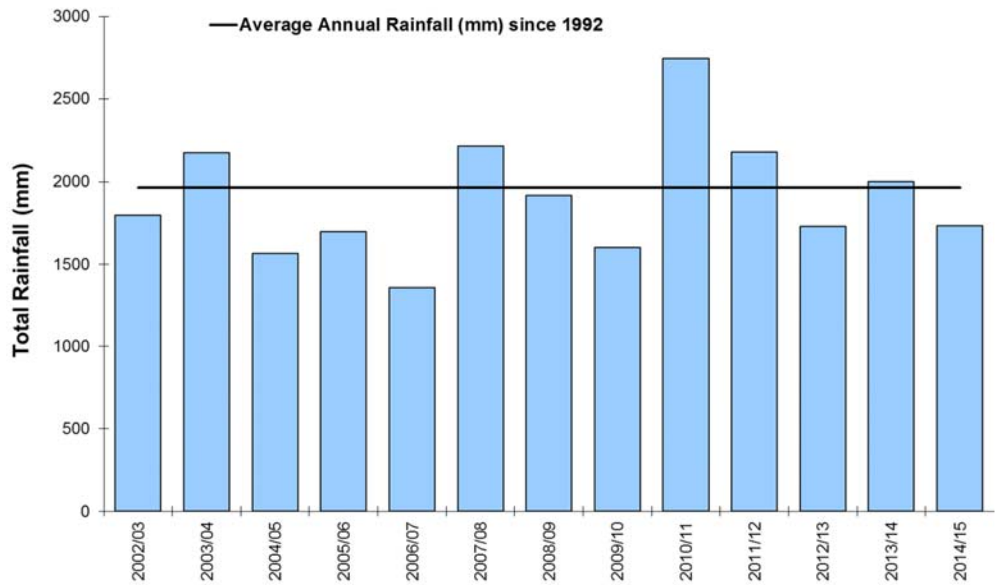

Figure 20. Total annual rainfall recorded at Weipa Airport; 2002-2015. Twelve month year (2014/15) is twelve months prior to survey. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

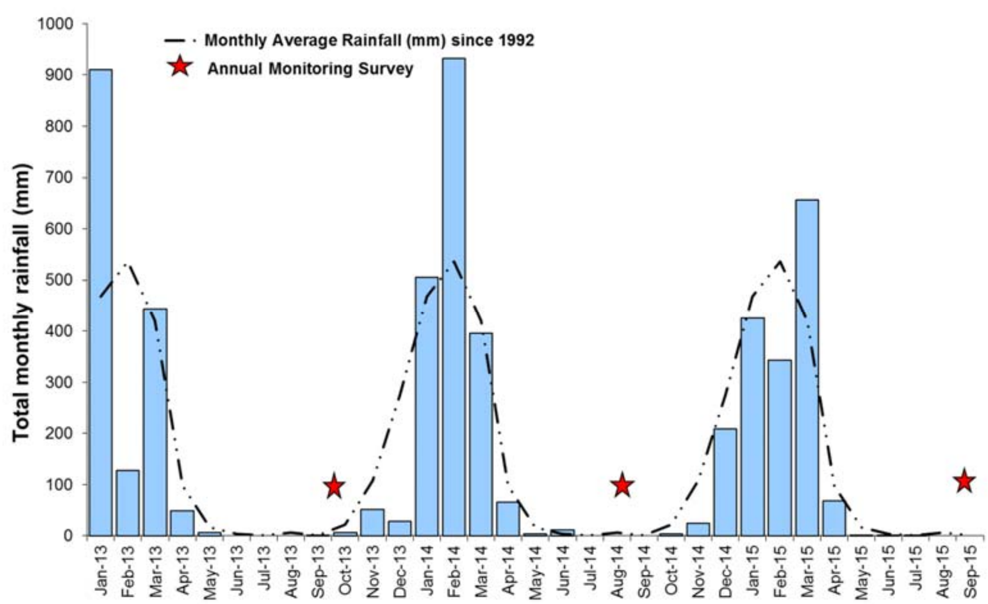

Figure 21. Total monthly rainfall (mm) between January 2013 – September 2015. Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

3.4.2 Daytime tidal exposure

Intertidal banks at Weipa were exposed to air for 394 hours during the 12 months prior to the September 2015 monitoring survey and was below the 16 year long-term average. Tidal exposure hours has been below the long-term average since 2008/09 (Figure 22). Tidal exposure hours for intertidal seagrass meadows in Weipa generally exhibit a greater amount of exposure during the winter/dry months, with July exposure peaking at 106 hours, and low to no exposure during the summer/wet season (Figure 23). Daytime exposure one month prior to the survey was similar to 2014 and slightly above the 16 year long-term average, while for the three months prior to the survey it was the highest recorded since 2008 and above the long-term average (Figure 24). Previous studies by the TropWATER group in Weipa have shown that it is the previous month to the survey of tidal exposure that has significant impacts on seagrass biomass (Unsworth et al. 2012).

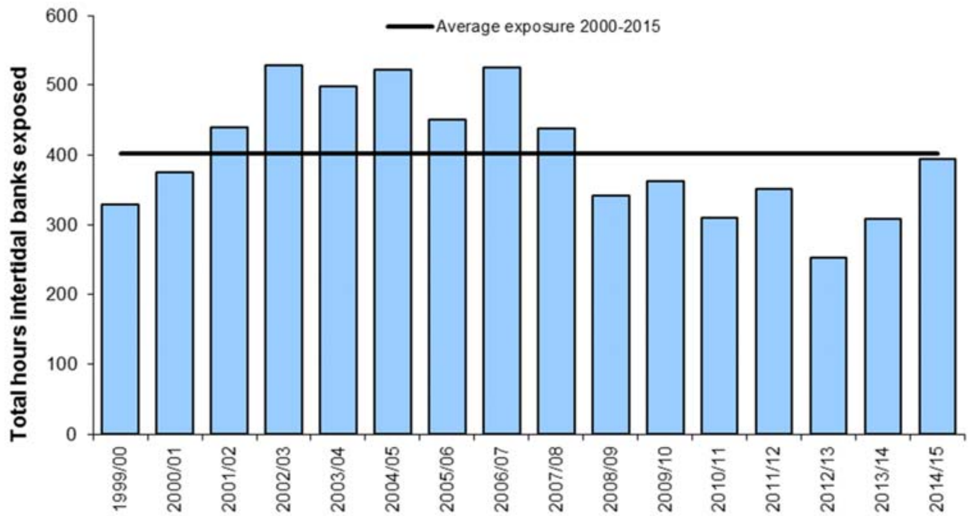

Figure 22. Annual total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa; 1999-2015. Twelve month year is twelve months prior to survey. 2015 tidal data © State of Queensland (Department of Transport and Main Roads).

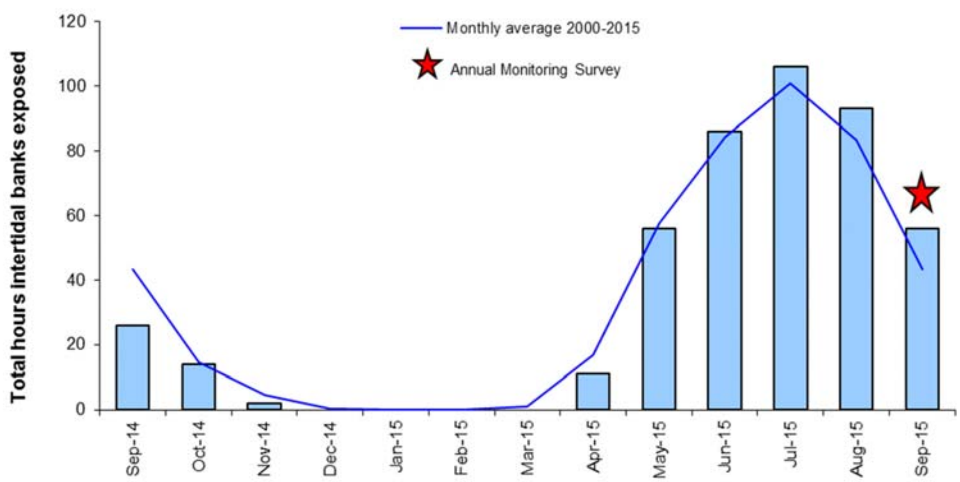

Figure 23. Monthly total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 12 months preceding the 2015 monitoring survey. Red bar indicates month when monitoring survey occurred. 2015 tidal data © State of Queensland (Department of Transport and Main Roads).

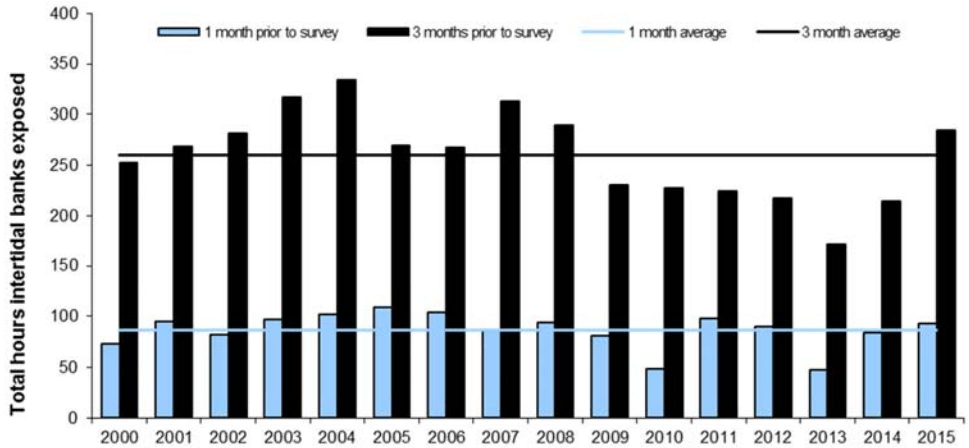

Figure 24. Total daytime tidal exposure (hours; ≤0.9m tidal height) in Weipa in the 1 and 3 month preceding each monitoring survey; 2000-2015. 2015 tidal data © State of Queensland (Department of Transport and Main Roads).

3.4.3 Solar Radiation

Daily global exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Mean daily solar radiation (global solar exposure) in 2014/15 was slightly higher than the long-term average for the area of 20.9 MJ m^{-2} (Figure 25). The highest daily global exposure recorded in the area in recent years occurred in 2012/13.

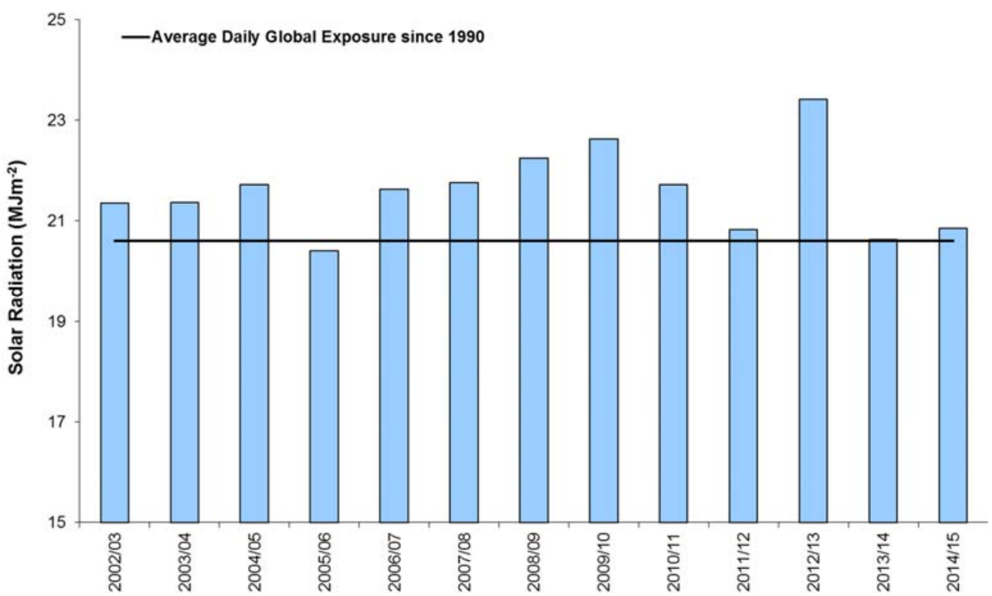

Figure 25. Average annual solar radiation (mJ m^{-2}) for the 12 months preceding each survey; 2002 – 2015.
Source: Bureau of Meteorology (BOM), Station 027045, available at www.bom.gov.au

3.4.4 Daily photosynthetically active radiation (light)

Total daily PAR in the shallower intertidal A2 meadow was greater and more variable than in the deeper subtidal/intertidal A7 meadow (Figure 26 and 27). Total daily PAR in the 12 months prior to the survey ranged from 0.02 to 33.54 mol photons m^{-2} day^{-1} in the A2 meadow, and from 0.30 to 18.14 mol photons m^{-2} day^{-1} in the A7 meadow (Figure 26). There were three occasions in in the twelve months prior to the survey (Nov 2014, Jan and Mar 2015) where PAR fell below 3.5 mol photons m^{-2} d^{-1} for up to 17 consecutive days (Figure 26 and 27), levels that are low enough to cause declines in *H. uninervis* (McKenna et al. 2015; Collier et al. 2016). This often coincided with rainfall events.

Total daily PAR was on average higher in the 2015 wet season compared to the 2013 and 2014 wet season, which coincided with a smaller amount of rainfall in 2015 compared to the previous two years (Figures 21, 26 and 27). PAR was also on average higher in the 2015 dry season compared to the 2013 and 2014 dry season.

3.4.5 Water temperature

Mean daily water temperature in the A2 meadow was 28.8°C (at both north and south sites) and 28.7°C in meadow A7 in the twelve months prior to the survey (Figure 26). Maximum daily water temperature peaked at over 40°C, and was sustained at this level for consecutive days on multiple occasions in the A2 meadow, particularly in the month prior to the survey (Figure 26). This has only been seen a couple of other times since 2010 when we started recording temperature data at the seabed. Similarly in the subtidal/intertidal A7 meadow, temperatures where sustained over 35°C for consecutive days. These peaks in maximum temperature coincided with periods of tidal air exposure of the meadow.

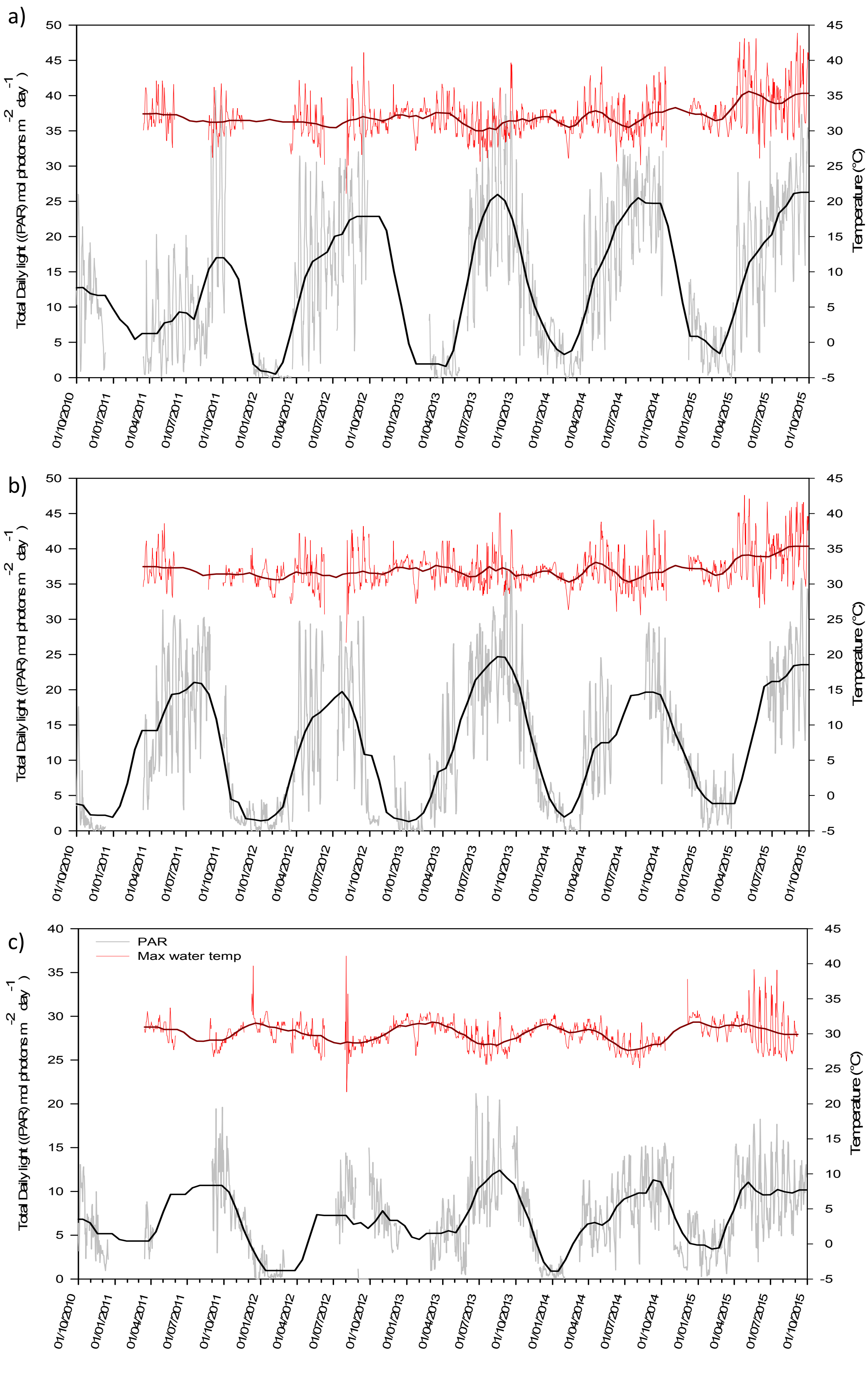

Figure 26. Daily photosynthetically active radiation (PAR mol photons m^{-2} day^{-1}) and mean and maximum daily water temperature (°C) at Weipa, 2010 – 2015, at meadow A2 (a & b) and meadow A7 (c).

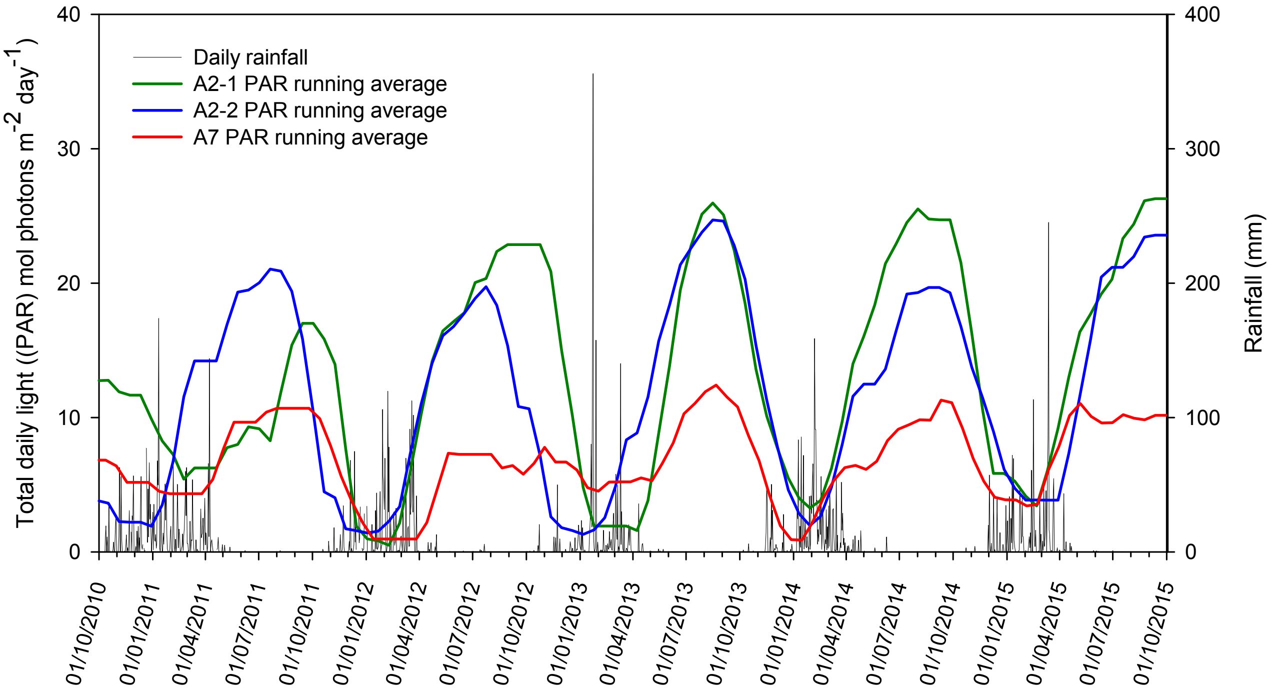

Figure 27. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa, October 2012 – September 2015, at Meadow A7 and Meadow A2 northern (A2-1) and southern (A2-2).

4 DISCUSSION

Seagrasses in Weipa were in a good condition in 2015. In the area closest to major port operations and town activity (Intensive Monitoring Area (IMA)), seagrass biomass remained near to or above the long-term average for all monitoring meadows and species composition remained stable. Despite being in good condition, total seagrass meadow area within the IMA decreased 7% between 2014 and 2015 and was the major driver of three of the five monitoring meadows being classified as satisfactory rather than good. The declines of area in meadows A2 and A7 were significant enough to change their condition from very good in 2014 to good in 2015 for A2, and very good to satisfactory for A7.

The overall good condition of Weipa's seagrasses in 2015 means they should remain resilient to planned maintenance dredging activities in 2016, without the requirement for additional mitigation measures. This expectation assumes the duration of dredging remains relatively short and that there are no major seagrass losses associated with climate or other impacts leading up to the 2016 maintenance dredging campaign.

The declines in area and biomass that occurred for many meadows in 2015 compared to the previous two years were likely linked to local environmental conditions, and in particular periods of extremely high water temperature coupled with tidal air exposure of the meadows. In 2015 many environmental factors were at levels considered to be favourable for seagrass growth; low tidal exposure, below average rainfall and average solar exposure, however most monitoring meadows experienced extreme peaks in water temperature in the latter half of the year. Water temperature peaked to over 40°C on eighteen occasions in the intertidal A2 meadow (up to two hours per day over three consecutive days), and at over 35°C sixteen times in the A7 meadow (up to two hours per day over four consecutive days) between May and September 2015. These peaks in temperature usually coincided with meadows being exposed to air. This was the most sustained level of such high temperatures that we have recorded since meadow temperature monitoring began in 2010.

Extreme water temperatures can affect the balance between photosynthesis and respiration in seagrasses and cause sharp reductions in photosynthetic efficiency after temperatures exceed optimum thresholds (Balthius 1987; Ralph 1998; Perez and Romero 1992; Campbell et al. 2006; Collier and Waycott 2014). Collier and Waycott (2014) found that 40°C represented a critical threshold for intertidal tropical seagrasses beyond which large impacts to growth and mortality occurred. Growth rates for *Halodule uninervis* were reduced by 88%, and at 43°C there was complete mortality after 2-3 days (Collier and Waycott 2014). Jiang et al. (2014) also demonstrated that *E. acoroides* is more resistant to the deleterious effects of desiccation during tidal exposure owing to *E. acoroides'* thick waxy leaves. However, this resilience is diminished when periods of tidal exposure coincide with periods of high temperature; as was the case in Weipa, and desiccation occurred faster, and critical threshold limits were reached sooner relative to other species. While daytime tidal exposure to air for intertidal seagrasses was below the long term average in 2015, exposure levels were the highest recorded since 2008 and likely added to the level of exposure related stresses to seagrasses compared to previous years. Seagrass biomass is negatively correlated with increased tidal exposure and high temperatures leading to desiccation stress in Weipa (Unsworth et al. 2012) and other tropical locations (Collier and Waycott 2014).

The local light environment also plays an important role in tropical seagrass dynamics. McKenna et al. (2015) reported that subtidal *H. uninervis* at Abbot Point required a fourteen day rolling average of 3.5 mol photons m^{-2} d^{-1} to maintain growth. Similarly Collier et al. (2012) reported that shallow coastal *H. uninervis* at three locations in the northern Great Barrier Reef required between 5 and 8.4 mol photons m^{-2} d^{-1} to maintain effective growth, and found a strong correlation between seagrass loss and repeated exposure to light levels below 4 mol photons m^{-2} d^{-1}. In Weipa there were three occasions in the twelve months prior to the survey where PAR fell below 3.5 mol photons m^{-2} d^{-1} for up to 17 consecutive days, levels that were low enough to cause declines in *H. uninervis* at other Queensland locations. At this stage specific light requirements to sustain *E. acoroides* meadows have not been determined, but expansion of the Weipa monitoring program in 2015 is now investigating light/biomass relationships of *E. acoroides* and over time will lead to locally applicable light thresholds for management of this species.

The management of seagrass resources in Weipa should remain focused on ensuring the resilience of local seagrasses remains high enough to withstand expected anthropogenic impacts and risks. The resilience of seagrasses in Weipa was likely to be at relatively high levels in 2015. This is similar to other seagrass meadows in the Gulf (Sozou et al. 2016). In summary, results of the 2015 monitoring indicate:

1. Seagrasses in the Port of Weipa were in a good condition with biomass and area near or above the long-term average and species composition stable.
2. The good condition of seagrass meadows indicates meadows should continue to be resilient to planned maintenance dredging activities in 2016, without the requirement for additional mitigation measures.
3. Although seagrasses in the Port of Weipa were considered to be in a good condition, total seagrass meadow area within the IMA did decrease between 2014 and 2015, and biomass decreased at some meadows.
4. Area in meadows A2 and A7 decreased considerably enough for their condition index to be downgraded from 2014 to 2015.
5. Results from light monitoring (photosynthetically active radiation (PAR)) indicates that the light environment remained favourable for seagrass growth during the majority of 2014-2015, but fell below the likely minimum light requirements for long periods of time during the wet season.
6. Results from water temperature monitoring within the meadows indicate that there were thermal peaks of over 40°C for consecutive days that were likely to lead to reduced growth and losses of seagrass.
7. Expansion of the monitoring program in 2015 will work towards developing locally relevant biomass and light relationships for Weipa *Enhalus acoroides*.

5 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. Species composition of monitoring meadows in the Po rt of Weipa; 2000 – 2015

Appendix 3a.

Mean above-ground seagrass biomass (g DW m^{-2}) ± standard error and number of biomass sampling sites (in brackets) for each core monitoring meadow within the Port of Weipa, 2000 – 2015.

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)															
	Sep-00	Sep-01	Sep-02	Sep-03	Aug-04	Aug-05	Aug-06	Sep-07	Sep-08	Sep-09	Sep-10	Aug-11	Aug-12	Sep-13	Aug-14	Sept-15
A2 Intertidal *Enhalus* dominated	33.63 ± 5.82 (17)	29.73 ± 2.88 (51)	22.84 ± 2.99 (50)	13.99 ± 1.96 (54)	11.47 ± 1.77 (51)	7.04 ± 0.72 (51)	6.43 ± 1.03 (54)	9.40 ± 0.90 (46)	4.65 ± 0.63 (48)	6.39 ± 0.77 (70)	15.36 ± 1.23 (52)	6.13 ± 0.82 (51)	14.60 ± 1.36 (65)	11.47 ± 1.01 (76)	12.55 ± 1.15 (81)	14.37 ± 0.66 (91)
A3 Intertidal *Halodule* dominated	3.34 ± 0.87 (11)	2.04 ± 0.33 (26)	0.38 ± 0.07 (30)	1.04 ± 0.29 (26)	0.10 ± 0.04 (26)	1.08 ± 0.41 (25)	0.11 ± 0.05 (31)	0.92 ± 0.36 (31)	0.08 ± 0.05 (28)	0.0002 ± 0.0001 (31)	1.05 ± 0.53 (26)	0.84 ± 0.26 (44)	2.42 ± 0.61 (34)	1.31 ± 0.28 (69)	1.62 ± 0.25 (71)	0.74 ± 0.12 (77)
A5 Intertidal *Halodule* dominated	2.55 ± 0.49 (9)	3.11 ± 0.31 (51)	2.03 ± 0.29 (51)	2.26 ± 0.23 (49)	4.18 ± 0.61 (50)	4.11 ± 0.54 (50)	1.75 ± 0.38 (57)	6.27 ± 0.74 (48)	1.87 ± 0.45 (48)	4.83 ± 0.61 (76)	2.52 ± 0.46 (62)	5.21 ± 0.66 (78)	4.17 ± 0.88 (60)	3.94 ± 0.47 (70)	4.38 ± 0.57 (67)	4.66 ± 0.55 (67)
A6 Intertidal/subtidal *Enhalus* dominated	9.63 ± 5.52 (9)	10.4 ± 2.79 (26)	9.5 ± 2.54 (25)	8.13 ± 2.90 (25)	1.14 ± 0.40 (26)	3.37 ± 1.00 (26)	3.45 ± 1.09 (26)	6.22 ± 1.01 (31)	2.83 ± 0.55 (25)	1.47 ± 0.47 (29)	4.14 ± 1.04 (25)	1.61 ± 0.41 (49)	4.49 ± 0.94 (28)	14.61 ± 4.29 (32)	6.64 ± 1.19 (32)	6.43 ± 1.03 (32)
A7 Intertidal/subtidal *Enhalus* dominated	9.63 ± 4.12 (14)	18.89 ± 3.88 (30)	10.03 ± 2.34 (33)	15.57 ± 3.39 (31)	10.71 ± 3.19 (24)	2.84 ± 0.58 (30)	3.06 ± 0.73 (33)	6.41 ± 0.97 (33)	5.85 ± 1.28 (21)	5.03 ± 1.22 (24)	3.46 ± 0.92 (21)	2.47 ± 0.65 (35)	1.58 ± 0.42 (36)	6.58 ± 1.20 (45)	12.31 ± 1.65 (39)	7.64 ± 1.20 (34)

Appendix 3b.

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2015.

Monitoring Meadow	Total meadow area + R (ha)															
	Sep-00	**Sep-01**	**Sep-02**	**Sep-03**	**Aug-04**	**Aug-05**	**Aug-06**	**Sep-07**	**Sep-08**	**Sep-09**	**Sep-10**	**Aug-11**	**Aug-12**	**Sep-13**	**Aug-14**	**Sep 16**
A2 Intertidal *Enhalus* dominated	253.0± 19.0	248.0± 19.0	255.0± 19.0	250.4± 19.7	256.0± 19.0	251.0± 20.0	245.0± 13.0	238.0± 6.0	244.5± 6.6	251.0± 7.0	250.7± 6.5	254.0± 6.5	233.0± 7.0	256.9± 6.6	267.7± 6.5	248.3± 6.5
A3 Intertidal *Halodule* dominated	30.0± 5.0	49.0± 5.0	34.0± 4.0	36.1± 4.3	41.0± 4.0	37.0± 5.0	31.0± 2.0	33.0± 2.0	31.7± 2.0	30.0± 2.1	22.2± 2.1	31.0± 2.1	28.0± 2.0	25.3± 2.2	31.8± 2.3	30.0± 2.2
A5 Intertidal *Halodule* dominated	95.0± 10.0	91.0± 11.0	102.0± 6.0	87.0± 9.3	94.0± 6.0	86.0± 10.0	58.0± 5.0	76.0± 6.0	66.0± 6.0	73.0± 6.0	70.5± 4.7	83.0± 5.5	73.0± 6.0	72.6± 5.5	69.9± 5.3	60.9± 10.8
A6 Intertidal/subtidal *Enhalus* dominated	5.0± 1.0	7.0± 1.0	7.0± 1.0	6.8± 1.0	7.0± 1.0	7.0± 1.0	7.0± 2.0	6.0± 0.5	7.5± 0.7	8.0± 0.7	7.8± 0.8	9.0± 0.7	8.0± 3.0	9.2± 1.6	9.8± 1.4	7.9± 1.4
A7 Intertidal/subtidal *Enhalus* dominated	19.0± 2.0	23.0± 1.0	19.0± 1.0	18.5± 1.0	18.0± 1.0	17.0± 1.0	17.0± 1.0	15.0± 2.0	8.7± 1.9	13.0± 5.0	18.3± 1.2	22.0± 3.4	21.0± 7.0	21.0± 3.5	21.0± 6.4	14.7± 6.0
Total	402.0± 37.0	418.0± 37.0	417.0± 31.0	398.8± 35.3	416.0± 31.0	398.0± 37.0	358.0± 23.0	368.0± 16.5	358.4± 17.0	375.0± 20.8	369.4± 15.3	399.0± 18.2	363.0± 25.0	384.9± 19.4	400.1± 21.8	361.8± 27.0

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