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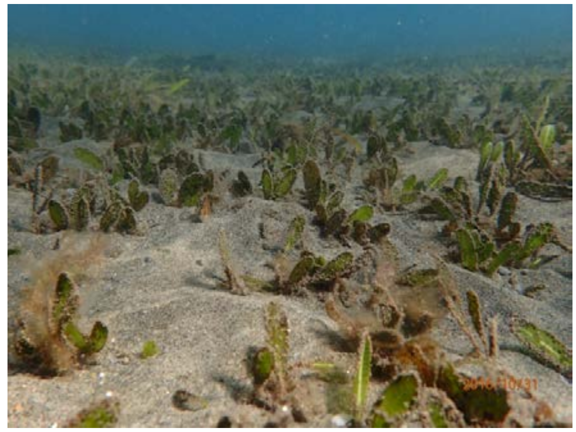

PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM: 2015 – 2016

McKenna SA, Scott ES and Rasheed MA

Report No. 17/19
May 2017

PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM: ANNUAL REPORT 2015-2016

A Report for North Queensland Bulk Ports Corporation (NQBP)

Report No. 17/19

May 2017

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KEY FINDINGS

Seagrass Condition 2016

Likely causes of seagrass condition:

↑ Overall favourable weather conditions for seagrass habitat

Offshore seagrass decline linked to short term localised weather conditions in dry season:

↑ rainfall and river flow.

↓ available light to offshore meadows.

- Seagrass habitat in the Abbot Point area was in a satisfactory condition in 2016.
  - Inshore seagrass habitat was in a good condition.
  - Offshore seagrass habitat was in a poor condition.

- Inshore seagrass continued to improve from 2015 with species composition returning to levels recorded before the weather associated losses in 2011 and 2013/14.

- Declines in offshore seagrass habitat were likely the result of unfavourable localised climate conditions (rainfall, river flow, light) in the months leading into, and during the seagrass growing season.

- Despite reductions in the condition of offshore seagrass habitat, seagrasses remain at relatively high biomass.

- Seagrass in the broader Abbot Point region (outside of designated monitoring meadows) were also mapped in 2016 and reflected trends seen in the annual monitoring areas.

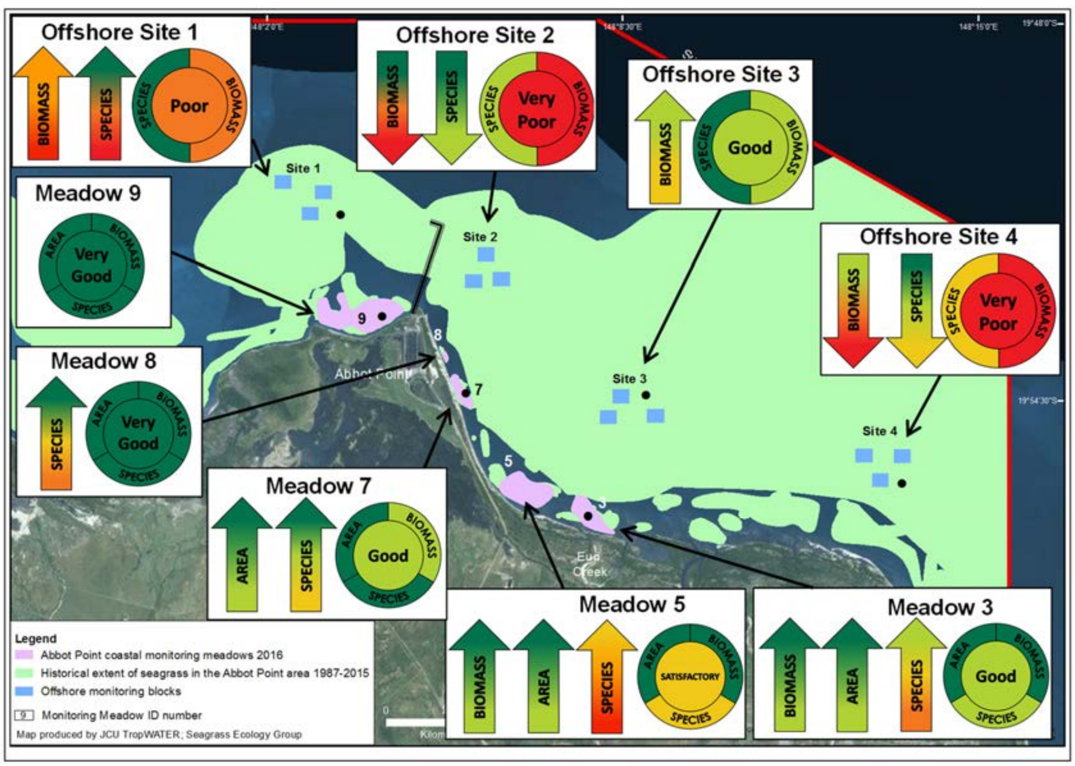
- Since the 2016 survey was completed severe tropical cyclone Debbie impacted the Bowen/Abbot Point region. The next annual survey (2017) will determine what impact TC Debbie had on seagrass habitat in the region.

IN BRIEF

A long-term seagrass monitoring program and strategy was established in the Abbot Point region in 2008. The original program involved monitoring biomass, distribution and species composition of selected key representative seagrass meadows on a quarterly basis. Photosynthetic Active Radiation (PAR) and temperature at the seabed was also monitored each quarter (until 2015). The program has included manipulative experiments looking at the recovery and recruitment processes of seagrass after disturbance, investigations into seagrass seed-banks, and five broad-scale surveys of all seagrass in the region. In 2015 the quarterly monitoring program was reduced to annual assessments. In addition to surveying the annual monitoring areas in 2016, a broader-scale survey of all seagrasses in the region was also conducted in 2016 and will be discussed in this report.

The overall condition of seagrass habitat in the Abbot Point region improved from poor in 2015 to satisfactory in 2016. The inshore seagrass meadows were good; an upgrade in condition from 2015, while the offshore seagrass areas of Abbot Point were poor; a downgrading from 2015 (Figure 1). This downgrading was primarily the result of lower seagrass biomass in offshore seagrass meadows.

The lower biomass scores in the offshore meadows was due to a reduction in the contribution of *H. spinulosa* to the overall species composition of the meadow compared to 2015. *Halophila spinulosa* is morphologically/structurally larger compared to other *Halophila* species and therefore contributes more to the overall biomass of a meadow.



*lack of arrows indicates no change in condition index from the previous year

Figure 1. Seagrass condition index for Abbot Point seagrass monitoring areas 2016.

Despite the loss in condition of offshore seagrass in 2016, deep water seagrasses are still at relatively high densities since the weather associated losses that occurred leading up to 2011, and during 2013/14 (Figure

2). Inshore seagrasses have also continued to improve since weather associated losses, with species composition returning to pre-disturbance levels; meadows consisted largely of more persistent species such as *H. uninervis* and *Z. muelleri* in 2016, rather than the less persistent *H. ovalis*. This was also evident in the broader Abbot Point region, where many of the meadows (outside of monitoring meadows) contained persistent species, compared to 2013 (the last broad scale survey) when many meadows were either absent, or those that were present were mostly dominated by *H. ovalis* or *H. decipiens*.

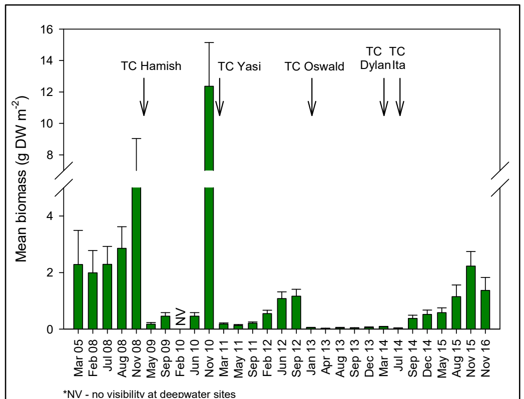


Figure 2. Mean biomass (g dw m^{-2}) of Abbot Point offshore seagrass monitoring sites from 2005 to 2016. Offshore site 1 excluded from calculations.

Environmental conditions have been mostly favourable for seagrass growth over the past three years (Figure 3) and were likely to be the reason increases in biomass and area were observed in offshore meadows in the previous survey: 2015 (McKenna et al. 2016). However, conditions leading up to the 2016 sampling were less favourable, particularly just before and during the key growing season window of 2016, and hence the observed declines in offshore seagrass. Higher than average rainfall and river flow of the Don River in the dry season between June and September 2016 (2 – 4 months before the 2016 survey) (Figures 25b & 26b) resulted in benthic light falling below required light levels for *Halophila* species for long periods of time during the key growing period. The reduction in light leading into the growing season may have affected the annual recruitment, or resulted in the early loss of germinated shoots for the offshore seagrass habitat around Abbot Point. Similar results occurred in Hay Point in 2016 where offshore seagrass declined from 2015 and local light conditions during the dry season were likely to have played a role in their decline (McKenna and Rasheed 2017).

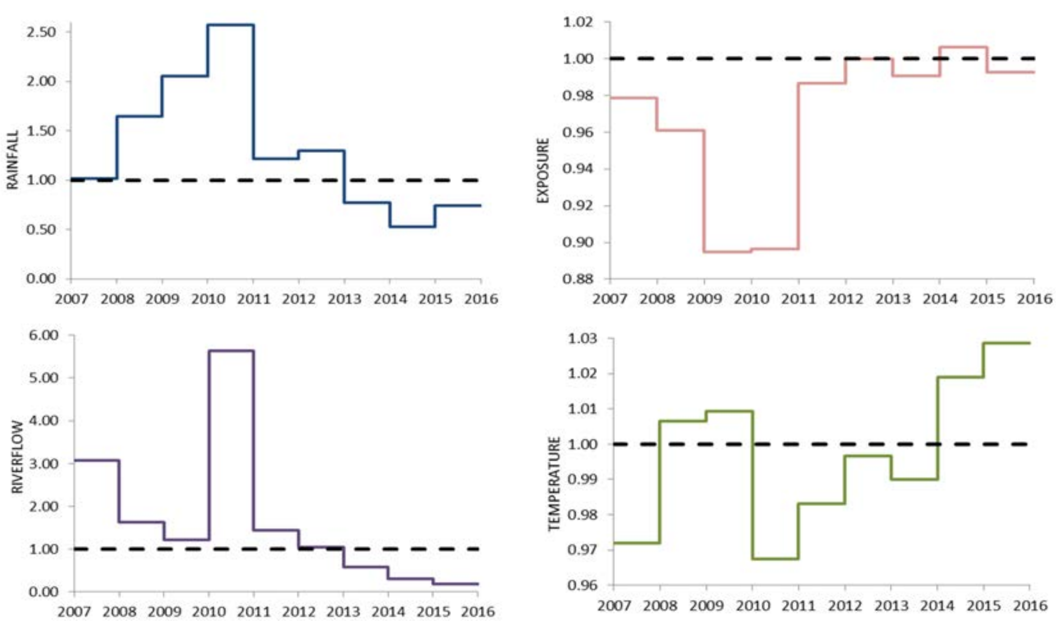


Figure 3. Recent climate trends in the Bowen/Abbot Point area 2000/01 to 2015/16: Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data.

Since the 2016 survey was completed, severe tropical cyclone Debbie made landfall (late March 2017) near Airlie Beach, 50km southeast of Bowen, affecting the Bowen/Abbot Point region. The next annual monitoring seagrass survey (2017) will determine what impact TC Debbie had on the seagrass habitat in the region. It is possible that multiple years of weather induced seagrass decline have left a legacy of reduced resilience to new impacts and the standing crop, and any remaining seed bank will be critical for the ongoing recovery of Abbot Point's seagrasses. The management of seagrass resources in the Abbot Point region should be focussed on ensuring that the resilience of local seagrass remains high enough to withstand anthropogenic impacts and risks.

The Abbot Point seagrass monitoring program forms part of a Queensland wide program that examines the 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. For full details of the Queensland ports seagrass monitoring program, see www.jcu.edu.au/portseagrassqld.

TABLE OF CONTENTS

KEY FINDINGS i

IN BRIEF i

1. **INTRODUCTION** 1

1.1 Queensland Ports Seagrass Monitoring Program 1
1.2 Abbot Point Seagrass Monitoring Program 2

2. **METHODS** 4

2.1 Sampling Approach and Methods 4
2.2 Seagrass meadow condition index 7
2.2.1 Baseline Calculations 7
2.3.2 Meadow Classification 8
2.3.3 Threshold Definition 8
2.3.4 Grade and Score Calculations 9
2.3.5 Score Aggregation 11

3. **RESULTS** 12

3.1 Seagrass in the Abbot Point region 12
3.2 Seagrass condition in the Abbot Point monitoring areas 14
3.2 Seagrass within the Broader Port of Abbot Point Region – Broad scale surveys 25
3.2.1 Seagrass species, distribution, abundance and changes in the 2016 broad scale survey 25
3.2.2 Comparison with previous broad scale surveys 27
3.2 Light (PAR) and sea surface temperature trends within the seagrass meadows 29
3.3 Abbot Point Climate Patterns During Monitoring 31

4. **DISCUSSION** 36

5. **REFERENCES** 38

6. **APPENDICES** 41

Appendix 1. Example of calculating a meadow score for biomass in satisfactory condition. 41
Appendix 2. Species composition of inshore and offshore monitoring meadows in the Abbot Point region: 2008 – 2016 42
Appendix 3. Biomass and area of inshore and offshore meadows 44

1. INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (Costanza et al. 1997; Hemminga and Duarte 2000). With globally developing carbon markets, the role that seagrasses play in sequestering carbon is also becoming more widely recognised (McLeod et al. 2011; Fourqurean et al. 2012; Macreadie et al. 2013). 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).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution and eutrophication (Short and Wyllie-Echeverria 1996). Locally in the Great Barrier Reef (GBR) coastal region, the hot spots with highest threat exposure for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot spots arise as seagrasses preferentially occur in the same sheltered coastal locations that ports and urban centres are established (Coles et al. 2015). In Queensland, this has been recognised and a strategic monitoring program of these high risk areas has been established to aid in their management and ensure impacts are minimised (Coles et al. 2015).

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 Queensland port authorities. While each location is funded separately and they have a range of requirements for use of the information, a common methodology and rationale is used to provide a network of seagrass monitoring locations throughout the state (Figure 4).

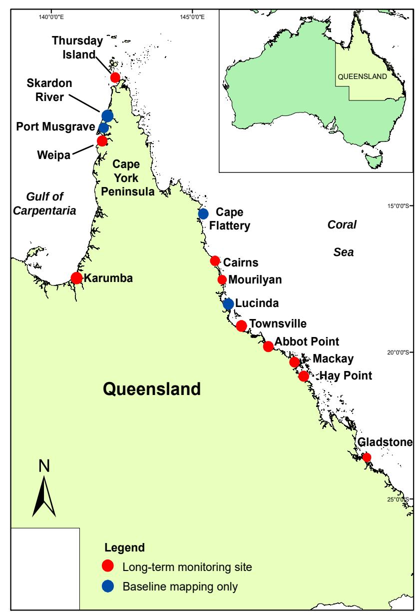


Figure 4. Location of Queensland Port Seagrass monitoring sites.

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

The program not only delivers key information for the management of port activities to minimise impacts on seagrass habitat 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 Abbot Point Seagrass Monitoring Program

North Queensland Bulk Ports Corporation (NQBP) in partnership with the Seagrass Ecology Group at TropWATER has been engaged in a seagrass assessment and monitoring program at Abbot Point since 2008. This program has involved six broad scale surveys (2005; two each in 2008 & 2013; 2016) of the marine habitat within the port limits, manipulative experiments investigating seagrass recovery, quarterly long-term monitoring of representative seagrass meadows at inshore and offshore areas, and light (PAR) and temperature assessments at the seabed (Figure 5). The long term monitoring areas represent the range of seagrass communities within the port and include meadows considered most likely to be influenced by port activity and development, and areas outside the zone of influence of port activity and development. This structure is defined in order to differentiate between port related versus regional causes of seagrass change detected in the monitoring program (Figure 5).

In 2015 the quarterly long-term monitoring program was reduced to an annual program; monitoring the same representative seagrass meadows that have been monitored in the past. The annual monitoring approach is based on periodic re-assessments of all seagrasses within the region (broad scale survey every three years) with a subset of representative areas monitored annually in the intervening years. This same approach is used as part of NQBP's other long-term seagrass programs in the Ports of Weipa and Mackay/Hay Point, and elsewhere in other Queensland ports. The PAR and temperature program also ceased in 2015.

Information collected in these programs aims to assist in planning and managing future developments in coastal areas. The monitoring program forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas. It also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition.

This report presents the findings of the annual seagrass monitoring for 2016. The objectives of the annual long-term seagrass monitoring program for the Port of Abbot Point are to:

- Map seagrass distribution and determine seagrass density (biomass), distribution (area) and community type (species composition) at representative long term monitoring meadows;
- Compare results of monitoring surveys and assess any changes in seagrass habitat in relation to natural events or human induced port and catchment activities;
- Provide up to date information to aid in the planning of potential port development that ensures the marine environment is protected and minimally affected;
- Incorporate the results into the Geographic Information System (GIS) database for the Port of Abbot Point;
- Discuss the implications of monitoring results for overall health of the Port of Abbot Point's marine environment and provide advice to relevant management agencies.

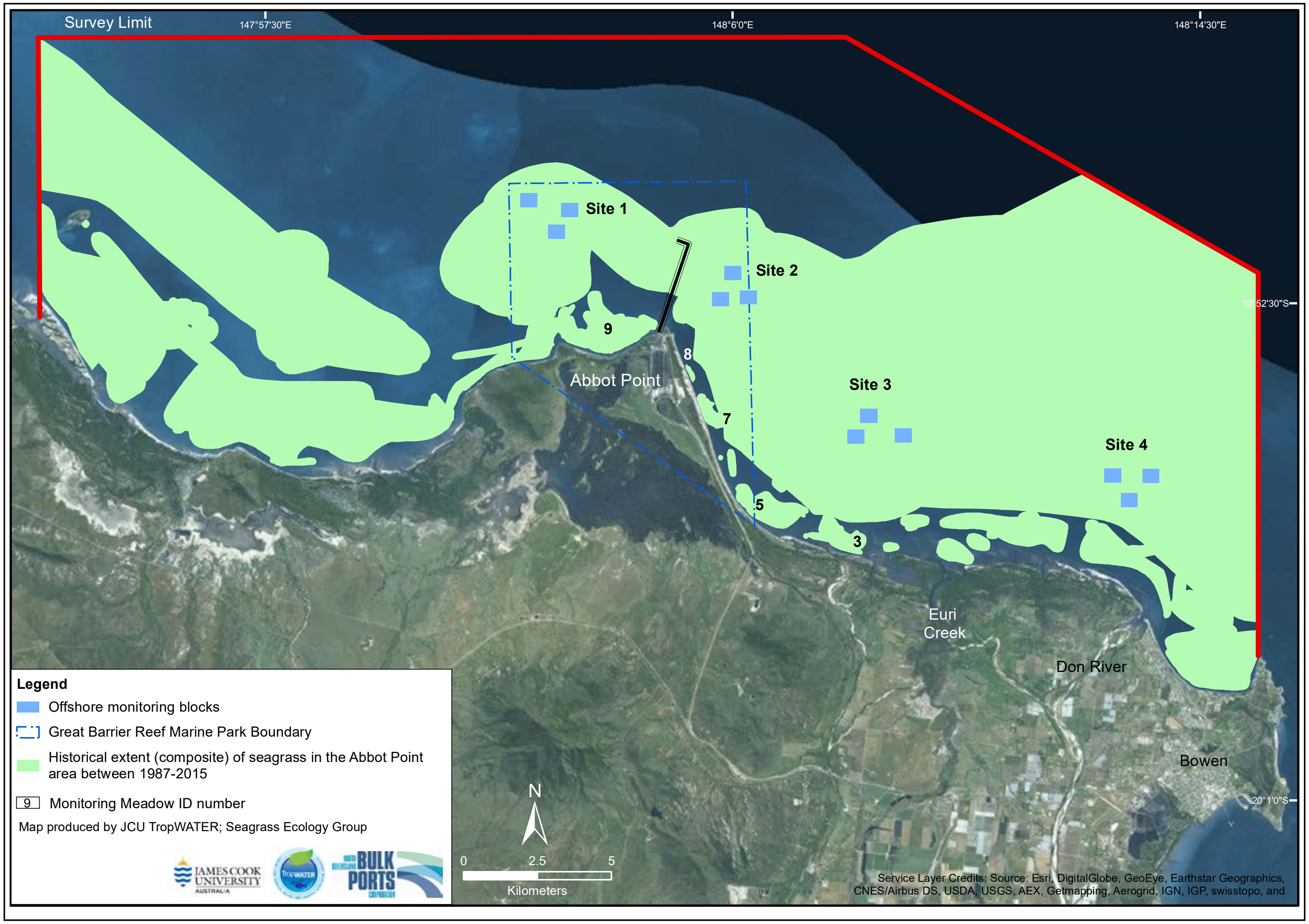


Figure 5. Location of inshore monitoring meadows and offshore monitoring areas in the Abbot Point region.

2. METHODS

2.1 Sampling Approach and Methods

Five coastal meadows and four offshore areas were identified as suitable for long term seagrass monitoring (Figure 5; McKenna et al. 2008). Monitoring meadows selected were representative of the range of seagrass communities identified in the 2008 baseline survey, and were located in areas considered ideal sensitive receptor sites for assessing seagrass condition.

Methods for assessing inshore and offshore seagrasses in the Abbot Point region have followed those of the seagrass program since 2008 (see McKenna et al. 2008; Unsworth et al. 2010 and McKenna & Rasheed 2011). The application of standardised methods at Abbot Point and throughout Queensland allows for direct comparison of local seagrass dynamics with the broader region.

Free diving and deep water sled tows using an underwater digital camera system were used to survey inshore and offshore areas for seagrass (Figure 6). At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (MSL), sediment type, time and position (GPS). The percent cover of other major benthos at each site was also recorded.

Seagrass above-ground biomass was measured using a "visual estimates of biomass" technique (Kirkman 1978; Mellors 1991). At free diving sites, this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m^2 quadrats at each site (Figure 6). At digital camera sled tow sites, this technique involved an observer ranking seagrass at 10 random time frames allocated within the 100m of footage for each site.

Ranks at all sites were made in reference to a series of quadrat photographs of similar seagrass habitats for which above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g dw m^{-2}). At the completion of sampling, each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats was harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to standardise the above-ground biomass estimates.

Figure 6. Assessment of seagrass habitat using sled tows and live camera feed, and free-divers.

All survey data was entered into a GIS for presentation of seagrass species distribution and density. Satellite imagery of the Bowen/Abbot Point area with information recorded during the surveys was combined to assist with mapping seagrass meadows. Three seagrass GIS layers were created in ArcMap:

- **Habitat characterisation sites** – site data containing above-ground biomass (for each species), dbMSL, sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.
- **Seagrass meadow biomass and community types** – area data for seagrass meadows with summary information on meadow characteristics. 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.

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.

Table 1. Nomenclature for seagrass community types in Queensland.

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 density in Queensland.

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

The boundary of seagrass meadows were mapped by free diving and underwater camera techniques, then assigned a mapping precision estimate (±ha) (Table 3). The precision of the boundary was determined using an estimate of mapping reliability (R) based on the distance between sampling sites and the presence and absence of seagrass at sites. This resulted in a range of meadow sizes, which is expressed as an error (±ha) around the total meadow area (ha).

The boundary of the offshore annual monitoring areas is not mapped. Boundary mapping of offshore seagrass habitat only occurs during the three yearly broad-scale surveys (2016) (see Figure 5 for offshore monitoring areas).

Table 3. Mapping precision and methodology for seagrass meadows in the Port Abbot Point 2016.

Mapping precision	**Mapping methodology**
20-50m	Subtidal meadow boundaries determined from free diving surveys; Relatively high density of survey sites; Recent digital maps/landsat imagery aided in mapping.
300-500m	Subtidal meadow boundaries determined from free diving and underwater digital camera tows; Moderate to high density of survey sites; Recent digital maps/landsat imagery aided in mapping.

2.2 Seagrass meadow condition index

A condition index was developed for the Abbot Point seagrass meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator at Abbot Point was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 7 summarises the methods used to calculate seagrass condition.

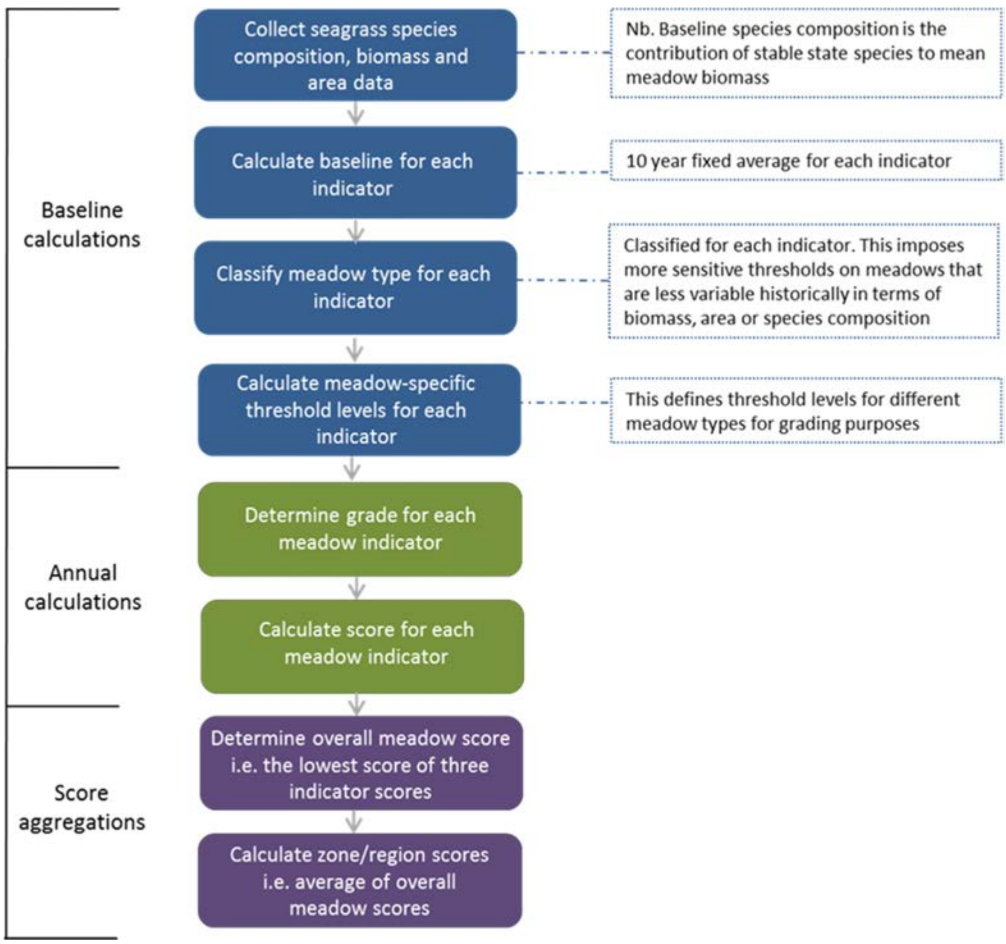


Figure 7. Flow chart to develop Abbot Point grades and scores.

2.2.1 Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated from 2008-2016 (9 years) 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. Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used for future assessments. This will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise ≤80% of baseline species composition). Similar to seagrass biomass and area, the species composition baseline was calculated from 2008-2016 (only in the years where species were present; 4 – 9 depending on meadow at Abbot Point). In 2016 an additional rule was applied: 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 8).

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). One further classification for meadow area was added in the 2016 reporting year: highly stable (Table 4). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each 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	-	< 40%	≥ 40%	-
Area	< 10%	≥ 10, < 40%	≥ 40, <80%	≥ 80%
Species composition	-	< 40%	≥ 40%	-

2.3.3 Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table 5).

Table 5. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

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

2.3.4 Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows in the Port Abbot Point (Table 6; see Carter et al. 2015 for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year, allocating a grade for each indicator by comparing 2016 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table 6). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period. For Abbot Point this upper limit will be recalculated each year until a 10 year baseline period is complete.

In previous report cards the upper limit was based on the mean + SE of any survey year, meaning biomass and area values in the very good range potentially would require constant recalculation; defining the upper limit using baseline years is a new approach in 2016 that "locks in" the upper value.

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 1.

Table 6. Score range and grading colours used in the 2016 Abbot Point report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥0.25	<0.50
E	Very poor	0.00	<0.25

Where species composition was determined to be anything less than in "perfect" condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were causing this grade/score (Figure 8). 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 8). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *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). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found in Gladstone Harbour, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure 8).

The decision tree used in 2016 expands on the 2015 model and provides a more thorough assessment of species composition condition. Specific changes include the separation and positioning of *Z. muelleri* subsp. *capricorni* above *H. uninervis* (grouped as equivalent species in 2015), the separation and positioning of *H. spinulosa* above *H. ovalis* (also grouped as equivalent species in 2015), and triggering the directional change assessment if the species composition score was <1.00 (the trigger was based on a grade less than very good in 2015, meaning no score adjustment occurred in the highest grade even if more persistent species present could have improved the score).

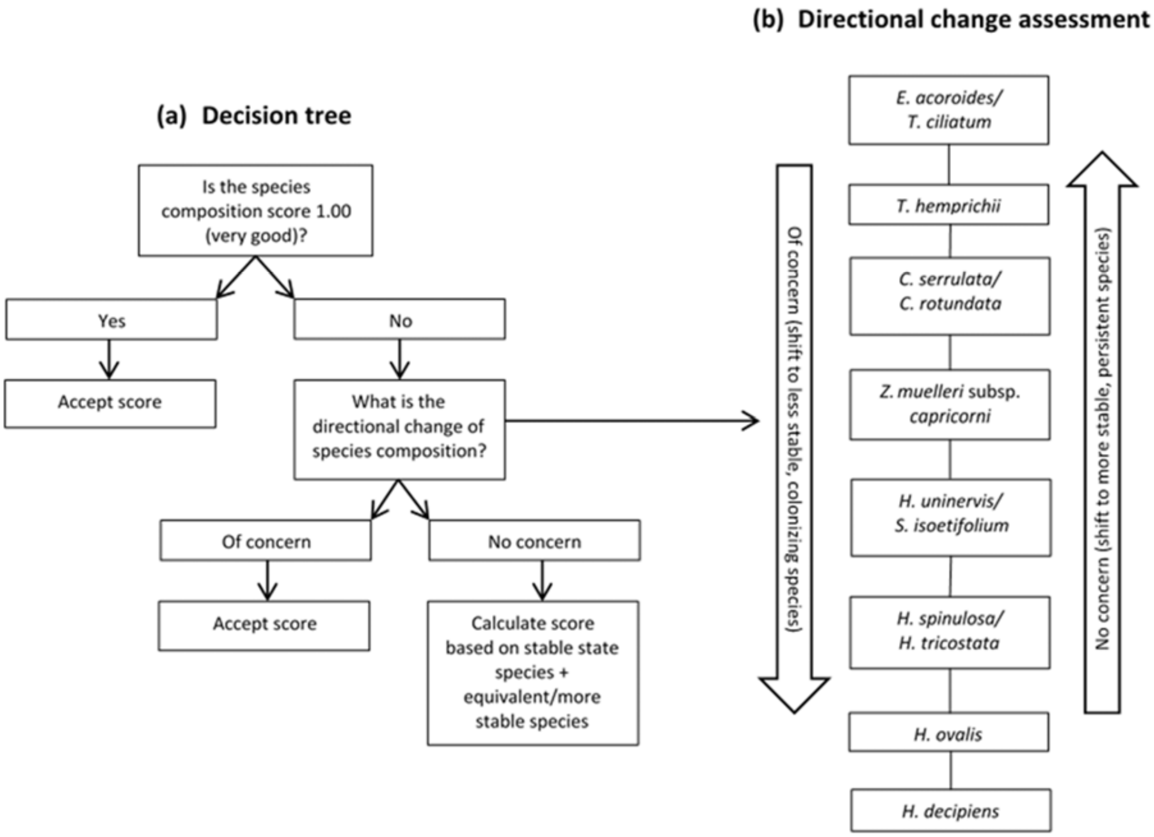


Figure 8. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

2.3.5 Score Aggregation

Each overall meadow grade/score was defined as the lowest grade/score of the three condition indicators 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 allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Abbot Point grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Figure 7; Table 6). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The classification process (outlined in Meadow Classification) at the meadow analysis stage applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows.

3. RESULTS

3.1 Seagrass in the Abbot Point region

A total of 393 sites were investigated as part of the 2016 broad scale Abbot Point survey. Seagrass was present at 53% of these sites. Approximately 18,583 ha of seagrass habitat was mapped in this broad scale survey (Figure 10).

Eight seagrass species have been identified within the Abbot Point region since broad-scale surveys of the area began in 1987 (Figure 9). All except *Cymodocea rotundata* and *Cymodocea serrulata* were present in the 2016 survey. The seagrass species found in the survey area were typical of those found for coastal and offshore seagrasses in Abbot Point and more broadly in Queensland.

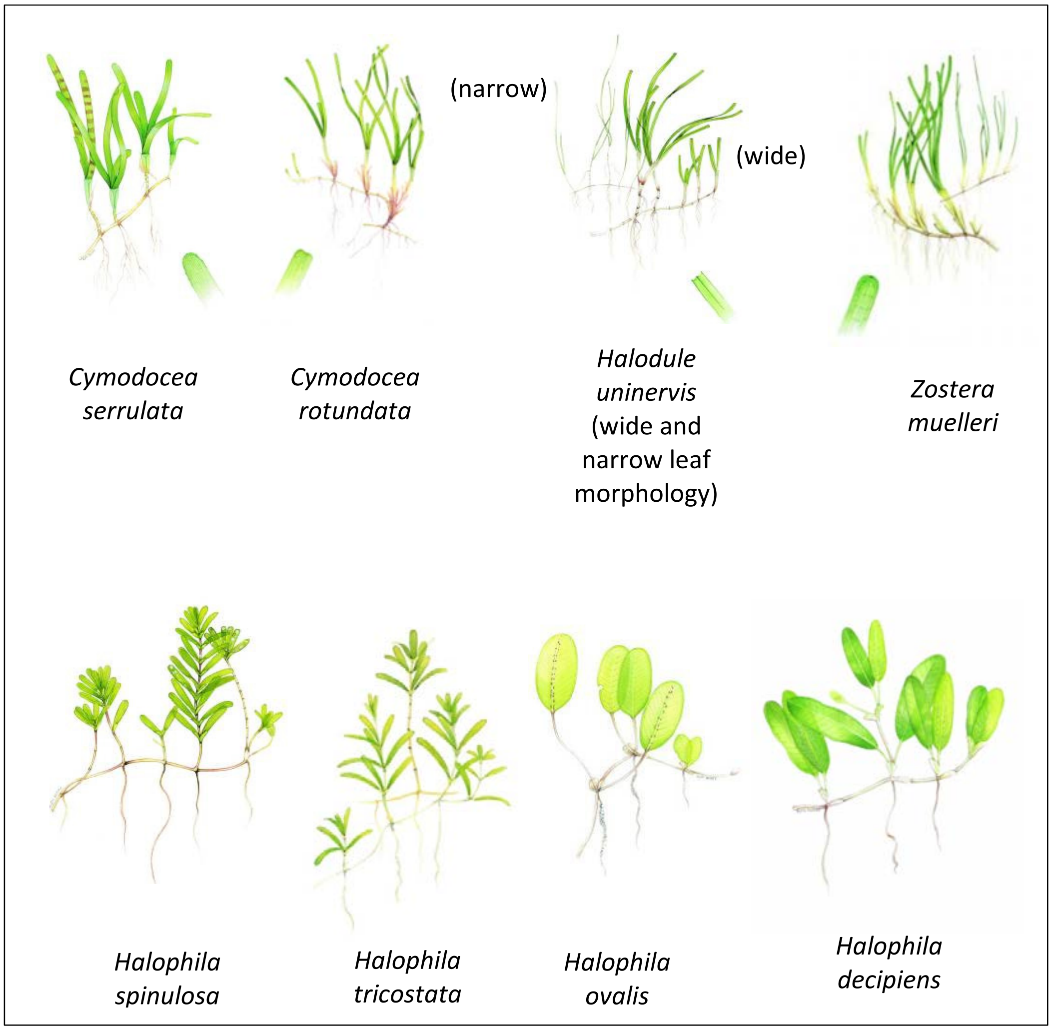


Figure 9. Seagrass species identified in the Abbot Point/Bowen region.

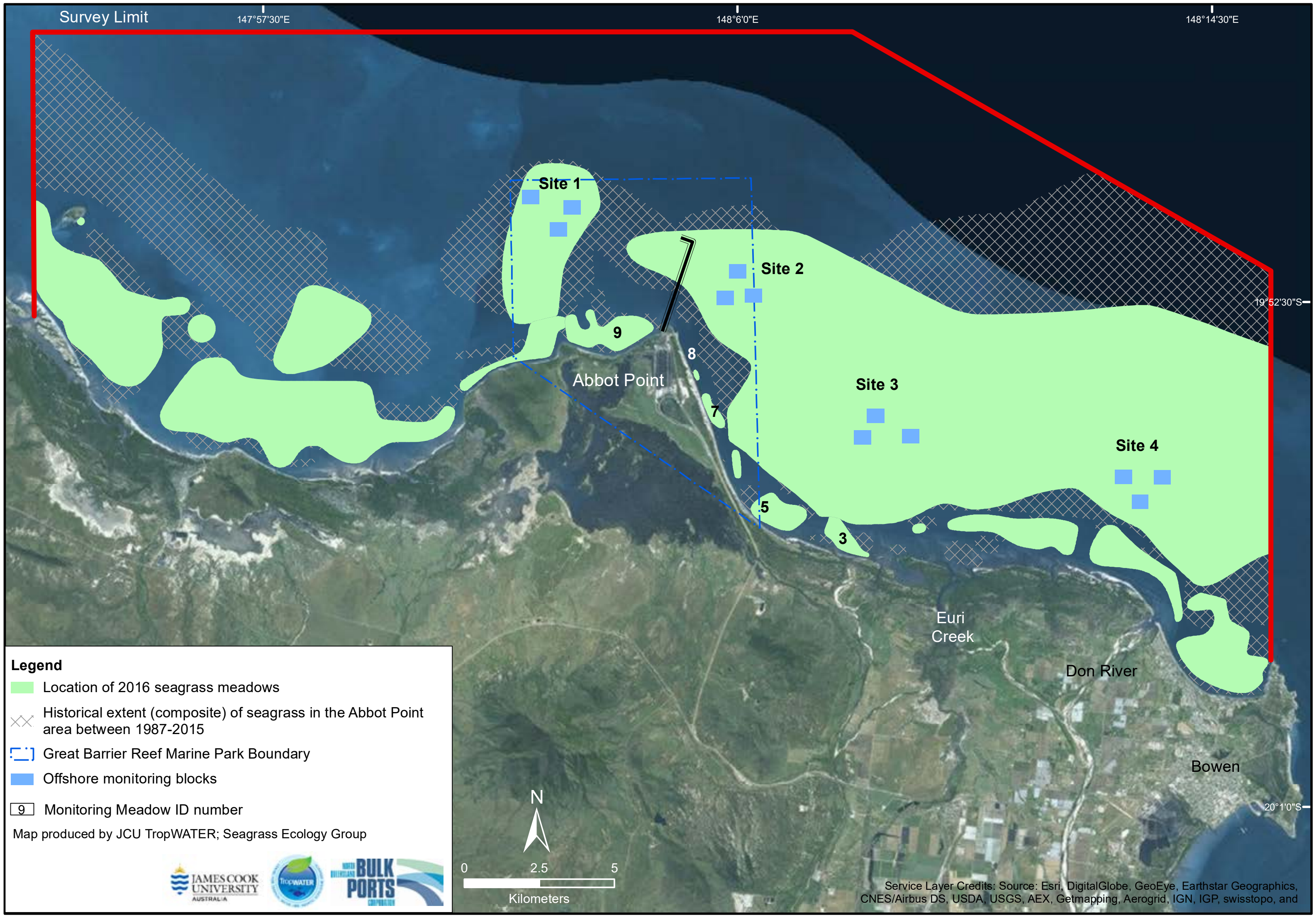


Figure 10. Location of inshore and offshore seagrass meadows in the 2016 broad scale seagrass survey of the Abbot Point region.

3.2 Seagrass condition in the Abbot Point monitoring areas

The overall condition of seagrass habitat in the Abbot Point region in 2016 was satisfactory (Table 7) and was an increase in grade from poor in 2015. The offshore seagrass areas of Abbot Point were poor, while the inshore seagrass meadows were good. The lower offshore seagrass score resulted in the overall Abbot Point score being only satisfactory (Table 7).

Within the offshore seagrass meadows of Abbot Point, it was the lower biomass indicator scores (rather than area or species change) that caused the offshore meadow score to be poor (Table 7). This was a decrease in grade from satisfactory for offshore meadows in 2015. In contrast, inshore meadows increased in grade from poor in 2015 to good in 2016.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score	Overall location Score
Offshore Monitoring Areas					
Offshore Site 1	0.31	0.94	N/A	0.31	0.31
Offshore Site 2	0.15	0.76	N/A	0.15	
Offshore Site 3	0.69	0.91	N/A	0.69	
Offshore Site 4	0.08	0.51	N/A	0.08	
Inshore Monitoring Areas					
Inshore Meadow 3	0.88	0.83	0.96	0.83	0.80
Inshore Meadow 5	0.90	0.64	0.97	0.64	
Inshore Meadow 7	0.74	0.90	0.93	0.74	
Inshore Meadow 8	0.85	1	0.92	0.85	
Inshore Meadow 9	0.96	1	0.91	0.91	
Overall score for seagrass in the Port of Abbot Point					**0.56**

N/A – area is not measured at offshore monitoring sites

Table 7. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2016.

Inshore monitoring meadows

Individual inshore monitoring meadows were categorised as being in satisfactory to very good condition in 2016 (Table 7). This was a substantial improvement from scores in 2015 where individual meadows were categorised as being in very poor to satisfactory condition. The increase in scores was driven by better species composition across most meadows; most meadows consisted of more persistent species such as *Z. muelleri* and *H. uninervis* in 2016, rather than the less persistent *H. ovalis* (Figure 11-15). The dominance of less persistent species in these meadows over the past few years has been the result of the significant losses of seagrass sustained after the 2010/11 floods and Tropical Cyclone Yasi, and the ensuing recovery of seagrass into the area. For some meadows, the contribution of the more persistent species to the overall meadow community type in 2016 was similar to 'pre-TC Yasi' species compositions (Figures 11-14; Appendix 2). The exception to this was Meadow 9, on the western side of the Abbot Point trestle jetty, which is now a *H. ovalis* dominated meadow.

Seagrass biomass and distribution at all inshore monitoring meadows were above or near to long-term averages. For most meadows, 2016 recorded the highest density and/or distribution of seagrass since TC Yasi (Figures 11-15).

The inshore monitoring meadows around Abbot Point have consisted of variable, isolated to aggregated patches of seagrass dominated by *H. uninervis* and *Z. muelleri* (Meadow 3 near Euri Creek) (Appendix 2). In this monitoring program (2008-2016) inshore seagrass above-ground biomass, has ranged from 0.005 ± 0.003 $gdwm^{-2}$ to 13.84 ± 4.6 $gdwm^{-2}$ (Appendix 3a and b). The area of individual meadows, has ranged from 0.91 ± 0.68 ha to 239.56 ± 57.53 ha (Appendix 3a and b). This variability and the values recorded are similar to those found in other comparable inshore meadows that are monitored using the same approach such as in Townsville and Gladstone.

Offshore monitoring sites

The offshore seagrass habitat in the Abbot Point region has been dominated by variable, low to moderate densities of *H. spinulosa* (Appendix 2). The exception to this is Offshore Site 1, which is dominated by *H. uninervis*. Offshore Site 1 is located on Clark Shoal and much shallower (~5-7m below MSL) than all other offshore monitoring sites (>10m below MSL), allowing *H. uninervis* to grow in this area. Due to its shallower depth and different community composition, Offshore Site 1 is treated separately to the other offshore sites when conducting analysis of changes.

Seagrass at the offshore monitoring sites (Sites 1–4) were in very poor to good condition (Table 7). It was the lower biomass indicator scores that caused the overall offshore meadow score of poor. Deep water seagrass biomass (Sites 2-4) displayed varying responses between 2015 and 2016 depending on location within the meadow; the biomass at Sites 2 and 4 decreased substantially between years from being very good/good in 2015, to both areas of the meadow being very poor in 2016 (Figures 17 & 19). In contrast, the condition of biomass at Site 3 increased from satisfactory to good; the highest biomass recorded since the 2010/2011 floods and TC Yasi (Figure 18). The loss in biomass at Sites 2 and 4 is a result of a decrease in the presence of the morphologically larger *H. spinulosa* at these sites, and an increase in the smaller *H. ovalis* and *H. decipiens* compared to other years (Figures 17 & 19; Appendix 2).

Seagrass at the shallower Offshore Site 1 has a history of rapid change in density and species composition. Seagrass biomass at this site has ranged between 0.0006 ± 0 $gdwm^{-2}$ to 0.2 ± 0.1 $gdwm^{-2}$ which is considered as light density for the species mix (Table 2; Appendix 2 and 3c). In the 2016 annual survey, seagrass condition at the site was poor, despite the species composition of the area changing from low biomass, less persistent *H. ovalis* to the more persistent *H. uninervis* (Figure 16).

In 2015 *C. serrulata*, a more persistent species than *H. spinulosa* (see Figure 9), had recruited back into the offshore seagrass meadow (Appendix 2). The last time this species was found in the offshore meadow was in 2012. The species was absent again in the 2016 broad-scale survey.

Seagrass biomass in these deep water monitoring areas has ranged between 0.0006 ± 0 $gdwm^{-2}$ to 25.76 ± 2.52 $gdwm^{-2}$ which is considered light to moderate densities for deep water *H. spinulosa* meadows in Queensland (Table 2; Appendix 3c).

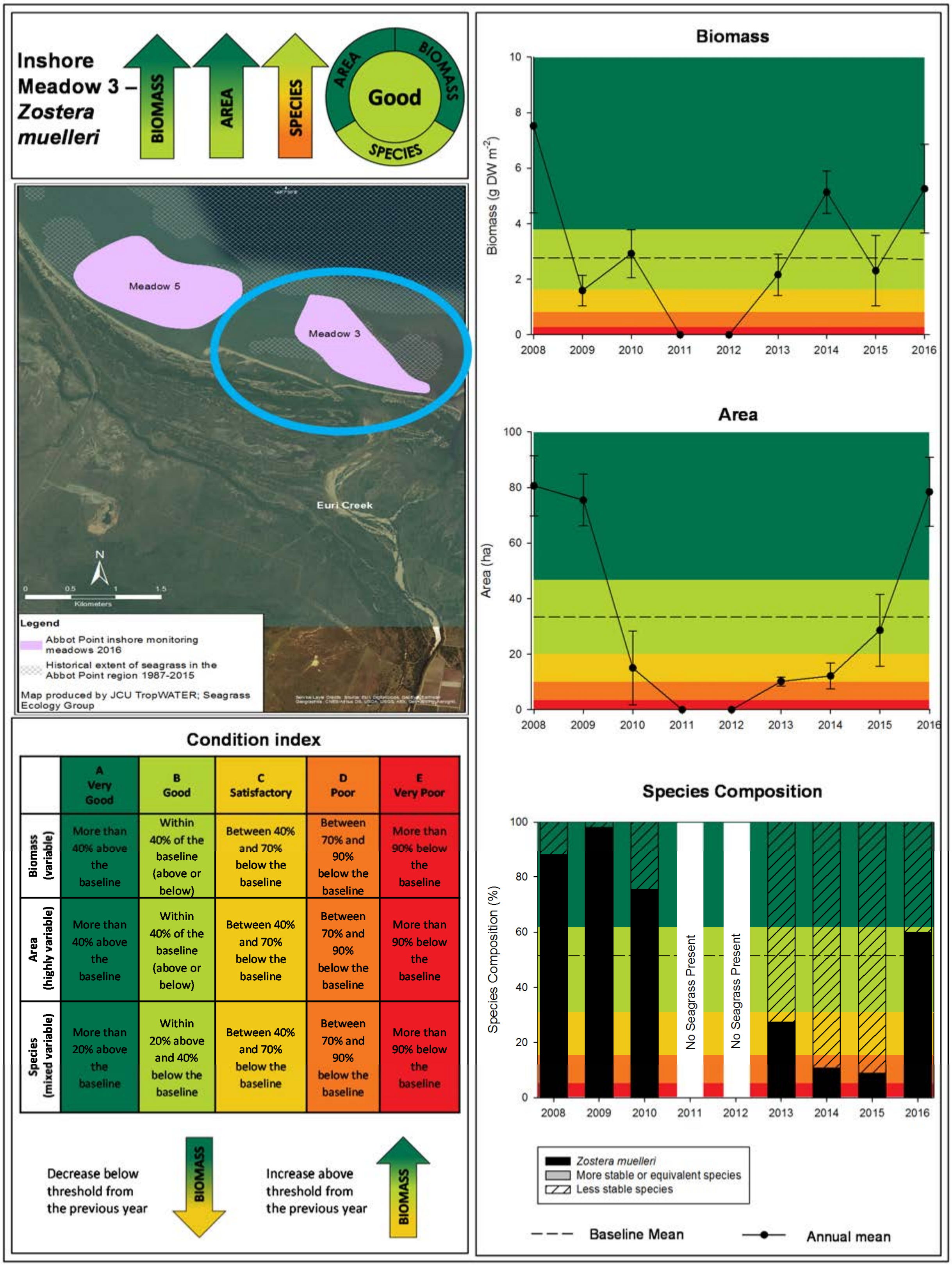


Figure 11. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3.

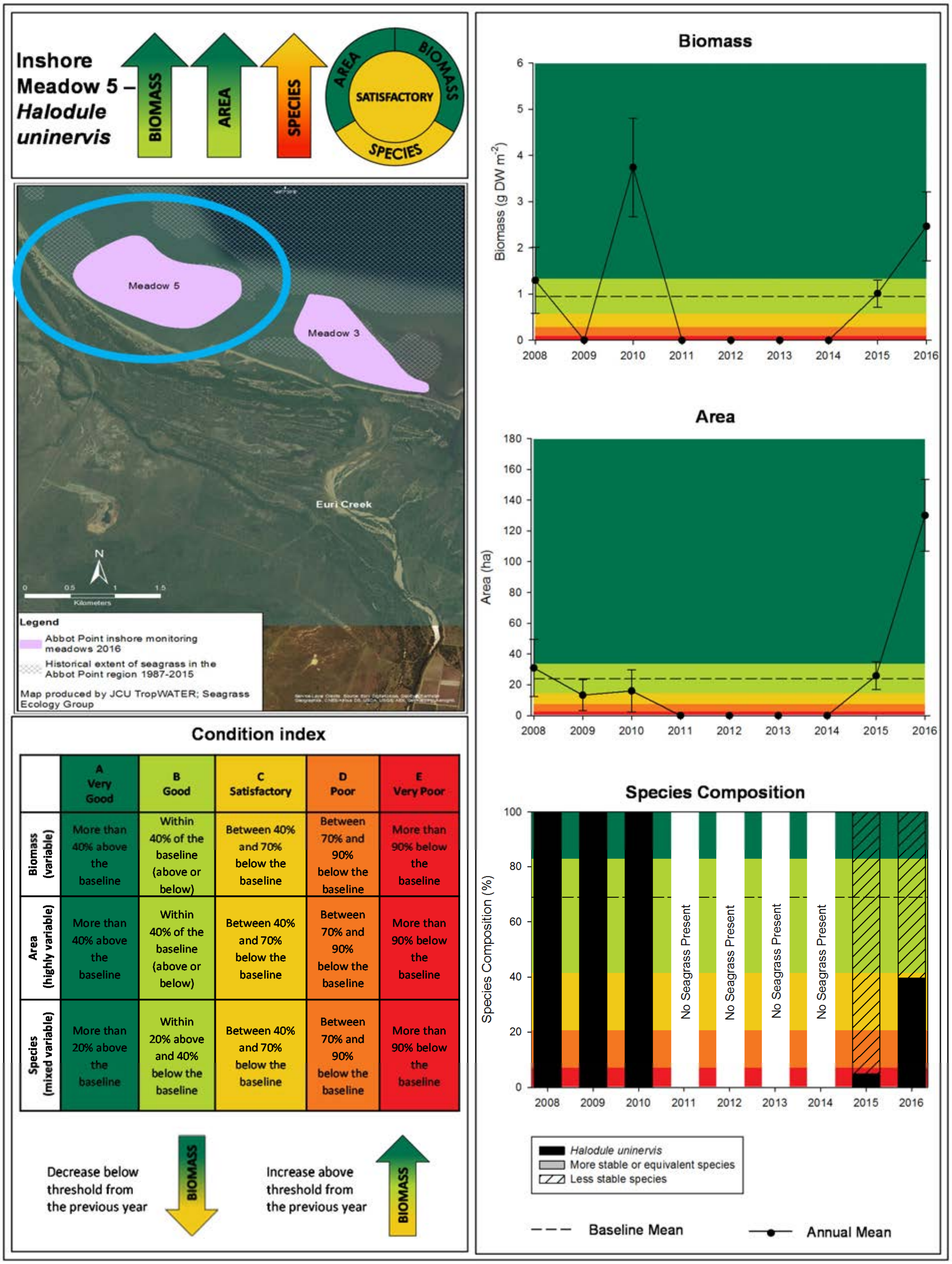


Figure 12. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5.

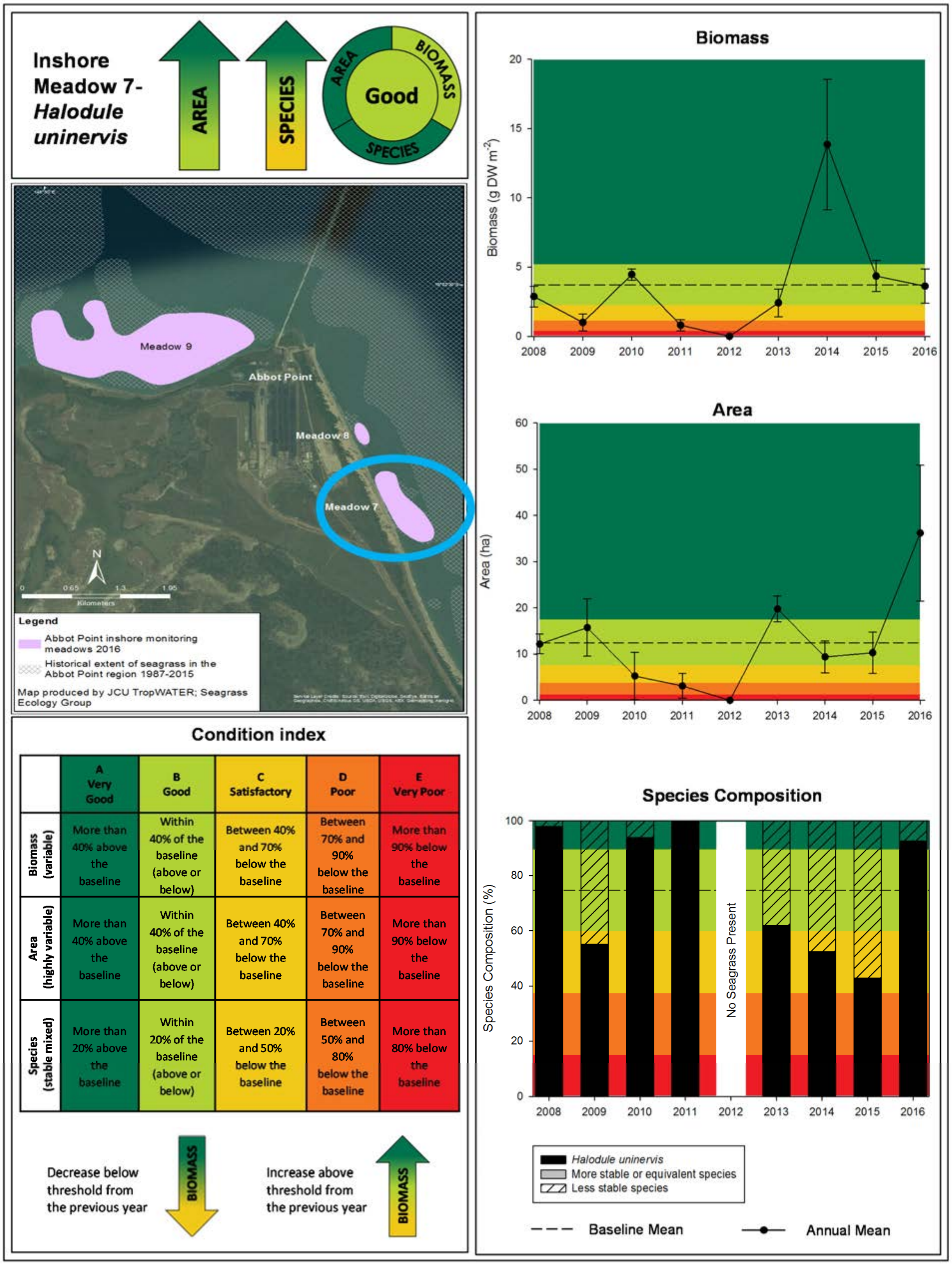


Figure 13. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 7.

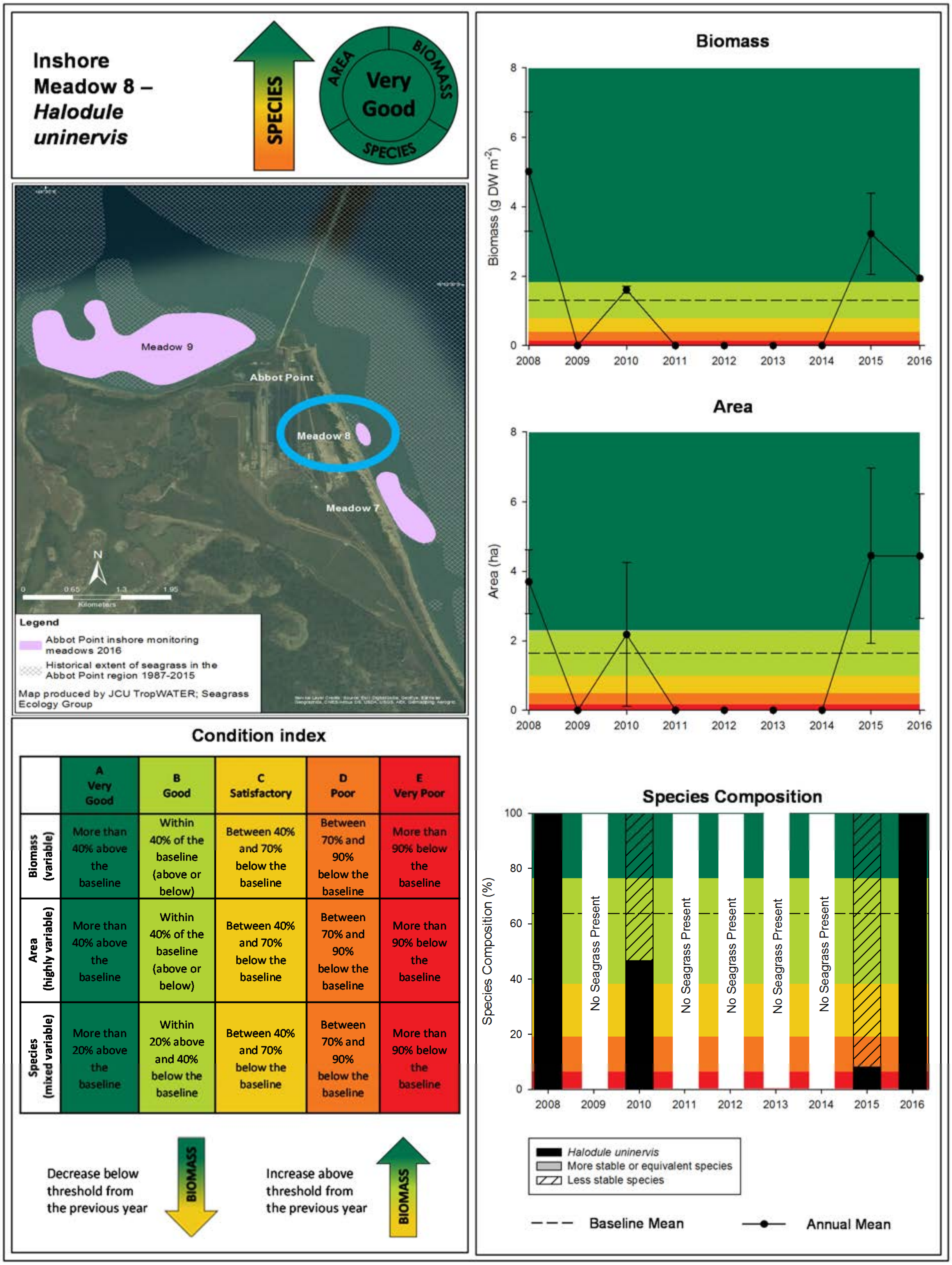
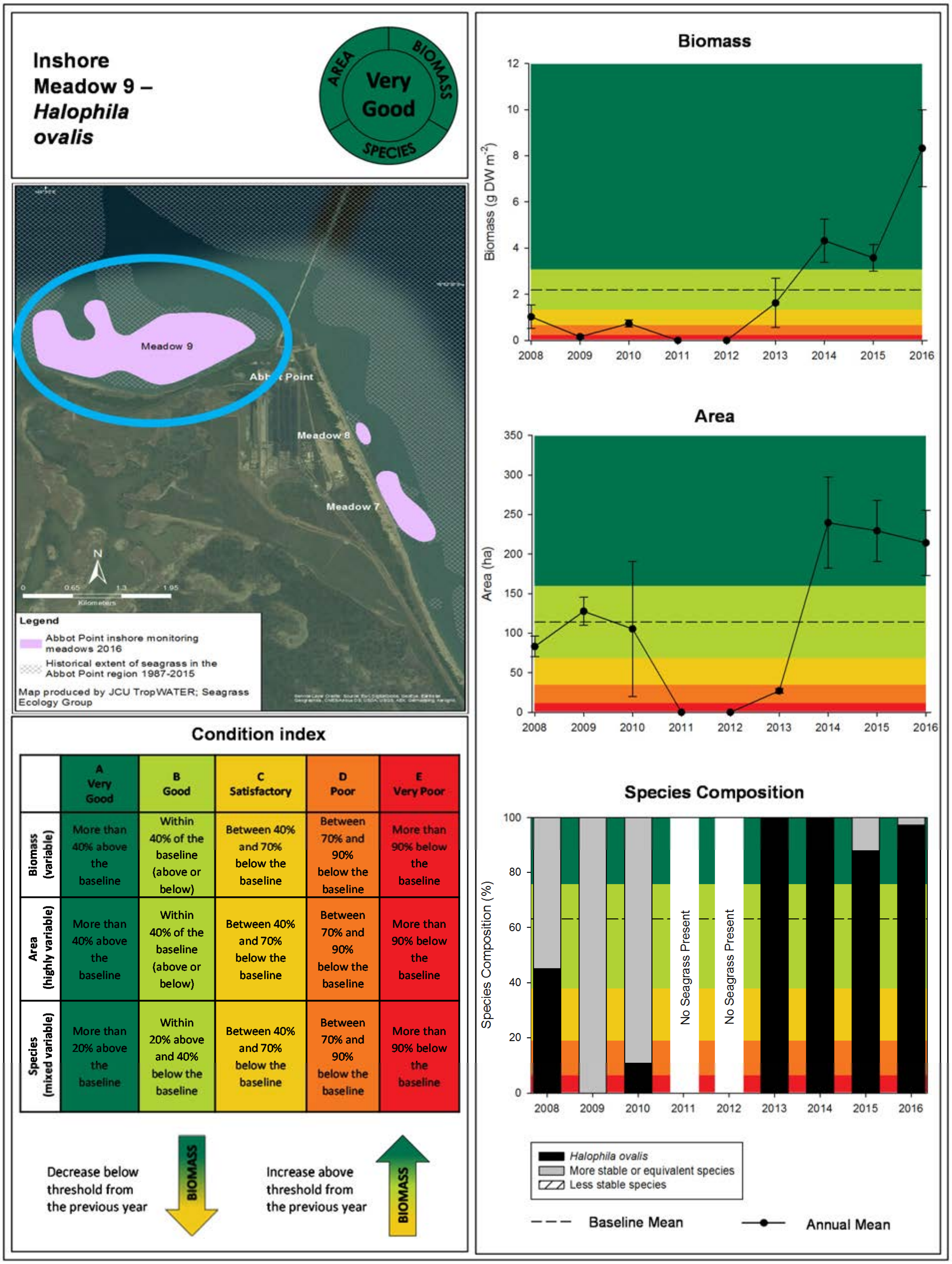
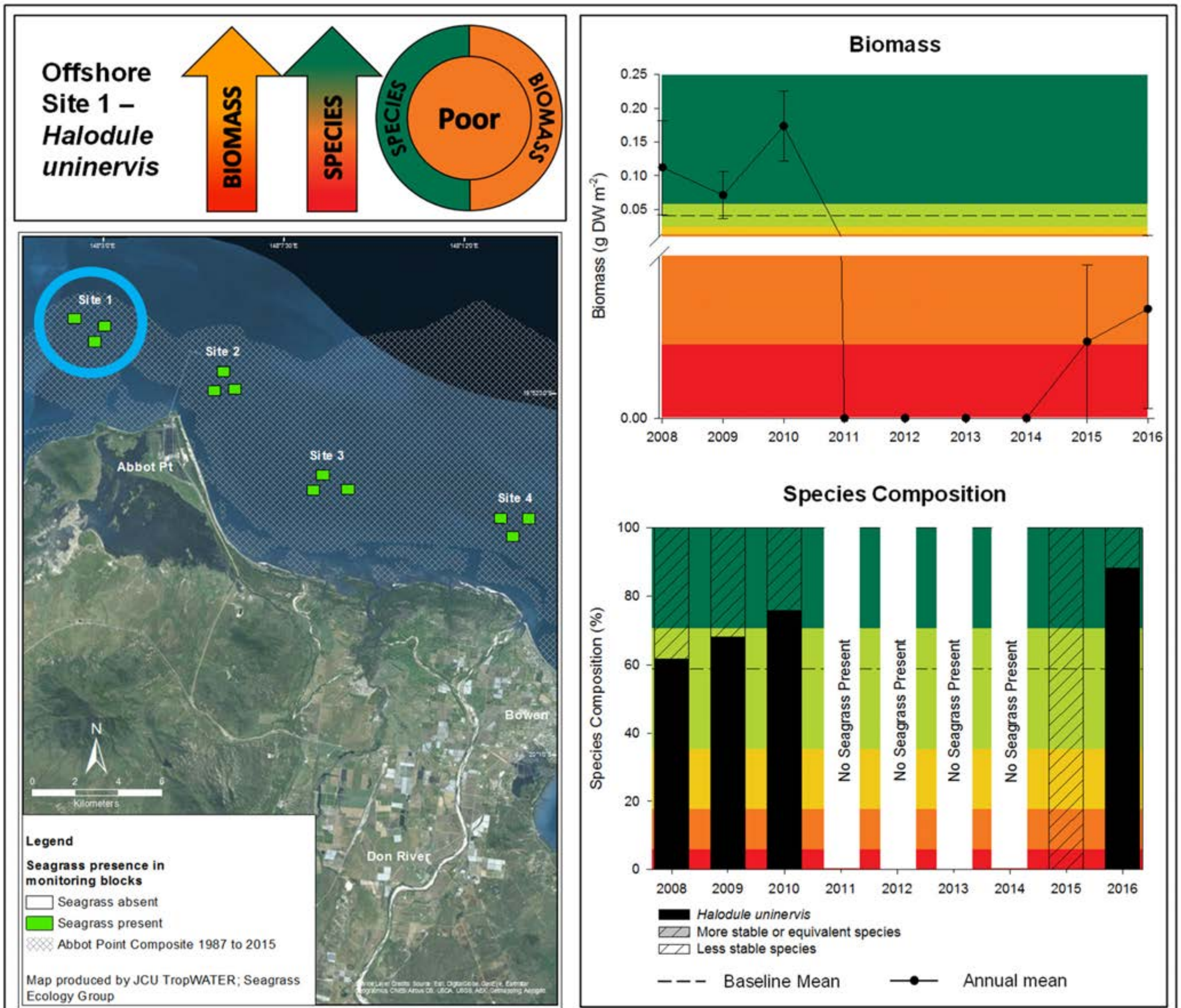


Figure 14. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 8.



*lack of arrows indicates no change in condition index from the previous year

Figure 15. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 9.



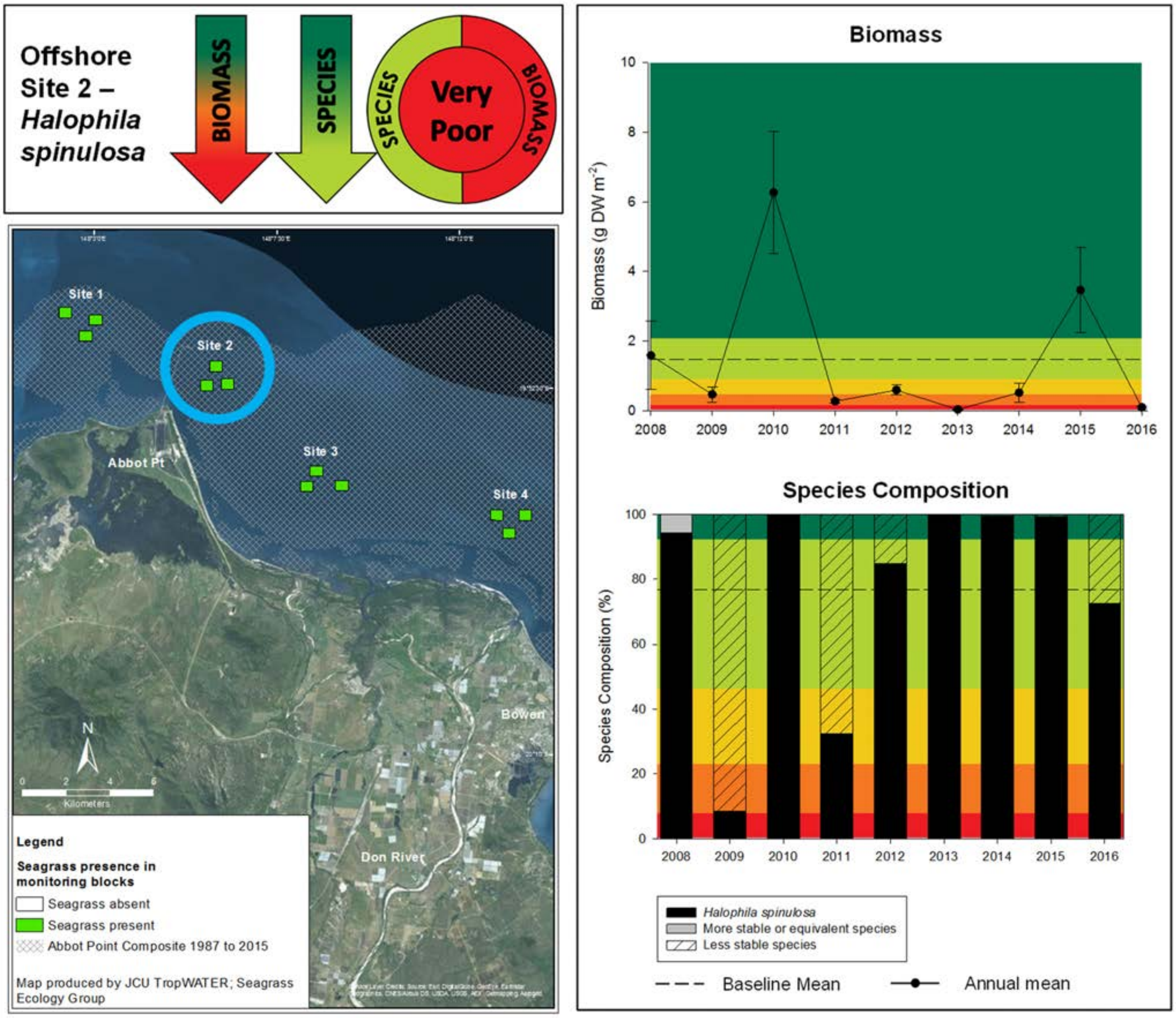
Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species (mixed variable)	More than 20% above the baseline	20% above and 40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline

Decrease below threshold from the previous year — BIOMASS

Increase above threshold from the previous year — BIOMASS

Figure 16. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 1.



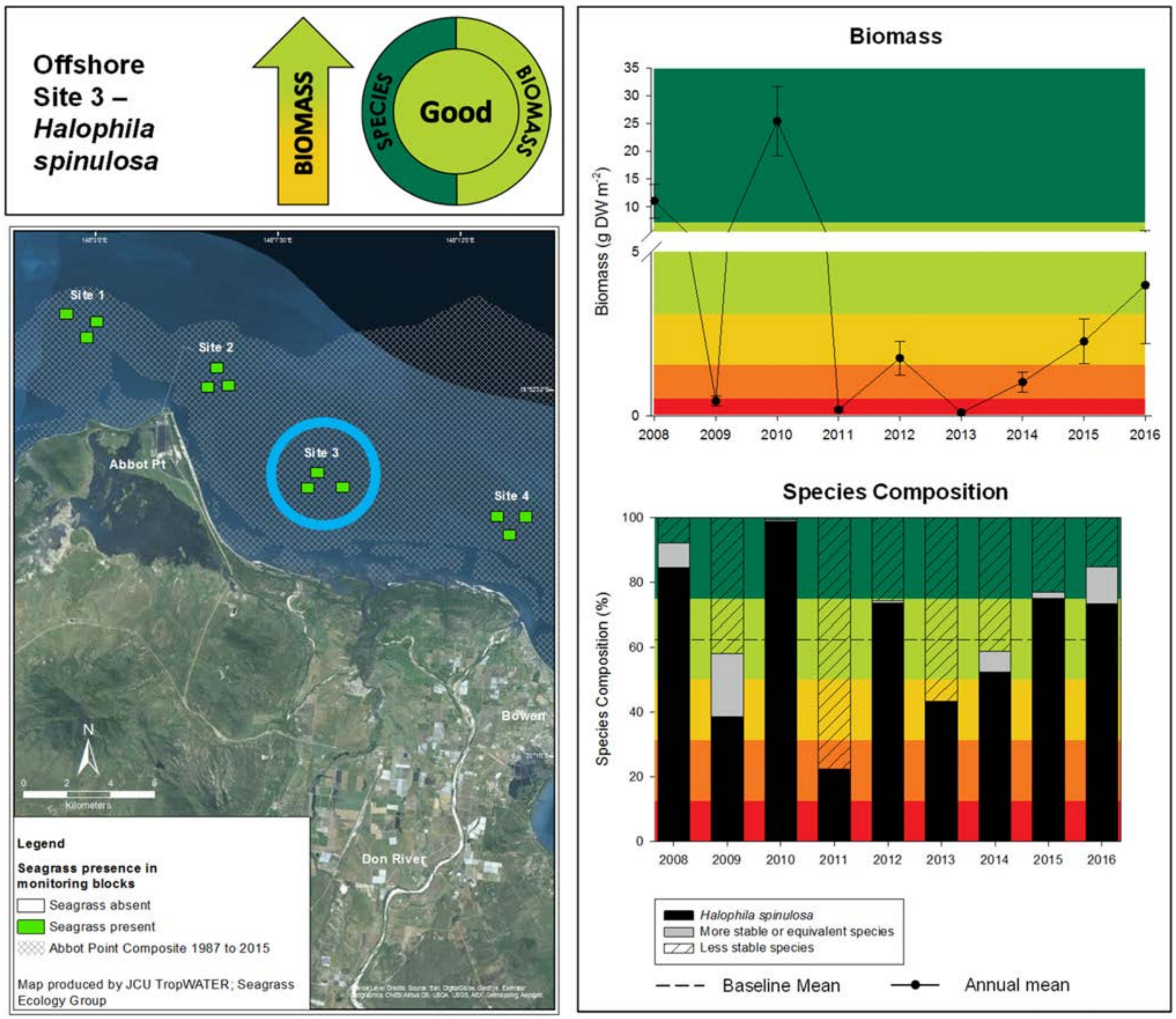
Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species (mixed variable)	More than 20% above the baseline	20% above and 40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline

Decrease below threshold from the previous year — BIOMASS

Increase above threshold from the previous year — BIOMASS

Figure 17. Mean meadow biomass (g DW m-2) and species composition at offshore monitoring Site 2.



Condition index

	A Very Goo	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species (mixed variable)	More than 20% above the baseline	20% above and 40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline

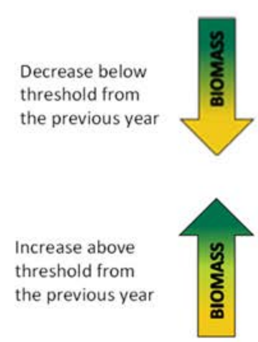


Figure 18. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 3.

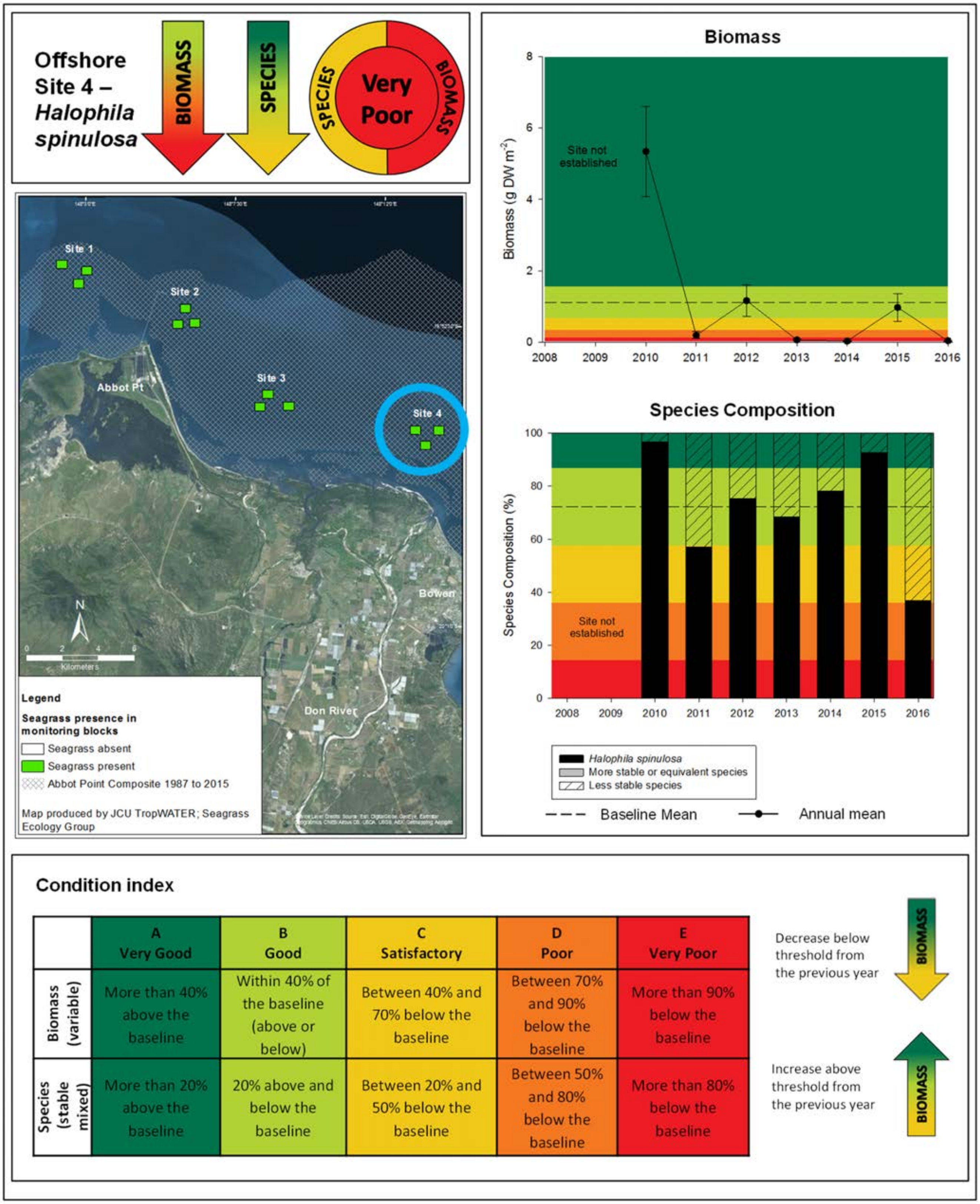


Figure 19. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 4.

3.2 Seagrass within the Broader Port of Abbot Point Region – Broad scale surveys

There have been five (2005, wet & dry season 2008, wet & dry season 2013) previous surveys of examining seagrass in the broader Abbot Point region. Results of those surveys found extensive areas of inshore and offshore seagrass meadows covering the region from Eliot River/Camp Island to Queens Bay, to a distance of approximately 10km offshore (see McKenna and Rasheed 2014). In order to update this baseline and periodically provide a region wide assessment of seagrass condition, a dry season survey of the entire area was conducted in 2016.

3.2.1 Seagrass species, distribution, abundance and changes in the 2016 broad scale survey

As part of the broad scale mapping, 393 habitat characterisation sites were sampled in 2016. Seagrass was present at 53% of these sites. Similar to previous broad scale surveys, seagrass occurred in a strip of relatively small meadows adjacent to the coast, and in three larger offshore meadows (Figure 20). Approximately 18,583 ha of seagrass habitat was mapped in this broad scale survey (Figure 20). Seagrass was found to a maximum depth of 26.7m below mean sea level.

Halophila spinulosa dominated the deeper sub-tidal areas while the inshore meadows were dominated by a mix of species including *H. spinulosa, H. ovalis, H. uninervis* and *Z. muelleri* (Figure 20). Most seagrass meadows in the survey area were of low to moderate density, consisting of isolated patches to a continuous cover of seagrass (Figure 20). The exception to this was monitoring Meadow 9 on the western side of the trestle jetty. This meadow had a dense cover of seagrass for the community type present. The mean above-ground biomass of seagrass in the offshore meadows ranged between 0.001 ± 0 gdwm^{-2} and 26.75 ± 0 gdwm^{-2}; a moderate cover of *H. spinulosa*, while the biomass of seagrass at inshore meadows ranged from 0.0009 ± 0 gdwm^{-2} to 21.30 ± 0.90 gdwm^{-2}; a moderate cover of *H. spinulosa*.

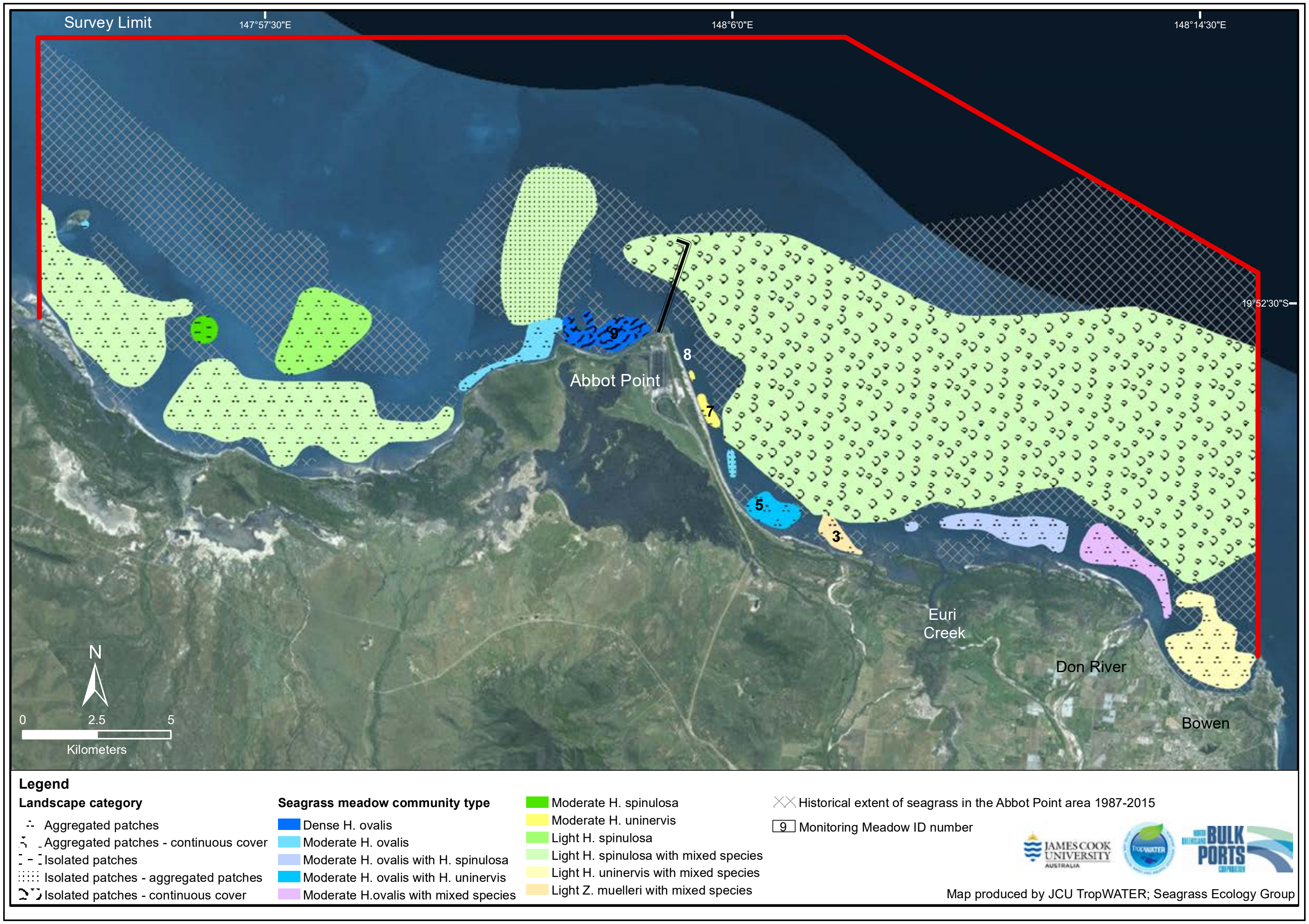


Figure 20. Seagrass meadow community types, distribution and landscape category in the Abbot Point region 2016.

3.2.2 Comparison with previous broad scale surveys

The 2005 survey (see Rasheed et al. 2005) was completed in the wet season at the same scale and intensity as the present broad scale survey although it covered a smaller section of the port limits. The 2008 and 2013 broad scale surveys were part of the current seagrass monitoring program and are directly comparable to the 2016 survey.

Overall the location and species composition of inshore and offshore seagrass meadows has been similar among all broad scale surveys (Figure 22). *Halophila ovalis* and *H. uninervis* have been the dominant species at inshore meadows, while *H. spinulosa* has dominated offshore seagrass meadows.

The overall mean density and distribution of inshore meadows mapped in the broader Abbot Point area was substantially higher in 2016 compared to 2008 and 2013 (Figure 21 & 22)). The mean density of inshore meadows between the 2008 (1.63 ± 0.67 g DW m^{-2}) and 2013 (1.53 ± 0.50 g DW m^{-2}) surveys were similar, however between these surveys there was a major change in species composition as a result of TC Yasi (February 2011) that impacted the area. The species composition of inshore meadows changed by a reduction in the larger species such as *H. uninervis* and *Z. muelleri*, and a higher dominance of the smaller *Halophila* species in the meadows (McKenna and Rasheed 2014). 2016 has seen the recovery of much of the inshore meadows where *H. uninervis* and *Z. muelleri* have recruited back into the Abbot Point region.

Mapping of offshore seagrass density found that the density of deep water seagrass dramatically declined between 2008 and 2013 (Figure 21 & 22). In 2008 the offshore meadows had an above ground biomass of 1.53 ± 0.44 g DW m^{-2}. By 2013 and after TC Yasi, offshore seagrass density declined to 0.04 ± 0.02 g DW m^{-2}. The density of offshore seagrass increased to 6.39 ± 0.54 g DW m^{-2} in 2016, however as discussed above (Section 3.2) offshore seagrass declined between 2015 and 2016 and remains in a poor condition despite evidence of substantial recovery since TC Yasi. The distribution of offshore seagrass in the Abbot Point region has not changed substantially over time(Figure 21 & 22).

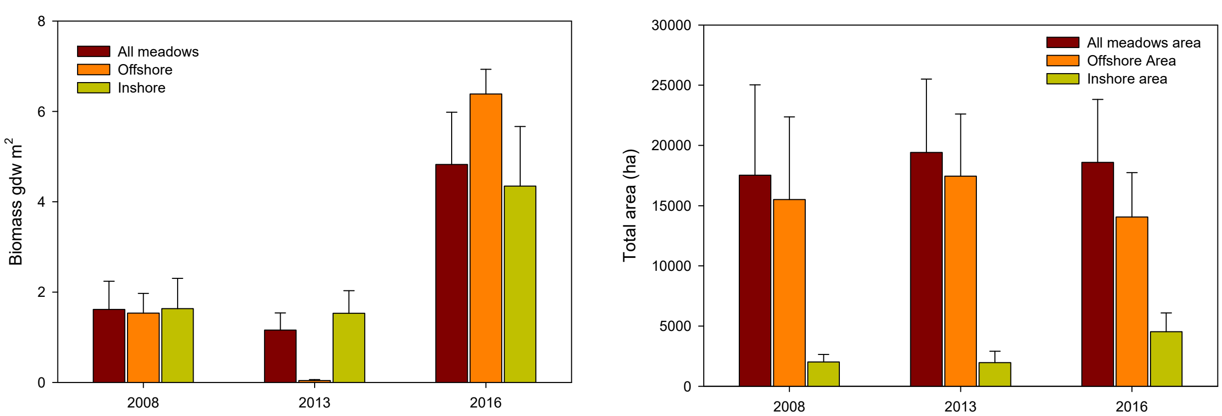


Figure 21. Mean meadow biomass (g DW m^{-2}) and total meadow area (ha) for all coastal and offshore seagrass meadows pooled in 2008, 2013 and 2016.

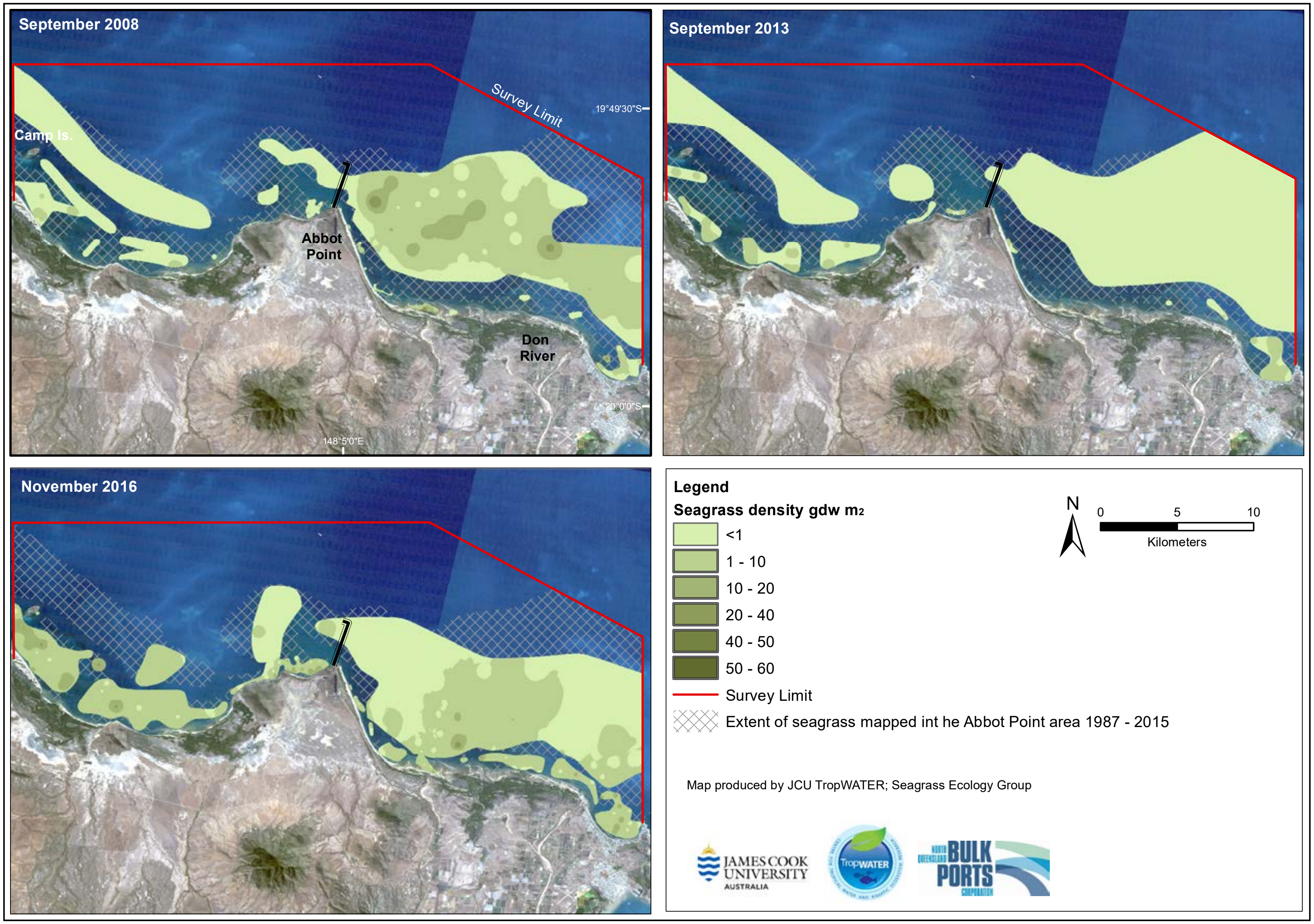


Figure 22. Seagrass distribution and density in the Abbot Point region in 2008, 2013 and 2016.

3.2 Light (PAR) and sea surface temperature trends within the seagrass meadows

The TropWATER/NQBP light and temperature program was discontinued in 2015. Light data presented below was collected at the seabed by Vision Environment between November 2015 and November 2016 as part of the Abbot Point ambient water quality monitoring program. Site AMB 1 is the only site that coincides with any of the TropWATER seagrass monitoring areas (Figure 23).

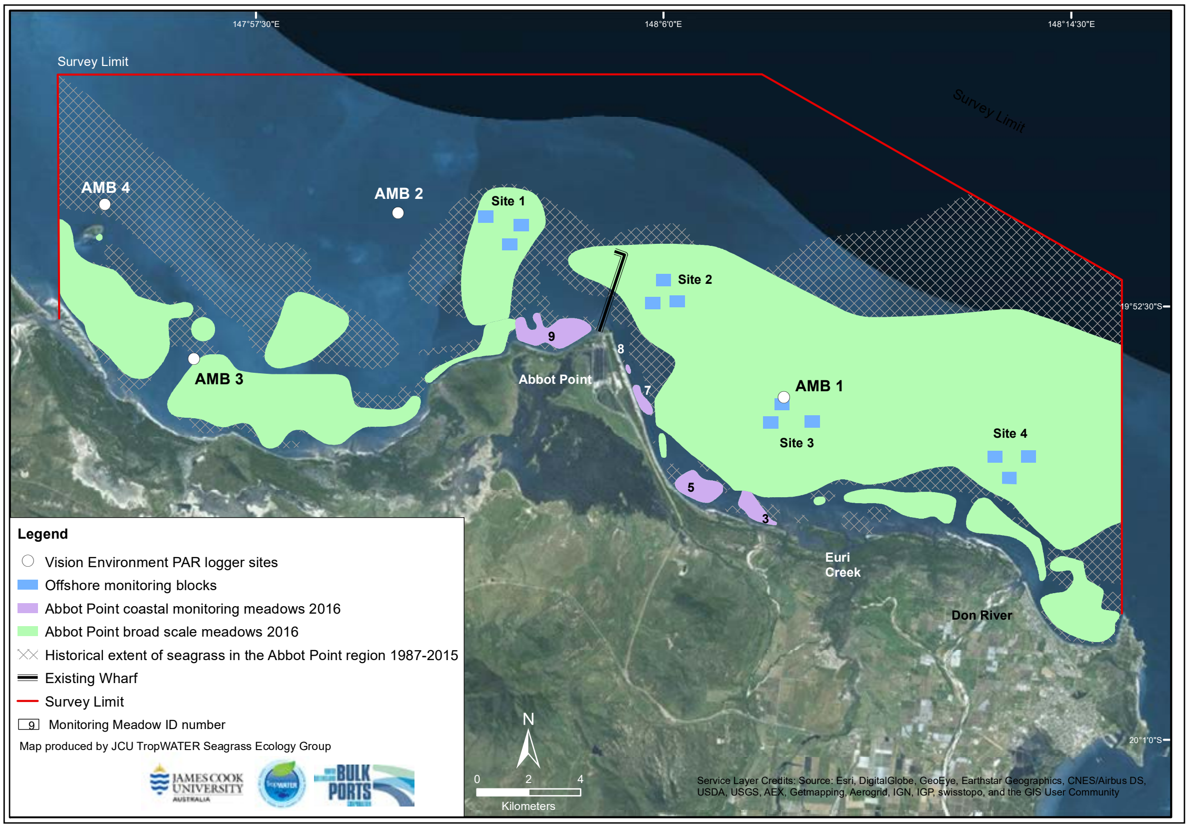


Figure 23. Location of Vision Environment PAR logger sites (AMB 1-4) at Abbot Point.

For *Halophila*, the dominant species in the offshore area at Abbot Point an acute light management threshold of 2–2.5 mol m^{-2} day^{-1} over an integration time of 1-7 days has been suggested for the GBR (Collier et al. 2016). This is likely to be a conservative threshold and higher than the biological thresholds derived from studies and long-term datasets that take into account species and site specificity (Collier et al. 2016). Recent studies of deep water *Halophila* in the GBR suggest a biological management threshold between 1.5-2 mol m^{-2} day^{-1} over an integration time of 7-14 days to incorporate the range in morphological and physiological capacity of the genus (Chartrand et al. 2017).

Total daily PAR at AMB 1; the closest logging site to the long term seagrass monitoring areas, in the 12 months prior to the survey ranged from 0.014 to 10.25 mol photons m^{-2} day^{-1} (Figure 24). At other AMB sites PAR ranged between 0.0004 mol photons m^{-2} day^{-1} (AMB 2) and 15.29 mol photons m^{-2} day^{-1} (AMB 3) (Figure 24).

PAR at AMB 1 fell below the *acute management threshold* (2 mol m^{-2} day^{-1} & integration time of 7 days) at least three times in 2016:

- 24 consecutive days in June 2016; coinciding with some rainfall days;
- 8 days in August 2016;
- 10 days in October 2016

AMB 2 and 4 were below this threshold for significantly longer periods of time, while AMB 3; the shallowest logging site did not fall below this threshold (Figure 24).

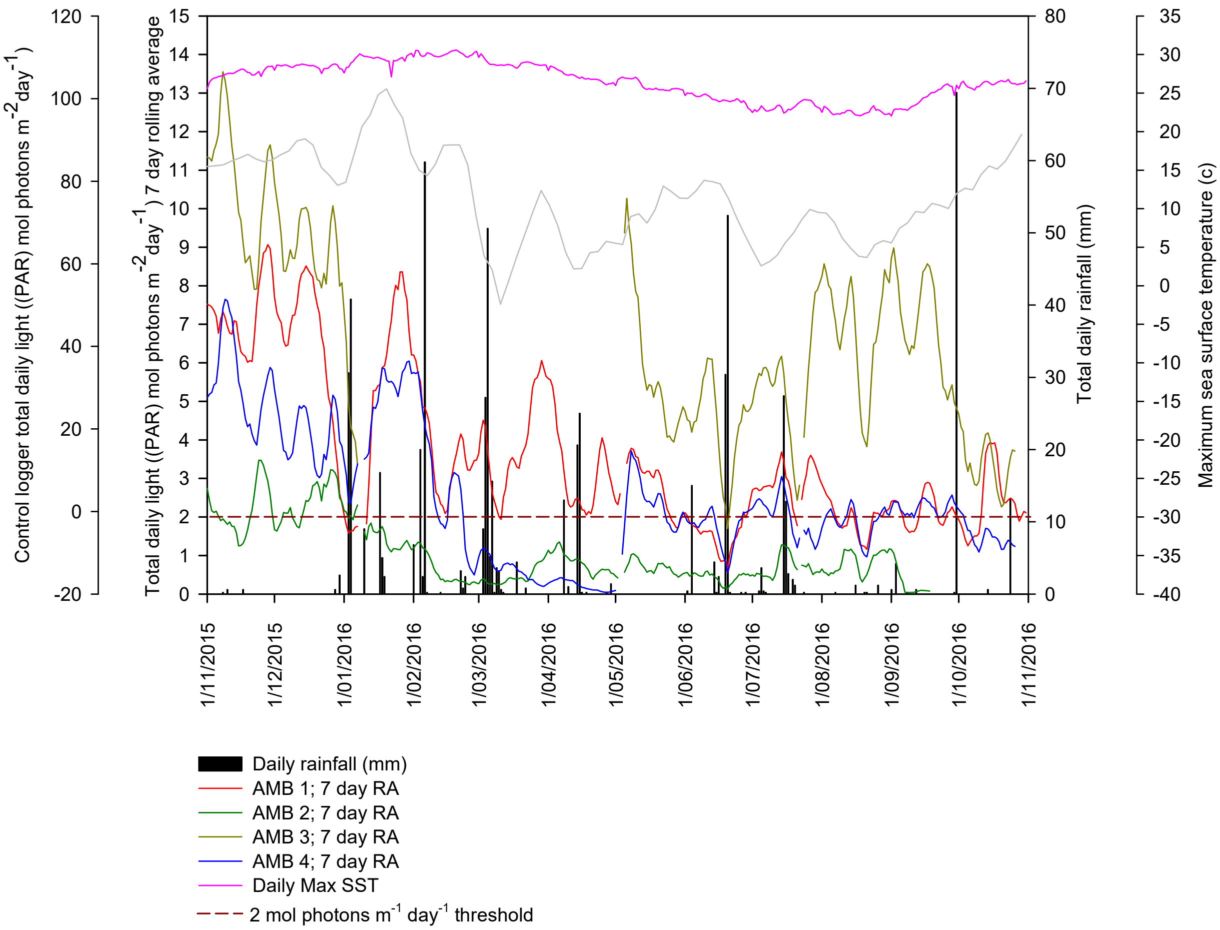


Figure 24. Seven day rolling average total daily PAR (mol photons m^{-1}day^{-1}), total daily rainfall, maximum daily sea surface temperature (°C) at ambient monitoring sites (AMB) 1-4, November 2015 – November 2016. Source: Vision Environment.

3.3 Abbot Point Climate Patterns During Monitoring

Rainfall

Annual rainfall has been below the long term average for the past three years (Figure 25a). Despite this, monthly data showed above average rainfall for numerous months during the dry season; June, July and September (Figure 25b).

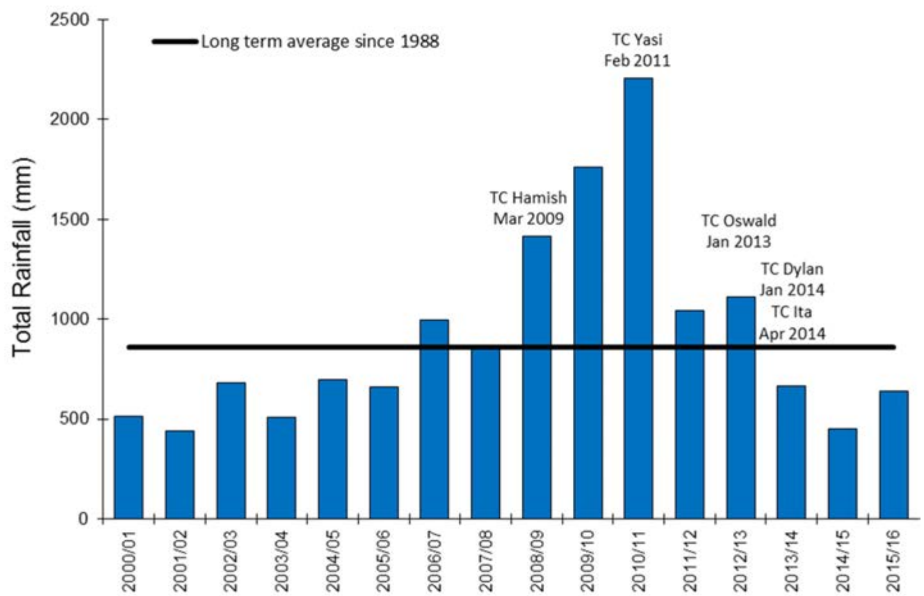


Figure 25a. Total annual rainfall (mm) recorded at Bowen, 2001/02-2015/16. Twelve month year is twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033257.

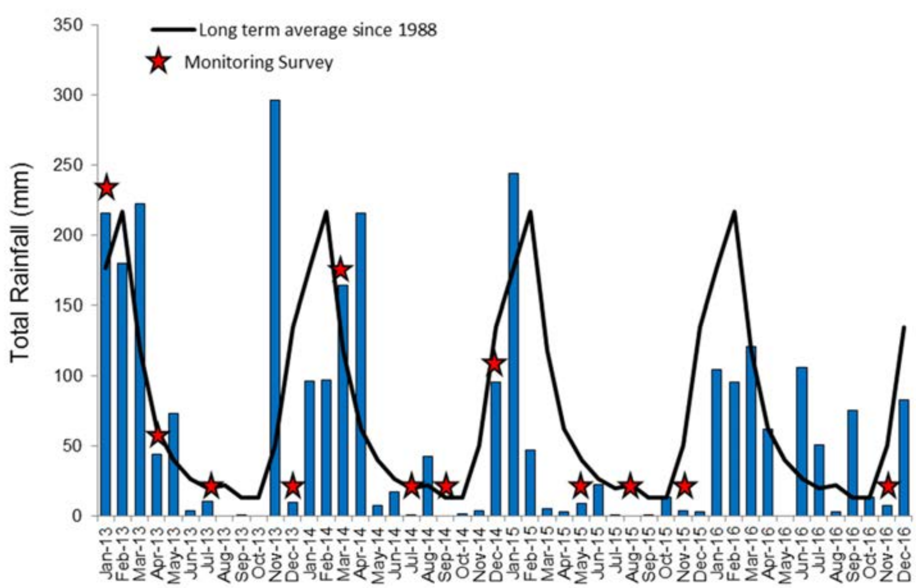


Figure 25b. Total monthly rainfall (mm) recorded at Bowen, January 2013-December 2016. Source: BOM, Station number 033257.

River Flow - Don River

River flow discharge has also been below the long term annual average of 150,464 ML for the past three years (Figure 26a), with 2015/16 recording the lowest annual river flow (27,478 ML) since prior to 2000/01. In the 12 months preceding the 2016 survey, river flow was above the long term average in June 2016, coinciding with above average monthly rainfall (Figure 26b).

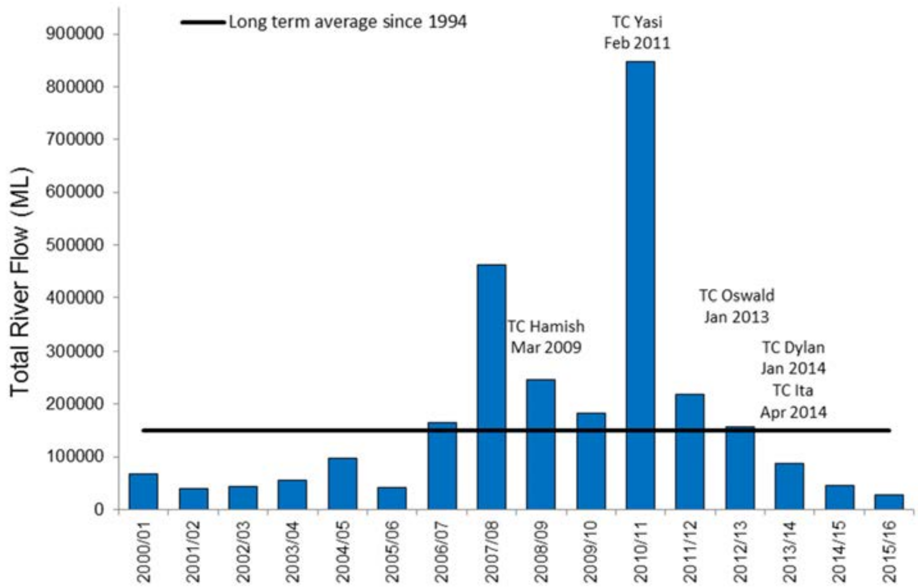


Figure 26a. Total annual river discharge of the Don River (Station 121003A) from 2000/01 to 2015/16. Twelve month year is twelve months prior to the survey. Source: Department of Natural Resources and Mines (DNRM).

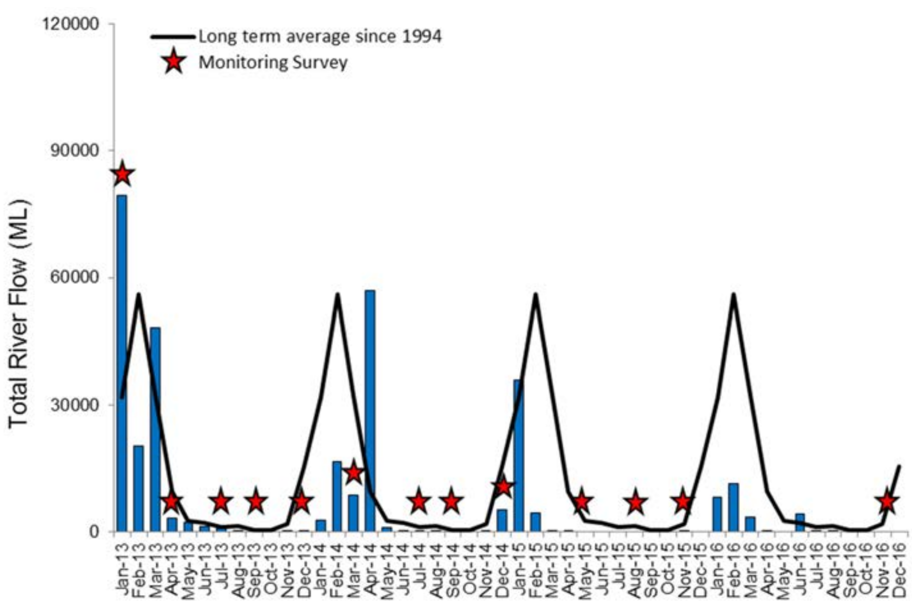


Figure 26b. Total monthly river discharge of the Don River (Station 121003A) from January 2013 to December 2016. Source: DNRM.

Air and Sea Surface Temperature

The annual average maximum air temperature was 0.82°C above the long term annual average (29.5°C) in 2015/16; a 0.24°C increase from 2014/15 (Figure 27a). This is the second year since 2009/10 that temperature has been above the long term average. Monthly maximum air temperatures were above or near the long-term average for the 12 months preceding the 2016 survey (Figure 27b).

Sea surface temperature has been collected half hourly at Abbot Point since May 2014 (QLD Department of Science, Information Technology and Innovation 2015). Mean monthly maximum surface temperature ranged between 22.5°C in August and 30.0°C in February for the 2015/16 period. Noticeably, January and February temperatures in 2016 have dropped by at least 2°C when compared to 2015 values.

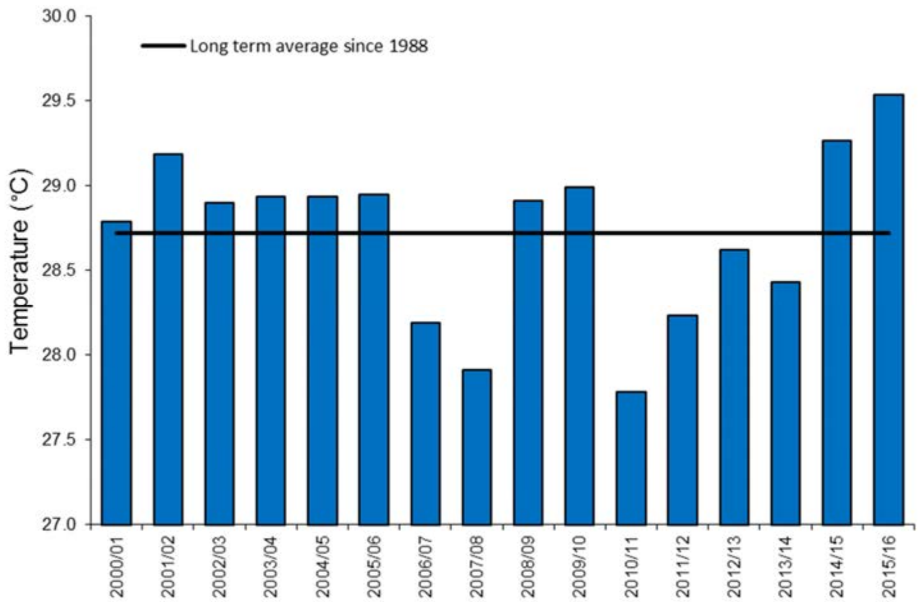


Figure 27a. Annual average maximum air temperature in the Bowen area (Station 33257) between 2000/01 and 2015/16. Source BOM.

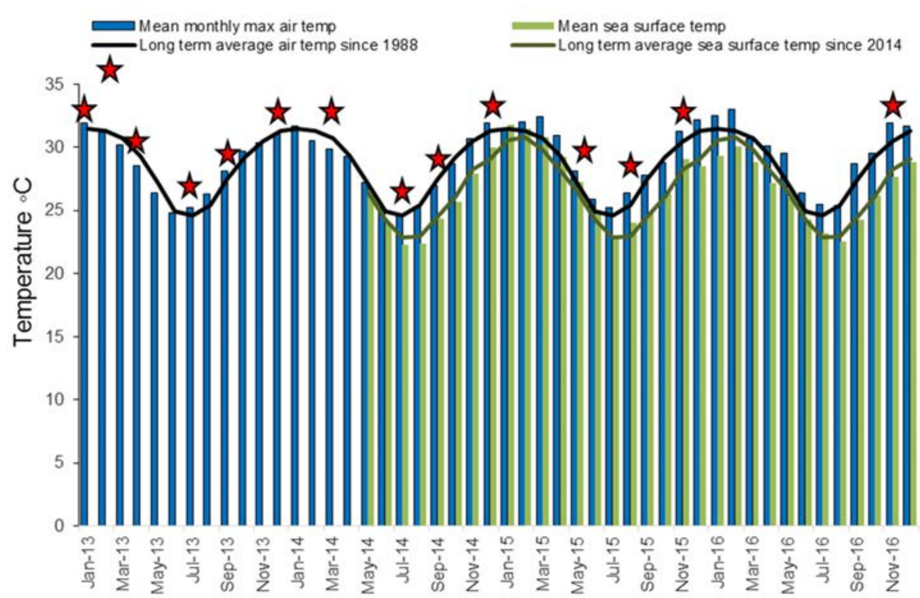


Figure 27b. Monthly mean maximum air temperature (Station 33257) and monthly mean maximum sea surface temperature at Abbot Point January 2013 – December 2016. Source: BOM and DSITI.

Daily Global Solar Radiation

Daily global exposure is a measure of the amount of the total 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. Solar exposure in the Bowen area fell below the long term average in 2015/16 with a measure of 21.14 MJ m^{-2} (Figure 28a). In the twelve months preceding the 2016 survey, exposure was above or near the monthly long term average except in March 2016 which recorded values of 2.8 MJ m^{-2} less than the long term average (Figure 28b).

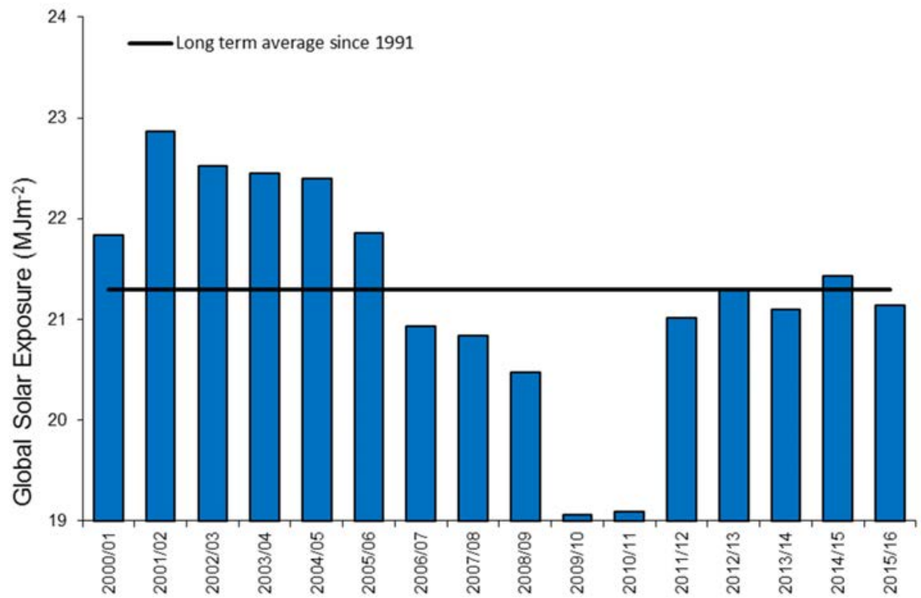


Figure 28a. Mean annual solar radiation (MJm-2) recorded in the Bowen area (Station 033327) 2000/01 -2015/16. Twelve month year is twelve months prior to the survey. Source: BOM.

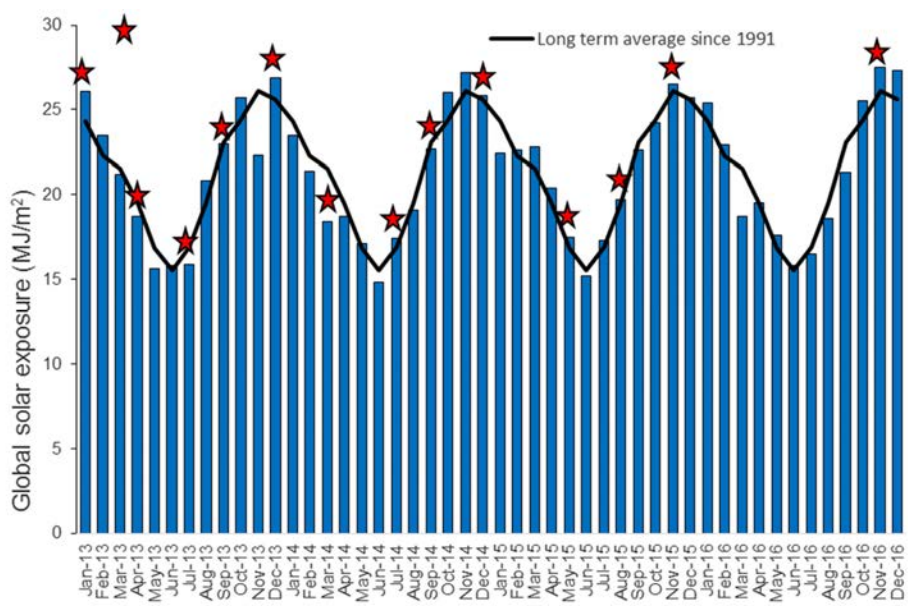


Figure 28b. Mean monthly daily global solar exposure (MJ m-2) recorded in the Bowen area (Station 033327) January 2013 - December 2016. Source: BOM.

Abbot Point Significant Wave Height

Wave height data has been collected half hourly at Abbot Point since May 2014. Maximum wave height is the maximum wave height in a record (26.6 minute recording period) (DSITI 2015). April 2016 had the highest maximum wave height since data has been recorded at the site reaching a height of 1.2 m (Figure 29). Prior to the survey there was a significant wave height occurrence in August 2016, which was 0.33 m higher than was recorded in August 2015.

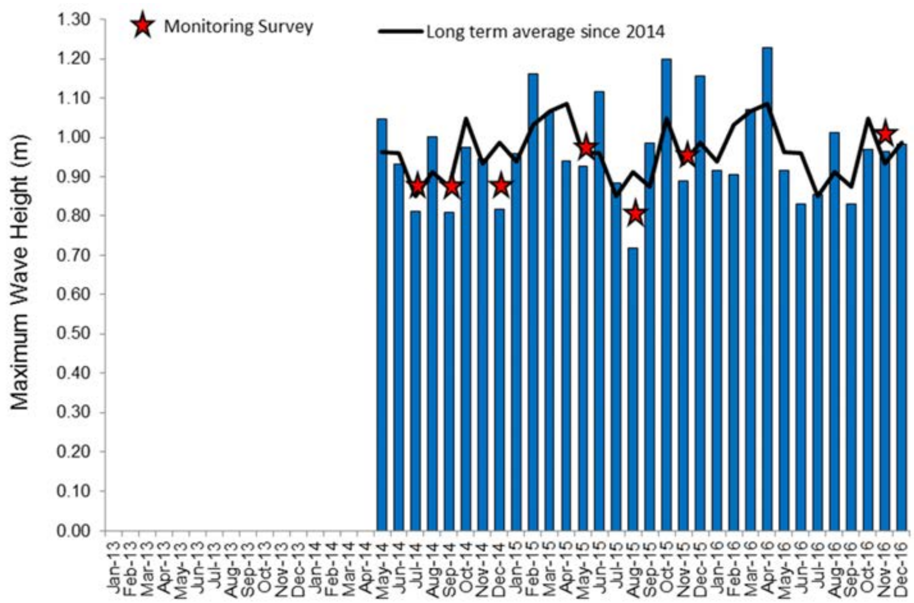


Figure 29. Mean monthly maximum wave height (m) recorded at Abbot Point May 2014 - December 2016. Source: DSITI.

4. DISCUSSION

The overall condition of seagrass habitat in the Abbot Point region improved from poor in 2015 to satisfactory in 2016. This improvement was due to significant improvement to inshore seagrass meadow condition, while the offshore seagrass areas of Abbot Point had declined from 2015 to be in poor condition. It was lower biomass that caused the poor condition of offshore seagrass meadows.

Despite the loss in condition of offshore seagrass, deep water seagrasses remained at relatively high densities since the weather associated losses that occurred leading up to 2011, and during 2013/14. Inshore seagrasses have also improved since these weather associated losses, with species composition returning to pre-disturbance levels. Meadows consisted largely of more persistent species such as *H. uninervis* and *Z. muelleri*, rather than the less persistent *H. ovalis*. This was also evident in the broader Abbot Point region, where many of the meadows (outside of annual monitoring meadows) also consisted more of persistent species, compared to 2013 (the last broad scale survey) (McKenna and Rasheed 2014).

Significant losses of seagrass biomass and distribution at Abbot Point were first observed following Tropical Cyclone Hamish (March 2009), the 2010/11 La Niña events, Tropical Cyclone Yasi (February 2011), and Tropical Cyclone Oswald (January 2013). After the 2010/11 La Niña and TC Yasi related losses, recovery of seagrass primarily occurred at the deep water monitoring sites, with limited to no recovery in the inshore meadows. Seagrass recovery was once again stalled after TC Oswald in early 2013, TC Dylan in January 2014 and TC Ita in April 2014, and seagrass at the inshore monitoring sites continued to show only limited signs of recovery. The continued increase of overall seagrass biomass and area in the Abbot Point region in 2016 is a positive sign of ongoing seagrass recovery.

The downgrading of offshore seagrass condition as a result of lower biomass scores was due to a reduction in the contribution of *H. spinulosa* to the overall species composition of the meadow compared to 2015. *Halophila spinulosa* is morphologically/structurally larger compared to other *Halophila* species and therefore generally contributes more to the overall biomass of a meadow. It is difficult to determine the exact cause of the reduction in the presence of *H. spinulosa* in 2016 at monitoring sites, however it may be due to local scale weather conditions rather than larger scale regional drivers influencing this seagrass change.

Deep water seagrasses in the Great Barrier Reef lagoon are highly variable (Rasheed et al. 2014; York et al. 2015; Chartrand et al. 2017). The biomass and distribution of these seagrass meadows and their dominant species is driven by temporal differences in climate such as rainfall events driving high river flow from nearby catchments that create turbid plumes, and wind patterns affecting resuspension of particles in the water column that impact on light availability. If light availability is compromised this has the potential to impact the germination of seeds and/or the maintenance of seagrass condition during key growing periods (~July – December). For the last three years, environmental conditions for offshore seagrass growth have been favourable with below average rainfall and river flow, and the prevailing El Niño climate pattern resulting in drier weather patterns with fewer episodic rainfall events. Favourable climate conditions are likely to have facilitated the increases in biomass and area for the monitoring meadows in 2015 (McKenna et al. 2016). The subsequent decrease in deep water seagrass biomass around Abbot Point in 2016 may be the result of higher than average rainfall and river flow of the Don River in the dry season; June to September 2016 (2–4 months before the 2016 survey). These events resulted in benthic light (PAR) falling below required light levels for *Halophila* species for long periods of time just before and during key growing periods (Collier et al. 2015; Chartrand et al. 2017). The reduction in light leading into, and during the critical annual growth period for deep water seagrasses may have impacted either the germination of offshore *Halophila* seeds, or resulted in inadequate light during the early growth period of germinated shoots. Similar results occurred in Hay Point in 2016 where offshore seagrass declined from 2015; local light conditions during the dry season there were also likely to have played a role in their decline (McKenna and Rasheed 2017).

Halophila species are small species that are structurally deplete below-ground compared to other morphologically large and long-lived species which rely on below-ground reserves to compensate for poor water quality over short durations (Collier et al. 2009; Collier et al. 2012). This means that they are generally quick to decline when stressed, but also well adapted for recovery once conditions become favourable as they are fast growing and rapid colonisers (Rasheed 2004; Hammerstrom et al. 2006; Ralph et al. 2007; Unsworth et al. 2010; Kilminster et al. 2015; Chartrand et al. 2017).

The generally favourable environmental conditions over the last three years were also likely to be beneficial for the inshore meadows at Abbot Point. The above average rainfall and river flow in some months through the dry season in 2016 did not appear to effect these meadows in the same way as the offshore deep water seagrasses. In 2016, the shallow meadows had returned to larger more persistent species, which have a much higher resistance to short periods of reduced light. These species have a longer growing season and a much greater ability to accumulate energy stores in their tissues than deep water *Halophila* species. It is possible that this difference allowed them to continue to improve from 2015 and not be unduly affected by the short periods of lower light. Also, there are currently no light monitoring stations in the shallow seagrass areas of Abbot Point, so it is difficult to say with certainty if the light environment here was effected, and it may be that light levels in the shallow coastal areas of Abbot Point remained suitable for seagrass growth throughout the year.

Results of the latest surveys indicate that there has been a significant increase in seagrass biomass, distribution and species composition at inshore seagrass meadows in the Abbot Point region, while seagrass in the offshore areas may have been more affected by local weather conditions in the growing season of 2016. Since the 2016 survey was completed, severe tropical cyclone Debbie made landfall in late March 2017 near Airlie Beach, 50km southeast of Bowen, affecting the Bowen/Abbot Point region. The 2017 annual monitoring seagrass survey will determine the impact TC Debbie had on the seagrass habitat in the region. It is likely that multiple years of climate induced seagrass decline have left a legacy of reduced resilience to further impacts and the standing crop and any remaining seed bank will be critical for the ongoing recovery of Abbot Point's seagrasses.

The management of seagrass resources in the Abbot Point region should remain focussed on ensuring that the resilience of local seagrass remains high enough to withstand anthropogenic impacts and risks.

5. REFERENCES

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

Bryant, C., Jarvis, JC., York, P. & Rasheed, M. 2014. Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/53, James Cook University, Cairns, 74 pp.

Bureau of Meteorology 2016, Australian Federal Bureau of Meteorology Weather Records, http://www.bom.gov.au

Carter AB., Jarvis JC., Bryant CV. & Rasheed MA. 2015. Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns, 71 pp.

Chartrand KM., Bryant CV., Sozou S., Ralph PJ and Rasheed MA 2017. Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Report No 17/16. Cairns, 68 pp.

Coles RG., Rasheed MA., McKenzie LJ., Grech, A., York, PH., Sheaves, MJ., McKenna, S. & Bryant, CV. 2015. The Great Barrier Reef World Heritage Area seagrasses: managing this iconic Australian ecosystem resource for the future. *Estuarine, Coastal and Shelf Science*, 153: A1-A12.

Collier, CJ. & Waycott, M. 2009. Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature Review and Gaps Analysis. Report to the Marine and Tropical Sciences Research Facility, Reef and Rainforest Research Centre Limited, Cairns pp. 55pp.

Collier CJ, Waycott M, and Ospina AG 2012. Responses of four Indo-West Pacific seagrass species to shading. *Marine Pollution Bulletin* 65:342-354.

Collier, CJ., Chartrand, K., Honchin, C., Fletcher, A. & Rasheed, M 2016. Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns (41pp.).

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

Dennison, WC., Orth, RJ., Moore, KA., Stevenson, JC., Carter, V., Kollar, S., Bergstrom, PW. & Batiuk, RA 1993. Assessing water quality with submersed aquatic vegetation. *BioScience*, vol. 43, pp. 86-94.

Department of Natural Resources and Mines, Water Monitoring Information Portal, https://water-monitoring.information.qld.gov.au/host.htm

Department of Science, Information Technology and Innovation, www.qld.gov.au/waves

Fourqurean, JW., Duarte, DM., Kennedy, H., Marba, N., Holmer, M. & Mateo, MA 2012. Seagrass ecosystems as a globally significant carbon stock. *National Geoscience* vol. 5, pp 505–509.

Grech, A., Coles, R. & Marsh, H 2011. A broad-scale assessment of the risk to coastal seagrasses from cumulative threats. *Marine Policy*, vol. 35: 560-567.

Hammerstrom KK, Kenworthy WJ, Fonseca MS, Whitfield PE 2006. Seed bank, biomass, and productivity of Halophila decipiens, a deep water seagrass on the west Florida continental shelf. *Aquatic Botany* 84:110-120.

Hemminga, MA. & Duarte, CM 2000. *Seagrass Ecology*, Cambridge University Press.

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G. A., Scanes, P., McKenzie, L., O'Brien, K. R., Lyons, M., Ferguson, A., Maxwell, P., Glasby, T. & Udy, J 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. *Science of The Total Environment*, vol 534: 97-109.

Kirkman, H 1978. Decline of seagrass in northern areas of Moreton Bay, Queensland. *Aquatic Botany*, vol. 5, pp. 63-76.

Macreadie, PI., Baird, ME., Trevathan-Tackett, SM., Larkum, AWD. & Ralph PJ 2013. Quantifying and modelling the carbon sequestration capacity of seagrass meadows – a critical assessment. *Marine Pollution Bulletin* doi:10.1016/j.marpolbul.2013.07.038.
Available at http://www.sciencedirect.com/science/journal/aip/0025326X

McKenna, SA., Rasheed, MA., Unsworth, RKF. & Chartrand KM 2008. Port of Abbot Point seagrass baseline surveys - wet & dry season 2008. DPI&F Publication PR08-4140', pp. 51.

McKenna, SA., and Rasheed, MA 2011. Port of Abbot Point Long-Term Seagrass Monitoring: Interim Report 2008-2011. DEEDI Publication, Fisheries Queensland, Cairns, 52 pp.

McKenna, SA & Rasheed, MA 2014. Port of Abbot Point Long-Term Seagrass Monitoring: Annual Report 2012-2013. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 45 pp.

McKenna SA and Rasheed MA 2017. Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2016. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication.

McKenna, SA, Sozou, AM, Scott, EL and Rasheed, MA 2016. Port of Abbot Point Long-Term Seagrass Monitoring: Annual Report 2014-2015. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

McLeod, E., Chmura, GL., Bouillon, S., Salm, R., Bjork, M. & Duarte, CM 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2 front. *Ecological Environment* vol. 9, pp 552–560.

Mellors, JE 1991. An evaluation of a rapid visual technique for estimating seagrass biomass. *Aquatic Botany*, vol. 42, pp. 67-73.

Orth, R J., Carruthers, TJB., Dennison, WC., Duarte, CM., Fourqurean, JW., Heck, KL., Hughes, AR., Kendrick, GA., Kenworthy, WJ., Olyarnik, S., Short, FT., Waycott, M. & Williams, SL 2006. A global crisis for seagrass ecosystems. *BioScience*, vol. 56 pp 987-996.

Ralph PJ, Durako MJ, Enríquez S, Collier CJ, Doblin MA 2007. Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology* 350:176-193.

Rasheed, MA 2004. Recovery and succession in a multi-species tropical seagrass meadow following experimental disturbance: the role of sexual and asexual reproduction. *Journal of Experimental Marine Biology and Ecology*, vol. 310, pp. 13-45.

Rasheed, MA., Thomas, R. and McKenna, SA 2005. Port of Abbot Point seagrass, algae and benthic macro-invertebrate community survey - March 2005. DPI&F Information Series QI05044 (DPI&F, Cairns), 27 pp.

Rasheed, MA., McKenna, SA., Carter, AB. & Coles, RG 2014. Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia. *Marine Pollution Bulletin*, vol. 83, pp. 491-499.

Short, FT. & Wyllie-Echeverria, S 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* vol. 23, 17–27.

Unsworth, RKF., McKenna, SA. and Rasheed, MA 2010. Seasonal dynamics, productivity and resilience of seagrass at the Port of Abbot Point: 2008-2010. DEEDI Publication, Fisheries Queensland, Cairns, pp. 68.

Waycott, M., Duarte, CM., Carruthers, TJB., Orth, R. Dennison, WC., Olyarnik, S., Calladine, A., Fourqurean, JW., Heck Jr., KL., Hughes, AR., Kendrick, GA., Kenworthy, WJ., Short, FT., Williams, SL 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* vol. 106, 12377–12381.

York, PH., Carter, AB., Chartrand, K., Sankey, T., Wells, L. and Rasheed, MA 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program. *Nature Scientific Reports*. 5:13167 DOI: 10.1038/srep13167.

6. APPENDICES

Appendix 1. Example of calculating a meadow score for biomass in satisfactory condition.

1. Determine the grade for the 2016 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in biomass (B_{diff}) between the 2016 biomass value (B_{2016}) and the area value of the lower threshold boundary for the satisfactory grade ($B_{satisfactory}$):

$$\mathrm{B_{diff}} = \mathrm{B_{2016}} - \mathrm{B_{satisfactory}}$$

Where $B_{satisfactory}$ 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 biomass values (B_{range}) in that grade:

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

Where $B_{satisfactory}$ 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 (B_{prop}) that B_{2016} takes up:

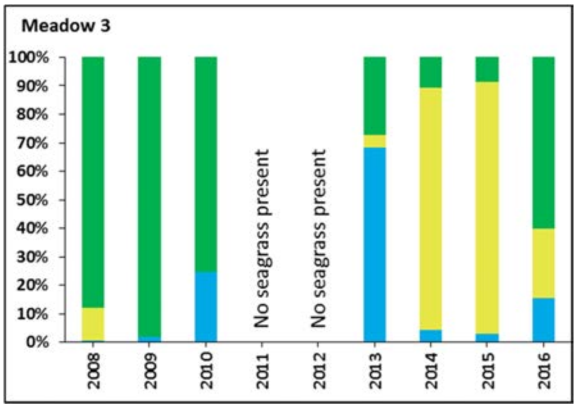
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

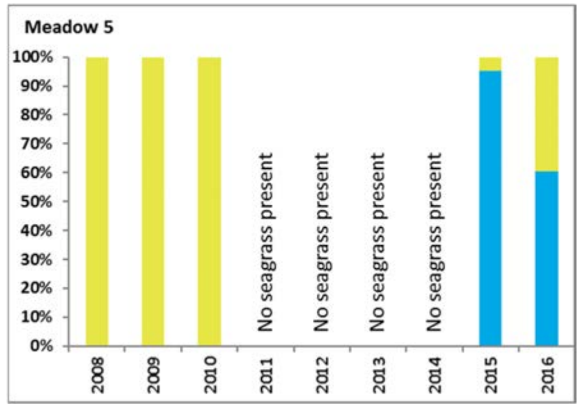
5. Determine the biomass score for 2016 ($Score_{2016}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

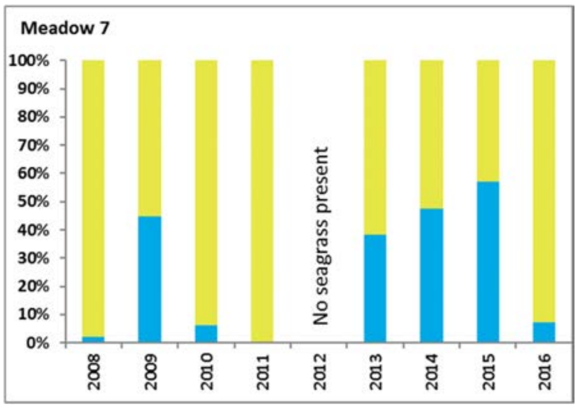
$$\mathrm{Score_{2016}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

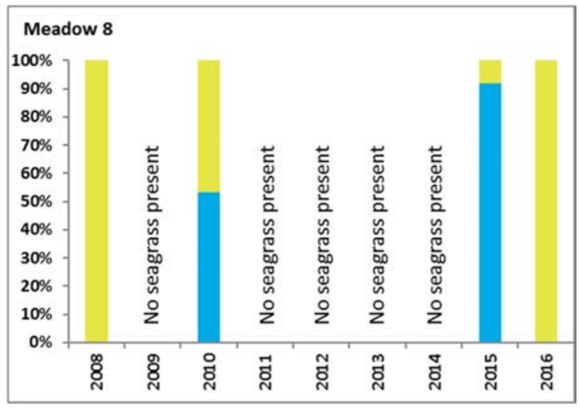
Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

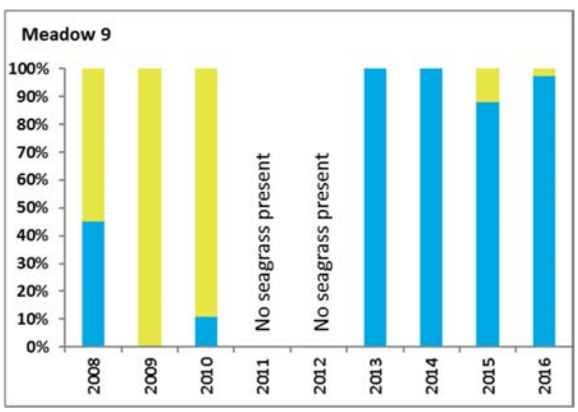
Appendix 2. Species composition of inshore and offshore monitoring meadows in the Abbot Point region: 2008 – 2016

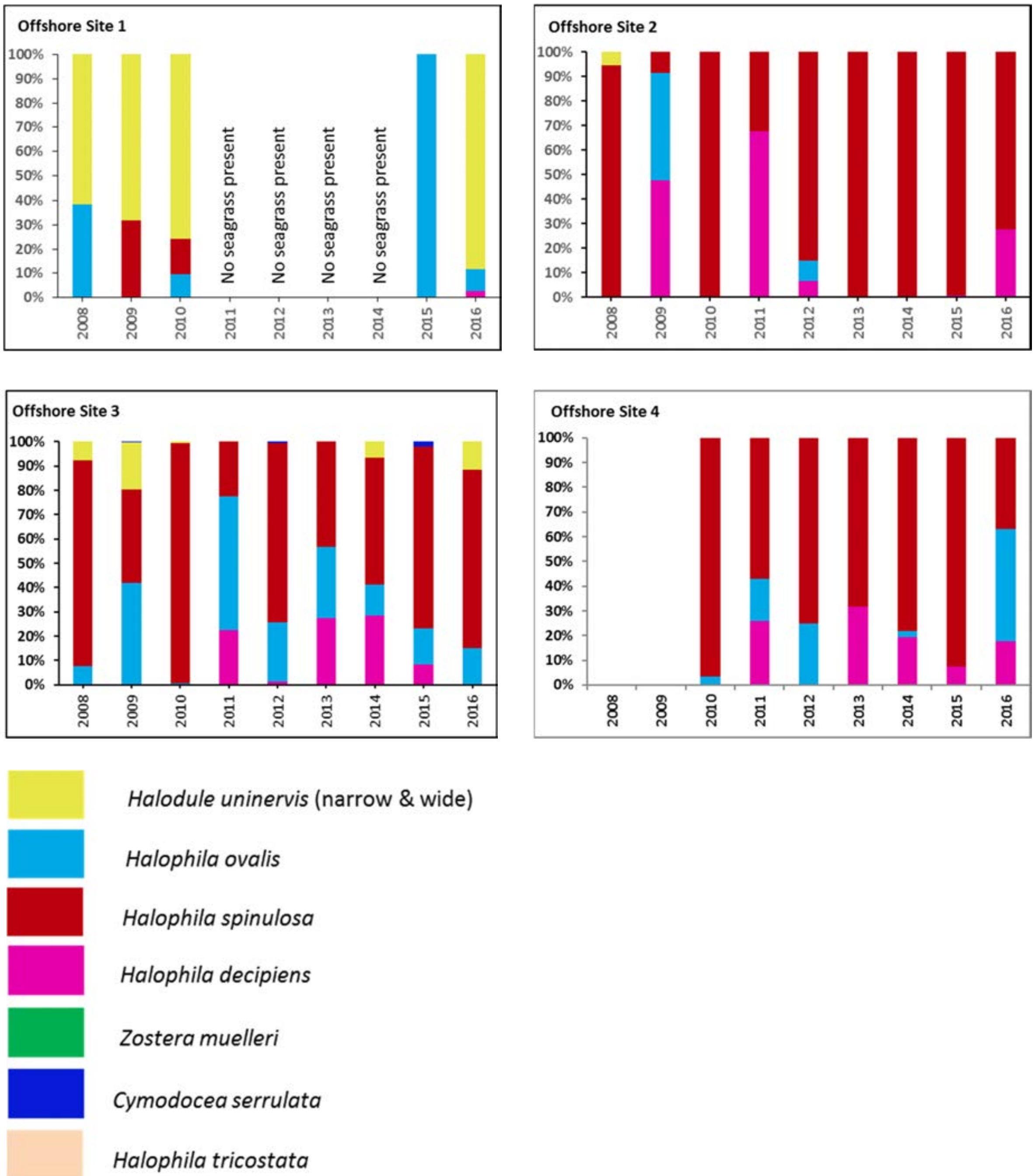











Offshore Site 1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No seagrass present
No seagrass present
No seagrass present
No seagrass present
2008
2009
2010
2011
2012
2013
2014
2015
2016
Offshore Site 2
Offshore Site 3
Offshore Site 4
Halodule uninervis (narrow & wide)
Halophila ovalis
Halophila spinulosa
Halophila decipiens
Zostera muelleri
Cymodocea serrulata
Halophila tricostata

Appendix 3. Biomass and area of inshore and offshore meadows

3A. Mean biomass of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2016.

	Mean Biomass ± SE (g DW m^{-2}) (no. sites present in meadow)				
Meadow #	**3**	**5**	**7**	**8**	**9**
Mar 05	0.09 ± 0.03 (6)	0.03 ± 0 (1)	0.06 ± 0 (1)	0.03 ± 0 (1)	1.63 ± 0.54 (16)
Mar 08	3.71 ± 1.72 (8)	0.05 ± 0.02 (9)	2.84 ± 0 (1)	0.52 ± 0.52 (2)	0.86 ± 0.47 (17)
Jul 08	4.55 ± 1.68 (15)	1.57 ± 0.08 (3)	3.72 ± 0.33 (4)	NP	1.10 ± 0.53 (12)
Sep 08	8.91 ± 4.17 (11)	1.54 ± 0.57 (6)	6.7 ± 2.21 (12)	1.65 ± 0.33 (2)	0.40 ± 0.15 (17)
Nov 08	6.98 ± 2.95 (14)	1.34 ± 0.71 (6)	2.87 ± 0.74 (9)	5.01 ± 1.72 (3)	1.02 ± 0.51 (20)
Apr 09	3.34 ± 0.95 (9)	NP	1.68 ± 0.46 (8)	NP	0.17 ± 0.08 (10)
Aug 09	2.76 ± 0.99 (14)	NP	0.43 ± 0.18 (7)	1.57 ± 1.18 (2)	0.63 ± 0.30 (23)
Dec 09	1.59 ± 0.55 (31)	0.005 ± 0.003 (5)	1.0 ± 0.62 (13)	NP	0.15 ± 0.08 (15)
Jun 10	0.84 ± 0.4 (13)	0.06 ± 0 (1)	0.76 ± 0.4 (4)	5.04 ± 0 (1)	0.11 ± 0.02 (6)
Nov 10	2.92 ± 0.86 (5)	3.74 ± 1.06 (3)	4.46 ± 0.41 (3)	1.61 ± 0 (2)	0.73 ± 0.16 (12)
Mar 11	NP	NP	2.03 ± 1.16 (5)	0.07 ± 0 (4)	NP
May 11	NP	NP	0.40 ± 0 (1)	NP	NP
Sept 11	NP	NP	0.69 ± 0.4 (3)	NP	NP
Feb 12	0.23 ± 0 (1)	NP	4.58 ± 0.19 (3)	NP	NP
Jun 12	NP	NP	0.82 ± 0.31 (5)	NP	NP
Sep 12	NP	NP	NP	NP	NP
Jan 13	NP	NP	NP	NP	NP
Apr 13	3.10 ± 0 (1)	NP	0.25 ± 0 (1)	NP	4.42 ± 0 (1)
3.40	NP	NP	2.74 ± 0.91 (5)	NP	1.67 ± 0 (1)
Sept 13	NP	NP	1.53 ± 0.72 (4)	NP	3.07 ± 1.55 (3)
Dec 13	2.16 ± 0.75 (3)	NP	2.40 ± 1 (4)	NP	1.60 ± 1.07 (3)
Mar 14	NP	NP	6.11 ± 1.2 (2)	NP	1.71 ± 0.7 (4)
Jul 14	0.06 (1)	NP	1.73 ± 0.73 (5)	NP	2.31 ± 0.65 (6)
Sep 14	1.67 ± 0.34 (3)	1.2 ± 0.04 (2)	3.98 ± 1.29 (3)	NP	4.36 ± 0.91 (8)
Dec 14	5.13 ± 0.76 (4)	NP	13.84 ± 4.6 (3)	NP	4.31 ± 0.93 (18)
May 15	0.83 ± 0.28 (5)	0.57 ± 0.39 (2)	4.61 ± 1.07 (4)	NP	3.40 ± 0.59 (15)
Aug 15	4.21 ± 3.96 (3)	2.14 ± 0.94 (5)	4.89 ± 1.91 (5)	1.84 ± 0 (2)	2.80 ± 0.50 (20)
Nov 15	2.3 ± 1.26 (6)	1.01 ± 0.29 (5)	4.35 ± 1.12 (5)	3.22 ± 1.17 (3)	3.57 ± 0.58 (16)
Nov 16	5.3 ± 1.59 (10)	2.47 ± 0.74 (5)	3.62 ± 1.24 (7)	1.94 ± 0 (1)	8.32 ± 1.66 (14)

NP – No seagrass present in meadow

3B. Area (ha) of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2016.

Area ± R (ha)						
Meadow #	**3**	**5**	**7**	**8**	**9**	**TOTAL meadow area**
Mar 05	25.6 ± 6	21.5 ± 6.1	19.5 ± 7.1	5.6 ± 2.7	125.8 ± 41	198 ± 62.9
Mar 08	55.5 ± 8	67.9 ± 27.6	4.2 ± 0.9	2.1 ± 0.7	120.8 ± 71.4	250.5 ± 108.6
Jul 08	53.1 ± 8.3	9.7 ± 1.9	3.6 ± 0.9	NP	67.0 ± 9	133.4 ± 20.1
Sep 08	56.95 ± 8.06	19.83 ± 17.1	21.47 ± 2.38	4 ± 0.81	83.96 ± 10.26	186.21 ± 38.61
Nov 08	83.6 ± 10.5	30.9 ± 18.6	12 ± 2.1	3.7 ± 1	83.1 ± 13.1	213.3 ± 45.3
Apr 09	32.4 ± 19.9	NP	9.2 ± 5.6	NP	38.20 ± 28.7	79.8 ± 54.2
Aug 09	44.2 ± 9.3	NP	13.2 ± 2.6	3 ± 0.7	22.9 ± 5.1	83.3 ± 17.7
Dec 09	75.4 ± 9.3	13.3 ± 10.1	15.7 ± 6.2	NP	127.5 ± 17.8	231.9 ± 43.4
Jun 10	24.6 ± 6.8	1.4 ± 1	5.1 ± 3	1.6 ± 1	56.3 ± 33.3	89 ± 45.1
Nov 10	15.04 ± 13.2	16.04 ± 13.67	5.25 ± 5.09	2.18 ± 2.07	105.38 ± 85.44	143.89 ± 119.47
Mar 11	NP	NP	8.58 ± 6.46	3.88 ± 2.78	NP	12.46 ± 9.24
May 11	NP	NP	3.01 ± 2.23	NP	NP	3.01 ± 2.23
Sep 11	NP	NP	3.12 ± 2.66	NP	NP	3.12 ± 2.66
Feb 12	2.48 ± 2.05	NP	5.55 ± 4.16	NP	NP	8.03 ± 6.21
Jun 12	NP	NP	10.97 ± 7.79	NP	NP	10.97 ± 7.79
Sep 12	NP	NP	NP	NP	NP	NP
Jan 13	NP	NP	NP	NP	NP	NP
Apr 13	6.28 ± 5.3	NP	6.81 ± 6.4	NP	1.2 ± 1	14.29 ± 12.7
Jul 13	NP	NP	13.27 ± 4.84	NP	1.23 ± 1.02	14.5 ± 5.86
Sept 13	NP	NP	28.86 ± 13.86	NP	35.11 ± 15.47	63.97 ± 29.33
Dec 13	10.19 ± 1.6	NP	19.76 ± 2.79	NP	27.08 ± 2.89	57.03 ± 7.28
Mar 14	NP	NP	6.3 ± 4.73	NP	45.46 ± 23.84	51.76 ± 28.57
Jul 14	3.31 ± 0.7	NP	15.55 ± 7.9	NP	64.97 ± 58.5	83.83 ± 67.1
Sep 14	12.19 ± 3.84	3.93 ± 1.02	6.56 ± 1.46	NP	92.42 ± 71.5	115.1 ± 77.82
Dec 14	12.17 ± 4.66	NP	9.38 ± 3.41	NP	239.56 ± 57.53	261.11 ± 65.6
May 15	14.18 ± 5.31	7.81 ± 3.51	5.40 ± 1.95	NP	189.48 ± 47.7	264.39 ± 58.47
Aug 15	8.84 ± 4.55	19.83 ± 16.83	4.50 ± 2.07	0.91 ± 0.68	180.27 ± 62.26	214.34 ± 86.39
Nov 15	28.58 ± 13.01	25.92 ± 9.04	10.30 ± 4.43	4.45 ± 2.52	229.36 ± 38.62	298.61 ± 67.62
Nov 16	78.40 ± 12.43	130.11 ± 23.32	36.17 ± 14.69	4.44 ± 1.79	214.02 ± 41.28	463.14 ± 93.51

NP – No seagrass present

3C. Mean above-ground biomass (g DW m^{-2}) of offshore monitoring sites in the Abbot Point region; quarterly 2005, 2008 – 2015.

Sampling Date	Mean Biomass ± SE (g DW m^{-2}) (dominating seagrass species)			
	Site 1	Site 2	Site 3	Site 4
Mar 05*	0.08 ± 0.07	0.59 ± 0.15	3.98 ± 1.43	Site not established
Feb/Mar 08*	0.04 ± 0.04	0.60 ± 0.57	3.28 ± 1.38	Site not established
Jul 08	0.17 ± 0.06	1.27 ± 0.44	3.31 ± 0.38	Site not established
Sept 08	0.02 ± 0.02	0.61 ± 0.17	5.10 ± 0.65	Site not established
Nov 08	0.11 ± 0.06	1.58 ± 0.55	11.07 ± 1.33	Site not established
Apr/May 09	0.0006 ± 0.0006	NP	0.34 ± 0.06	Site not established
Aug 09	0.07 ± 0.04	0.46 ± 0.11	0.45 ± 0.09	Site not established
Feb 10**	0.07	3.75	12.69	Site not established
June 10	NP	0.14 ± 0.05	0.77 ± 0.12	Site not established
Nov 10	0.17 ± 0.07	6.26 ± 0.89	25.76 ± 2.52	5.34 ± 0.76
Mar 11	0.03	0.20 ± 0.08	0.20 ± 0.08	0.14 ± 0.06
May 11	NP	0.23 ± 0.09	0.20 ± 0.08	0.07 ± 0.05
Sep 11	NP	0.26 ± 0.07	0.18 ± 0.06	0.19 ± 0.06
Feb 12	NP	0.31 ± 0.09	0.97 ± 0.17	0.37 ± 0.10
Jun 12	NP	0.44 ± 0.09	1.97 ± 0.24	0.83 ± 0.18
Sep 12	NP	0.59 ±0.16	1.76 ± 0.26	1.16 ± 0.21
Jan 13	0.01 ± 0.009	NV	0.14 ± 0.03	0.04 ± 0.02
Apr 13	0.01 ± 0.009	0.04 ± 0.01	0.03 ± 0.02	0.01 ± 0.009
Jul 13	NP	0.02 ± 0.01	0.09 ± 0.05	NP
Sept 13	NP	0.08 ± 0.03	0.02 ± 0	0.02 ± 0.01
Dec 13	NP	0.03 ± 0.02	0.09 ± 0.03	0.06 ± 0.02
Mar 14	NP	0.06 ± 0.03	0.14 ± 0.04	0.05 ± 0.02
Jul 14	0.2 ± 0.1	0.04 ± 0.02	0.03 ± 0.01	0.03 ± 0.02
Sep 14	0.009 ± 0.005	0.81 ± 0.2	0.32 ± 0.12	0.004 ± 0.002
Dec 14	NP	0.51 ± 0.16	1.02 ± 0.19	0.02 ± 0.01
May 15	0.09 ± 0.03	0.22 ± 0.07	1.41 ± 0.23	0.10 ± 0.05
Aug 15	0.09 ± 0.08	0.61 ± 0.31	2.71 ± 1.04	0.15 ± 0.10
Nov 15	0.004 ± 0.003	3.46 ± 1.22	2.27 ± 0.68	0.97 ± 0.39
Nov 16	0.006 ± 0.005	0.09 ± 0.04	3.98 ± 1.80	0.03 ± 0.02

* - Mar 05 & Feb/Mar 08 surveys were Baseline surveys so the location of Monitoring Blocks were not established thus Biomass is derived from transects in the baseline survey that were located closest to monitoring blocks that were established in July 2008.

** - No visibility at monitoring sites; Biomass calculations approximate only: Biomass derived from calculation of shoot counts converted to biomass based on biomass and shoot relationships of similar meadow and species composition

NP – No seagrass present in monitoring blocks NV – No visibility at site