Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING:

ANNUAL REPORT 2014 - 2015

McKenna SA, Sozou AM, Scott EL and Rasheed MA

Report No. 16/21

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A Report for North Queensland Bulk Ports Corporation (NQBP)

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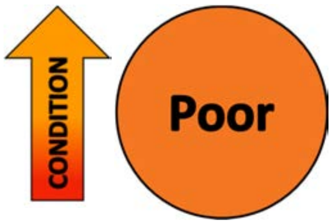
KEY FINDINGS

Seagrass Condition 2015



- The overall condition of seagrass in the Abbot Point region improved from very poor in 2014 to poor in 2015 showing some recovery after large scale losses associated with numerous climate events from 2010/11 onwards.

- Deep water seagrasses were at their highest density (biomass) since the major losses and species composition was at levels recorded prior to the major disturbances.

- Inshore seagrass biomass and area were near to or above long-term averages, however species composition remained poor between 2014 and 2015.

- Favourable climate conditions over the last two years are likely to have facilitated the increases in biomass and area of seagrass meadows in 2015.

- The slow recovery of more persistent foundation species within inshore meadows is likely due to the near complete disappearance of these species in 2011 and the necessity for their recruitment back into the area and to re-establish a seed bank.

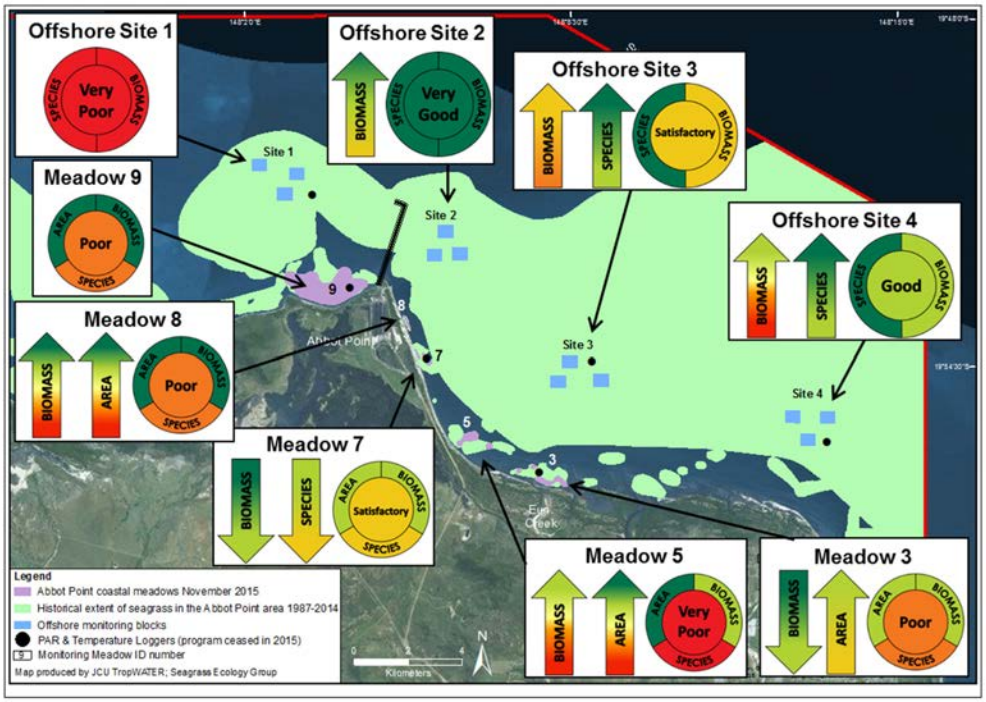
- After seven years of quarterly surveys to examine seagrass abundance and distribution patterns at Abbot, the program was scaled back to focus on ambient trends and align with the annual seagrass monitoring framework implemented in the majority of Queensland ports. This has reduced the Abbot Point seagrass monitoring program from quarterly surveys to an annual survey, and the benthic light and temperature component of the program has also been removed.

- Ongoing monitoring at the site will provide critical insights into the recovery of seagrasses in the Abbot Point region, and the program can be scaled up to more frequent sampling prior to potential future port development as required.

IN BRIEF

A long-term seagrass monitoring program and strategy was established in the Abbot Point area in 2008. The program has involved monitoring biomass, distribution and species composition of selected key representative seagrass meadows, and Photosynthetic Active Radiation (PAR) and temperature at the sea bed each quarter. The program has also involved four whole of port/broad-scale surveys and manipulative experiments looking at the recovery and recruitment processes of seagrass after disturbance. Investigations into seagrass seed-banks and recovery have also been conducted as part of the program. In 2015 the frequency of monitoring at the site was reduced to an annual assessment.

While the area and biomass of Abbot Point seagrasses were near to or above long term averages, the overall condition of seagrass in the Abbot Point area was poor in 2015. This classification was primarily driven by a high proportion of colonising species at sites leading to low species composition scores at all inshore monitoring meadows, and a very poor score at Offshore Site 1 (Figure 1). The species composition at offshore sites 2 – 4 was very good.



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

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

Seagrasses in the Abbot Point area have slowly been recovering from significant losses following the summer floods of 2010/2011 and TC Yasi, and also from the impacts sustained from TC Oswald in January 2013 (Figure 2). The recovery phase has seen most of the monitoring areas dominated by colonising/less persistent species such as *Halophila ovalis* and *Halophila decipiens*, rather than the more persistent species *Zostera muelleri* and *Halodule uninervis* at inshore sites, and *Halophila spinulosa* at deep water sites.

Despite the overall poor condition of seagrass, deep water seagrass biomass was at the highest it has been since losses sustained leading up to 2011 (Figure 2), and species composition has returned to pre-disturbance levels with *H. spinulosa* now making up over 90% of the deep water composition. Similarly, although inshore meadows had low species composition scores, seagrass biomass and distribution were near to or above long-term averages, and for some meadows, seagrass density and distribution was the highest it has been since before TC Yasi.

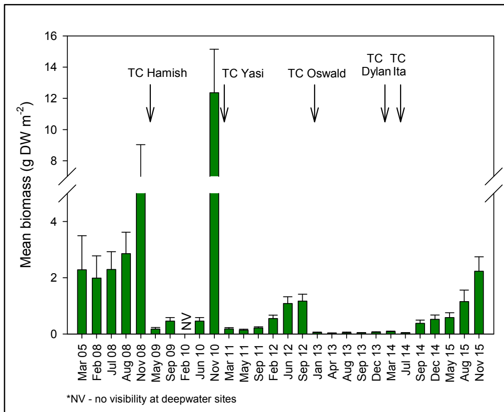


Figure 2. Mean biomass (g DW m^{-2}) of Abbot Point offshore seagrass monitoring sites from 2005 to 2015.

Seagrass biomass and distribution are strongly influenced by local environmental conditions and for the last two years many of these environmental variables were favourable for seagrass growth and survival, particularly for deep water seagrass. Below average rainfall and river flow, and the prevailing El Nińo climate pattern resulted in drier weather patterns with fewer episodic rainfall events (Figure 3). Benthic light data (PAR) up until August 2015 indicated that light levels were sufficient for seagrass growth and maintenance at most sites. Although temperatures were higher in 2015 compared to other years, temperature at the seabed did not exceed maximum temperature thresholds for *Z. muelleri* (33°C) or *H. uninervis* (40°C) for long enough to cause any significant impacts. Similarly, higher temperatures at deep water meadows (up to 30.9°C) are not beyond the optimal growth temperatures for *Halophila*. At other Queensland seagrass monitoring sites the increase in temperature and solar and tidal exposure in 2015 was linked to decreases in intertidal and inshore seagrass biomass through heat stress/desiccation and reductions in photosynthetic efficiency.

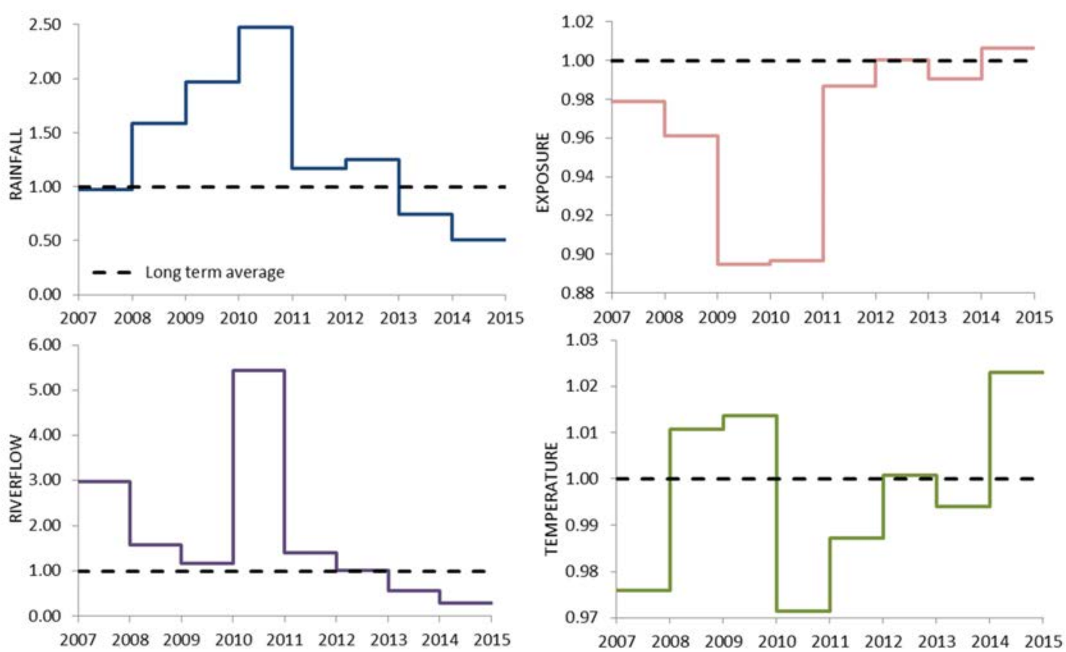


Figure 3. Recent climate trends in the Bowen/Abbot Point area 2000/01 to 2014/15: Change in climate variables as a proportion of the long term average. See section 3.3 for detailed climate data.

The lack of recovery of persistent species at inshore monitoring sites was likely linked to recruitment processes after the near complete disappearance of meadows and species, with little remaining seagrass from which recovery could occur. While still in a 'recovery phase' it is probable that the standing crop of *H. uninervis* and *Z. muelleri* at Abbot Point are diverting energy into replenishing stored carbohydrates and clonal expansion after each senescent season, rather than investing energy into replenishing/establishing a seed bank from which recruitment and germination can occur. The lack of a seed bank, coupled with the high reliance on asexual reproduction for recovery of these species at Abbot Point has implications for recovery potential, and suggests that re-establishing these meadows may be a slow process. The poor condition of seagrasses in the Abbot Point area in 2015 means they remain susceptible to future anthropogenic influences or major climatic events. Future activities and the management of activities should consider the current state of seagrass and their likely continued vulnerability to future impacts.

The Abbot Point seagrass monitoring program forms part of a broader Queensland program that examines condition of seagrasses in the majority of Queensland commercial ports and is a component of James Cook University's (JCU) broader seagrass assessment and research program. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld.

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1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (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 at ever increasing rates due to both 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 the various 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 utilised to provide a network of seagrass monitoring locations throughout the state (Figure 4).

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.

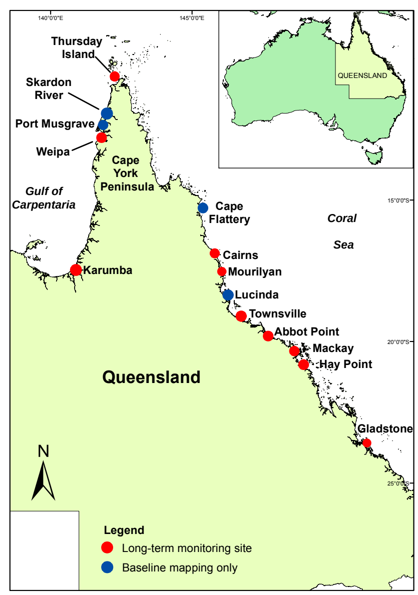


Figure 4. Location of Queensland Port Seagrass assessment sites

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 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 four broad scale surveys (two each in 2008 & 2013) 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 (Photosynthetically Active Radiation (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, as well as areas likely to be 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 scaled down to an annual program; monitoring the same representative seagrass meadows that have been monitored in the past. The annual long-term monitoring approach is based on periodic re-assessments of all seagrasses within the region (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 Hay Point, and elsewhere in other Queensland ports.

The Abbot Point seagrass program was initially developed to aid in the management of planned port expansions and to minimise potential impacts on seagrass habitats; alongside assessments of the long-term condition and trend of this important fisheries habitat. Seagrass monitoring surveys are used by management agencies to assess the status and condition of seagrass resources in the region. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important seagrass habitats in high risk areas.

This report presents the finding of the annual seagrass monitoring for 2015. 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 and community type at long-term monitoring meadows;
- Compare results of monitoring surveys and assess any changes in seagrass distribution and density 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.

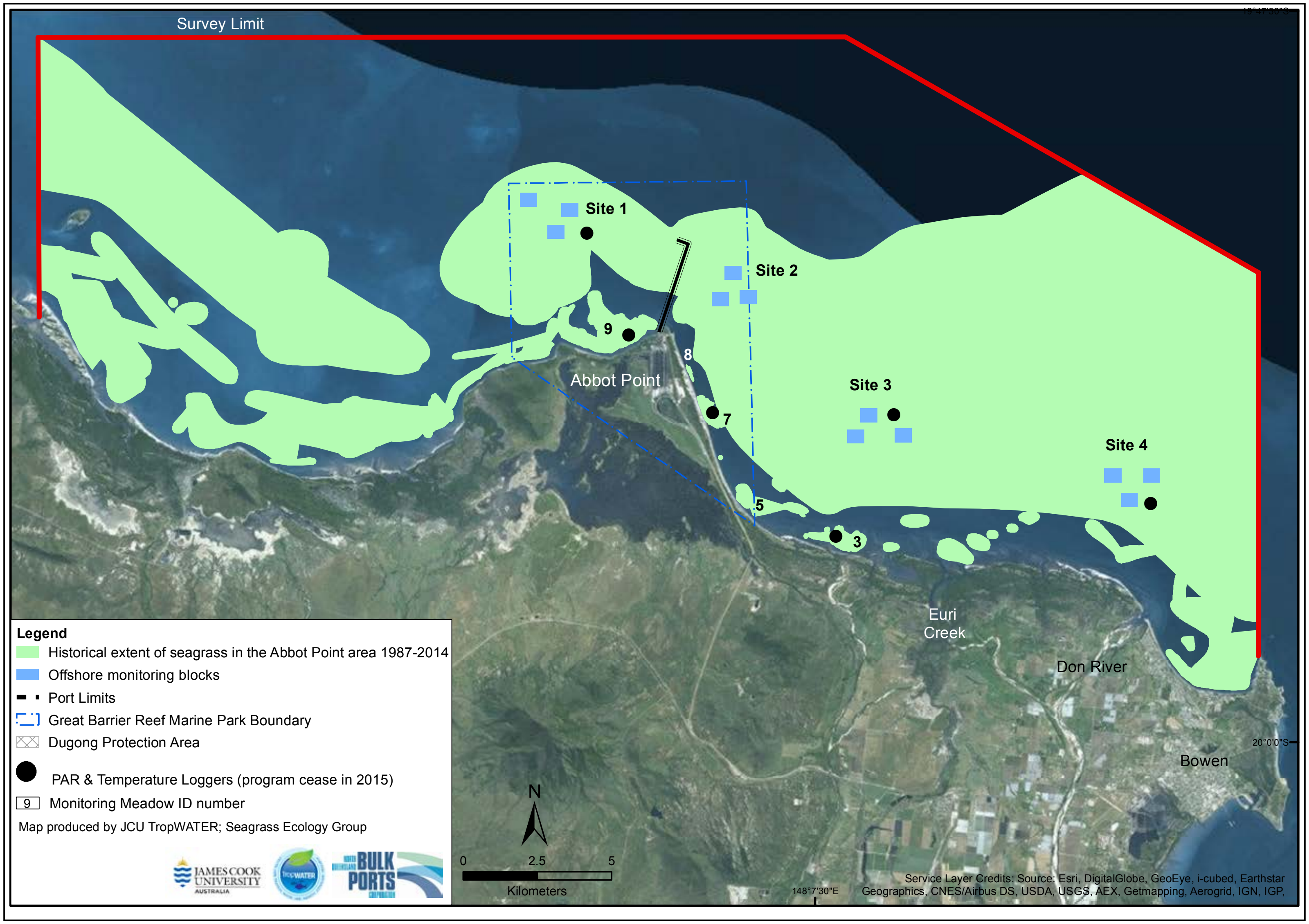


Figure 5. Location of inshore monitoring meadows, offshore monitoring sites and PAR and temperature loggers in the Abbot Point region.

2 SAMPLING APPROACH AND METHODS

From the results of the baseline surveys in 2008 (McKenna et al. 2008), five coastal meadows and four offshore areas were identified as suitable for long-term seagrass monitoring (Figure 5). Monitoring meadows selected were representative of the range of seagrass communities identified in the 2008 baseline surveys and were also located in areas considered ideal sensitive receptor sites for assessing seagrass condition during and after port activity and development.

Methods for assessing inshore and offshore seagrasses in the monitoring and the baseline surveys followed those established for the Abbot Point 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) (see McKenna et al. 2008 for full description of methods). 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.

At sites where seagrass presence was noted seagrass above-ground biomass was determined. Above-ground seagrass 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. The video was paused at each of the ten time frames then advanced to the nearest point on the tape where the bottom was visible and sled was stable on the bottom. From this frame an observer recorded an estimated rank of seagrass biomass and species composition. A 0.25m^2 quadrat, scaled to the video camera lens used in the field, was superimposed on the screen to standardise biomass estimates.

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. Sites were assessed by sled tows with digital camera free-divers to measure seagrass biomass and species composition.

All survey data was entered into a Geographic Information System (GIS) for presentation of seagrass species distribution and density. Satellite imagery of the Bowen/Abbot Point area with information recorded during the monitoring 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 and 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. This resulted in a range of meadow sizes which is expressed as error (±ha) around the total meadow area (ha).

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

Mapping precision	Mapping methodology
20-50m	Subtidal meadow boundaries determined from free diving surveys; Relatively high density of survey sites; Recent aerial photography aided in mapping.

2.3 Seagrass meadow condition index

This is the first year of applying the seagrass condition index method developed across the Queensland Ports Monitoring Program, to Abbot Point seagrass habitats.

A condition index was developed for the Abbot Point seagrass meadows based on changes in mean above-ground biomass, total meadow area (inshore meadows only) and species composition, and follows the index that is applied across other long-term seagrass monitoring programs in ports throughout Queensland (see Davies et al. 2016a & b, McKenna et al. 2016, Sozou et al. 2016). 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 7).

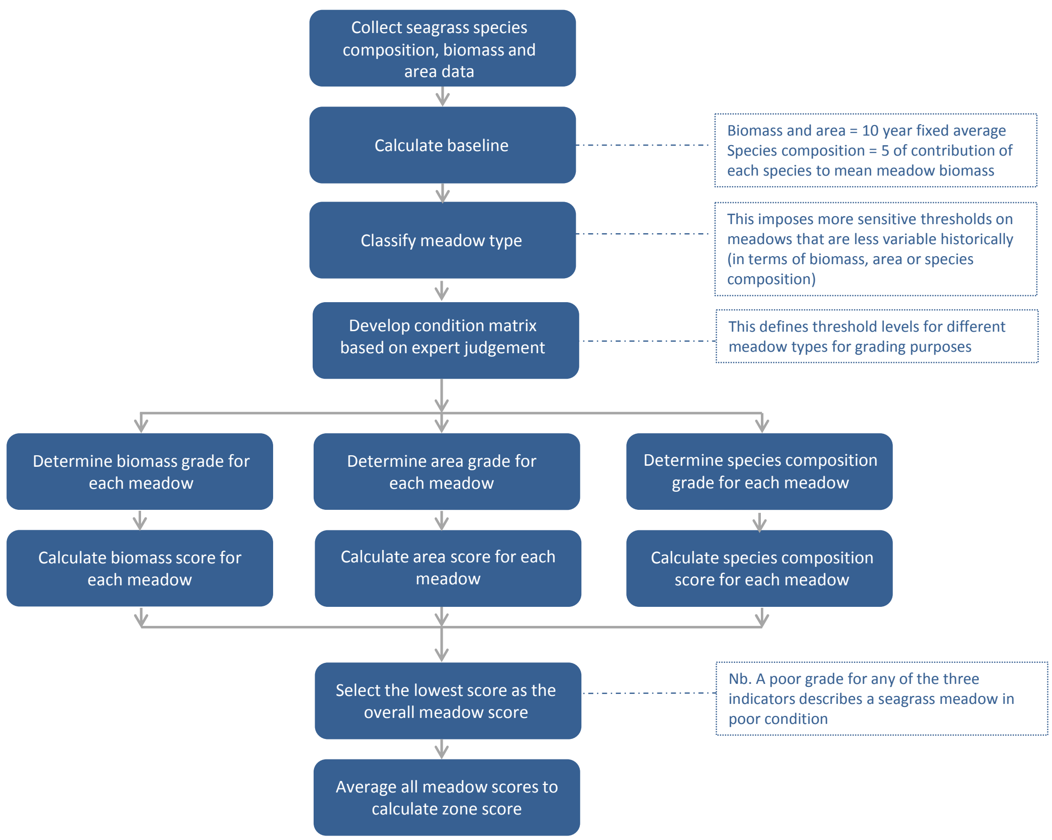


Figure 7. Flow chart to develop the TropWATER seagrass monitoring meadow condition index.

Baseline Conditions

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated from 2008-2014 (7 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.

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 2008-2014 (only in the years where species were present; 2 – 7 depending on meadow at Abbot Point). The baseline calculation was based only on the percent composition of what was considered to be the stable state species in the offshore meadow.

Meadow Classification

A meadow classification system was developed for the 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 and species composition.

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

Threshold 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
Biomass	Variable	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Area	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
Area	Stable	More than 10% above the baseline	Within 10% of the baseline (above or below)	Between 10% and 30% below the baseline	Between 30% and 50% below the baseline	More than 50% below the baseline
Area	Variable	More than 20% above the baseline	Within 20% of the baseline (above or below)	Between 20% and 50% below the baseline	Between 50% and 80% below the baseline	More than 80% below the baseline
Area	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
Species composition	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
Species composition	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
Species composition	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 previous year 

Decrease below threshold from previous year 

Grades and Scores

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

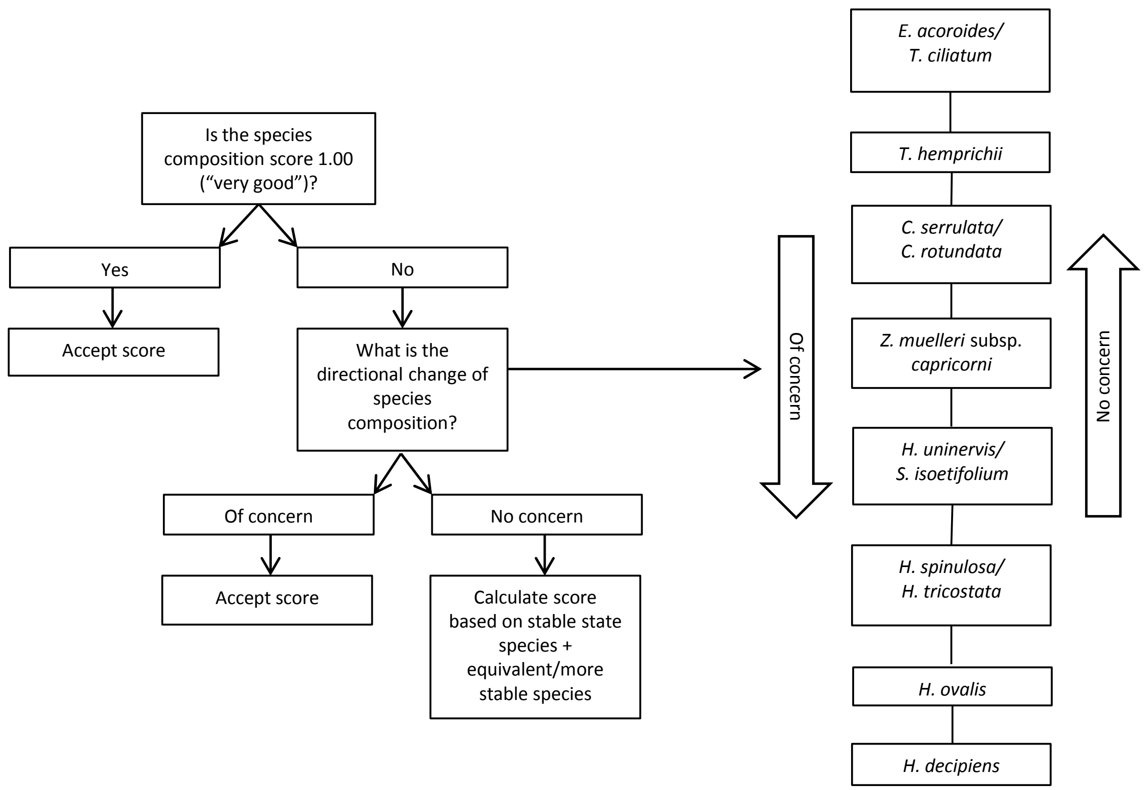


Figure 8. Decision tree and directional change assessment for grading and scoring seagrass species composition.

3 RESULTS

3.1 Seagrass in the Abbot Point region

A total of 92 inshore sites and 36 offshore transects were surveyed in the Abbot Point monitoring areas in November 2015 as part of the annual seagrass monitoring program. Seagrass was present at 37% of the inshore sites and at 72% of the offshore transects.

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* were present in the 2015 monitoring survey. Of note was the re-appearance of *Cymodocea serrulata* in Offshore Site 3 in 2015 (Appendix 2B). The last time this species was found at Abbot Point was in 2012.

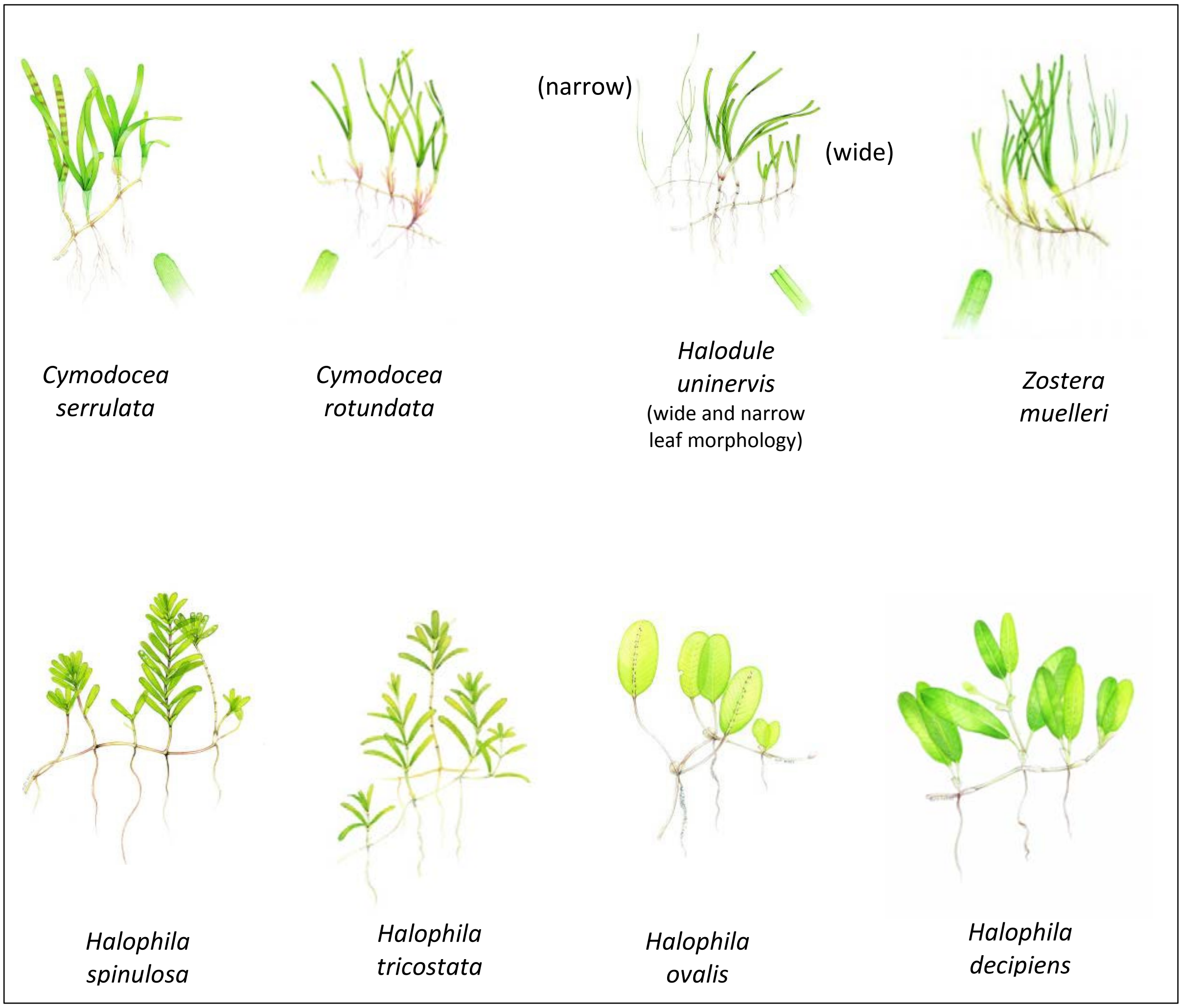


Figure 9. Seagrass species identified in the Abbot Point/Bowen region.

3.2 Seagrass condition in the Abbot Point monitoring areas

The overall condition of seagrass in the Abbot Point area in 2015 was scored as poor (Table 7). This score was driven by the lower species composition scores at inshore monitoring meadows, and the very poor scores at Offshore Site 1 (Table 7).

Seagrasses in the Abbot Point area have slowly been recovering from significant losses following the summer floods of 2010/2011 and Tropical Cyclone Yasi, and also from the impacts sustained from cyclone Oswald in January 2013. This recovery phase has seen most of the monitoring areas being dominated by colonising/less persistent species such as *Halophila ovalis* and *Halophila decipiens*, rather than more persistent species such as *Zostera muelleri, Halodule uninervis* at inshore sites, and *Halophila spinulosa* in the deep water meadow.

Table 7. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2015.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score
Offshore Site 1	0.21	0	N/A	0
Offshore Site 2	0.89	0.99	N/A	0.89
Offshore Site 3	0.55	0.88	N/A	0.55
Offshore Site 4	0.68	0.89	N/A	0.68
Inshore Meadow 3	0.71	0.31	0.76	0.31
Inshore Meadow 5	0.85	0.06	0.91	0.06
Inshore Meadow 7	0.80	0.63	0.80	0.63
Inshore Meadow 8	0.90	0.26	0.99	0.26
Inshore Meadow 9	0.93	0.44	0.94	0.44
Overall score for seagrass in the Port of Abbot Point				0.42

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

Inshore monitoring meadows

Inshore monitoring meadows were categorised as being in very poor to satisfactory condition in 2014 (Table 7), similar to 2014. Scores were driven by the low species composition scores as a result of the meadows consisting largely of less persistent colonising species such as *H. ovalis,* rather than the more persistent *H. uninervis* or *Z. muelleri* (Figures 10 – 14; Appendix 2a). 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 TC Yasi, and the ensuing recovery of seagrass into the area.

Despite the low species composition scores, seagrass biomass and distribution at all inshore monitoring meadows were near to, or above long-term averages even though there were some small decreases in these two conditions between 2014 and 2015. For some meadows, November 2015 recorded the highest density and/or distribution of seagrass since TC Yasi (Figures 10 - 14). Of note was the re-emergence of

Meadow 8 in August 2015, and in particular the presence of *H. uninervis* in the meadow in the November 2015 survey (Figure 13; Appendix 2a and 3a). This meadow has been absent in the area since TC Yasi.

The inshore monitoring meadows around Abbot Point have consisted of variable, isolated to aggregated patches of seagrass previously dominated by *H. uninervis* (Appendix 2a). The exception to this is Meadow 3 west of Euri Creek which was dominated by *Z. muelleri* (Appendix 2a). In this monitoring program (2008-2015) seagrass above-ground biomass, when present, at the inshore monitoring meadows has ranged from 0.005 ± 0.003g DW m^{-2} to 13.84 ± 4.6g DW m^{-2}. The area of individual meadows when present, have ranged from 0.91 ± 0.68ha to 234.28 ± 115.41ha (Appendix 2a and 3b). 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 generally been dominated by variable, low to moderate densities of *H. spinulosa* (Appendix 2b). The exception to this is Offshore Site 1 which was previously 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 any analysis.

Seagrass at the deep water monitoring sites (Sites 2 – 4) were categorised as being in satisfactory to very good condition (Table 7). Deep water seagrass biomass increased throughout 2014 and 2015, and by November 2015 seagrass density was the highest it has been since the 2010/2011 floods and TC Yasi (Figure 2). Recruitment of the more stable species; *H. spinulosa* into the offshore monitoring areas has increased since 2010/2011, to the point where the species now makes up over 90% of the species composition (Appendix 2b). Additionally, *C. serrulata*, a more persistent species than *H. spinulosa* (see Figure 8) has recruited back into the offshore seagrass meadow, albeit at low densities (Appendix 2b). The last time this species was found in the offshore meadow was in 2012. Seagrass biomass in these deep water monitoring areas has ranged between 0.004 ± 0.002g DW m^{-2} to 25.76 ± 2.52g DW m^{-2} which is considered light to moderate densities for deep water *H. spinulosa* meadows in Queensland (Table 2; Appendix 3c).

Seagrass at Offshore Site 1 has a history of rapid change in density and species composition. Seagrass biomass at this site has ranged between 0.006 ± 0g DW m^{-2} to 0.2 ± 0.1g DW m^{-2} which is considered as light density for the species mix (Table 2; Appendix 2b and 3c). In the 2015 annual survey seagrass condition at the site was very poor; dominated by low biomass *H. ovalis* (Figure 15). Analysis of the quarterly data however, shows that seagrass in this offshore area peaked early in the growing season in both 2014 and 2015 (July and August respectively) (Appendix 2b). In July 2014 seagrass biomass was at the highest density since before TC Yasi and was completely comprised of *H. uninervis*. Seagrass biomass then decreased at the site until seagrass was absent at the end of the year (Appendix 2b). By May 2015 seagrass biomass had increased again, however the site was dominated by colonising *Halophila* species. *H. uninervis* (wide form) recruited back into the area in August 2015 making up 86% of the species composition, but at very low density, before declining again by November 2015 (the annual survey).

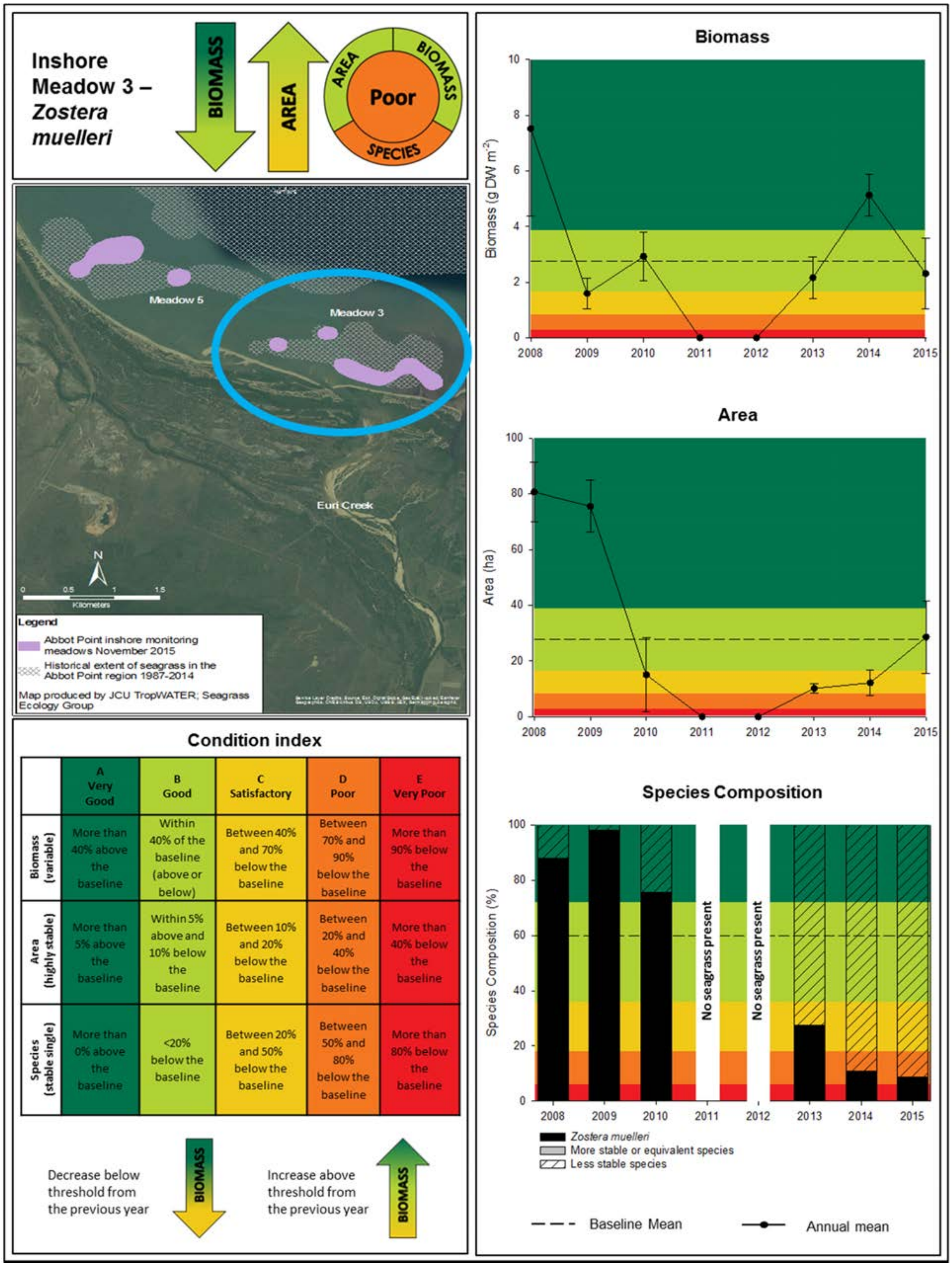


Figure 10. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3.

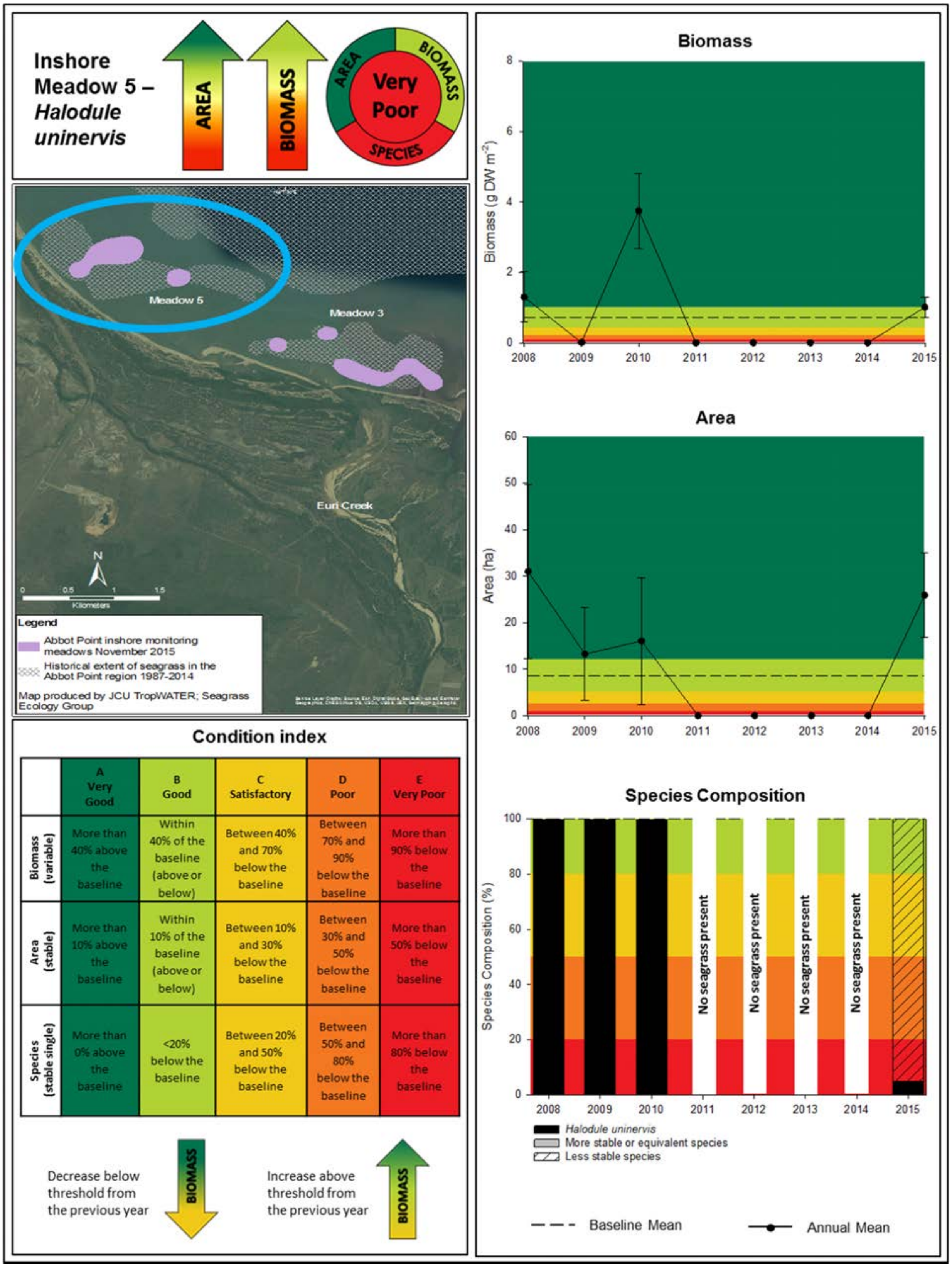


Figure 11. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5.

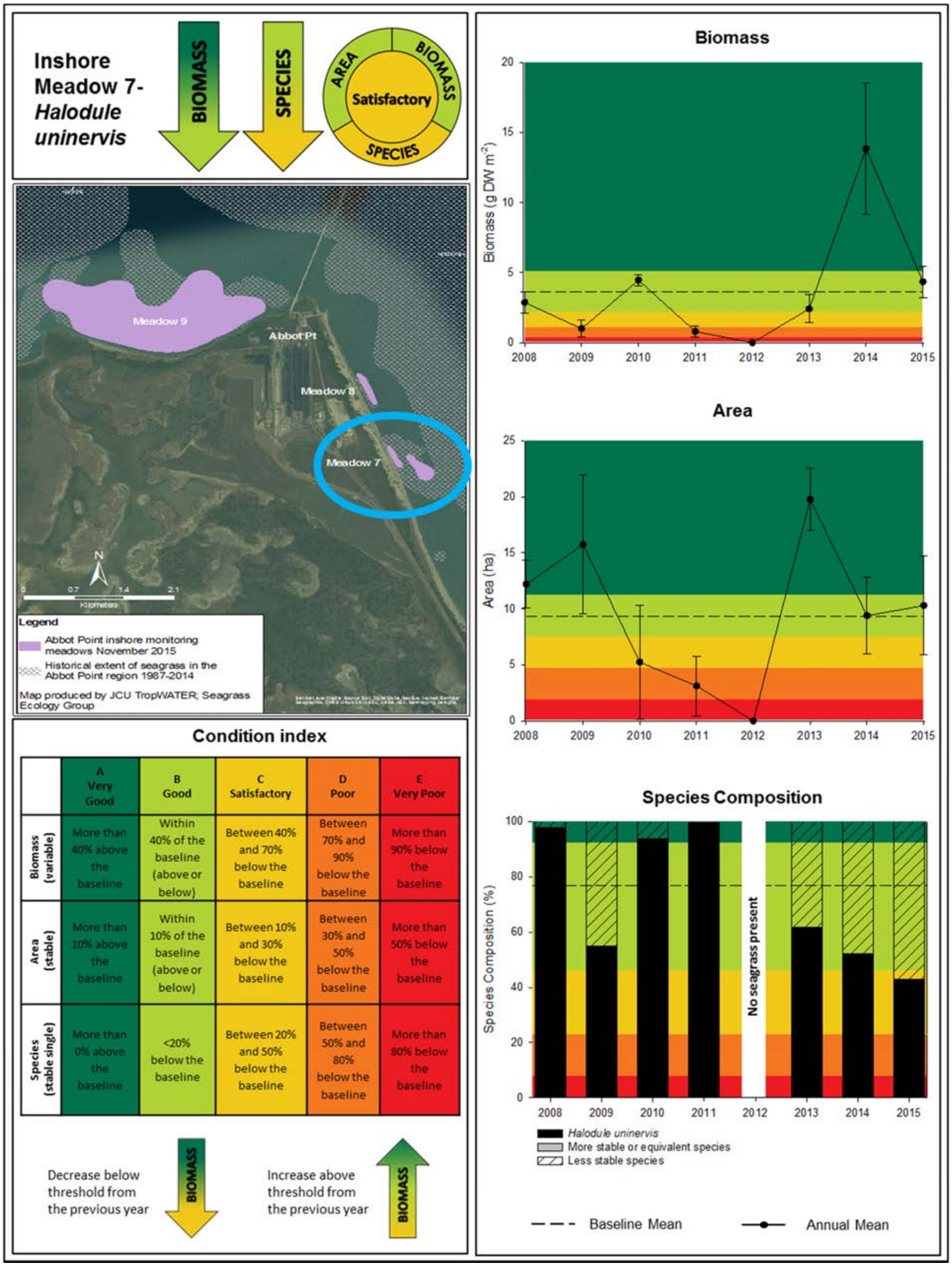


Figure 12. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 7.

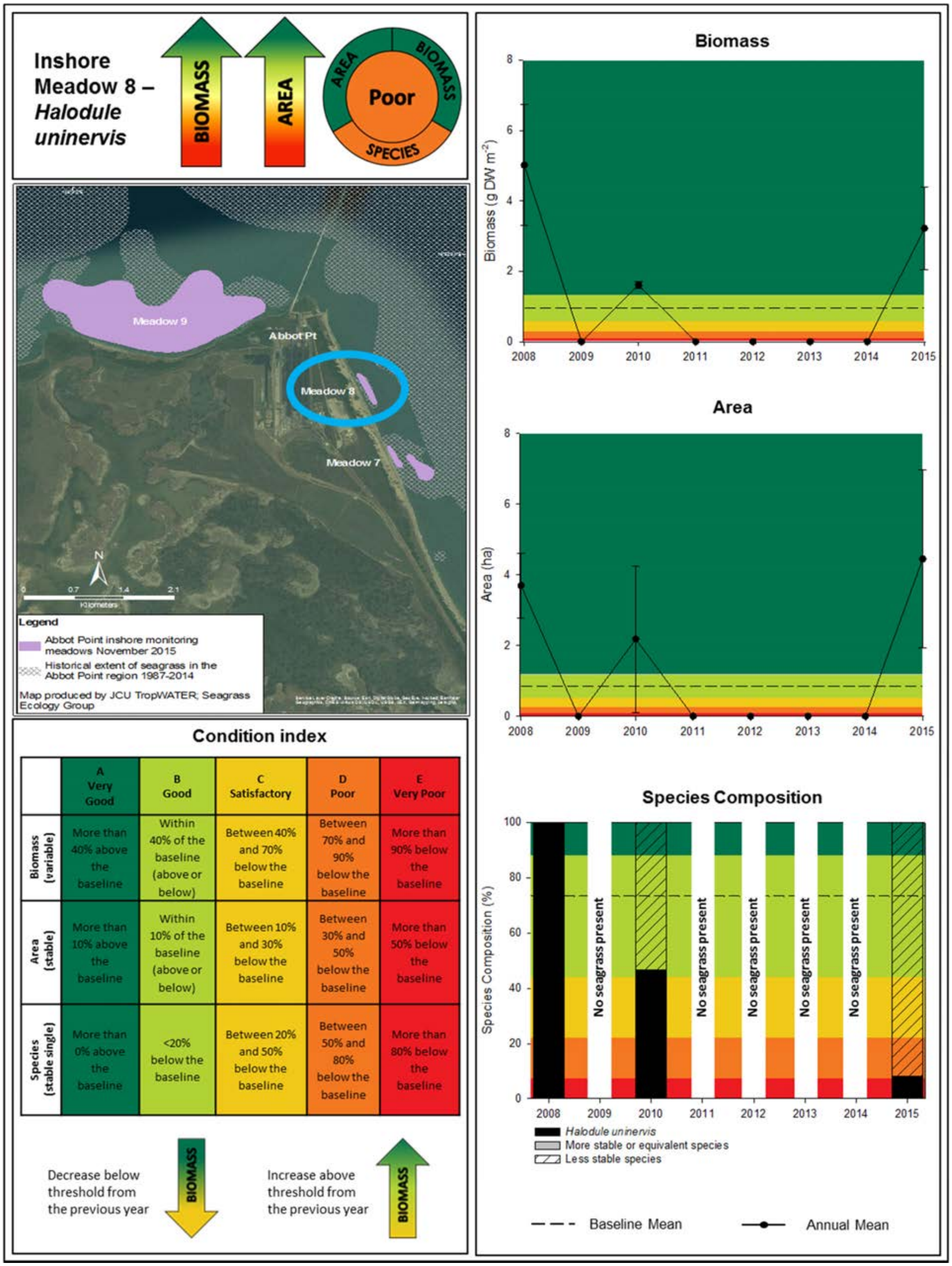
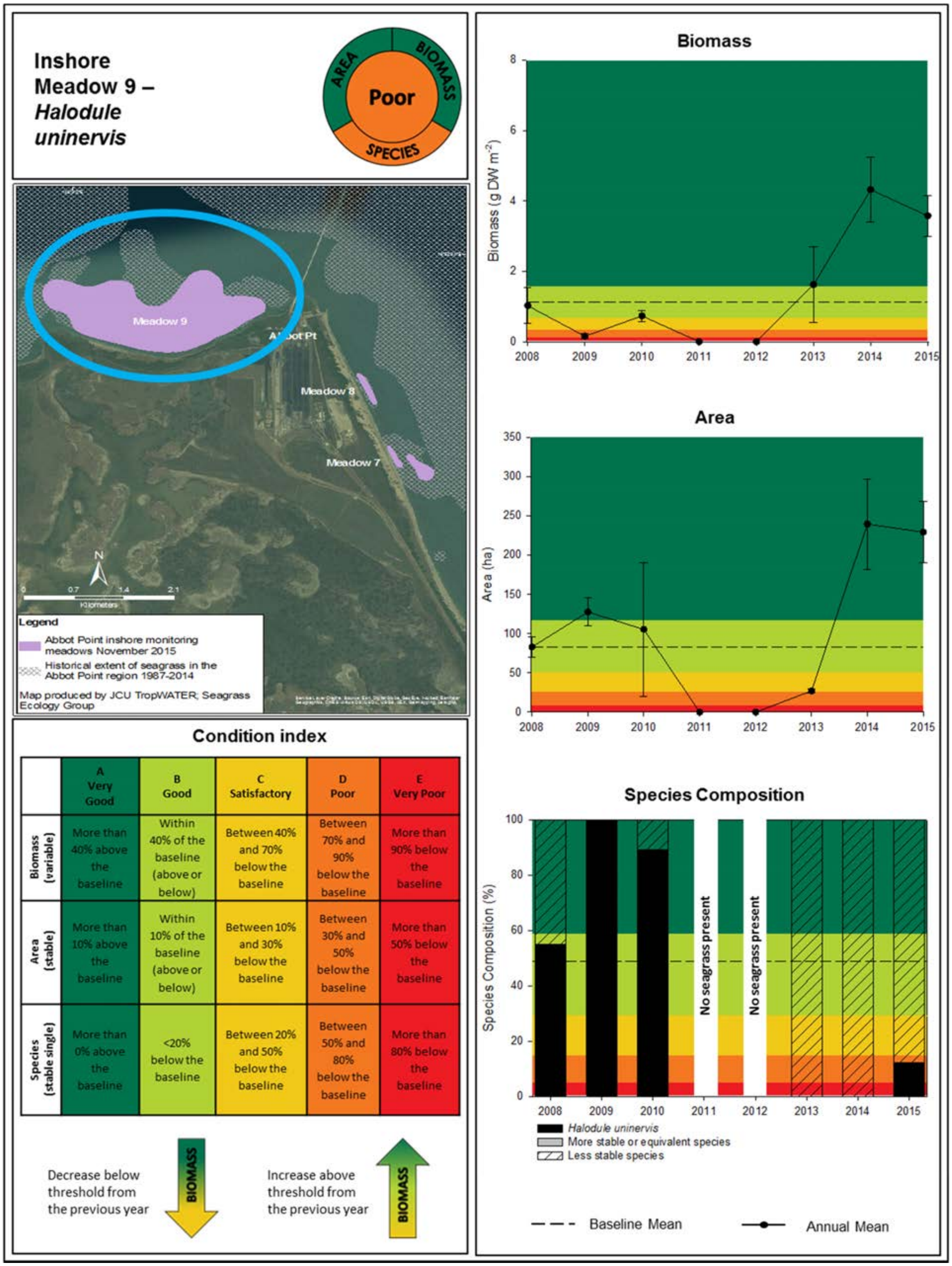
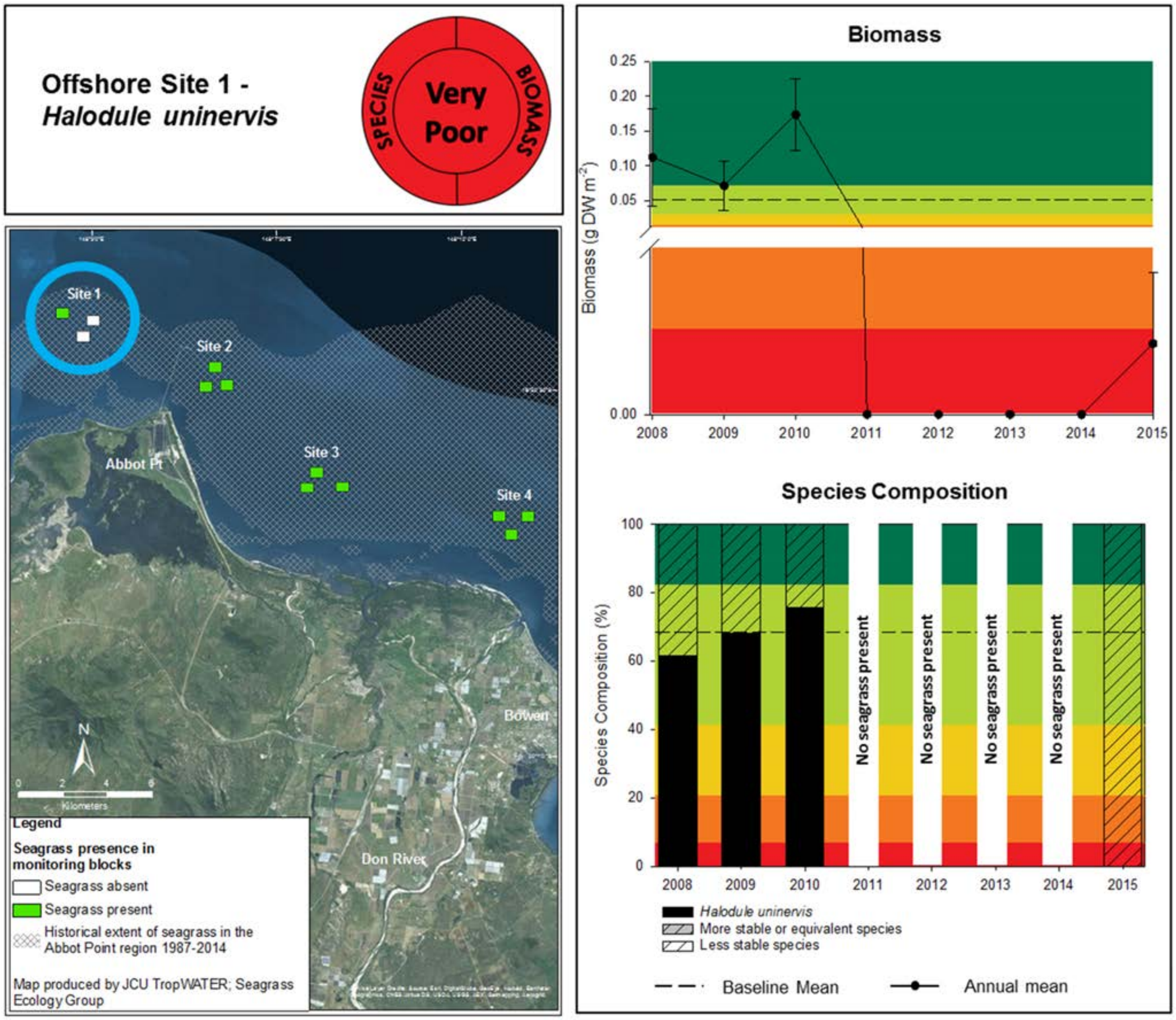


Figure 13. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 8.



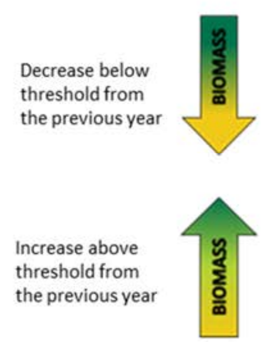
- lack of condition index arrows indicates no change between years

Figure 14. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 9.



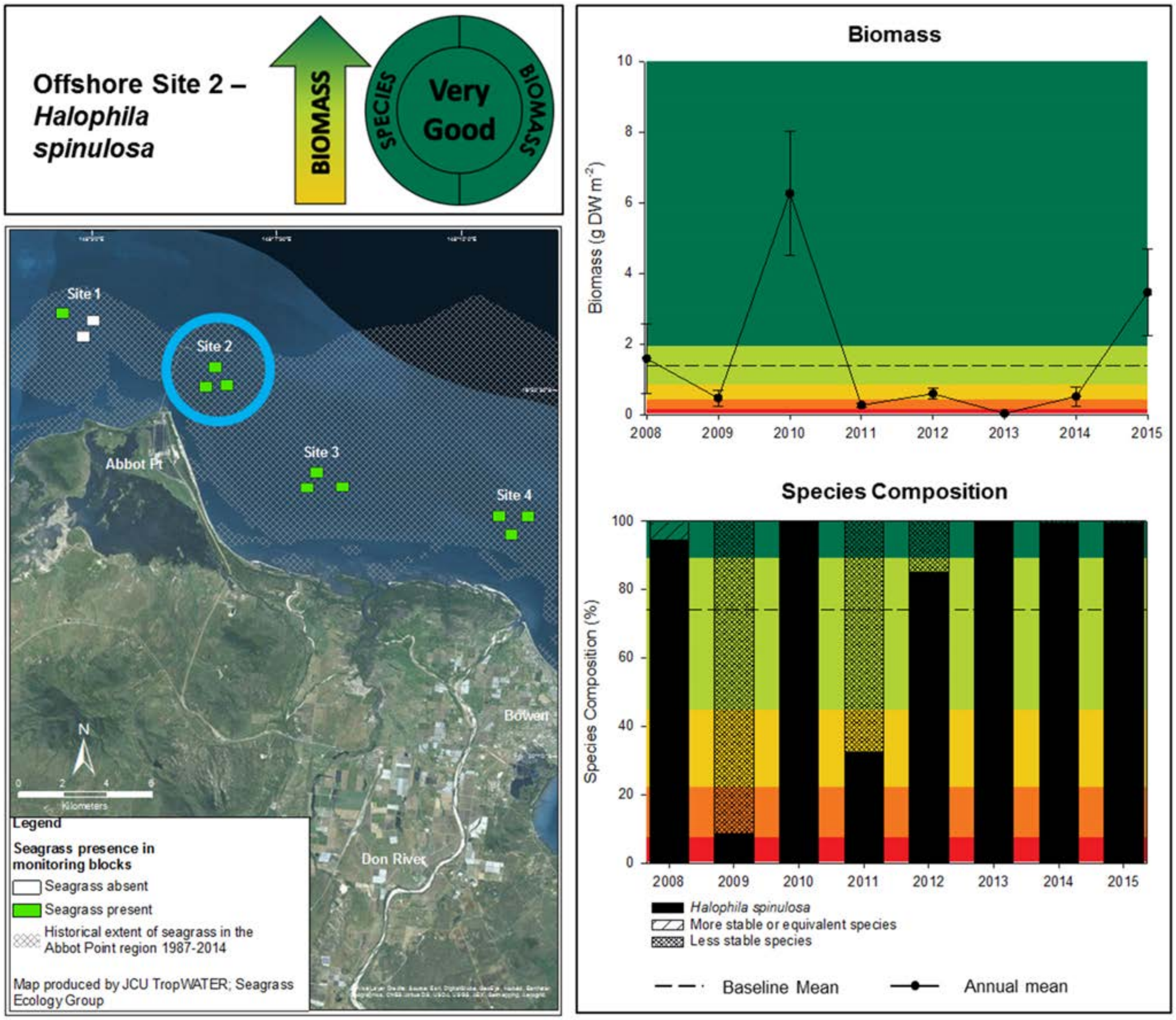
Condition index

	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 (stable single)	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



- lack of condition index arrows indicates no change between years

Figure 15. 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 (stable single)	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

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 2.

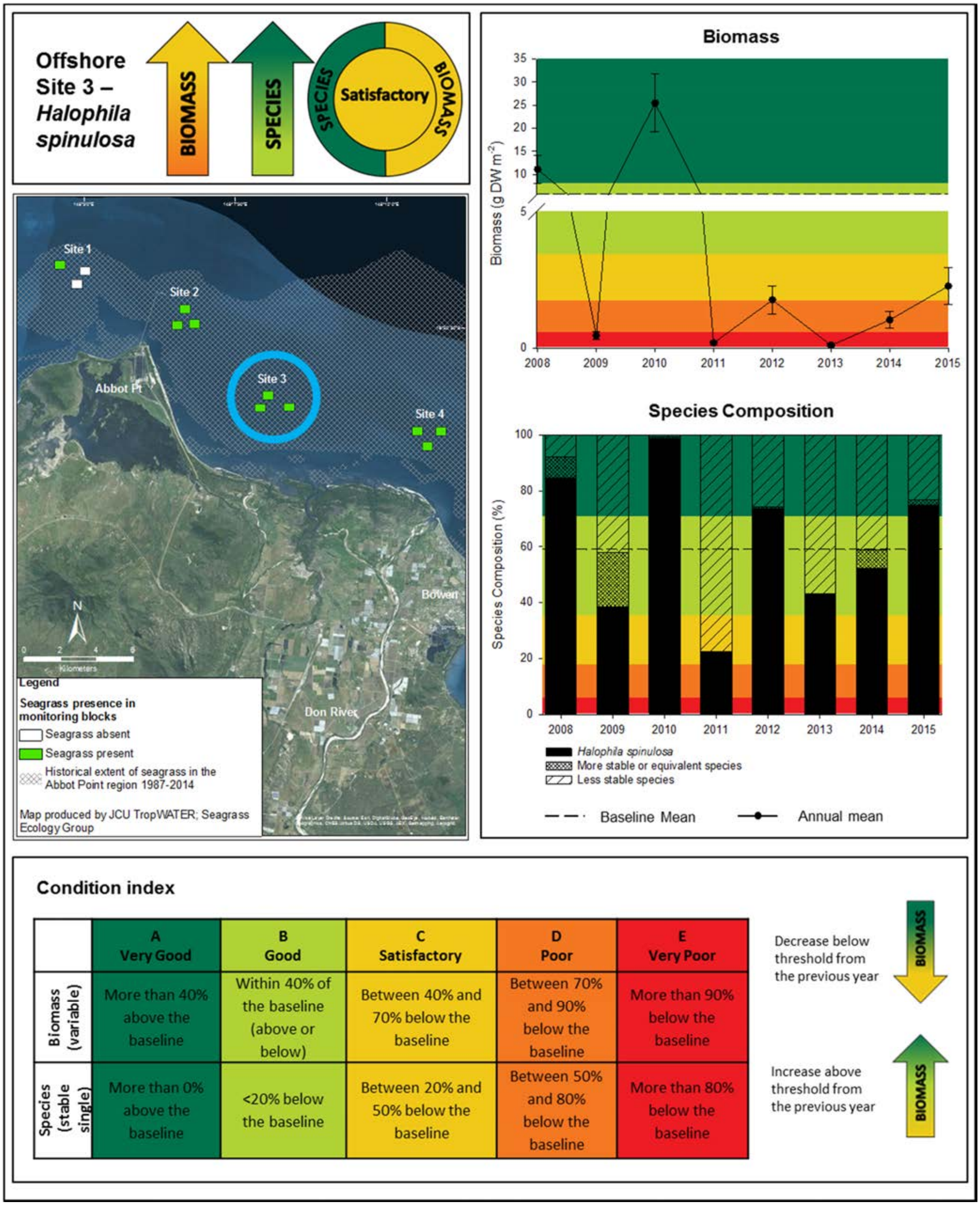
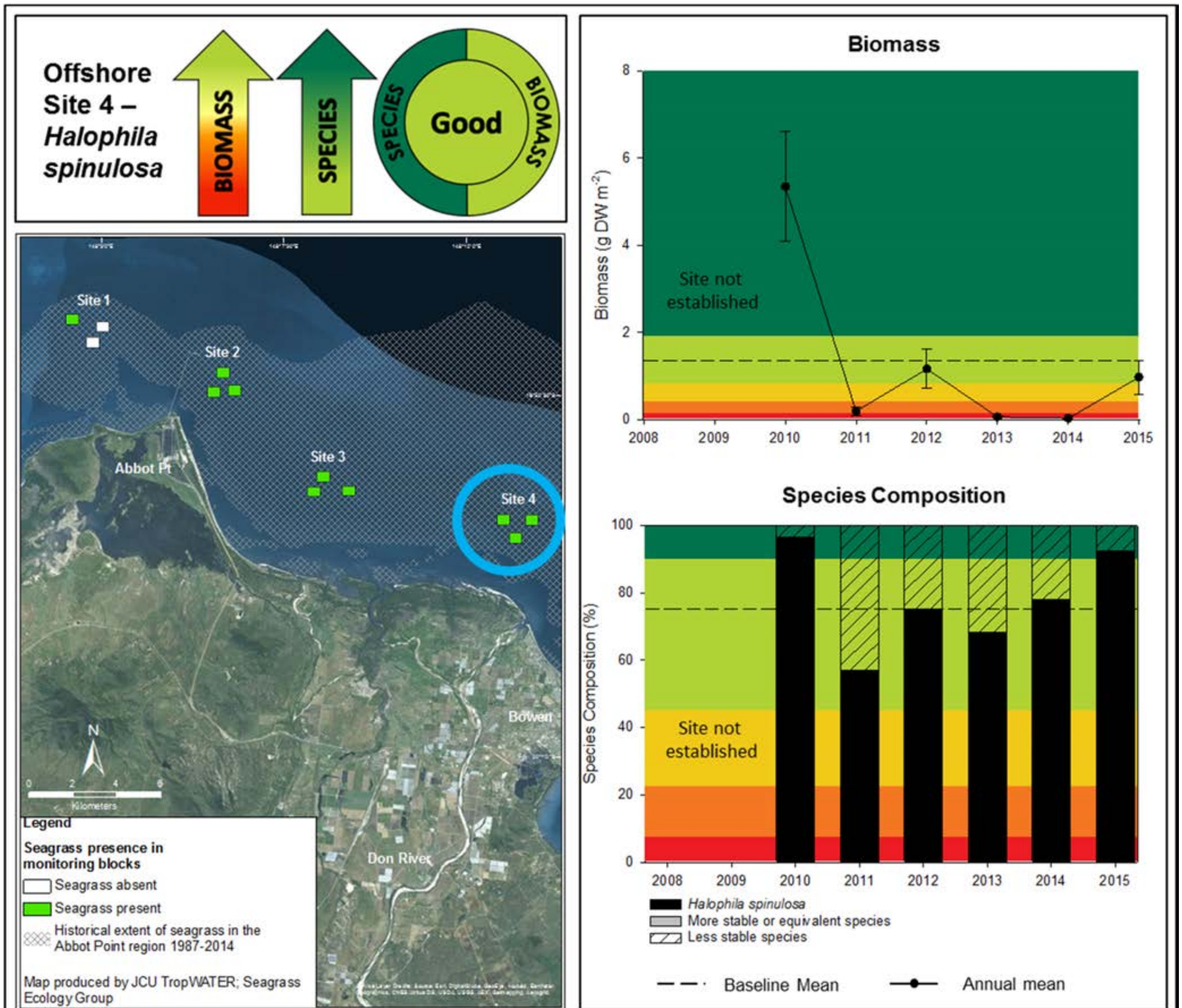


Figure 17. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 3.



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 (stable single)	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

Decrease below threshold from the previous year — BIOMASS

Increase above threshold from the previous year — BIOMASS

Figure 18. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 4.

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

Light and water temperature data was collected at the seabed between September 2011 and August 2015. The light and temperature program, as part the long term seagrass monitoring program, has now been discontinued. Light and temperature at monitoring sites generally followed established seasonal trends; water temperature peaking in summer and light in spring. Light was also generally affected by rainfall in the wet season (Figures 19 - 22).

At offshore Site 1, the shallower site on Clark shoal, available light ranged from 0 – 13.03 mol photons m^{-2} d^{-1} (maximum in May 2014) (Figure 21). At the inshore monitoring sites, available light has ranged from 0 – 39.19 mol photons m^{-2} d^{-1}(maximum at Meadow 3; the shallowest site, June 2014) (Figure 19). At these shallower *Halodule* sites, we found that a light threshold of 3.5 mol photons m^{-2} d^{-1} over a 14 day rolling average best described the light condition at which seagrass biomass was maintained (Mckenna et al. 2015; Collier et al. 2016). In 2015 light did not fall below 3.5 mol photons m^{-2} d^{-1} for longer than 10 days at inshore monitoring sites (Figure 19). In contrast, light at Offshore Site 1 fell below 3.5 mol photons m^{-2} d^{-1} for nearly three months (February - April 2015) (the senescent season).

Available light at deep water sites (Offshore Sites 3 & 4) has ranged from 0 – 6.2 mol photons m^{-2} d^{-1} (maximum in August 2014) (Figure 21). At Abbot Point we have found that a light threshold of between 1-2 mol photons m^{-2} d^{-1} best described the light conditions at which deep water *Halophila* seagrass biomass was maintained (McKenna et al. 2015; Collier et al. 2016). Between January and August 2015 light fell below 1 mol photons m^{-2} d^{-1} at least three times at Sites 3 and 4. This drop in light lasted for nearly three months at Site 4 between February and April 2015 (the senescent season) (Figure 21). Despite this, seagrass was present in the May 2015 survey and biomass increased as light increased through to August 2015.

The maximum instantaneous water temperature recorded at the seabed at any of the sites was 34.6°C in January 2015 at inshore Meadow 3 (Euri Creek) (Figure 19). Sea temperature was above 33°C at Meadow 3 during this time for up to four days. These higher temperatures coincided with early to late afternoon low tides. Meadow 3 is the shallowest of all monitoring areas and during low tide the shallow water over the meadow can become super-heated. Sea bed temperature was in general much higher in 2015 compared to previous years where light and temperature data within the seagrass canopy has been collected. Sea bed temperature was over 30°C for longer periods of time at both deep water sites (Offshore Site 3 (~10m below MSL and Offshore Site 4 (~12m below MSL)) through January – March 2015 compared to other years (Figure 21). These sites recorded temperatures of 30.9°C and 30.6°C respectively, the highest temperatures recorded in the program (2011 – 2015).

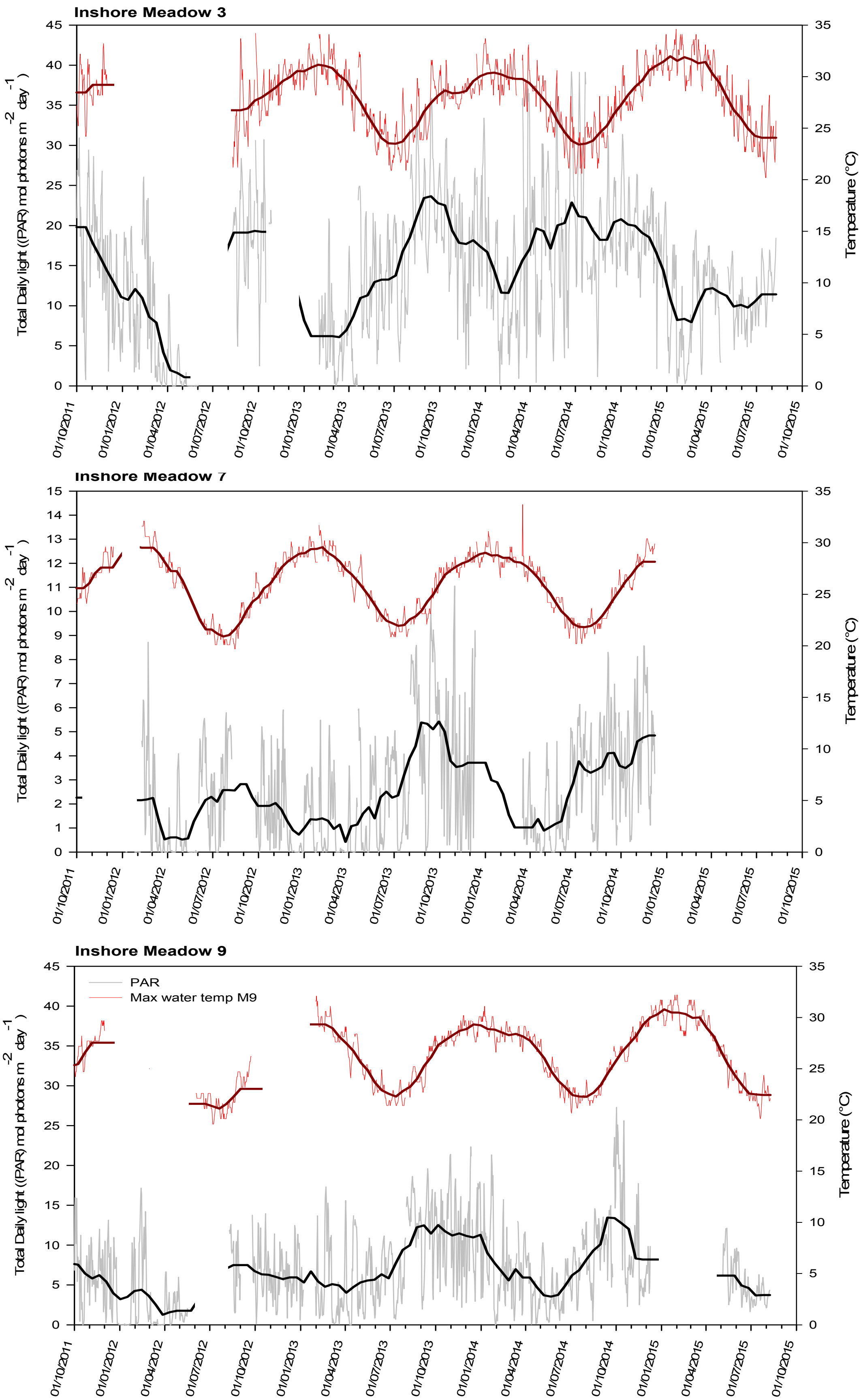


Figure 19. Total daily PAR (mol photons $m^{-2}day^{-1}$) and maximum daily water temperature (°C) at meadows 3, 7 and 9; September 2011-August 2015

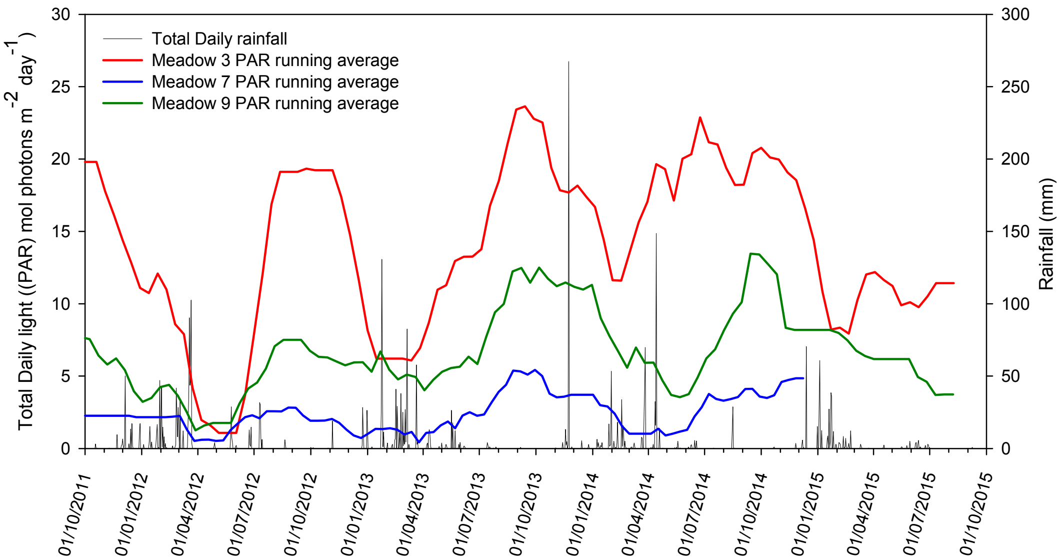


Figure 20. Total daily PAR (mol photons $m^{-1}day^{-1}$) at inshore meadows 3, 7 and 9, September 2011-August 2015 and total daily rainfall (mm)

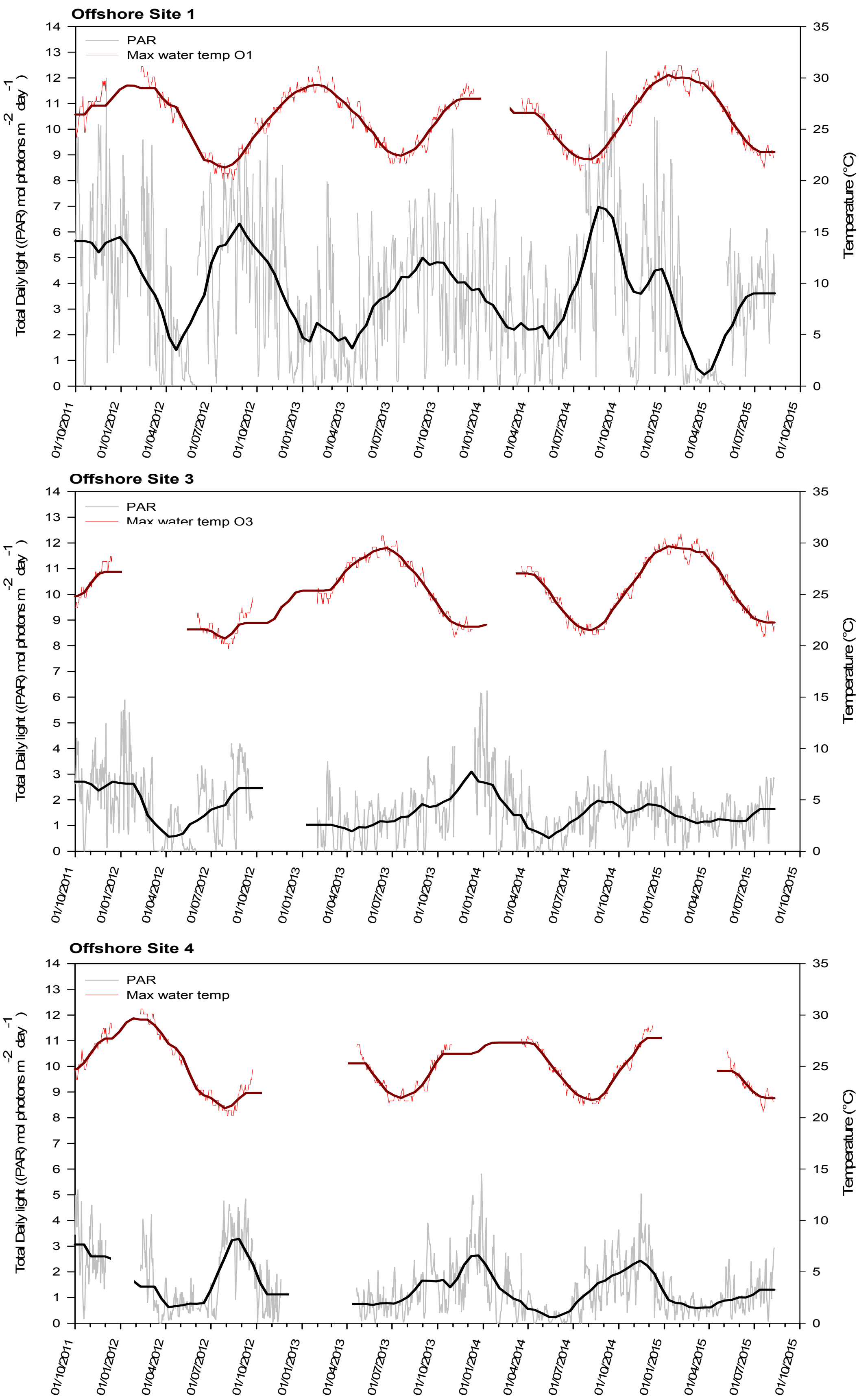


Figure 21. Total daily PAR (mol photons $m^{-1}day^{-1}$) and maximum daily water temperature (°C) at offshore sites 1, 3 and 4, September 2011-August 2015.

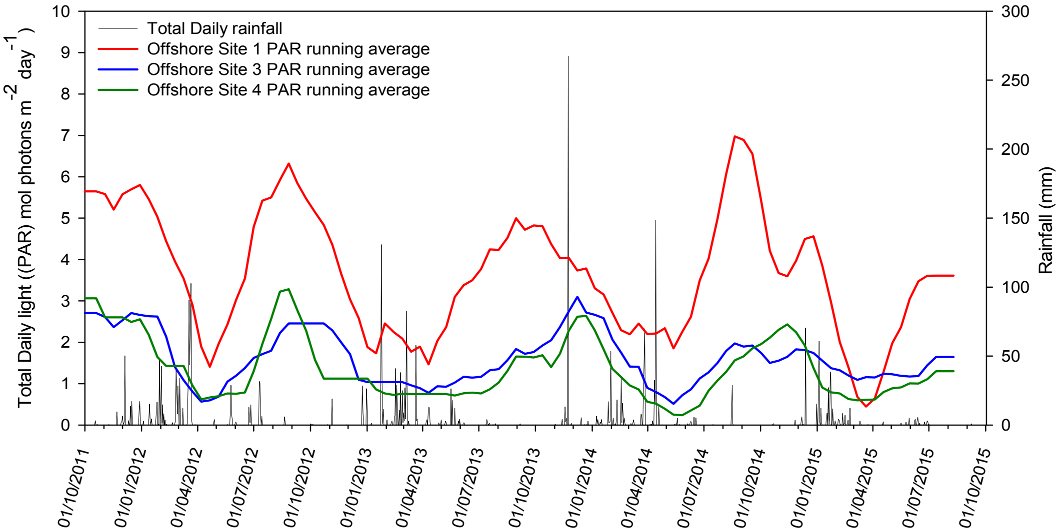


Figure 22. Total daily PAR (mol $m^{-1}day^{-1}$) with total daily rainfall (mm) at all offshore monitoring sites, September 2011 – August 2015.

3.3 Abbot Point Climate Patterns During Monitoring

Rainfall

Annual rainfall has been below the long term average for the past two years, with 2014/15 recording the lowest annual rainfall (450 mm) since 2001/02 (Figure 23a). Rainfall was only above the long term monthly average once (January 2015) in the twelve months preceeding the survey (Figure 23b).

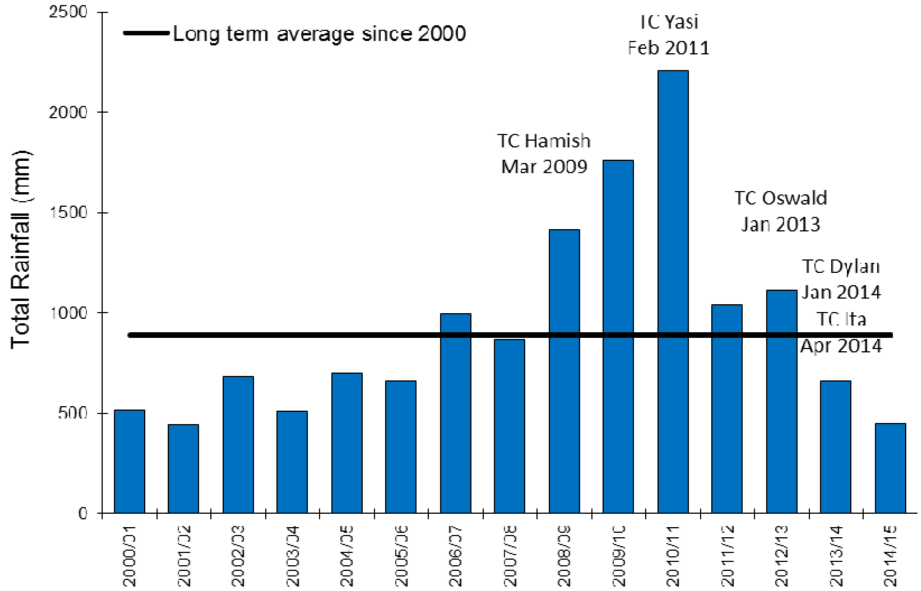


Figure 23a. Total annual rainfall (mm) recorded at Bowen, 2001/02-2014/15. Twelve month year is twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033257.

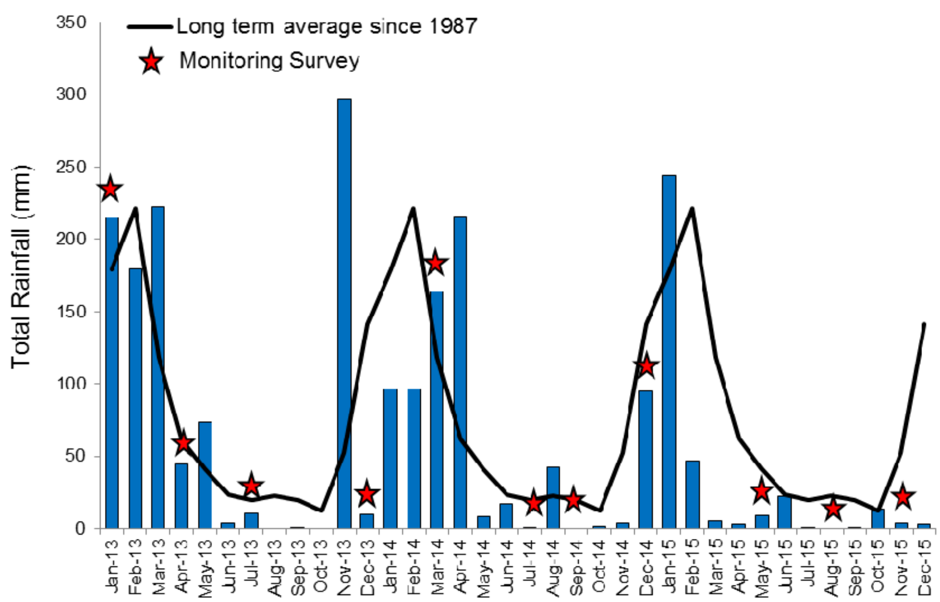


Figure 23b. Total monthly rainfall (mm) recorded at Bowen, January 2013- October 2015. Source: BOM, Station number 033257.

River Flow - Don River

River flow discharge has been near to or below the long term annual average of 156,056 ML for the past three years (Figure 24a). In the12 months preceding the 2015 survey, river flow was slightly above average in January which coincided with above average rainfalls (Figure 24b). This rainfall/river flow event coincided with a severe thunderstorm event that lasted from the 19th of January to the 23rd of January.

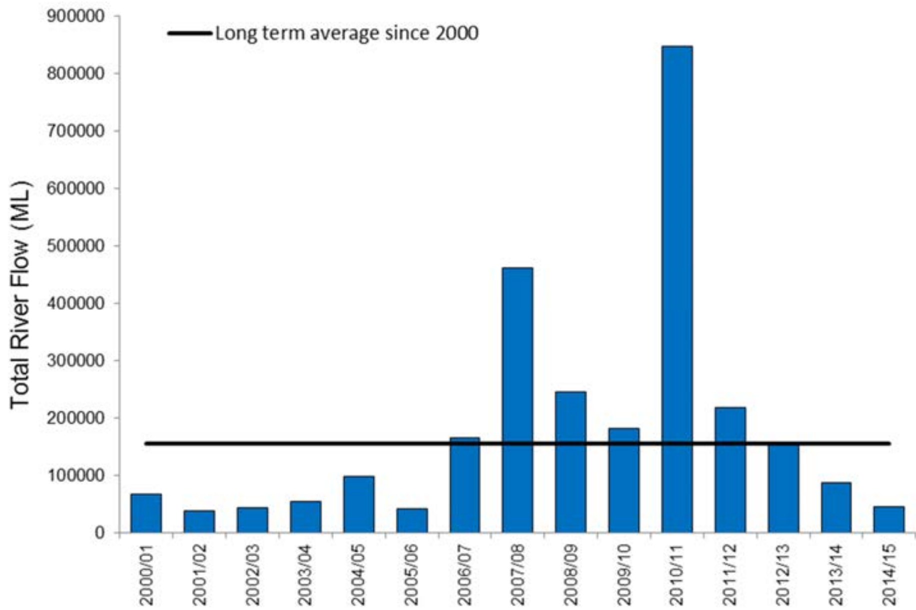


Figure 24a. Total annual river discharge of the Don River (Station 121003A) from 2000/01 to 2014/15. Twelve month year is twelve months prior to the survey. Source: Department of Natural Resources and Mines (DNRM).

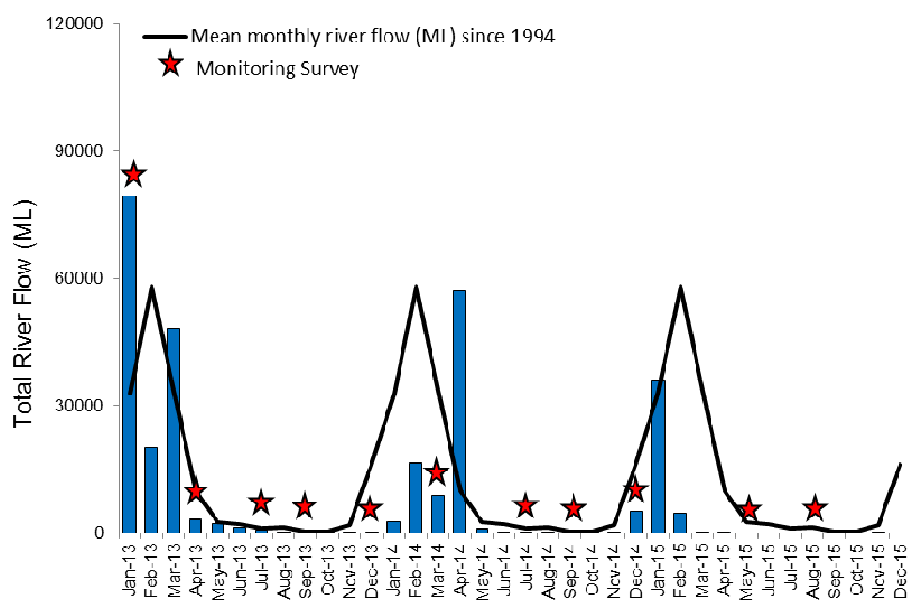


Figure 24b. Total monthly river discharge of the Don River (Station 121003A) from January 2013 to December 2015. Source: DNRM.

Air and Sea Surface Temperature

The annual average maximum air temperature was 0.66°C above the long term annual average (28.6°C) in 2014/15 (Figure 25a). This is the first time it has been above the long term average since 2009/10. Monthly data shows that air temperature has been above the monthly long term averages since November 2014 (Figure 25b). Sea surface temperature has been collected half hourly at Abbot Point since May 2014 (QLD Department of Science, Information Technology and Innovation 2015). During this time mean monthly maximum sea surface temperature has ranged between 22.3°C in July 2014 to 31.8°C in January 2015.

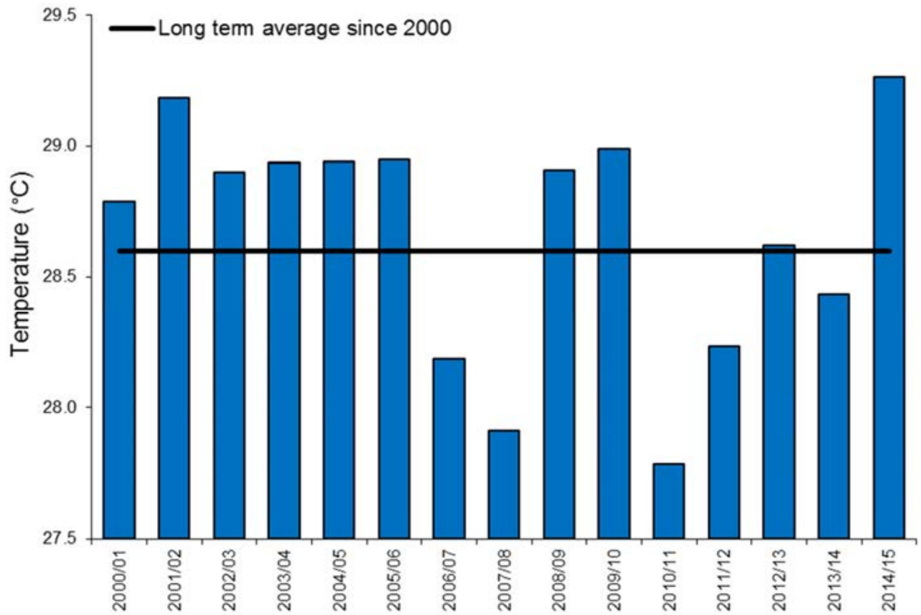


Figure 25a. Annual average maximum air temperature in the Bowen area (Station 33257) between 2000/01 and 2014/15. Source BOM.

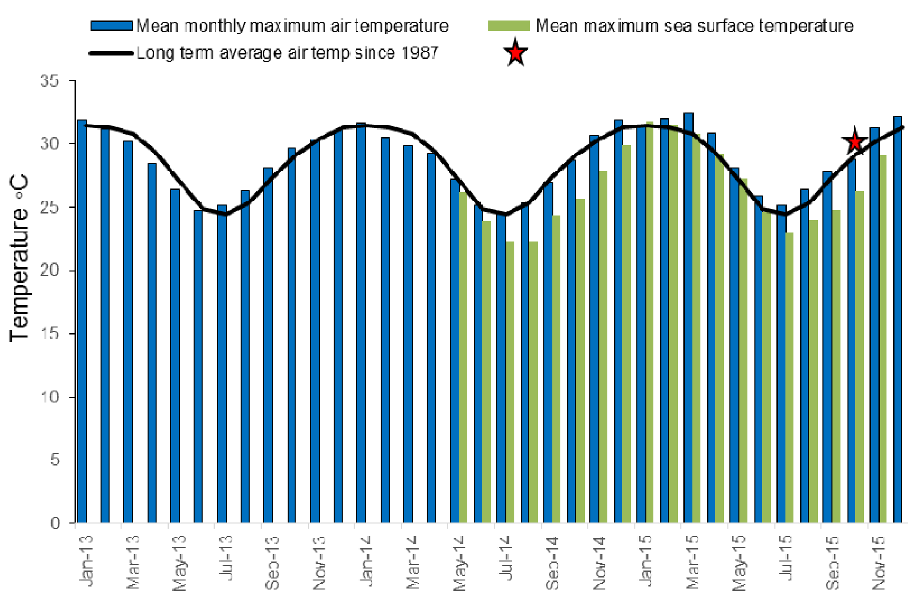


Figure 25b. Monthly mean maximum air temperature (Station 33257) and monthly mean maximum sea surface temperature at Abbot Point January 2013 – December 2015. Source: BOM and DSITI.

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 was just above the long term average in 2014/15 with a measure of 21.44 MJ m^{-2} (Figure 26a). In the twelve months preceding the 2015 survey, exposure was above the monthly long term average for seven of the twelve months mainly through February to May 2015 (Figure 26b).

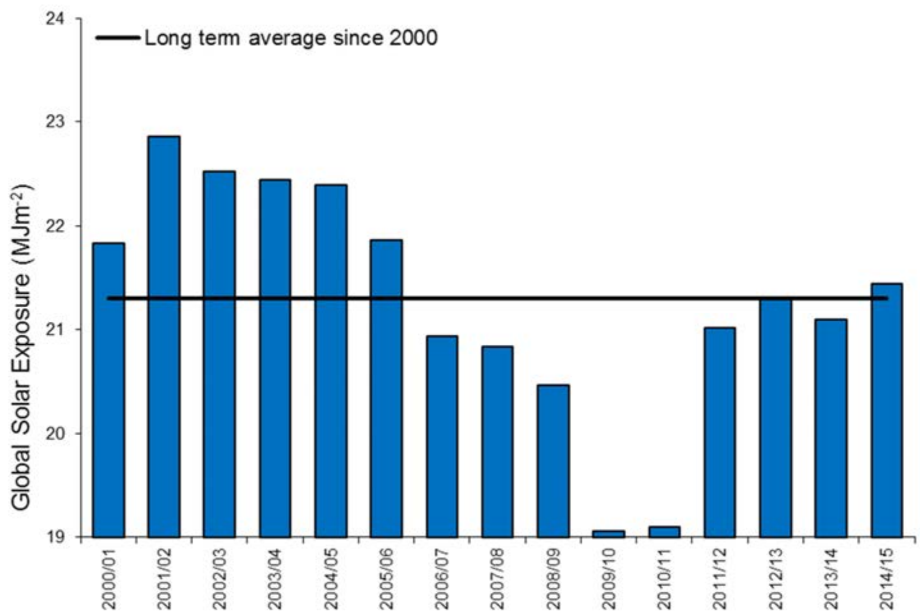


Figure 26a. Mean annual solar radiation (MJm^{-2}) recorded in the Bowen area (Station 033327) 2000/01 - 2014/15. Twelve month year is twelve months prior to the survey. Source: BOM.

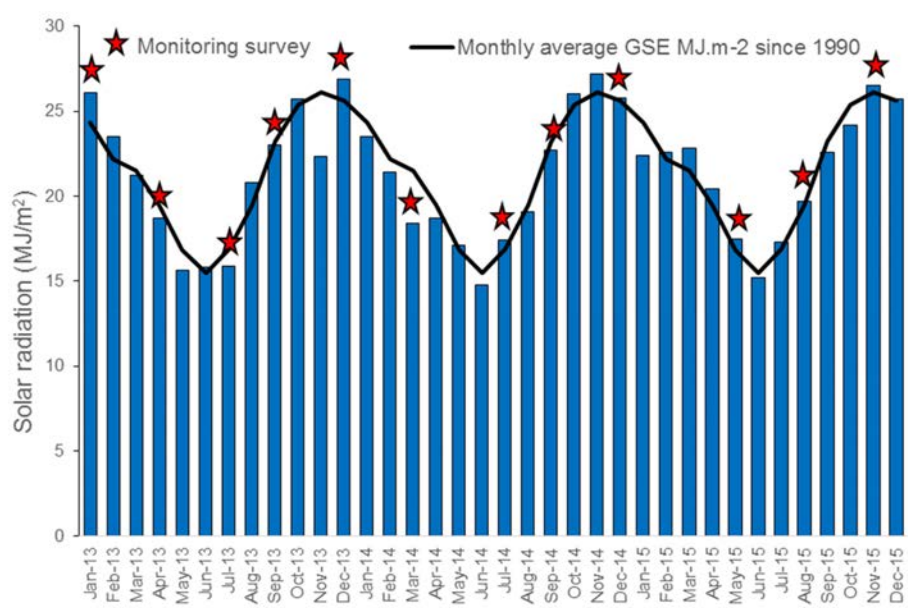


Figure 26b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded in the Bowen area (Station 033327) January 2013 - December 2015. Source: BOM.

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). In the last nineteen months average maximum wave height was the highest in October 2015, 1 month before the 2015 annual survey (Figure 27). Other significant wave heights occurred in February and June 2015.

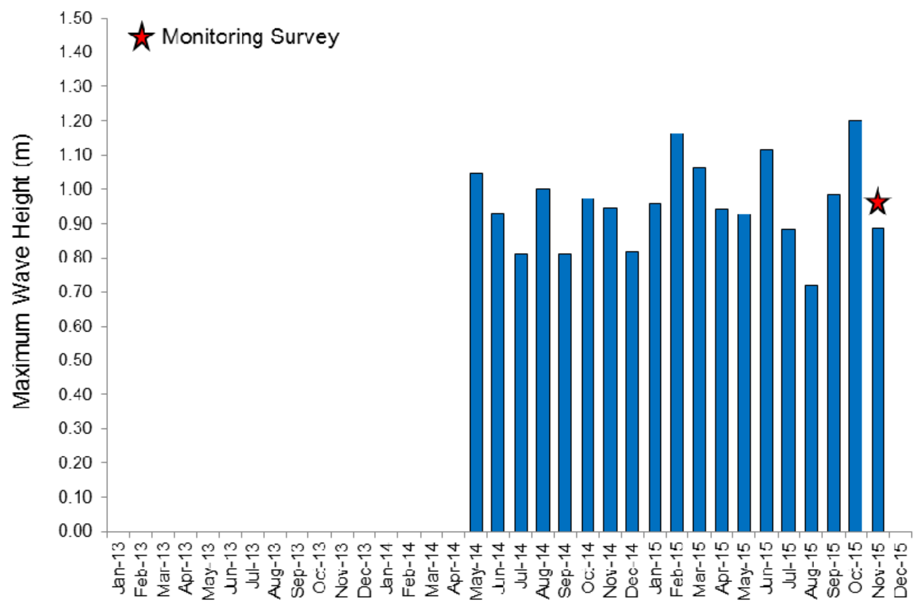


Figure 27. Mean monthly maximum wave height (m) recorded at Abbot Point May 2014 - November 2015. Source: DSITI.

4 DISCUSSION

The overall condition of seagrass in the Abbot Point region improved from very poor in 2014 to poor in 2015. The poor condition of seagrass was primarily driven by low species composition condition at inshore monitoring meadows, and the very poor condition of seagrass at Offshore Site 1. Despite this, deep water seagrasses were at the highest density they have been since climate associated losses that occurred leading up to 2011, with species composition also returning to pre-disturbance levels. Seagrass biomass and area at inshore coastal meadows were also near to, or above long-term averages. Species composition within the inshore meadows however, is still poor with many of the meadows remaining dominated by less persistent colonising species; *Halophila ovalis* rather than the more persistent larger *H. uninervis* and *Z. muelleri* that once dominated these inshore meadows.

Significant losses of seagrass density and distribution at Abbot Point were first observed following major climate events including 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 monitoring 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 initial recovery.

The continued increase of overall seagrass biomass and area in the Abbot Point region was a positive sign of ongoing seagrass recovery since major losses associated with the above climatic events. In particular the presence of the larger and persistent species *Cymodocea serrulata* in the offshore meadow, a species with a relatively high light requirement and large above-ground biomass (Collier and Waycott 2009), was encouraging. Deep water seagrass biomass and distribution is driven by seasonal 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 light availability. In particular, peak rainfall during the wet season (January – April) leads to reduced water quality and irradiances. For the last two years (2014 and 2015) these environmental conditions were at levels considered to be favourable, particularly for deep water seagrass; rainfall and river flow were below long term averages, and benthic PAR data indicated that over the 2013 and 2014 growing season, and most likely the 2015 growing season (~July to December), there has been enough light to support and maintain deep water seagrass at Abbot Point (McKenna et al. 2015a & b). These good growing conditions have most likely facilitated the expansion and growth of deep water *Halophila* in the Abbot Point region. Similar results occurred in Townsville in 2015 where the greatest increase in meadow area was for subtidal *H. spinulosa* meadows, which nearly doubled in size between 2014 and 2015, a strong indicator of improved light conditions in deeper areas of Townsville (Davies et al. 2016a).

These favourable environmental conditions were also likely to be beneficial for the subtidal inshore meadows at Abbot Point, and PAR data certainly indicated that there was enough light for *H. uninervis* and *Z. muelleri* growth and maintenance. In addition, although temperatures were higher in 2015 compared to other years, temperature at the seabed at the inshore meadows did not exceed the maximum temperature thresholds for growth (33°C for *Z. muelleri* or 40°C for *H. uninervis*) for long enough to cause any significant impacts (Collier et al. 2011; Collier and Waycott 2014). Similarly, Chartrand et al. (2014) demonstrated in their lab study that 30°C is not beyond the optimal growth temperatures for *H. decipiens* or *H. spinulosa*.

At other Queensland seagrass monitoring locations such as Townsville, Gladstone and Weipa, the increase in temperature, solar exposure and tidal exposure in 2015 did exceed recognised thresholds for seagrass growth and survival and was likely responsible for noted impacts on seagrass (heat stress/desiccation, reductions in photosynthetic efficiency, mortality) leading to decreases in intertidal seagrass meadow biomass (Davies et al. 2016a & b; McKenna et al. 2016). At Abbot Point coastal seagrasses are generally deeper than these other sites, with most sub-tidal, so they would be protected from the worst of these effects as they are rarely or never exposed to the air at low tide. In 2015 inshore seagrasses at Abbot Point were therefore able to continue to improve from 2014. Their poor condition is likely due to recruitment issues following the near complete disappearance of meadows and species as a result of severe climatic events, with little remaining seagrass from which recovery, maintenance, growth and expansion could occur. The reappearance of the more persistent foundation species for many of these meadows is a positive sign for ongoing recovery.

While the presence of *H. uninervis* and *Z. muelleri* is a positive sign, recovery is at a critical juncture and it will be important that these adult plants persist and expand to ensure ongoing recovery, particularly in the absence of substantial seed reserves (Rasheed et al. 2014) for the species at Abbot Point. Unlike the deep water *Halophila* meadow, seagrass species composition at the inshore meadows in 2015 has still not returned to pre-disturbance levels and meadows are still in the process of recovery. It is likely that the standing crop of *H. uninervis* and *Z. muelleri* at Abbot Point are diverting most of their energy into replenishing stored carbohydrates and clonal expansion through lateral growth of rhizomes after each senescent season, rather than investing energy into replenishing/establishing a seed bank from which recruitment and germination can occur (Shafer and Bergstrom 2010). The lack of a seed bank, coupled with the high reliance on asexual reproduction for recovery of these species at Abbot Point (Rasheed 2004; Rasheed et al. 2014) has important implications for recovery potential, and suggests that re-establishing these meadows may be a slow process which in other locations has taken more than ten years (Kirkman 1978; Birch and Birch 1984; Hyland et al. 1989; Poiner et al. 1989; Campbell and McKenzie 2004).

Results of the latest surveys indicate that there has been a significant increase in seagrass biomass at offshore *Halophila* spp. meadows in 2015, while seagrass recovery at inshore sites has been slower due to limited recruitment of propagules of more persistent species. It is likely that multiple years of climate induced seagrass decline have left a legacy of reduced resilience to further impacts and the next twelve months will be critical for ongoing recovery of Abbot Point's seagrasses, particularly for the inshore meadows and species. If there are no major climatic events that impact meadows, then we would expect continued growth and expansion of seagrass through 2016. 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 expected anthropogenic impacts and risks, particularly for inshore seagrasses.

In summary, results of the 2015 Abbot Point long-term seagrass surveys indicate:

- The overall condition of seagrass in the Abbot Point region improved from very poor in 2014 to poor in 2015 showing some recovery after large scale losses associated with numerous climate events from 2010/11 onwards;
- Despite this deep water seagrasses were at their highest density (biomass) since the major losses associated with climatic events and species composition was at levels recorded prior to the major disturbances;
- Biomass and area at inshore meadows were also near to or above long-term averages, however species composition remained dominated by colonising species;
- Favourable light and climate conditions over the last two years are likely to have facilitated the increases in biomass and area of seagrass meadows in 2015;
- The delay in persistent species dominating inshore meadows is likely due to limited opportunities for recruitment after the near complete disappearance of meadows and species;
- If there are no major climatic events that impact meadows, it is expected that there will be continued growth and expansion of seagrass through 2016;
- Ongoing seagrass monitoring will provide critical insights into the recovery of seagrasses in the Abbot Point region and their ability to remain resilient to future impacts.

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6 APPENDICES

Appendix 1.

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

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

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

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

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_{2015} takes up:

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

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

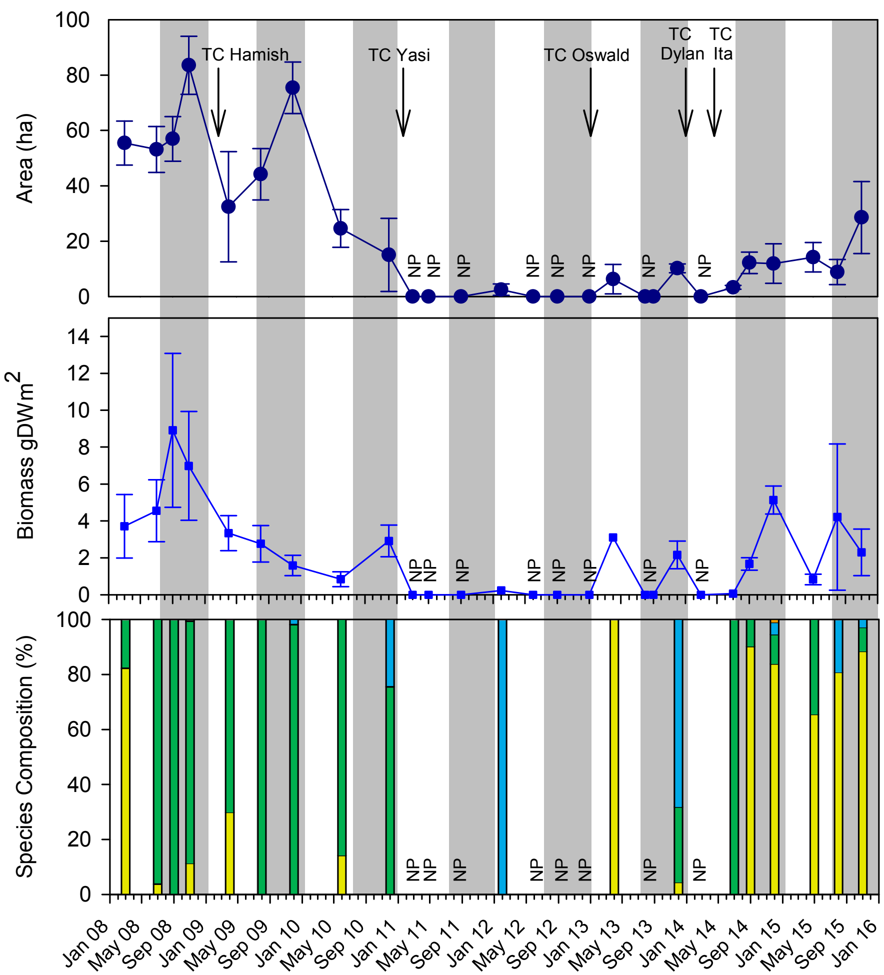
$$\mathrm{Score_{2015}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

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

Appendix 2.

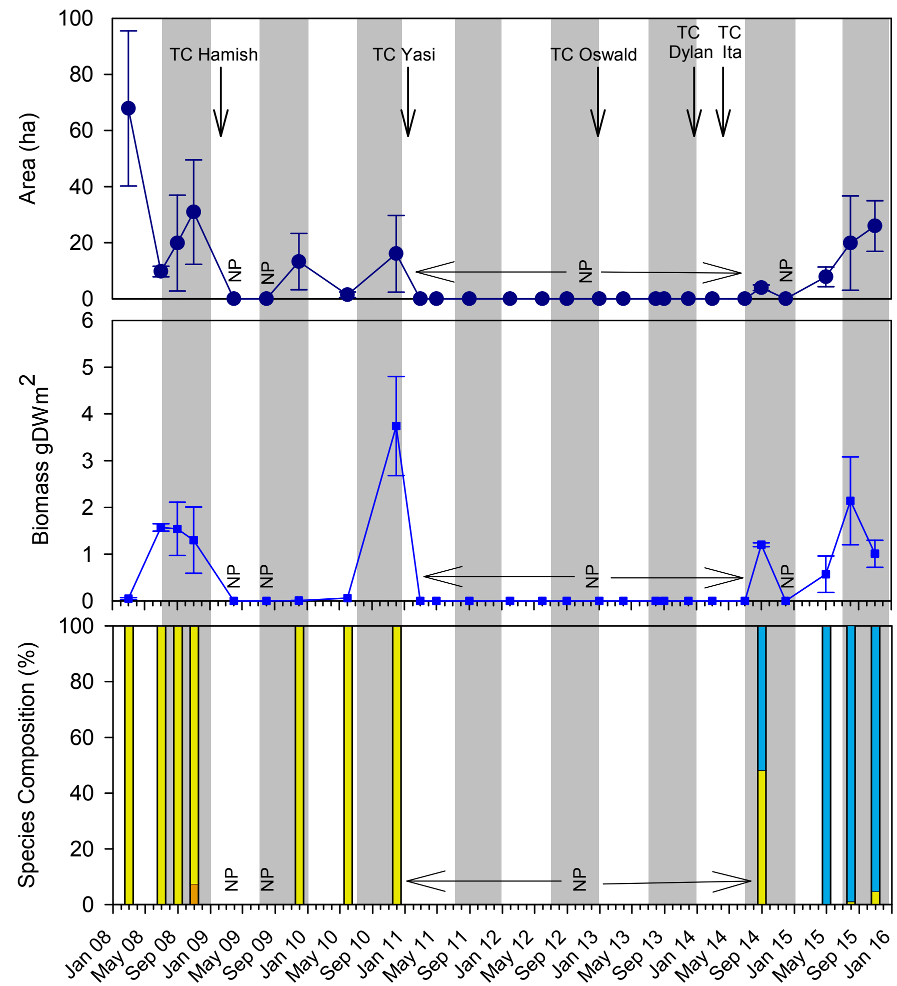
A. Area, biomass and species composition of inshore monitoring meadows in the Abbot Point region; quarterly surveys 2008 – 2015.

Inshore Meadow 3



* NP - Meadow not present

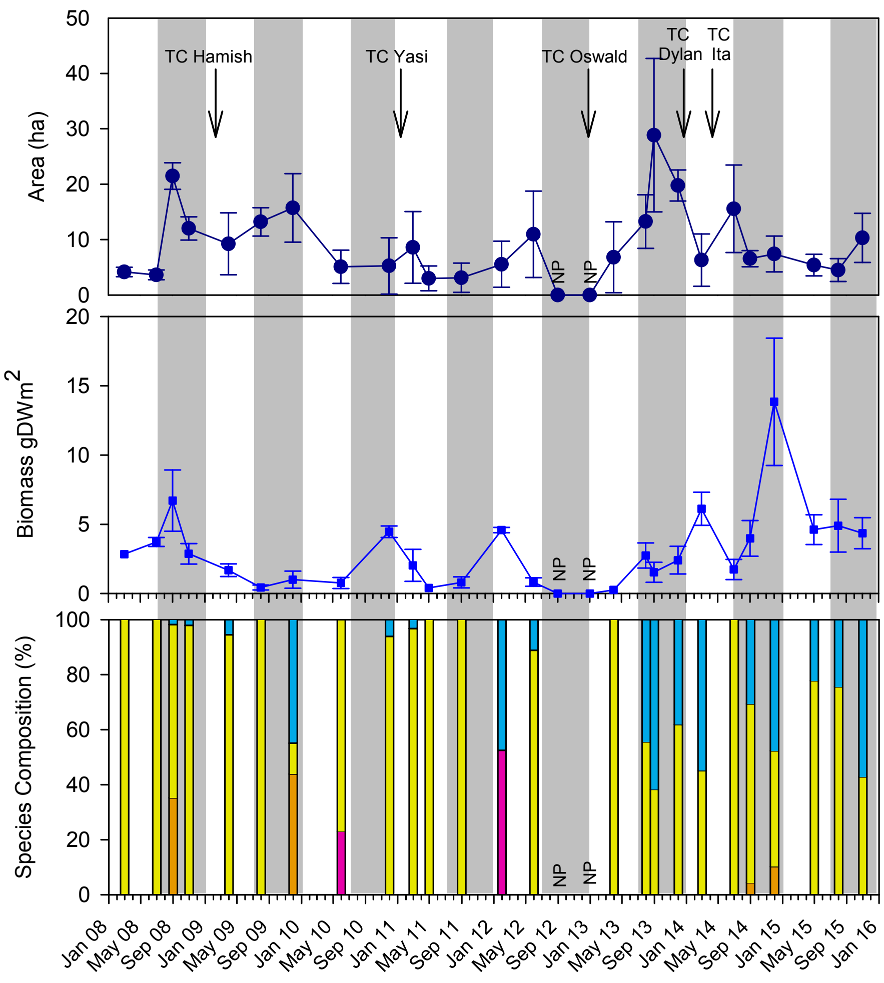
Inshore Meadow 5



* NP - Meadow not present

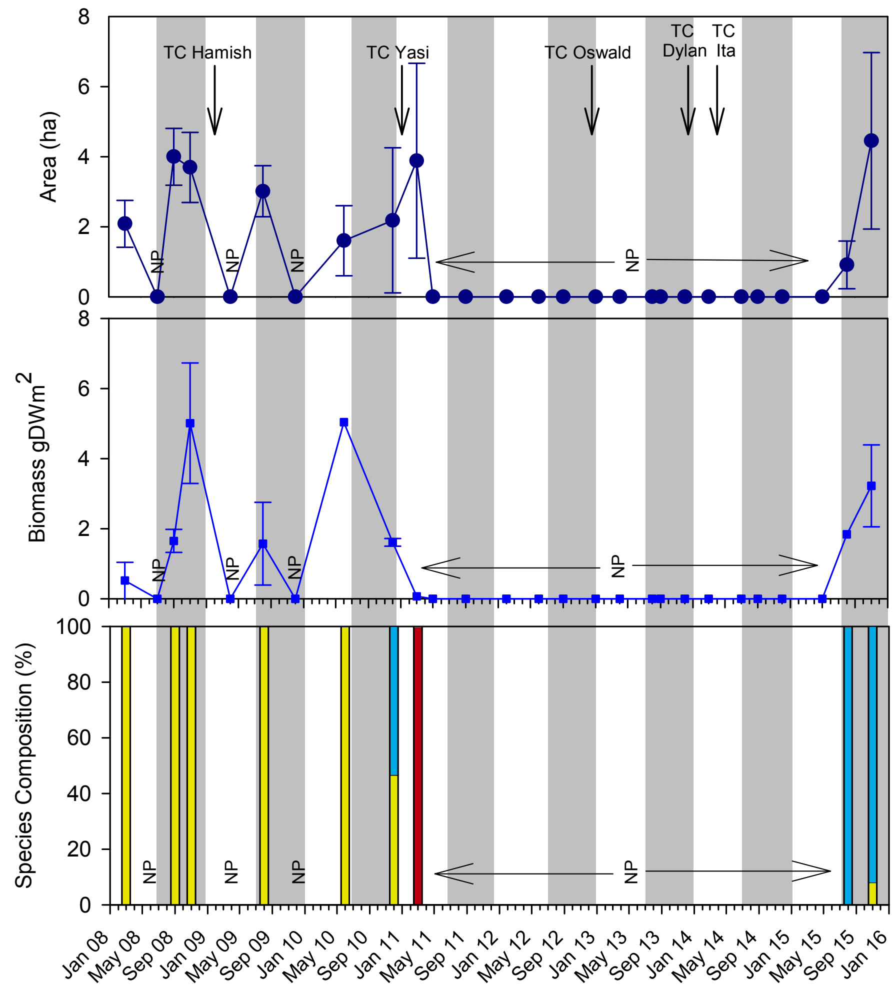
A cont. Area, biomass and species composition of inshore monitoring meadows in the Abbot Point region; quarterly surveys 2008 – 2015.

Inshore Meadow 7



* NP - Meadow not present

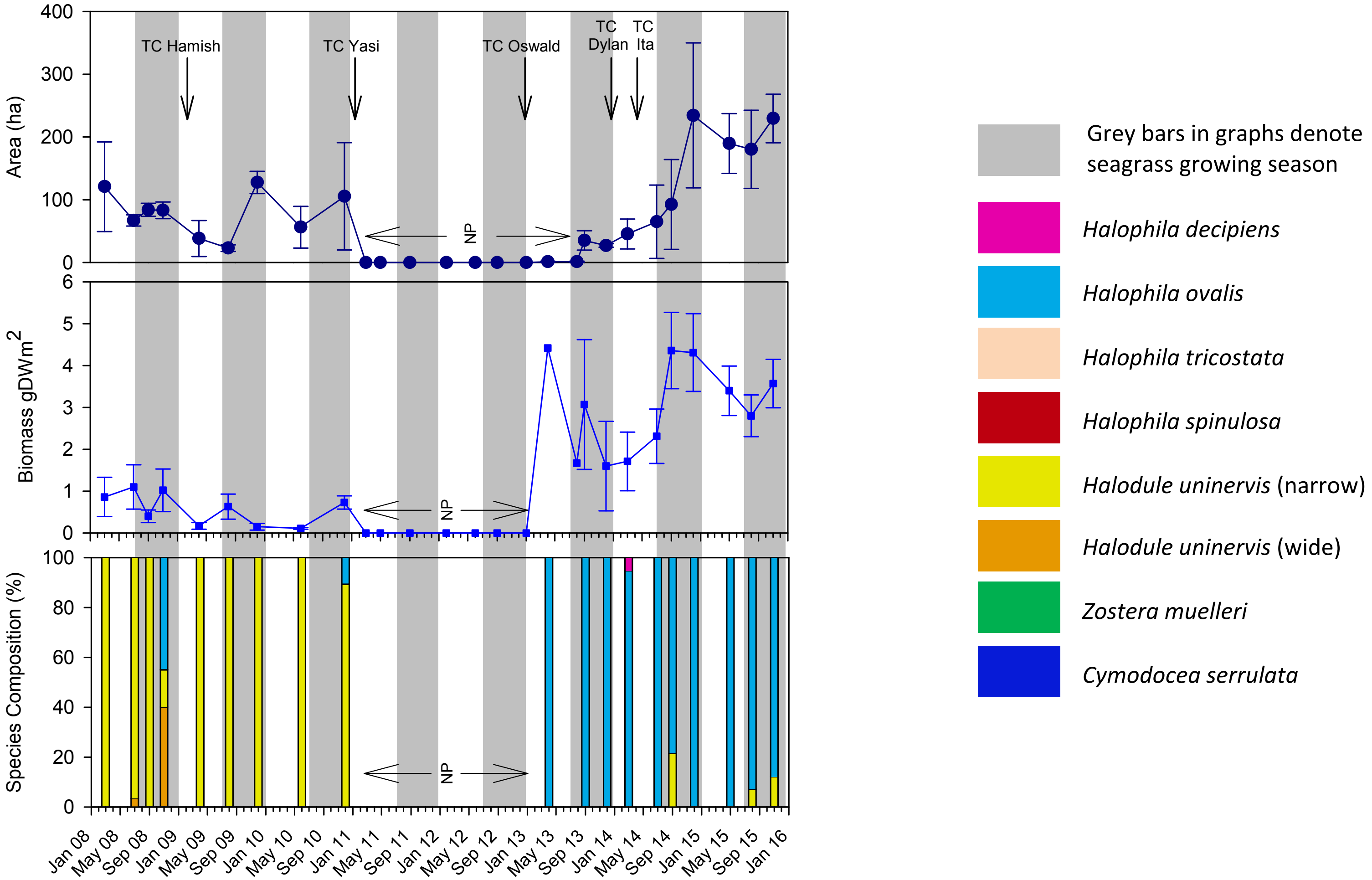
Inshore Meadow 8



* NP - Meadow not present

A cont. Area, biomass and species composition of inshore monitoring meadows in the Abbot Point region; quarterly surveys 2008 – 2015.

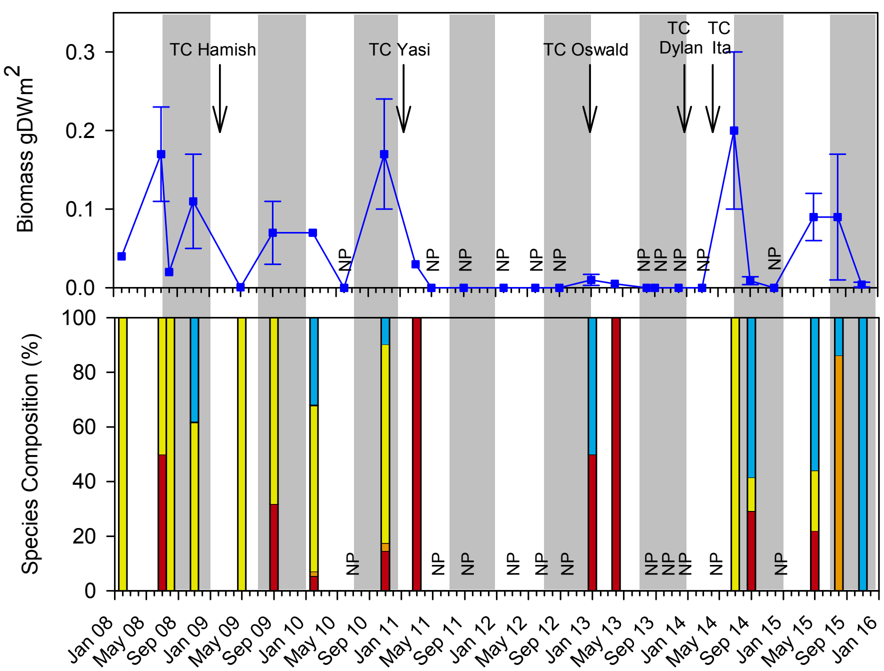
Inshore Meadow 9



* NP - Meadow not present

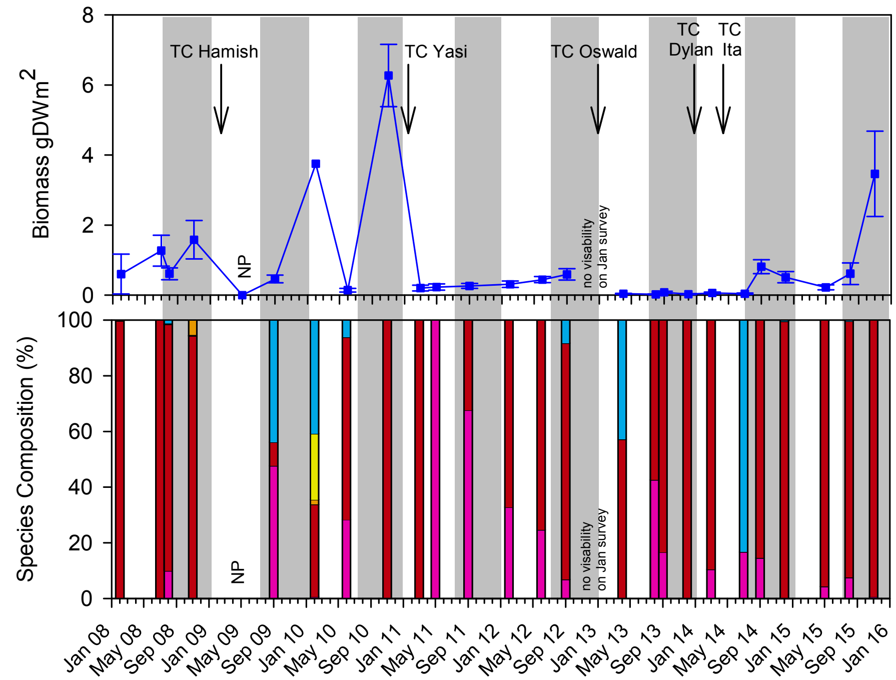
B. Mean biomass and species composition of offshore monitoring sites in the Abbot Point region; quarterly surveys 2008 – 2015.

Offshore Site 1



* NP - Meadow not present

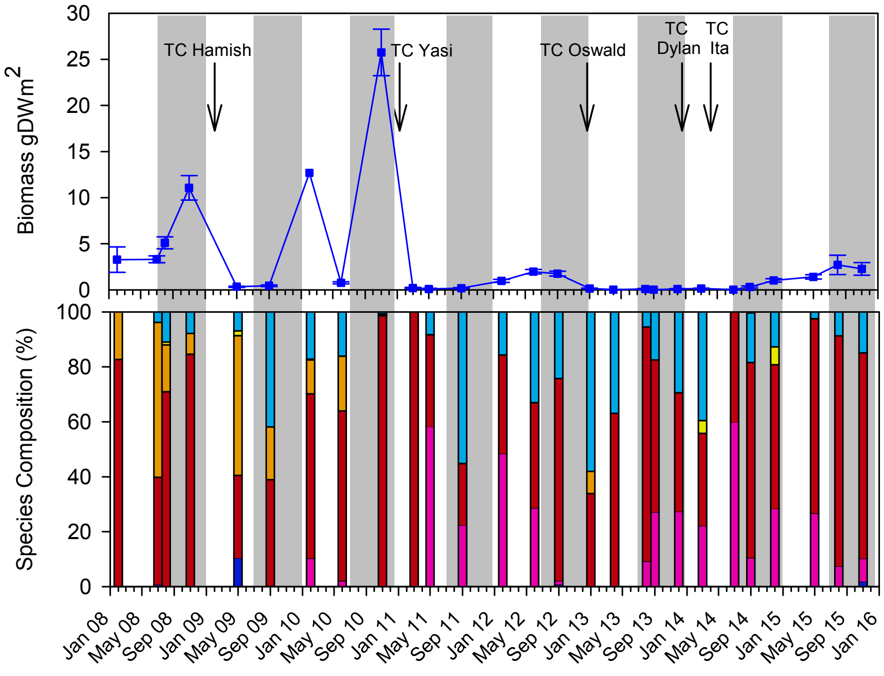
Offshore Site 2



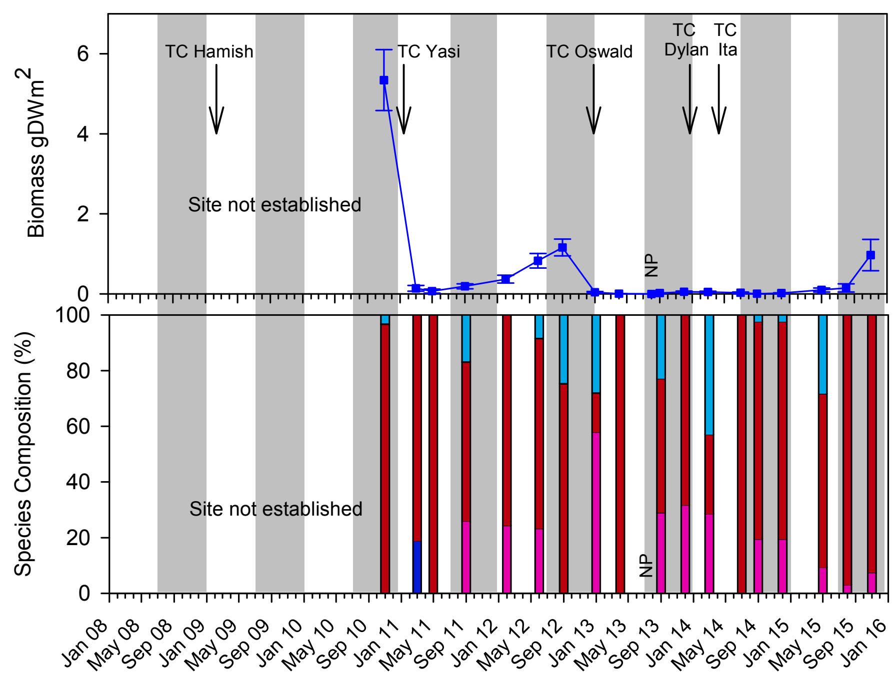
* NP - Meadow not present

B cont. Mean biomass and species composition of offshore monitoring sites in the Abbot Point region; quarterly surveys 2008 – 2015.

Offshore Site 3



Offshore Site 4



* NP - Meadow not present

Grey bars in graphs denote seagrass growing season

Halophila decipiens

Halophila ovalis

Halophila tricostata

Halophila spinulosa

Halodule uninervis (narrow)

Halodule uninervis (wide)

Zostera muelleri

Cymodocea serrulata

Appendix 3

3A. Mean biomass of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2015.

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)

NP – No seagrass present in meadow

3B. Area (ha) of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2015.

			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	11.9 ± 7.12	NP	7.4 ± 3.24	NP	234.28 ± 115.41	**253.59 ± 125.77**
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**

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

* - 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