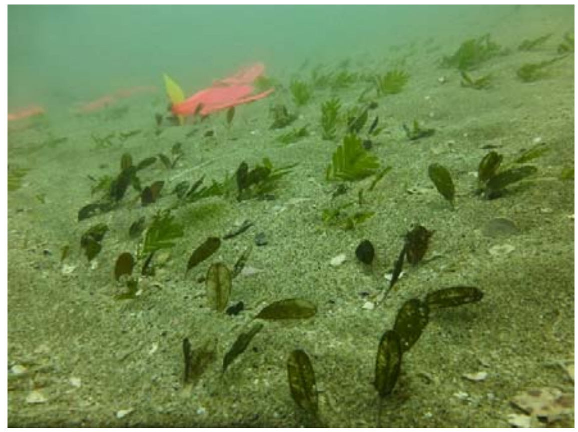

# PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM - 2018

**McKenna SA, Rasheed MA, Reason CL, Wells JN & Hoffman LR**

**Report No. 19/20**

# PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM 2018

A Report for North Queensland Bulk Ports Corporation (NQBP)

Report No. 19/20

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# KEY FINDINGS

**Seagrass Condition 2018**


**Likely causes of seagrass condition:**

↑ *Favourable climate conditions for seagrass growth*

↑ *Favourable light conditions*

↑ *Continued recovery from the impacts of TC Debbie*

- Seagrasses in Abbot Point were in a satisfactory condition in 2018.

- Overall seagrass condition had improved from the reductions caused by Tropical Cyclone Debbie in 2017. However, results for individual meadows varied:
    - Shallow coastal meadows to the southeast of Abbot Point had better recovery than those to the northwest.
    - Deepwater seagrasses in offshore areas also recovered better than the shallower offshore meadows

- These patterns of differential recovery were similar to past cyclone impacts in the area with deeper meadows generally able to recover faster due to differences in reproductive strategies of the seagrass species.

- Environmental conditions that can effect seagrass growth; rainfall, river flow & light were generally favourable for seagrass growth during 2018.

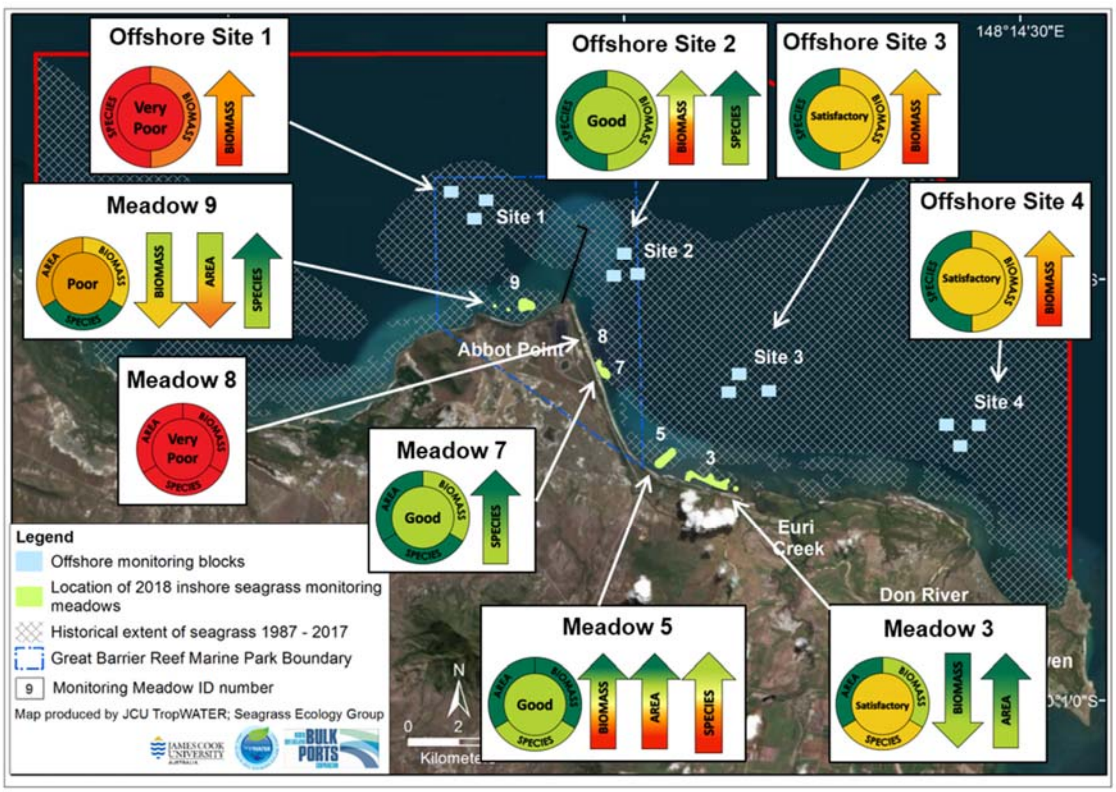
- In early 2019 following this survey, several weather events including sustained flooding of local rivers occurred and had the potential to impact on the recovering seagrasses.

- We have recommended pooling the three shallow *Halodule uninervis* meadows southeast of Abbot Point into one for future scoring and classification.

# IN BRIEF

A long-term seagrass monitoring program and strategy was established in the Abbot Point region in 2008. The current program is based on annual surveys of representative monitoring meadows with broader whole of port mapping occurring every third year (last completed in 2016 – for a full distribution of seagrasses and species within the broader port limits see McKenna et al. 2017). In late 2017, PAR and temperature assessments at two inshore monitoring meadows were re-established as part of the NQBP/JCU partnership. Monitoring in 2018 focussed on the five inshore seagrass meadows and four offshore monitoring sites selected for long term monitoring.

In 2018 the overall condition of seagrasses in the Abbot Point area was satisfactory and had improved from the reductions caused by Tropical Cyclone Debbie in 2017. Results for individual seagrass meadows varied with shallow coastal meadows to the southeast of Abbot Point generally showing better recovery than those to the northwest and deep-water seagrasses in offshore areas recovering faster than the shallower offshore meadows (Figure 1 & 2). Seagrass remained absent from one of the five inshore monitoring areas. This meadow (meadow 8) has been highly variable in its presence, biomass and area throughout the monitoring program, often being absent for long periods of time, then reappearing again when environmental and recruitment conditions are optimal.




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

**Figure 1**. Seagrass condition index for Abbot Point seagrass monitoring areas 2018.

These patterns of differential recovery were similar to past cyclone impacts in the area with deeper meadows generally able to recover faster due to availability of seeds and rapid colonising strategies of the *Halophila* species that make up these meadows (Figure 2). In contrast, studies conducted by our group at Abbot Point, found that shallow species did not recover quickly from disturbance, had poor seed reserves and relied on asexual propagation. The potential for shallow species to recover rapidly from widespread losses was limited as seed banks were limited or non-existent.

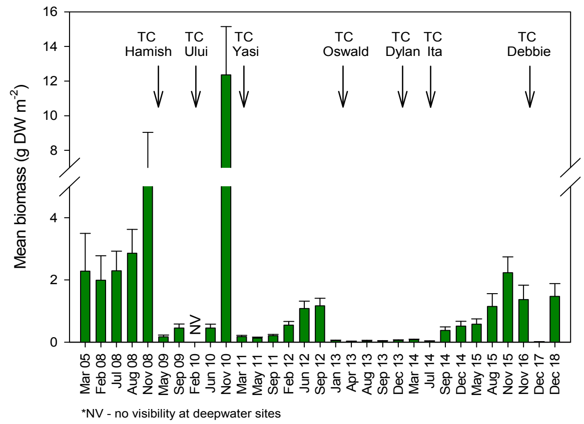



**Figure 2**. Mean biomass (gdwm$^{-2}$) of Abbot Point offshore seagrass monitoring sites from 2005 to 2018. Offshore site 1 is excluded from calculations.

Environmental conditions in the twelve months leading up to the 2018 survey were generally favourable for seagrass growth, likely assisting processes of recovery from the impacts of TC Debbie (Figure 3). Light, one of the key drivers for the persistence and growth of seagrass followed typical seasonal patterns with extended low light periods occurring during the wet season and generally favourable light conditions occurring for seagrasses outside of this during dry season months. Ongoing light assessments in the key seagrass community types at Abbot Point, indicate that the inshore species; *Halodule uninervis* and the offshore *Halophila* species, are likely to have lower light requirement thresholds than those suggested for the species in other monitoring locations.

The continued increase of overall seagrass biomass and the presence of persistent species such as *H. uninervis* and *Z. muelleri* in the Abbot Point region in 2018 is a positive sign of ongoing seagrass recovery since losses associated with TC Debbie in 2017. In addition, the continued presence of meadows of the same species within a few hundred metres of the meadows not present in 2018 provides a good potential source for new seagrass recruits. Continued recovery of the shallower seagrass meadows at Abbot Point will be contingent on environmental conditions being favourable for seagrass growth, particularly during the 2019 growing season. Since the completion of the 2018 survey, however, the Abbot Point region experienced long periods of high rainfall and flooding associated with TC Oma during early 2019, which had the potential to impact on seagrass meadows.

The long-term monitoring program has given us an understanding of the natural variability in presence, density and spatial footprint of the inshore seagrass meadows. As we have developed a more detailed understanding of the local dynamics, we have suggested a modification to the way we have classified meadows for the purpose of scoring. From 2019, we recommend that the three *H. uninervis* meadows on the southeastern side of Abbot Point (meadows 5, 7 & 8; Figure 1) be combined to form one monitoring area. This will allow for a more robust assessment of biomass and area change for these inshore variable meadows.

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 areas where seagrasses face the highest levels of cumulative risk. It also forms a component of James Cook University's (JCU) broader seagrass assessment and research program (see https://www.tropwater.com).

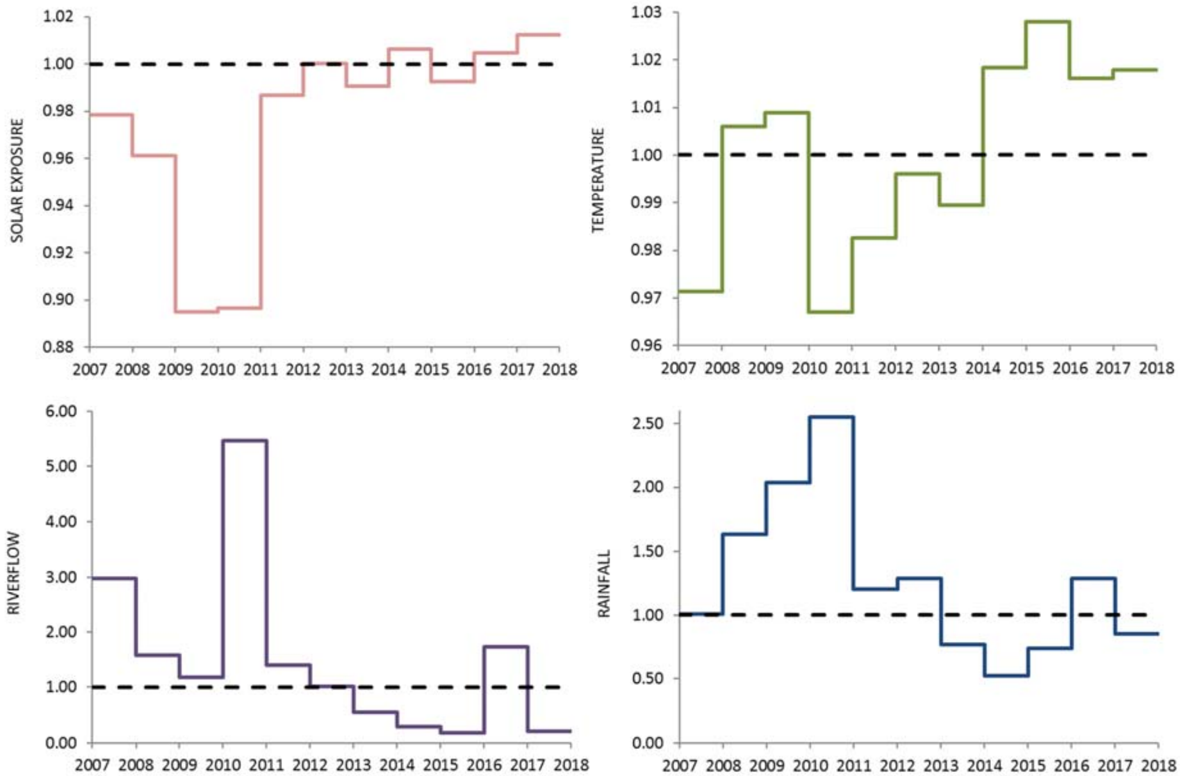



**Figure 3**. Recent climate trends in the Bowen/Abbot Point area 2000/01 to 2017/18: Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data.

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# 1. INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem functions and services including nutrient cycling and particle trapping that improves water quality, coastal protection, support of fisheries production and the capture and storage of carbon (Hemminga and Duarte 2000; Orth et al. 2006; Barbier et al. 2011; Fourqurean et al. 2012; Costanza et al. 2014). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Lavery et al. 2013; Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

Globally, seagrasses have been declining due to natural and anthropogenic disturbance events (Waycott et al. 2009). Explanations for seagrass decline include increasing frequency of severe weather events; disease; overgrazing by herbivores; 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). In the Great Barrier Reef (GBR) coastal region, the highest threat exposure for seagrass exists in the southern two thirds, 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 is recognised and a strategic monitoring program of these high-risk areas has been established to aid in their (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. Each location is funded separately, but the common methods and rationale between locations provides a network of seagrass monitoring locations comparable across the State (Figure 4).

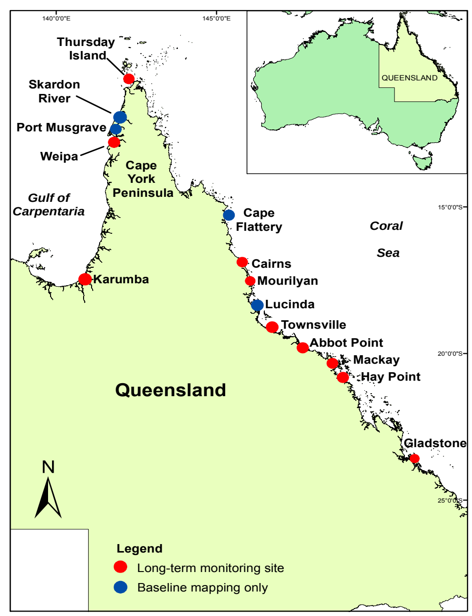



**Figure 4.** Location of Queensland Port Seagrass monitoring sites.

This strategic long-term assessment and monitoring program for seagrass provides port managers and regulators with key information to ensure effective management of seagrass habitat and ecosystem function. This information is often central to planning and implementing port development and maintenance programs that ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass habitats. The program also has provided significant advances in the science and knowledge of tropical seagrass and habitat ecology. This includes the development of tools, indicators, and thresholds for the protection and management of seagrass, and an understanding of the drivers of seagrass change.

For more information on the program and reports from the other monitoring locations see https://www.tropwater.com

## 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 within meadows. 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 (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 (Figure 5). This same approach is used as part of NQBP's other long-term ambient seagrass monitoring programs in the Ports of Weipa and Mackay/Hay Point, and elsewhere in other Queensland ports.

As part of the NQBP/JCU partnership, PAR and temperature assessments at two of the inshore monitoring meadows was re-established in late 2017, running parallel to other water quality monitoring stations (5 stations) managed by the JCU Geophysics team as part of the partnership (see Waltham et al. 2018).

Information collected in these seagrass monitoring 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 2018. The objectives of the annual long-term seagrass monitoring program for the Port of Abbot Point are to:

- Assess and map seagrass to 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.

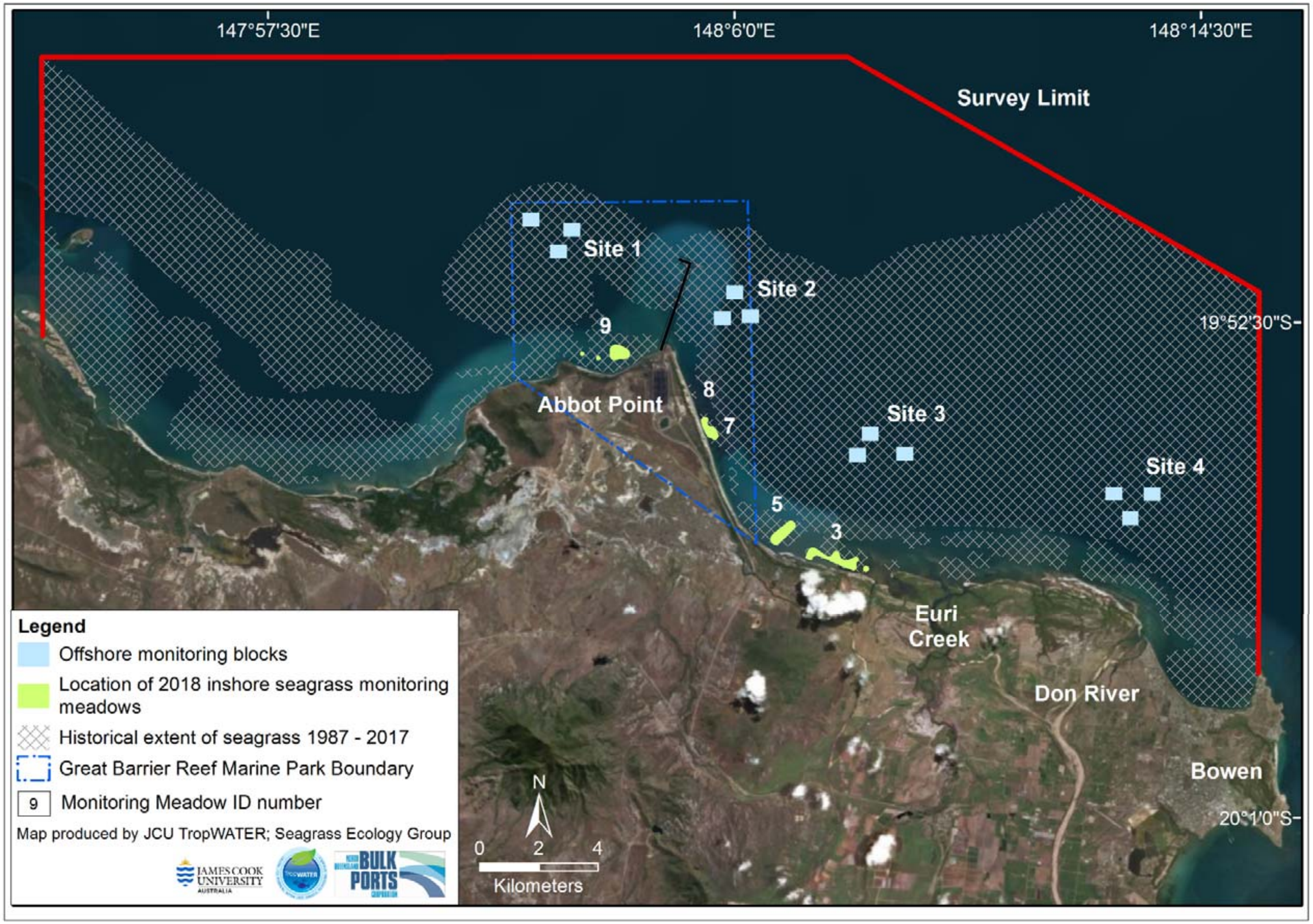



**Figure 5**. Location of 2018 inshore monitoring meadows and offshore monitoring areas in the Abbot Point region.

# 2. METHODS

## 2.1 Sampling Approach and Methods

Five coastal meadows and four offshore areas were identified in 2008 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 in the Abbot Point area.

Methods for assessing inshore and offshore seagrasses in the Abbot Point region follow those of the established seagrass program at Abbot Point (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 Queensland 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) fixes.

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 calibration quadrats were generated for each observer and applied to the field survey data to standardise above-ground biomass estimates.

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

## 2.2 Habitat mapping and Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.4®. Three GIS layers were created to describe seagrass in the survey area: a site layer, meadow layer and biomass interpolation layer.

- *Site Layer:* The site (point) layer contains data collected at each site, including:
    - Site number
    - Temporal details – Survey date and time.
    - Spatial details – Latitude, longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
    - Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail (DFT) presence/absence.
    - Sampling method and any relevant comments.

- *Meadow layer:* The meadow (polygon) layer provides summary information for all sites within each meadow, including:
    - Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys
    - Temporal details – Survey date.
    - Habitat information – Mean meadow biomass ± standard error (SE), meadow area (hectares) ± reliability estimate (R) (Table 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1 and 2), meadow landscape category (Figure 14).
    - Sampling method and any relevant comments.

- *Interpolation layer*: The interpolation (raster) layer describes spatial variation in seagrass biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Community density was based on mean biomass of the dominant species within the meadow (Table 2).

**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 |

*Isolated seagrass patches*
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

*Aggregated seagrass patches*
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

*Continuous seagrass cover*
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

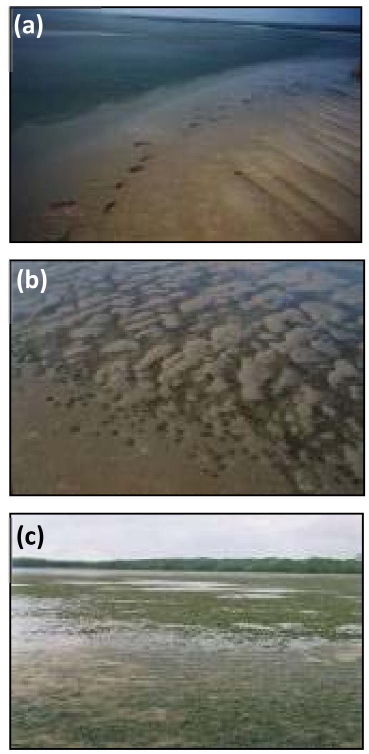



**Figure 7.** Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

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

Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 3). The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

### 2.3 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in each meadow 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). Overall meadow condition is the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The flow chart in Figure 8 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation. The flow chart in Figure 8 summarises the methods used to calculate seagrass condition.

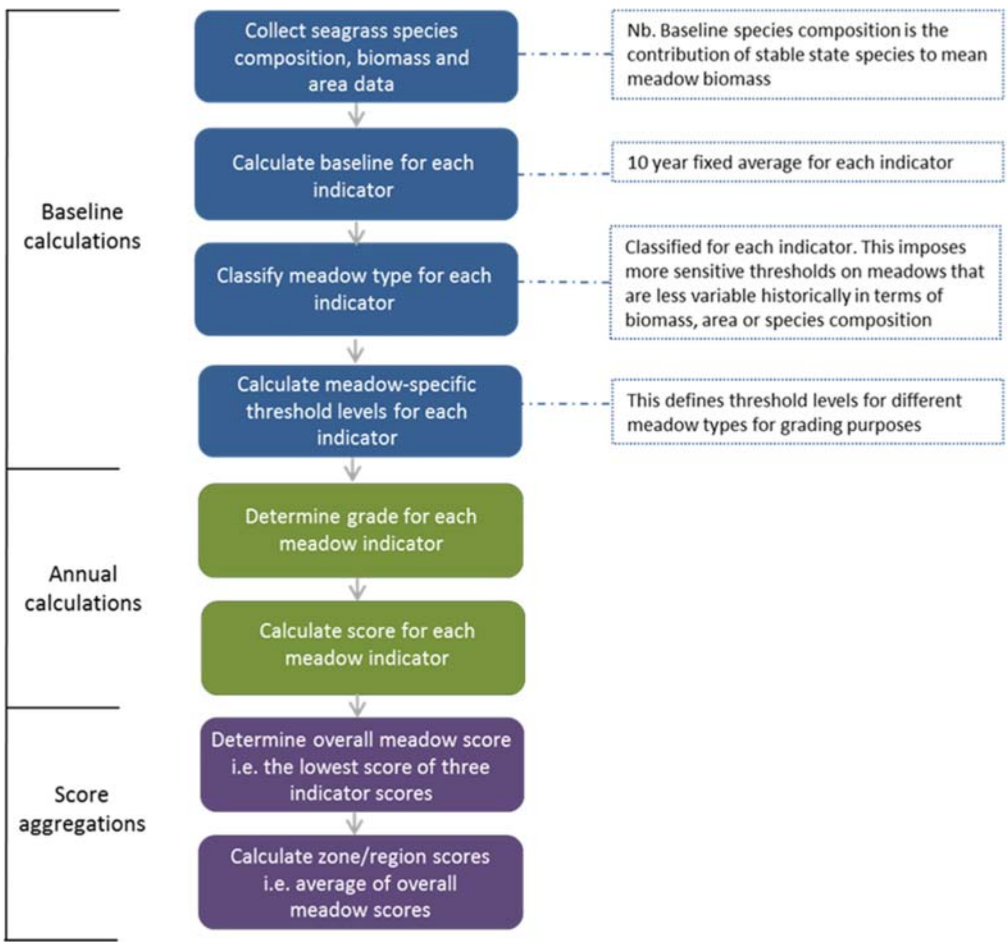



**Figure 8.** Flow chart to assess seagrass monitoring meadow condition.

## 2.4 Environmental data

Environmental data was collated for the twelve months preceding each survey. Total daily rainfall (mm) and river flow data of the Don River was obtained for the nearest weather station from the Australian Bureau of Meteorology and the Department of Natural Resources, Mines and Energy (DNRME). RMS wave height data was collected from the JCU Geophysics team.

The original TropWATER/NQBP light and temperature monitoring program within seagrass meadows was discontinued in 2015. Two of the inshore meadow logging stations have since been re-established in late 2017 (TW1 and TW2) (Figure 9). As part of the NQBP/JCU partnership, the JCU GeoPhysics team has also had PAR loggers deployed in the greater Abbot Point region since late 2017. GeoPhysics site AMB 1 coincides with offshore site 3 (Figure 9) and this data has been used to represent the availability of light in the offshore seagrass meadows.

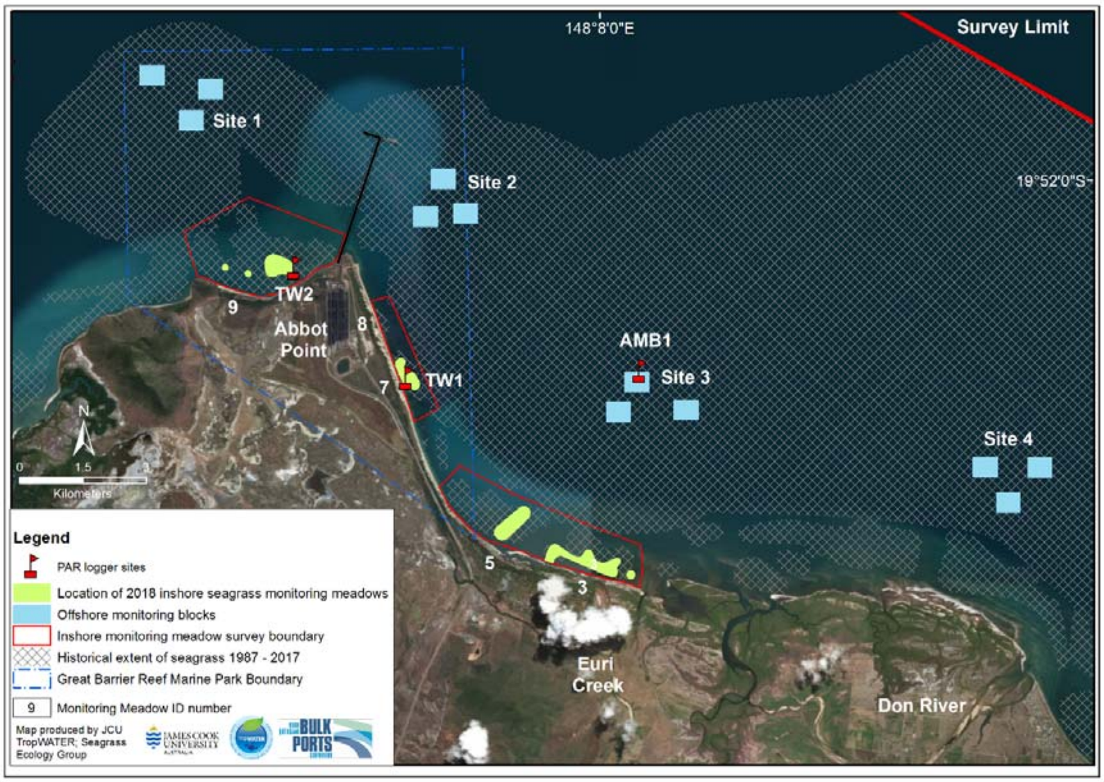



**Figure 9**. Location of James Cook University light (PAR) loggers at Abbot Point.

At the two inshore logging stations (TW1 & TW2), each independent logging station within the meadows consists of 2π cosine-corrected irradiance loggers (Submersible Odyssey Photosynthetic Irradiance Recording Systems) with supporting electronic wiper units (Figure 10). Irradiance loggers were calibrated using a cosine corrected Li-Cor underwater quantum sensor (LI-190SA; Li-Cor Inc., Lincoln, Nebraska USA) and corrected for immersion effect using a factor of 1.33 (Kirk 1994). Readings were made at 15 minute intervals and used to estimate total daily irradiance (PAR) reaching seagrasses. The electronic wiper unit fitted to each irradiance logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling.

Autonomous Thermodata® iBTag submersible temperature loggers recorded seabed temperature every 30 minutes.

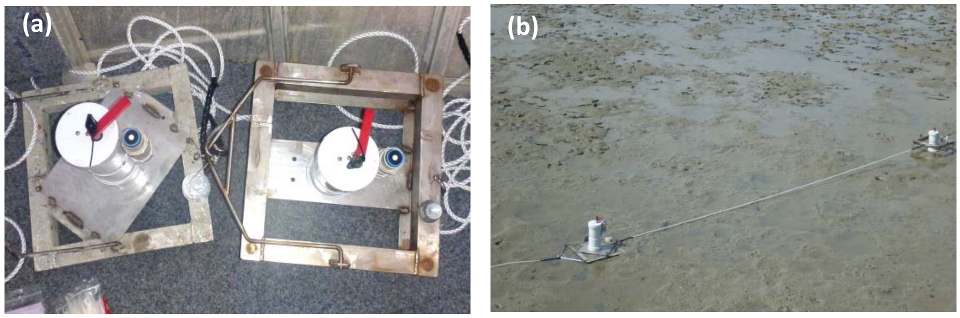



**Figure 10.** (a) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units (b) example of deployment of logging stations (Abbot Point stations are subtidal only).

# 3. RESULTS

## 3.1 Seagrass in the Abbot Point monitoring areas

A total of 122 inshore sites and thirty-six offshore transects were sampled as part of the 2018 Abbot Point monitoring. Seagrass was present at 33% of inshore sites, while twenty-three of the offshore transects contained seagrass. The inshore monitoring meadows covered 127.03 ± 20.16 ha (Figure 12). For a full distribution of seagrass and species within the broader port limits/Abbot Point region, the full baseline surveys conducted every three years should be consulted (see McKenna et al. 2017).

Eight seagrass species have been identified within the Abbot Point region since surveys of the area began in 1987 (Figure 11). All species except *Cymodocea rotundata*, *C. serrulata* and *Halophila tricostata* were present in the 2018 monitoring meadow survey. However, as this only examines a subset of the total seagrass distribution these species may have been present in areas outside of the monitoring locations.

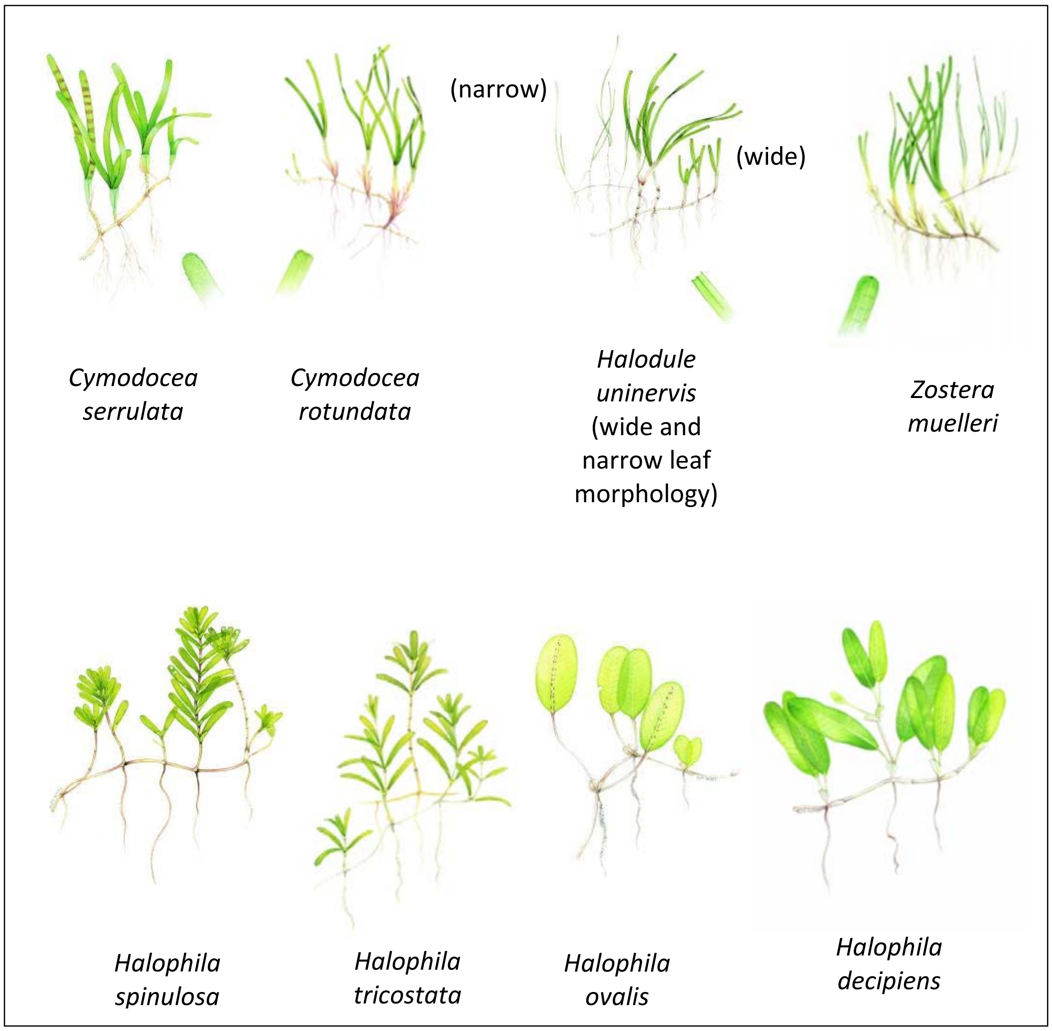



**Figure 11.** Seagrass species identified in the Abbot Point/Bowen region since 1987.

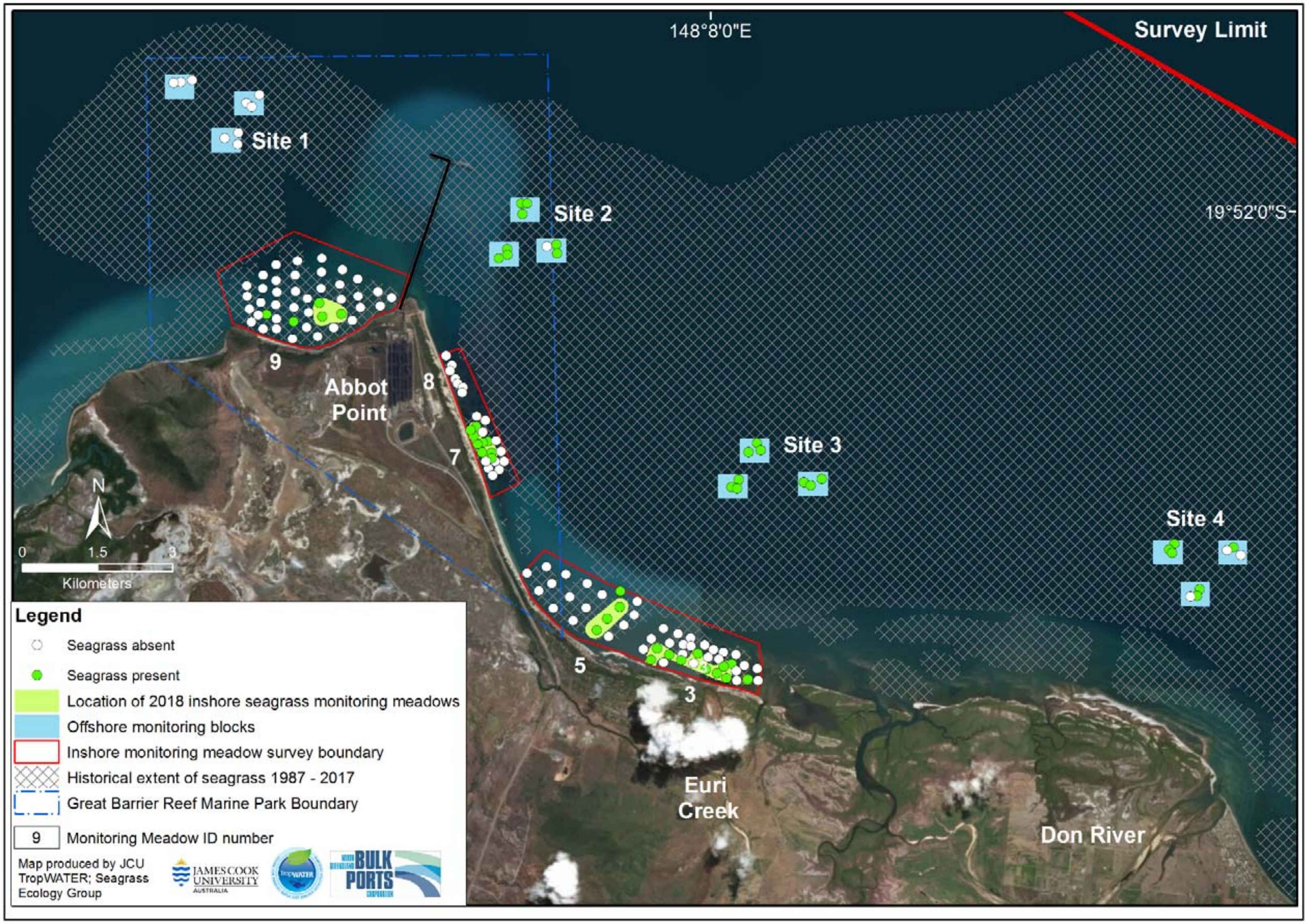



**Figure 12**. Location of inshore seagrass monitoring meadows, offshore monitoring locations and seagrass assessment sites in 2018

### 3.2 Seagrass condition in the Abbot Point monitoring areas

The overall condition of seagrass monitoring meadows in the Abbot Point region was classed as satisfactory in 2018, with both the inshore and offshore seagrass habitats classed as satisfactory (Table 3). This was an improvement in condition from 2017, with the second half of 2017 and 2018 being a phase of recovery from Tropical Cyclone Debbie that affected the area in March 2017.

In general, both the inshore and offshore areas to the south-east of Abbot Point had shown improvement since TC Debbie, while the two monitoring areas to the north-west of Abbot Point did not show the same degree of improvement.

| Meadow | Biomass | Species Composition | Area | Overall Meadow Score | Overall location Score |
|---|---|---|---|---|---|
| **Offshore Monitoring Areas** | | | | | |
| **Offshore Site 1** | 0.48 | 0.00 | N/A | 0.24 | 0.54 |
| **Offshore Site 2** | 0.77 | 1.00 | N/A | 0.77 | |
| **Offshore Site 3** | 0.64 | 1.00 | N/A | 0.64 | |
| **Offshore Site 4** | 0.50 | 0.92 | N/A | 0.50 | |
| **Inshore Monitoring Areas** | | | | | |
| **Inshore Meadow 3** | 0.71 | 0.57 | 0.85 | 0.64 | 0.51 |
| **Inshore Meadow 5** | 0.92 | 0.69 | 0.85 | 0.77 | |
| **Inshore Meadow 7** | 0.67 | 0.92 | 0.86 | 0.67 | |
| **Inshore Meadow 8** | 0.00 | 0.00 | 0.00 | 0.00 | |
| **Inshore Meadow 9** | 0.55 | 0.94 | 0.45 | 0.45 | |
| **Overall score for seagrass in the Port of Abbot Point** | | | | | **0.52** |

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

**Table 3**. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2018.

***Inshore monitoring meadows***

The inshore meadows have been variable in their recovery and condition since TC Debbie with the overall condition of each meadow ranging from very poor to good (Table 3; Figures 13-17).

Four of the five inshore monitoring meadows were present in 2018, an improvement from 2017. The inshore monitoring meadow that was absent in 2018 (Meadow 8), has been a highly variable meadow throughout the monitoring program, often being absent for long periods of time, then reappearing again when environmental and recruitment conditions are optimal (Figure 16).

For the inshore monitoring meadows on the southeastern side of Abbot Point that were present (meadows 3, 5 & 7), all seagrass indicators were classed as being in good or very good condition (Table 3; Figures 13-15). The exception to this was the species composition of meadow 3 at Euri Creek. The Euri Creek monitoring meadow, traditionally dominated by *Zostera muelleri*, has been dominated by *H. uninervis* for the last two years (Figure 13; Appendix 3). This change in dominant species in the meadow is a common occurrence when the meadow undergoes recovery following a disturbance, such as cyclones (Appendix 3). All other inshore monitoring meadows were dominated by *H. uninervis* in 2018, with a light biomass for the species.

The one inshore monitoring meadow on the northwestern side of Abbot Point (meadow 9), did not show the same recovery trends as the southeastern meadows. While the species condition within the meadow improved from 2017, both the biomass and area of the meadow decreased to being classed as satisfactory and poor respectively (Table 3; Figure 17). These decreases were likely driven by the reduction of colonising *H. ovalis* in the meadow from the previous year. *Halophila ovalis* has dominated the meadow for the last few years (Figure 17; Appendix 3).

***Offshore monitoring sites***

There are three deep-water (>10m below MSL) and one shallow (~5-7m below MSL) offshore monitoring sites that are assessed each year in the monitoring program (Figure 12). The shallower Site 1 is located on the northwestern side of Abbot Point on Clark Shoal and has been highly variable in its presence throughout the monitoring program (Figure 18). Site 1 has typically been dominated by *Halodule uninervis*, while the deep-water offshore sites 2-4 to the southeast of Abbot Point consist of low light adapted *Halophila* species (Appendix 3). Due to these differences, offshore site 1 is treated separately to the other deeper water offshore sites when conducting analysis of changes.

Seagrass condition at all offshore monitoring locations ranged from very poor to satisfactory (Table 3). For the most part, this was an improvement on seagrass condition from 2017. Biomass increased at all offshore monitoring locations with species composition in very good condition for all but offshore site 1. Despite TC Debbie, species composition has been improving at the deeper offshore areas (sites 2 – 4) for the last couple of years due to an increased presence of *H. spinulosa* (Figures 19 – 21; Appendix 3).

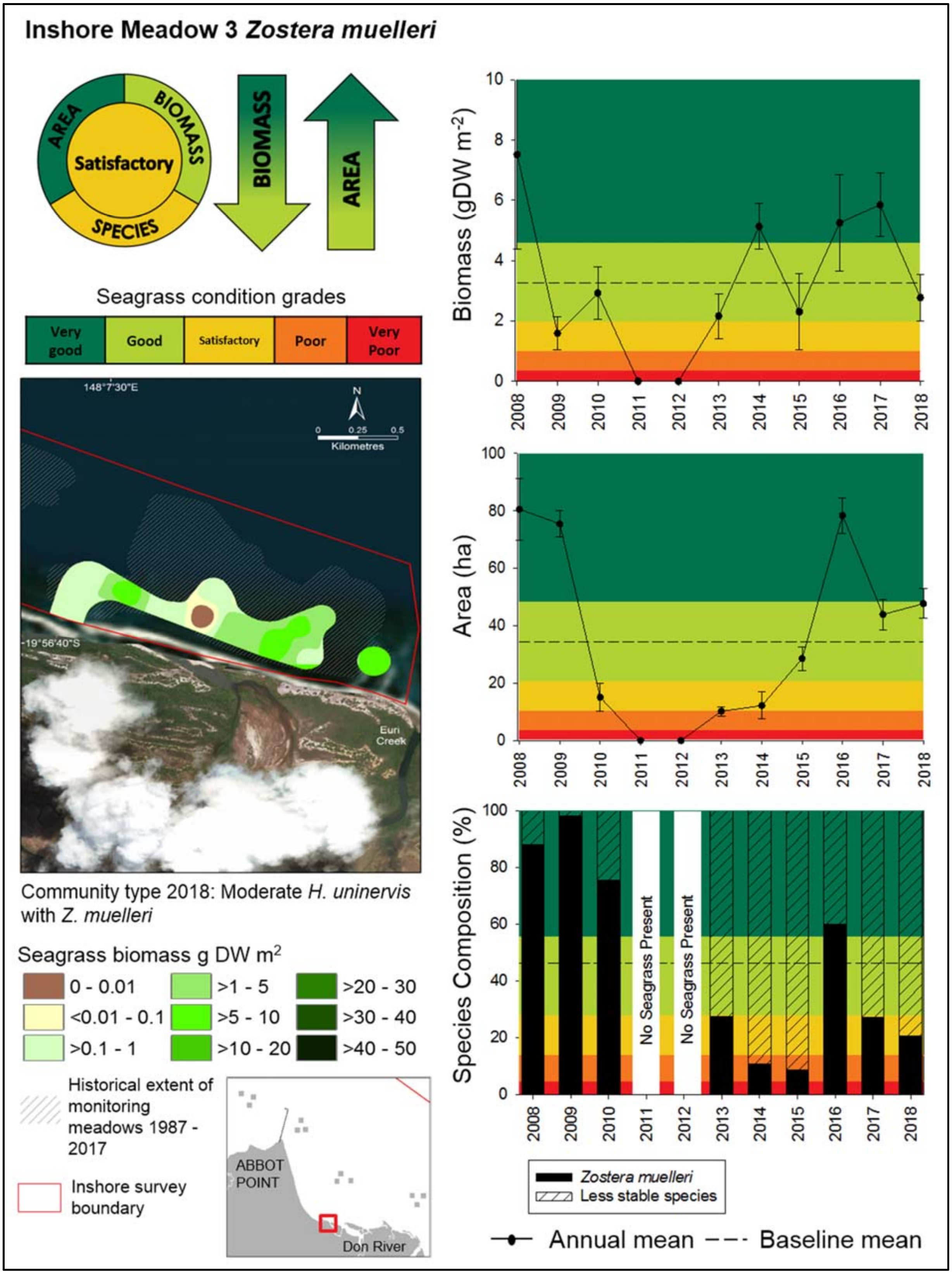



**Figure 13.** Mean meadow biomass (g DW m$^{-2}$), total meadow area (ha) and species composition at inshore monitoring Meadow 3.

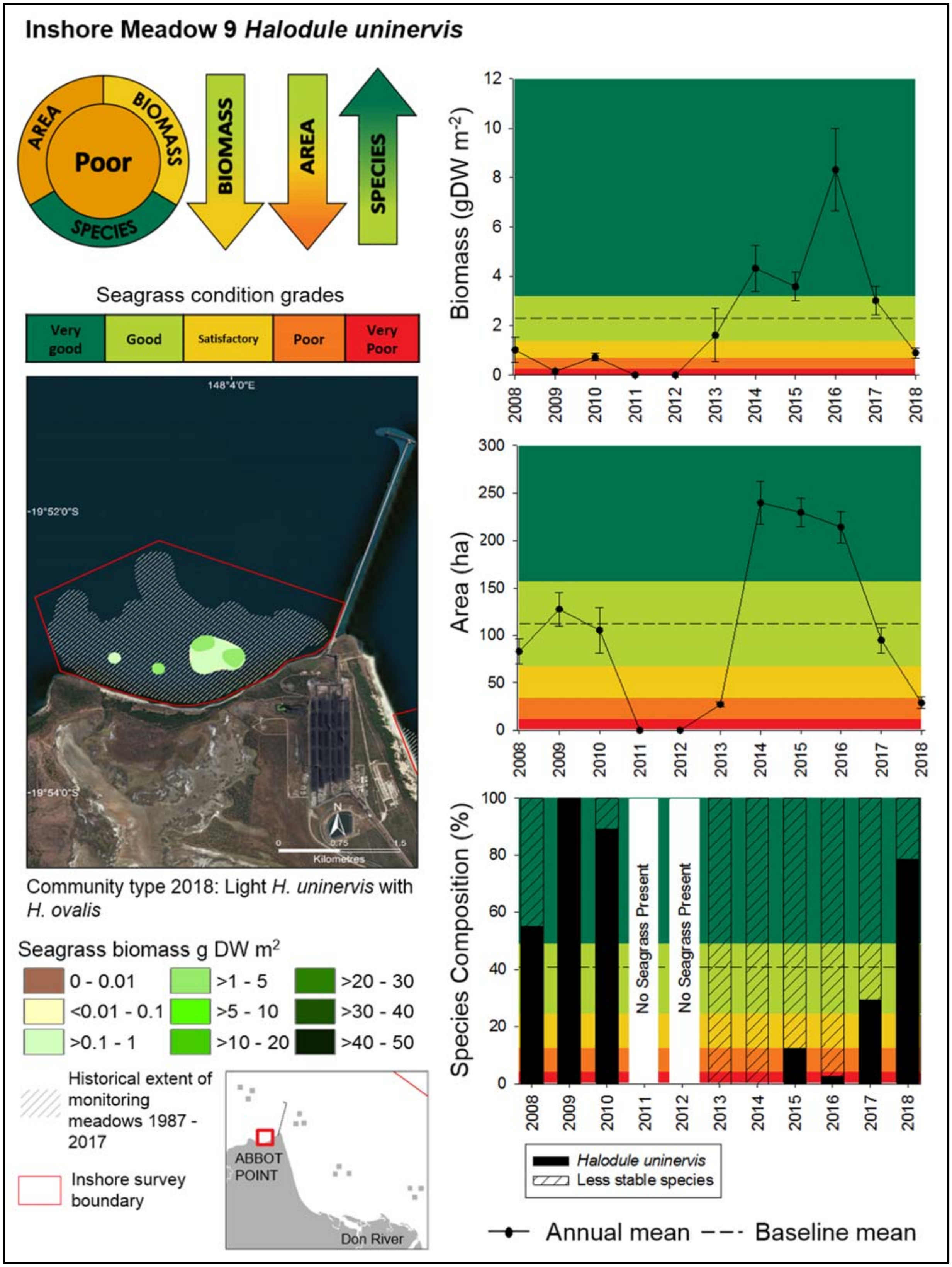



**Figure 14.** Mean meadow biomass (g DW $m^{-2}$), total meadow area (ha) and species composition at inshore monitoring Meadow 5.

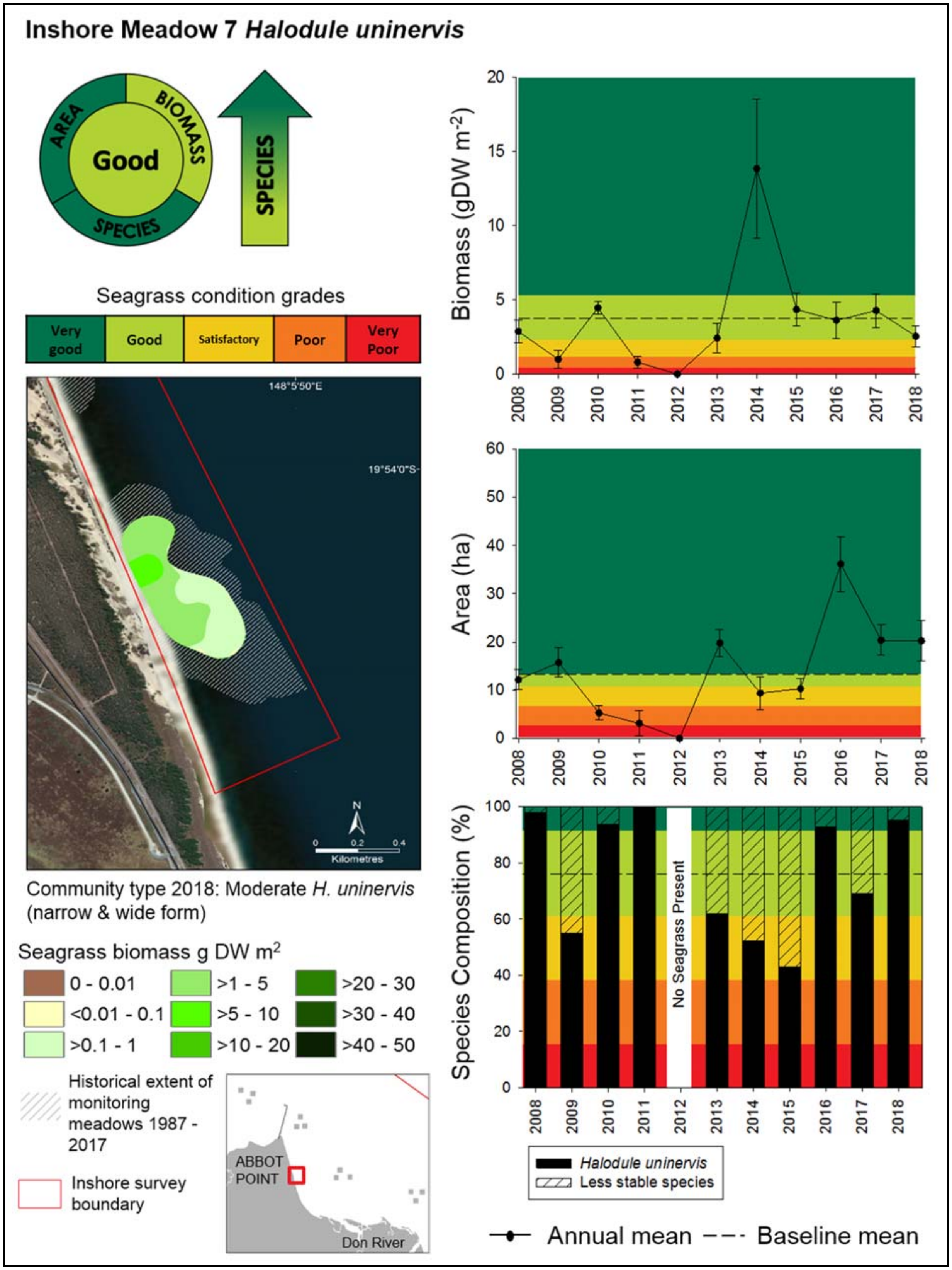
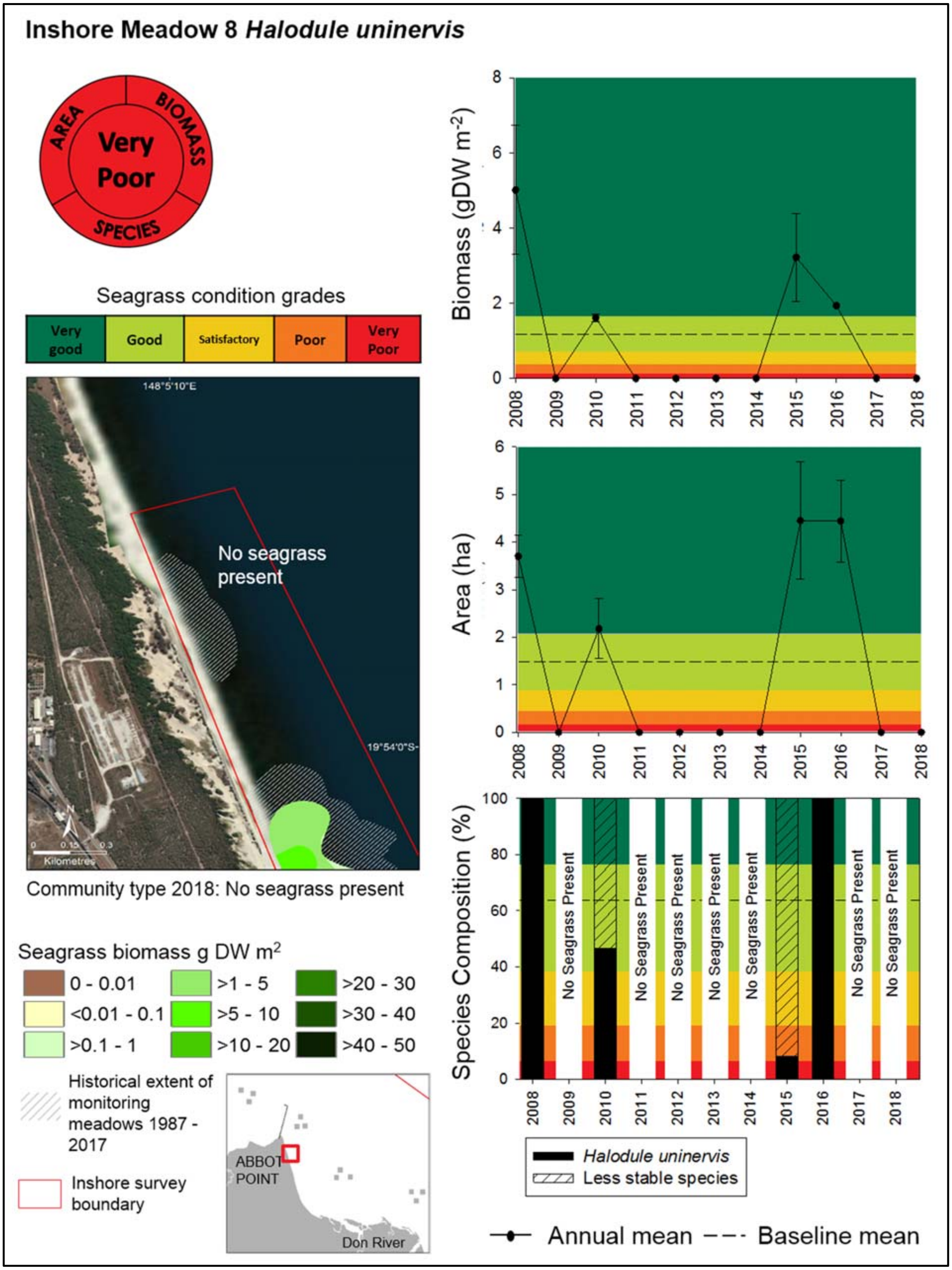



**Figure 15.** Mean meadow biomass (g DW $m^{-2}$), total meadow area (ha) and species composition at inshore monitoring Meadow 7.




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

**Figure 16.** Mean meadow biomass (g DW $m^{-2}$), total meadow area (ha) and species composition at inshore monitoring Meadow 8.

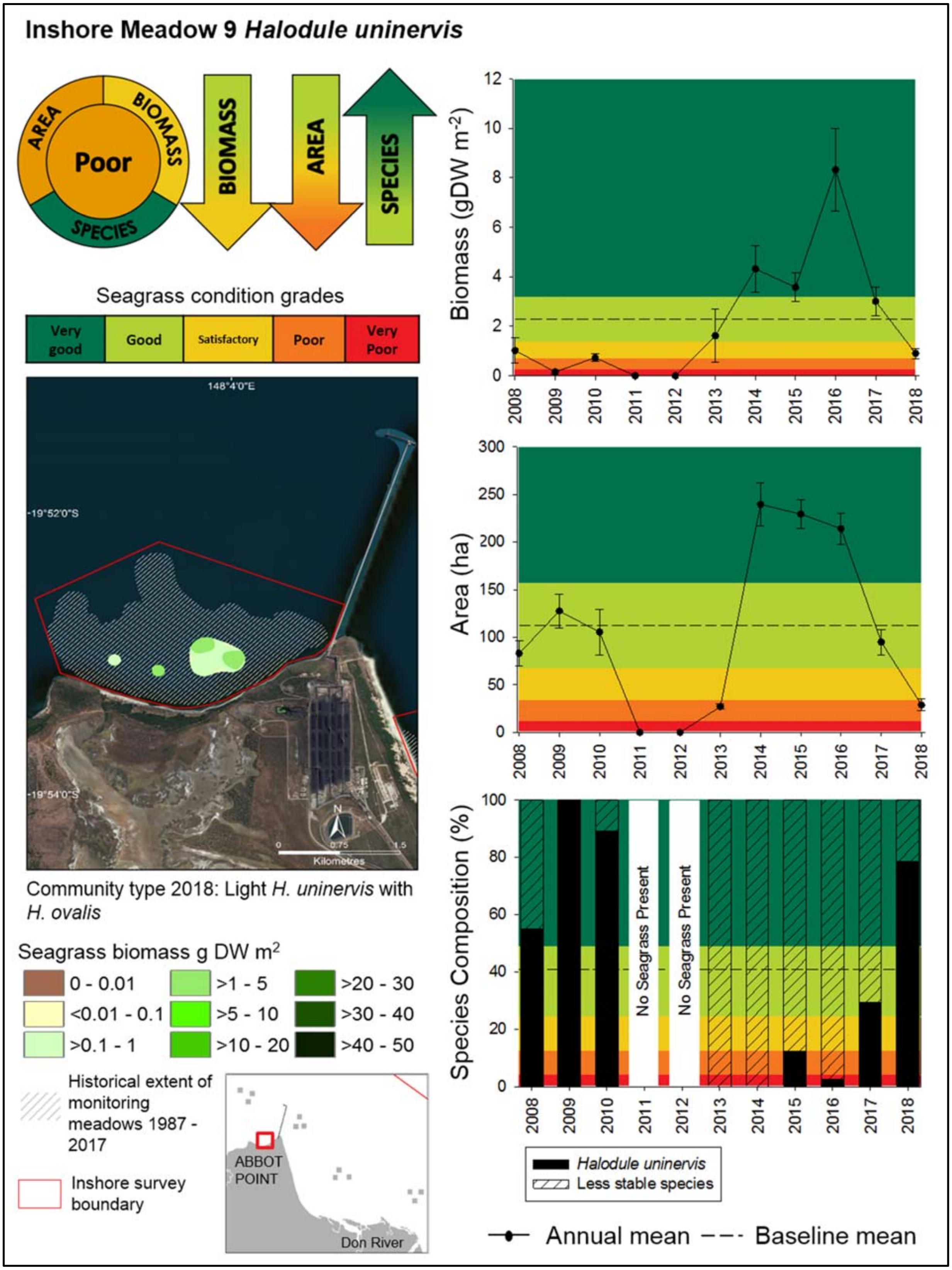



**Figure 17.** Mean meadow biomass (g DW $m^{-2}$), total meadow area (ha) and species composition at inshore monitoring Meadow 9.

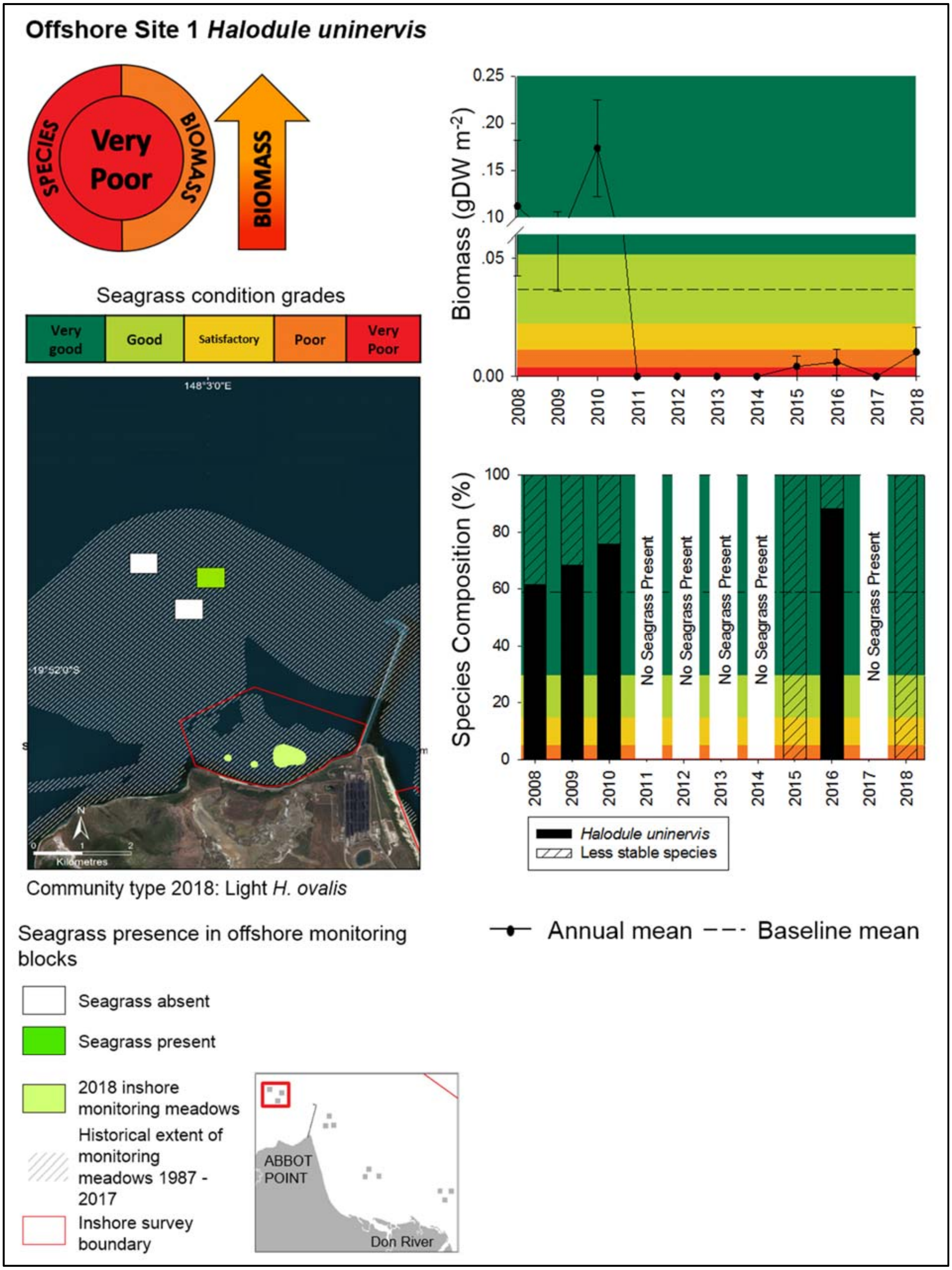



**Figure 18.** Mean meadow biomass (g DW $m^{-2}$) and species composition at offshore monitoring Site 1.

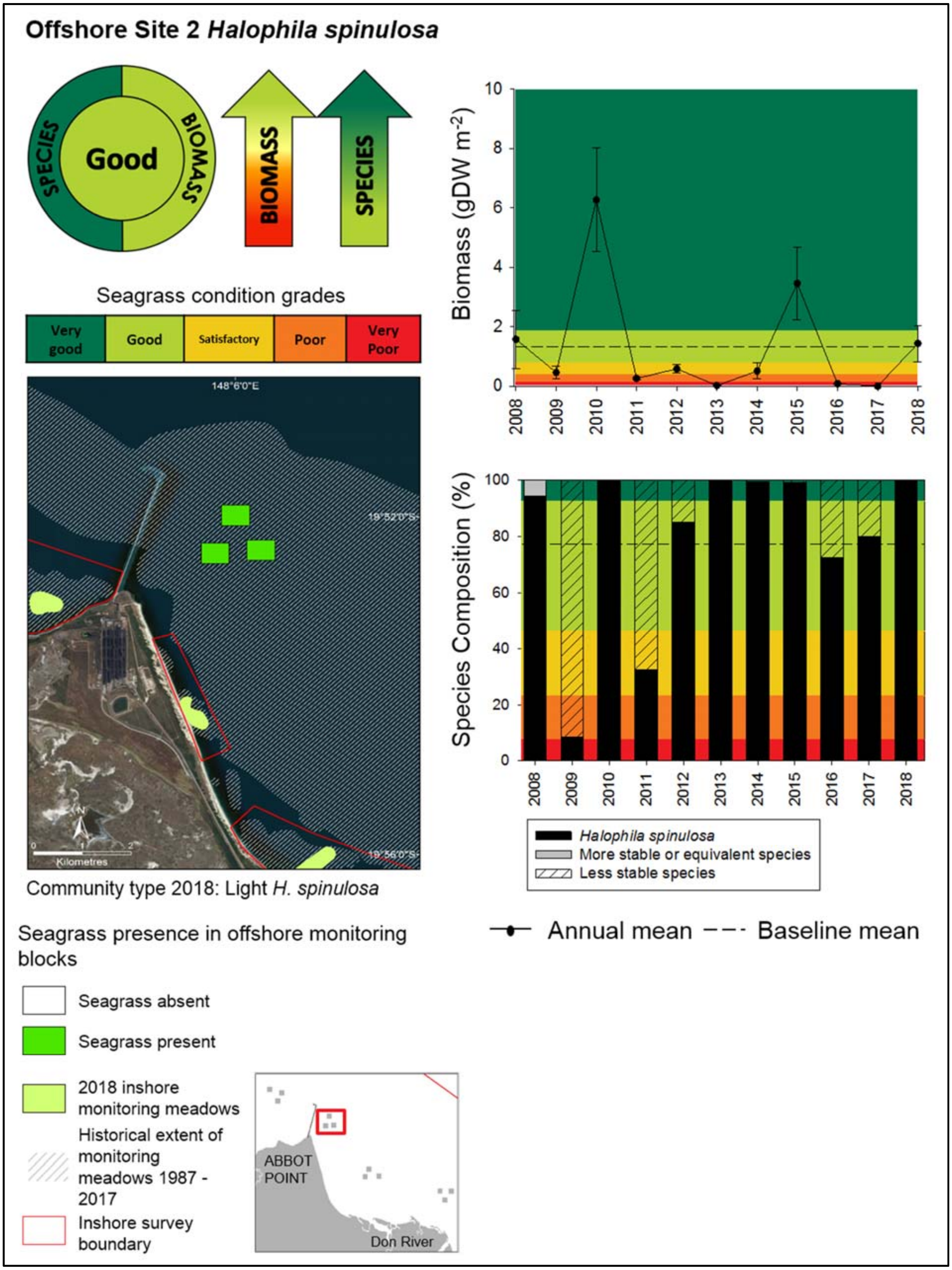



**Figure 19**. Mean meadow biomass (g DW m-2) and species composition at offshore monitoring Site 2.

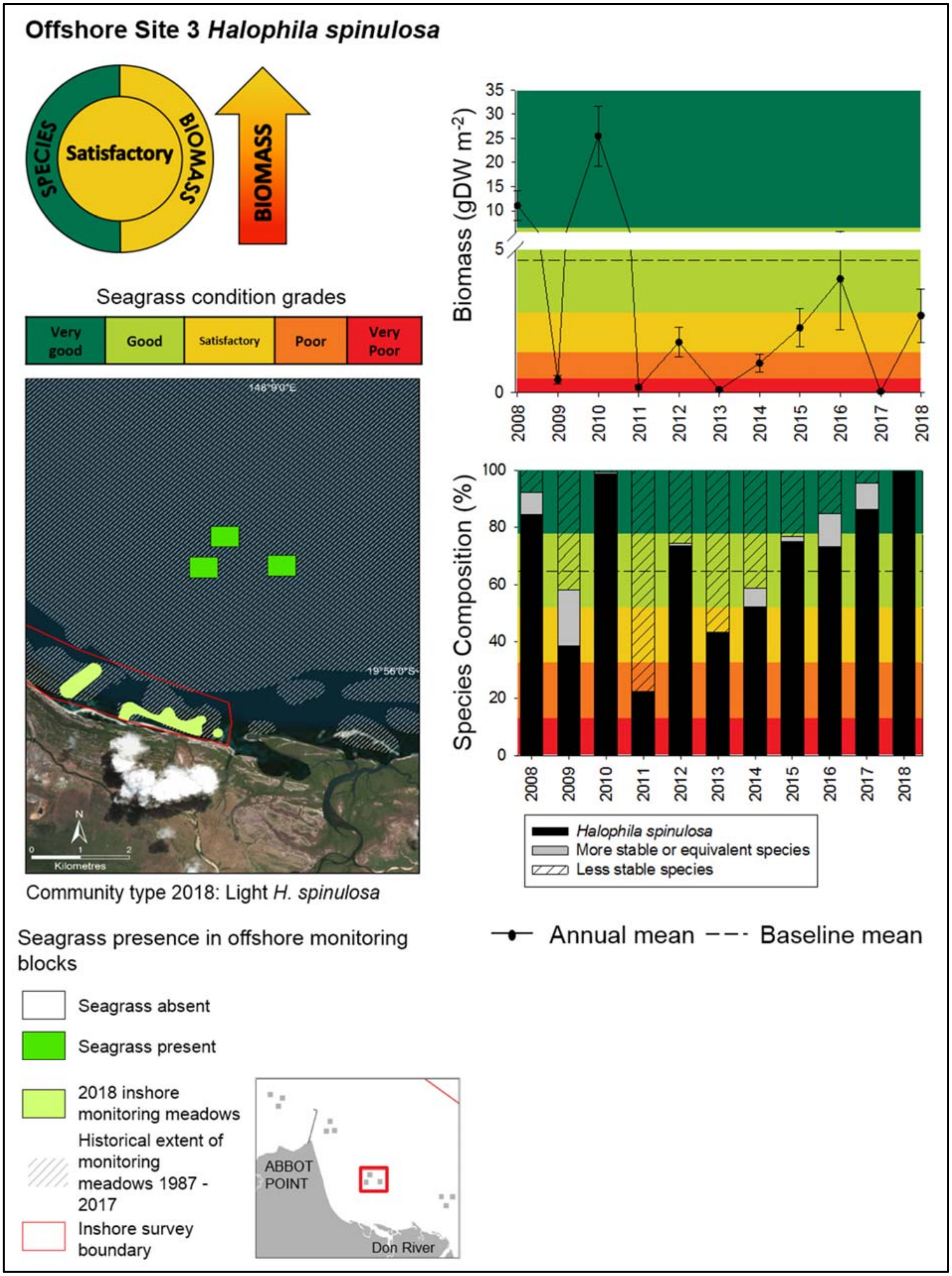



**Figure 20.** Mean meadow biomass (g DW m$^{-2}$) and species composition at offshore monitoring Site 3.

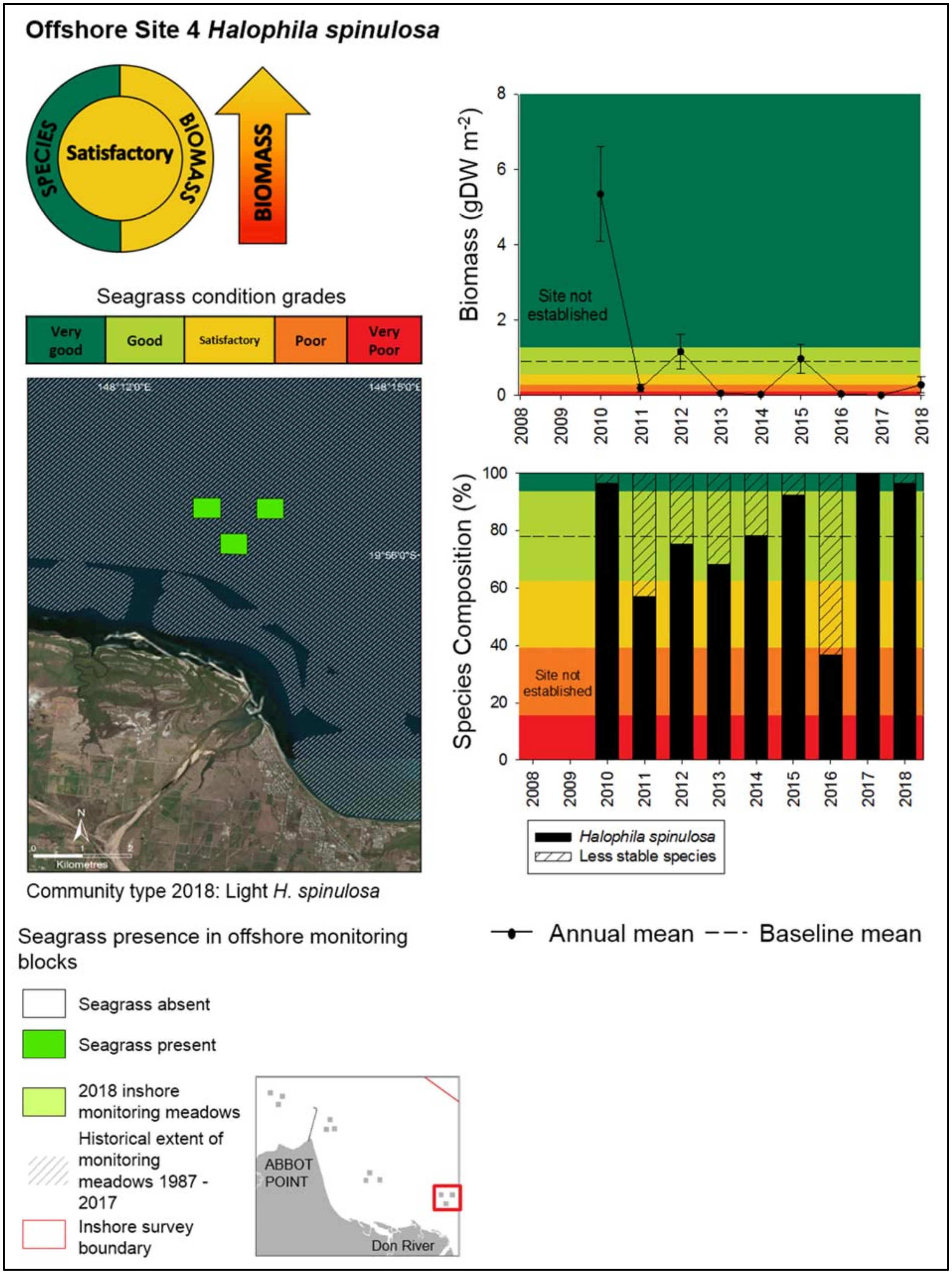



**Figure 21.** Mean meadow biomass (g DW $m^{-2}$) and species composition at offshore monitoring Site 4.

## 3.2 Abbot Point climate data

### *3.2.1 Benthic daily photosynthetically active radiation (PAR(light))*

The light available to seagrasses changed with season in 2018 and followed a typical pattern with lower levels of light during the wet season associated with higher rainfall, river flow and wind events, followed by higher light levels supporting seagrass growth during the dry season (Figure 22).

The inshore PAR sites; TW1 & TW2 are at different depths to each other and represent the depth gradient that inshore seagrasses can be found at Abbot Point. As such, the total daily light at each of these logging stations differs in their ranges. TW2 is the shallowest site, followed by TW1 then AMB 1, located offshore. Total daily PAR (rolling averages) at the three sites ranged from:

- TW1: 0 – 6.7 mol photons $m^{-2}$ $day^{-1}$
- TW2: 0.62 – 14.17 mol $m^{-2}$ $day^{-1}$
- AMB 1: 0 – 5.61 mol $m^{-2}$ $day^{-1}$

Locally derived light thresholds for the Abbot Point region were determined in 2015 (McKenna et al. 2015) and based on local data collected by this monitoring program. Analysis of the data collected at Abbot Point indicated that for the offshore areas of deep-water *Halophila* species a 1.5 mol $m^{-2}$ $day^{-1}$ over a rolling 7 day average described light conditions that supported maintenance of deep-water *Halophila* species. For the shallow inshore areas dominated by *Halodule uninervis* a threshold was 3.5 mol $m^{-2}$ $day^{-1}$ over a rolling 14 day average was recommended. There were sustained periods of time where light fell below these thresholds for the applicable species, however these periods occurred, as expected, during the wet season when seagrass undergoes seasonal senescence at the site.

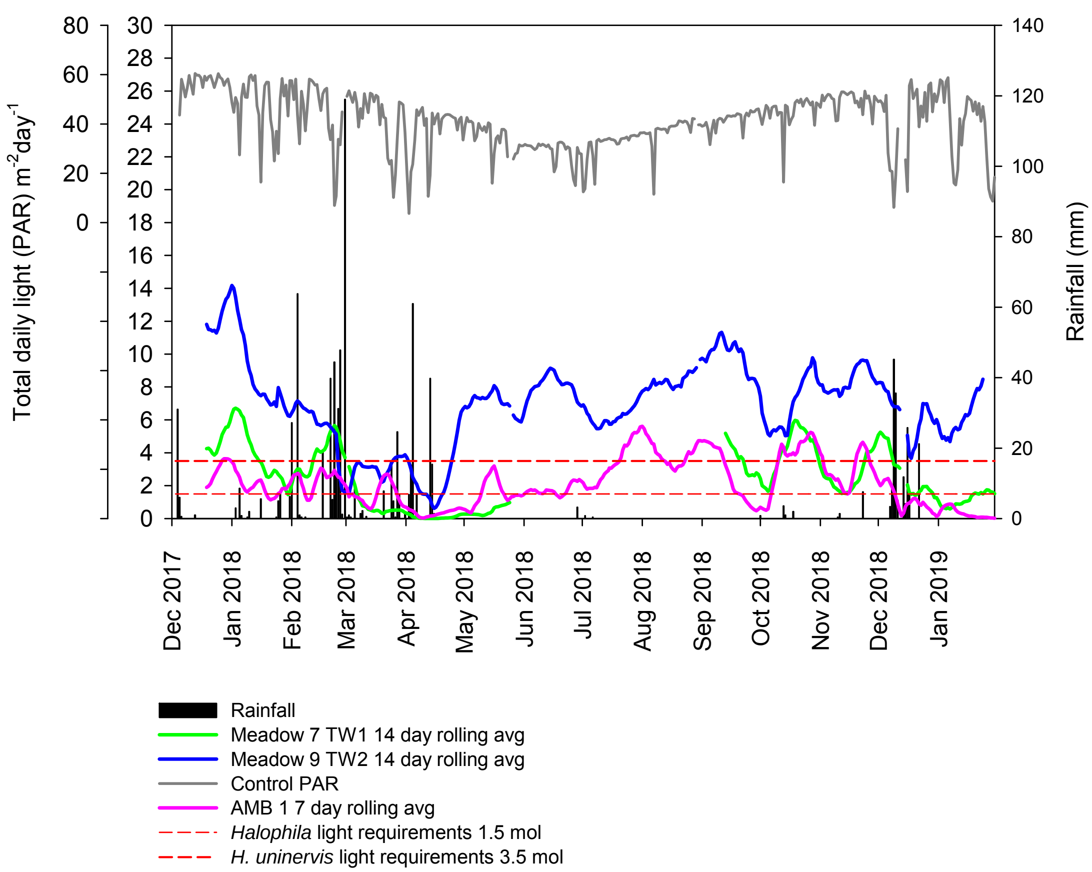



**Figure 22.** Fourteen & seven day rolling average total daily PAR (mol photons $m^{-1}day^{-1}$), total daily rainfall, and *H. uninervis* & *Halophila* light requirement December 2017 – January 2019.

### *3.2.2 Benthic water temperature*

Water temperature within the seagrass canopy followed seasonal patterns with higher temperatures during the summer followed by lower temperatures during winter (Figure 23). As expected, temperature within the seagrass canopy was lowest at the deeper offshore monitoring site compared to inshore monitoring sites (Figure 23). Maximum daily water temperature ranges at the three sites were:

Meadow 7 (TW1):

- Maximum daily water temperature ranged between 23.1 – 34.1°C. Maximum daily water temperature within the seagrass canopy was sustained over 30°C for 13 consecutive days.

Meadow 9 (TW2):

- Maximum daily water temperature ranged between 21.5 – 36.2°C. Maximum daily water temperature within the seagrass canopy was sustained over 30°C for 28 consecutive days.

Offshore site AMB 1:

- Maximum daily water temperature ranged between 20.24 – 30.6°C. Maximum daily water temperature within the seagrass canopy was sustained over 30°C for 1 day.

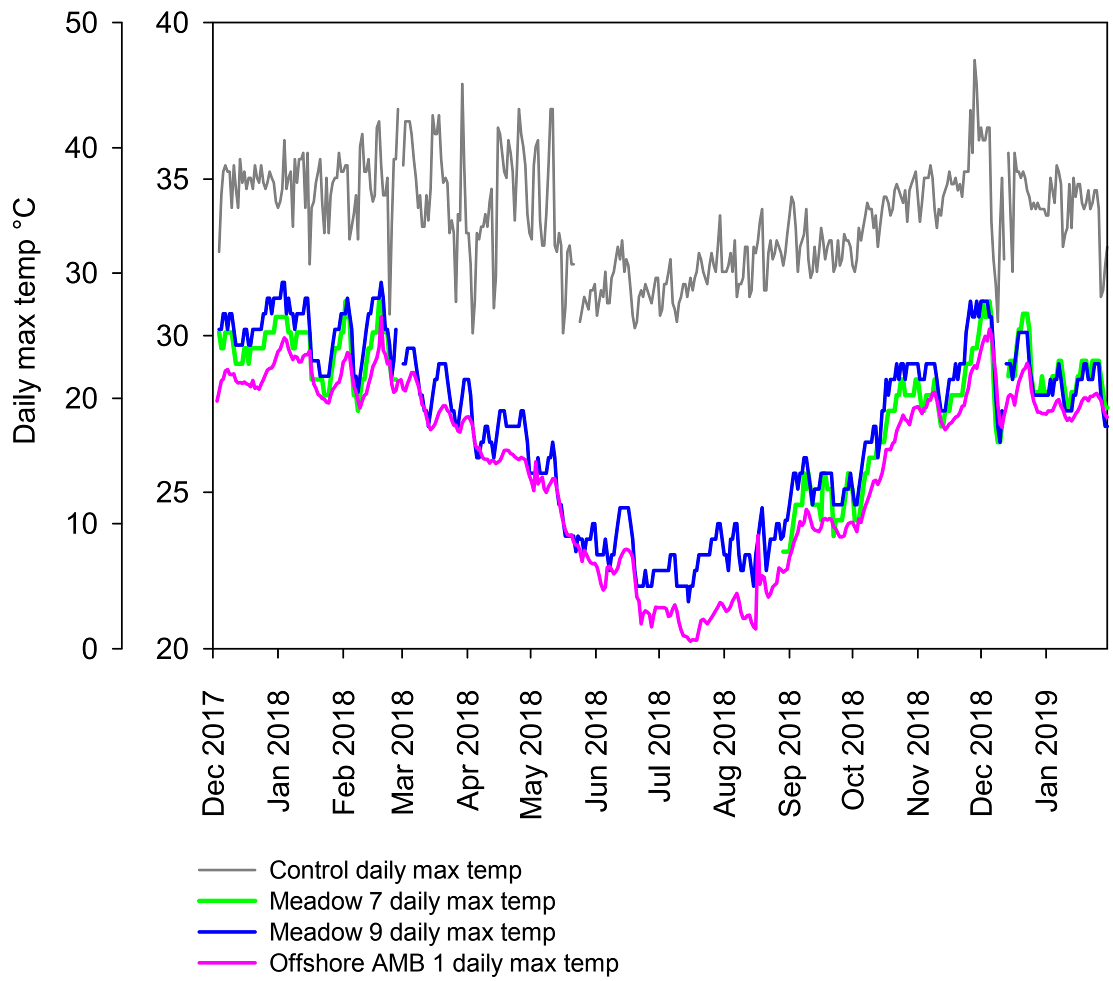



**Figure 23.** Maximum daily water temperature (°C) within the seagrass canopy at the two inshore monitoring sites and one offshore monitoring site December 2017 – January 2019.

### *3.2.3 Rainfall*

Total annual rainfall was 738mm and below the long term average in 2017/18 (Figure 24a). Rainfall followed similar wet season trends leading up to the annual survey, with February having the highest rainfall of 387 mm (Figure 24b). February, April and December (survey month) rainfall exceeded the historical monthly long-term average (Figure 24b).

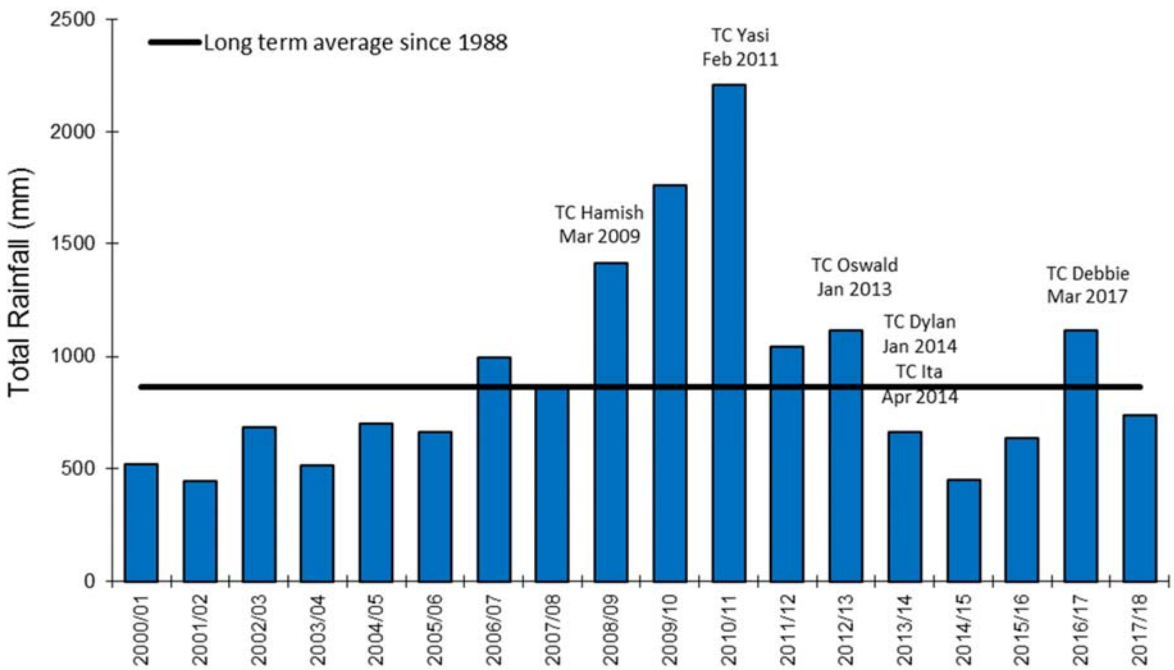



**Figure 24a.** Total annual rainfall (mm) recorded at Bowen, 2001/02-2017/18. Twelve month year is twelve months prior to the survey. Source: BOM, Station number 033257.

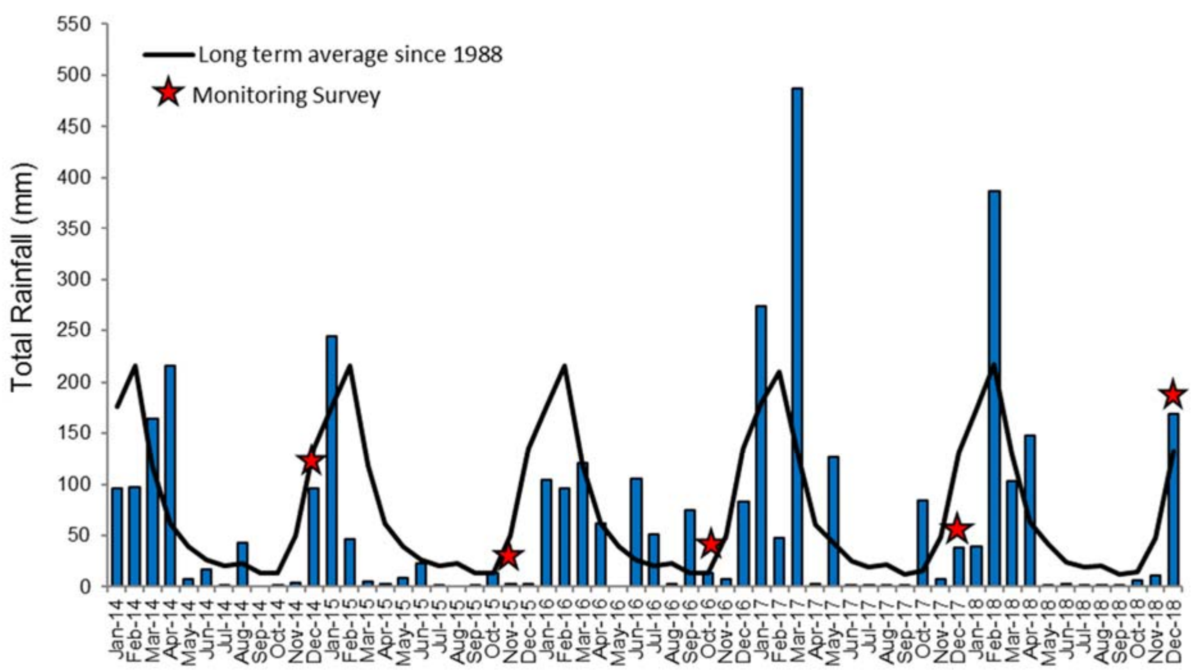



**Figure 24b.** Total monthly rainfall (mm) recorded at Bowen, January 2014- December 2018. Source: BOM, Station number 033257.

### *3.2.4 River Flow - Don River*

River flow for the Don River was well below the long-term annual average of 155,407 ML in 2017/18 (Figure 25a). The highest amount of river flow in the survey year occurred between February and April but remained below long term monthly averages (Figure 25b).

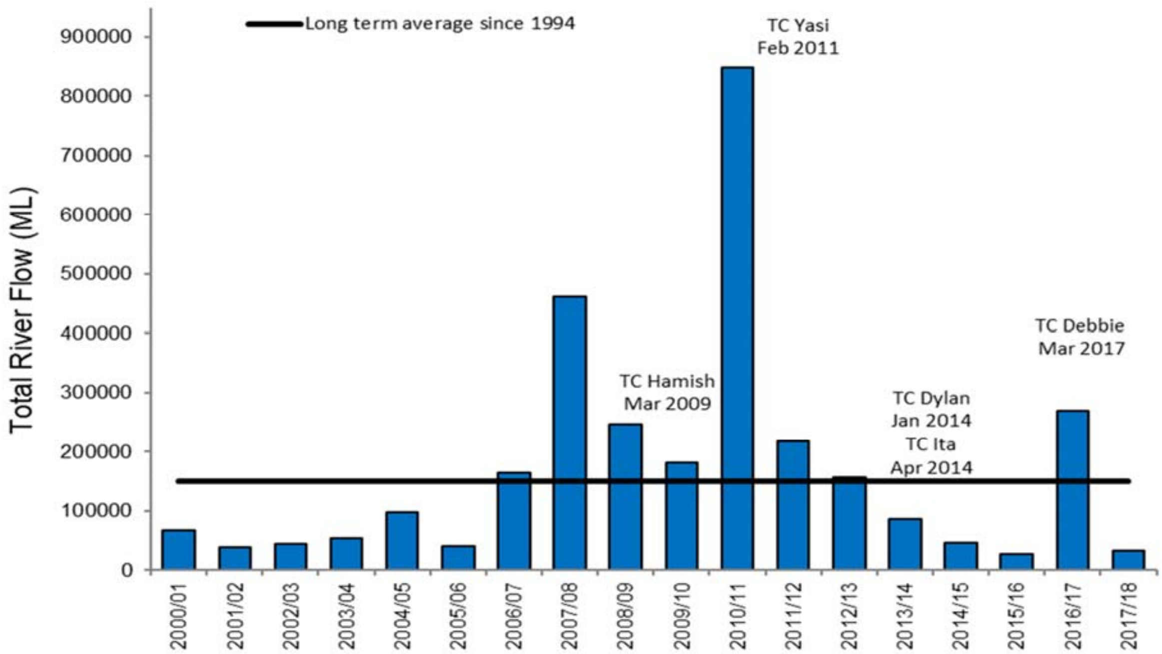



**Figure 25a.** Total annual river discharge of the Don River (Station 121003A) from 2000/01 to 2017/18. Twelve month year is twelve months prior to the survey. Source: Department of Natural Resources and Mines (DNRM).

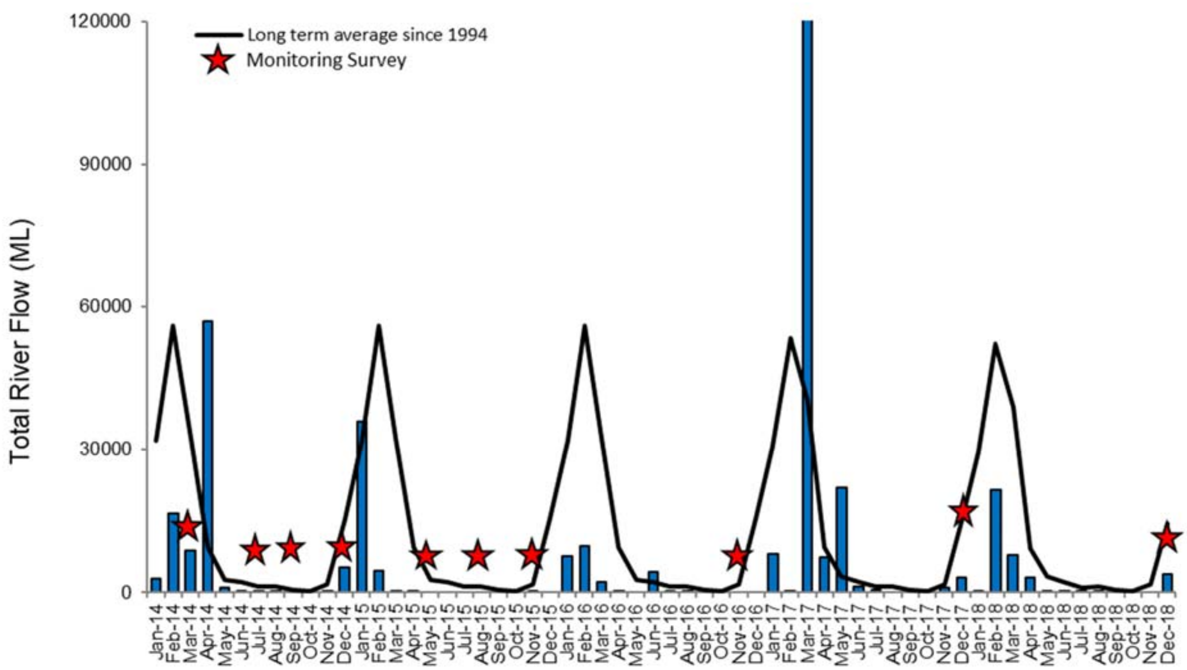



**Figure 25b.** Total monthly river discharge of the Don River (Station 121003A) from January 2014 to December 2018. Source: DNRM.

### *3.2.5 Significant Wave Height*

RMS water height data has been collected by the JCU Geophysics team at Abbot Point as part of the NQBP/JCU partnership. Data presented below is from the partnership and detailed data from the water quality-monitoring program can be found in Waltham et al. (2018)

RMS water height values are mostly driven by weather events. The data presented below is RMS data at water quality monitoring site AMB 1 which is closest to the offshore seagrass monitoring sites 2-4. Maximum RMS peaked between March and April (Figure 26), coinciding with high wind events (BOM 2019), rainfall, river flow and low light periods. Peaks in RMS water height can cause peaks in turbidity and sediment deposition (Waltham et al. 2018).

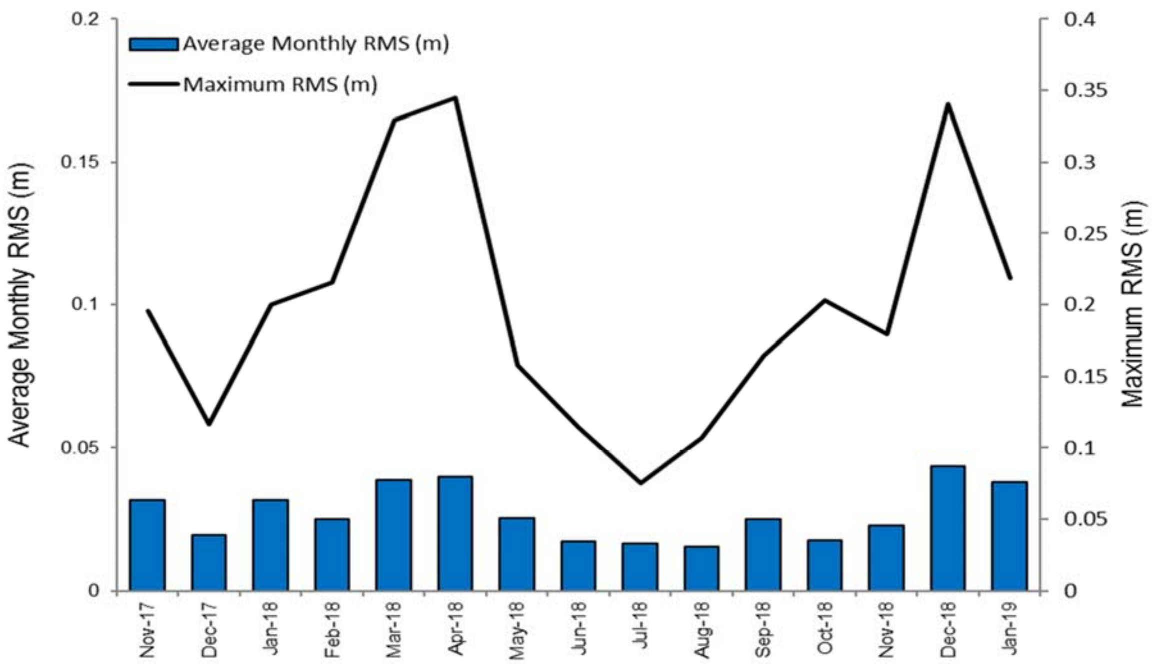



**Figure 26**. Mean monthly and maximum RMS recorded at Abbot Point water quality site AMB 1 November 2017 – January 2019.

# 4. DISCUSSION

Seagrasses in the Port of Abbot Point were in a satisfactory condition in 2018, improving from the reductions caused by Tropical Cyclone Debbie in 2017. Results for individual seagrass meadows varied with shallow coastal meadows to the southeast of Abbot Point generally showing better recovery than those to the northwest, and deep-water seagrasses in offshore areas recovering faster than the shallower offshore meadows. The improvements to seagrass and presence of the key foundation species were good signs for the recovery of seagrass resilience at Abbot Point, however another round of flooding and wind and storm events in the months following the 2018 survey had the potential to once again reduce seagrass condition.

The rate of recovery following a disturbance event such as a cyclone, can depend on factors such as magnitude of the disturbance, the seagrass species affected, the existence of seed banks or remnant patches from which recovery can occur, and the intrinsic environmental conditions of the affected area (McKenna et al. 2015; Rasheed et al. 2014; Carruthers et al. 2002). Varying rates of seagrass species recovery following cyclone impacts has previously been observed at Abbot Point (Rasheed et al. 2014). Experimental studies along with this monitoring program have shown that the deeper meadows at Abbot Point are generally able to recover faster due to availability of seeds and rapid colonising strategies of the *Halophila* species that make up these meadows (Rasheed et al. 2014). In contrast, the same studies showed that shallow species; *H. uninervis* and *Z. muelleri* at Abbot Point were slow to recover, taking 3 – 4 years to return to pre-disturbance levels (McKenna et al. 2016; Rasheed et al. 2014).

*Halophila* species are a genus well adapted to low light conditions (Chartrand et al. 2018; Fourqurean et al. 2003; Udy and Levy 2002) but quick to decline when stressed (Chartrand et al. 2018; York et al. 2015). The life history strategy of *Halophila* species means they are also well adapted for recovery once conditions become favourable. Their high fecundity and rapid rate of rhizome growth makes this species well suited to high-disturbance environments (Rasheed et al. 2014; Unsworth et al. 2010; Hammerstrom et al. 2006; Rasheed 2004). In contrast, experiments conducted by our group at Abbot Point, found that shallow species did not recover quickly from disturbance, had poor seed reserves and relied on asexual propagation. The potential for shallow species to recover rapidly from widespread losses was limited when the adult population was lost as seed banks were limited or non-existent (Rasheed et al. 2014). In 2018 many of these meadows had improved post TC Debbie, most likely due to some seagrass remaining from which asexual recolonization could occur. It is interesting that the one meadow that had completely disappeared following TC Debbie has yet to re-establish, most likely due to the lack of local seeds observed for most of these meadows and existing at the margins of light availability.

Environmental conditions were generally favourable at Abbot Point during the 2018 growing season and likely assisted the continued recovery of seagrasses in the area. Light in particular is a major driver of seagrass condition, and shifts in available light have the ability to significantly affect seagrasses and their recovery. In 2018 light at Abbot Point during the seagrass growing season, generally met locally derived requirements (McKenna et al. 2015).

At Abbot Point it appears the locally realised light thresholds for seagrass meadows may be somewhat lower than the regional values suggested in guiding documents for seagrass light requirements in the Great Barrier Reef (Collier et al. 2016). Our work at Abbot Point has indicated that for the inshore areas dominated by *H. uninervis*, the light threshold is likely to be 3.5 mol $m^{-2}$ $day^{-1}$ over a 14 day integration period and for the offshore areas of deep-water *Halophila* species 1.5 mol $m^{-2}$ $day^{-1}$ over a 7 day integration period (see also McKenna et al. 2015). Both of these values are lower than those suggested as a GBR wide guide for the species in Collier et al. (2016) (5 mol $m^{-2}$ $day^{-1}$ and 2 mol $m^{-2}$ $day^{-1}$). This difference is likely because the majority of studies on *Halodule uninervis* and *Zostera muelleri* light requirements have been performed at intertidal locations, where seagrasses are periodically exposed to the air and the full light that would reach the water surface during low tide (Chartrand et al. 2016; Collier et al. 2016; Collier et al. 2012; Longstaff and Dennison 1999). While this results in higher overall light values than subtidal areas, it appears that seagrasses are not able to gain a net benefit of the high light during exposure to air, due to exposure related stresses (Petrou et al. 2013). This has the effect of inflating the light threshold value for intertidal species compared to subtidal populations where seagrasses are able to effectively use all of the light they receive, as they are not subjected to tidal exposure stresses. This is supported by the one study conducted subtidally where an impact on *H. uninervis* was not realised until light fell below 4 mol $m^{-2}$ $day^{-1}$ (Collier et al. 2012). All of the *Halodule* uninervis and *Halophila* seagrasses at Abbot Point are subtidal.

Seagrasses at Abbot Point were one of the worst affected seagrass areas in our monitoring network from TC Debbie in 2017. The continued increase of overall seagrass biomass and the presence of persistent species such as *H. uninervis* and *Z. muelleri* in the Abbot Point region in 2018 was a positive sign of ongoing seagrass recovery and gains to their resilience to future impacts. In addition, the continued presence of meadows of the same species within a few hundred metres of the meadows not present in 2018 (inshore meadow 8 & offshore site 1) provides a good potential source for new seagrass recruits (Grech et al 2016). Continued recovery of the shallower seagrass meadows will be contingent on environmental conditions being favourable for seagrass growth, particularly during the 2019 growing season. Since the completion of the 2018 survey, however, the Abbot Point region experienced long periods of high rainfall associated with TC Oma resulting in extensive flooding and river flow events. This had the potential to once again impact on seagrass meadows.

Results of seagrass condition in Abbot Point were generally in line with other seagrass monitoring results for the east coast of Queensland in 2018. Seagrass condition generally improved or had stabilised during 2018 in the other east coast ports where our seagrass monitoring program is conducted (e.g. Gladstone – Chartrand et al. 2019, Hay Point – York and Rasheed 2019, Townsville - Bryant et al. 2019, Cairns - Reason et al. 2019, Weipa –McKenna et al. 2019). Although in the southern Gulf of Carpentaria, seagrasses had declined in response to local pressures from regional floods, that did not impact the east coast (e.g. Karumba – van de Wetering et al. 2019).

***Potential changes for ongoing monitoring***

The long-term monitoring program has given us an understanding of the natural variability in presence, density and spatial footprint of the inshore seagrass meadows. The five inshore meadows that were selected for monitoring were identified in 2008 (McKenna et al. 2008) and while they continue to be the most suitable areas for monitoring, the first 10 years of data suggest that three of the meadows that have been treated individually really represent one seagrass habitat that has a variable spatial footprint. Ideally, these three *H. uninervis* meadows on the southeastern side of Abbot Point (meadows 5, 7 & 8; Figure 26) should be combined to form one *H. uninervis* monitoring area for the purpose of determining scores and condition from 2019 (Figure 27). Combining these meadows would not cause any significant changes in historical results, and the different types of seagrass communities and habitat types would still be represented. The change in approach would effectively reduce the influence of this strip of similar seagrass habitat when rolled up into the overall score for the inshore zone, and the larger Abbot Point regional score to more appropriately reflect their composition of the total Abbot Point seagrass community.

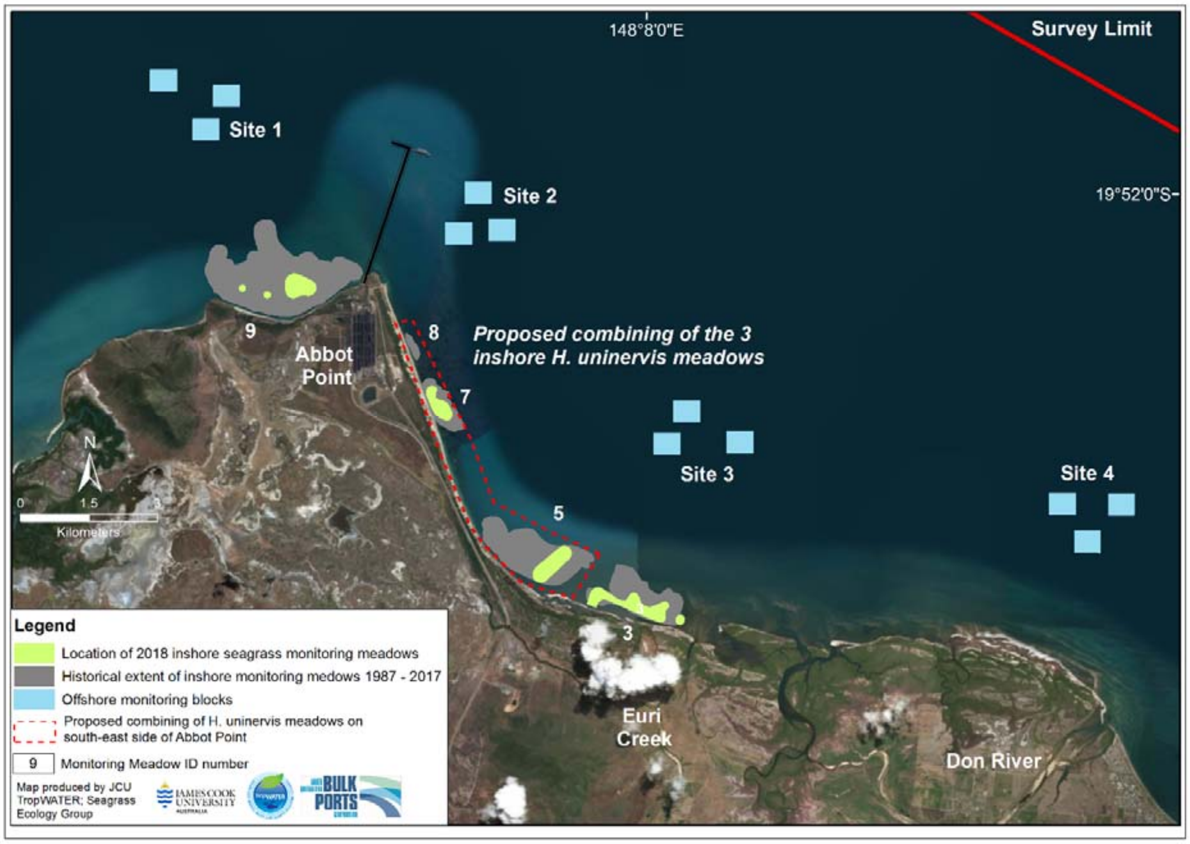



**Figure 27.** Location of inshore monitoring meadows and the area proposed to be combined to form one monitoring area from 2019 onwards.

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# 6. APPENDICES

## Appendix 1. Scoring, grading and classification of seagrass meadows

### *1.1 Baseline Calculations*

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2008-2017). This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014). The 2008-2017 period incorporates a range of conditions present in the Abbot Point region, including El Niño and La Niña periods, and multiple extreme weather events. A 10 year long-term average will be used for future assessments and 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). 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 Grade and Score Calculations section and Figure A1).

### *1.2 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 and species composition were classified as either stable or variable (Table A1). Meadow area was classified as either highly stable, stable, variable, or highly variable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

**Table A1.** 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% | - |

**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 A2).

**Table A2.** 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 | |   |

### *1.3 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, and for the Abbot Point region (Table A3; see Carter et al. 2016; 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 (see Baseline Calculations section), allocating a grade for each indicator by comparing the current years 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 A3). 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.

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 2.

**Table A3.** Score range and grading colours used in the 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 driving this grade/score (Figure A1). 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 A1). 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 the Abbot Point region, 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 A1).

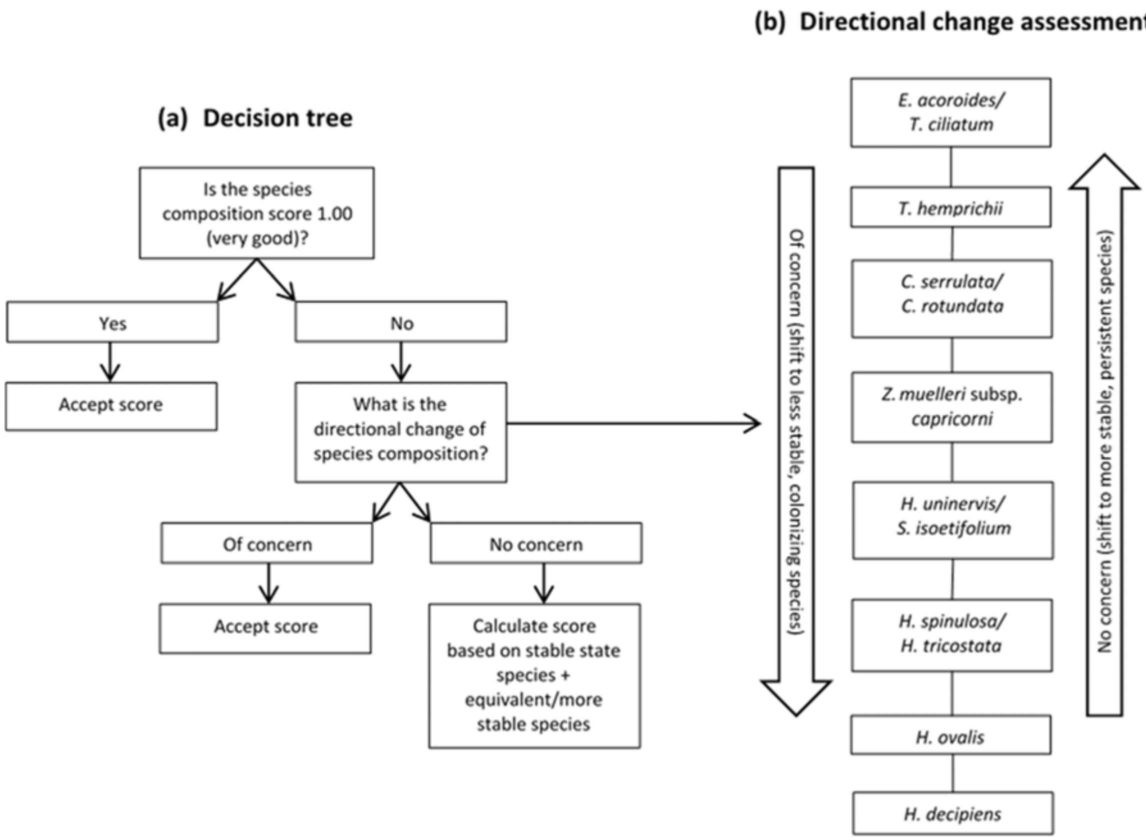



**Figure A1**. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

***1.4 Score Aggregation***

A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years' annual report. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change acknowledges that species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014b).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such a food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a "0" score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lower of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in the Abbot Point region as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Weipa, Mackay, Hay Point, Mourilyan Harbour, Torres Strait, Gladstone and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across Weipa (and the other locations), where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Overall 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 (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process 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. Port grades are therefore more sensitive to changes in stable than variable meadows.

## Appendix 2. Calculating meadow scores

An example of calculating a meadow score for biomass in satisfactory condition in 2016.

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:

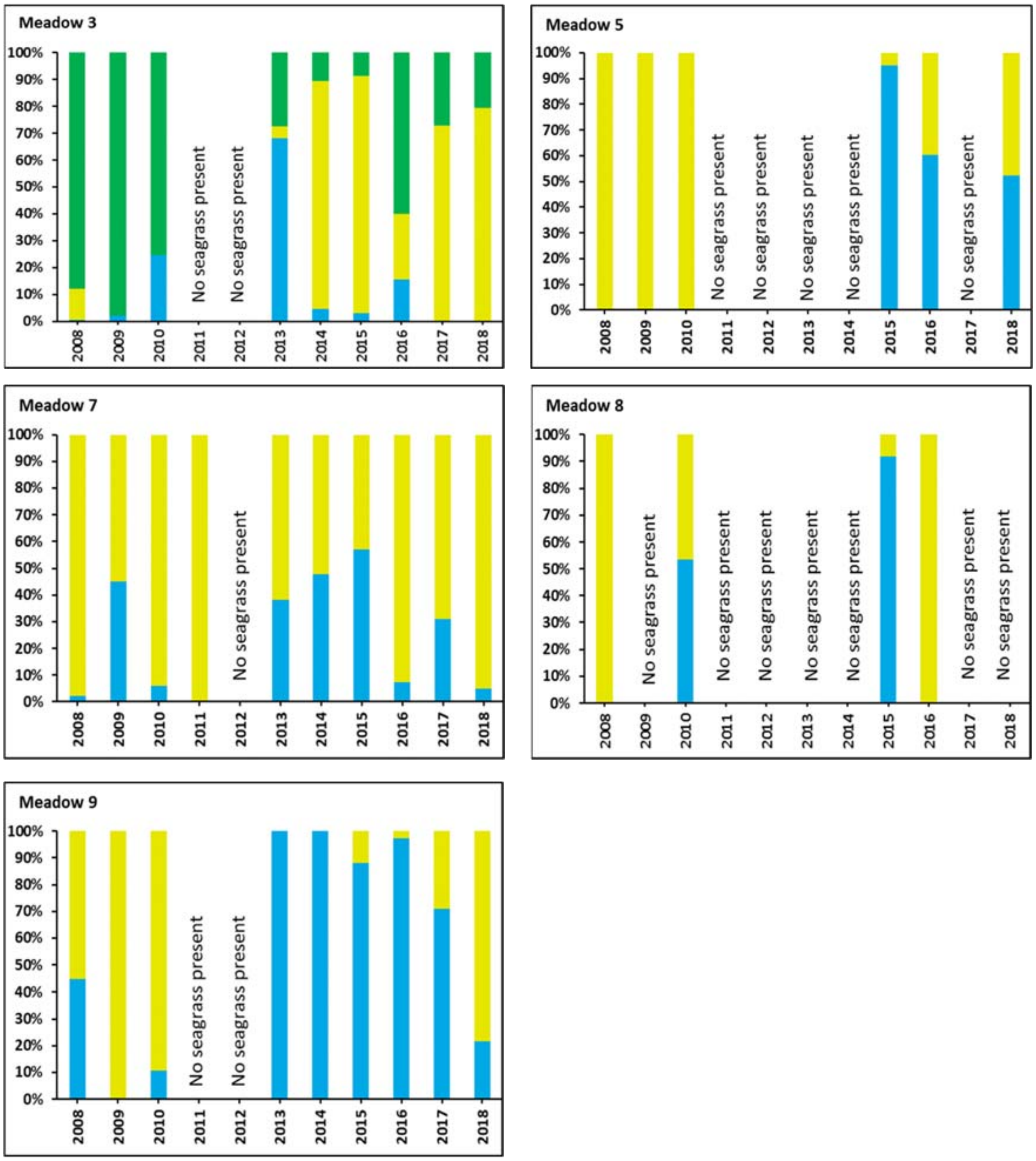
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

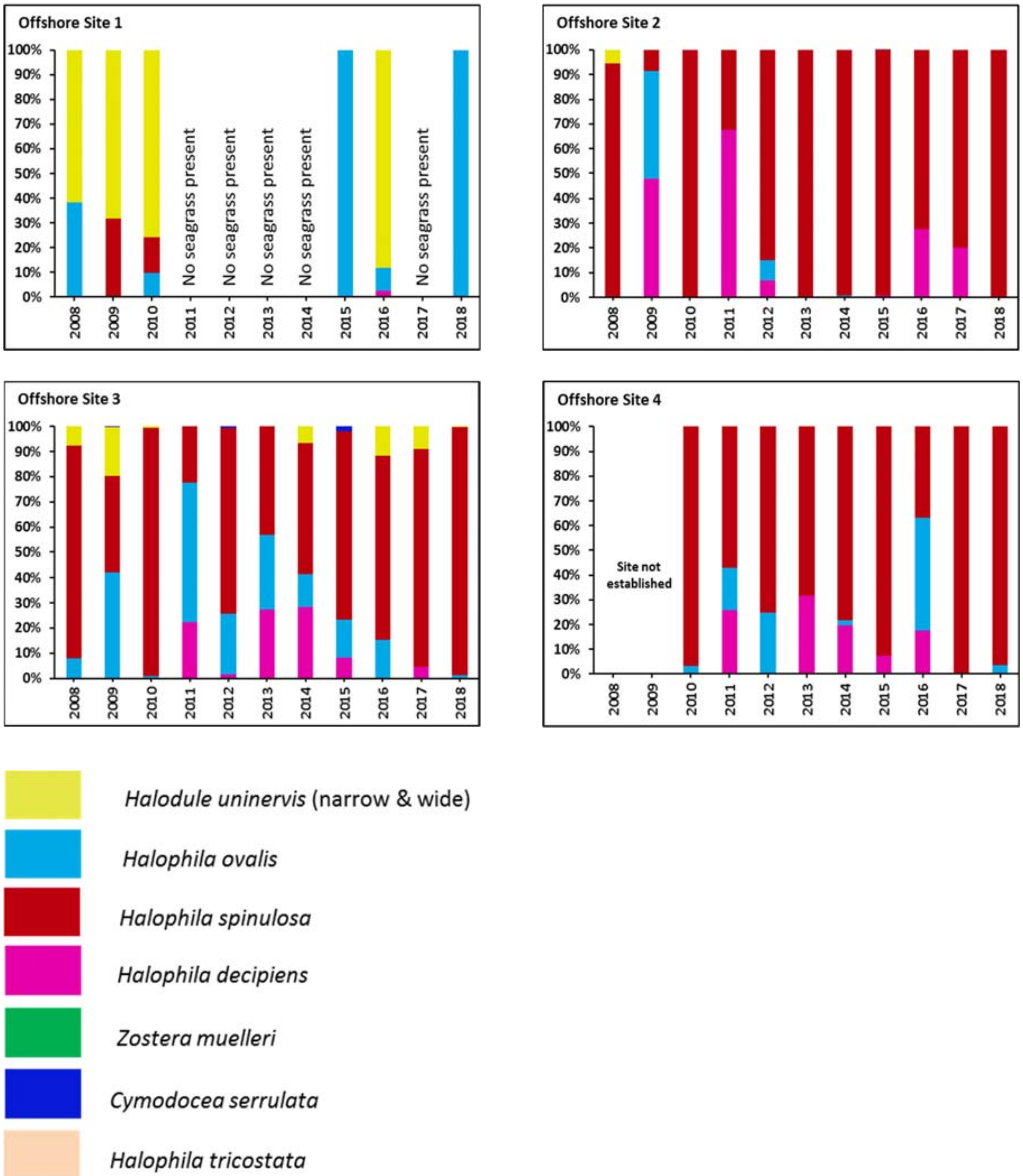
5. Determine the biomass score for 2016 ($Score_{2016}$) by scaling $B_{prop}$ against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

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

**Appendix 3. Species composition of inshore and offshore monitoring meadows in the Abbot Point region: 2008 – 2018**




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
No seagrass present
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Offshore Site 2
Offshore Site 3
Offshore Site 4
Site not established
Halodule uninervis (narrow & wide)
Halophila ovalis
Halophila spinulosa
Halophila decipiens
Zostera muelleri
Cymodocea serrulata
Halophila tricostata

## Appendix 4. Biomass and area of inshore and offshore meadows

**3A.** Mean biomass of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2018.

| 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) |
| Dec 17 | 5.85 ± 1.05 (13) | NP | 4.27 ± 1.13 (9) | NP | 3.0 ± 0.57 (20) |
| Dec 18 | 2.77 ± 0.76 (12) | 2.78 ± 1.16 (3) | 2.55 ± 0.70 (9) | NP | 0.90 ± 0.20 (5) |

NP – No seagrass present in meadow

**3B.** Area (ha) of inshore monitoring meadows in the Abbot Point region; quarterly 2005, 2008 – 2018.

| 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 ± 0.45 | 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 ± 4.62 | 13.3 ± 10.1 | 15.7 ± 3.06 | 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 ± 4.9 | 16.04 ± 6.55 | 5.25 ± 1.51 | 2.18 ± 0.63 | 105.38 ± 85.44 | 143.89 ± 23.66 |
| 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 ± 22.83 |
| 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 ± 4.15 | 25.92 ± 2.89 | 10.30 ± 2.15 | 4.45 ± 1.23 | 229.36 ± 38.62 | 298.61 ± 15.26 |
| Nov 16 | 78.40 ± 6.17 | 130.11 ± 9.14 | 36.17 ± 14.69 | 4.44 ± 0.86 | 214.02 ± 41.28 | 463.14 ± 16.32 |
| Dec 17 | 43.91 ± 5.33 | NP | 20.38 ± 3.13 | NP | 94.91 ± 16.76 | 159.20 ± 13.40 |
| Dec 18 | 47.67 ± 5.15 | 30.31 ± 4.8 | 20.25 ± 4.19 | NP | 28.80 ± 6.02 | 127.04 ± 6.02 |

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 – 2018.

| 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 |
| Dec 17 | NP | 0.007 ± 0.003 | 0.03 ± 0.015 | 0.004 ± 0.002 |
| Dec 18 | 0.01 ± 0.01 | 1.44 ± 0.61 | 2.70 ± 0.93 | 0.28 ± 0.21 |

* - 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