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PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM - 2019

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Report No. 20/12

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A Report for North Queensland Bulk Ports Corporation (NQBP)

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KEY FINDINGS

Inshore Seagrass Condition

Satisfactory

Likely causes of seagrass condition:

↑ *Favourable climate conditions in the growing season*

↑ *Continued recovery from climate related events*

Offshore Seagrass Condition

GOOD

Likely causes of seagrass condition:

↑ *Favourable climate conditions in the growing season*

↑ *Continued recovery from climate related events*

- *Fast colonising species*

- In 2019 seagrass in the annually monitored meadows at Abbot Point were in an overall satisfactory condition, similar to 2018 and remain in a recovery phase

- Inshore seagrass meadows were in a satisfactory condition and offshore seagrass was in a good condition. For offshore shore seagrass, this was an improvement from satisfactory the previous year and poor in 2017 following TC Debbie.

- The 2019 survey also examined all seagrasses within the broader port limits (conducted every 3 years):
  - Seagrass covered a slightly lower area compared to previous surveys, and seagrass biomass across the region was lower than the previous survey in 2016, but greater than 2008 and 2013.

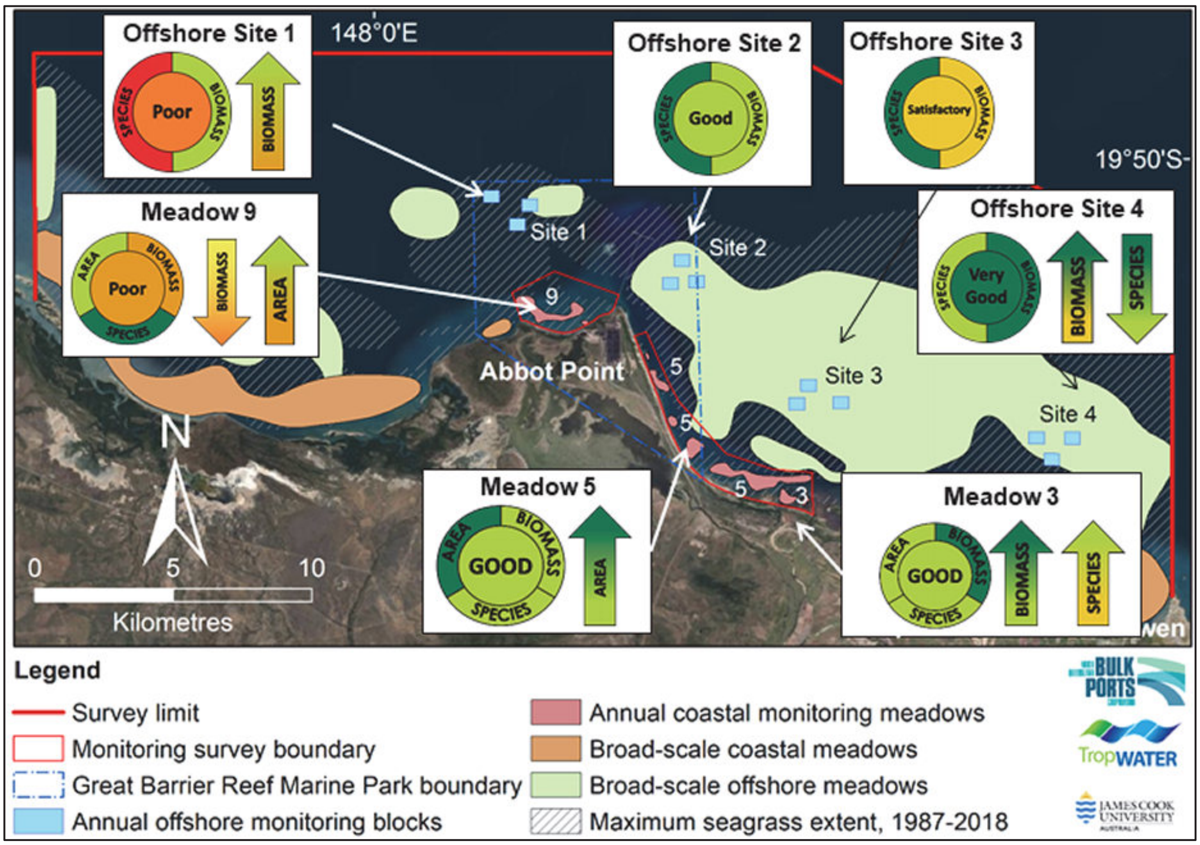
- Environmental conditions were favourable for seagrass growth from March through to the end of the year, with only a short period of high rainfall at the beginning of the year.

- Successive years of climate impacts on Abbot Point seagrass meadows are likely to have reduced the resilience of seagrass in the area to future natural and anthropogenic disturbances. Continued recovery will be contingent on future weather being favourable for seagrass growth.

IN BRIEF

A long-term seagrass monitoring program and strategy was established in the Abbot Point region in 2008 following initial surveys of the area in 2004 and 2005. The present program has evolved to consist of annual surveys of three representative monitoring areas inshore and four monitoring areas offshore with a broad scale assessment occurring every third year; completed again in 2019 (Figure 1).

In 2019 the overall condition of seagrasses in the Abbot Point area was satisfactory; offshore seagrass was in good condition, while inshore seagrass monitoring meadows remained in satisfactory condition. For offshore seagrasses this represents an improvement in seagrass condition in the region from poor in 2017 following reductions caused by Tropical Cyclone Debbie (Figure 1 & 2). The broad scale survey in 2019 (conducted every three years) found total area and footprint of seagrass was slightly below previous surveys in 2008, 2013 and 2016. Seagrass biomass across the region was lower than the previous broad scale assessments in 2016, but greater than 2008 and 2013.



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

Figure 1. Seagrass condition index for Abbot Point seagrass monitoring areas 2019.

The general trend from the 2019 survey was of a continued phase of recovery, building on losses that occurred in 2018 following TC Debbie. In early 2019, there were additional pressures from TC Oma, TC Penny and Tropical Low 13U.

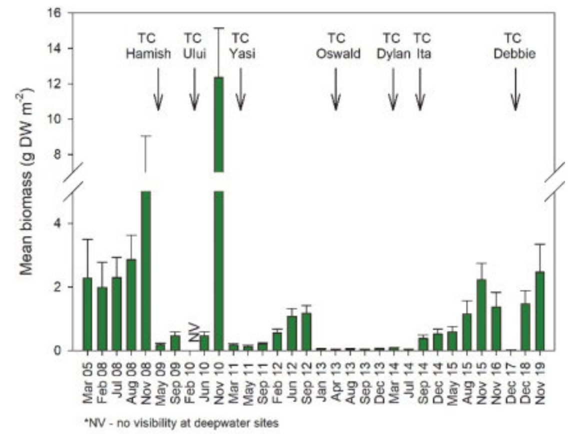


Figure 2. Mean biomass (g dw m^{-2}) of Abbot Point offshore seagrass monitoring sites from 2005 to 2019. Offshore site 1 is excluded from calculations.

Varying rates of seagrass recovery following climate impacts have previously been observed at Abbot Point following TC Yasi with deeper meadows recovering faster, while shallow coastal meadows were slow to recover, taking 3 – 4 years to return to pre-disturbance levels. The pattern of recovery over the last two years has been similar with deeper offshore meadows containing colonising *Halophila* species showing greater signs of recovery and slower recovery at inshore meadows. In 2019 the inshore coastal meadows containing more opportunistic species such as *Halodule uninervis* and *Zostera muelleri* showed some more recovery and were expanding at most monitoring meadows (Figure 1).

During the 2019 seagrass growing season, environmental conditions returned to being favourable and likely assisted the continued recovery of seagrasses in the area. Prior to the survey, rainfall was above the long-term annual average for the region as a result of heavy rainfall in January and March of 2019 (Figure 3). Heavy rainfall combined with overcast conditions can lead to declines in water quality reducing the amount of light available for seagrasses to photosynthesise. Light, one of the key requirements for the persistence and growth of seagrass followed typical seasonal patterns with extended low light periods occurring during the wet season, and at levels above the recommended minimum light requirements for seagrass during dry season when seagrasses are actively growing and expanding.

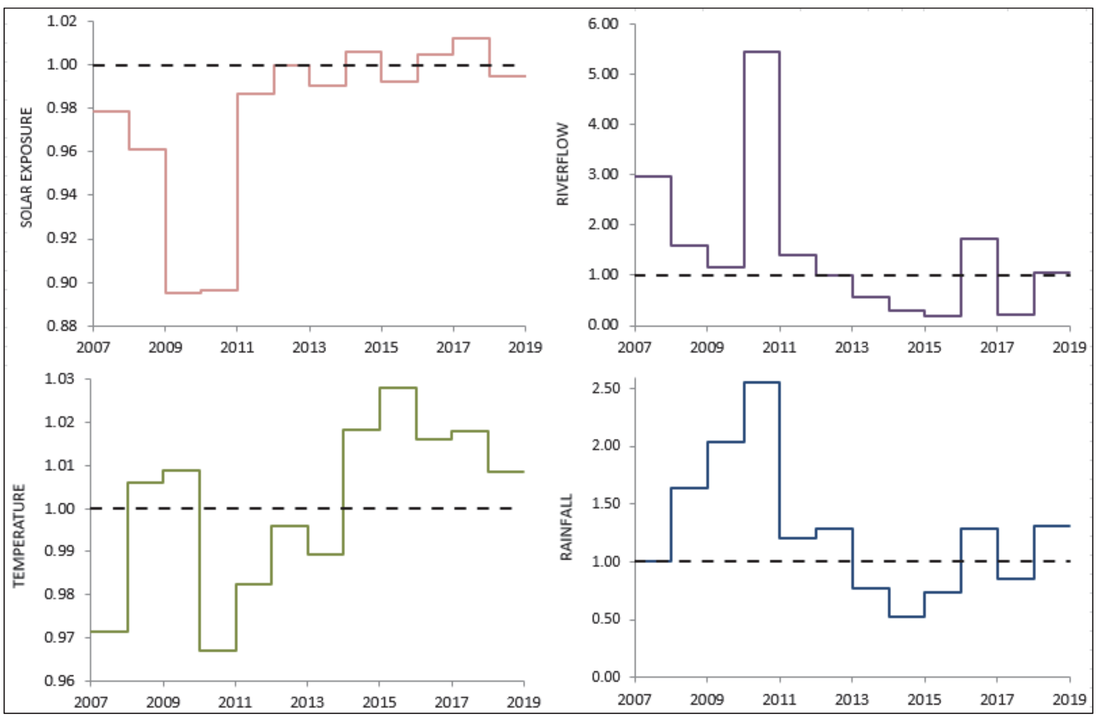


Figure 3. Recent climate trends in the Bowen/Abbot Point area 2000/01 to 2018/19: Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data.

The Abbot Point long-term monitoring program is incorporated into the broader Queensland Ports seagrass monitoring program that uses a consistent state-wide monitoring methodology (see https://www.tropwater.com). This enables direct comparisons with regional and state-wide trends to put local changes into context. The Abbot Point seagrass meadows were less affected than meadows in Townville about 140 km to the north which had large scale declines following severe flooding in early 2019. The persistence of Abbot Point seagrass condition is in line with other locations in the central and north Queensland region such as Gladstone and Hay Point/Mackay to the south and Cairns to the north that experienced improvements in seagrass condition in 2019. Successive years of climate impacts on Abbot Point seagrass meadows are likely to have reduced the resilience of seagrass in the area to future natural and anthropogenic disturbances. Continued recovery will be contingent on future weather being favourable for seagrass growth.

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1. INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services worth substantial economic value (Barbier et al. 2011; Costanza et al. 2014). These services include the provision of nursery habitat for economically-important fish and crustaceans (Coles et al. 1993; Heck et al. 2003), and food for grazing megaherbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018). Seagrasses also play a major role in the cycling of nutrients (McMahon and Walker 1998), sequestration of carbon (Fourqurean et al. 2012; Lavery et al. 2013; York et al. 2018, Rasheed et al. 2019), stabilisation of sediments (James et al. 2019), and the improvement of water quality (McGlathery et al. 2007).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution and eutrophication (Short and Wyllie-Echeverria 1996). In the Great Barrier Reef (GBR) coastal region, the hot spots with the 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 occur in the same sheltered coastal locations where 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 (Coles et al. 2015).

1.1 Queensland Ports Seagrass Monitoring Program

A long term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with Queensland port authorities. A common methodology and rationale is used 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 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 provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program delivers key information for the management of port activities to minimise impacts on seagrass habitat and has 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 causes 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 https://www.tropwater.com.

Figure 4. Location of Queensland Port Seagrass monitoring sites.

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. There have also been broad scale surveys of the marine habitat within the port limits (2005, 2008, 2013, 2016 and 2019), as well as 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, along with areas outside the zone of influence of port activity and development (Figure 5).

In 2015 the program was revised from quarterly to annual surveys; monitoring the same representative seagrass meadows that have been monitored in the past and supplemented by broad-scale surveys every three years (Figure 5). The results from three different seagrass condition indicators measured in the annual monitoring (meadow area, biomass and species composition) are assessed to provide an overall condition of seagrass status within the port region (see Section 2 for more detail). 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 in the remaining Queensland ports integrated with the seagrass monitoring program. As part of a 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) (see Waltham et al. 2019).

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 both the annual seagrass and broad-scale monitoring for 2019. The objectives of these monitoring programs for the Port of Abbot Point include:

- Assess and map seagrass to determine seagrass density (biomass), distribution (area) and community type (species composition) at representative long term monitoring meadows;
- Map and quantify the distribution and abundance of all seagrass in Abbot Point region to provide an updated picture of seagrass on a broader scale;
- Compare results of monitoring surveys and assess any changes in seagrass habitat in relation to natural events or human induced port and catchment activities;
- 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.

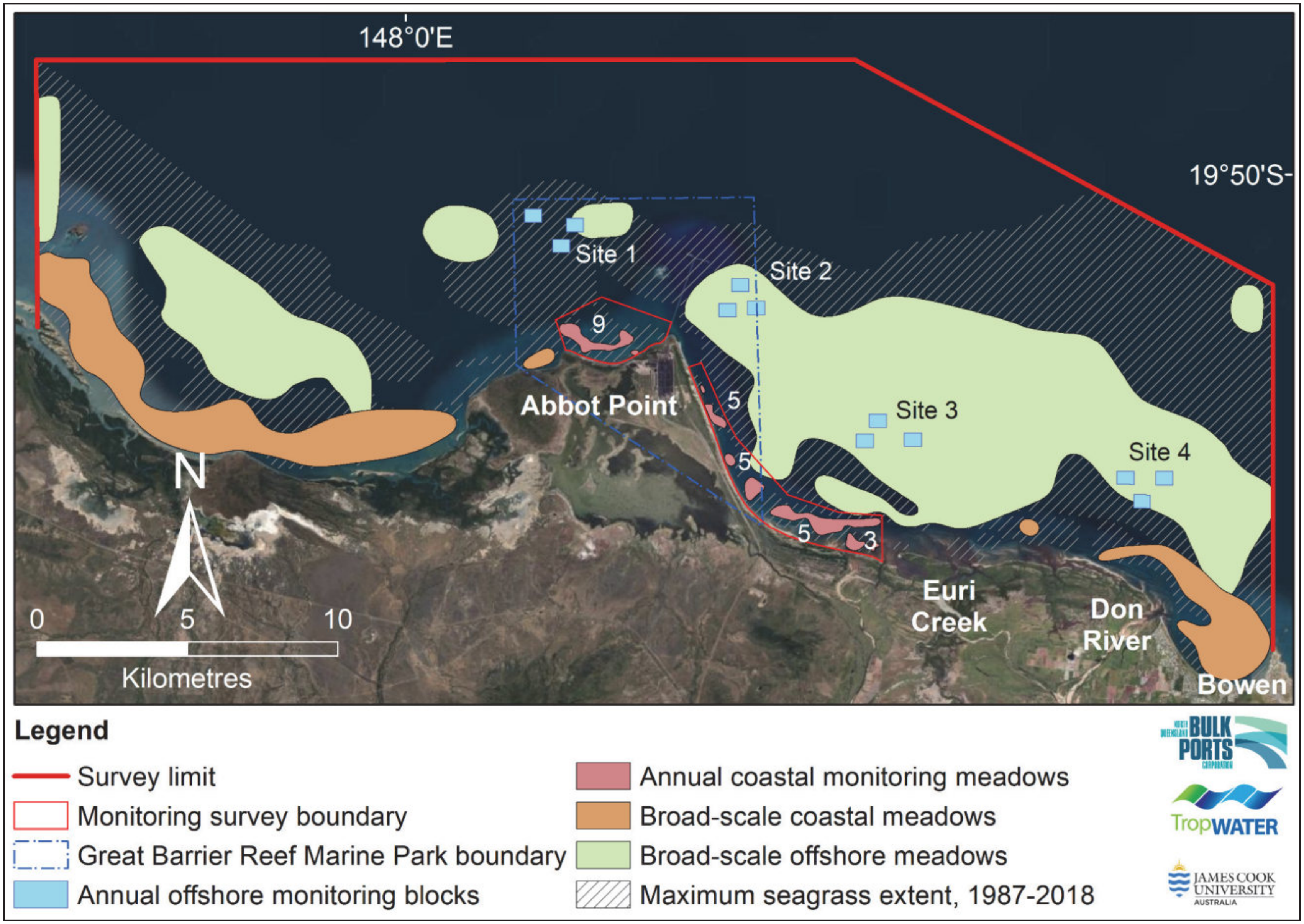


Figure 5. Location of inshore and offshore Abbot Point monitoring areas, and location and extent of seagrass meadows in the broad scale survey.

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). In 2019, three of the coastal meadows to the southeast of Abbot Point (Meadows 5, 7 and 8) were combined into one large meadow based on their proximity and similar species structure and referred to in this report and future reports as meadow 5.

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 and Rasheed 2011). The application of standardised methods at Abbot Point and throughout Queensland allows for direct comparison of local seagrass dynamics with other seagrass monitoring programs in the broader Queensland region.

2.2 Seagrass monitoring, habitat mapping and Geographic Information System

Sampling methods were chosen based on existing knowledge of benthic habitats and physical characteristics of the location such as depth, visibility and logistical and safety constraints. Three sampling techniques were used:

1. Intertidal and shallow subtidal areas <8m below MSL: Boat based underwater digital camera mounted downward facing on a drop frame; or visual observation by an experienced free diver;
2. Offshore subtidal areas >8m below MSL: Boat based digital camera sled tows with sled net attached.

At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (dbMSL), sediment type, time and position (GPS). The percent cover of other major benthos at each site was also recorded.

At sites where seagrass was present, seagrass above-ground biomass was measured using a "visual estimates of biomass" technique (Kirman 1978; Mellors 1991). At camera drop and free diving sites this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m^2 quadrats at each site (Figure 6A-B). 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 (Figure 6C-D). 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 ranked 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.

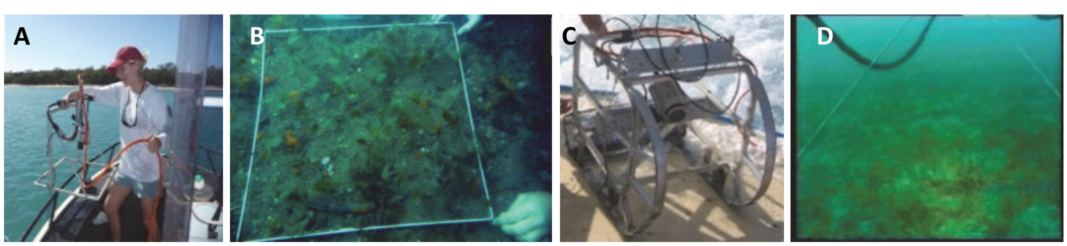


Figure 6. (A) Shallow subtidal assessments of seagrass meadows using digital camera mounted on a 0.25m^2 drop frame, (B) visual observation by free diver and (C-D) offshore underwater sled tows with digital camera.

2.3 Habitat mapping and Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.8®. 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 7).
  - 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.

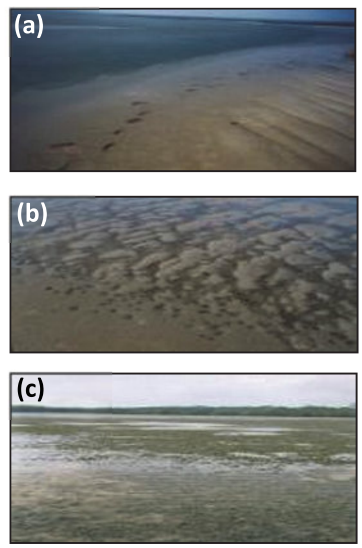
Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Community density was based on mean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

Table 3. Mapping precision and methodology for seagrass meadows in the Abbot Point region, 2019.

Mapping precision	Mapping methodology
30m	Subtidal meadow boundaries determined from free diving surveys &/ digital camera with drop frame; Relatively high density of survey sites; Recent digital maps/ imagery aided in mapping; Distance between sites with/without seagrass aided in mapping.
100-200m	Subtidal meadow boundaries determined from digital camera with sled tows; Moderate - low density of survey sites; Recent digital maps/landsat imagery aided in mapping; Distance between sites with/without seagrass aided in mapping.

2.4 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.

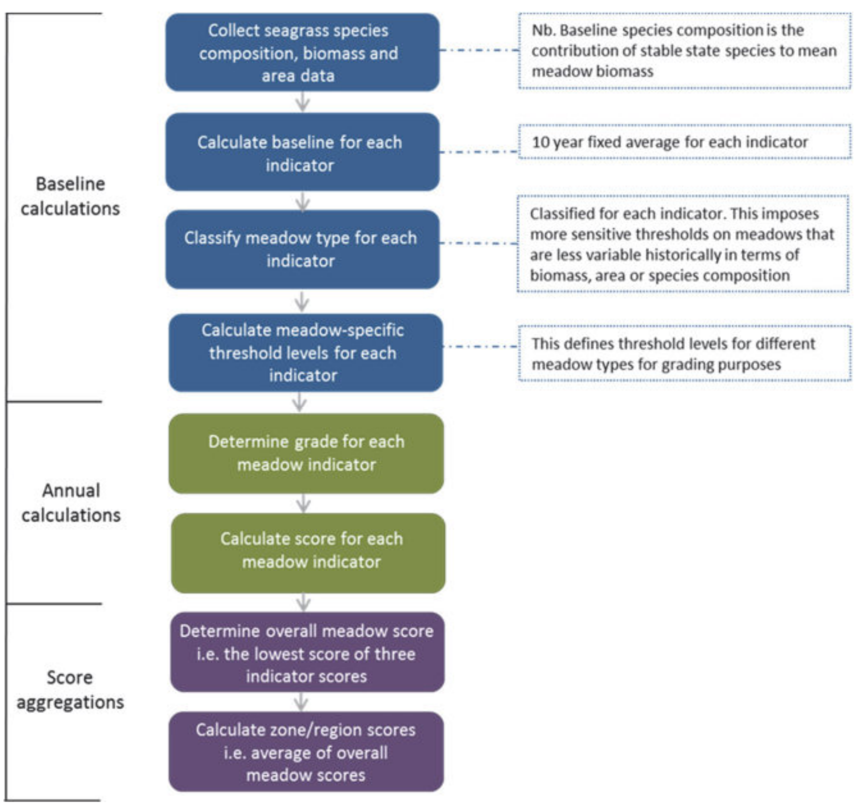


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.5 Environmental data

Temperature, river flow and tidal exposure are environmental conditions that impact seagrass biomass and distribution (Rasheed & Unsworth 2011). Increased rainfall and flooding events can cause sudden changes in water quality, in particular increased turbidity that reduces the light available for photosynthesis (Collier et al. 2016). During dry periods with minimal rainfall, elevated turbidity along the coastline is caused by the re-suspension of sediment from wind-driven waves (Orpin and Ridd 2012). To provide insight on what is influencing seagrass conditions we need to analyse broader environmental data such as tides, rainfall, river-flow, and solar exposure, as well as data collected on water temperature, turbidity and wave height from the ambient water quality monitoring program.

Environmental data was collated for the twelve months preceding each survey. Total daily rainfall (mm), temperate, solar exposure 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). Root Mean squared (RMS) wave height data has been collected by the JCU Geophysics team at Abbot Point site AMB1 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. (2019).

Two inshore meadow logging stations were established by TropWATER in late 2017 (TW1 and TW2) to collect water temperature and light measured as Photosynthetically Active Radiation (PAR) from within meadow 5 and meadow 9 respectively (Figure 9). As part of the NQBP/JCU partnership, the team has also had PAR loggers deployed in the greater Abbot Point region since late 2017. The AMB 1 site as part of that program coincides with offshore site 3 (Figure 9) and this data has been used to represent the availability of light in the offshore seagrass meadows (see Waltham et al. 2019).

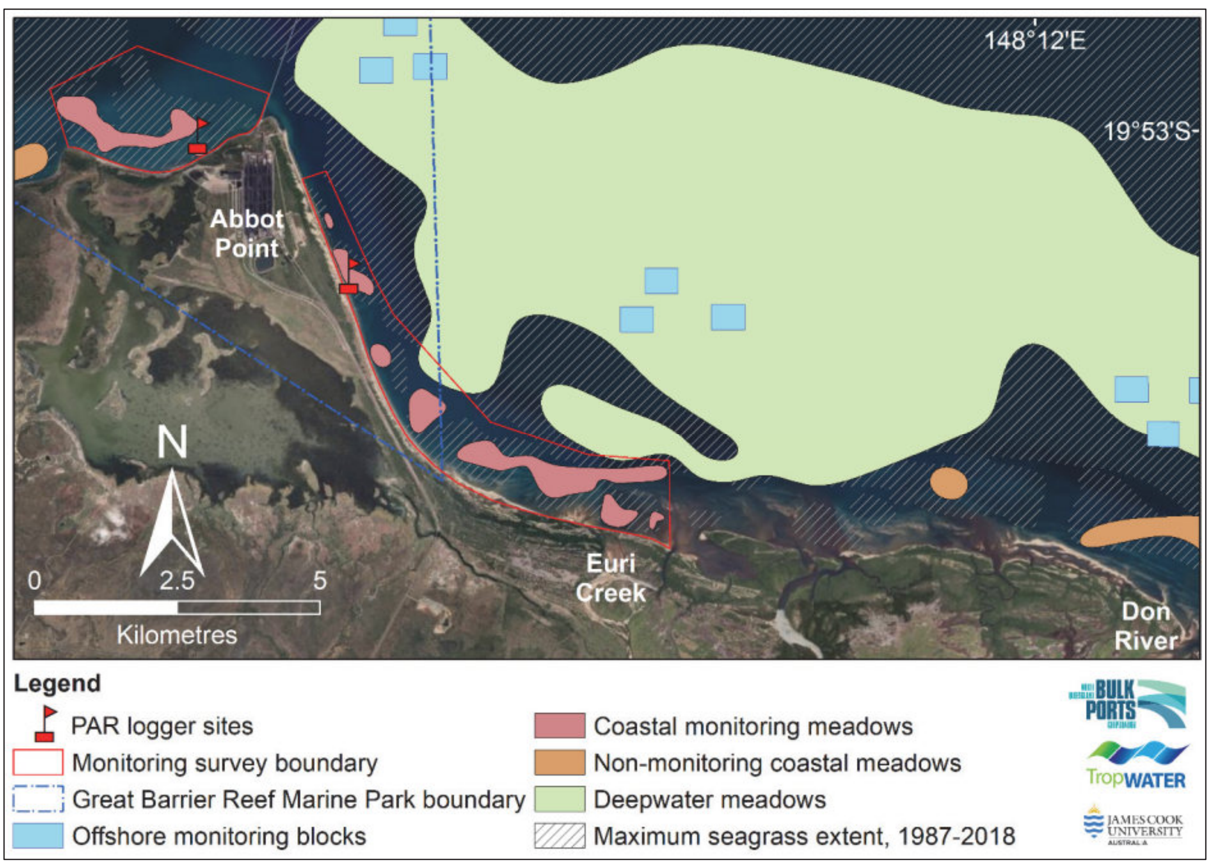


Figure 9. Location of TropWATER, James Cook University light (PAR) loggers at Abbot Point.

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.

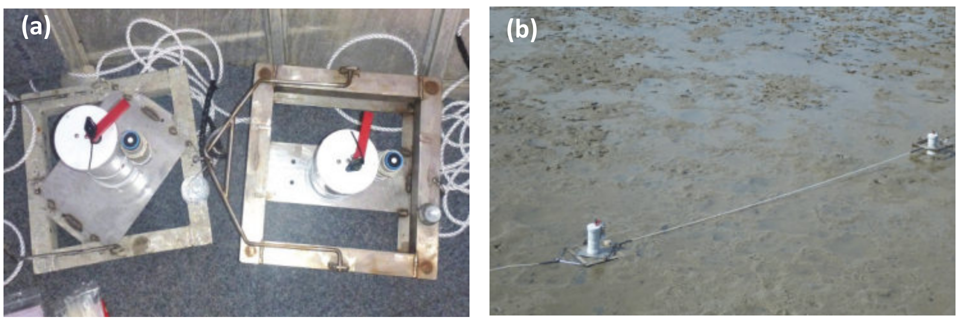


Figure 10. (a) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units; (b) example of deployment of logging stations (Abbot Point stations are subtidal only).

3. RESULTS

3.1 Seagrass in the Abbot Point monitoring areas

A total of 432 sites were sampled as part of the 2019 Abbot Point whole of port survey (Figure 12). Seagrass was present at 46% of the survey sites. The inshore monitoring meadows covered 303.19 ± 74.18 ha (Appendix 4B). Seagrass biomass was higher closer to the coast and reduced offshore with increasing water depth (Figure 13).

The seagrass species found in the monitoring meadows were typical of those in coastal and offshore seagrasses in Abbot Point and more broadly in central Queensland (Figure 11, Appendix 3). Five seagrass species were observed in 2019 (Figure 11). Deepwater assemblages offshore from Abbot Point were dominated by *Halophila spinulosa* while *H. decipiens* and *H. ovalis* were also present. *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows with *H. ovalis* also present, and Z*ostera muelleri* occurring near the mouth of Euri Creek.

Cymodocea rotundata, *Cymodocea serrulata, Syringodium isoetifolium* and *Halophila tricostata* have been recorded in the area in the past but occurrences are rare and they were not present in 2019. *H. tricostata* was last observed in the 2016 broad-scale survey, *C. serrulata* was last observed in 2015 and *C. rotundata* and *S. isoetifolium* were only observed in the 2005 baseline survey.

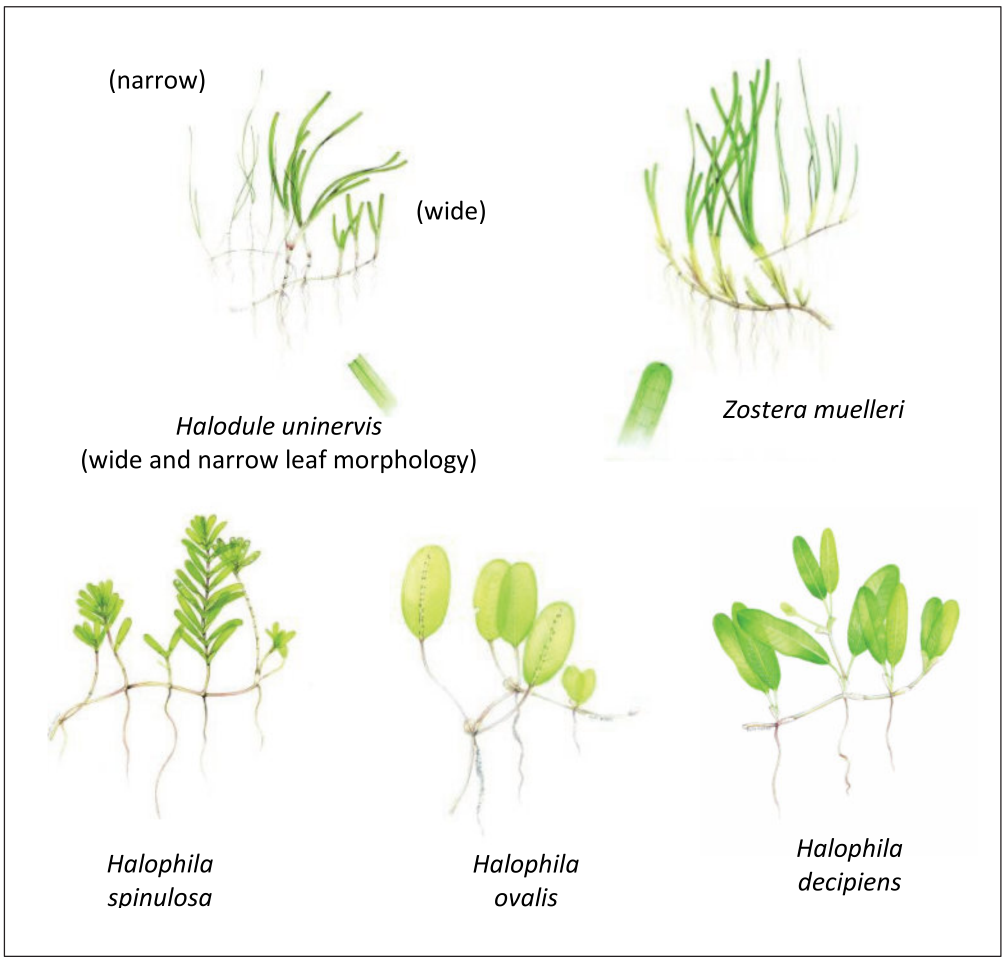


Figure 11. Seagrass species identified in the Abbot Point/Bowen region in 2019.

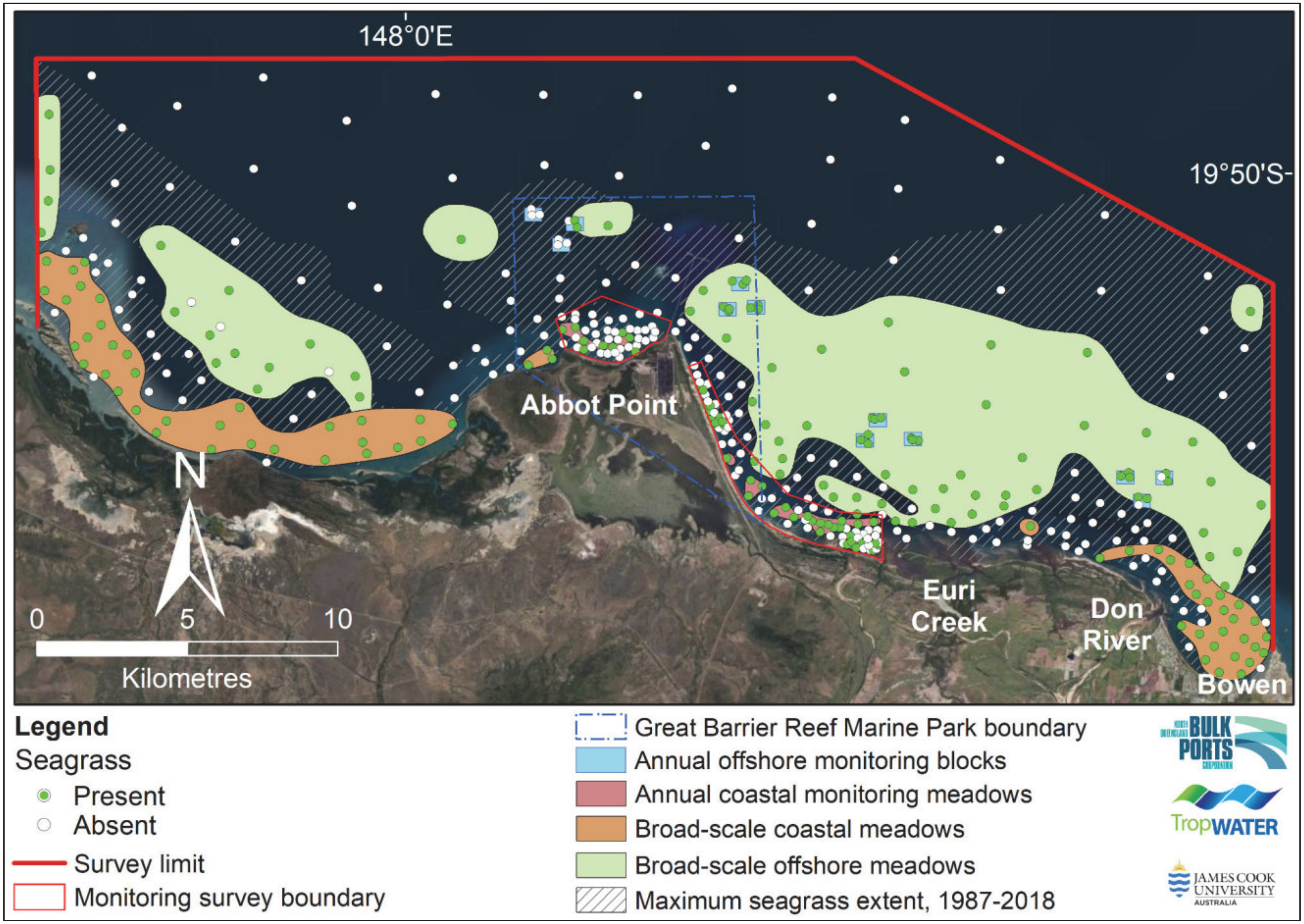


Figure 12. Location of seagrass assessment sites in the 2019 Abbot Point broad scale survey.

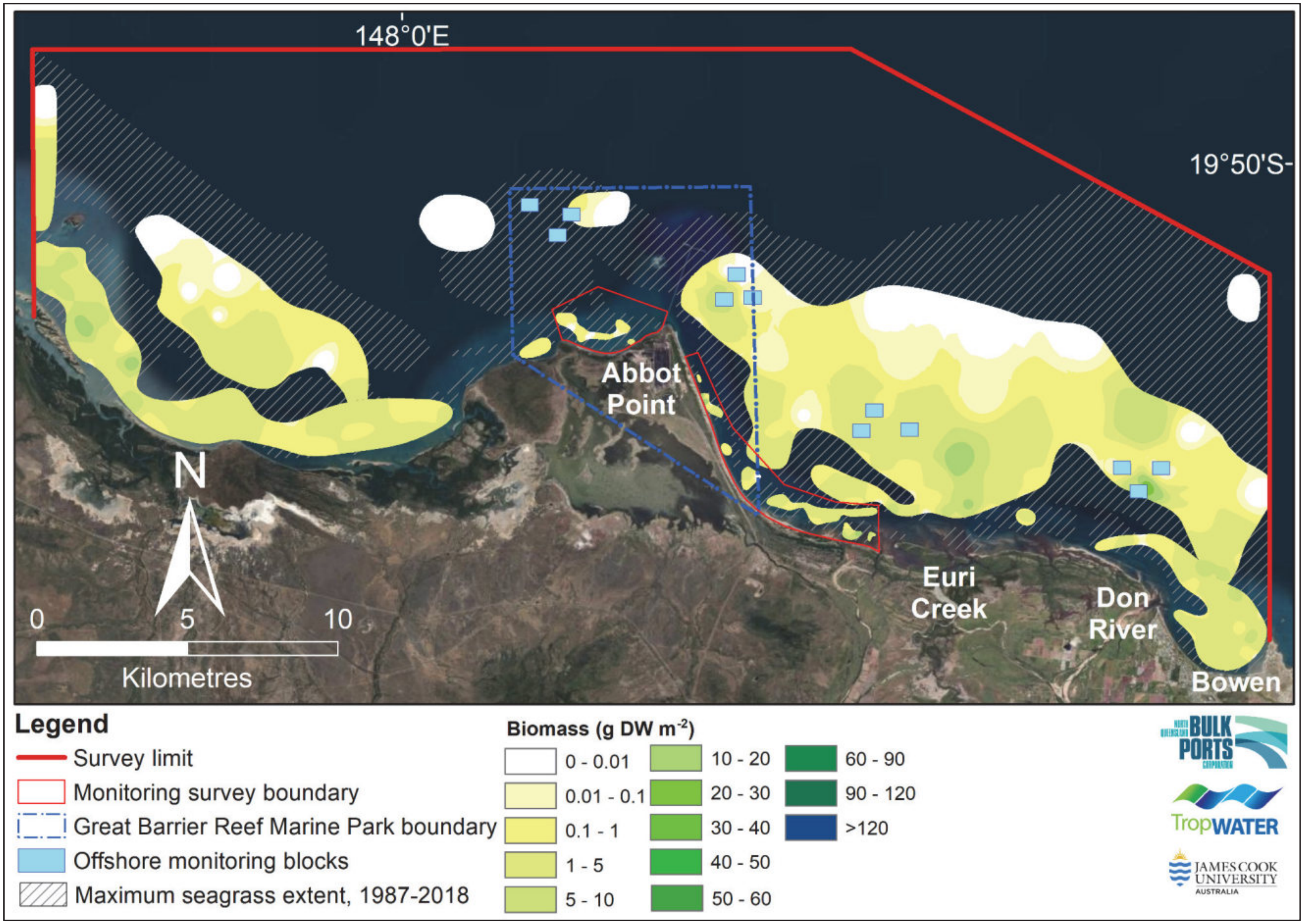


Figure 13. Seagrass biomass (g DW m^{-2}) interpolation for the Abbot Point survey 2019.

3.2 Seagrass condition in the Abbot Point monitoring areas

The overall condition of seagrass monitoring meadows in the Abbot Point region was satisfactory in 2019. Offshore seagrass habitat scored as good, and the inshore monitoring meadows scored as satisfactory (Table 4). The overall score of satisfactory is the same condition from the 2018 survey that was still recovering from Tropical Cyclone Debbie which affected the area in March 2017. The score for offshore seagrass improved in condition however from 2018.

Table 4. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2019.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score	Overall location Score
Offshore Monitoring Areas					
Offshore Site 1	0.67	0	N/A	0.34	0.65
Offshore Site 2	0.84	0.94	N/A	0.84	
Offshore Site 3	0.57	0.94	N/A	0.57	
Offshore Site 4	0.91	0.78	N/A	0.85	
Inshore Monitoring Areas					
Inshore Meadow 3	0.89	0.77	0.69	0.69	0.62
Inshore Meadow 5	0.75	0.94	0.97	0.75	
Inshore Meadow 9	0.41	0.97	0.70	0.41	
Overall score for seagrass in the Port of Abbot Point					**0.63**

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

Inshore monitoring meadows

In 2008 five inshore meadows were identified as seagrass habitats that could be representative of the whole port for long term monitoring (McKenna et al. 2008). After 10 years of monitoring it was decided that the three *H. uninervis* meadows on the south eastern side of Abbot Point (Meadows 5, 7 & 8) would be combined to form one monitoring area (Meadow 5) (McKenna et al. 2019). This is the first survey with the historic meadows 5, 7 and 8 now all being combined with data being reanalysed to meet this new monitoring criteria.

Meadow 3 and 5 are located to the southeast of Abbot Point while Meadow 9 is the only inshore monitoring meadow located on the western side (Figure 5). Meadow 5 and 9 are *H. uninervis* dominated meadows made up of aggregated patches (Figure 21). Meadow 3 at Euri Creek is traditionally a *Z. muelleri* dominated meadow that is currently dominated by *H. uninervis* (Figure 14 & 21). In 2019 Meadow 3 had good overall condition with improvements in biomass (from good to very good) and species composition (satisfactory to good), with an increase in the relative abundance of *Z. muelleri* since the 2018 survey. The spatial footprint of the meadow (area) was in good condition despite a reduction in meadow size from 2018 (Figure 14). Meadow 5 was in a good condition in 2019, with biomass and species composition in a stable condition since 2016. Area improved from good to very good with more than a 2-fold increase since the previous survey to register the largest total coverage on record at 188.46 ± 44.09 ha in 2019 (Figure 15, Appendix 4B). Meadow 9 remained in poor condition in 2019, similar to 2018. The poor condition of the meadow was driven by poor biomass in 2019, whereas in 2018, it was driven by a poor area score. Area improved from poor to good in 2019 (Figure 16).

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 1). The shallower Site 1 is located on the north-western side of Abbot Point on Clark Shoal and seagrass has been intermittent in its presence throughout the monitoring program at this site (Figure 17). Site 1 has typically been dominated by *H. 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 offshore monitoring locations ranged from poor to very good in 2019 (Table 4). Offshore Site 1 generally varies between no or very low biomass of seagrass dominated by *H. uninervis* (narrow leaf variety). In 2019 the seagrass biomass at the site was in good condition, however this is a bit of an anomaly as it is caused by one transect of relatively high biomass *H. ovalis* (Figure 17; Appendix 3). Offshore Site 2 and 3 remained in the same condition as 2018; good and satisfactory condition respectively (Table 4, Figure 18 and 19). In 2019, Site 3 had a higher presence of the more stable *H. uninervis* throughout the site than 2018, but similar to 2017. Site 4 had an improvement in biomass from satisfactory to very good in 2019, and is also the highest recorded since 2011. Species composition at the site was in a good condition, with *H. ovalis* and *H. decipiens* contributing a higher biomass to the site in 2019 compared to the last two years (Figure 20; Appendix 3).

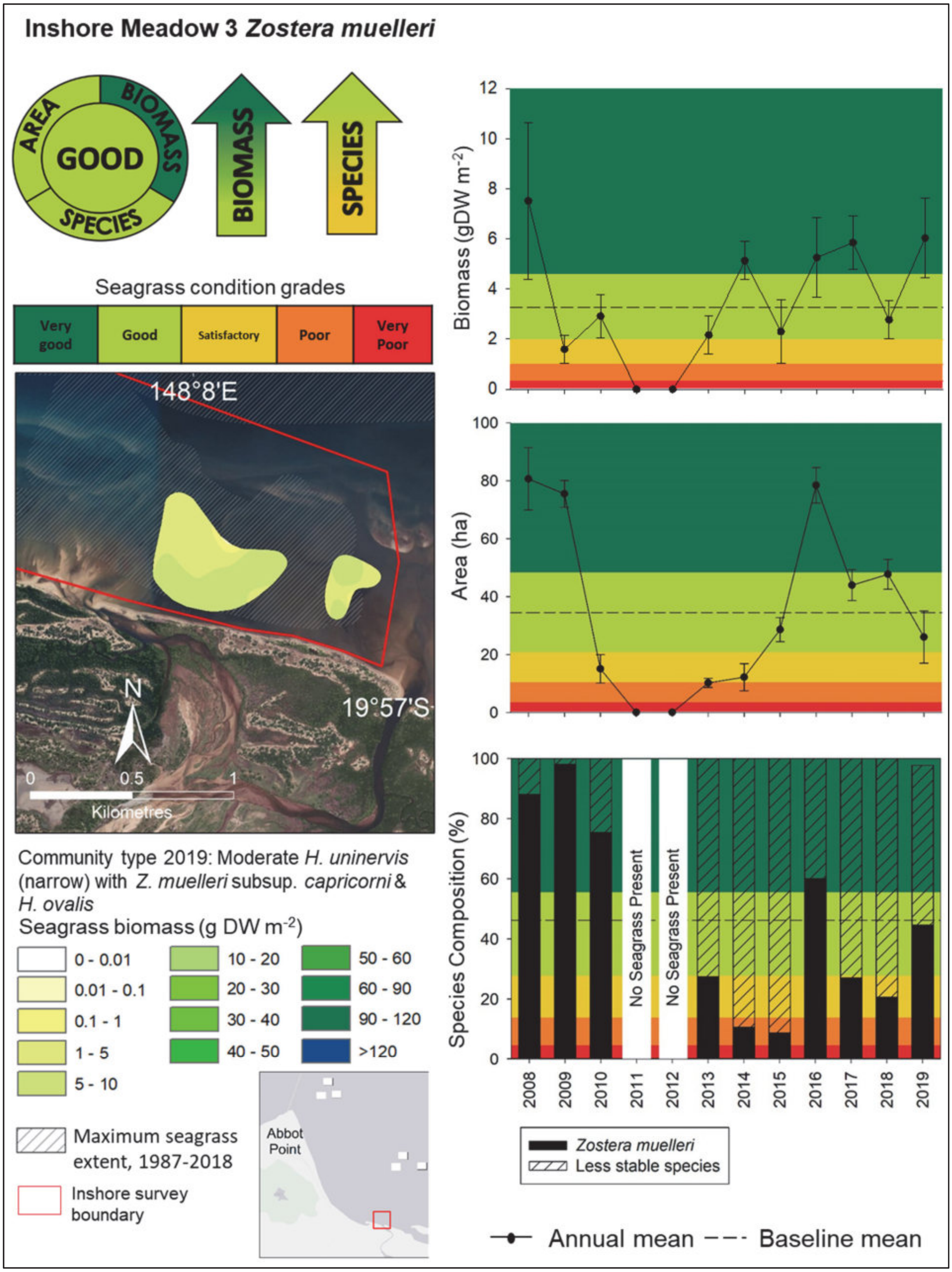


Figure 14. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3.

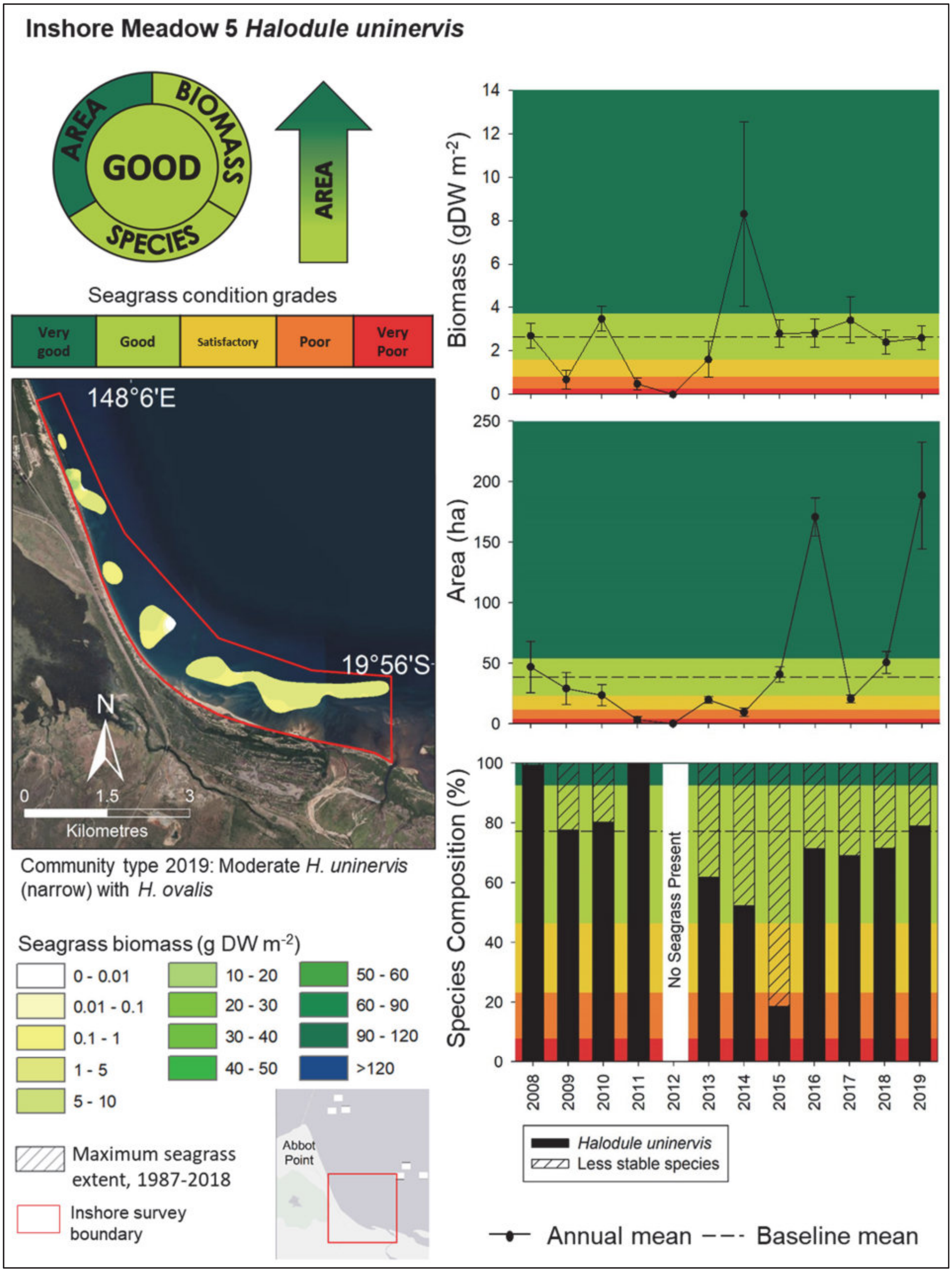


Figure 15. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5.

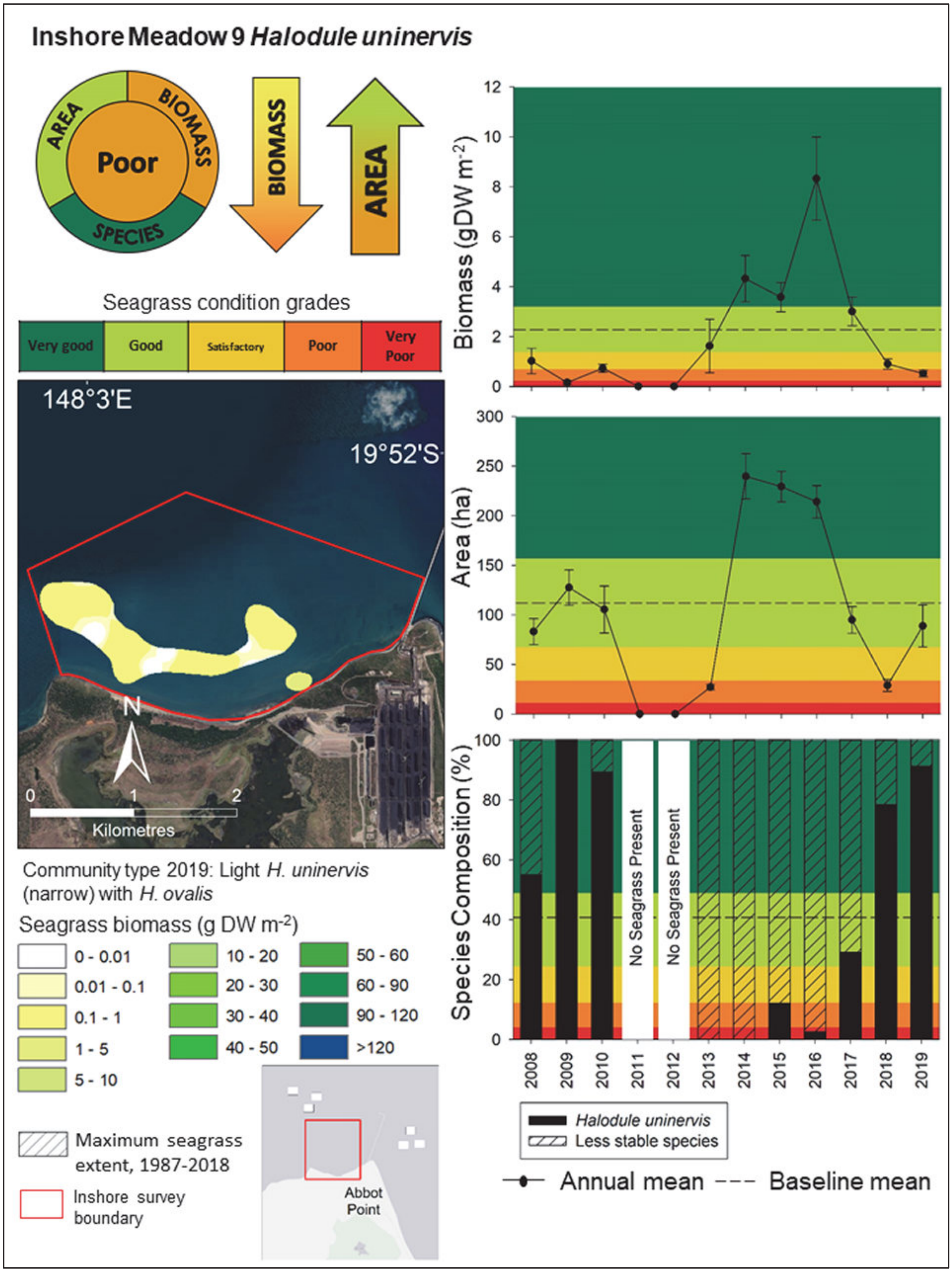


Figure 16. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 9.

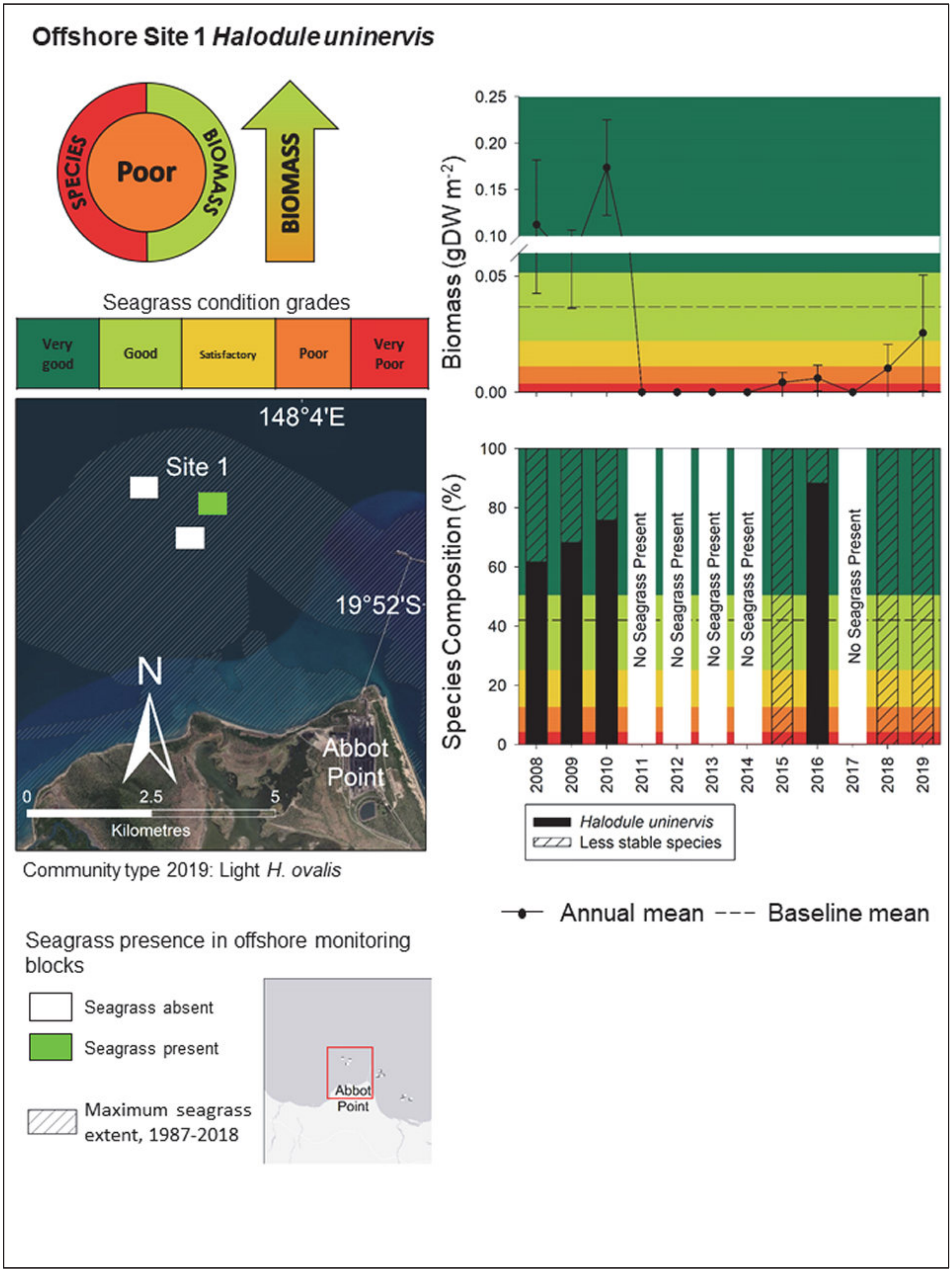


Figure 17. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 1.

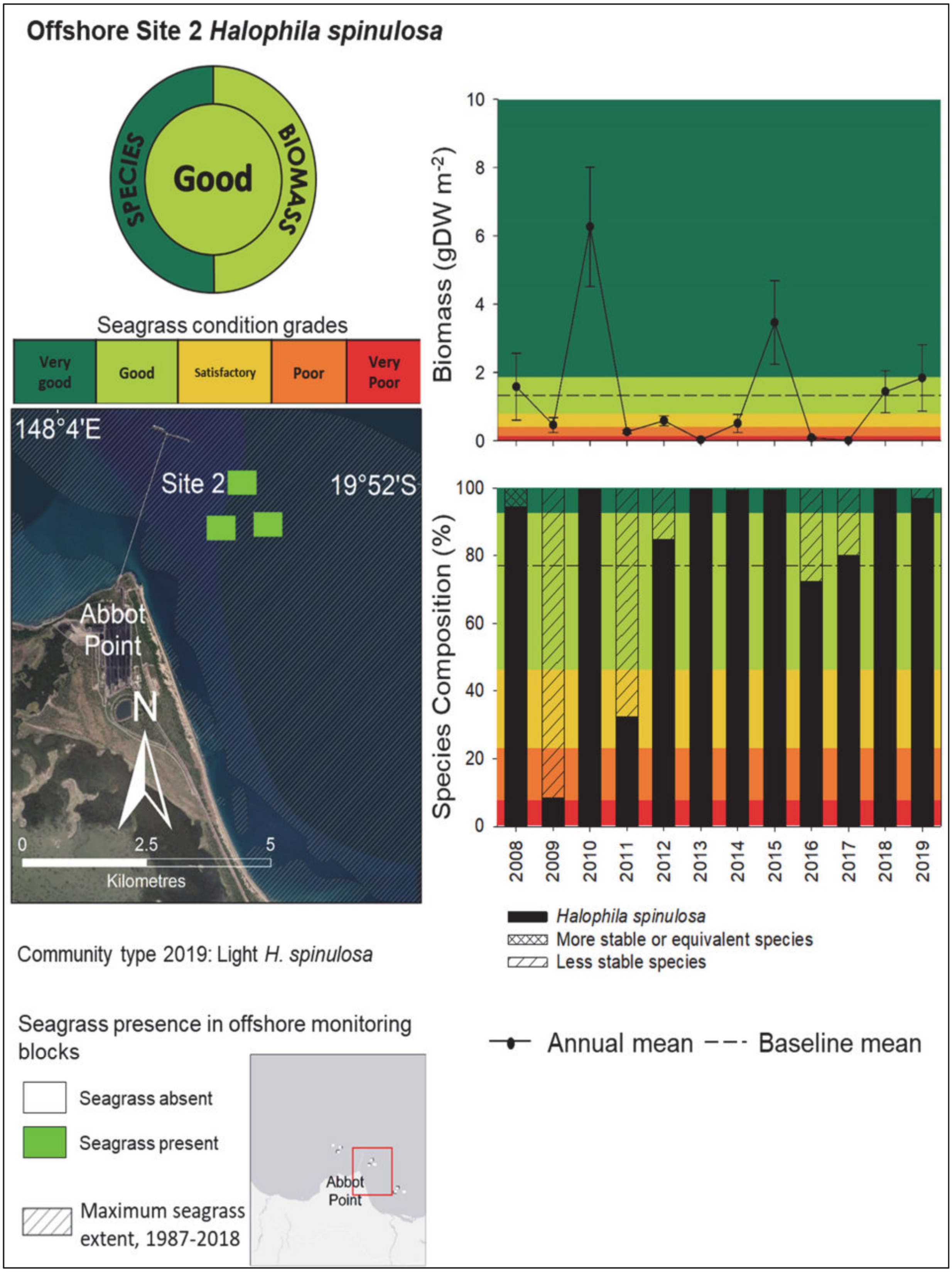


Figure 18. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 2.

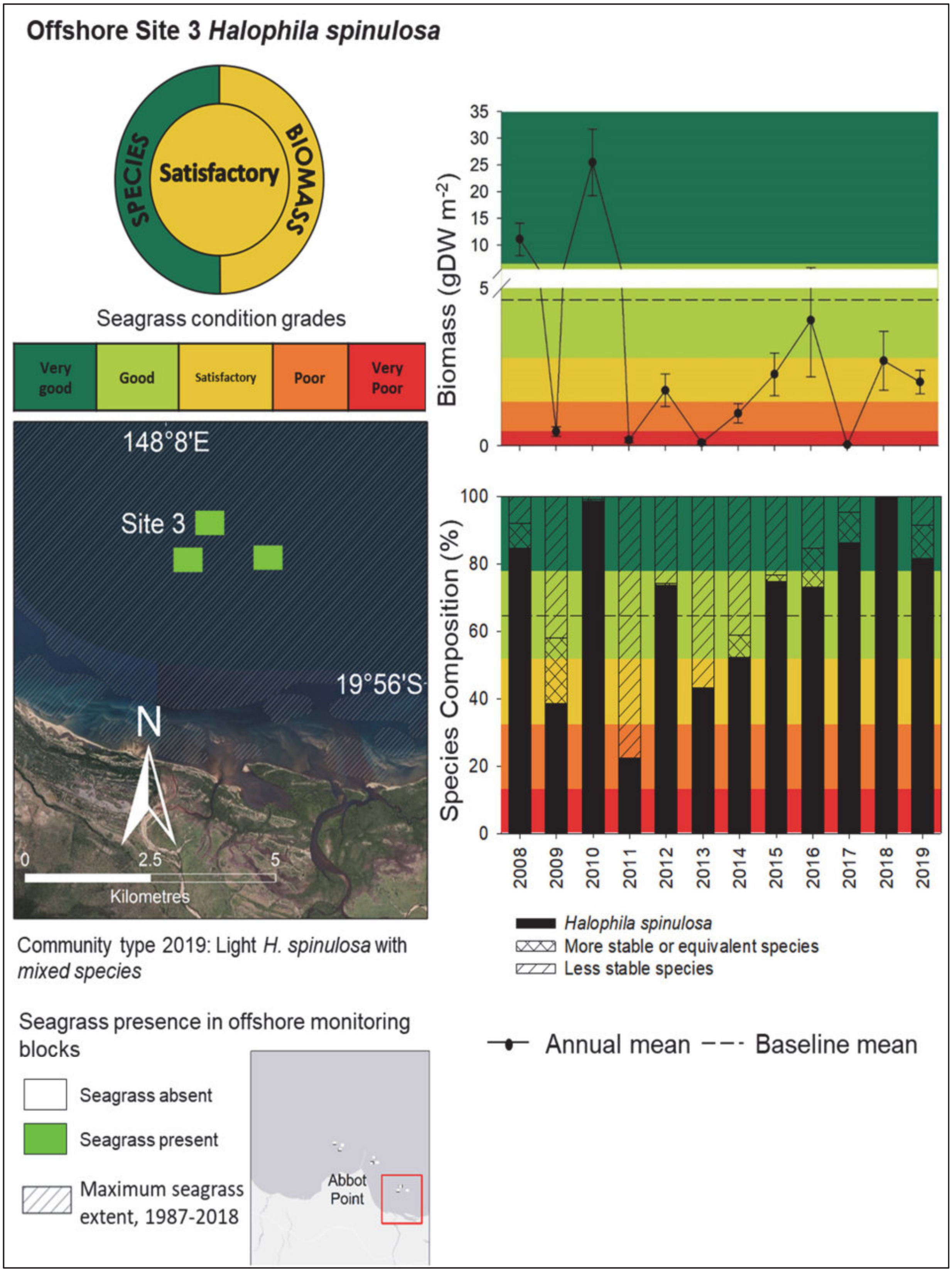


Figure 19. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 3.

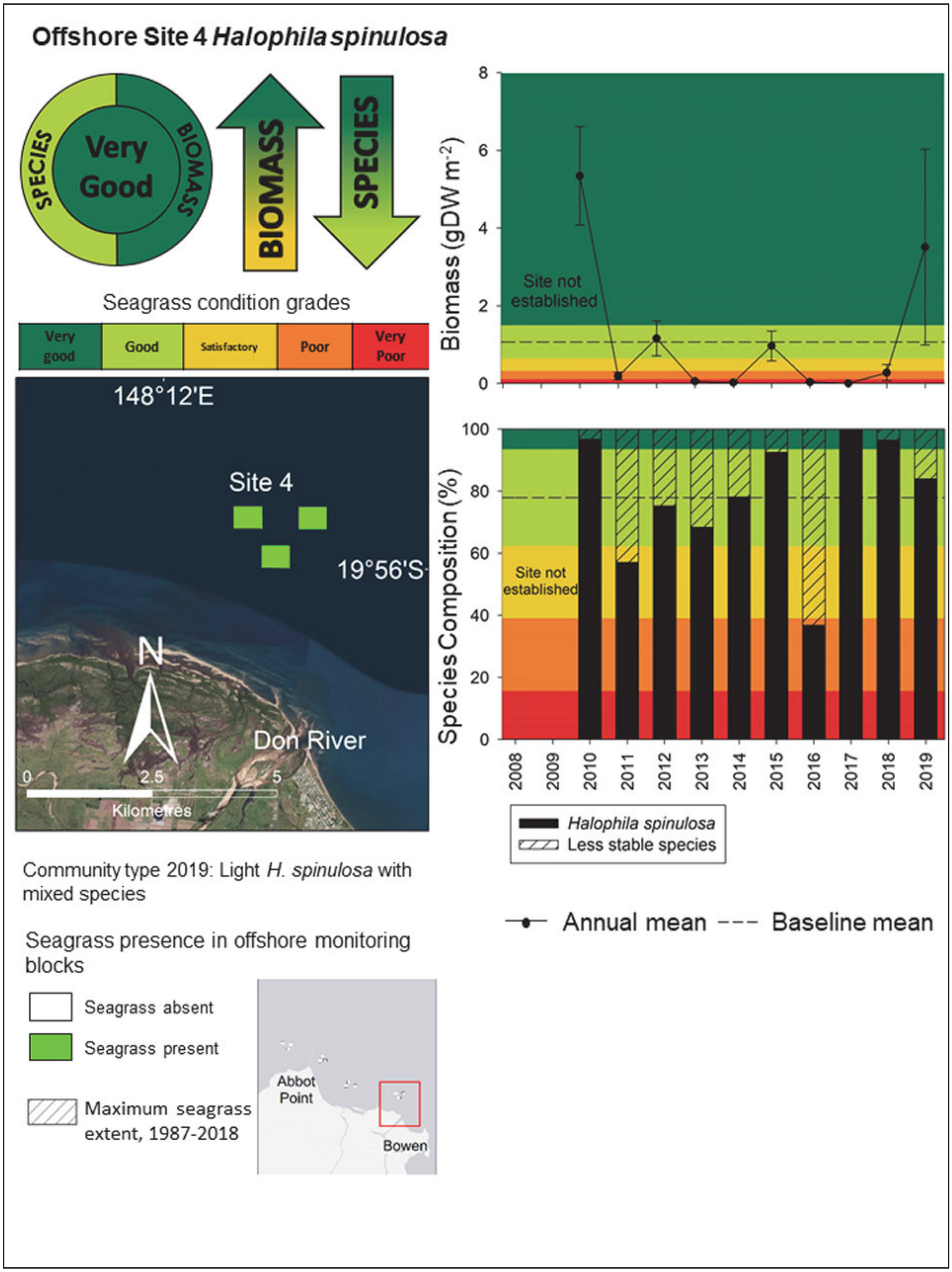


Figure 20. Mean meadow biomass (g DW m^{-2}) and species composition at offshore monitoring Site 4.

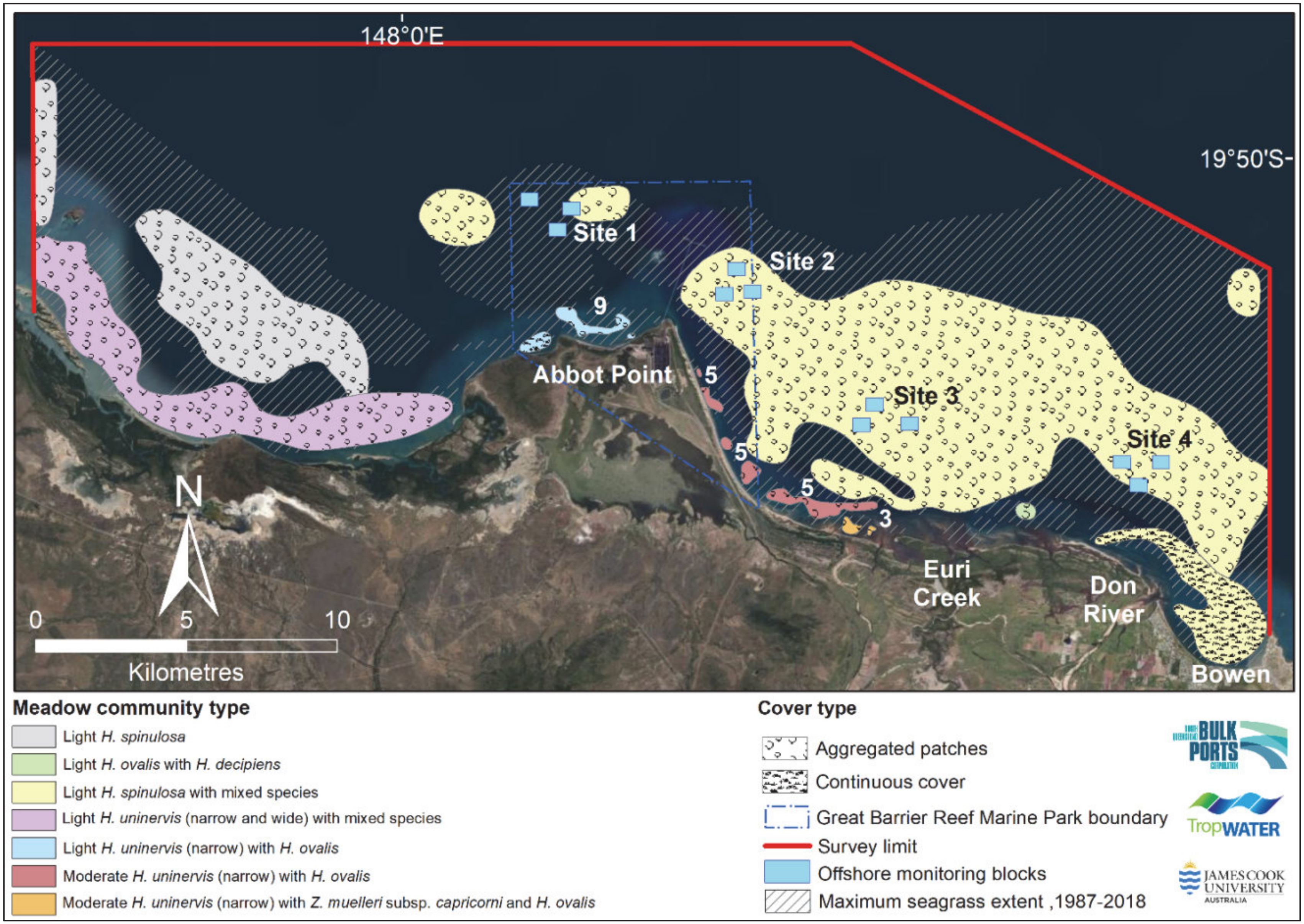


Figure 21. Seagrass meadow community type and landscape cover type for seagrass meadows surveyed in Abbot Point 2019.

3.3 Comparison with previous whole of port surveys

Every 3 years a survey mapping all seagrass in the broader port area is conducted to get a better understanding of the entire seagrass habitat in the region (Figure 23). In 2019, the total area and footprint of seagrass in the expanded monitoring area was slightly below previous surveys in 2008, 2013 and 2016 (Figures 22 and 23). Seagrass biomass across the region was lower than the previous survey in 2016, but greater than 2008 and 2013.

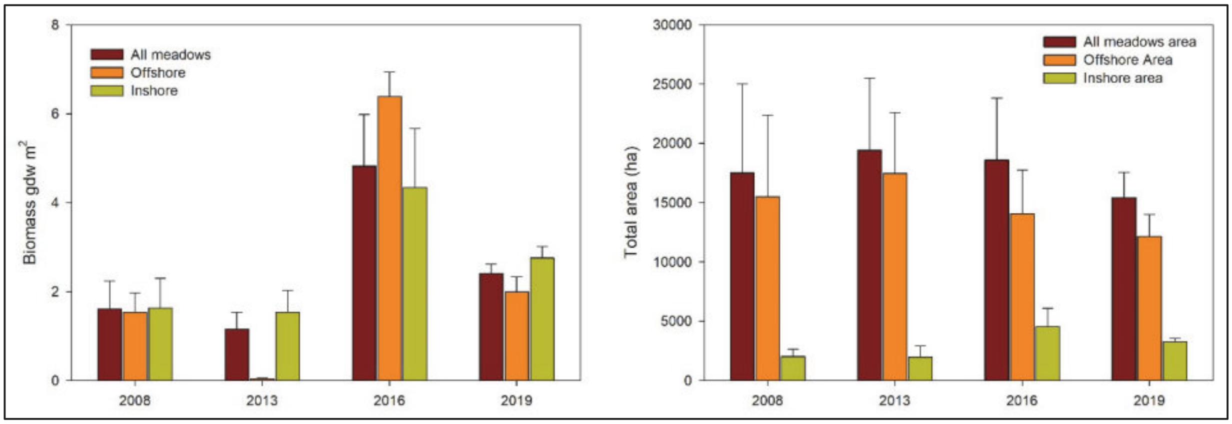


Figure 22. Comparison of biomass (g DW m^{-2}) and total area (ha) of meadows during the whole of port surveys in Abbot Point for 2008, 2013, 2016, 2019.

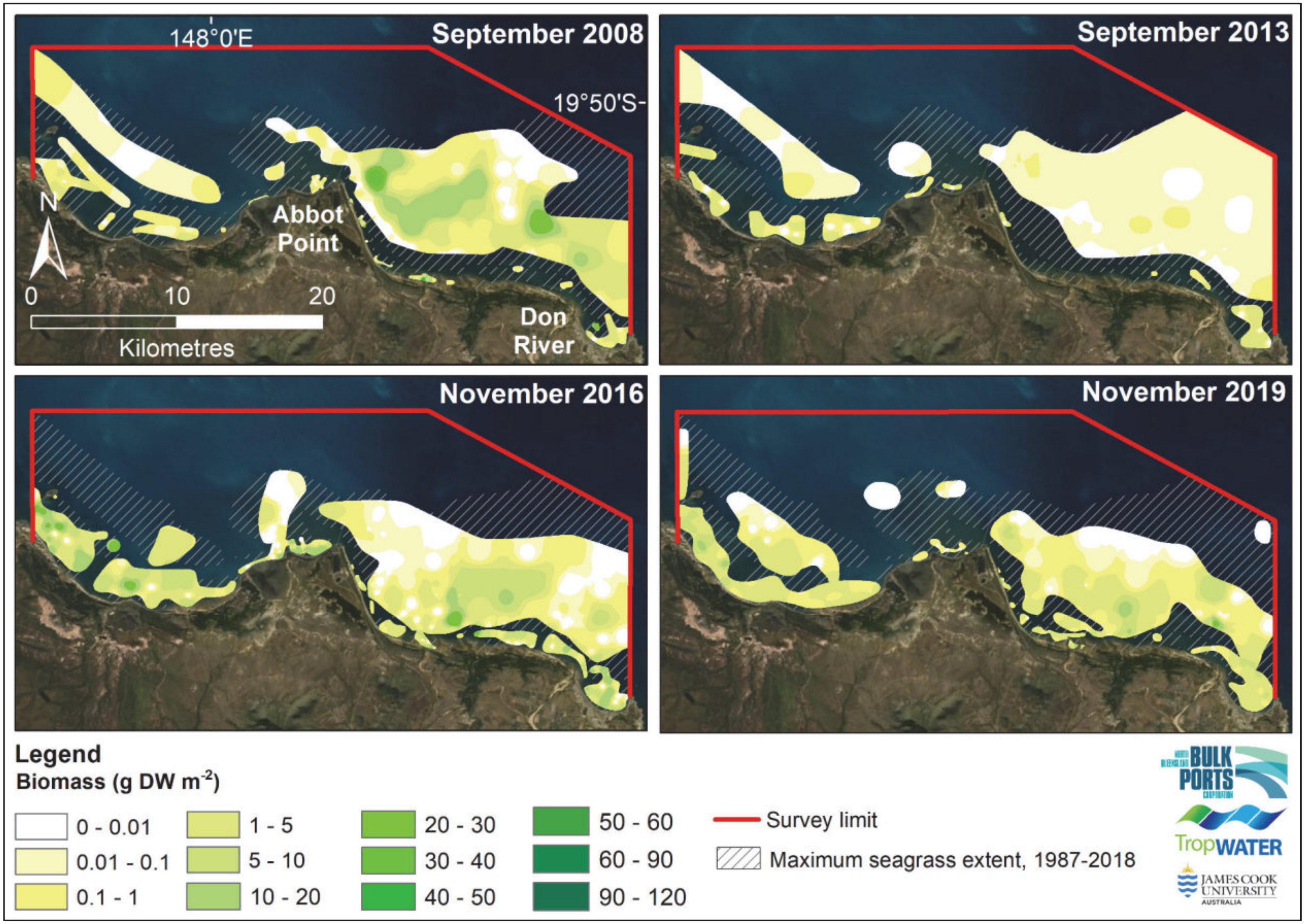


Figure 23. Comparison of biomass (g DW m^{-2}) and total area (ha) of monitoring meadows during the broad scale surveys in Abbot Point for 2008, 2013, 2016, and 2019.

3.4 Abbot Point environmental data

3.4.1 Benthic daily light - photosynthetically active radiation (PAR)

The light available to seagrasses changed with season in 2019 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 24).

The inshore PAR sites; TW1 & TW2 are at different depths and represent the depth gradient where inshore seagrasses can be found at Abbot Point. Because of this the total daily light at each of these logging stations differs in range. TW2 is the shallowest site, followed by TW1 then AMB 1, located offshore. Total daily PAR (rolling averages) at the three sites ranged from 0.004 to 8.987 mol m^{-2} day^{-1} for TW2, 0.002 to 8.757 mol photons m^{-2} day^{-1} for TW1 and 0 to 2.024 mol m^{-2} day^{-1} for AMB 1 (Figure 24).

Locally derived light thresholds for the Abbot Point region were determined in 2015 (McKenna et al. 2015b) 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 (McKenna et al. 2015b). For the shallow inshore areas dominated by *H. uninervis* a threshold of 3.5 mol m^{-2} day^{-1} over a rolling 14 day average was recommended. There were sustained periods of time in the 12 months prior to the survey 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.

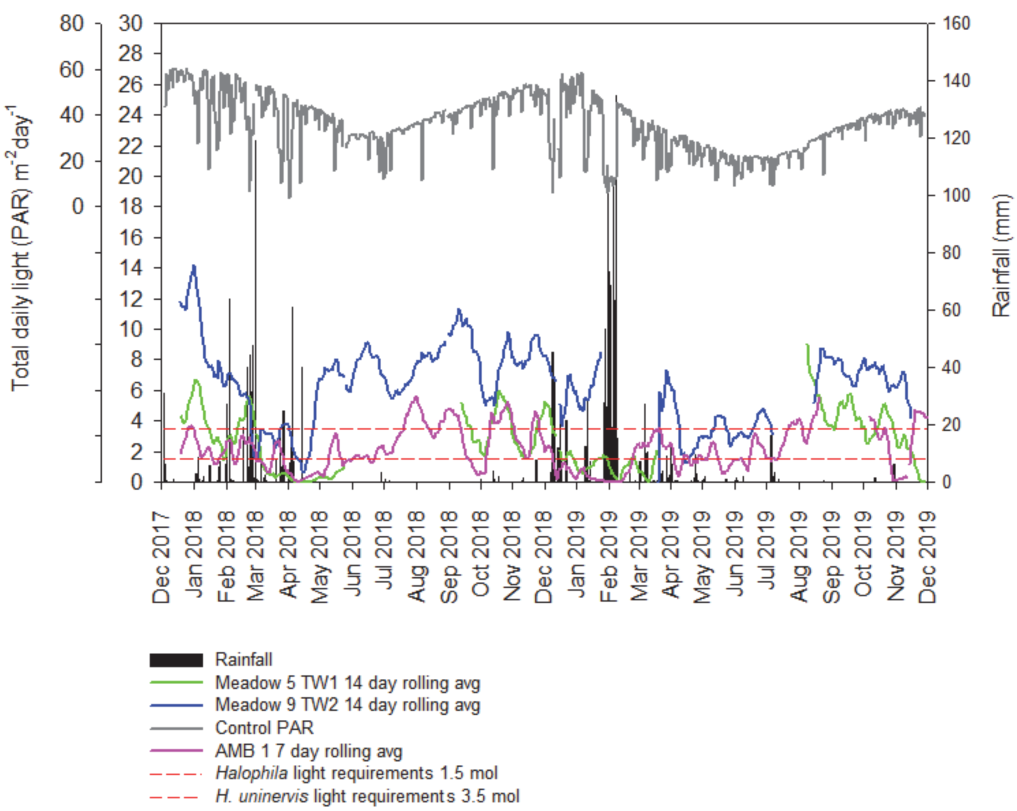


Figure 24. Fourteen & seven day rolling average total daily PAR (mol photons $m^{-1}day^{-1}$), total daily rainfall, and *H. uninervis* & *Halophila* light requirement December 2017 – December 2019.

3.3.2 Benthic water temperature

Water temperature within the seagrass canopy followed seasonal patterns with the highest temperatures from December to March, followed by lower temperatures during winter (Figure 25). As expected, temperature within the seagrass canopy was lowest at the deeper offshore monitoring site compared to inshore monitoring sites (Figure 25). Maximum daily water temperature for the 12 months prior to the survey ranged from 20.6 – 31.2°C at TW1 and AMB1, and from 21.1 – 30.2°C at TW2. In the months leading up to the survey, water temperatures were on average several degrees lower than those experienced over a similar time frame in the previous two years.

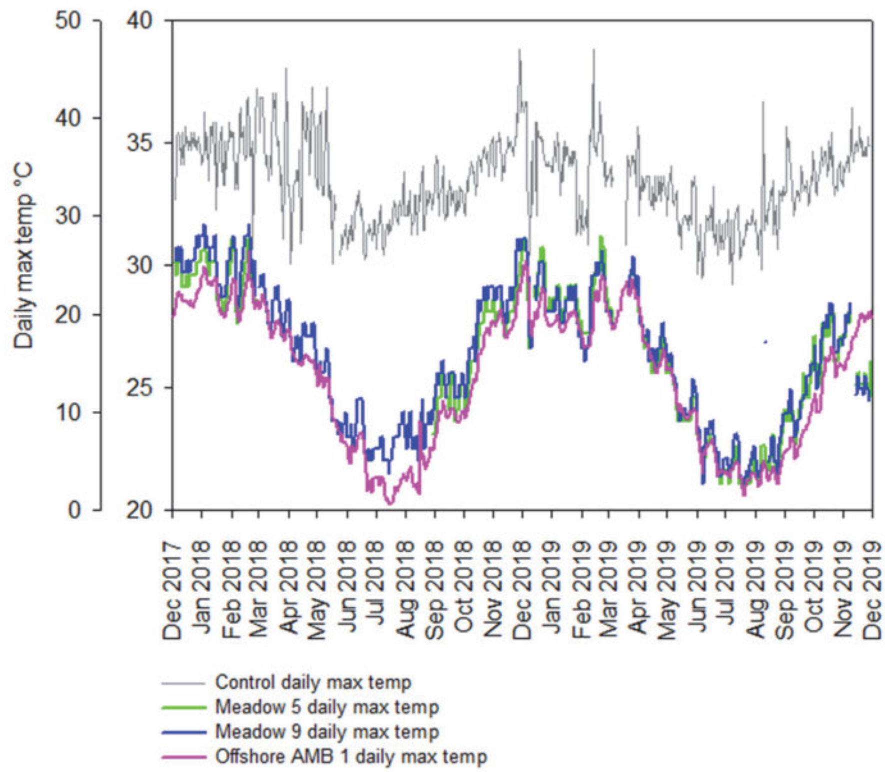


Figure 25. Maximum daily water temperature (°C) within the seagrass canopy at the two inshore monitoring sites and one offshore monitoring site December 2017 – December 2019. Control daily maximum temperature was from a nearby temperature logger on land in the Port of Bowen.

3.4.3 Rainfall

Total annual rainfall was 1134.8mm and above the long term average in 2018/19 (Figure 26a). Rainfall followed similar wet/dry season trends leading up to the annual survey, with February having the highest rainfall of 491.8mm (Figure 26b). January and February 2019 rainfall, substantially exceeded the historical monthly long-term average due to rainfall events following Tropical Cyclones Oma in January and Penny in February (Figure 26b).

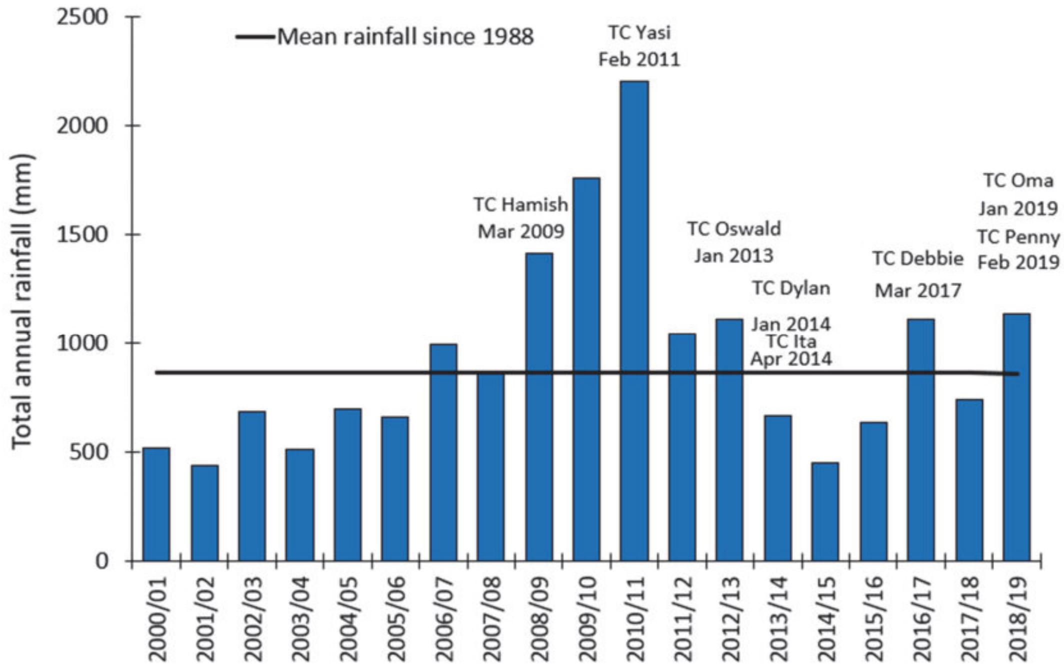


Figure 26a. Total annual rainfall (mm) recorded at Bowen, 2001/02-2018/19. Year represented in columns is twelve months prior to the survey.

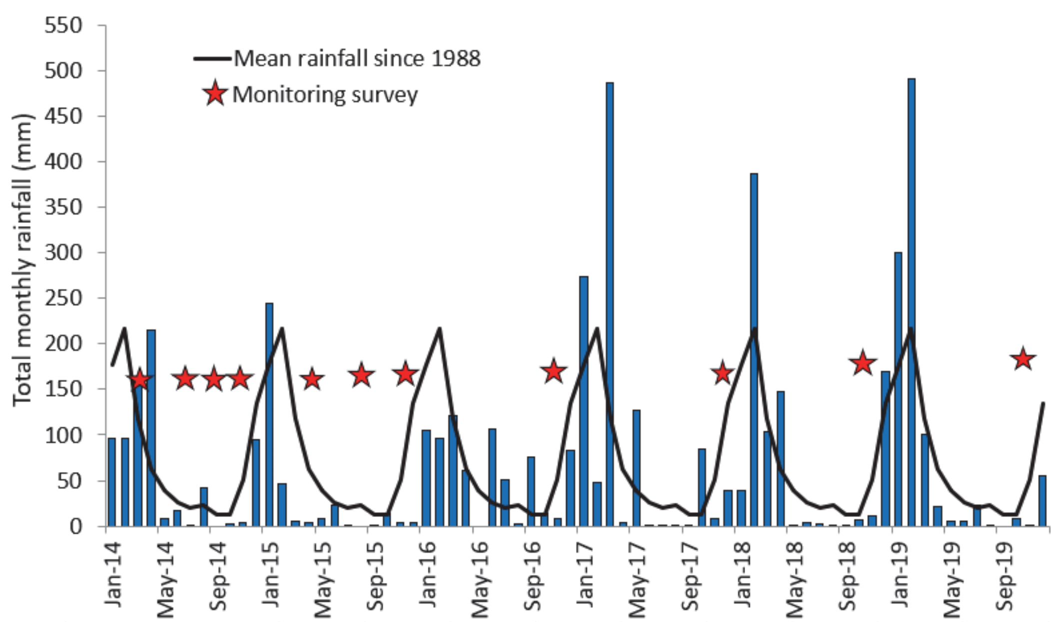


Figure 26b. Total monthly rainfall (mm) recorded at Bowen, January 2014 - December 2019.

3.4.4 River Flow - Don River

River flow for the Don River was slightly above the long-term annual average of 173,593 ML in 2018/19 (Figure 27a). The highest amount of river flow in the survey year occurred between January and February, both recording above the long term monthly averages (Figure 27b).

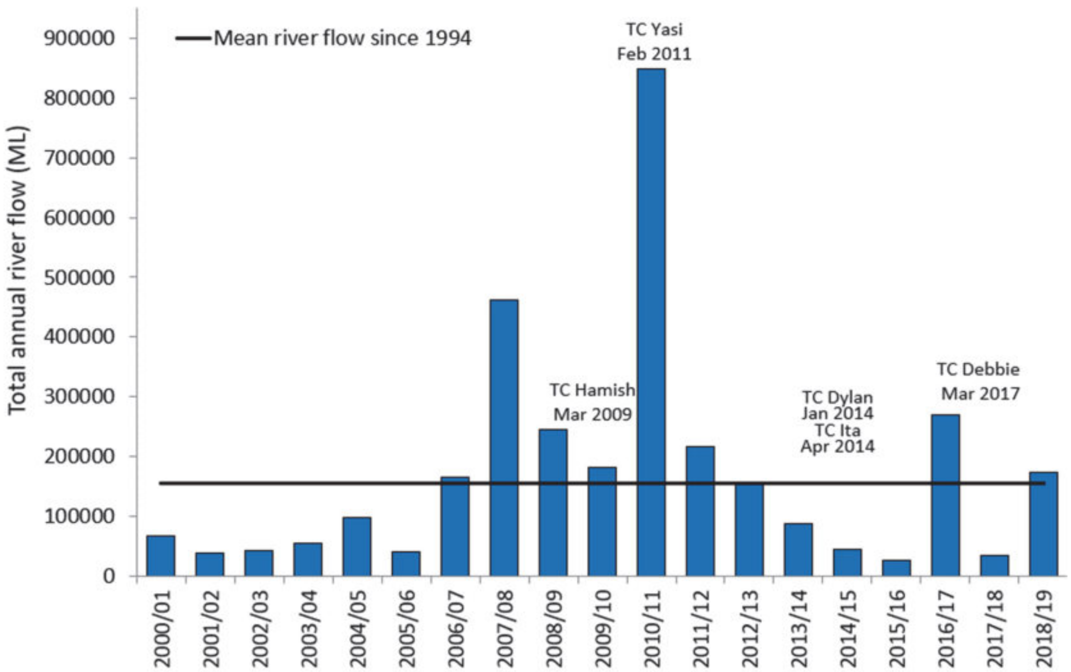


Figure 27a. Total annual river discharge of the Don River (Station 121003A) from 2000/01 to 2018/19. Year represented in columns is twelve months prior to the survey.

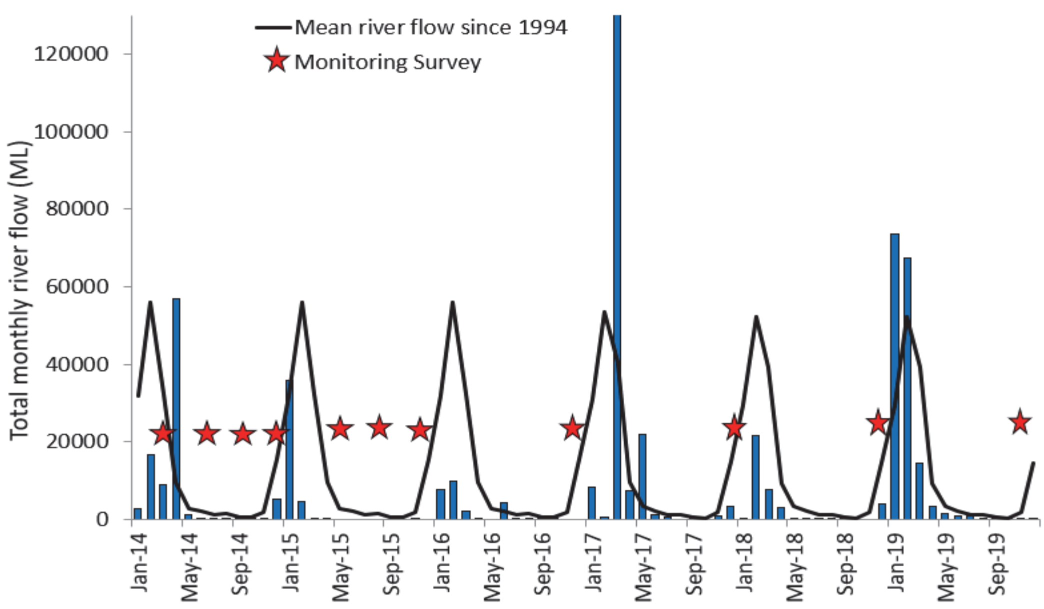


Figure 27b. Total monthly river discharge of the Don River (Station 121003A) from January 2014 to December 2019.

3.4.5 Significant Wave Height

RMS water height values are mostly the result of 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 December and April (Figure 28), coinciding with high wind events (BOM 2019), rainfall, river flow and low light periods. Peaks in RMS wave height can cause peaks in turbidity and sediment deposition (Waltham et al. 2019).

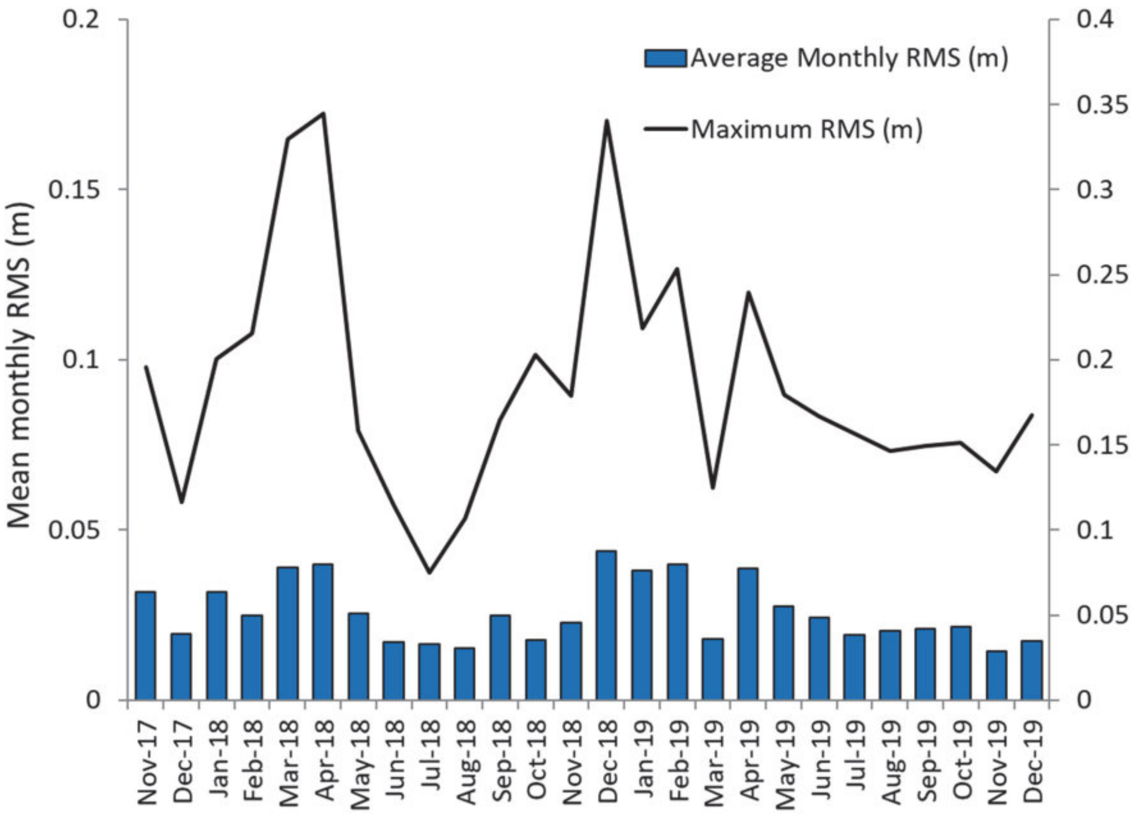


Figure 28. Mean monthly and maximum RMS recorded at Abbot Point water quality site AMB 1 November 2017 – December 2019.

4. DISCUSSION

Seagrasses in the Port of Abbot Point monitoring meadows were in a satisfactory condition overall in 2019, similar to 2018, and remain in a recovery phase. There were however, improvements in deep-water seagrasses; a change from satisfactory condition in 2018 to good in 2019. This was mainly due to the recovery of seagrass biomass at most of the offshore monitoring sites. Inshore meadows remained in a satisfactory condition due to biomass in some meadows remaining low. The broad-scale survey in 2019 (conducted every three years) found seagrass covered a slightly lower area compared to previous surveys, and seagrass biomass across the region was lower than the previous survey in 2016, but greater than 2008 and 2013. The continued satisfactory condition of seagrass at Abbot Point is likely due to cumulative years of impacts from climate related events: Tropical Cyclone Debbie 2017, TC Penny 2019; TC Oma, Tropical Low 13U, which all caused heavy rainfall, extensive flooding and high winds in the area. The persistence of seagrass in the Abbot Point area is likely due to the fact that the climate events of 2019 occurred early in the year, with favourable seagrass growing conditions for the rest of the year. Successive years of climate impacts on Abbot Point seagrass meadows are likely to have reduced the resilience of seagrass in the area to future natural and anthropogenic disturbances. Continued recovery will be contingent on future weather being favourable for seagrass growth.

For the past two years seagrasses have been recovering from the impacts of the above climate events. Offshore *Halophila* meadows have been the first to recover each year. This has been followed by the larger growing species in coastal meadows. The biomass in at least one of the coastal meadows (Meadow 9) is still recovering, not yet reaching pre TC Debbie densities. Differential rates of seagrass recovery between deep and shallow seagrass meadows have been observed previously at Abbot Point following cyclone impacts (Rasheed et al. 2014). After TC Yasi severely impacted the seagrass in the region in 2011, deeper meadows recovered faster, while shallow coastal meadows were slower, taking 3 - 4 years to return to pre-disturbance levels (McKenna et al. 2016; Rasheed et al. 2014). The rate of recovery following a disturbance 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, connectivity to other meadows and the movement of propagules, and the environmental conditions of the affected area following the disturbance (Carruthers et al. 2002; Grech et al. 2018; McKenna et al. 2015a; Rasheed et al. 2014). Colonising species from the genus *Halophila* that occur in offshore meadows are well adapted for recovery due to their reliance on a seed bank that quickly germinates once conditions become favourable, and rapid rates of rhizome growth (Kilminster et al. 2015; Rasheed 2004; Rasheed et al. 2014; Unsworth et al. 2010; Hammerstrom et al. 2006). In contrast more opportunistic species such as *Halodule* and *Zostera* species that are the dominant species in the coastal areas of Abbot Point have slower growth and recovery rates (Rasheed 2004; Rasheed et al. 2014; Unsworth et al. 2010).

The sustained satisfactory condition of inshore seagrass was likely facilitated by favourable environmental conditions for seagrass growth, during the growing season, over the past two years. Heavy rainfall and wind-driven waves are two of the most important environmental factors for seagrass growth in the region as they can negatively impact water quality. Rainfall in the year prior to the survey was above the long-term average for the region, however, all this rainfall occurred in January and February of 2019. There was very little precipitation in the eight months leading up to the survey providing clearer water for seagrass to thrive during the growing season. Significant wave height also peaked during the wet season from December 2018 to April 2019 and then eased off for the 6 months prior to the seagrass survey. Wind-driven waves can resuspend fine sediments in the water column so the long period of low wave height would have also facilitated clearer water which is beneficial to seagrass growth and condition.

As a result of the favourable environmental conditions seagrasses received light above their growing requirements for the majority of the 2019 growing season. Inshore seagrass meadows where *H. uninervis* dominates remained at or above the recommended minimum light requirements throughout most of the growing season (3.5 mol m^{-2} day^{-1} over a 14 day integration period (McKenna et al. 2015b)). Light for the offshore seagrasses was above the minimum threshold for deep-water *Halophila* species during the growing season (1.5 mol m^{-2} day^{-1} over a 7 day integration period (McKenna et al. 2015b)).

The Abbot Point long-term monitoring program is part of the broader Queensland Ports seagrass monitoring program using consistent state-wide monitoring methodology. This enables comparisons with regional and state-wide trends to put local changes in seagrass resources into context. Monitoring at other sites in the network has shown a range of results during 2019. Along the coast of north Queensland seagrass condition improved at most locations due to favourable growing conditions (e.g. Gladstone – Smith et al. 2020; Hay Point and Mackay – York and Rasheed 2020; Mourilyan - van de Wetering et al. 2020; Cairns - Reason et al. 2020; and Weipa – Hoffmann et al. 2020). In other locations where local flooding occurred in early 2019 seagrass condition has declined (e.g. Karumba – Shepherd et al. 2020; and Townsville – McKenna et al. 2020). The major decline in Townsville, just 140 km to the north of Abbot Point occurred due to the largest rainfall event in the past 120 years. This event caused prolonged and large-scale flooding in February 2019. While the Abbot Point and Bowen region also received high rainfall at this time, the extent of the flooding was far less and it therefore did not have had the same impact on local seagrass meadows.

Changes for ongoing monitoring

From 2020 the annual monitoring of offshore seagrass will shift from assessing the seagrass monitoring blocks to a more extensive assessment that incorporates changes in seagrass area into the monitoring design (see Figure 29). The new design will allow for the full suite of indicators used in the meadow condition index (area, biomass, species composition) to be assessed and reported on for offshore meadows for the first time. This shift will bring the monitoring into line with offshore assessments in Hay Point and Mackay which changed from monitoring blocks to a more expansive spatial survey in 2017, and with the inshore meadows at Abbot Point and other monitoring sites in the broader Queensland Ports program. This is an improved way to quantify change in these highly variable, deep-water seagrass meadows that have large changes in their spatial footprint from year to year.

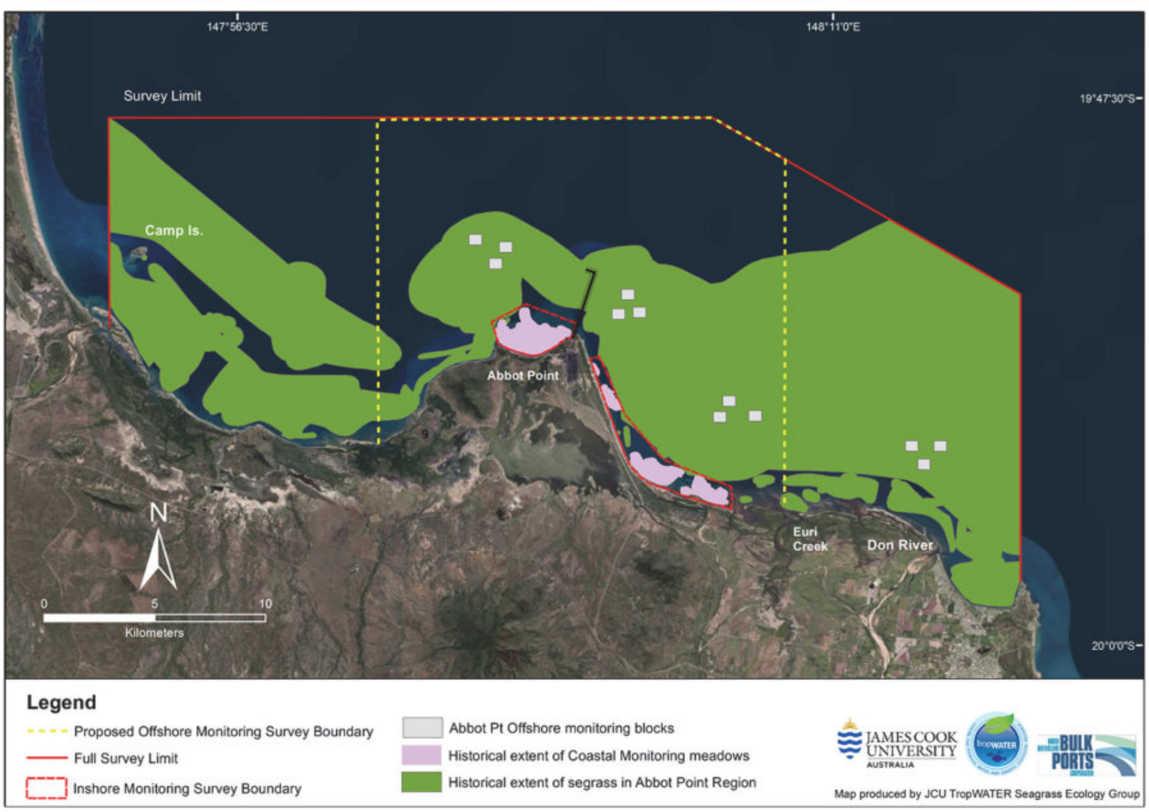


Figure 29. Proposed new survey limit for offshore seagrass monitoring from 2020.

Conclusion

Seagrasses in the Abbot Point region were in satisfactory condition in 2019, similar to 2018 and still in a recovery phase from consecutive years of severe weather events. The persistence of seagrass in the Abbot Point area is likely due to the fact that the climate events of 2019 occurred early in the year, with favourable seagrass growing conditions for the rest of the year. The Abbot Point seagrass meadows were less affected than nearby meadows in Townville which had large declines following severe flooding in early 2019. This is because the rainfall and flooding in the Abbot Point region did not reach the record levels experienced in Townsville. The persistence in Abbot Point seagrass condition is in line with other locations in the central and north Queensland region such as Gladstone and Hay Point/Mackay to the south and Cairns to the north that also experienced improvements in seagrass condition in 2019. Successive years of climate impacts on Abbot Point seagrass meadows are likely to have reduced the resilience of seagrass in the area to future natural and anthropogenic disturbances. Continued recovery will be contingent on future weather being favourable for seagrass growth.

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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		 BIOMASS	Decrease below threshold from previous year		 BIOMASS

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. 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).

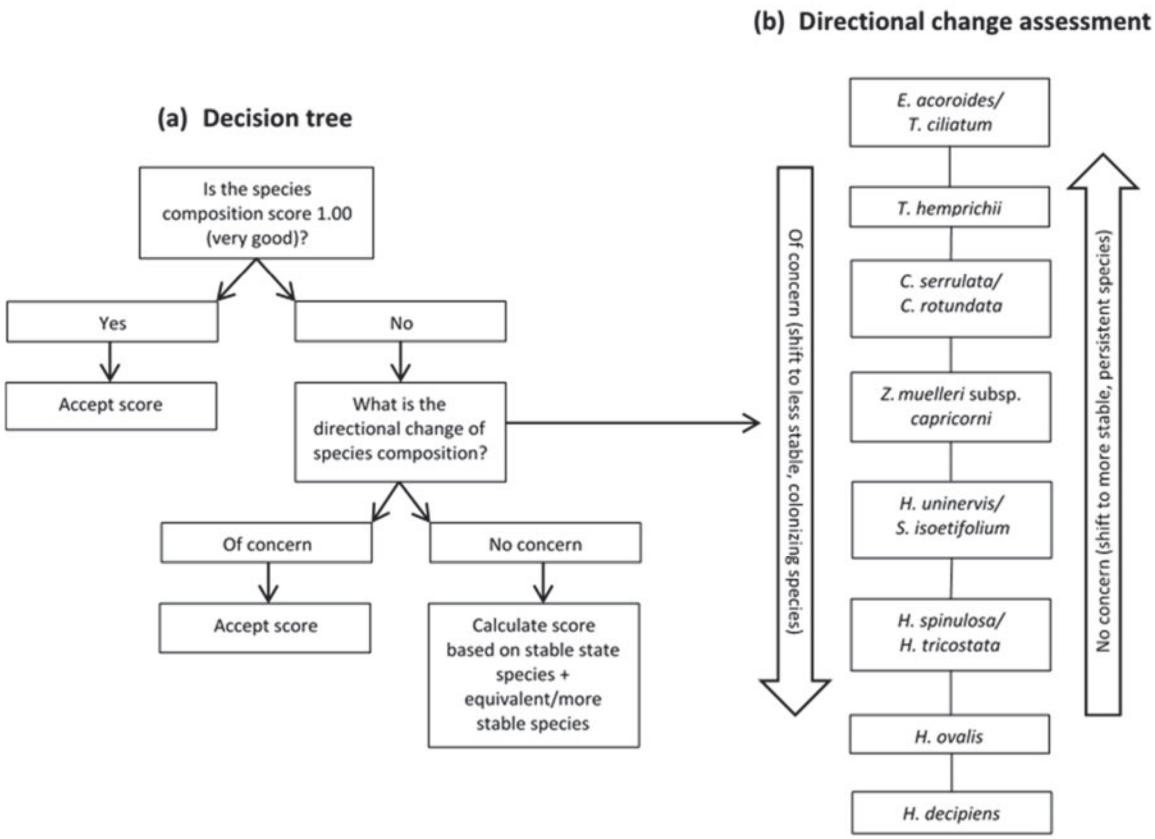


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

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:

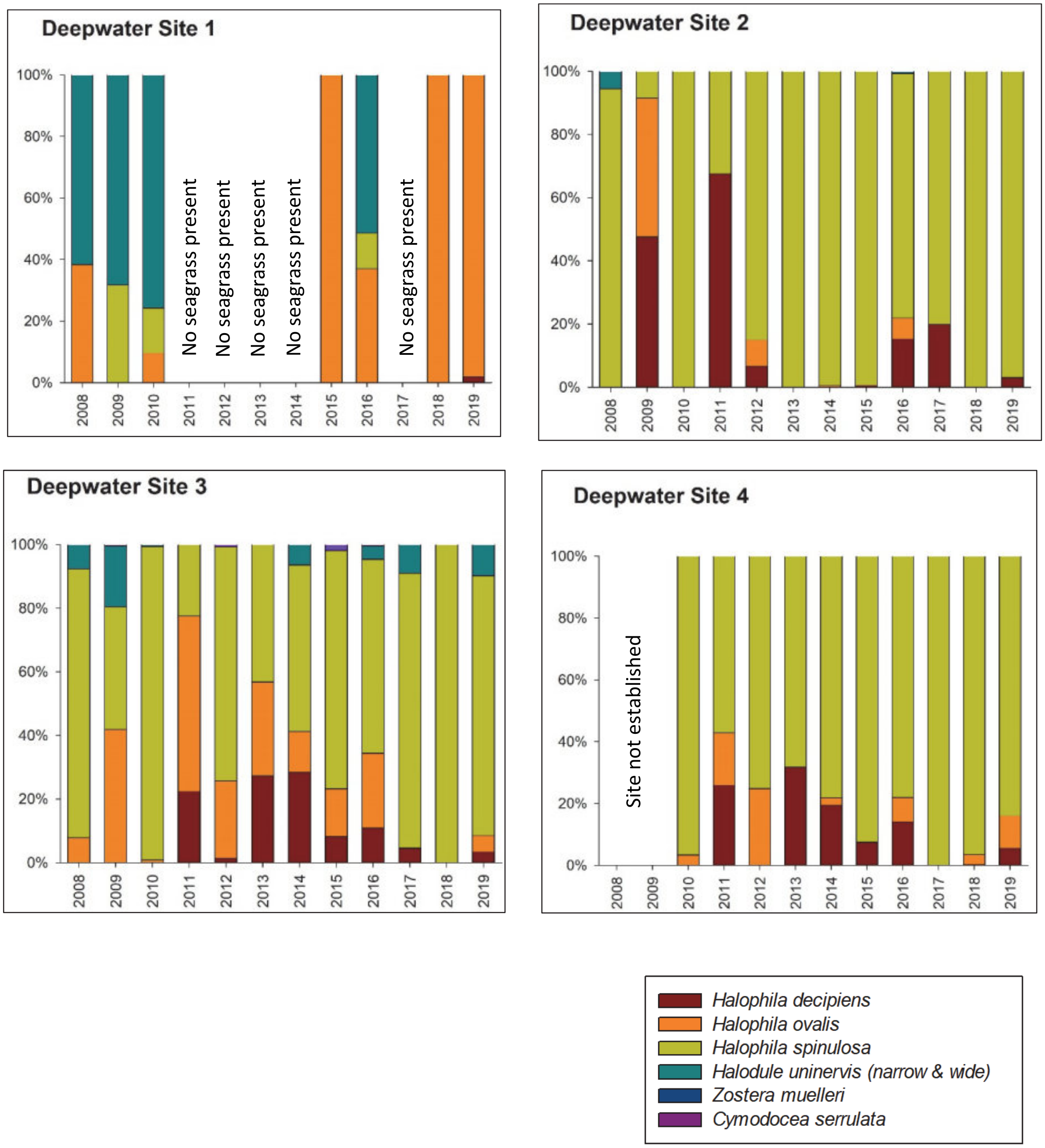
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

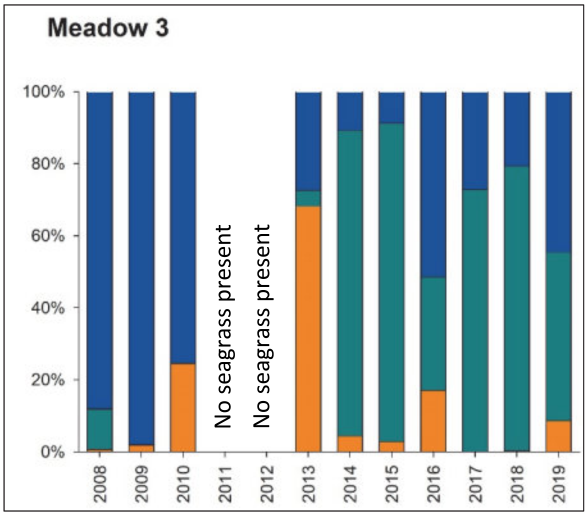
5. Determine the biomass score for 2016 ($Score_{2016}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

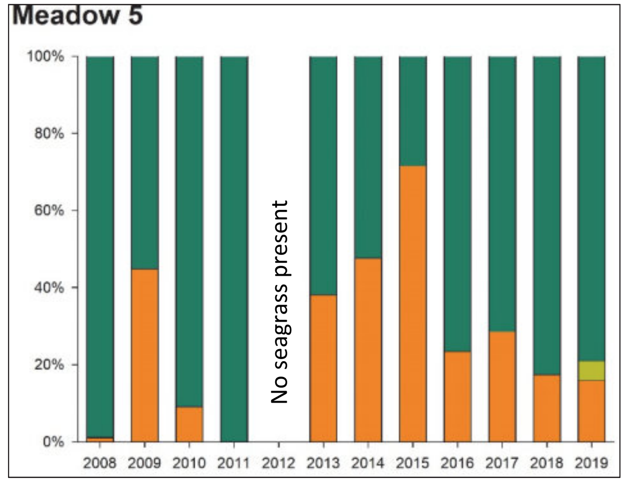
$$\mathrm{Score_{2016}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

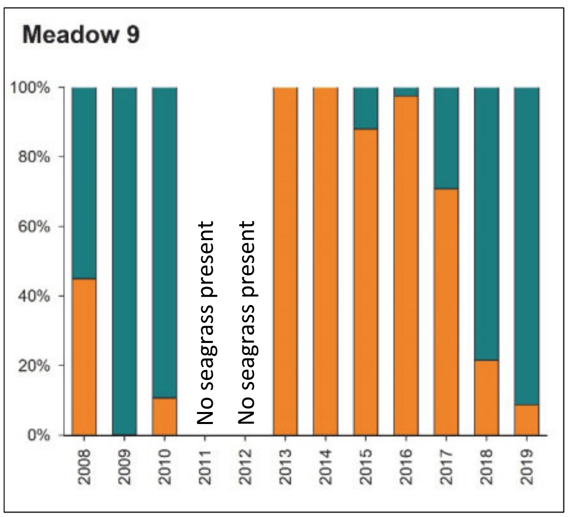
Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

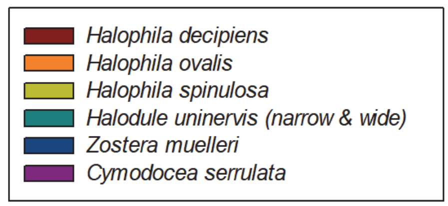
Appendix 3. Species composition of inshore and offshore monitoring meadows in the Abbot Point region: 2008 – 2019




Meadow 3
100%
80%
60%
40%
20%
0%
No seagrass present
No seagrass present
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Meadow 5
100%
80%
60%
40%
20%
0%
No seagrass present
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


Meadow 9
100%
80%
60%
40%
20%
0%
No seagrass present
No seagrass present
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Halophila decipiens
Halophila ovalis
Halophila spinulosa
Halodule uninervis (narrow & wide)
Zostera muelleri
Cymodocea serrulata

Appendix 4. Biomass and area of inshore and offshore meadows

4A. Mean biomass of inshore monitoring meadows in the Abbot Point region; 2005, 2008 – 2019.

Mean Biomass ± SE (g DW m^{-2}) (no. sites present in meadow)			
Meadow #	**3**	**5**	**9**
2005	36.1 ± 16.07 (6)	0.06 ± 0.02 (6)	1.45 ± 0.50 (16)
2008	8.91 ± 4.17 (11)	2.7 ± 0.57 (18)	0.40 ± 0.15 (17)
2009	2.76 ± 0.99 (14)	0.68 ± 0.43 (19)	0.63 ± 0.30 (23)
2010	2.92 ± 0.86 (5)	3.48 ± 0.29 (8)	0.73 ± 0.16 (12)
2011	NP	0.48 ± 0.10 (5)	NP
2012	NP	NP	NP
2013	NP	1.61 ± 0.81 (6)	3.07 ± 1.55 (3)
2014	1.67 ± 0.34 (3)	8.3 ± 4.26 (5)	4.36 ± 0.91 (8)
2015	4.21 ± 3.96 (3)	2.8 ± 0.64 (13)	2.80 ± 0.50 (20)
2016	5.25 ± 1.59 (10)	2.83 ± 0.65 (15)	8.32 ± 1.66 (14)
2017	5.85 ± 1.05 (13)	3.42 ± 1.06 (10)	3.0 ± 0.57 (20)
2018	2.77 ± 0.76 (12)	2.41 ± 0.57 (13)	0.90 ± 0.20 (5)
2019	6.04 ± 1.58 (8)	2.6 ± 0.54 (27)	0.52 ± 0.13 (12)

NP – No seagrass present in meadow

4B. Area (ha) of inshore monitoring meadows in the Abbot Point region; 2005, 2008 – 2019.

Area ± R (ha)				
Meadow #	3	5	9	TOTAL meadow area
2005	25.6 ± 6	46.6 ± 15.9	125.8 ± 41	198 ± 62.9
2008	56.95 ± 8.06	45.3 ± 20.29	83.96 ± 10.26	186.21 ± 38.61
2009	44.2 ± 9.3	16.2 ± 3.3	22.9 ± 5.1	83.3 ± 17.7
2010	15.04 ± 4.9	23.47 ± 8.69	105.38 ± 85.44	143.89 ± 23.66
2011	NP	3.12 ± 2.66	NP	3.12 ± 2.66
2012	NP	NP	NP	NP
2013	NP	28.86 ± 13.86	35.11 ± 15.47	63.97 ± 29.33
2014	12.19 ± 3.84	10.49 ± 2.48	92.42 ± 71.5	115.1 ± 77.82
2015	8.84 ± 4.55	25.24 ± 19.58	180.27 ± 62.26	214.34 ± 86.39
2016	78.40 ± 6.17	191.71 ± 35.74	214.02 ± 41.28	463.14 ± 16.32
2017	43.91 ± 5.33	20.38 ± 3.13	94.91 ± 16.76	159.20 ± 13.40
2018	47.67 ± 5.15	50.56 ± 8.27	28.80 ± 6.02	127.04 ± 6.02
2019	25.98 ± 8.98	188.46 ± 44.09	88.75 ± 21.11	303.19 ± 74.18

NP – No seagrass present

3C. Mean above-ground biomass (g DW m^{-2}) of offshore monitoring sites in the Abbot Point region; 2005, 2008 – 2019.

Sampling Date	Mean Biomass ± SE (g DW m^{-2}) (dominating seagrass species)			
	Site 1	Site 2	Site 3	Site 4
2005*	0.08 ± 0.07	0.59 ± 0.15	3.98 ± 1.43	Site not established
2008	0.02 ± 0.02	0.61 ± 0.17	5.10 ± 0.65	Site not established
2009	0.07 ± 0.04	0.46 ± 0.11	0.45 ± 0.09	Site not established
2010	0.17 ± 0.07	6.26 ± 0.89	25.76 ± 2.52	5.34 ± 0.76
2011	NP	0.26 ± 0.07	0.18 ± 0.06	0.19 ± 0.06
2012	NP	0.59 ±0.16	1.76 ± 0.26	1.16 ± 0.21
2013	NP	0.08 ± 0.03	0.02 ± 0	0.02 ± 0.01
2014	0.009 ± 0.005	0.81 ± 0.2	0.32 ± 0.12	0.004 ± 0.002
2015	0.004 ± 0.003	3.46 ± 1.22	2.27 ± 0.68	0.97 ± 0.39
2016	0.006 ± 0.005	0.09 ± 0.04	3.98 ± 1.80	0.03 ± 0.02
2017	NP	0.007 ± 0.003	0.03 ± 0.015	0.004 ± 0.002
2018	0.01 ± 0.01	1.44 ± 0.61	2.70 ± 0.93	0.28 ± 0.21
2019	0.03 ± 0.02	1.84 ± 0.97	2.02 ± 0.37	3.5 ± 2.52

* - 2005 survey was a 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