PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM - 2020

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Report No. 21/25

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A Report for North Queensland Bulk Ports Corporation (NQBP)

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KEY FINDINGS

Seagrass Condition 2020

GOOD

Likely causes of seagrass condition:

⬆ *Favourable climate conditions for seagrass growth*

- In 2020 seagrass in the annually monitored meadows at Abbot Point were in an overall good condition, improving in status from satisfactory the previous two years and poor in 2017 following TC Debbie.
- Inshore seagrasses ranged in condition from good to very good, while the offshore seagrass meadow was in satisfactory condition.
- *Cymodocea serrulata* was present in the monitored meadows for the first time since 2015.
- *Halodule uninervis*, a higher light requiring species had a greater presence in the offshore monitoring meadow and was found to 11.4 m below mean sea level.
- In 2020 environmental conditions were favourable for seagrass growth with a mild wet season and no extreme weather events.
- This is the first year that a full condition score has been applied to the Abbot Point offshore monitoring meadow incorporating area into the indices as well as biomass and species composition.
- The improved condition of seagrass at Abbot Point in 2020 means they were likely to have increased resilience to future natural and anthropogenic pressures compared with recent years.

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 program has evolved to consist of annual surveys of representative monitoring meadows with broader whole-of-port mapping occurring every third year. Annual monitoring is conducted at three inshore areas and a large region of the deeper offshore area (Figure 1). Prior to 2020 the offshore seagrasses were assessed at several smaller monitoring blocks. The shift to assessing a more extensive offshore region in 2020 allows the full suite of seagrass indicators (area, biomass, species composition) to be assessed and reported on for offshore seagrass for the first time.

In 2020 the overall condition of seagrasses in Abbot Point was good. This represents an improvement in seagrass condition in the region from poor in 2017 following reductions caused by Tropical Cyclone Debbie, and a further improvement from the satisfactory scores in 2018 and 2019. Individual coastal meadows scored good-very good, while the offshore seagrass meadow scored satisfactory (Figure 1). Coastal meadows have increased in biomass and area over the last three years, and while the offshore meadow decreased in biomass and area from 2019 to 2020, values remain within the range previously recorded (Figure 2).

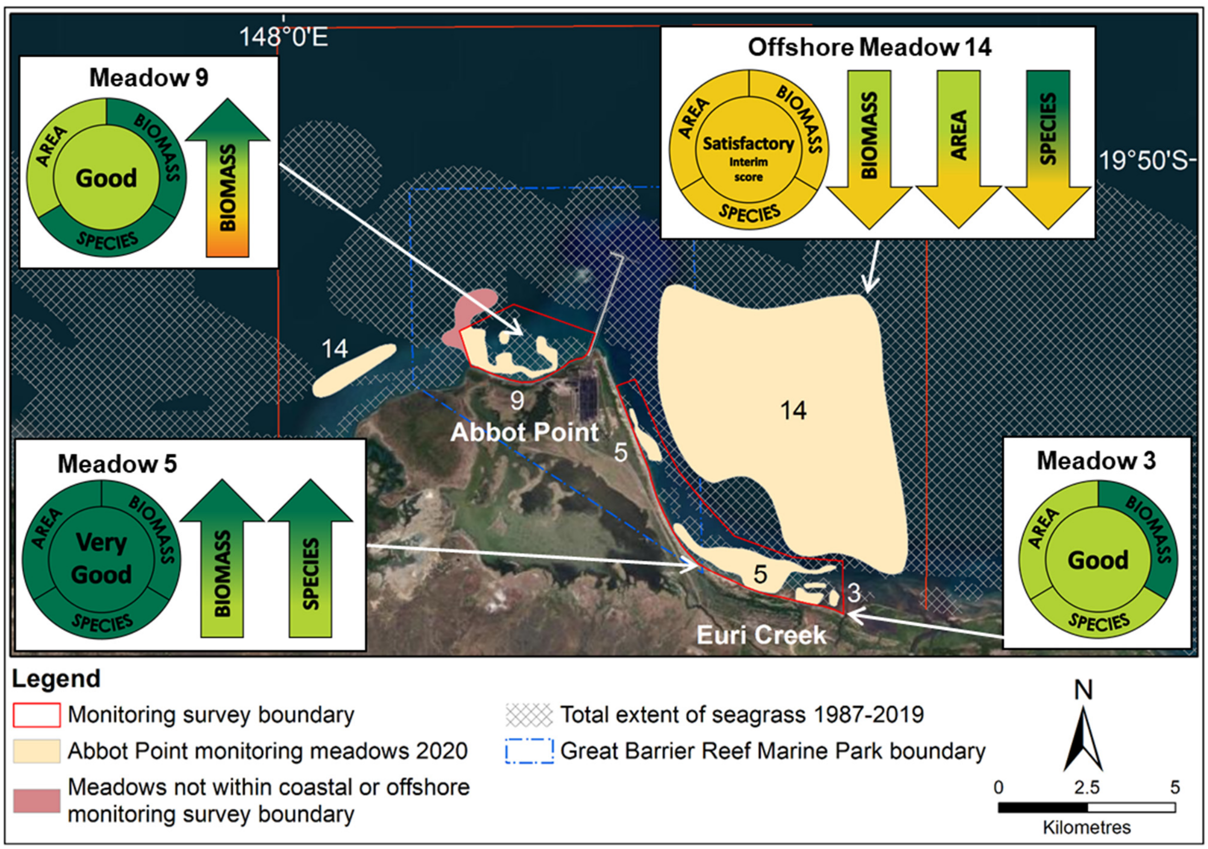

Figure 1. Seagrass condition for Abbot Point seagrass monitoring areas 2020.

Other key findings include *Cymodocea serrulata* being found near the mouth of Euri Creek. This species has not been found in the Abbot Point monitoring areas since 2015. *Halodule uninervis* had a greater presence in the offshore monitoring meadow and was found to 11.4 m below mean sea level (MSL). *H. uninervis* is a higher light requiring species than the *Halophila* species that dominate these deep-water areas.

Between 2017 and 2019 seagrasses around Abbot Point were recovering from successive years of climate impacts: TC Debbie, TC Penny 2019; TC Oma 2019 and Tropical Low 13U in 2019. Offshore *Halophila* meadows were the first to recover, expanding in 2018 (McKenna et al. 2019). This has been followed by the larger growing species in coastal meadows which have now returned to their pre TC Debbie state (Figure 2). The recovery of seagrasses was facilitated by favourable environmental conditions for seagrass growth over the past year (Figure 3). Key environmental conditions that can negatively affect seagrass; rainfall, river flow and wave height (RMS) were all below long-term averages for the region in 2020 providing clearer water for seagrass to thrive during the growing season.

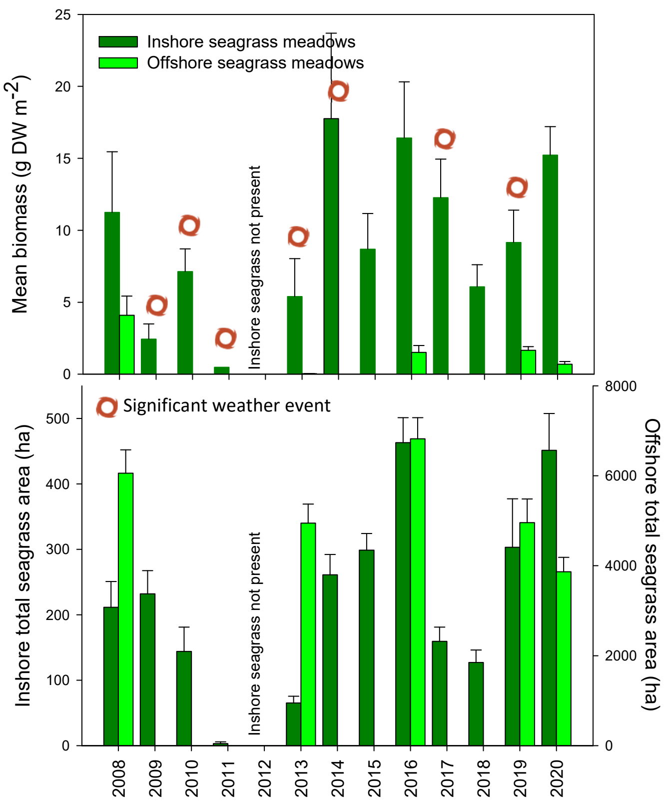

Figure 2. Mean biomass (gdwm^{-2}) and area (ha) of Abbot Point inshore and offshore monitoring areas from 2008 to 2020.

Despite mild environmental conditions in 2020, offshore seagrasses were in a satisfactory condition, with all three seagrass indicators declining below the respective interim baselines. The decline in biomass can be explained by a greater presence in the meadow of the smaller, lighter *H. decipiens* and *H. ovalis* species, and a corresponding decline in the presence of the larger, heavier *H. spinulosa* that traditionally dominates the meadow. The decline in *H. spinulosa* is more difficult to explain, considering there was enough benthic light to sustain *H. uninervis*, a higher light requiring species, in the offshore meadow. The declines in offshore seagrass are more likely to be a reflection of how variable offshore *Halophila* dominated seagrass meadows are, combined with the small number of years (5) that currently contribute to the interim baseline values for the offshore seagrass meadow.

The interim baseline for offshore seagrasses is currently dominated by the 2008 survey where seagrass was at a density and species composition not since observed, and an order of magnitude higher than the four subsequent surveys (Figure 2). As the monitoring program progresses, and the seagrass indicator baselines incorporate new data, the power of that high year will be reduced if the current condition of seagrasses reflects a more typical condition for seagrasses.

The Abbot Point long-term monitoring program is incorporated into the broader Queensland Ports seagrass monitoring program using a consistent state-wide monitoring methodology (see www.tropwater.com.au). This enables direct comparisons with regional and state-wide trends to put local changes into context. It also provides a key input into the condition and trend of seagrasses in the Mackay Whitsunday Isaac NRM region, an area which otherwise has a poor coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2020. Coastal areas to the north and south of Abbot Point had seagrass in good condition (e.g. Gladstone – Smith et al. 2021a; Cairns Harbour - Reason et al. 2021; and Townsville – McKenna et al. 2021). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2021), and coastal meadows around Hay Point were in satisfactory condition while their offshore counterparts were in poor condition reflecting localised drivers of seagrass health.

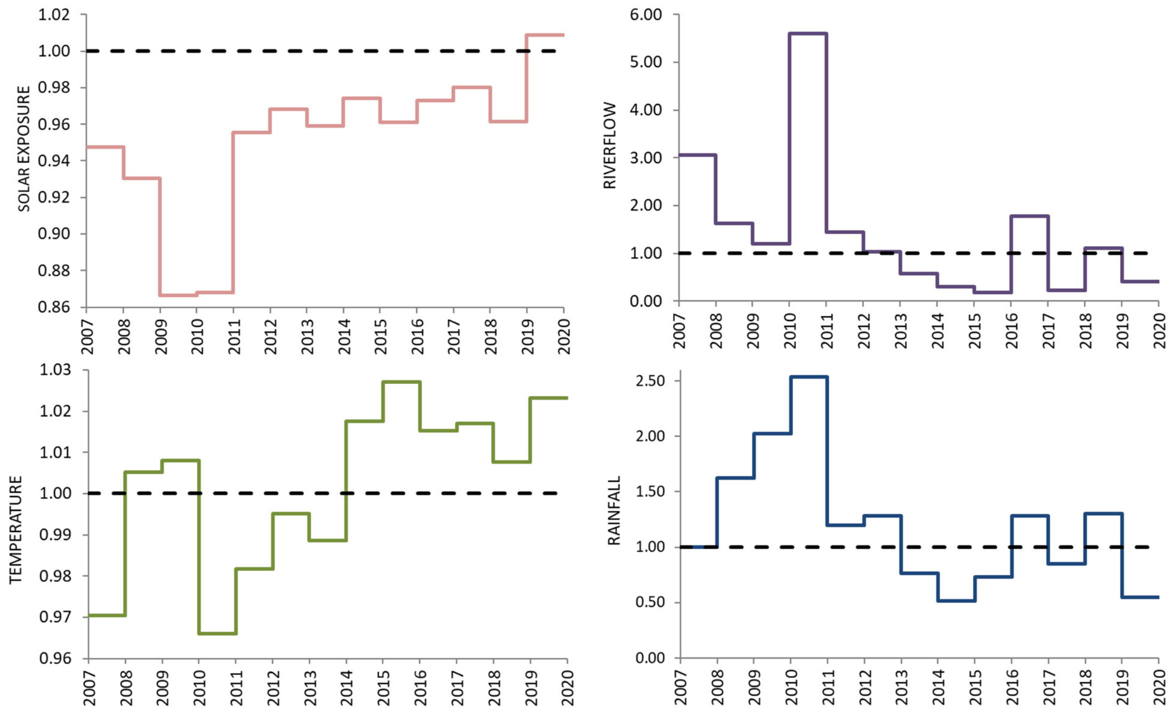

Figure 3. Recent climate trends in the Bowen/Abbot Point area 2006/07 to 2019/20: Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data.

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1. INTRODUCTION

Seagrasses 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 (Dunic et al. 2021; 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).

Figure 4. Location of Queensland port seagrass monitoring sites.

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

The program 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.

1.2 Abbot Point Seagrass Monitoring Program

North Queensland Bulk Ports Corporation (NQBP) in partnership with the Seagrass Ecology Group at TropWATER have been engaged in a seagrass assessment and monitoring program at Abbot Point since 2008. The annual long-term seagrass monitoring program has evolved over time as more data has been collected and end-users have been expanded (i.e. Mackay Whitsunday Healthy Rivers to Reef). The current program consists of annual surveys of representative monitoring meadows with a broader whole of port mapping occurring every third year; last completed 2019. The areas selected for annual monitoring 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 2019, three of the coastal meadows to the southeast of Abbot Point (Meadows 5, 7 and 8) were combined for analysis and reporting based on their proximity and similar species structure, and have since been referred to as Meadow 5 (Figure 5). In 2020 the annual monitoring of offshore seagrass shifted from assessing fixed monitoring blocks to a more extensive assessment of seagrass habitat within a larger survey area, to be able to incorporate changes in seagrass area into the offshore monitoring design (Figure 5). This new assessment strategy for offshore seagrasses allows for the full suite of seagrass 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 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.

As part of a NQBP/JCU partnership, light (Photosynthetic Active Radiation (PAR)) and temperature assessments within two of the inshore monitoring meadows are also conducted, and run parallel to other water quality monitoring stations in the region (5 stations) (see Waltham et al. 2020 for the full NQBP/JCU partnership water quality program).

Information collected in the strategic monitoring program aims to assist in planning and managing future developments in coastal areas in the region. 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 Whitsunday Isaac 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 2020. Objectives include:

- 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;
- 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.

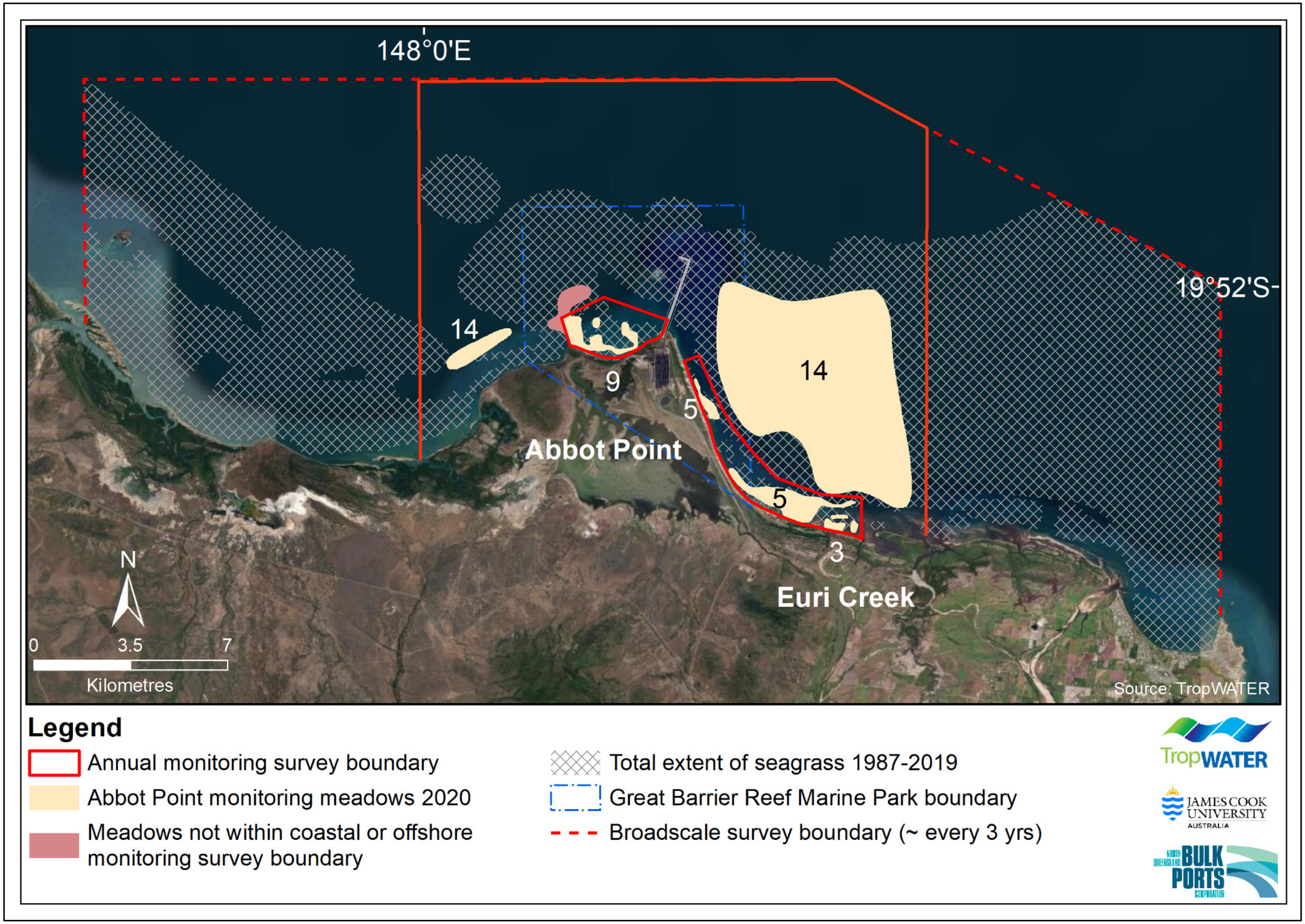


Figure 5. Location of annual coastal monitoring meadows and offshore monitoring areas around Abbot Point.

2. METHODS

2.1 Sampling Approach

In the 2008 baseline survey five coastal meadows and four offshore areas were identified for long term seagrass monitoring (McKenna et al. 2008). In 2019, three of the coastal meadows to the southeast of Abbot Point (Meadows 5, 7 and 8) were combined for analysis and reporting based on their proximity and similar species structure, and referred to in this report as Meadow 5. Coastal monitoring meadows now encompass Meadows 3, 5 and 9 (Figure 5).

In 2020 changes were also made to the way the offshore seagrass meadows at Abbot Point were surveyed, analysed and reported on. These changes were proposed in the 2019 annual seagrass report (Van De Wetering et al. 2020). The change included;

- A shift from assessing seagrass in 'monitoring blocks' to a more extensive assessment of seagrass in a larger survey boundary (Figure 5).
- This new design allows for the full suite of seagrass health indicators used in the meadow condition index (area, biomass, species composition) to be assessed and reported on for offshore meadows.
- The new design brings the Abbot Point offshore monitoring into line with offshore assessments in Hay Point and Mackay which changed from monitoring blocks to a more expansive spatial survey in 2017. It also brings the monitoring into line with the coastal 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.

Methods for assessing coastal 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) and other Queensland ports. 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 Sampling methods

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. Two sampling techniques were used for the survey:

1. Intertidal and subtidal areas <8m below MSL: Boat based underwater digital camera mounted on a drop frame (Figure 6 A & B);
2. Offshore subtidal areas >8m below MSL: Boat based digital camera sled tows with sled net attached (Figure 6 C-D).

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

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, and 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 (Kirkman 1978; Mellors 1991). At camera drop 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.

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, seagrass meadow layer and seagrass 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 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.

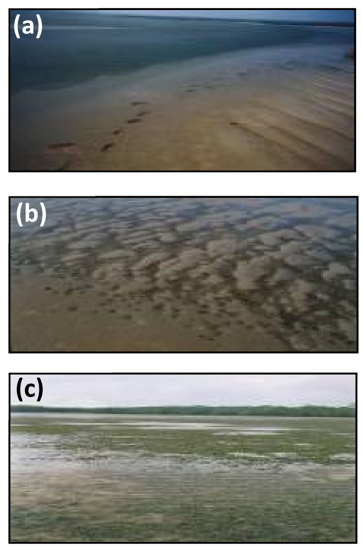


Figure 7. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

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 2020.

Mapping precision	Mapping methodology
10-20m	Subtidal meadow boundaries determined from 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.
100m	Subtidal meadow boundaries determined from digital camera with sled tows; Moderate 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

We have previously established baseline conditions for seagrass meadow biomass, area and species composition at the three coastal monitoring areas (meadows 3, 5 & 9). The baseline conditions for the new offshore monitoring meadow (Meadow 14) has been extracted from the historical data available (2008, 2013, 2016, 2019, 2020) and calculated. The baseline conditions for each seagrass indicator for Meadow 14 are interim baselines and will continue to be adjusted with additional years of monitoring data until ten years of data is incorporated.

A condition index has been 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.

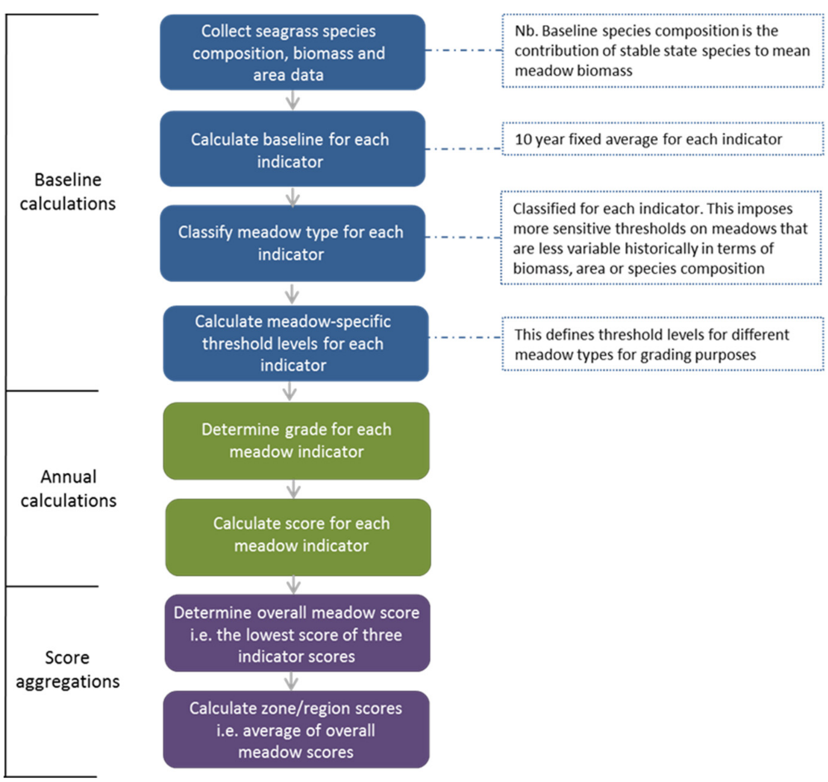


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.5 Environmental data

To provide insight on what is influencing seagrass condition we need to analyse environmental data such as tides, rainfall, river-flow and solar exposure, as well as data collected on water temperature, turbidity, wave height and light (PAR) from the ambient water quality monitoring program.

Environmental data was collated for the twelve months preceding the 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 (station 033327; Bowen Airport AWS) and the Queensland Governments Water Monitoring Information Portal (station 121003A – Don River at Reeves). Root Mean squared (RMS) wave height data has been collected by JCU at Abbot Point site AMB1 as part of the NQBP/JCU partnership since 2017 (Figure 10).

Three logging stations (two coastal stations (TW1 and TW2) and one offshore station AMB 1) collect water temperature and light (PAR) at the seabed within the seagrass monitoring areas (Figure 9). This data has been used to represent the availability of light and temperature in the monitored seagrass meadows.

As part of the NQBP/JCU partnership, the team has also had water quality loggers deployed in the greater Abbot Point region since late 2017 (Figure 10). Detailed data from the water quality monitoring program can be found in Waltham et al. (2020).

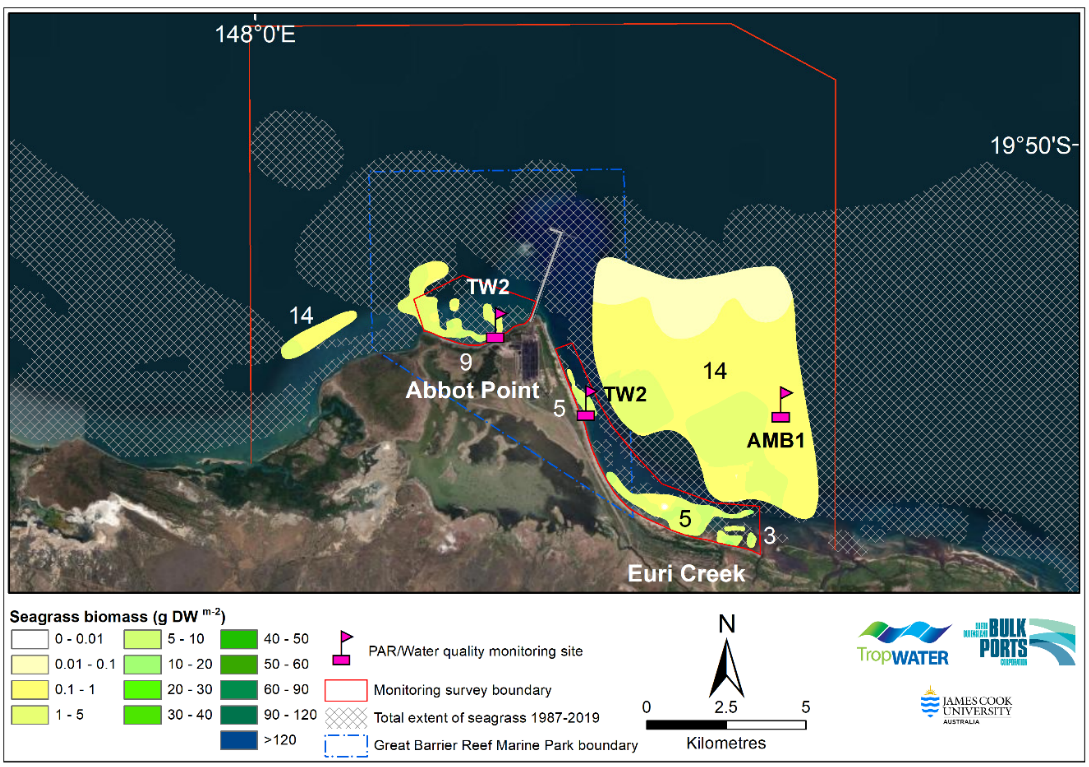


Figure 9. Location of TropWATER, James Cook University light (PAR) loggers at Abbot Point.

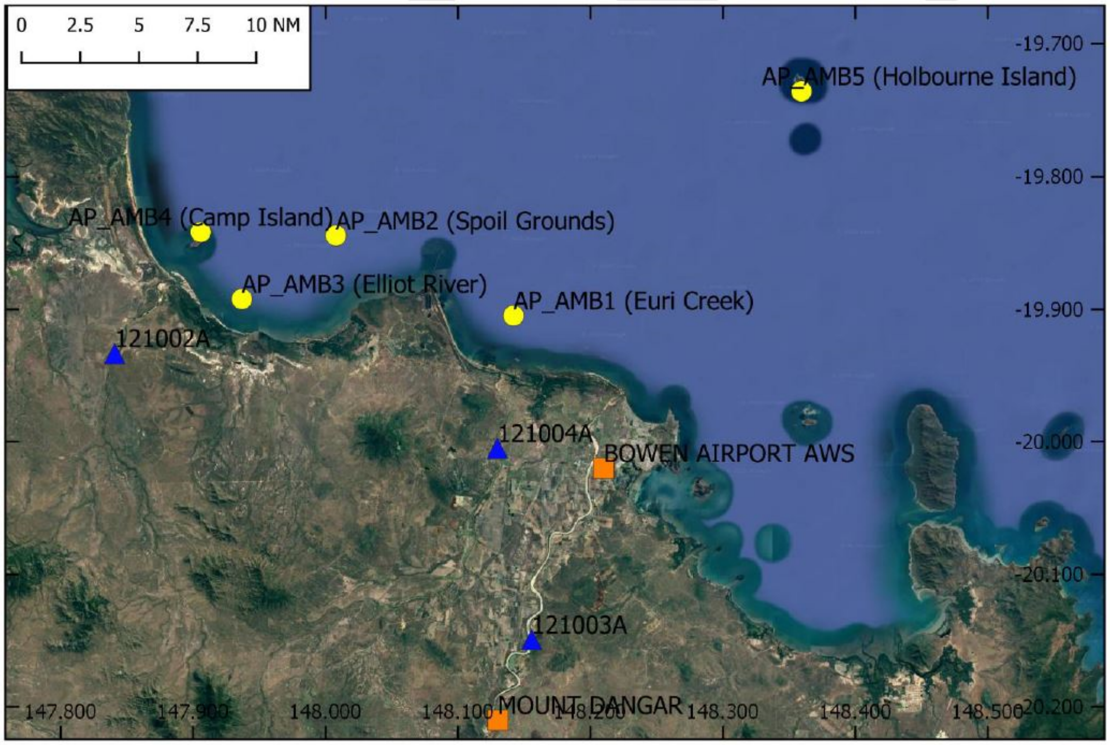


Figure 10. From Waltham et al. (2020): Location of TropWATER, James Cook University water quality monitoring sites (yellow circles). Also shown are meteorological stations (orange square), and stream gauging stations (blue triangle).

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 11). 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.

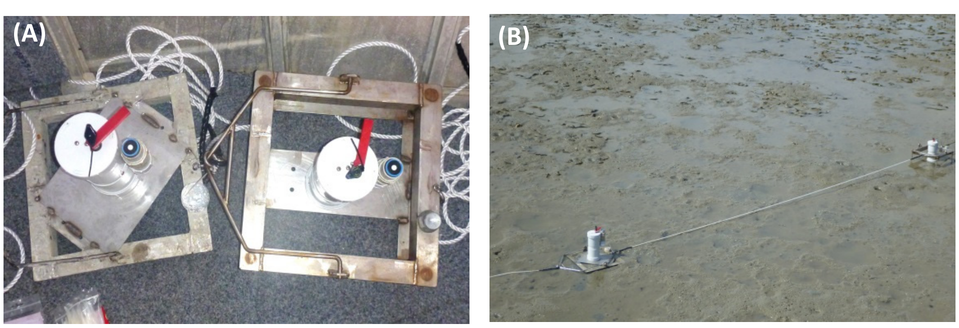


Figure 11. (A) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units; (B) example of deployment of logging stations (Abbot Point stations are subtidal only).

3. RESULTS

3.1 Seagrass in the Abbot Point monitoring areas

A total of 220 sites were assessed as part of the November 2020 Abbot Point annual monitoring survey (Figure 13). Seagrass was present at 44% of the survey sites. The coastal monitoring meadows covered 451.44 ± 56.26 ha while seagrass in the offshore monitoring area covered 3865.81 ± 321.55 ha (Figure 13; 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 the Abbot Point region and more broadly in Queensland (Figure 12, Appendix 3). Six seagrass species were observed in 2020 (Figure 12). In 2020, offshore seagrass habitat was dominated by *Halophila decipiens* while *H. spinulosa*, *H. ovalis* and *Halodule uninervis* were also present. *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows with *H. ovalis* and *H. decipiens* also present. *Zostera muelleri* and *Cymodocea serrulata* were found near the mouth of Euri Creek. *Cymodocea serrulata* has not been found in the Abbot Point monitoring areas since 2015.

Cymodocea rotundata, Syringodium isoetifolium and *Halophila tricostata* have been recorded in the area in the past but occurrences are rare and they were not present in 2020. *H. tricostata* was last observed in the 2016 broad scale survey, and *C. rotundata* and *S. isoetifolium* were only observed in the 2005 baseline survey.

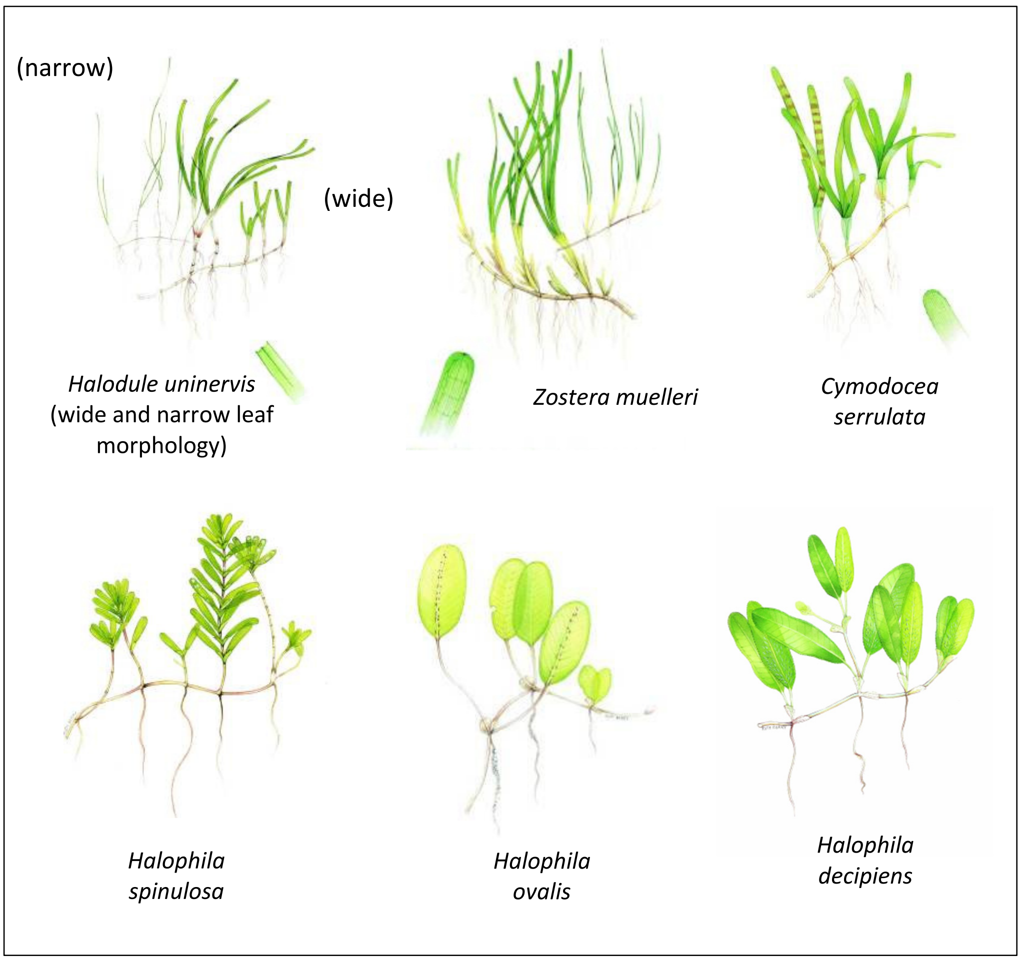


Figure 12. Seagrass species identified in the Abbot Point/Bowen region in 2020.

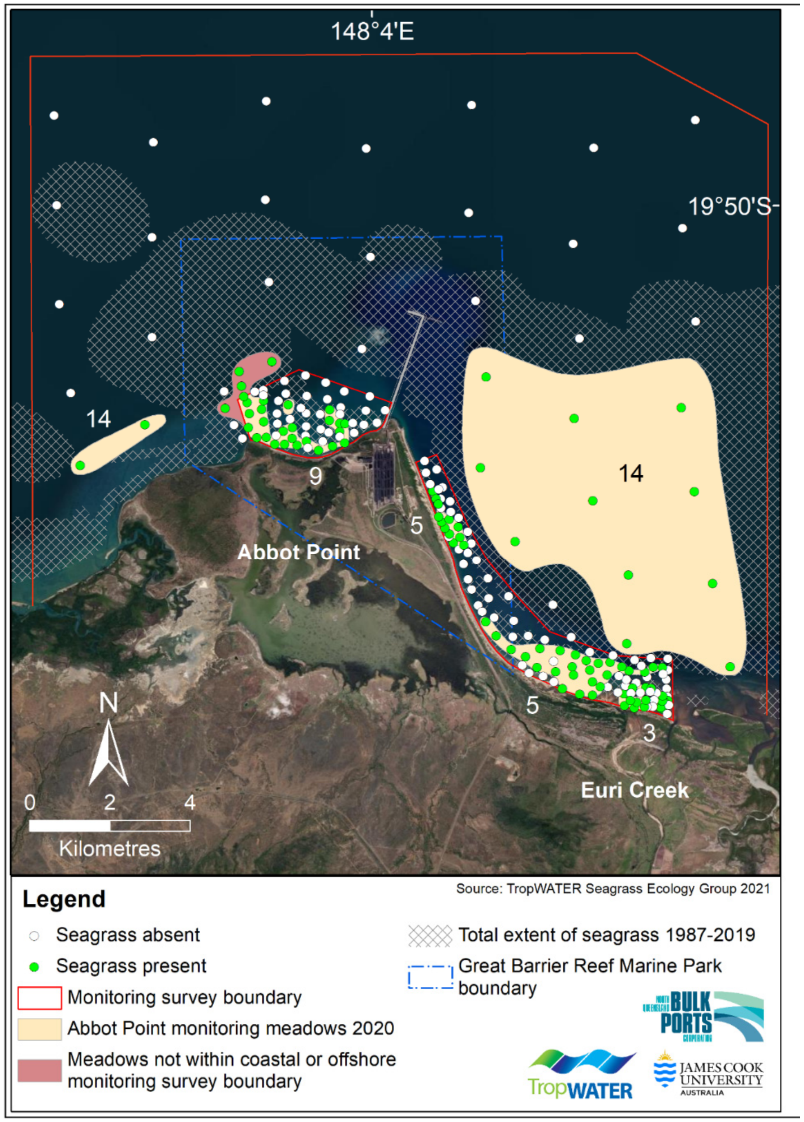


Figure 13. Location of seagrass assessment sites in the 2020 annual monitoring survey.

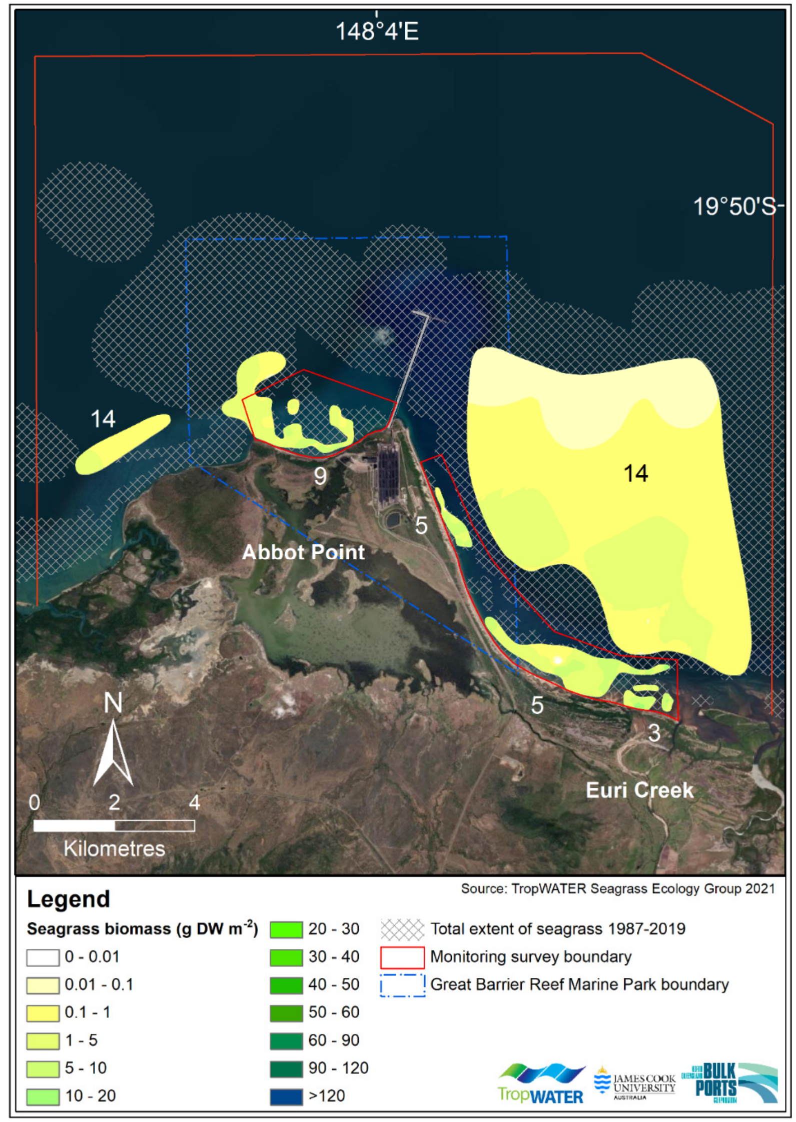


Figure 14. Seagrass biomass (g DW m^{-2}) interpolation for Abbot Point survey 2020.

3.2 Seagrass condition in the Abbot Point monitoring areas

The overall condition of seagrass monitoring meadows in the Abbot Point region was good in 2020. Individual coastal meadows scored good-very good, while the offshore seagrass habitat scored as satisfactory (Table 4). This was an improvement in condition from the last two years; seagrass habitat around Abbot Point has been in a 'recovery phase' after impacts from multiple climate related events between 2017 and 2019: Tropical Cyclone Debbie 2017, TC Penny 2019; TC Oma 2019, Tropical Low 13U 2019.

Table 4. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2020.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score
Inshore meadow 3	0.91	0.72	0.73	0.73
Inshore meadow 5	0.87	0.93	1	0.87
Inshore meadow 9	0.85	0.91	0.83	0.83
Offshore meadow 14	0.57	0.56	0.52	0.52
Overall score for seagrass in the Port of Abbot Point				**0.73**

Inshore monitoring meadows

Meadow 3 and 5 are located to the southeast of Abbot Point while Meadow 9 is the only coastal monitoring meadow located on the western side of Abbot Point (Figure 14). Meadows 5 and 9 are *H. uninervis* dominated meadows made up of aggregated patches of seagrass, while Meadow 3 at Euri Creek is historically a *Z. muelleri* meadow that is currently dominated by *H. uninervis* (Figure 17; Appendix 3).

For the past two years Meadow 3 has been in good condition (Table 4, Figure 15). The area of the meadow increased between 2019 and 2020 by 21% to 31.4 ± 3.25 ha, and biomass increased by a similar amount between years (Figure 15, Appendix 4).There was a slight decrease in the relative abundance of *Z. muelleri* in the meadow compared to 2019, but this was within the range of previously recorded values (Appendix 3). Interestingly, *C. serrulata* was recorded in the meadow at one site (Figure 15; Appendix 3). This species has not been recorded in any surveys since 2015, and has not previously been found in the coastal meadows around Abbot Point. In the past *C. serrulata* has only been found in the offshore seagrass habitat (Appendix 3).

Meadow 5 was in a very good condition in 2020, with biomass and species composition increasing in condition from good to very good between 2019 and 2020 (Table 4, Figure 16). In 2020, the meadows increased by 45%, to register the largest total coverage on record: at 274 ± 31.19 ha (Figure 16, Appendix 4B). This is the third consecutive year that the meadows have expanded in size, after significant losses from TC Debbie in early 2017 (Figure 16). Seagrass biomass also significantly increased in the meadows, recording the highest density of seagrass since 2014 (Figure 16, Appendix 4A). Species composition remained stable in the meadow, with *H. uninervis* the dominant species. *Zostera muelleri* was present in the meadow for the first time, however this was because of the proximity of Meadows 5 and 3 in this survey, with some species mixes occurring at the meadow edges.

Meadow 9 was in a good condition in 2020, an improvement in condition from poor for the last two years (Table 4, Figure 17). This improvement was driven by the significant increase in seagrass biomass (>500% increase) over the previous twelve months; meadow biomass improved from poor condition in 2019 to very good in 2020 (Figure 17, Appendix 4A). Seagrass density in the meadow has not been in 'very good' condition since 2016 (Figure 17). The area of the meadow within the survey boundary also increased by 65% between

2019 and 2020 (Figure 17, Appendix 4B). Species composition of the meadow has been in very good condition for the past three years with *H. uninervis* the dominant species in the meadow (Appendix 3).

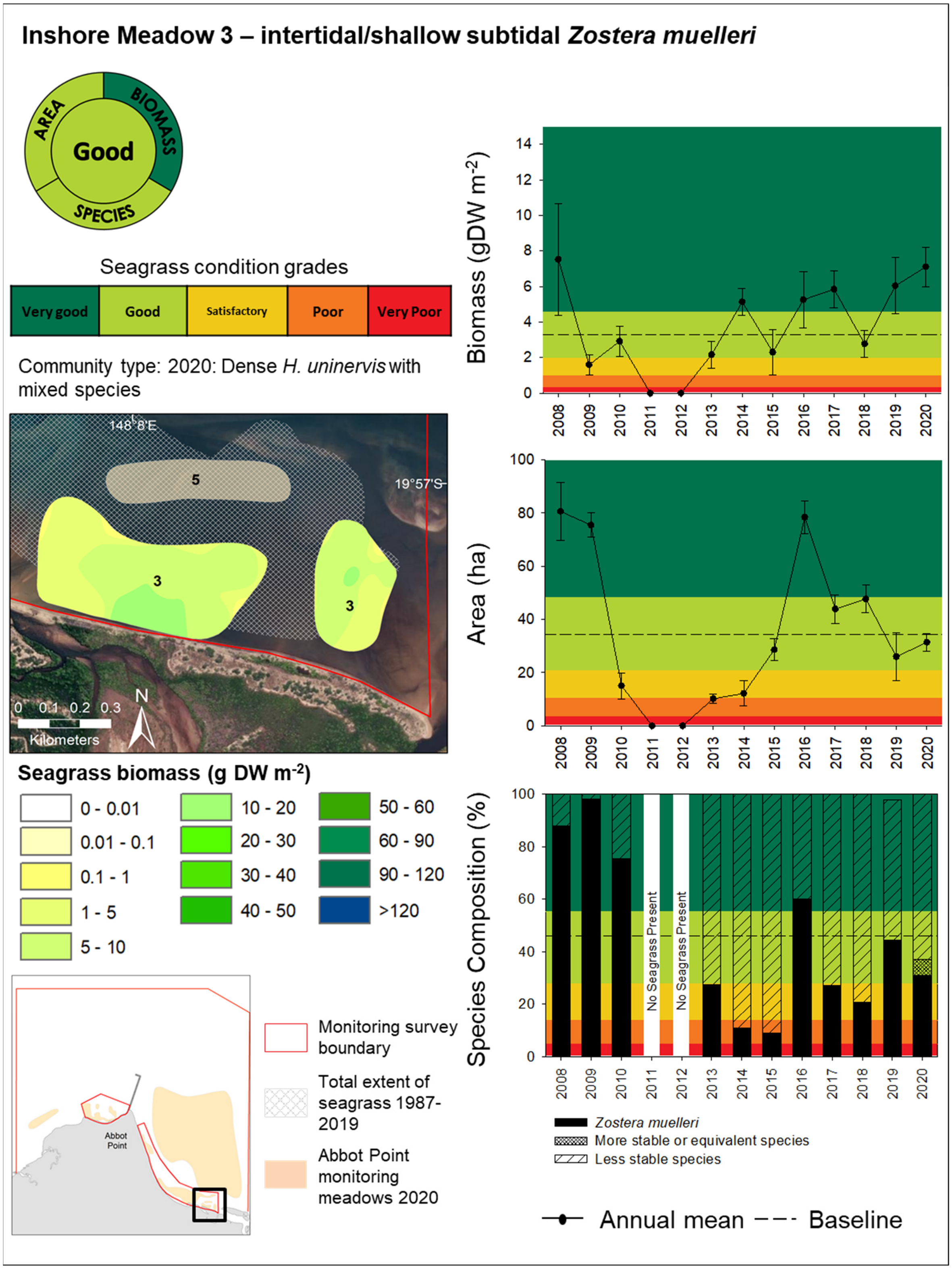
Meadow 9 extended beyond the fixed survey boundary for annual monitoring for the first time since monitoring began in 2008 (Figure 17). The total area of the meadow including the section outside the annual monitoring survey boundary was 251.08 ± 31.19 ha. For the purpose of the long-term monitoring program however, only results from within survey boundaries are reported on for condition assessments.

Offshore monitoring area

In 2020 the annual monitoring of offshore seagrass shifted from assessing monitoring blocks to a more extensive assessment within a larger fixed survey area. This shift in monitoring approach allows the incorporation of changes in seagrass area into the monitoring design, and hence the full suite of seagrass indicators (area, biomass, species composition) to be assessed and reported on for the first time (Figure 18). An interim baseline for each seagrass indicator has been extracted from the historical data available that covered the same survey region (2008, 2013, 2016, 2019, 2020) and calculated. The baseline conditions for each seagrass indicator for offshore seagrass (Meadow 14) are interim baselines and will continue to be adjusted with additional years of monitoring data until ten years of baseline data is reached.

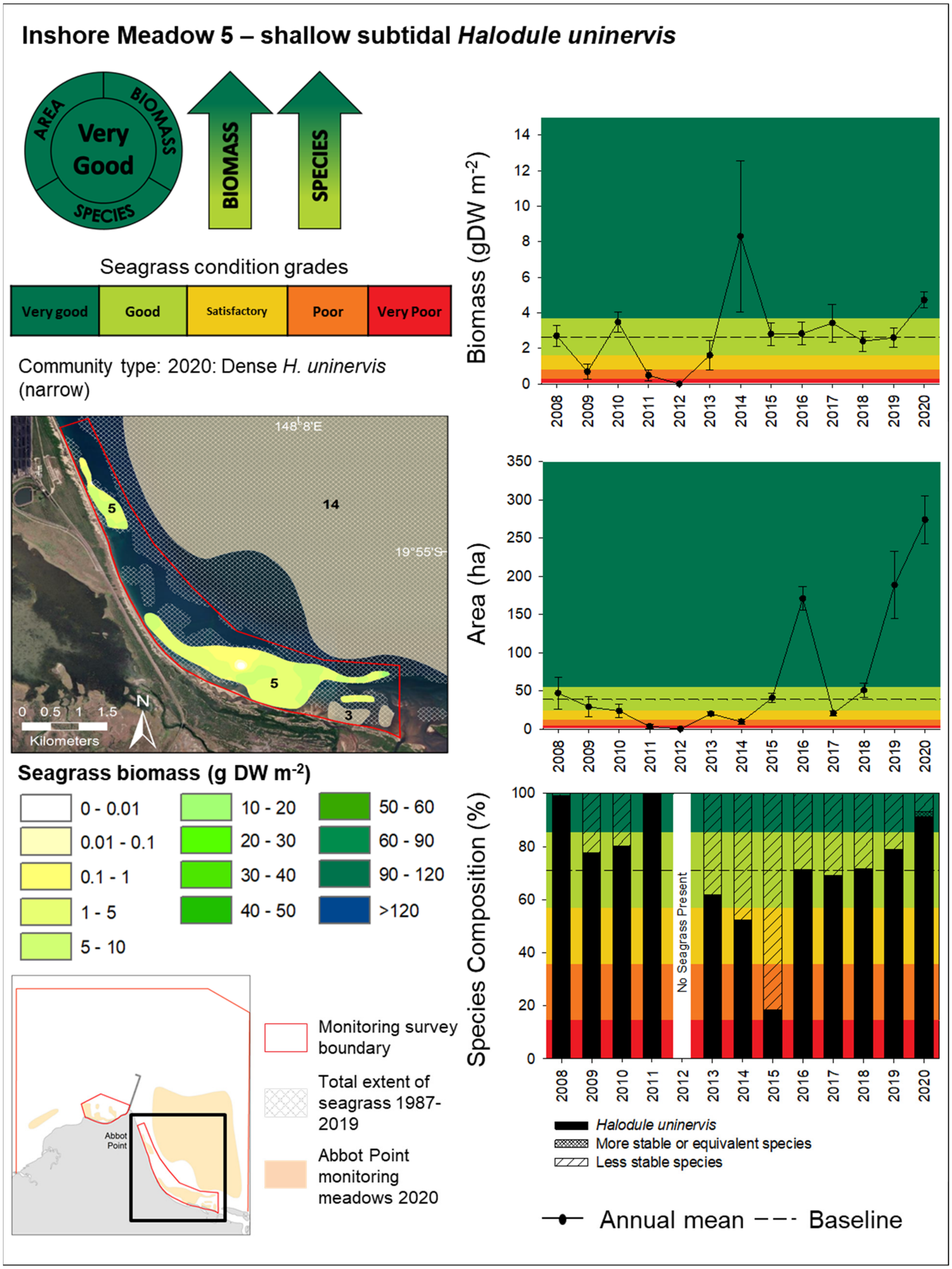
The offshore monitoring area encompasses seafloor from ~5m to 26m below MSL. The shallowest offshore area is located on the north-western side of Abbot Point on Clark Shoal. Seagrass in this area has been intermittent in its presence throughout the monitoring program and has typically been dominated by *H. uninervis* (Van de Wetering et al. 2020). The deeper areas generally consist of low light adapted *Halophila* species; dominated by *H. spinulosa*.

Seagrass condition in the offshore monitoring area was in satisfactory condition in 2020 (Table 4, Figure 18). Offshore seagrass condition reduced between 2019 and 2020 with all seagrass indicators shifting from good/very good in 2019 to satisfactory in 2020 (Table 4, Figure 18). Seagrass was found from 5 – 16m below MSL and covered a total area of 3,865.81 ± 321.55 within the fixed survey boundary; the lowest area recorded in the five years of baseline data available (Figure 18). The decline in offshore seagrass biomass was likely driven by a reduction in the larger, heavier *H. spinulosa* that historically dominates the meadow (Figure 18, Appendix 3). There was a higher presence of the more stable *H. uninervis* in the meadow, which was found in waters closer to the coast; less than 12m below MSL and only present in a small section of the meadow.



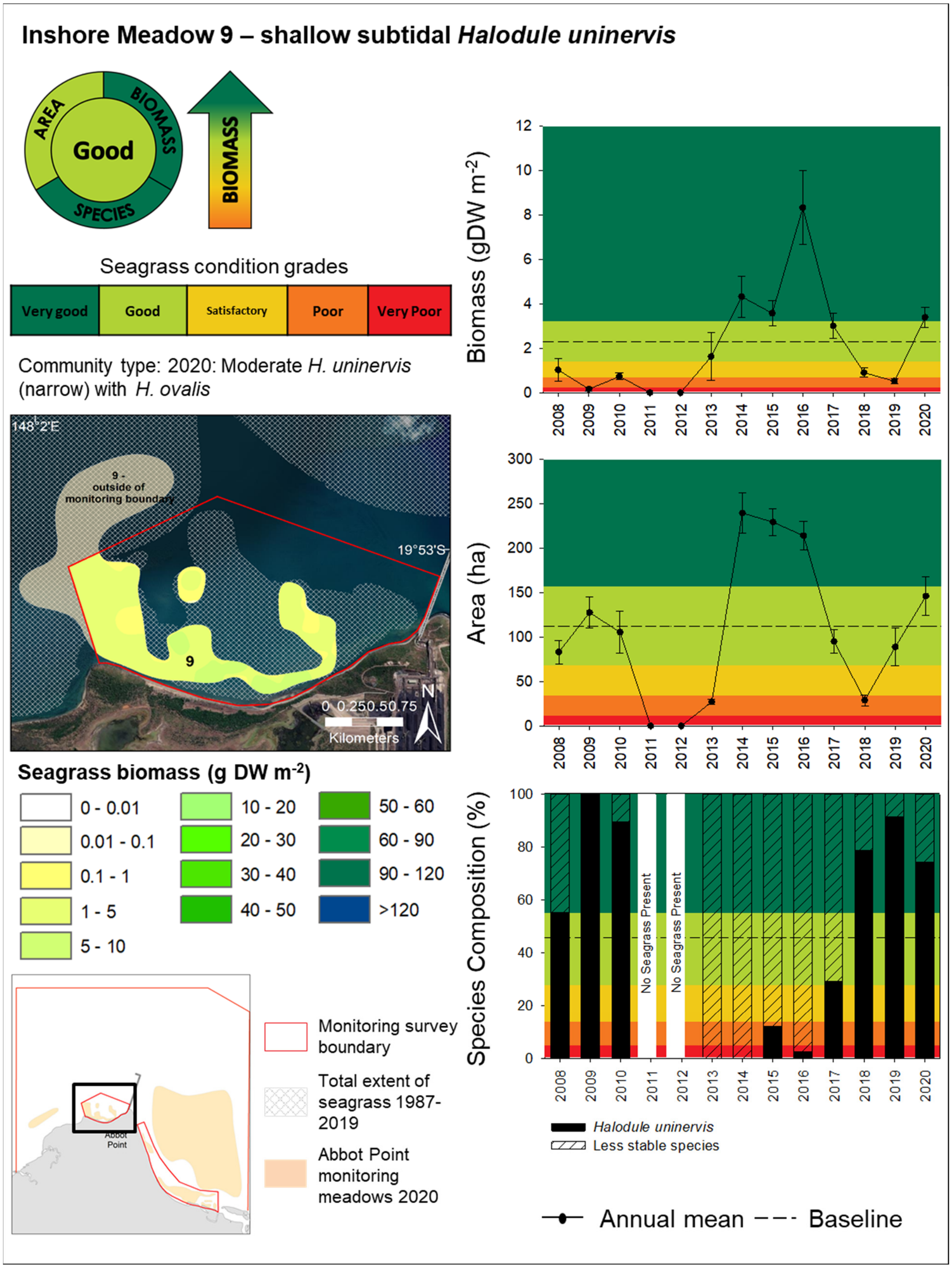
*lack of arrows indicates no change in condition index from the previous year

Figure 15. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3.



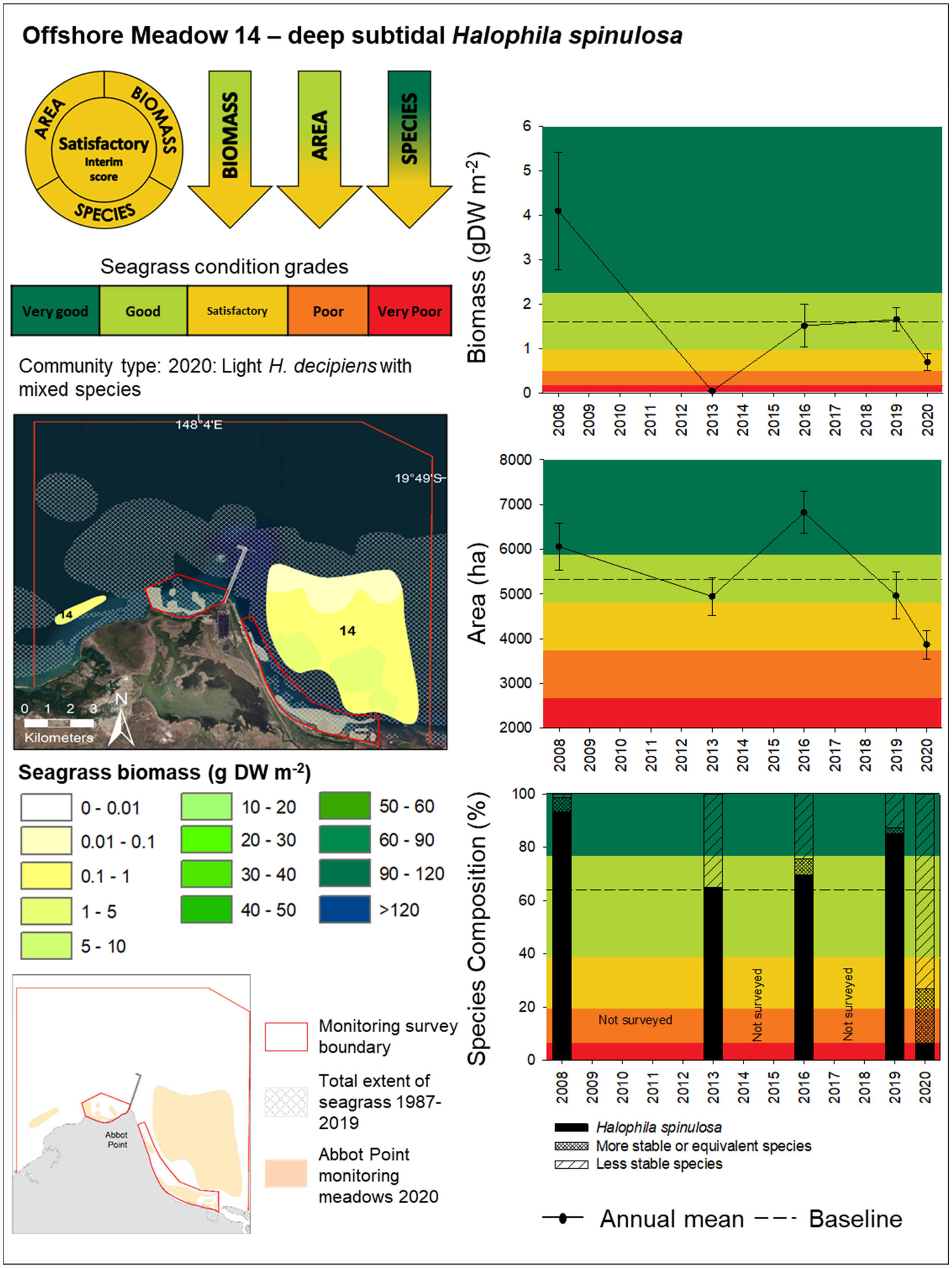
*lack of arrows indicates no change in condition index from the previous year

Figure 16. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5.



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

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



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

Figure 18. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Meadow 14.

3.3 Abbot Point environmental data

3.3.1 Benthic daily light - photosynthetically active radiation (PAR)

The inshore PAR sites; TW1 & TW2 are at different depths and represent the depth gradient where coastal seagrasses can be found at Abbot Point (Figure 9). 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.

Due to COVID-19 restrictions and loss/equipment failure in 2020 there are large gaps in PAR data in the 12 months preceding the November 2020 survey. Where data was available and passed quality control processes, results are presented below (Figure 19). There was not enough data from the inshore PAR sites to report on.

Typically, light available to seagrass changes with season; lower light levels during the wet season associated with higher rainfall, higher cloud cover, river flow and wind events, followed by higher light levels supporting seagrass growth during the dry season (Figure 19). In addition, semi-regular fluctuations between low and high PAR are often overridden by larger episodic events caused by storm or rainfall (Waltham et al. 2020).

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 of 3.5 mol m^{-2} day^{-1} over a rolling 14 day average was recommended.

Data available for AMB 1 recorded a daily light range from less than 0.1 – 6.8 mol m^{-2} day^{-1} in 2020 (Figure 19). Data from the water quality monitoring program suggests that there was not a strong seasonal signal in PAR at any monitoring sites, and total daily light was generally similar between seasons (Waltham et al. 2020). For the data that is available at AMB 1, there were some periods of time where light fell below thresholds for *Halophila*. We are not sure if these periods were sustained long enough to potentially have an impact on offshore seagrass. For inshore seagrass there was not a sufficient amount of reliable data to report on.

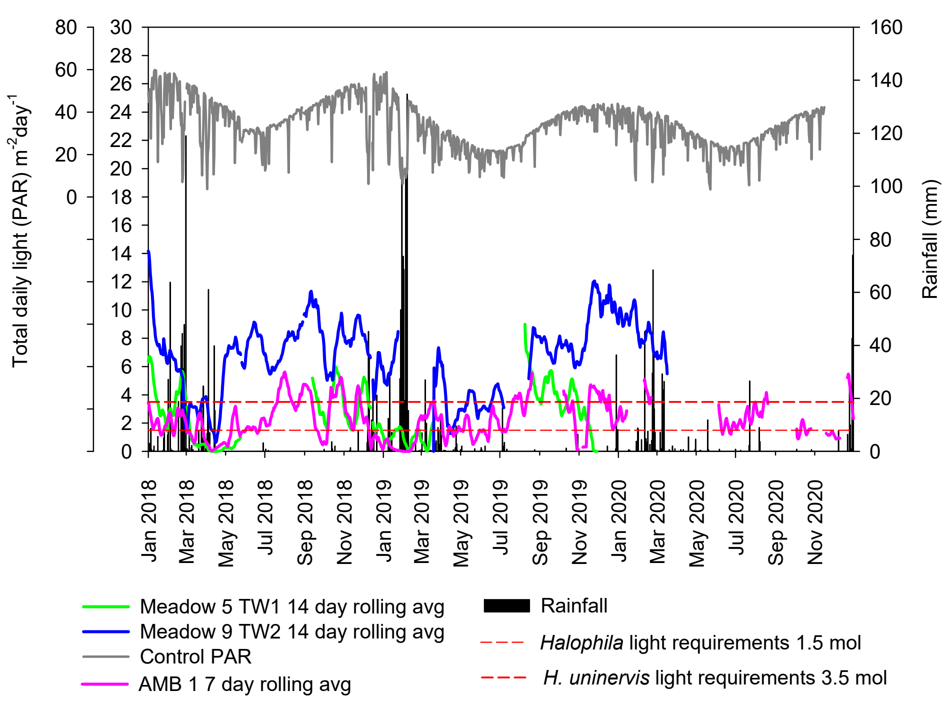


Figure 19. Fourteen and seven day rolling average total daily PAR (mol photons $m^{-1}day^{-1}$), total daily rainfall, and *H. uninervis* & *Halophila* light requirement threshold January 2018 – December 2020.

3.3.2 Benthic water temperature

Due to COVID-19 restrictions in 2020 there are large gaps in benthic water temperature data at our monitoring sites in the 12 months preceding the November 2020 survey. Where data was available and passed quality control processes, results are presented below (Figure 20).

Water temperature within the offshore seagrass canopy at AMB 1 followed seasonal patterns with the highest temperatures during the wet season from December to March followed by lower temperatures during winter (Figure 20). Temperature in the offshore seagrass meadow ranged from 20.05°C in July to 31.66°C in February.

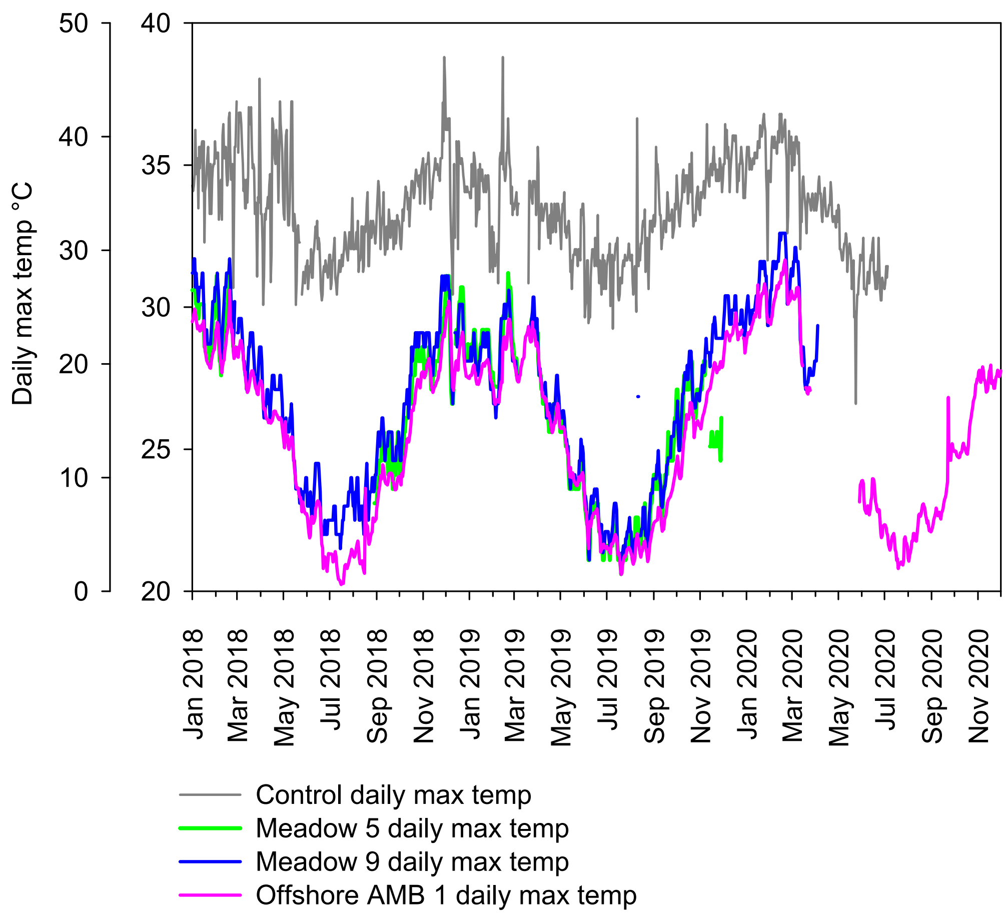


Figure 20. Maximum daily water temperature (°C) within the seagrass canopy at the two inshore monitoring sites and one offshore monitoring site January 2018 – December 2020. Control daily maximum temperature was from a nearby temperature logger on land in the Port of Bowen.

3.3.3 Rainfall

Total annual rainfall was 478.6mm and well below the long term average in 2019/20 (Figure 21a). Rainfall followed similar wet/dry season trends leading up to the annual survey, with February having the highest rainfall of 242mm, similar to the long term average (Figure 26b). Rainfall conditions for 2019/20 were considered mild for the area.

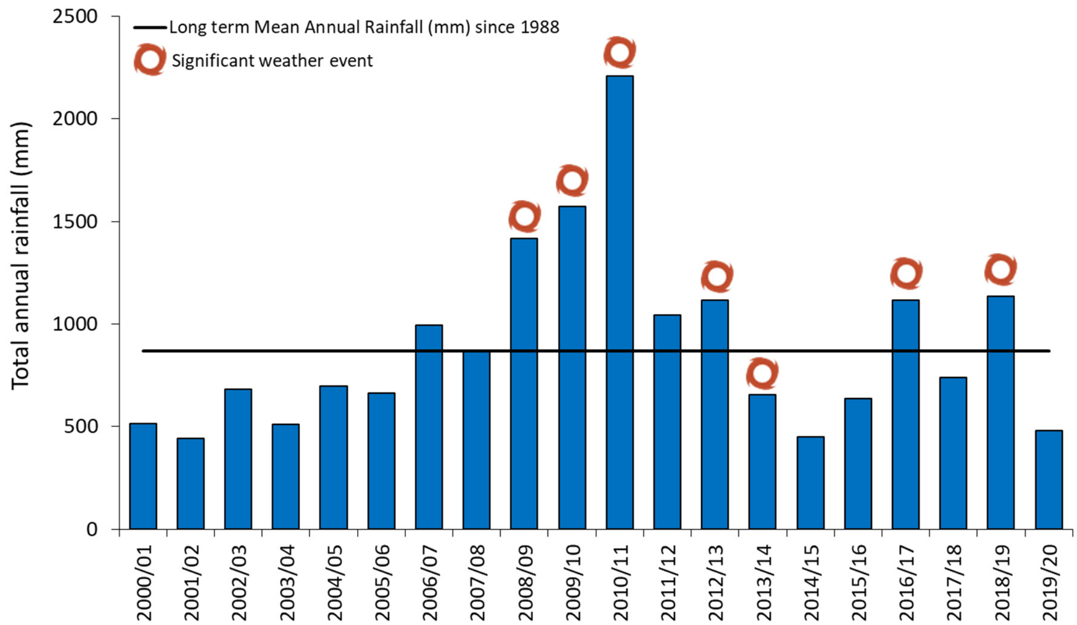


Figure 21a. Total annual rainfall (mm) recorded at Bowen, 2000/01-2019/20. Year represented in columns is twelve months prior to the survey.

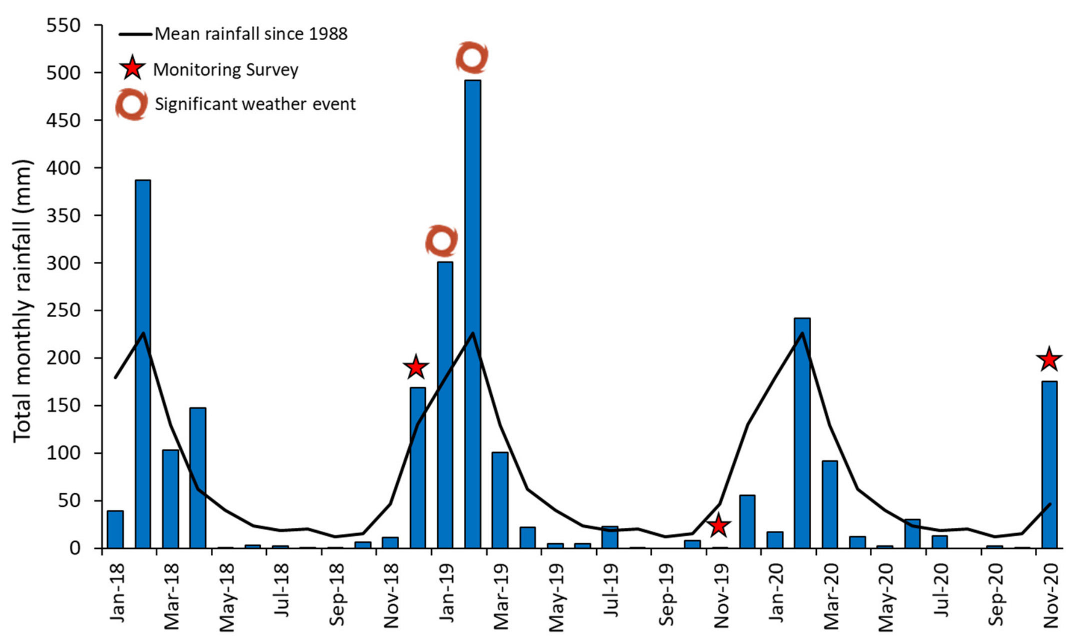


Figure 21b. Total monthly rainfall (mm) recorded at Bowen, January 2018 – October 2020.

3.3.4 River Flow - Don River

River flow for the Don River was below the long-term annual average in 2019/20 (Figure 22a). The highest amount of river flow in the survey year occurred between February and March, but was below the long term monthly averages (Figure 22b).

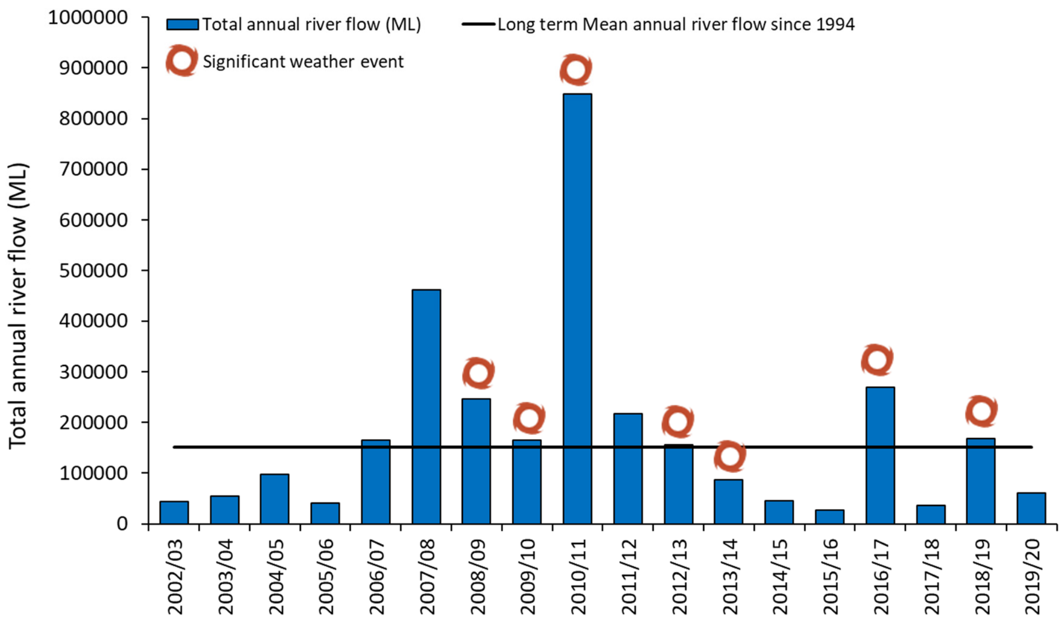


Figure 22a. Total annual river discharge of the Don River from 2002/03 to 2019/20. Year represented in columns is twelve months prior to the survey.

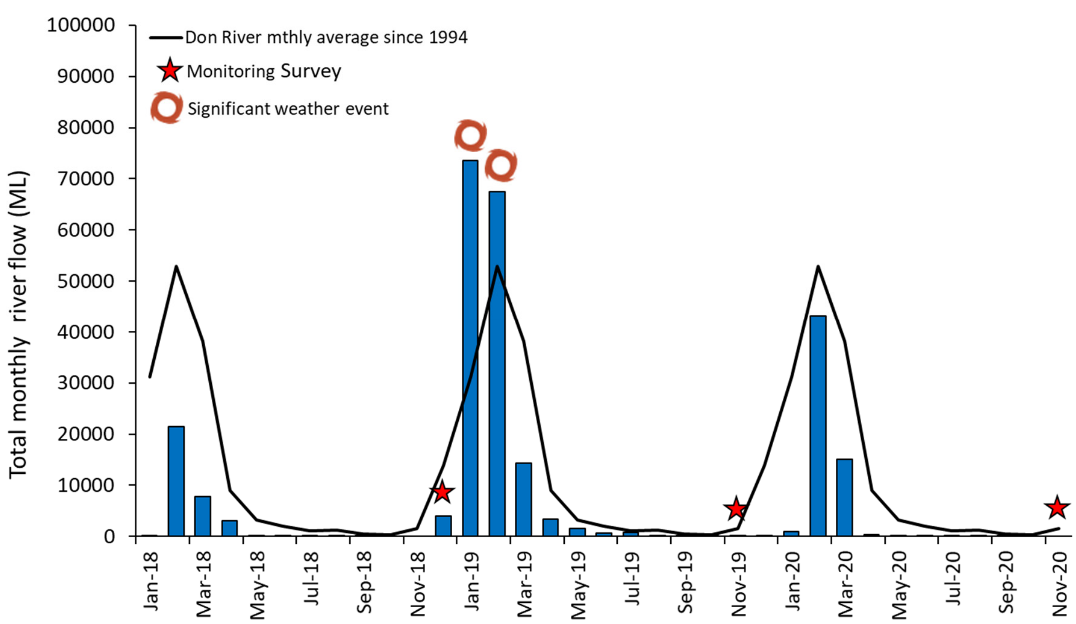


Figure 22b. Total monthly river discharge of the Don River from January 2018 to December 2020.

3.3.5 Significant Wave Height (RMS)

Root mean square (RMS) water height is not a measurement of wave height at the sea surface (Waltham et al. 2020). RMS is a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. The summary data presented below is RMS water height at monitoring station AMB 1, within the offshore seagrass monitoring area. For the full suite of water quality monitoring stations and results, see Waltham et al. (2020).

RMS at AMB 1 in the 12 months before the November 2020 survey was relatively mild compared to the previous two years (Figure 23). In the 12 months before the survey, monthly mean RMS was below the long-term average (red line in Figure 23) until June 2020. Monthly RMS and RMS max peaked over the August/September period coinciding with dry season south easterly trade winds. Peaks in RMS wave height can cause peaks in turbidity and sediment deposition (Waltham et al. 2020).

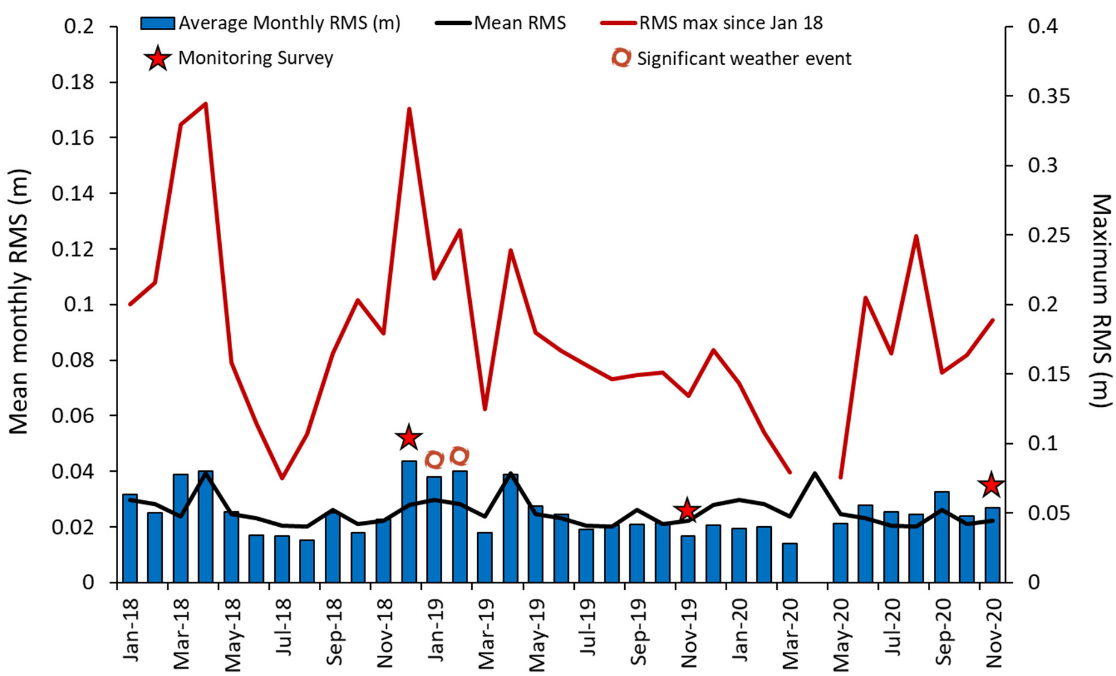


Figure 23. Mean monthly, long-term monthly mean, and maximum RMS recorded at Abbot Point water quality site AMB 1 January 2018 – December 2020.

4. DISCUSSION

Seagrasses in the annually monitored Port of Abbot Point meadows were in a good condition in 2020. This has been an improvement from a satisfactory condition the previous two years where seagrass habitat around Abbot Point had been in a 'recovery phase' after impacts from multiple climate related events between 2017 and 2019: Tropical Cyclone Debbie 2017, TC Penny 2019; TC Oma 2019, Tropical Low 13U 2019. The biggest improvement occurred in the shallow coastal meadow on the north western side of Abbot Point.

From 2020 there was a change in approach to annual monitoring and reporting of the highly variable offshore seagrasses at Abbot Point; a shift from monitoring fixed blocks to monitoring a more expansive area with an increased sampling effort. This has allowed the first full condition assessment of the deep-water meadows offshore from Abbot Point. The new reporting incorporates area as a metric into the scoring to supplement biomass and species composition which had been used in previous years.

Between 2017 and 2019 seagrasses around Abbot Point were recovering from the impacts of TC Debbie, TC Penny 2019; TC Oma 2019 and Tropical Low 13U 2019. Offshore *Halophila* meadows were the first to recover expanding in 2018 (McKenna et al. 2019). This has been followed by the larger growing species in coastal meadows which have now returned to their pre TC Debbie state. The recovery of seagrasses was likely facilitated by favourable environmental conditions for seagrass growth over the past year. Heavy rainfall, river flow and wind-driven/high RMS re-suspension of sediment are important environmental factors that can have a negative effect on seagrass growth in the region as they can negatively impact water quality and in-turn, light available to seagrasses. Rainfall, river flow and RMS in the year prior to the survey were generally below long-term averages for the region providing clearer water for seagrass to thrive during the growing season. Clearer water also results in seagrasses receiving light above their growing requirements. The fact that coastal seagrasses were in good or very good condition indicate that light was above the minimum requirements (3.5 mol m^{-2} day^{-1} over a 14 day integration period (McKenna et al. 2015)) throughout the growing season. In addition, the greater presence of *H. uninervis* in the deeper offshore meadow in 2020 also indicates that light was of a good enough quantity and quality to sustain a higher light requiring species at greater depths: *H. uninervis* both wide and narrow morphologies were found at 11.4 m below MSL.

Despite generally favourable environmental conditions throughout 2020, offshore seagrasses reduced in condition to satisfactory between 2019 and 2020 with all three indicators declining below the respective interim baselines. The decline in biomass can be explained by a reduction in the presence of the higher biomass *Halophila spinulosa* leaving the smaller, lighter *H. decipiens* and *H. ovalis* to dominate the offshore meadow. The decline in *H. spinulosa* is more difficult to explain, considering there was enough benthic light to sustain *H. uninervis*, a higher light requiring species (McKenna et al. 2015; Collier et al. 2016). The declines in offshore seagrass are more likely to be a reflection of how variable offshore *Halophila* dominated seagrass meadows can be, and also the fact that currently there are only a few years (5) that contribute to the interim baseline figures.

The interim baselines for the offshore seagrasses is dominated by the 2008 survey where seagrass was at a density and species composition not since observed, and an order of magnitude higher than the four subsequent surveys. Since 2008 there have been regular disturbances (i.e. significant climate events) that may have kept the seagrass meadow biomass supressed. As the monitoring program progresses and the seagrass indicator baselines incorporate new data a more representative baseline will be achieved, and the seagrass biomass and species composition metrics will either improve to levels closer to or above the current baselines, or the larger number of low-biomass years will reduce the influence of outlier years to levels more commonly observed in this meadow.

The Abbot Point long-term monitoring program is incorporated into the broader Queensland Ports seagrass monitoring program using a consistent state-wide monitoring methodology. This enables direct comparisons with regional and state-wide trends to put local changes into context. It also provides a key input into the condition and trend of seagrasses in the Mackay Whitsunday Isaac NRM region, an area which otherwise has a poor coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2020. Coastal areas to the north and south of Abbot Point had seagrass in good condition (e.g. Gladstone – Smith et al. 2021a; Cairns Harbour - Reason et al. 2021; and Townsville – McKenna et al. 2021). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2021), coastal meadows around Hay Point were in satisfactory condition and offshore meadows were in poor condition. In the Gulf of Carpentaria, seagrass at Weipa was in good condition (Smith et al. 2021b) while seagrass condition at Karumba was satisfactory (Scott and Rasheed 2021).

Conclusion

Seagrasses in the Abbot Point region were in good condition in 2020, recovering from a poor state in 2017 following Tropical Cyclone Debbie. The improvement is likely due to favourable growing conditions for seagrass over the twelve months prior to the survey.

In 2020 the annual monitoring of offshore seagrass shifted from assessing the seagrass monitoring blocks to a more extensive assessment of a large offshore area allowing for the full suite of seagrass indicators (area, biomass, species composition) to be assessed for meadow condition index. An interim baseline for each seagrass indicator has been developed and will continue to be adjusted with additional years of monitoring data until ten years of baseline data is reached.

The improved condition of seagrass at Abbot Point in 2020 means they were likely to have increased resilience to future natural and anthropogenic pressures compared with recent years. However, continuation of good seagrass condition in the region will be contingent on future weather being favourable for seagrass maintenance and 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 for coastal meadows from annual means calculated over the first 10 years of monitoring (2008-2017). Interim baseline conditions for the offshore meadow were calculated based on five years of data (see methods). Baseline for the offshore meadow will continue to change until ten years of data has been collected. Baselines were 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. 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).

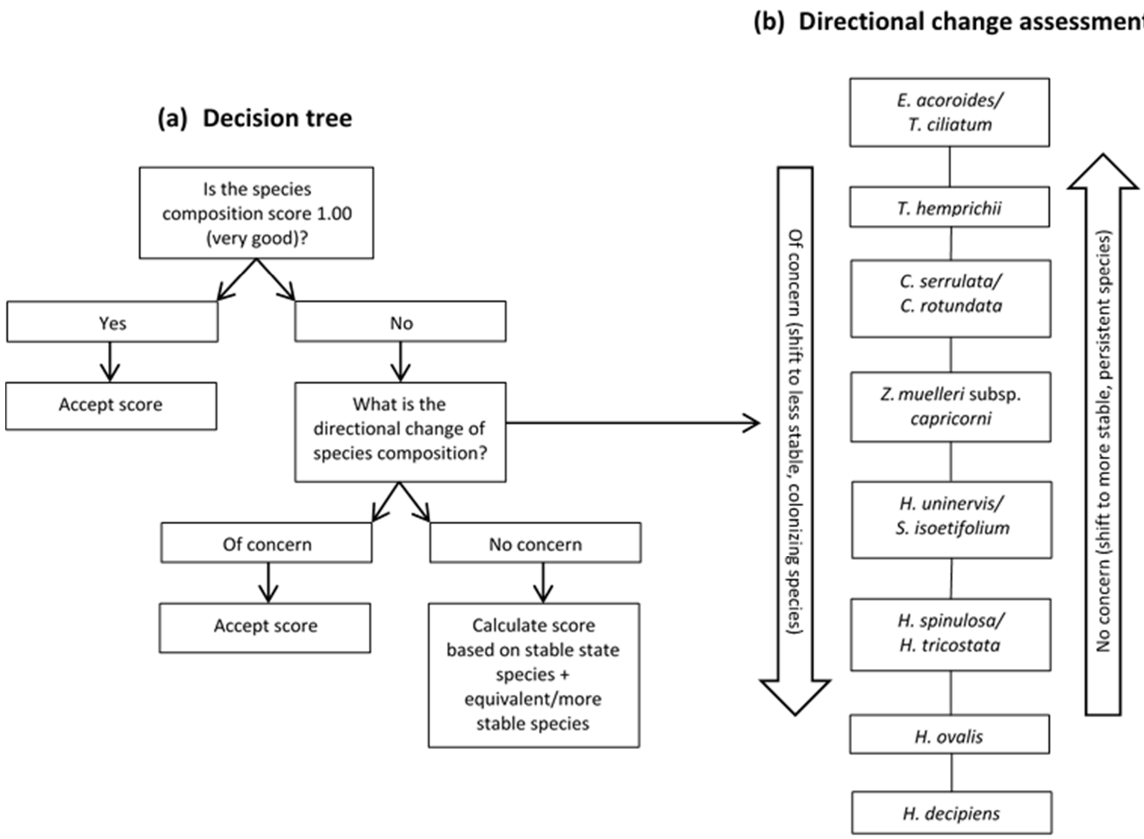


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

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:

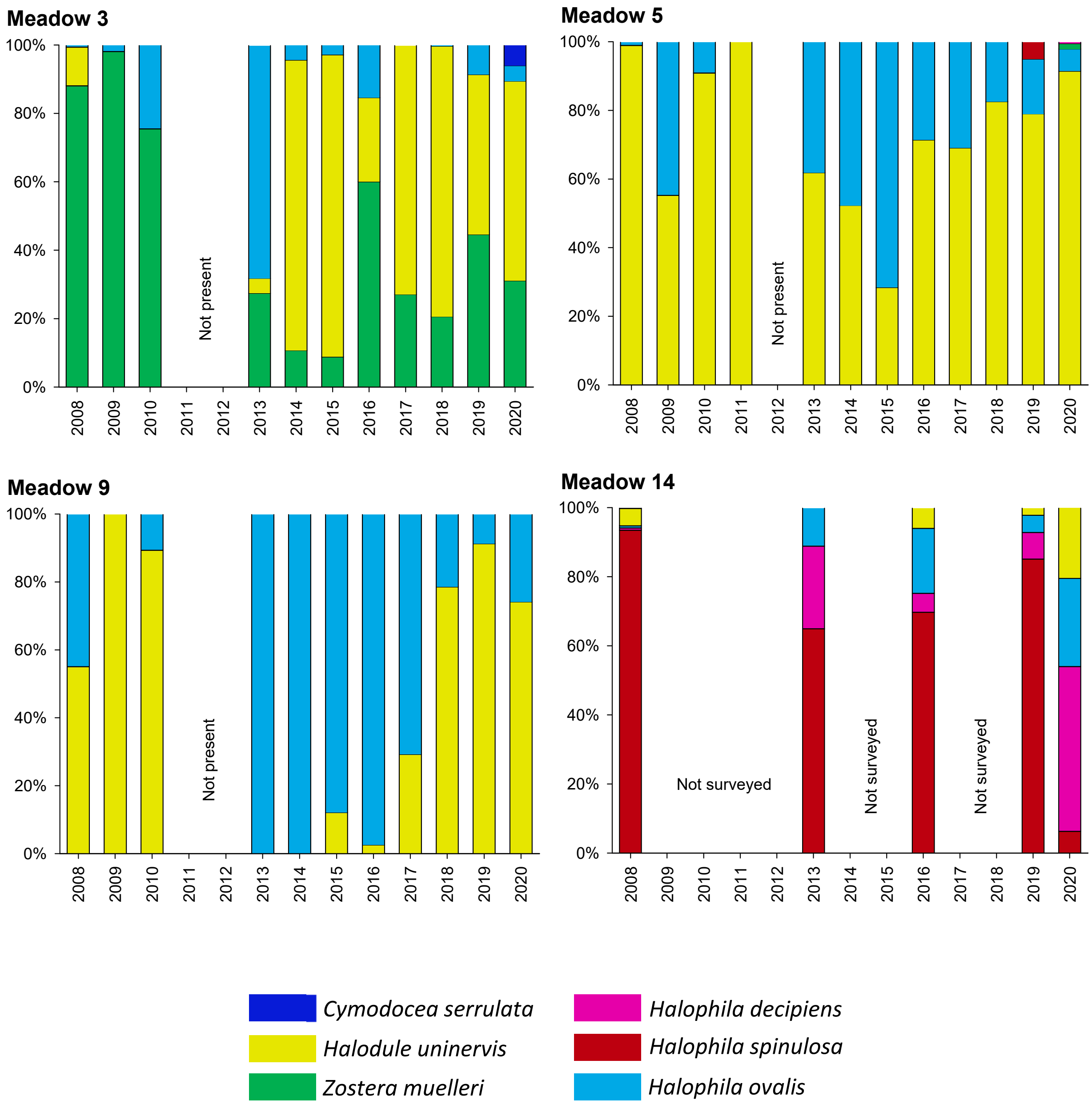
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

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 – 2020



Appendix 4. Biomass and area of inshore and offshore meadows

4A. Mean biomass of monitoring meadows in the Abbot Point region; 2005, 2008 – 2020.

Mean Biomass ± SE (g DW m^{-2}) (no. sites present in meadow)				
	Inshore meadow 3	**Inshore meadow 5**	**Inshore meadow 9**	**Offshore meadow 14**
2005	36.1 ± 16.07 (6)	0.06 ± 0.02 (6)	1.45 ± 0.50 (16)	NS
2008	8.91 ± 4.17 (11)	2.7 ± 0.57 (18)	0.40 ± 0.15 (17)	4.10 ± 1.33 (32)
2009	2.76 ± 0.99 (14)	0.68 ± 0.43 (19)	0.63 ± 0.30 (23)	NS
2010	2.92 ± 0.86 (5)	3.48 ± 0.29 (8)	0.73 ± 0.16 (12)	NS
2011	NP	0.48 ± 0.10 (5)	NP	NS
2012	NP	NP	NP	NS
2013	NP	1.61 ± 0.81 (6)	3.07 ± 1.55 (3)	0.04 ± 0.010 (31)
2014	1.67 ± 0.34 (3)	8.3 ± 4.26 (5)	4.36 ± 0.91 (8)	NS
2015	4.21 ± 3.96 (3)	2.8 ± 0.64 (13)	2.80 ± 0.50 (20)	NS
2016	5.25 ± 1.59 (10)	2.83 ± 0.65 (15)	8.32 ± 1.66 (14)	1.51 ± 0.48 (68)
2017	5.85 ± 1.05 (13)	3.42 ± 1.06 (10)	3.0 ± 0.57 (20)	NS
2018	2.77 ± 0.76 (12)	2.41 ± 0.57 (13)	0.90 ± 0.20 (5)	NS
2019	6.04 ± 1.58 (8)	2.6 ± 0.54 (27)	0.52 ± 0.13 (12)	1.65 ± 0.27 (48)
2020	7.11 ± 1.11 (14)	4.72 ± 0.44 (42)	3.39 ± 0.44 (25)	0.69 ± 0.19 (13)

NP – No seagrass present in meadow; NS – Seagrass meadow not surveyed (offshore meadow have only been surveyed in whole-of-port surveys: 2008, 2013, 2016, 2019, 2020. Offshore meadow 14 has was added to the long-term monitoring program in 2020.

4B. Area (ha) of monitoring meadows in the Abbot Point region; 2005, 2008 – 2020.

Area ± R (ha)				
	Inshore meadow 3	**Inshore meadow 5**	**Inshore meadow 9**	**Offshore meadow 14**
2005	25.6 ± 6	46.6 ± 15.9	125.8 ± 41	NS
2008	56.95 ± 8.06	45.3 ± 20.29	83.96 ± 10.26	6056.14 ± 518.09
2009	44.2 ± 9.3	16.2 ± 3.3	22.9 ± 5.1	NS
2010	15.04 ± 4.9	23.47 ± 8.69	105.38 ± 85.44	NS
2011	NP	3.12 ± 2.66	NP	NS
2012	NP	NP	NP	NS
2013	NP	28.86 ± 13.86	35.11 ± 15.47	4944.41 ± 426.88
2014	12.19 ± 3.84	10.49 ± 2.48	92.42 ± 71.5	NS
2015	8.84 ± 4.55	25.24 ± 19.58	180.27 ± 62.26	NS
2016	78.40 ± 6.17	191.71 ± 35.74	214.02 ± 41.28	6821.67 ± 468.29
2017	43.91 ± 5.33	20.38 ± 3.13	94.91 ± 16.76	NS
2018	47.67 ± 5.15	50.56 ± 8.27	28.80 ± 6.02	NS
2019	25.98 ± 8.98	188.46 ± 44.09	88.75 ± 21.1	4959.81 ± 523.70
2020	31.4 ± 3.25	274 ± 31.19	146.04 ± 21.82	3865.81 ± 321.55

NP – No seagrass present in meadow; NS – Seagrass meadow not surveyed