PORT OF ABBOT POINT LONG-TERM SEAGRASS MONITORING PROGRAM - 2021

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Report No. 22/13

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A Report for North Queensland Bulk Ports Corporation
(NQBP)

Report No. 22/13

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KEY FINDINGS

Seagrass Condition 2021

Likely causes of seagrass condition:

Favourable climate conditions for seagrass growth

- In 2021 seagrass in the annually monitored meadows at Abbot Point were in an overall good condition for the second consecutive year, stabilising their status following recovery from poor condition in 2017 following TC Debbie.

- Inshore seagrasses meadows dominated by *Halodule uninervis* were in very good condition while the inshore *Zostera muelleri* dominated meadow was in good condition.

- The offshore meadows improved in overall condition from satisfactory in 2020 to good in 2021 due to an increase in condition of all three indices (area, biomass and species composition).

- In 2021 environmental conditions were favourable for seagrass growth with a mild wet season and no extreme weather events.

- The continued good condition of seagrass at Abbot Point in 2021 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.

In 2021 the overall condition of seagrasses in Abbot Point remained good for the second consecutive year with some improvements in the condition of individual meadows (Figure 1). This continues a trend of improvement in seagrass condition in the region from poor in 2017 following reductions caused by Tropical Cyclone Debbie. The greatest shift in seagrass condition occurred in the offshore meadows which improved from satisfactory in 2020 to good in 2021 with increases in all three indicators of biomass, area and species composition. The coastal meadow at the mouth of Euri Creek remained in good condition with an improvement in species composition to very good due to a return to dominance of the foundation species *Z. muelleri. T*he meadow to the east of the Abbot Point wharf improved to very good due to an increase in area from the previous year, while the other coastal meadow remained stable (Figure 1).

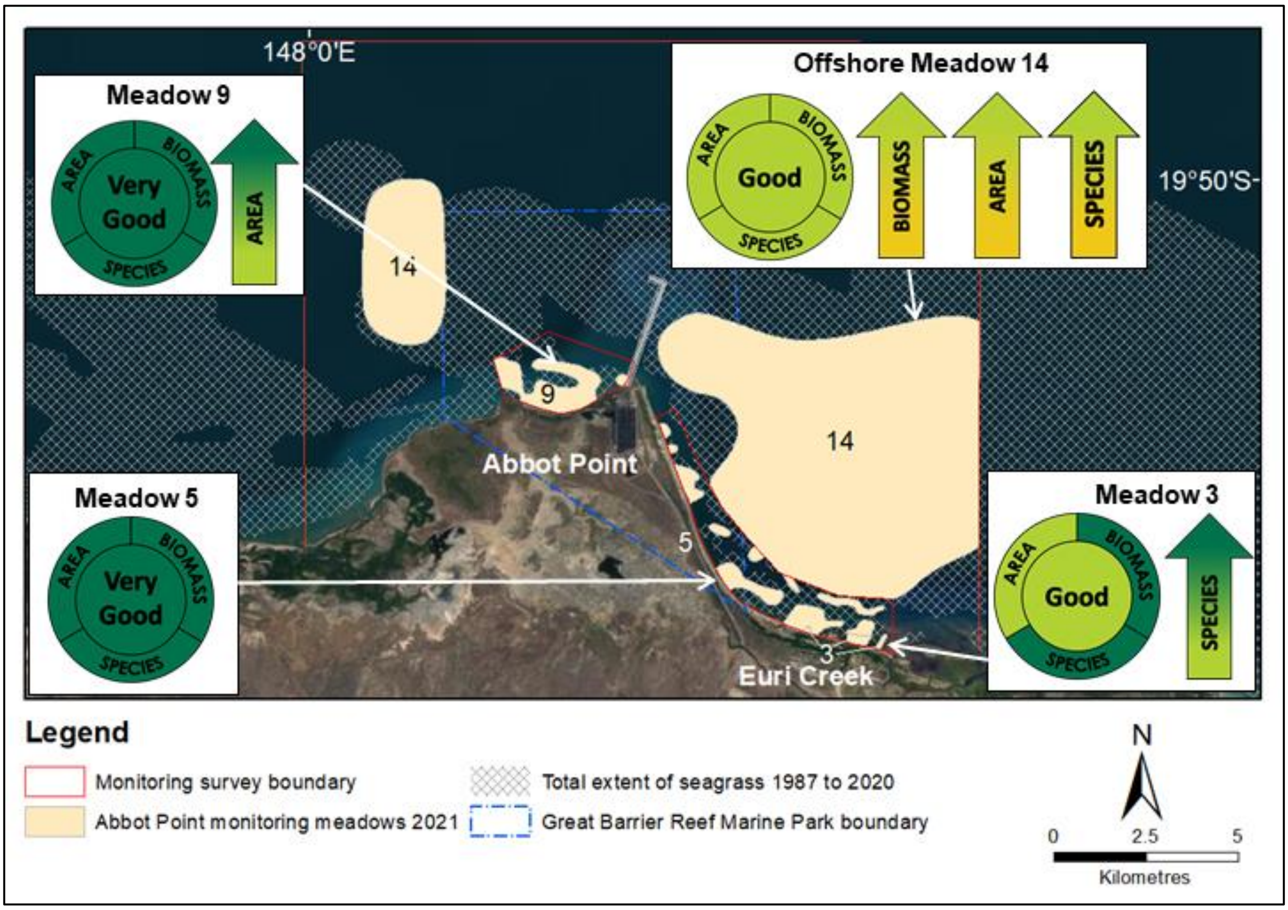
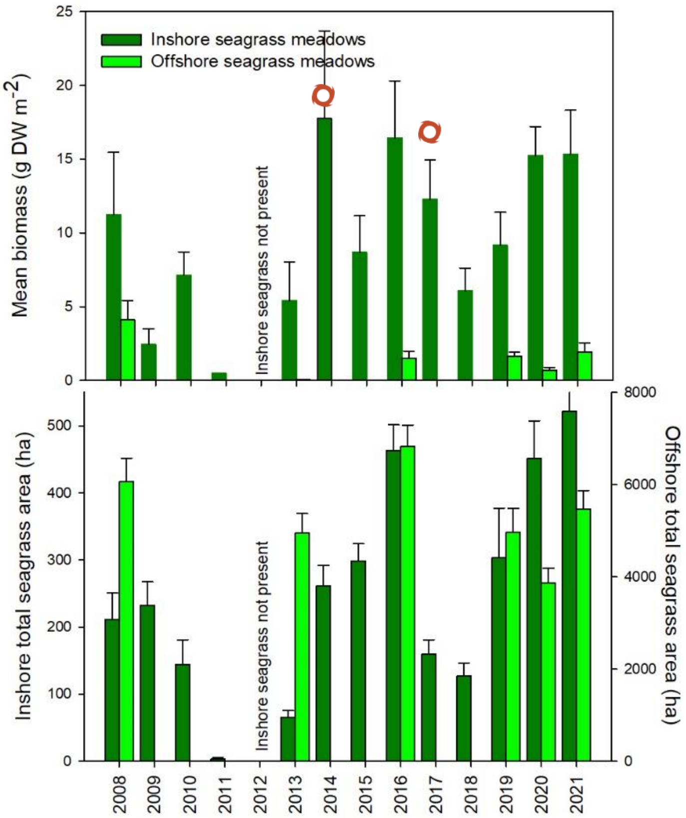


Figure 1. Seagrass condition for Abbot Point seagrass monitoring areas 2021.

Between 2017 and 2019 seagrasses around Abbot Point were recovering from successive years of climate impacts, particularly following large reductions in seagrass area and biomass due to TC Debbie. The seagrass meadows around Abbot Point have now recovered to levels approaching or exceeding levels of biomass and area recorded in their pre TC Debbie state (Figure 2). The main reason for the continued improvement in seagrass condition in the Abbot Point region is likely due to the favourable conditions for seagrass growth over the last two years and extending from the previous survey in 2020. During this time the region experienced below average river flow, rainfall slightly over the long-term average and no damaging weather and climate events that were prevalent from 2017-19 (Figure 3).



Weather driven events that bring heavy rainfall, high river flow and flooding and wind-driven 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. Clearer water, particularly during the growing season from June to December results in seagrasses receiving light above their growing requirements allowing them to increase in condition. The fact that both offshore and coastal seagrass meadows were in good or very good condition indicate that light was above the minimum requirements throughout the growing season.

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 2021. Coastal areas to the north and south of Abbot Point had seagrass in good condition (e.g. Hay Point – York et al. 2022; Gladstone - Smith et al. 2022; Cairns Harbour - Reason et al. 2022; and Townsville – McKenna et al. 2022). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2022). Seagrass in the Gulf of Carpentaria in Weipa and Karumba were in a good and very good condition also due to favourable climate conditions (McKenna et al. 2021; Scott et al. 2022).

The improved condition of offshore seagrass at Abbot Point in 2021 and the stable and good condition of inshore meadows indicates they were likely to be building resilience to withstand and recover from future natural and anthropogenic pressures. For seagrass to remain in a good condition or improve in status in the Abbot Point region it will require ongoing favourable weather and climate conditions that allow for seagrass maintenance and growth.

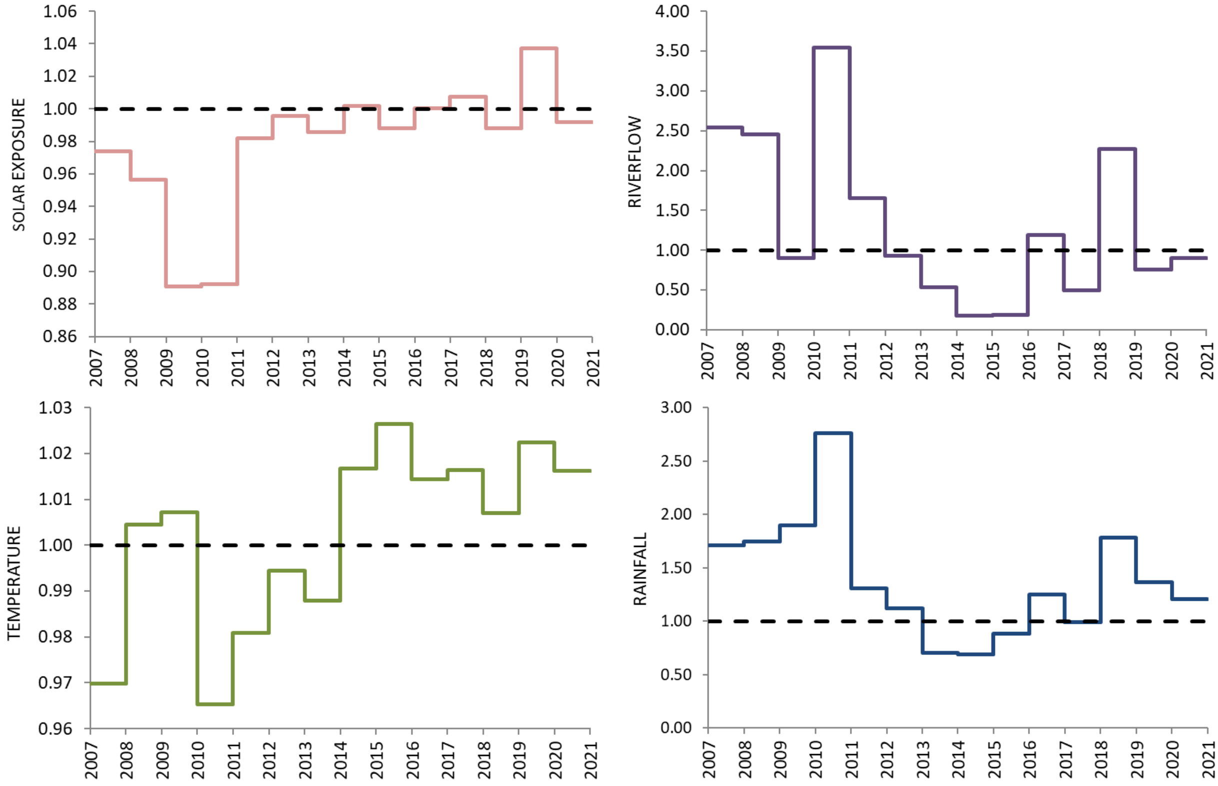


Figure 3. Recent climate trends for temperature and solar exposure (Bowen) and rainfall and river flow (Gathulungra/Elliot River) from 2006/07 to 2020/21: Change in climate variables as a proportion of the long-term average. See section 3.3 for detailed climate data.

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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, Hayes et al. 2020), 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 2004. 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 Isaac Healthy Rivers to Reef Partnership). 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. 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 2021. Objectives include to:

- Assess and map seagrass to determine seagrass density (biomass), distribution (area) and community type (species composition) at representative long term monitoring meadows;
- Compare results of monitoring surveys to baseline (long-term averages) for each meadow to determine their condition and assess any changes in seagrass habitat in relation to natural events or human induced port and catchment activities;
- Discuss the implications of monitoring results for the overall health of the Port of Abbot Point's marine environment.

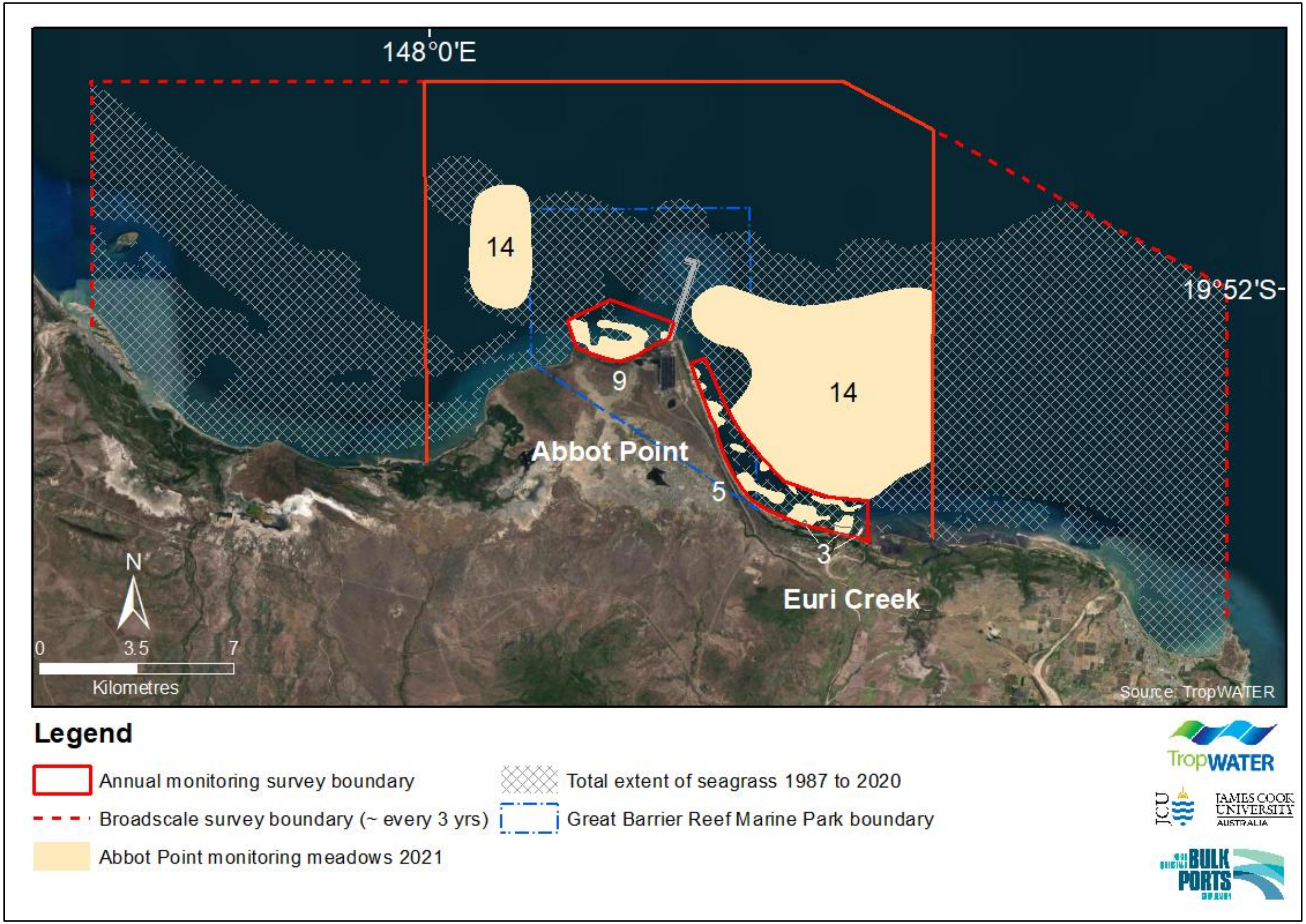


Figure 5. Location of annual coastal monitoring meadows and offshore monitoring areas around Abbot Point.

2. METHODS

2.1 Sampling Approach

The approach of annual monitoring of representative meadows with a broader survey every three years has been adopted as part of NQBP's long-term seagrass programs including at Abbot Point. Monitoring meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in initial surveys. In the initial 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. 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) to allow 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.

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 2021.

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 offshore monitoring meadow (Meadow 14) are based on the historical data available (2008, 2013, 2016, 2019, 2020 and 2021) and recalculated to the new survey boundary. 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.

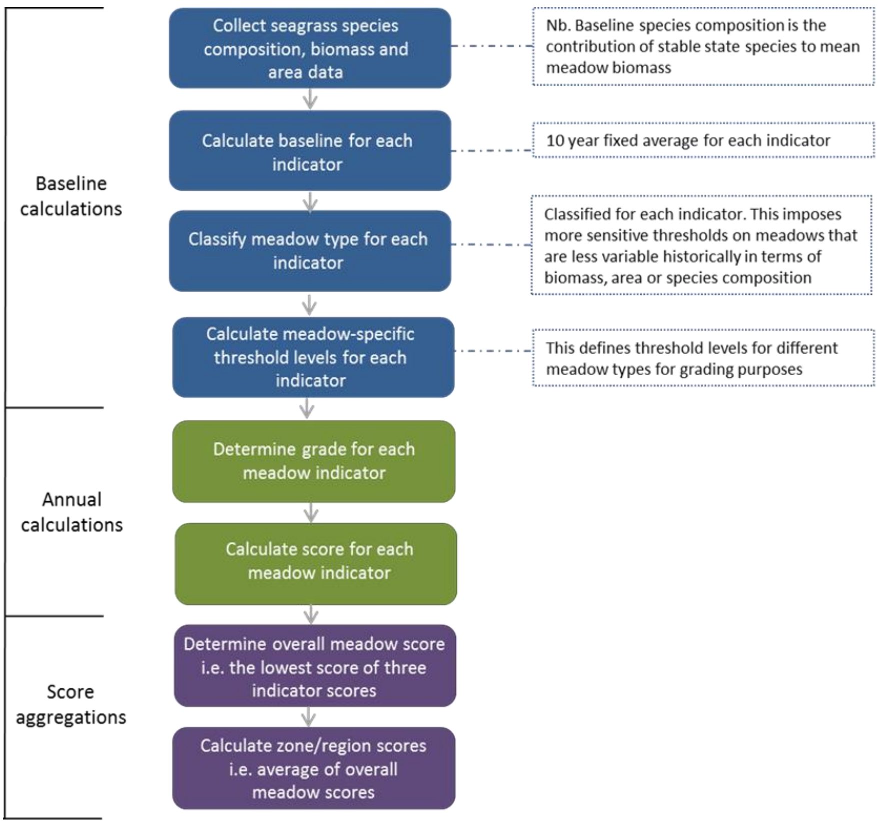


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

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. Temperate and solar exposure was obtained for the nearest weather station from the Australian Bureau of Meteorology (station 033327; Bowen Airport AWS). Total daily rainfall (mm) and river flow data was obtained by the Queensland Governments Water Monitoring Information Portal (station 121002A – Elliot River at Guthalungra). 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. (2021).

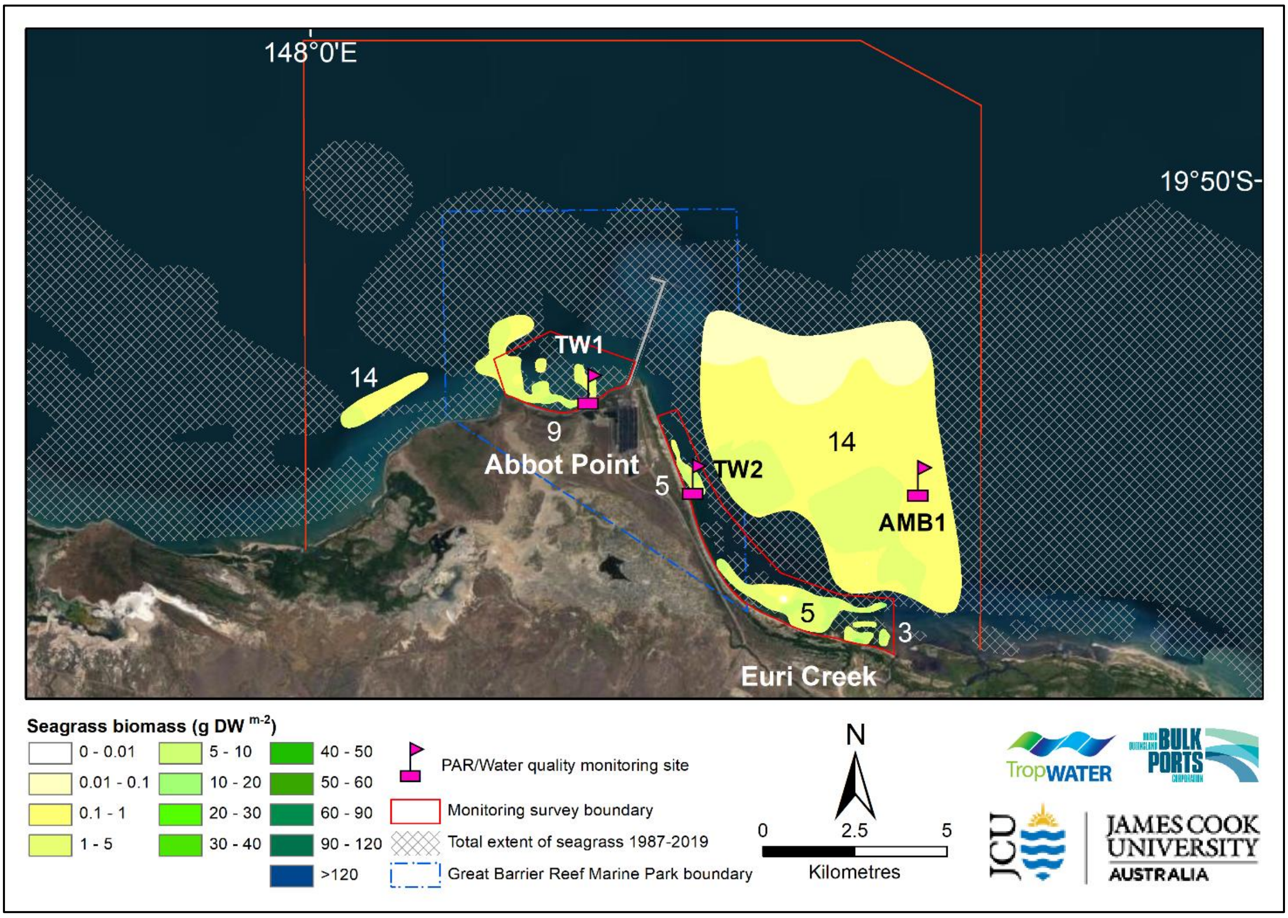


Figure 9. Location of TropWATER, James Cook University light (PAR) loggers at Abbot Point.

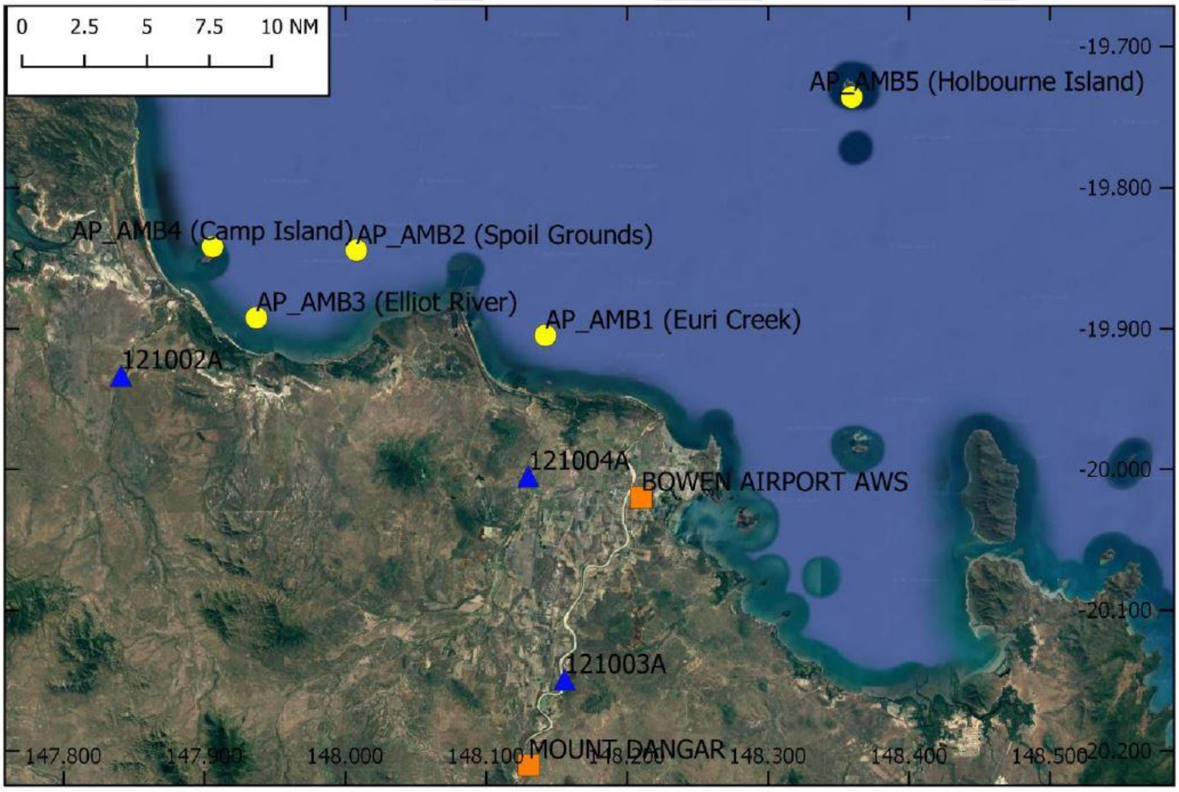


Figure 10. From Waltham et al. (2021): Location of TropWATER, James Cook University water quality monitoring sites (yellow circles). Also shown are meteorological stations (orange square), and stream gauging stations (blue triangle).

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.

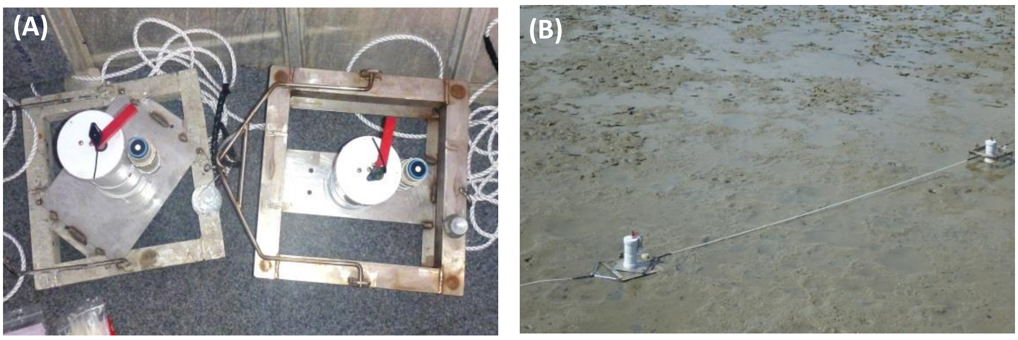


Figure 11. (A) Logging station consisting of a stainless steel frame with PAR loggers and temperature loggers attached, and wiper units; (B) example of deployment of logging stations (Abbot Point stations are subtidal only).

3. RESULTS

3.1 Seagrass in the Abbot Point monitoring areas

A total of 230 sites were assessed as part of the November 2021 Abbot Point annual monitoring survey (Figure 13). Seagrass was present at 42.2% of the survey sites. The coastal monitoring meadows covered 521.4 ± 74.8 ha while seagrass in the offshore monitoring area covered 5464.7 ± 406.2 ha (Figure 13; Appendix 4B). Seagrass biomass was generally 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). Five seagrass species were observed in 2021 (Figure 12). In 2021, offshore seagrass habitat was dominated by *Halophila decipiens* with *H. spinulosa*, *H. ovalis* and *Halodule uninervis* also present. *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows (5 and 9) with *H. ovalis* and *H. decipiens* also present. Z*ostera muelleri* was found near the mouth of Euri Creek (Meadow 3).

Cymodocea rotundata, C. 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 2021 within the surveyed area. *Cymodocea serrulata* was observed 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.

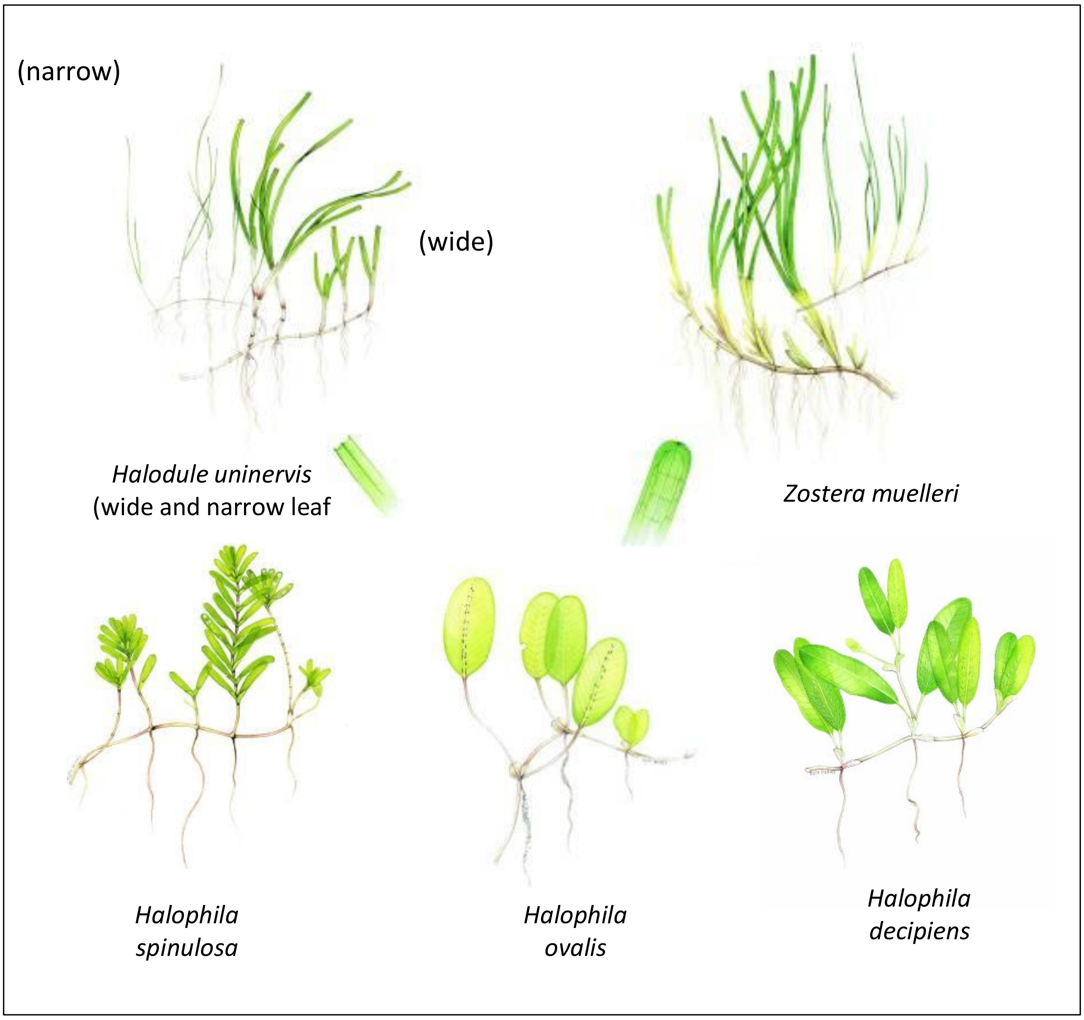


Figure 12. Seagrass species identified in the Abbot Point/Bowen region in 2021.

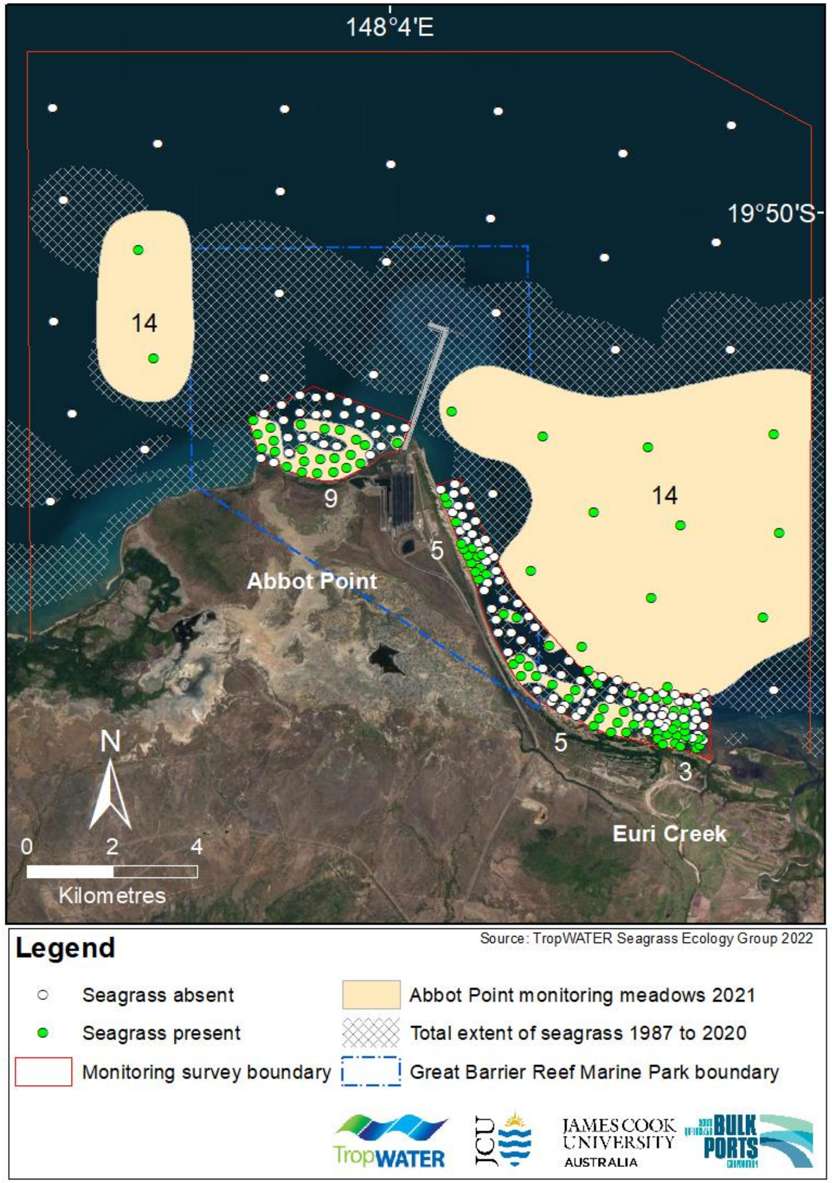


Figure 13. Location of seagrass assessment sites in the 2021 annual monitoring survey.

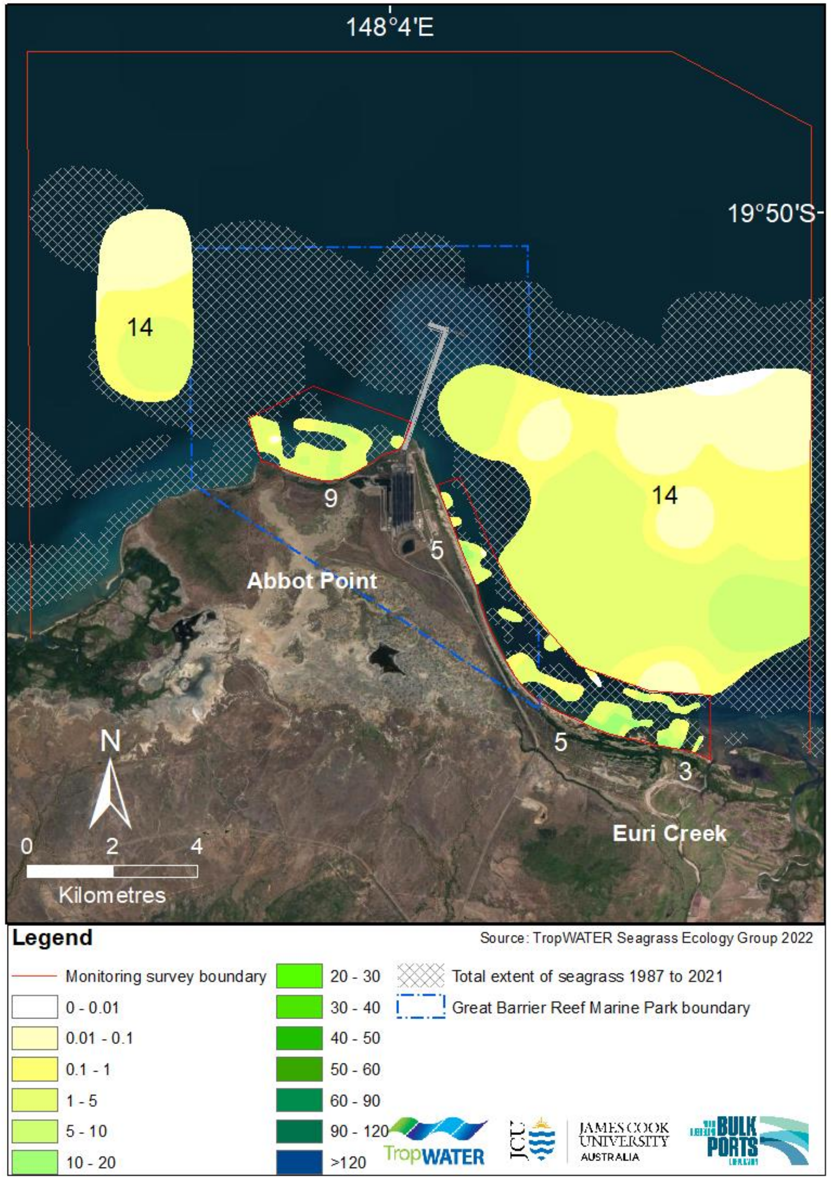


Figure 14. Seagrass biomass (g DW m^{-2}) interpolation for Abbot Point survey 2021.

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 2021. Individual coastal meadows scored good or very good, while the offshore seagrass habitat scored as good (Table 4). This was the same overall condition as the previous survey in 2020; 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 and now appears to be stabilising.

Table 4. Scores for seagrass indicators (biomass, area and species composition) for the Abbot Point region 2021.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score
Inshore meadow 3	0.93	0.88	0.66	0.66
Inshore meadow 5	0.86	0.92	1	0.86
Inshore meadow 9	0.85	0.90	0.96	0.85
Offshore meadow 14	0.79	0.74	0.77	0.76
Overall score for seagrass in the Port of Abbot Point				**0.78**

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 has recently been dominated by *H. uninervis* (Figure 17; Appendix 3).

For the past three years Meadow 3 has been in good condition and improvements were seen in species composition and biomass in 2021 due to a return of *Z. muelleri* as the dominant species (Table 4, Figure 15). The area of the meadow however decreased by 31% from the previous year of 31.4 ± 3.25 ha in 2020 to 21.6 ± 3.4 ha 2021 in 2021 driving the overall meadow condition score down but still remaining in good condition. Biomass increased for the third successive year in this meadow to remain in a very good condition likely driven by a relative increase in the abundance of *Z. muelleri* , which also improved the species composition to a very good condition in 2021 (Figure 15, Appendix 4). *Cymodocea serrulata* was recorded in the meadow at one site in 2020 but was not identified in the meadow this year (Figure 15; Appendix 3).

Meadow 5 remained in a very good condition for a second consecutive year in 2021 (Table 4, Figure 16). Both the biomass and the area of this meadow remained stable at historically high levels for this meadow in 2021 indicating a strong recovery after significant losses from TC Debbie in early 2017 (Figure 16).

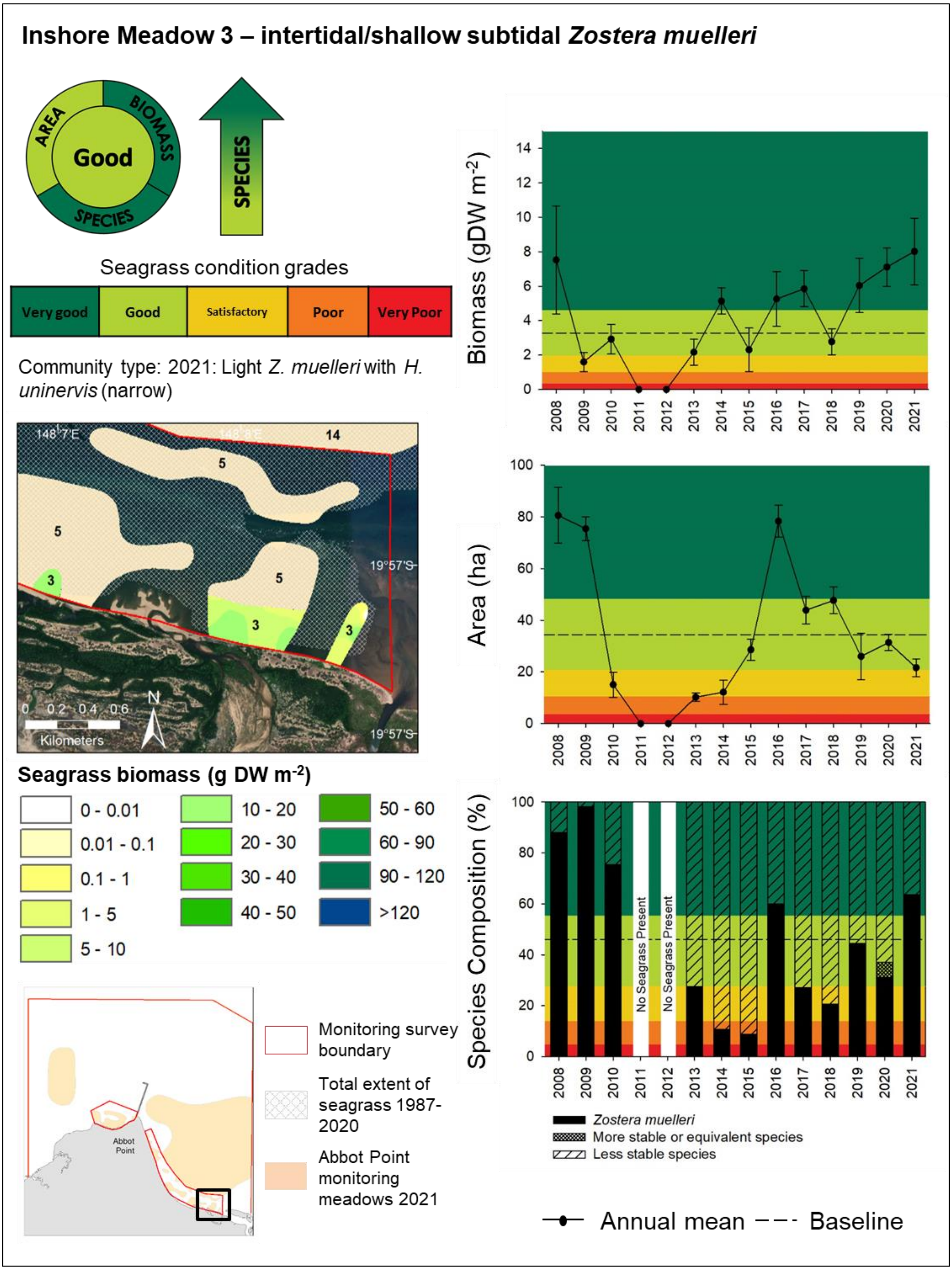
Meadow 9 improved from a good condition in 2020 to very good in 2021, a rapid improvement in condition from a poor status in 2019 (Table 4, Figure 17). This improvement was driven by the 58 % increase in the area of the meadow over the previous twelve months from 146.0 ± 21.8 ha in 2020 to 231 ± 23.6 ha in 2021 (Figure 17, Appendix 4A). Meadow 9 extended beyond the fixed survey boundary for annual monitoring for the second consecutive year, however for the purpose of the long-term monitoring program the meadow was only mapped to the survey boundaries for condition assessment. Seagrass biomass and species composition remained in very good condition and fairly stable compared to the previous survey in 2020 (Figure 17, Appendix 4A). Species composition of the meadow has been in very good condition for the past four years with *H. uninervis* the dominant species in the meadow (Appendix 3).

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 to allow for changes in seagrass area to be assessed and reported on for the first time (Figure 18). An interim baseline for each seagrass indicator has been calculated from the historical data available that covered the same survey region which now consists of six years (2008, 2013, 2016, 2019, 2020 and 2021). The interim baselines for Meadow 14 will continue to be adjusted with additional years of monitoring data until ten years of baseline data is reached.

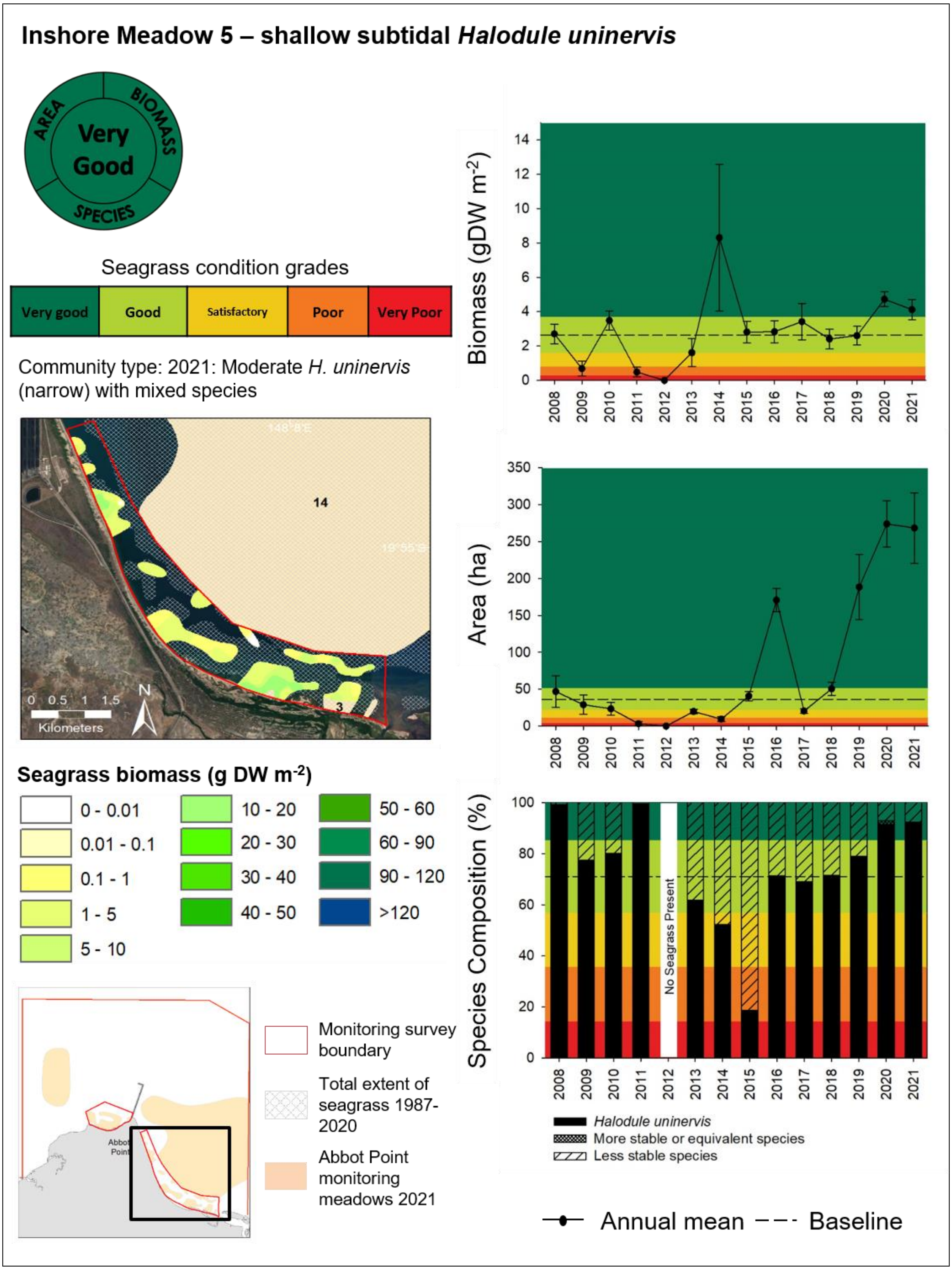
The offshore monitoring area encompasses seafloor from ~5m to 26m below MSL. The shallowest offshore area is located on the north-western side of Abbot Point on Clark Shoal. Seagrass in this area has been intermittent in its presence throughout the monitoring program and has typically been dominated 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 improved from a satisfactory condition in 2020 to good in 2021 (Table 4, Figure 18). Significant increases in the biomass (280 %) and Area (143 %) from the survey in 2020 saw both indicators improve from satisfactory to good in 2021 (Table 4, Figure 18). Species composition also improved from satisfactory to good with an increase in the relative abundance of *H. spinulosa* in 2021 (Table 4, Figure 18). Seagrass was found from 7.4 – 15.8 m below MSL and covered a total area of 5,464.7 ± 406.2 within the fixed survey boundary (Figure 18).



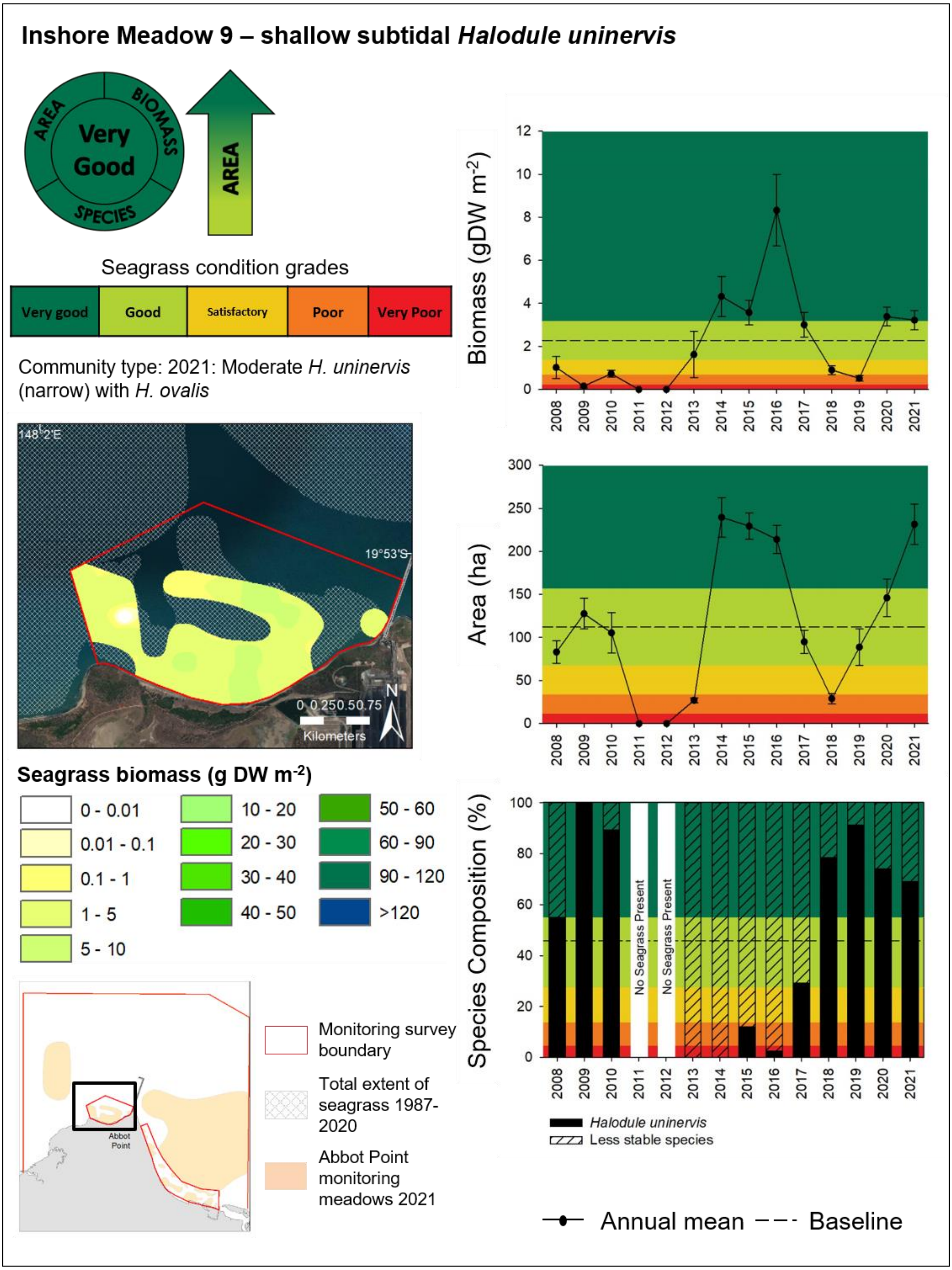
*lack of arrows indicates no change in condition index from the previous year

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



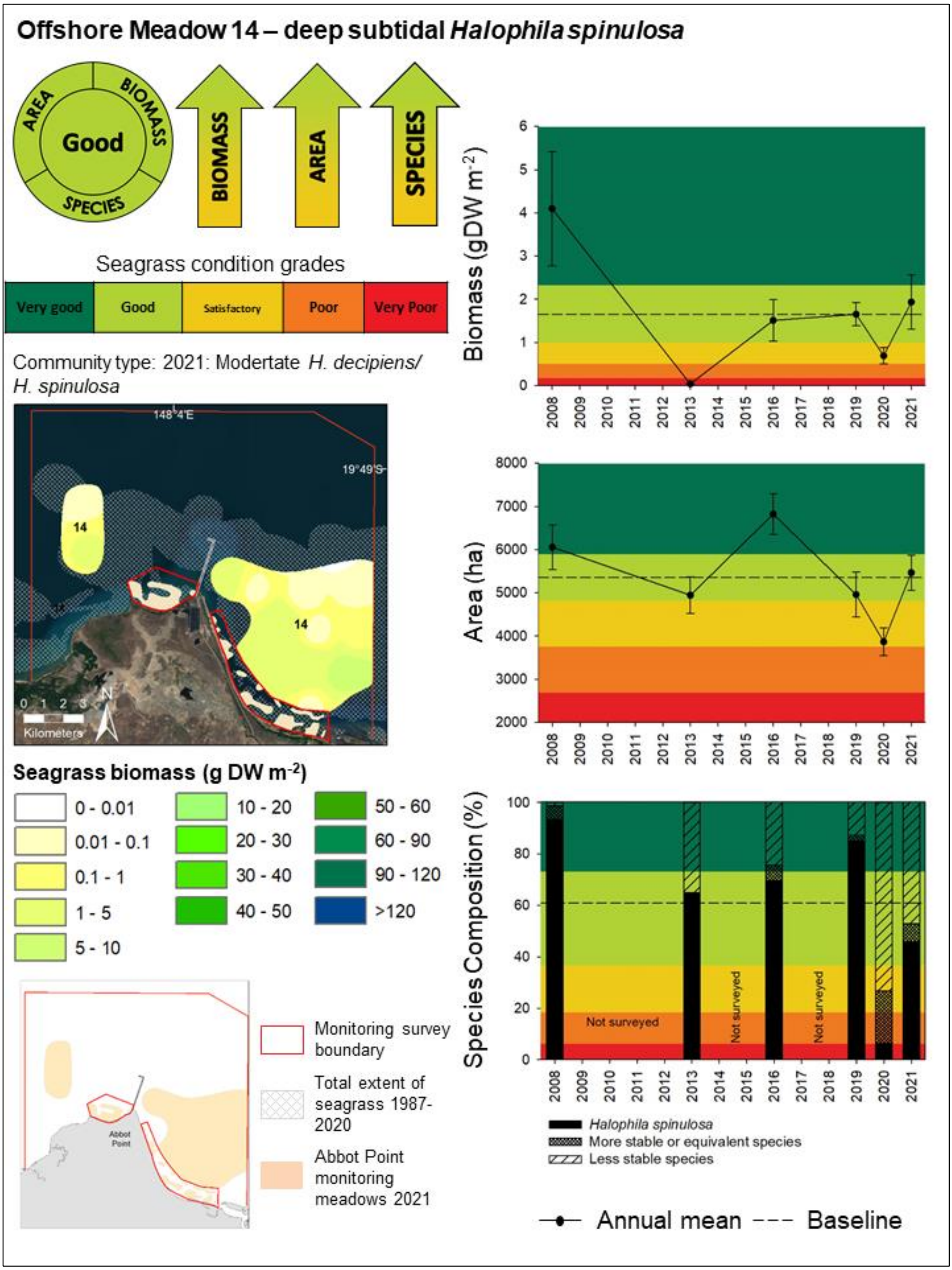
*lack of arrows indicates no change in condition index from the previous year

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.

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. 2021).

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.

Light loggers at the two inshore logging sites showed PAR levels to be generally high and particularly TW2 remained above the thresholds for growth of coastal seagrass species throughout most of the year with very brief dips below the threshold in July and September. At TW1 the PAR levels were also above the threshold for most of the growing season (after June) with the exception of a drop in light levels in September corresponding with the same trend at the other coastal site. PAR data at AMB1 in the period preceding the November 2021 survey is currently only available until 31st July and during the wet season the PAR levels at this site were low.

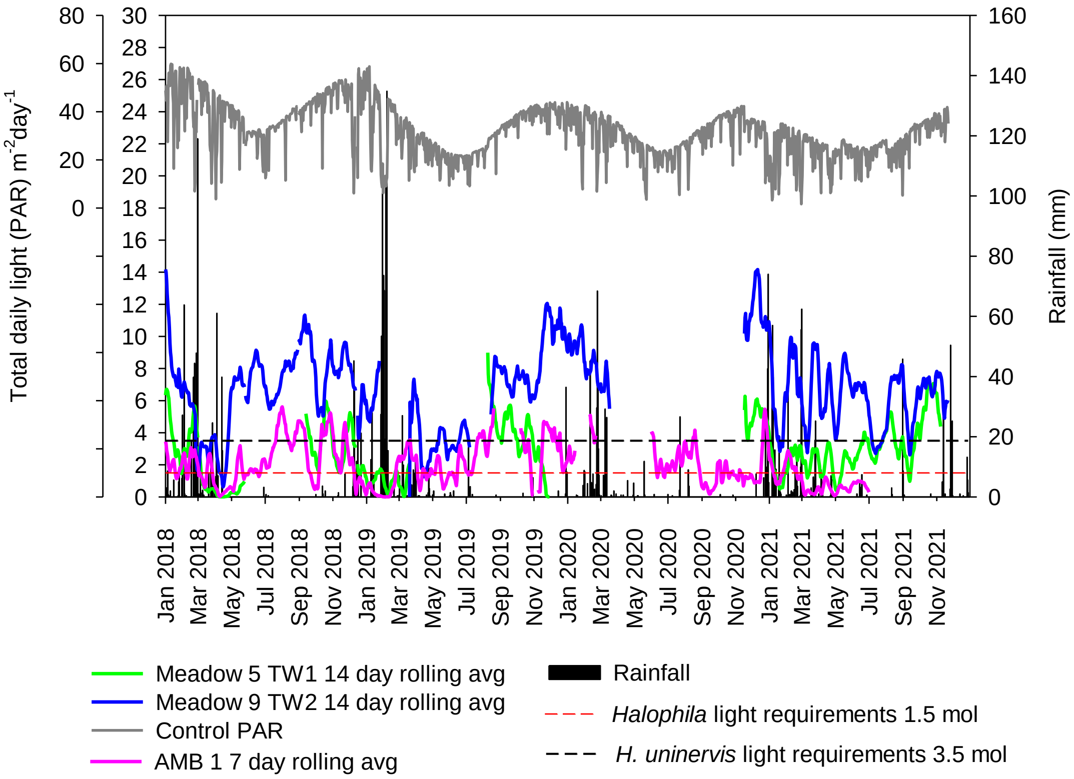


Figure 19. Fourteen and seven day rolling average total daily PAR (mol photons $m^{-1}day^{-1}$), total daily rainfall, and *H. uninervis* & *Halophila* light requirement threshold January 2018 – November 2021.

3.3.2 Benthic water temperature

Due to COVID-19 restrictions in 2021 there are gaps in benthic water temperature data at some of our monitoring sites. Where data was available and passed quality control processes, results are presented below (Figure 20). Temperature in the inshore seagrass meadows (e.g., meadow 9 and Meadow 5) had a similar trend to each other and ranged from highs of approximately 31.5°C in December 2020 and lows of around 21.8°C in June 2021 (Figure 20). The temperature around the time of sampling in November 2021 was approximately 30.0°C. Water temperature within the offshore seagrass canopy at AMB 1 showed a similar trend to the coastal meadows though peaking slightly lower in the summer months from December 2020 to March 2021 compared to meadow 5 (Figure 20).

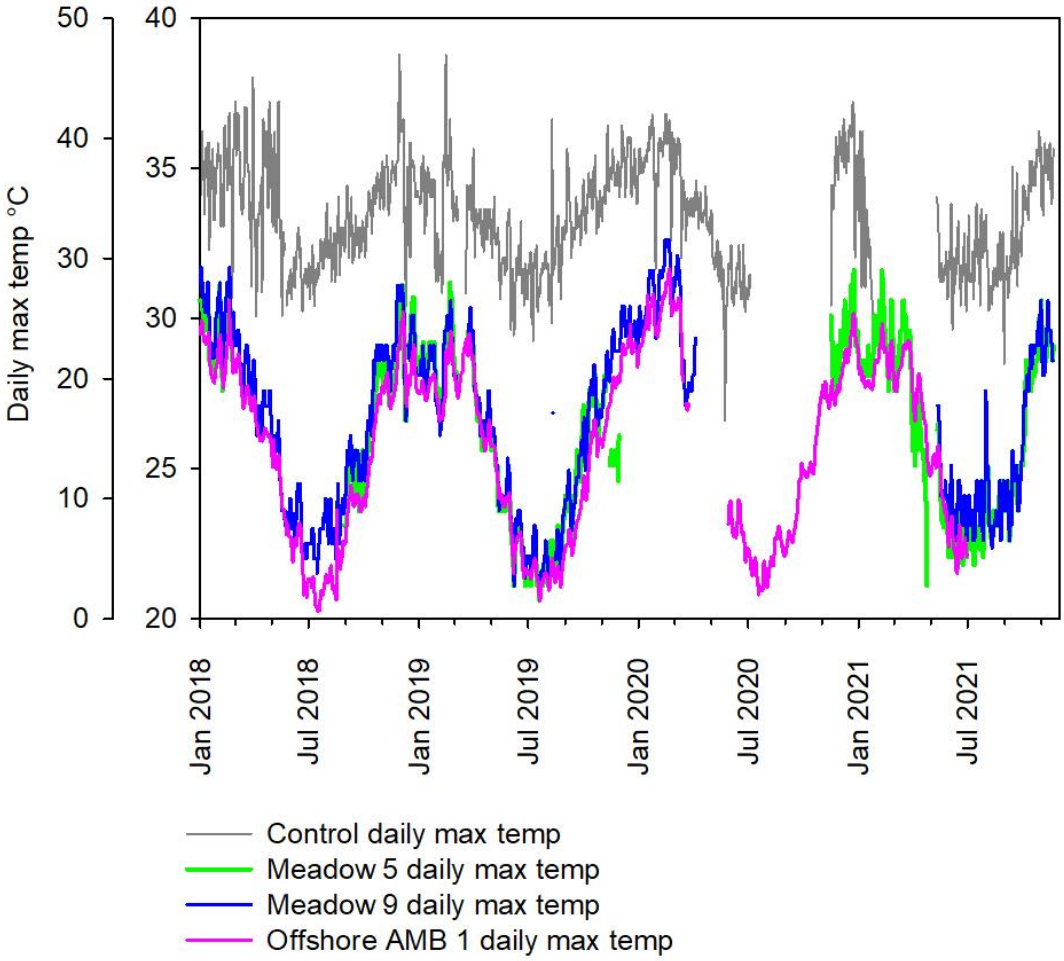


Figure 20. Maximum daily water temperature (°C) within the seagrass canopy at the two inshore monitoring sites and one offshore monitoring site January 2018 – December 2021. Control daily maximum temperature was from a nearby temperature logger on land in the Port of Bowen.

3.3.3 Rainfall

Total annual rainfall in the 12 months proir to the survey was 864 mm, above the long term average of 673 mm in 2020/21 (Figure 21a). Rainfall followed wet/dry season trends leading up to the annual survey, with January having the highest rainfall of 282 mm (Figure 26b). Significant and above average rainfall fell in the survey months of January, June, August and November 2021.

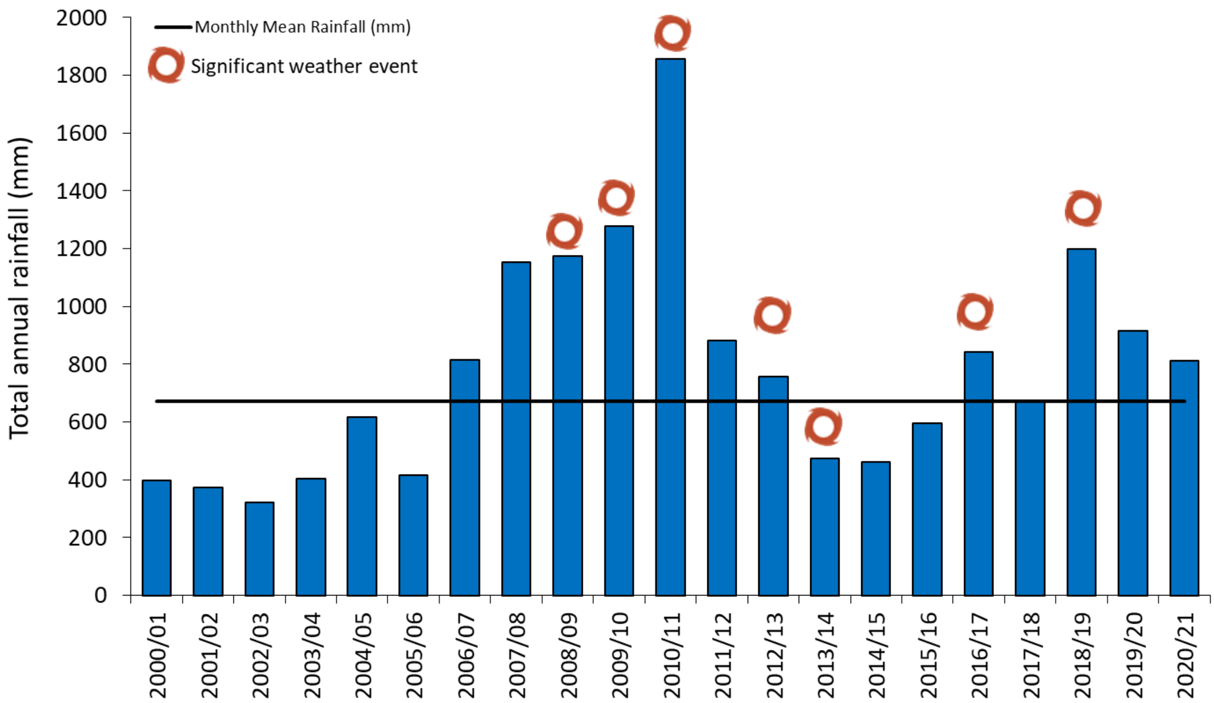


Figure 21a. Total annual rainfall (mm) recorded at Guthalungra, 2000/01-2020/21. Year represented in columns is twelve months prior to the survey.

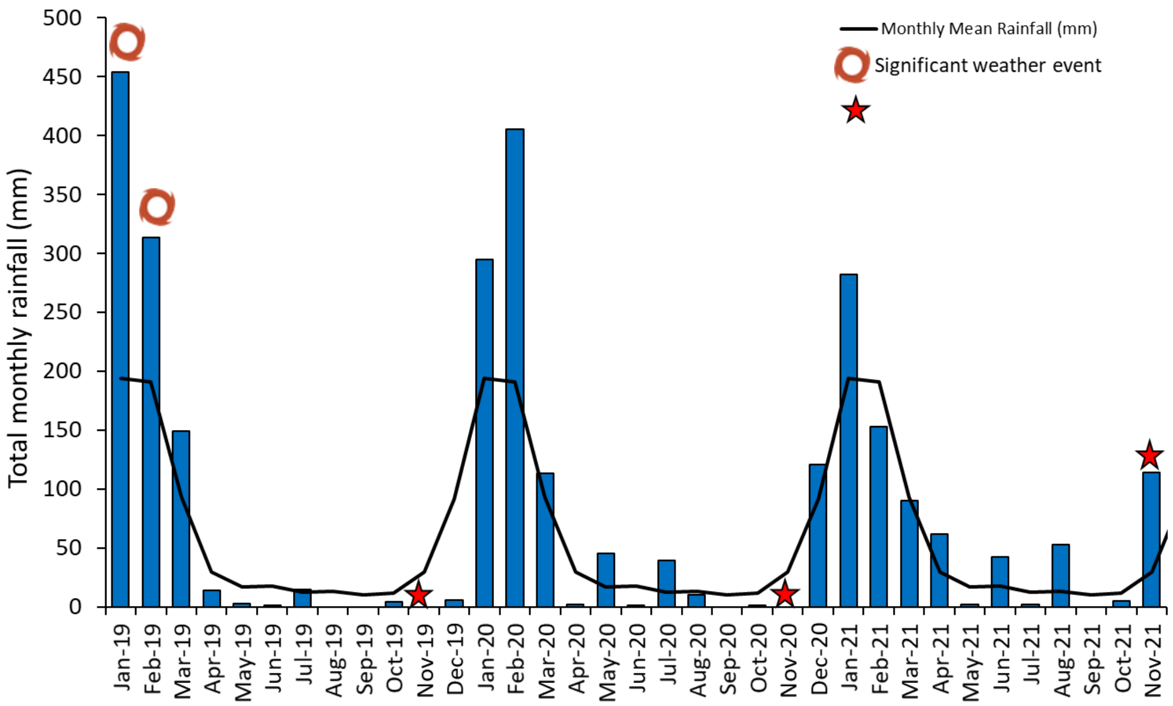


Figure 21b. Total monthly rainfall (mm) recorded at Guthalungra, January 2019 – November 2021.

3.3.4 River Flow - Elliot River

River flow for the Eliot River was below the long-term annual average in 2020/21 for the second consecutive year (Figure 22a). The highest river flow in the survey year occurred in January 2021, well above the long-term average rainfall for that month, however all other months were below the long term monthly averages (Figure 22b).

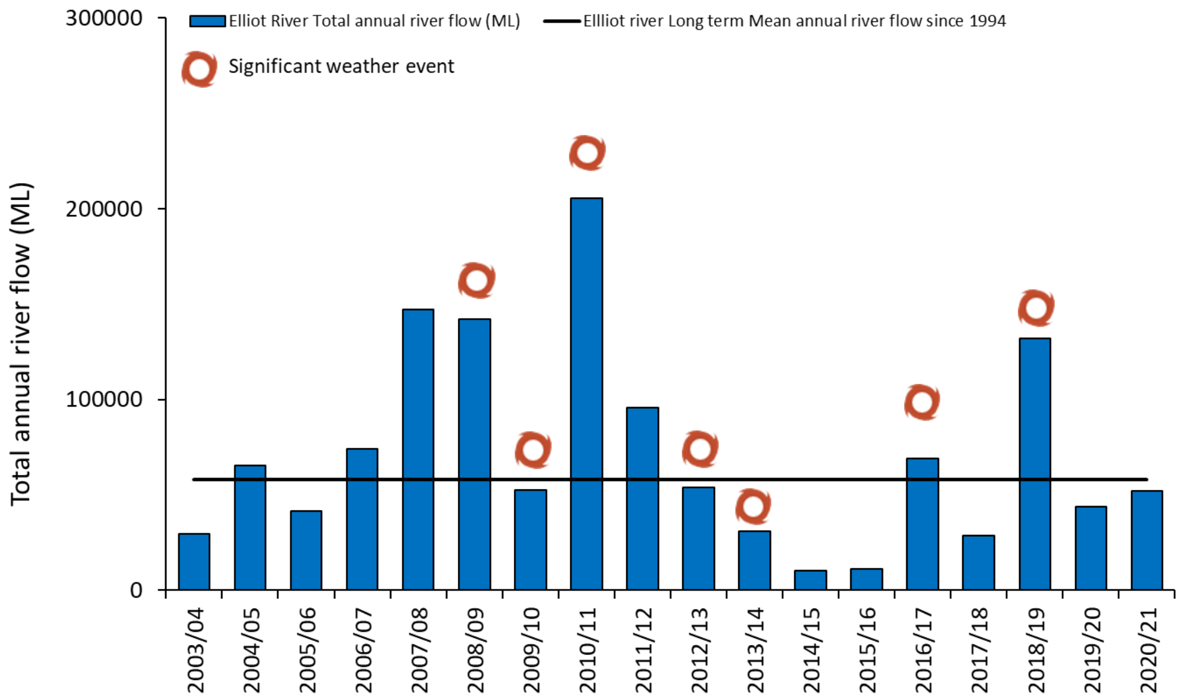


Figure 22a. Total annual river discharge of the Elliot River from 2003/04 to 2020/21. Year represented in columns is twelve months prior to the survey.

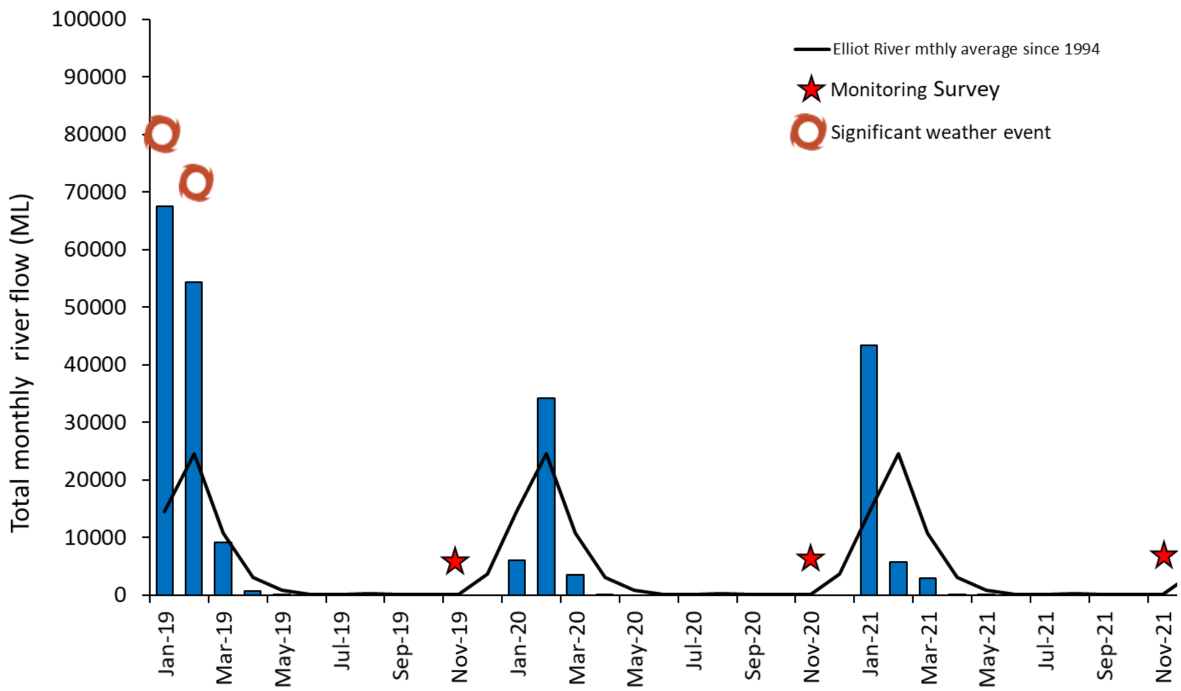


Figure 22b. Total monthly river discharge of the Elliot River from January 2019 to December 2021.

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. 2021). 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. (2021).

RMS at AMB 1 was recorded up until June 2021 by the ambient water quality monitoring program, five months before the seagrass survey. There were several peaks in maximum RMS (red line) in December 2020 and March 2021 that were of similar magnitude to those seen in the wet season in previous years (Figure 23). Peaks in RMS wave height can cause peaks in turbidity and sediment deposition (Waltham et al. 2021).During this period, however, the average monthly RMS was below the long-term average with the exception of a slightly above average monthly RMS in March 2021.

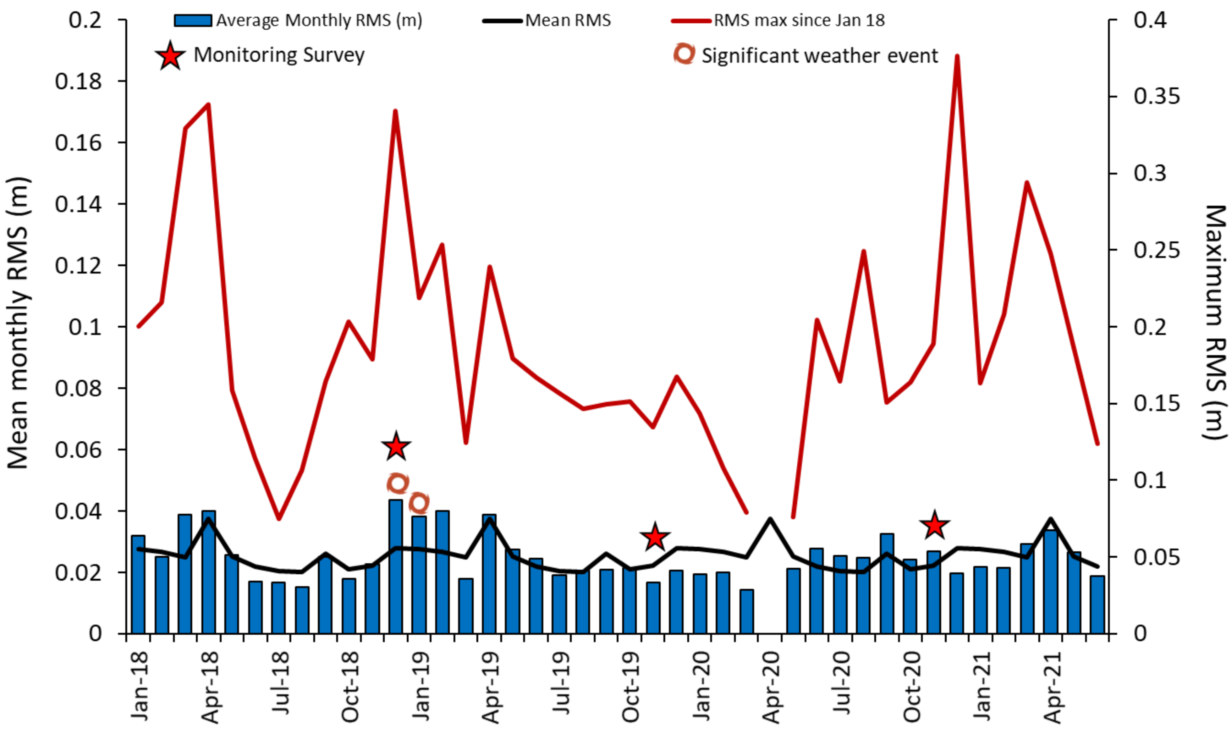


Figure 23. Mean monthly, long-term monthly mean, and maximum RMS recorded at Abbot Point water quality site AMB 1 January 2018 – December 2021.

4. DISCUSSION

Seagrasses in the annually monitored meadows of the Port of Abbot Point remained in a good condition overall in 2021 for the second consecutive year with some improvements in the condition of individual meadows. In the two years prior to this period (2018-2019) seagrass had been in a satisfactory condition following recovery after multiple impacts from climate related events between 2017 and 2019: including Tropical Cyclone Debbie 2017, TC Penny 2019 and TC Oma 2019. The greatest shift in seagrass condition occurred in the offshore meadows which improved from satisfactory in 2020 to good in 2021.

A change in approach to annual monitoring and reporting of the highly variable offshore seagrasses at Abbot Point in 2020 allowed for the condition assessment of meadow area in the 2021 survey for the second time. The seagrass in these offshore meadows have gained condition over the last 12 months due to an improvement in their indicator score for total meadow area, mean above ground biomass and the composition of species assemblages. This follows declines in condition scores at the 2020 survey from good to satisfactory in all three of these metrics. In 2021 the mean biomass of the offshore meadow more than doubled to be above the long-term average. The area of the meadow also increased by over forty percent and the species assemblage has shifted over the last 12 months so that *H. spinulosa*, traditionally the dominant species in this meadow, has increased from 6 % of the meadow in 2020 to 45 % in 2021.

In general there was also an increase in the condition of the coastal meadows at Abbot Point over the previous 12 months. The meadow at the mouth of Euri Creek improved in species composition from good to very good due to an increase in the dominant species (*Z. muelleri*) doubling in percent composition. The meadow to the north of the Abbot Point wharf that is dominated by *H. uninervis* also improved to very good due to an increase in area over the previous year, while the other coastal meadow, also dominated by *H. uninervis* remained stable and in very good condition.

The main reason for the continued improvement in seagrass condition in the Abbot Point region is likely due to the favourable conditions for seagrass growth over the last two years and extending from the previous survey in 2020. During this time the region experienced below average river flow and rainfall and did not experience any of the damaging weather and climate events that were prevalent from 2017-19. Weather driven events that bring heavy rainfall, high river flow and flooding and wind-driven 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. These large events, particularly TC Debbie resulted in a decline in seagrass condition to very poor in 2017. Since then, first offshore, and then inshore meadows have been constantly improving in condition with the exception of a decline in the offshore meadows in 2020 (McKenna et al. 2021). Clearer water, particularly during the growing season from June to December results in seagrasses receiving light above their growing requirements allowing them to increase in condition (Chartrand et al. 2017). The fact that both offshore and coastal seagrass meadows were in good or very good condition indicate that light was above the minimum requirements (McKenna et al. 2015) throughout the growing season and this was supported by the inshore PAR levels recorded in the program.

The long-term monitoring program at Abbot Point is part of a broader Queensland Ports seagrass monitoring program using a consistent state-wide monitoring methodology. This enables 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 2021. Coastal areas to the north and south of Abbot Point had seagrass in good condition (e.g. Hay Point – York et al. 2022; Gladstone – Smith et al. 2022; Cairns Harbour - Reason et al. 2022; and Townsville – McKenna et al. 2022). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2022). Seagrass in the Gulf of Carpentaria in Weipa and Karumba were in a good and very good condition also due to favourable climate conditions (McKenna et al. 2021; Scott et al. 2022).

Conclusion

Seagrasses in the Abbot Point region were in good condition in 2021 for the second consecutive year, recovering from a poor state in 2017 following Tropical Cyclone Debbie. The improvement is likely due to ongoing favourable growing conditions for seagrass over the twelve months prior to the survey.

The improved condition of offshore seagrass at Abbot Point in 2021 and the stable and good to very good condition of inshore meadows indicates they were likely to be building resilience to withstand and recover from future natural and anthropogenic pressures. For seagrass to remain in a good condition or improve in status in the Abbot Point region it will require ongoing favourable weather and climate conditions that allow 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.

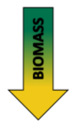
Table A1. Coefficient of variation (CV; %) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

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
Biomass	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
Area	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
Area	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Area	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
Species composition	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
Species composition	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).

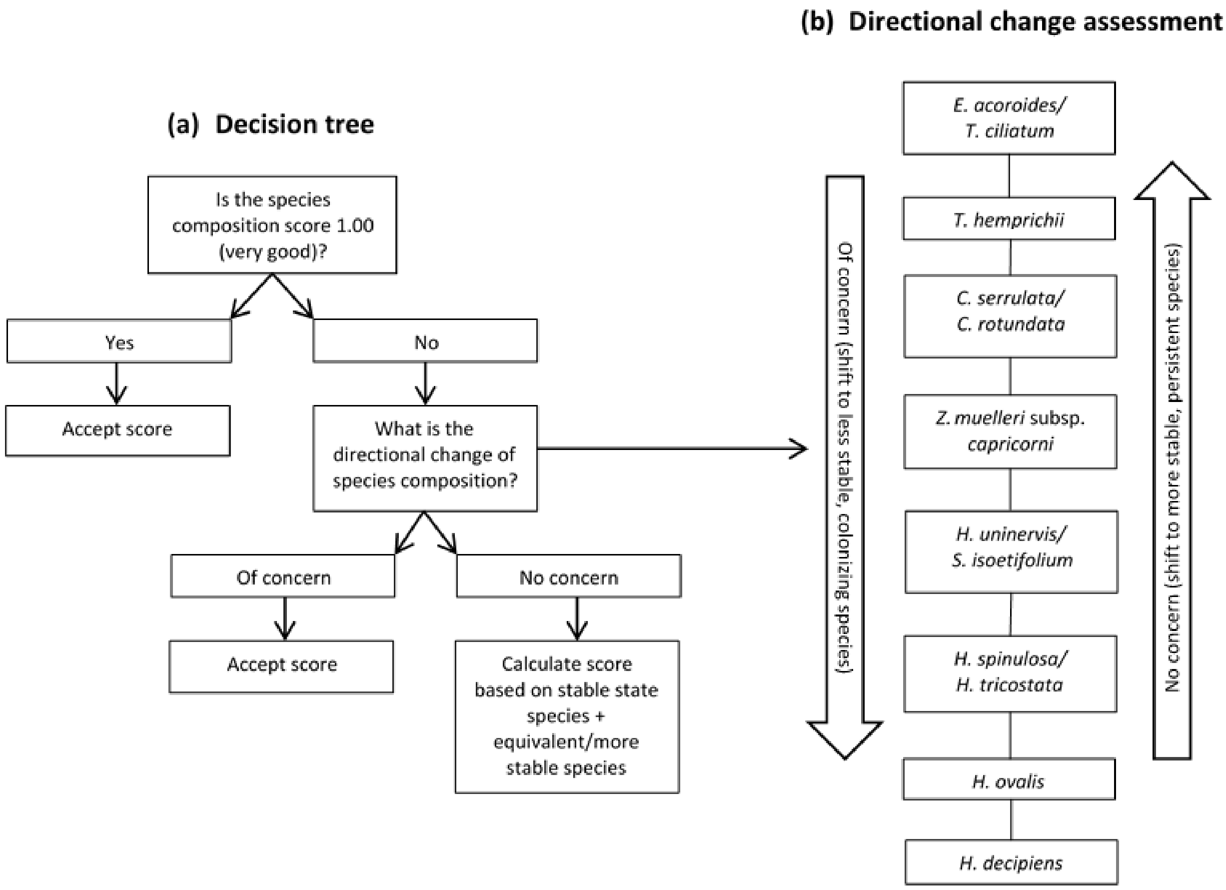


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

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:

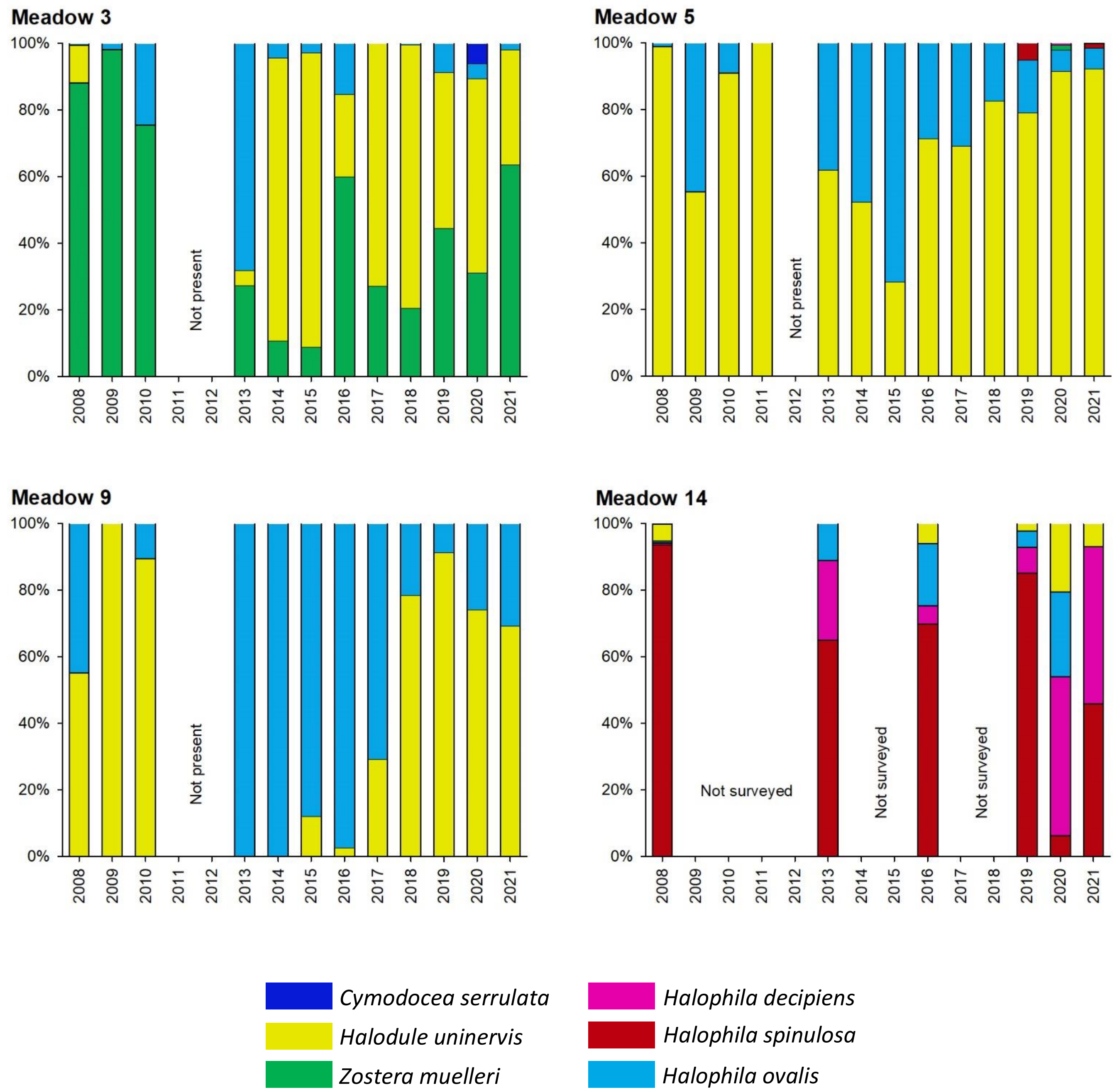
$$\mathrm{B_{prop}} = \frac{\mathrm{B_{diff}}}{\mathrm{B_{range}}}$$

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 – 2021



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)
2021	8.02 ± 1.93 (10)	4.12 ± 0.59 (50)	3.22 ± 0.45 (23)	1.93 ± 0.63 (14)

NP – No seagrass present in meadow; NS – Seagrass meadow not surveyed (offshore meadows 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
2021	21.62 ± 3.40	268.45 ± 47.75	231.45 ± 23.63	5464.70 ± 406.24