Port of Abbot Point Long-Term Seagrass Monitoring Program 2024

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Port of Abbot Point Long-Term Seagrass Monitoring Program 2024

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Acknowledgments

We acknowledge the Australian Aboriginal and Torres Strait Islander peoples as the traditional owners of the lands and waters where we live and work.

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CONTENTS

1 KEY FINDINGS

Seagrass Condition 2024

SATISFACTORY

Likely causes of seagrass condition:

Decline in condition of biomass in some meadows.

Significant wave height peaks = likely reduction in light

This report compiles findings of the annual Abbot Point Long-Term Seagrass Monitoring Program conducted in October-December 2024.

- Overall, Abbot Point seagrass remained in satisfactory condition at the end of 2024 compared with the expected baseline conditions.

- For all monitoring meadows both area and species composition were rated as good or very good against their baseline conditions.

- Seagrass biomass was also rated as good in the two coastal meadows south of Abbot Point but was in poor condition for the large variable offshore meadow (Meadow 14) and the smaller coastal meadow adjacent to the Abbot Point wharf (Meadow 9).

- Total seagrass extent increased for inshore meadows in 2024 and was similar to the previous year for offshore seagrasses.

- There were no major climate events during 2024 that were likely to have had significant impacts on seagrass, with rainfall and river flow below annual averages. However, there were some rainfall events and significant peaks in wave heights in the three months leading up to the annual survey. These events likely led to the observed reduction in benthic light (PAR) at coastal and offshore sites, leading to biomass declines for some meadows.

2 IN BRIEF

A long-term seagrass monitoring program and strategy were established in the Abbot Point region in 2008 following initial surveys of the area in 2004 and 2005. Annual monitoring occurs in 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). In addition to the established annual monitoring program, benthic light (Photosynthetic Active Radiation (PAR)), and temperature (continuously logged) data is collected at two inshore sites through the seagrass monitoring program and at offshore sites through the TropWATER/NQBP Ambient Water Quality Monitoring program (Figure 1; Section 4.5).

The overall condition of Abbot Point seagrasses was satisfactory in 2024. All meadows maintained a good or very good score for area and species composition, but two of the four long-term monitoring meadows had declines in biomass (Meadow 9 and offshore Meadow 14) resulting in them being in an overall poor condition. The two coastal monitoring meadows south of Abbot Point were in good condition with improvements in biomass area and species composition for the Euri Creek meadow, Meadow 3, in 2024 (Figure 1).

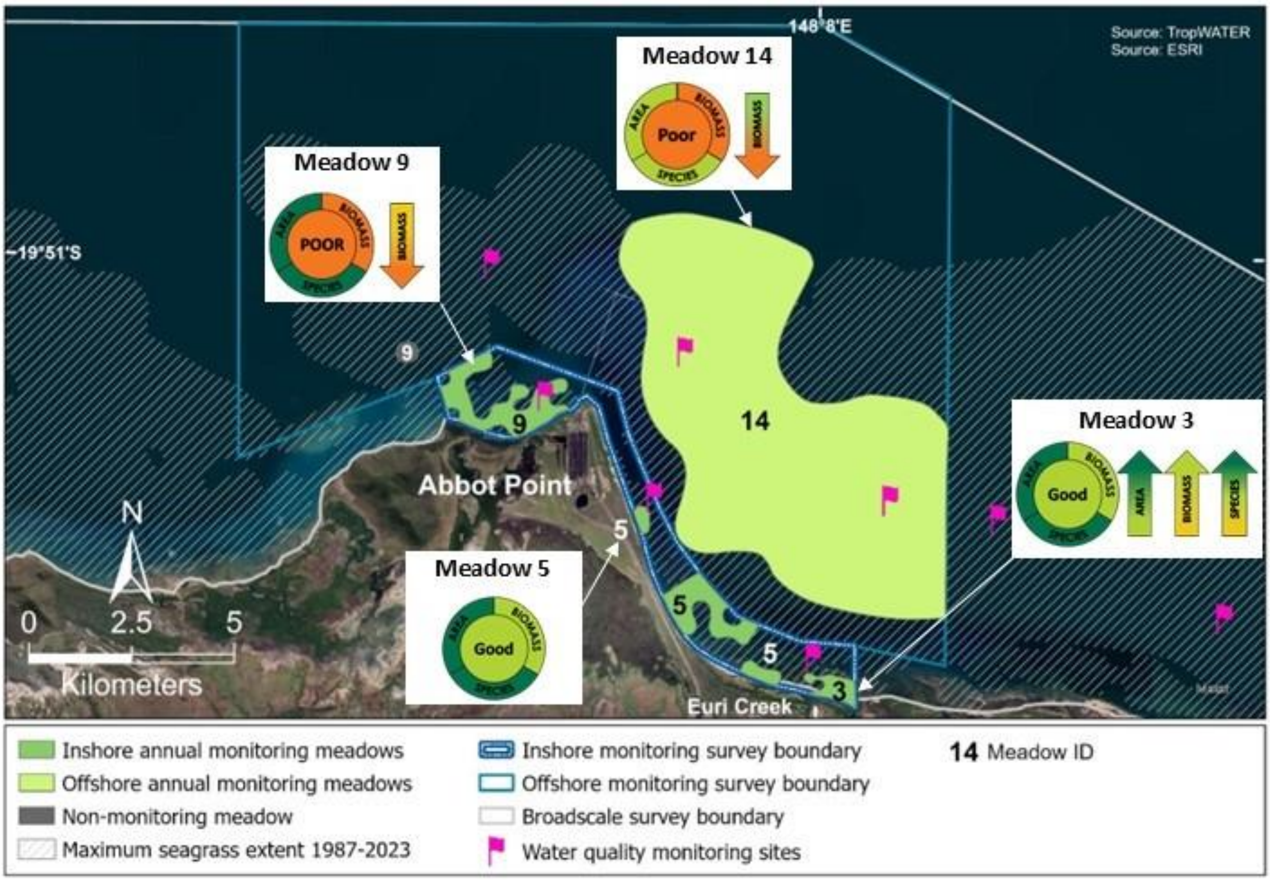

Figure 1. Seagrass condition for Abbot Point seagrass monitoring areas 2024.

Collectively, the biomass of the inshore long-term monitoring meadows has shown a slight increase after a decline over the past two years, while the offshore seagrass biomass considerably decreased in 2024 (Figure 2). The total seagrass extent in the Abbot Point region has increased during this survey, following a decline in 2023 (Figure 2).

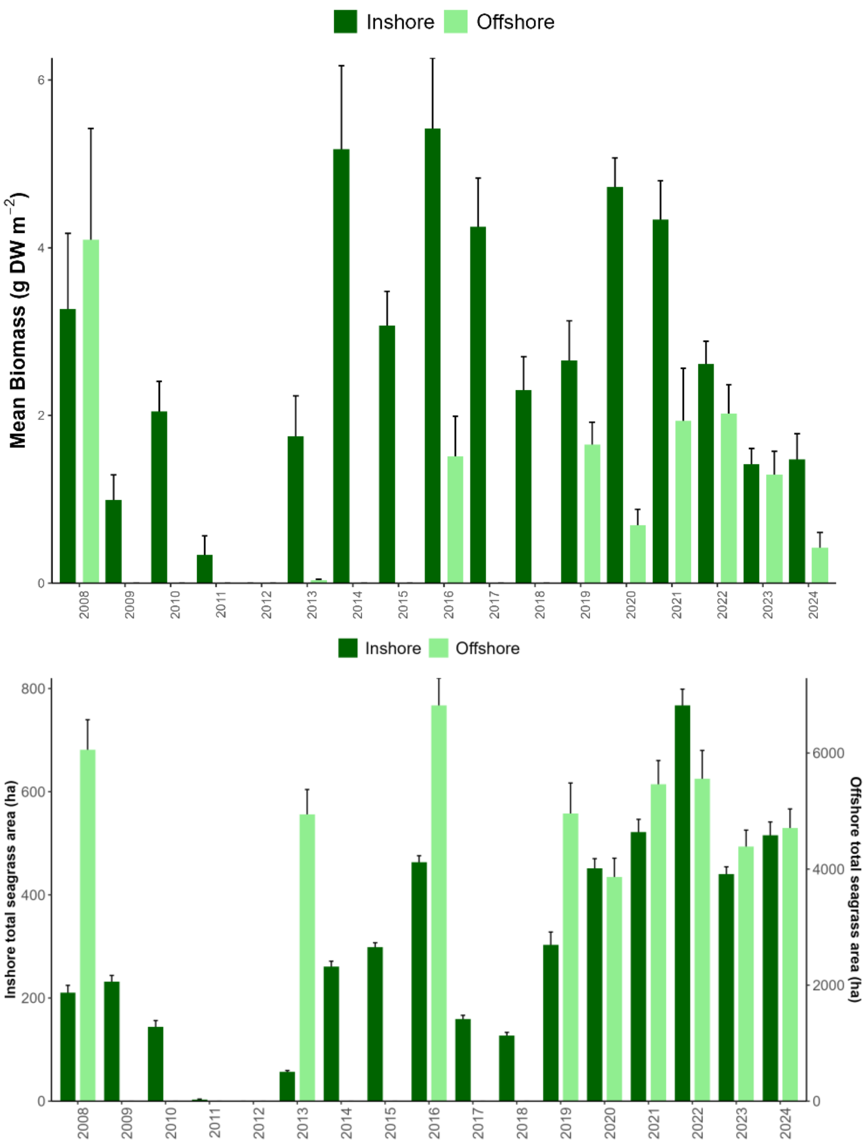

Figure 2. Comparison of mean biomass (g DW m^{-2}) and area (ha) for inshore and offshore seagrass monitoring meadows from 2008 to 2024.

There were no major unfavourable climate events in the Abbot Point region over the past 12 months that would impact seagrasses, with rainfall and river flow below the annual averages. However, there were periodic rainfall peaks in February and June 2024 and sustained large wave heights in the three months leading up to the survey, which likely caused the resuspension of sediments, leading to reduced light (PAR) levels. This resulted in PAR below the seagrass growth threshold for sustained periods of time in Meadow 9 and in deeper offshore regions where decreases in seagrass biomass were recorded.

The Abbot Point seagrass monitoring forms part of a broader program that examines the condition of seagrasses in most Queensland commercial ports and areas of high cumulative anthropogenic risk. In the broader Queensland monitoring network, seagrass to the north of Abbot Point, in Townsville, were in a poor condition (McKenna et al. 2024). To the south in Mackay/Hay Point seagrasses were in overall satisfactory condition (York et al. 2025). In the Gulf of Carpentaria, in Weipa and Karumba, seagrasses were in good and poor condition, respectively (Reason et al. 2024a; Scott and Rasheed 2024). The variation in seagrass condition across the long-term monitoring locations was generally linked with local environmental factors influencing meadow status.

Seagrass meadows around Abbot Point were in an overall satisfactory condition at the end of 2024 and while there were reductions in biomass for some meadows, the maintenance of seagrass across their historical footprint and the continued presence of the foundation species means they have a good potential to increases in biomass should favourable environmental conditions occur during 2025.

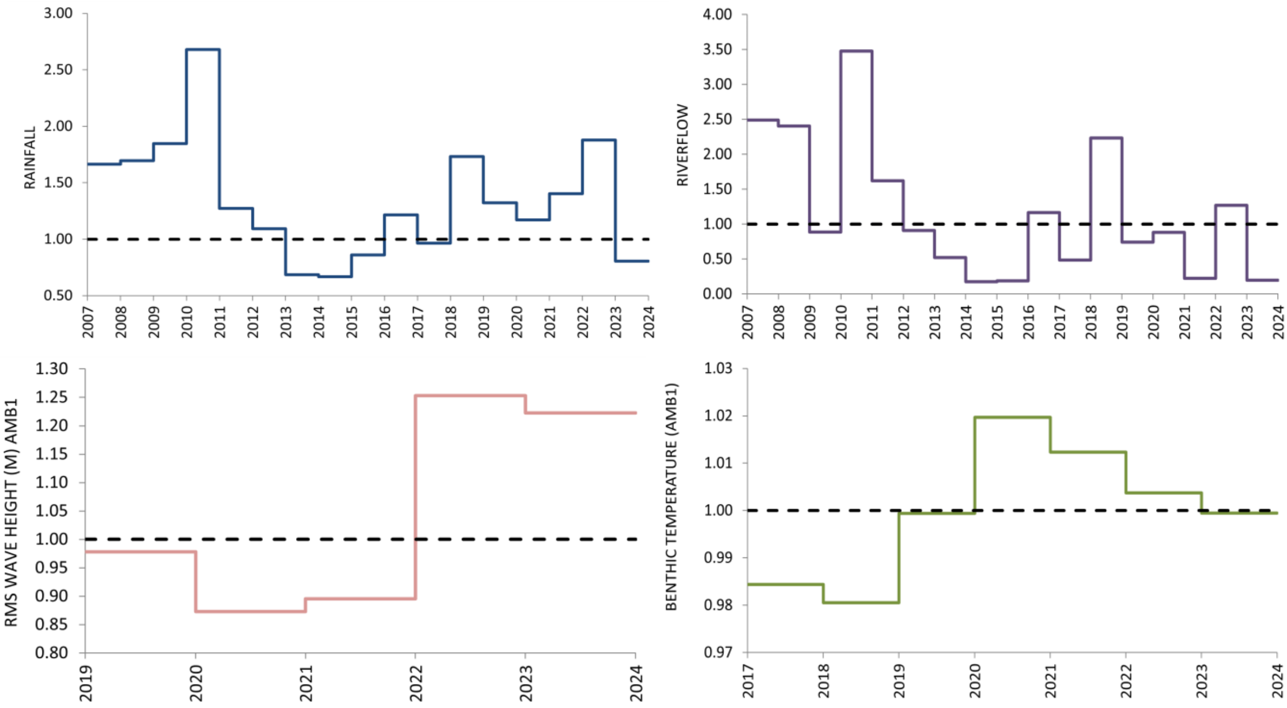

Figure 3. Climate trends for rainfall, river flow (Guthalungra/Elliot River) and benthic RMS wave height, temperature and PAR (light) at AMB1: Change in climate variables as a proportion of the long-term average (LTA – dashed line). See section 5.3 for detailed climate data.

3 INTRODUCTION

Seagrasses are recognised as highly productive marine habitats that provide a variety of ecosystem services important to human wellbeing and worth substantial economic value. Services include nursery habitat for economically important fisheries species, food for megaherbivores (e.g., dugongs and turtles), sediment stabilisation, nutrient cycling across the coastal zone and sequestration of atmospheric carbon (Coles et al. 1993; Heck et al. 2003; Barbier et al. 2011; Lavery et al. 2013; Costanza et al. 2014; Scott et al. 2018; York et al. 2018, Rasheed et al. 2019; Macreadie et al. 2024). Coastal communities and Traditional Owners rely on seagrass meadows for food and livelihoods (Hayes et al. 2020; Jänes et al. 2020a, 2020b).

There has been a net decline in seagrass meadows in recent decades due to natural and anthropogenic causes (Dunic et al. 2021; Turschwell et al. 2021; Waycott et al. 2009). Climate change stressors such as increases in water temperature and frequency and severity of tropical storms have the potential to exacerbate this decline (Strydom et al. 2020; Serrano et al. 2021; Carter et al. 2022; Shepherd et al. 2024). 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).

3.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in most Queensland commercial ports. The program was developed by James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with Queensland port authorities. A common methodology and rationale are 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. This information is useful for planning and implementing port development and maintenance programs that have minimal impact on seagrasses. The program also 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/project/management-of-ports-and-coastal-facilities/.

3.2 Abbot Point Seagrass Monitoring Program

North Queensland Bulk Ports Corporation (NQBP) in partnership with James Cook University's TropWATER Centre have been engaged in a seagrass assessment and monitoring program at Abbot Point since 2005. 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 broader whole-of-port mapping occurring every third year. 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, as well as reference areas outside the zone of influence of port activity (Figure 5).

As part of the seagrass monitoring program, benthic light (Photosynthetic Active Radiation (PAR)) and temperature data are also continuously collected within two of the inshore monitoring meadows (Figure 5). These logging stations sit in parallel to other water quality monitoring stations in the region (5 stations) (see Waltham et al. 2022 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 2024. 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 to baselines (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.

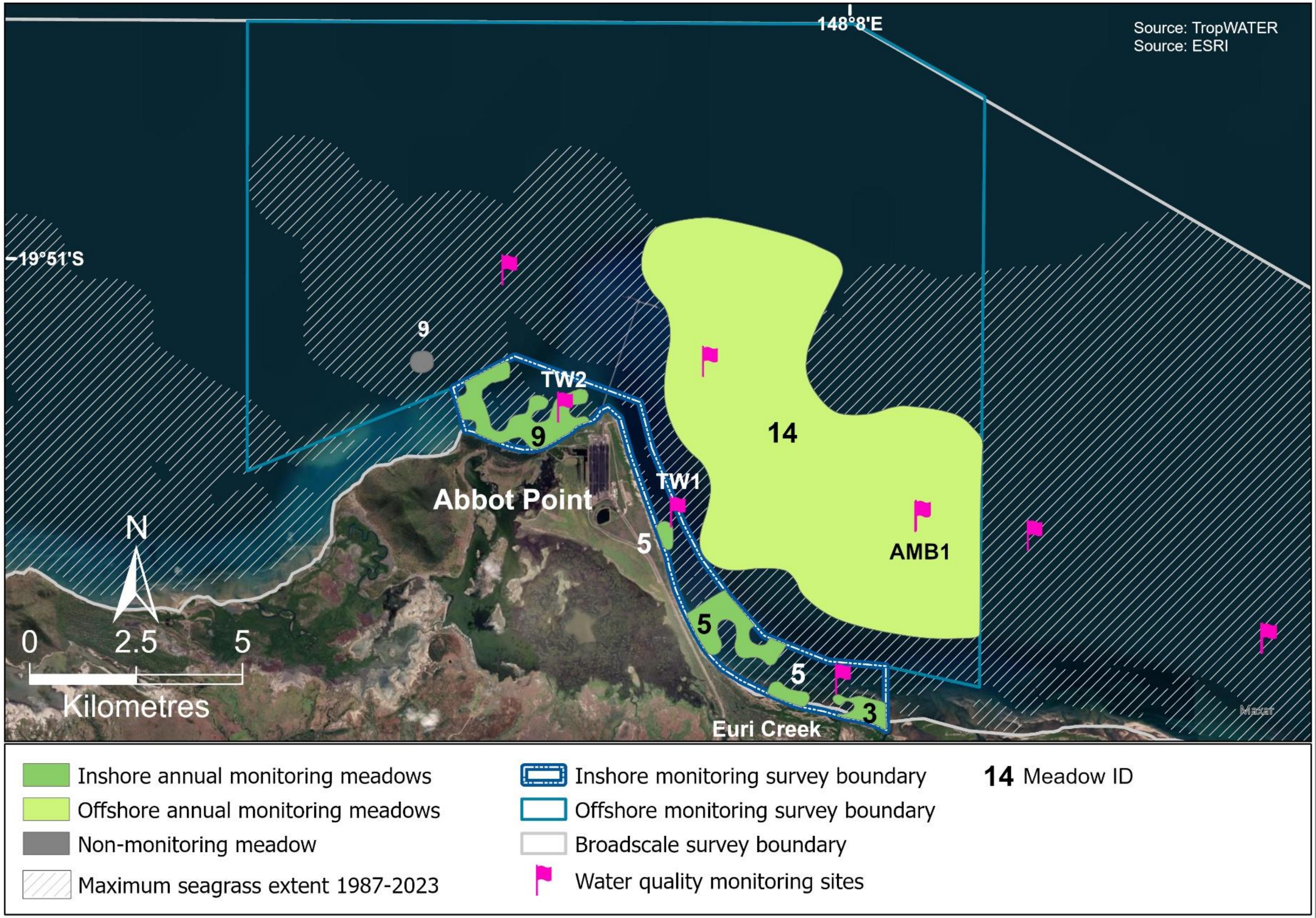

Figure 5. Location of annual inshore and offshore monitoring areas, broadscale survey areas and water quality sites. Water quality sites include inshore light (PAR) and temperature loggers (TW1 & TW2), as well as the TropWATER Ambient Water Quality monitoring site in Meadow 14 (AMB1) at Abbot Point.

4 METHODS

4.1 Sampling approach

In the initial 2008 baseline survey five coastal meadows and four offshore areas were identified for long-term seagrass monitoring (McKenna et al. 2008). Monitoring meadows were selected for detailed annual assessment because they were representative of the range of seagrass meadow communities identified in initial surveys. Annual surveys are conducted between September and December when tropical seagrass species are at their peak distribution and biomass. The Abbot Point Long-Term Monitoring Program has occurred annually since 2008 during that peak seagrass season.

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 fixed '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. For the offshore Meadow 14 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 nine years (2008, 2013, 2016, 2019, 2020, 2021, 2022, 2023 and 2024). The interim baselines for Meadow 14 will continue to be adjusted until ten years of baseline data is reached.

In 2023, a new survey area between Meadow 9 and 5 (around the Abbot Point Marine Offloading Facility (MOF), and currently a gap in information) was added to the program and reported on (Figure 5 & 6). For this area, we will not be determining condition scores as there is currently not enough data for the area.

Figure 6. Location of the new Marine Offloading Facility (MOF) benthic habitat survey area.

4.2 Sampling methods

Survey and monitoring methods for assessing seagrass in the Abbot Point region follow those of the established techniques for Abbot Point and TropWATER's Queensland-wide seagrass monitoring programs. 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.

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 7A & B).
2. Offshore subtidal areas >8m below MSL: Boat based digital camera sled tows with sled net attached (Figure 7C-D).

Figure 7. (**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 7A-B). At digital camera sled tow sites, this technique involved an observer ranking seagrass at ten random time frames allocated within the 100m of footage for each site (Figure 7C-D). The video was paused at each of the ten time frames and then advanced to the nearest point on the tape where the bottom was visible, and the 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.

4.3 Habitat mapping and Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS Pro 3.1.2®. Three GIS layers were created to describe seagrass in the survey area: a site layer, a seagrass meadow layer and a seagrass biomass interpolation layer.

- *Seagrass 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.

- *Seagrass 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 8).
  - Sampling method and any relevant comments.

- *Interpolation layer*: The interpolation (raster) layer describes spatial variation in seagrass biomass across each meadow. It 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 the 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.

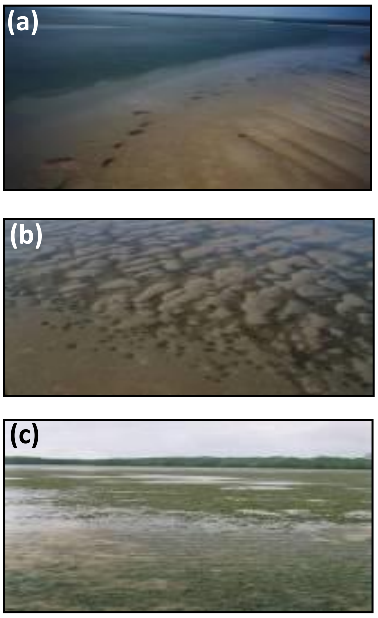

Figure 8. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

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 area reliability estimate (R) in hectares.

Table 3. Mapping precision and methodology for seagrass meadows in the Abbot Point region 2023.

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.

4.4 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline (see Carter et al. 2023 for full details). Seagrass condition for each indicator at Abbot Point 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% (Carter et al. 2023).

For the purpose of the annual monitoring program and determining condition scores, meadow area, biomass, and species composition are only calculated on the portion of the meadow that is within the respective fixed survey boundary.

4.5 Environmental data

Available environmental data was collated for the twelve months preceding the 2024 survey. Total daily rainfall (mm) and river flow data were obtained by the Queensland Government's 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).

As part of the seagrass monitoring program, benthic light (Photosynthetic Active Radiation (PAR)) and temperature data are continuously collected within two of the inshore monitoring meadows. These logging stations sit in parallel to other water quality monitoring stations in the region (3 stations) (Figure 9) (see Waltham et al. 2022 for the full NQBP/JCU partnership water quality program). From the Water Quality Program, Offshore Station AMB 1 is relevant to the annual monitoring meadows (Figure 5). This data has been used to represent the availability of light and temperature in the monitored seagrass meadows.

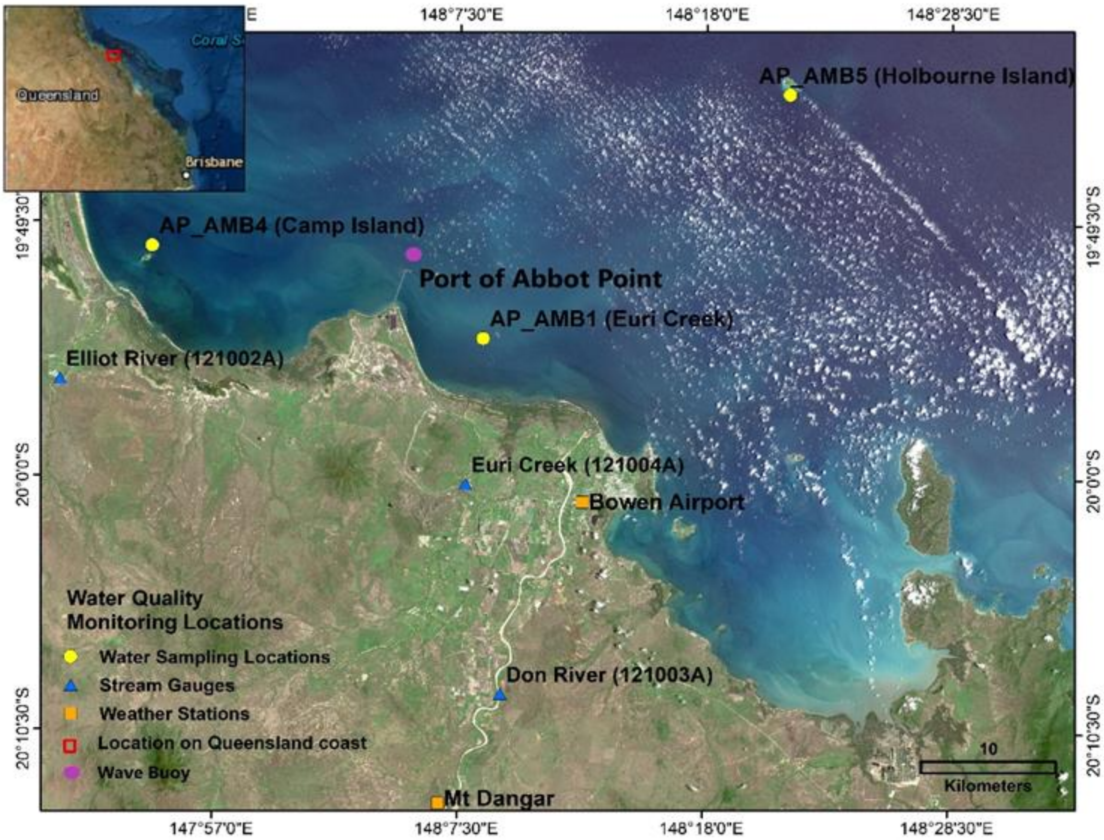

Figure 9. Location of TropWATER water quality monitoring sites (yellow circles). Also shown are meteorological stations (orange square), and stream gauge stations (blue triangle). Taken from Waltham et al. 2022

At the two inshore logging stations (TW1 & TW2), each independent logging station within the meadows consists of 2π cosine-corrected irradiance loggers (Submersible Odyssey Photosynthetic Irradiance Recording Systems) with supporting electronic wiper units (Figure 10). Irradiance loggers were calibrated using a cosine corrected Li-Cor underwater quantum sensor (LI-190SA; Li-Cor Inc., Lincoln, Nebraska USA) and corrected for immersion effect using a factor of 1.33 (Kirk 1994). Readings were made at 15-minute intervals and used to estimate total daily irradiance (PAR) reaching seagrass. The electronic wiper unit fitted to each irradiance logger automatically cleaned the optical surface of the sensor every 15 minutes to prevent marine organism fouling. Autonomous Thermodata® iBTag submersible temperature loggers recorded seabed temperature every 30 minutes.

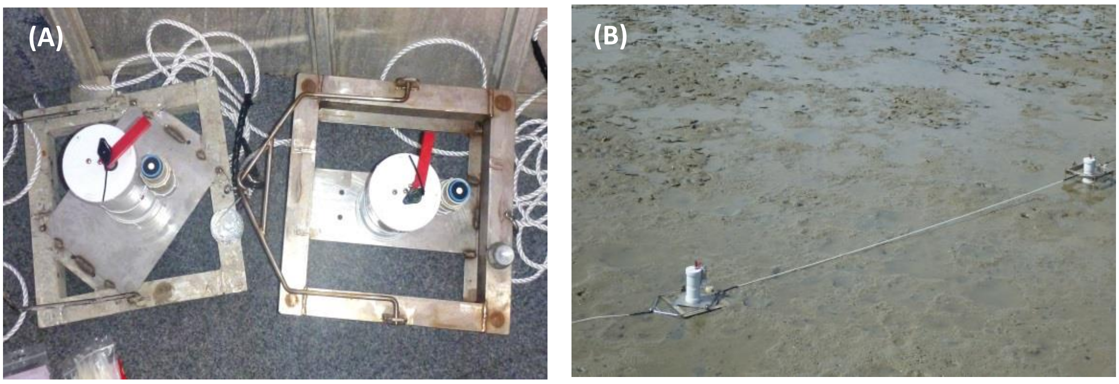

Figure 10. (**A**) Logging station consisting of a stainless steel frame with PAR loggers, temperature loggers and wiper units attached; (**B**) example of deployment of logging stations (Abbot Point stations are subtidal only).

5 RESULTS

5.1 Seagrass in the Abbot Point long-term monitoring areas.

The 2024 annual monitoring survey was conducted in November 2024. Benthic habitat was assessed at 149 sites in the Abbot Point monitoring meadows (Figure 12). Seagrass was present at 32% of the habitat assessment sites. Seagrass in the inshore annual monitoring areas covered 515.83 ± 76.6 ha, while seagrass in the offshore monitoring area covered 4,709.4 ± 327.3 ha (Figure 12; Appendix 8.2). The seagrass meadows around Abbot Point tend to be of low biomass, light-moderate density meadows (Figure 13). The maximum biomass of inshore seagrass meadows only reaches around 9 g DW m^{-2}, while the offshore *Halophila* meadow has reached around 5 g DW m^{-2}, typical of biomass for offshore *Halophila* meadows (Figure 13).

Five seagrass species were observed in the 2024 survey and were typical of those found in the Abbot Point region and more broadly in Queensland (Figure 11). The offshore seagrass habitat was dominated by *H. spinulosa,* with *H. ovalis*, *H. decipiens,* and *H. uninervis* (wide form) present in the meadow as well (Appendix 8.1). Inshore meadows 5 and 9 were dominated by *H. uninervis* (narrow form) (Appendix 8.1), whereas the Euri Creek meadow (Meadow 3) was dominated by *Z. muelleri* and *H. uninervis* (narrow form).

Cymodocea rotundata, Cymodocea serrulata, and *Syringodium isoetifolium* have been recorded in the region in the past, but occurrences are uncommon, and they were not present in the surveyed area in 2024. *C. serrulata* was last recorded in 2020, and *C. rotundata* and *S. isoetifolium* have only been recorded in the 2005 baseline survey.

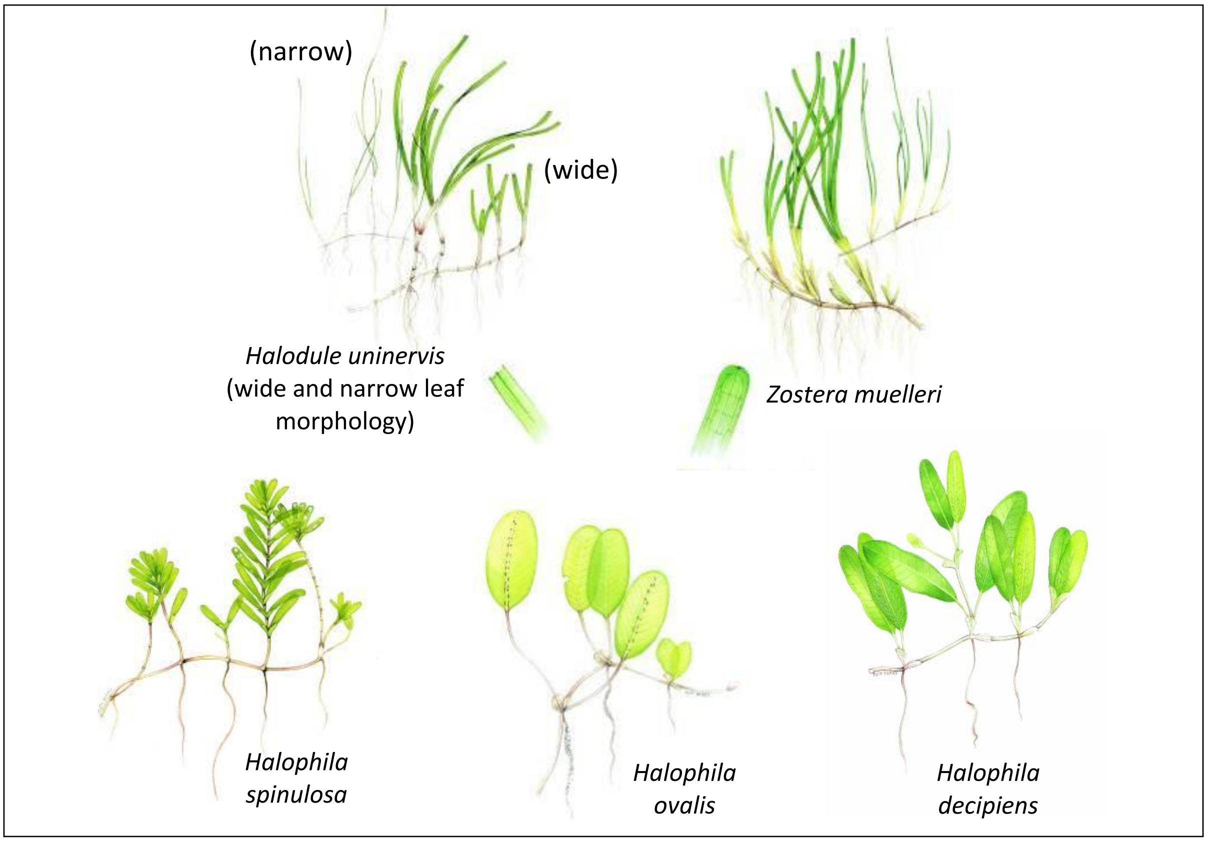

Figure 11. Seagrass species identified in the Abbot Point region in 2024.

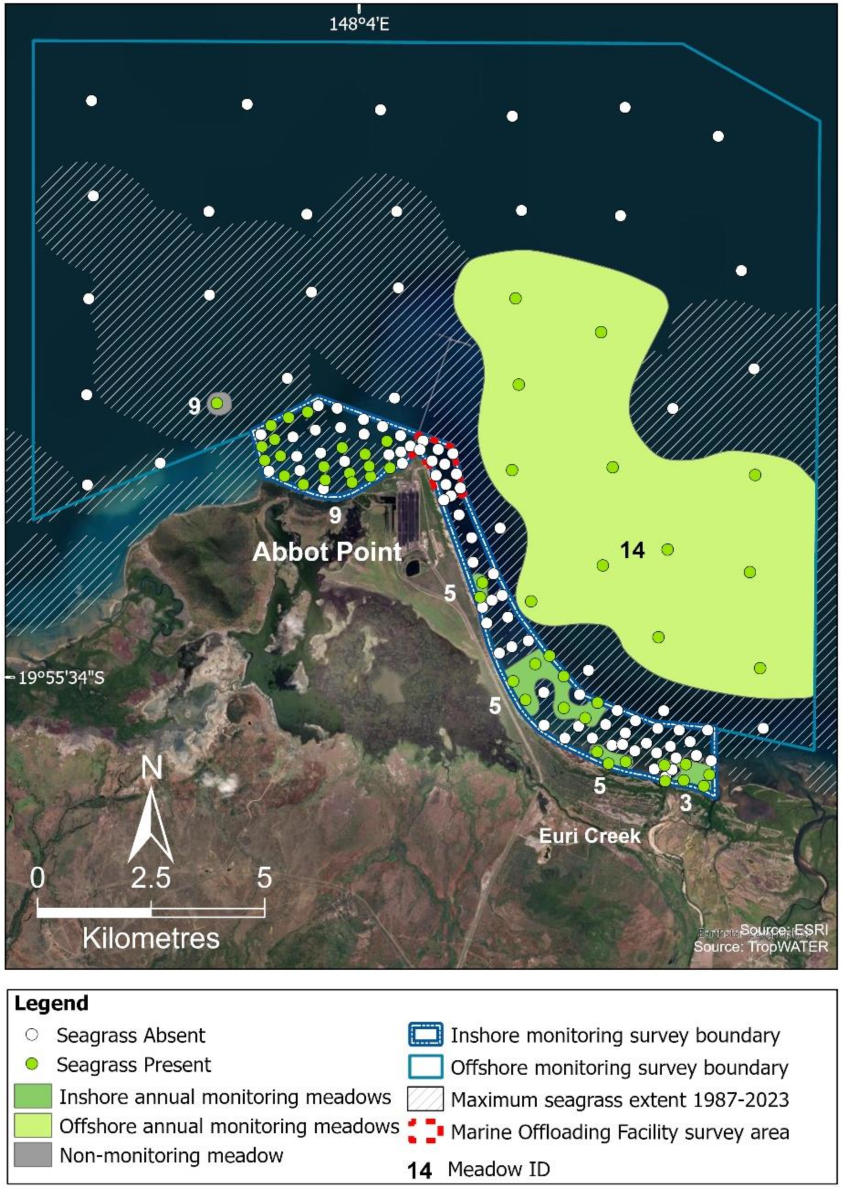

Figure 12. Location of seagrass assessment sites and seagrass meadows in the 2024 annual monitoring survey.

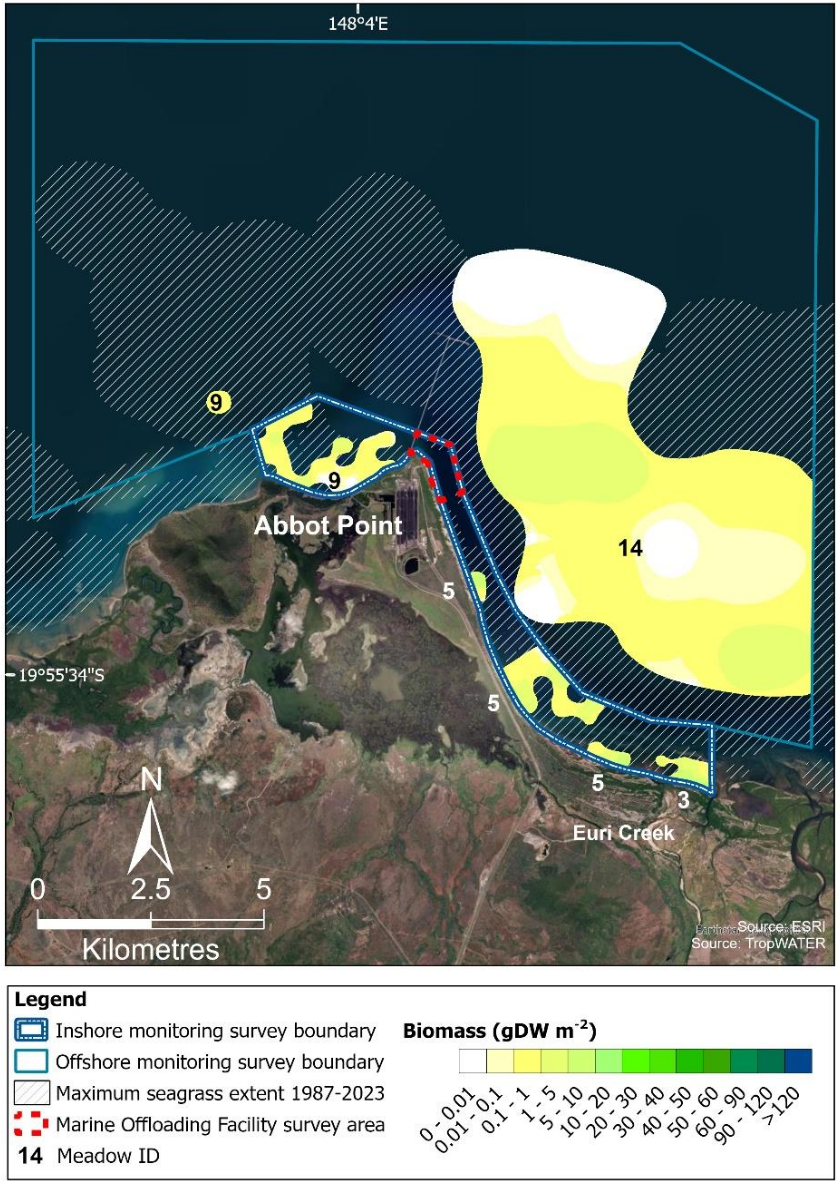

Figure 13. Seagrass density (Biomass g DW m^{-2}) and distribution for the 2024 annual Abbot Point seagrass survey.

5.2 Seagrass condition in the Abbot Point monitoring areas

The Abbot Point monitoring meadows were in an overall satisfactory condition at the end of 2024 (Table 4), similar to the previous year.

All monitoring meadows maintained a good or very good condition for species composition and area in 2024, but two meadows had poor biomass scores (Table 4). This resulted in two of the three inshore monitoring meadows (Meadow 3 and 5) being in good condition. Meadow 3 improved from the previous year, increasing in biomass (1.94 g DW m^{-2} increase), species composition (driven by an increase in *Z. muelleri*), and area (22.63 ha increase). While Meadow 5 remained in good condition for the third consecutive year. Meadow 9 has experienced a decline in biomass since 2022, decreasing from good (2.09 g DW m^{-2}) to poor (0.48 g DW m^{-2}) condition in the last three surveys, which led to an overall poor condition. The offshore meadow, Meadow 14, declined to a poor condition due to a decline in biomass (from 1.29 g DW m^{-1} to 0.42 g DW m^{-1}). Despite that, the area increased by 323 ha (from 4,386.3 in 2023 to 4,709.35 ha).

Table 4. Condition scores for seagrass indicators (biomass, area, and species composition) for the Abbot Point region in 2024.

Meadow	Biomass	Species Composition	Area	Overall Meadow Score
Inshore meadow 3	0.78	0.85	0.88	0.78
Inshore meadow 5	0.68	0.96	1	0.68
Inshore meadow 9	0.39	0.93	0.98	0.39
Offshore meadow 14	0.47	0.84	0.66	0.47
Overall condition score for seagrass in the Port of Abbot Point				**0.58**

= very good condition = good condition = satisfactory condition

= poor condition = very poor condition

5.2.1 Inshore monitoring meadows

There are three inshore annual long-term monitoring meadows around Abbot Point. Meadows 3 and 5 are located to the southeast of Abbot Point, while Meadow 9 is located on the northwestern side of Abbot Point (Figure 13). Meadows 5 and 9 are *H. uninervis*-dominated meadows, while the foundation species in Meadow 3 at Euri Creek is *Z. muelleri* (Figure 14-16; Appendix 8).

The Euri Creek *Z. muelleri* meadow (Meadow 3) improved in condition in this survey (Figure 14). All three condition indicators increased in 2024, with species and area obtaining a very good condition (Figure 14). Biomass, species, and area recovered to levels above the long-term baseline for the meadow after falling below it in 2023 for the first time in four years (Figure 14). The recovery was driven by an increase in the presence of the indicator species, *Z. muelleri* which improved from 26% of 56% of the meadow biomass in 2024. Similarly, the area of Meadow 3 increased from below the long-term baseline to a very good condition, increasing by 22.6 ha in 2024.

The *H. uninervis* monitoring meadow on the southeastern side of Abbot Point wharf (Meadow 5) was in good condition in 2024 for the third year in a row (Table 4; Figure 15). The extent of the meadow remains well above the long-term average, and both the species composition and the area of the meadow were in very good condition. Meadow biomass remained good and has been in either good or very good condition for the last ten years (Figure 15). While the area remained in very good condition it still maintained the fragmented form it adopted in 2023, compared to 2022, when the seagrass formed one consolidated meadow.

The *H. uninervis* monitoring meadow on the western side of Abbot Point (Meadow 9) decreased to a poor condition in 2024, due to the poor biomass condition of the meadow (Table 4; Figure 16). This meadow has only ever been a light-moderate density meadow in 2016, when it had a biomass of 8.32 g DW m^{-2}, the highest biomass recorded throughout the monitoring program. Due to the impact of Cyclone Debbie and other weather events in 2017, the meadow experienced an abrupt drop in biomass that has not yet returned to pre-disturbance levels. This survey marks the third consecutive year of biomass decline, with 3.22 g DW m^{-2} in 2021 and only 0.48 g DW m^{-2} of biomass in 2024. Despite biomass declines the extent and species composition remained above the expected long-term baseline and scored as very good condition for the third year in a row (Table 4; Figure 16).

5.2.2 Offshore monitoring area

The offshore monitoring area encompasses seafloor from ~5m to 26m below mean sea level. The shallowest offshore area is located on the northwestern 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*. The deeper areas generally consist of low-light-adapted *Halophila* species, dominated by *H. spinulosa*.

The overall seagrass condition in the offshore monitoring area reduced from satisfactory to poor in 2024 (Table 4; Figure 17). This reduction was due to a loss of biomass which decreased by 0.87 g DW m^{-2} from 2023 (Figure 17). Despite the decline in biomass area of the meadow increased by over 323 ha, improving from satisfactory to good condition. Species composition was in good condition in 2024 (Figure 17).

Seagrass was recorded to a maximum depth of 21m below mean sea level similar to previous years.

5.2.3 Marine Offloading Facility (MOF)

In 2024, the area between Meadow 5 and Meadow 9, surrounding the Abbot Point Marine Offloading Facility (MOF), was surveyed (Figures 6 & 12). Twelve sites were assessed for benthic habitat, with no seagrass or macroalgae found in the area (Figure 12). There have been at least four previous surveys conducted by JCU around Abbot Point that have assessed sites within the MOF, and no seagrass has ever been recorded here.

5.2.4 Seagrass outside of long-term monitoring areas

For the purpose of the annual monitoring program and determining condition scores, meadow area, biomass and species composition have only been calculated on the portion of the meadows that is within the fixed respective survey boundaries.

One area of seagrass outside of the annual long-term monitoring meadows/survey boundaries (non-monitoring meadows) was also mapped in the 2024 survey (Figure 12). A patch of *H. uninervis* was mapped just outside of the Meadow 9 long-term monitoring survey boundary (but within the offshore survey boundary at Clark Shoal), so not included as part of the metric/score calculations. If the survey were the 3-yearly broadscale survey, this area of seagrass would be mapped within Meadow 9 because of the species composition and the depth of the site (being on Clark Shoal). The extent, footprint and density of seagrass on Clark Shoal is very dynamic and changes from year to year or may not be present at all in some annual surveys.

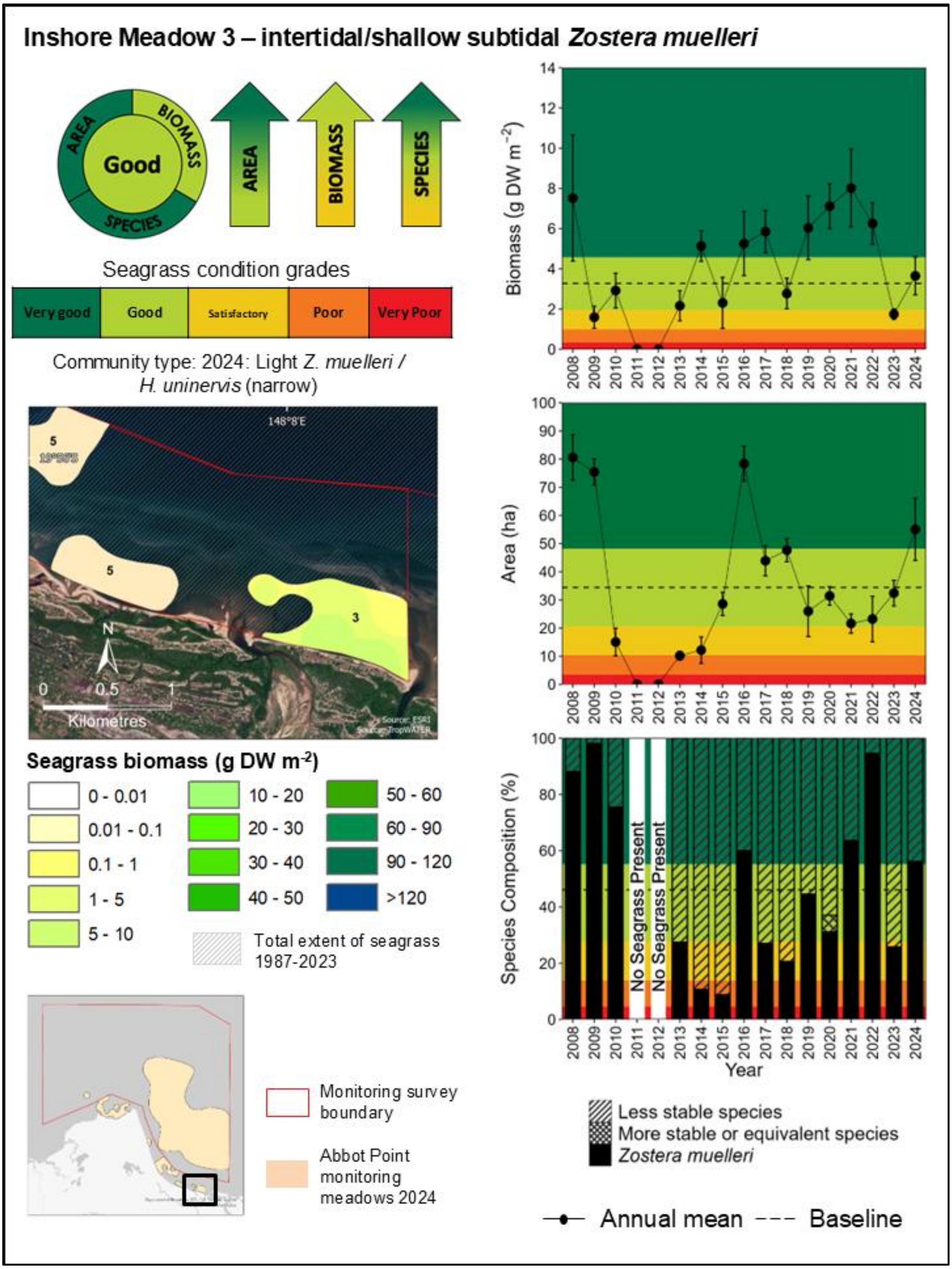

Figure 14. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 3. *Lack of arrows indicates no change in condition index from the previous year.

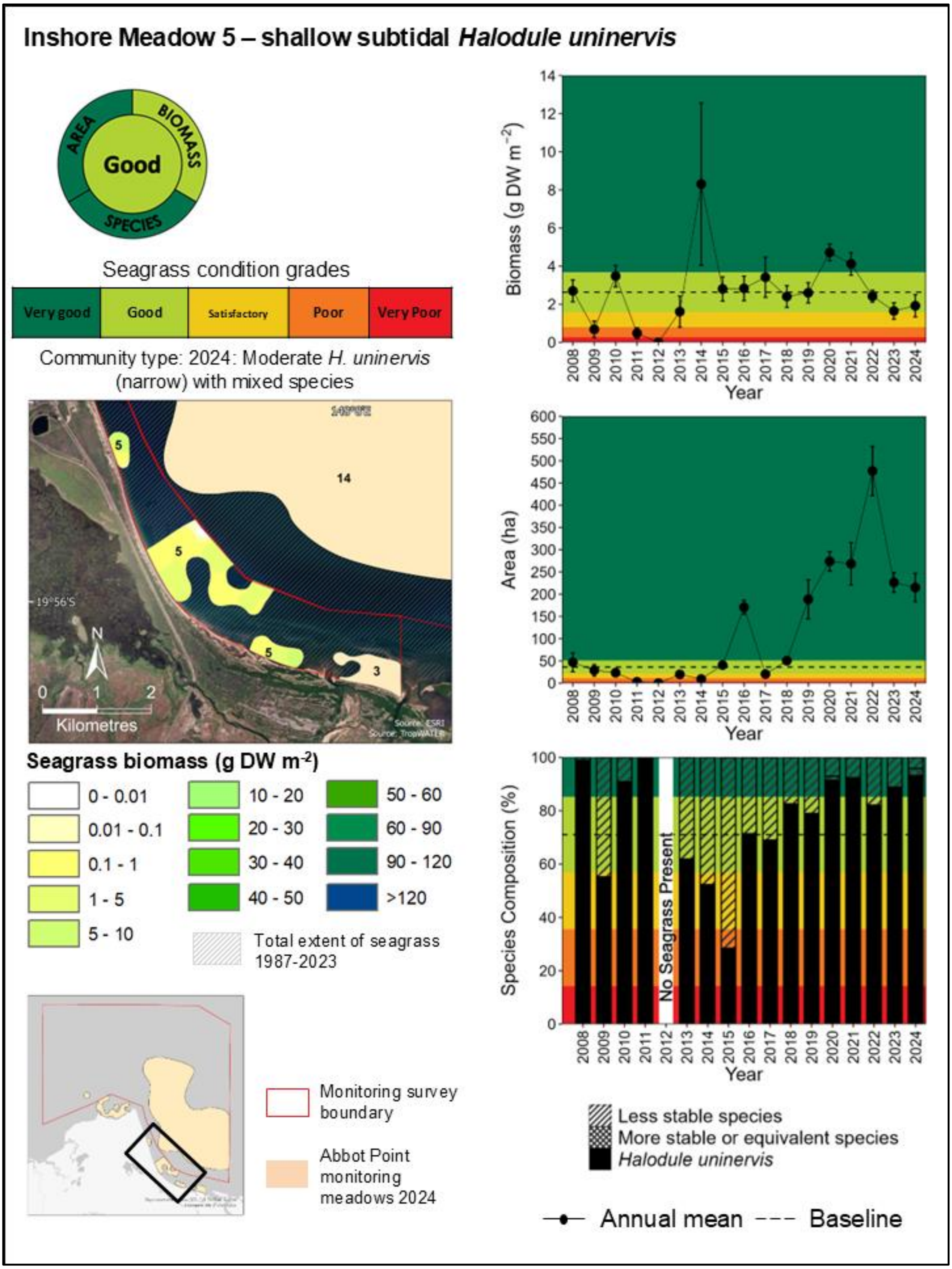

Figure 15. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 5. *Lack of arrows indicates no change in condition index from the previous year.

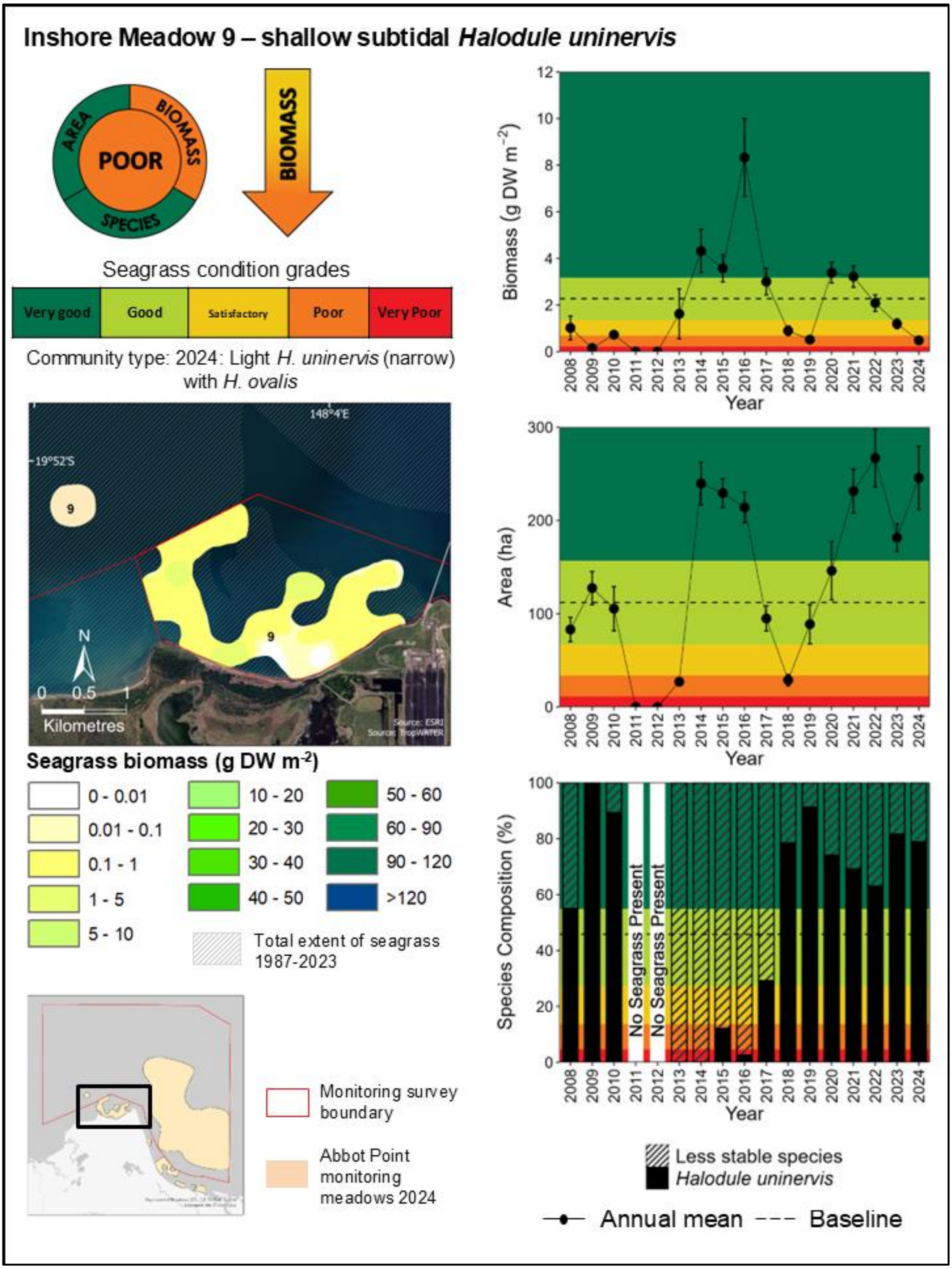

Figure 16. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at inshore monitoring Meadow 9. *Lack of arrows indicates no change in condition index from the previous year.

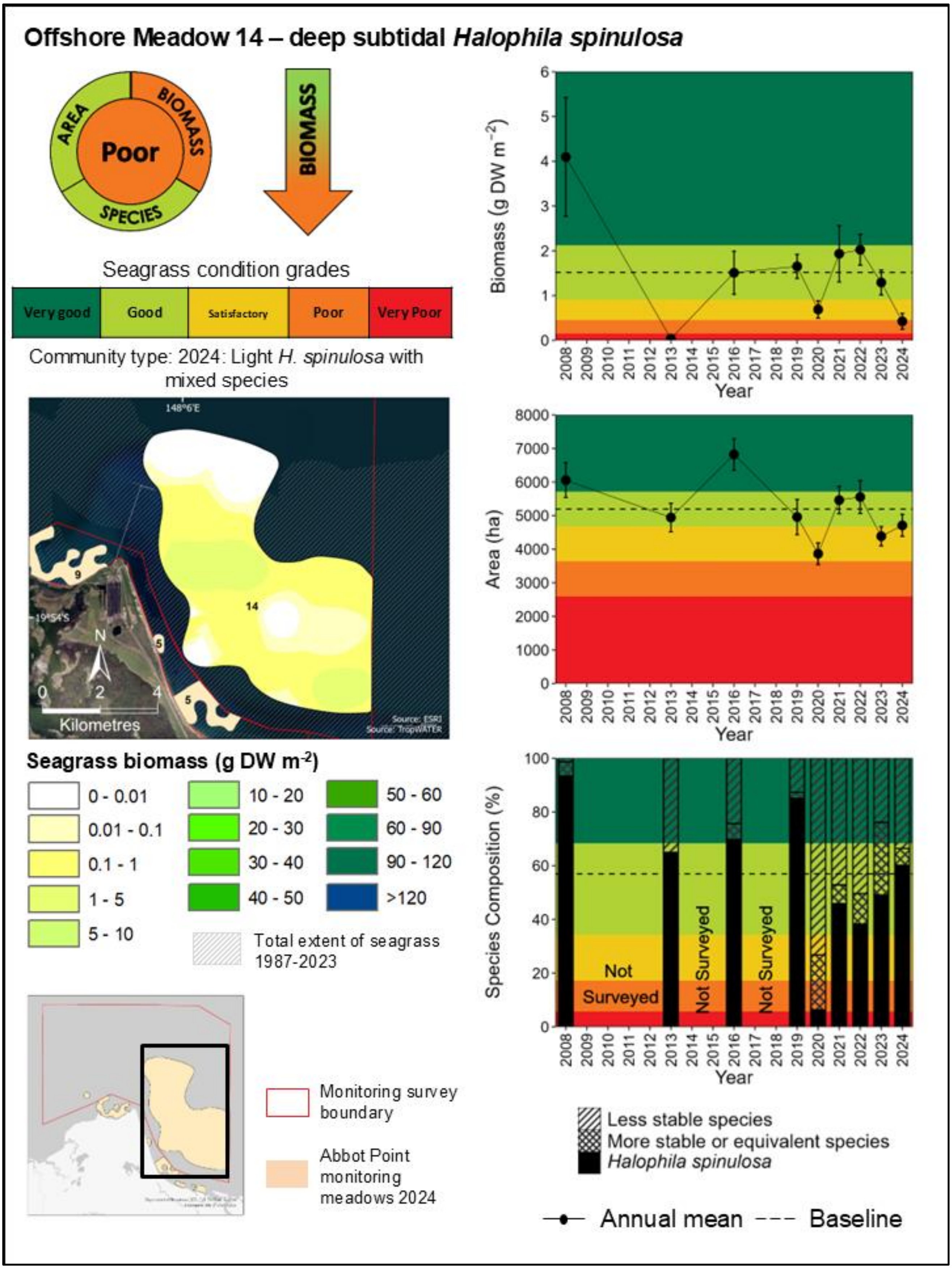

Figure 17. Mean meadow biomass (g DW m^{-2}), total meadow area (ha) and species composition at offshore monitoring Meadow 14. *Lack of arrows indicates no change in condition index from the previous year.

5.3 Abbot Point environmental data

5.3.1 Benthic water temperature

Maximum daily benthic temperatures at sites in the twelve months before the survey ranged from 20.1 °C (AMB1) – 32.6 °C (TW2, Meadow 9) (Figure 18a; 19a). The daily maximum temperature on land (control logger) ranged from 22.2 – 38.2 °C (Figure 19a). Data from the Ambient Water Quality Program has shown that the variation in benthic temperature in the Abbot Point region is smaller than in other regions along the east coast of Queensland and that the water column is mostly well mixed, with depth profiles for temperature showing only minor gradients of change (Cartwright et al. 2025).

5.3.2 Benthic daily light – photosynthetically active radiation (PAR)

Light available to seagrass changes with the season, with lower light levels during the wet season due to higher rainfall, increased cloud cover, river flow, and wind events, followed by higher light levels that support seagrass growth during the dry season (Figure 18b, 19b). In addition, semi-regular fluctuations between low and high PAR are often overridden by larger episodic events caused by storms, rainfall, or wind events (Cartwright et al. 2025). Low PAR also often corresponds with periods of high turbidity at Abbot Point (Cartwright et al. 2025).

Locally derived light requirements for the maintenance of seagrass biomass were previously developed for seagrass around Abbot Point (McKenna et al. 2015). For the offshore areas dominated by *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 *H. uninervis,* a threshold of 3.5 mol m^{-2} day^{-1} over a rolling 14-day average was required. These values are indicative of conditions that support seagrass positive growth, however they don't represent a threshold for applied management in this case as the area naturally experiences periods of light below these levels and is part of the reason behind natural fluctuations in seagrasses in the area.

The inshore PAR sites, TW1 and TW2, are at different depths and represent the depth gradient where coastal seagrasses can be found at Abbot Point (Figure 5). Because of this, the total daily light at each of these logging stations differs in range. TW2 on the western side of the Abbot Point wharf is the shallowest site of the three PAR logging stations and therefore has the highest PAR overall (Figure 18b, 19b). This is followed by inshore TW1, then offshore AMB 1.

In the twelve months before the seagrass survey, PAR (7 day (AMB1) and 14 day (TW1 & TW2) rolling averages) ranged from (see Figures 18b & 19b):

- Control logger (above water): 3.79 (Jun 2024) – 41.14 (Nov 2023) mol m^{-2} day^{-1}.
- TW2 (Meadow 9): shallow subtidal inshore *H. uninervis* meadow: 0.76 (Sep 2024) – 7.6 (Apr 2024) mol m^{-2} day^{1}.
- TW1 (Meadow 5): shallow subtidal inshore *H. uninervis* meadow: 1.0 (March 2024) – 7.4 (Jan 2024) mol m^{-2} day^{-1}.
- AMB1 (Meadow 14) subtidal offshore *Halophila* meadow: 0.97 (Feb 2024) – 6.7 (Nov 2023) mol m^{-2} day^{-1}.

There were some periods in the twelve months prior to the annual survey where light fell below seagrass biomass maintenance thresholds for inshore and offshore seagrass, which can have an impact on the distribution and biomass of seagrass. For example, in Meadow 9, light fell below maintenance thresholds for *Halodule uninervis* from June 2024 through to the survey in October with only brief periods above the threshold (Figure 19b). Similarly, PAR at the deeper AMB1 was below the *Halophila* threshold on several occasions throughout the year (Figure 19b).

Data recovery and quality control of PAR and temperature in Meadow 9 on the northern side of Abbot Point wharf was quite low for the period prior to June 2024. PAR loggers were deployed in October 2023, retrieved prior to threat of TC Kirrily and on retrieval one logger and wiper unit had been snapped off and the 2nd independent logger had flooded. Loggers were re-deployed in January 2024 but on retrieval in March 2024 loggers and wiper units were missing from the stainless-steel base (see image below).

Wiper unit casing, wiper units and loggers missing from Meadow 9 upon the March 2024 retrieval.

For Meadow 5 on the southern side of Abbot Point wharf, PAR data loss occurred due to a series of equipment malfunctions where the wiper units flooded/stopped working so the sensors got fouled and data was flagged as bad data and removed, or the odyssey logger itself flooded and there was data loss.

Missing PAR data from AMB 1 was due to the logger frame becoming tilted on the seafloor and therefore the PAR data from that period was deemed bad data and discarded. If a frame/logger is tilted, it affects the accurate detection of ambient light. A logger frame with a tilt greater than 20% results in a red flag (bad data, and it is removed).

Missing PAR data from the control logger between December 2023 and March 2024 (Figure 19b) was due to the on-land logger being taken down before TC Kirrily and the logger not reinstalled until JCU's next mobilisation to Bowen.

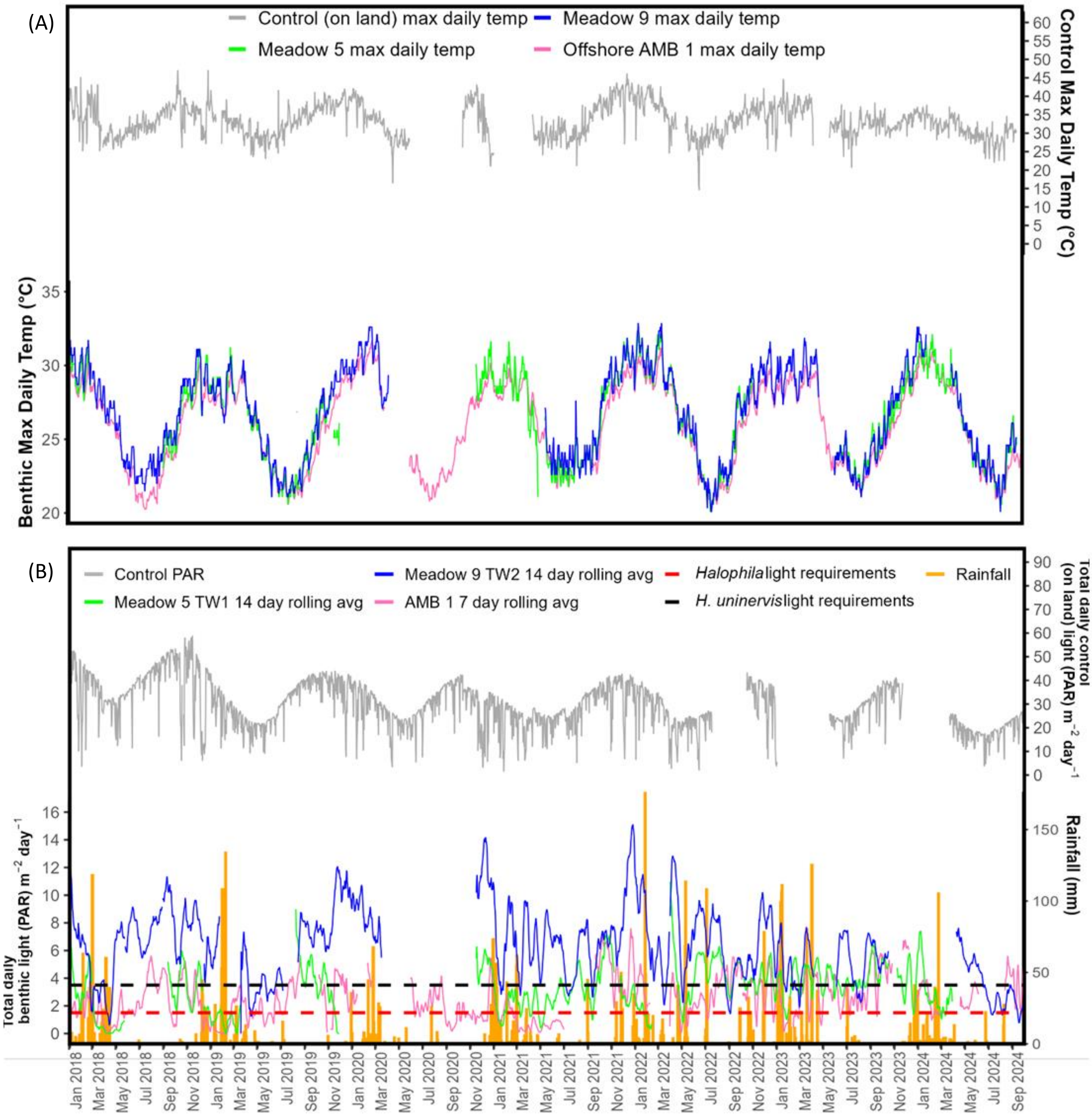

Figure 18. (A) Total daily maximum temperatures at in water and control (on land) logging stations; (B) Total daily PAR (mol photons $m^{-1}day^{-1}$) at sites expressed as 14- and 7-day rolling averages, *Halodule uninervis* and *Halophila* light requirement thresholds and total daily rainfall January 2018 – September 2024. Data gaps are due to equipment malfunction or loss.

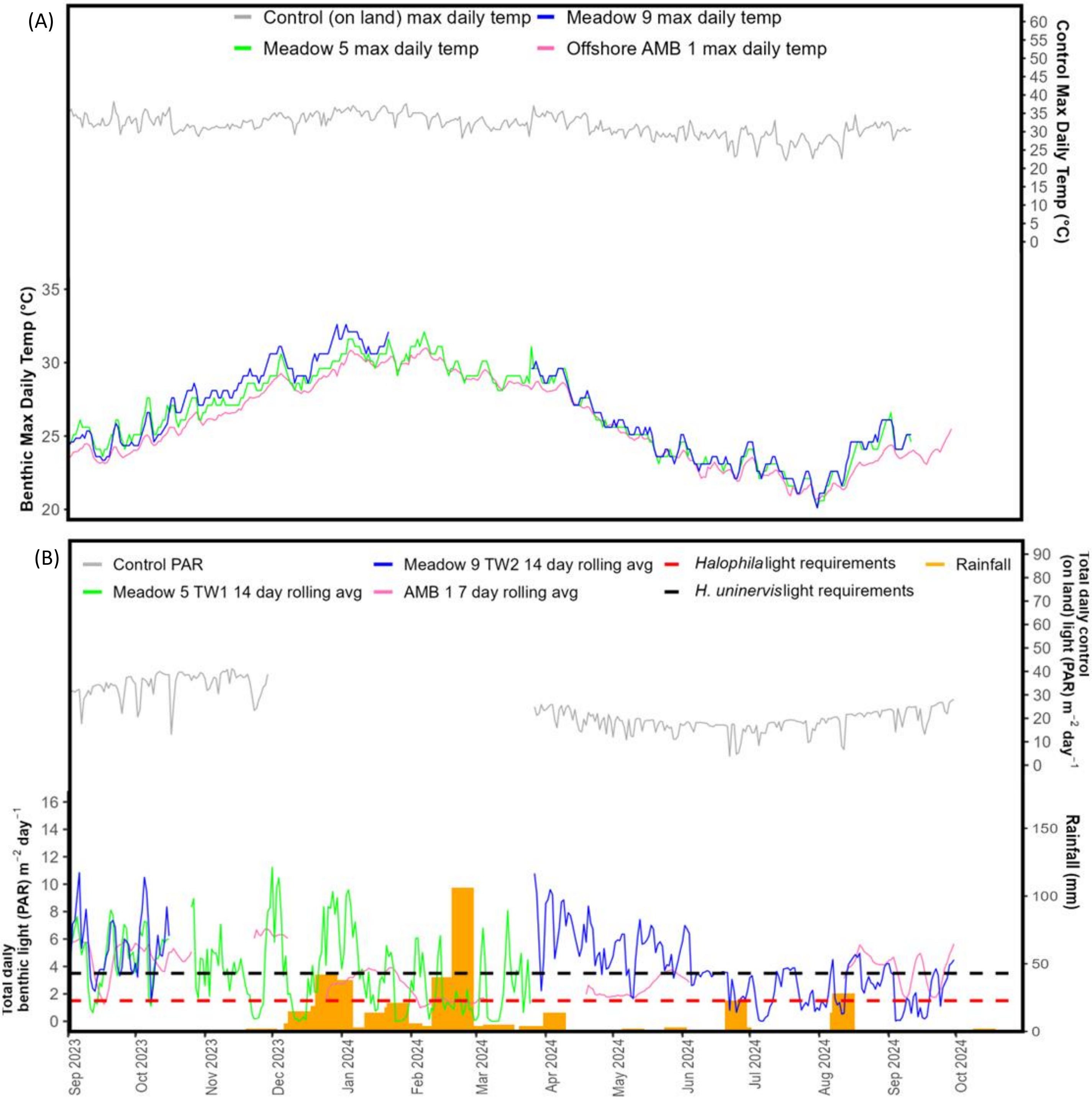

Figure 19. (A) Total daily maximum temperatures at in water and control (on land) logging stations; (B) Total daily PAR (mol photons $m^{-1}day^{-1}$) at sites expressed as 14- and 7-day rolling averages, *H. uninervis* and *Halophila* light requirement thresholds and total daily rainfall in the 12 months prior to the survey: September 2022 – October 2023. Data gaps are due to equipment malfunction or loss.

5.3.3 Root mean square water height – wave stress

RMS provides a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. Higher RMS water height values indicate stronger wave action. RMS water height can be used to analyse the influence that wave action, tide and water depth may have on turbidity, deposition, and light levels (Iles & Waltham 2020). Waltham et al. 2022 explain RMS using the following example: "*where two sites both have the same surface wave height, if site one is 10 m deep and has a measurement of 0.01 RMS water height, and site two is 1m deep and has a measurement of 0.08 RMS water height, even though the surface wave height is the same at both sites, the RMS water height is greater at the shallower site, and we would expect more resuspension due to wave shear stress at this site.*"

The summary data presented below (Figure 20) is the RMS water height at monitoring station AMB1 within the offshore seagrass monitoring area. For the full suite of water quality monitoring stations and results, see Cartwright et al. 2025.

Mean daily RMS in the twelve months prior to the survey ranged from 0.01m (December 2023) to 0.19 m (January 2024) (Figure 20a). RMS peaks generally coincided with periods of low PAR and/or high rainfall. Peaks throughout 2024 were recorded over periods longer than a week, which can cause resuspension events. RMS was generally higher, more often and for longer periods of time in 2024 compared to the previous two years (Figure 20a & b), giving rise to the notion that wave shear stress and potentially resuspension leading to lower PAR were greater overall in 2024 compared to the previous two years. The RMS was significantly higher than average in the months leading up to the monitoring survey (Figure 20b).

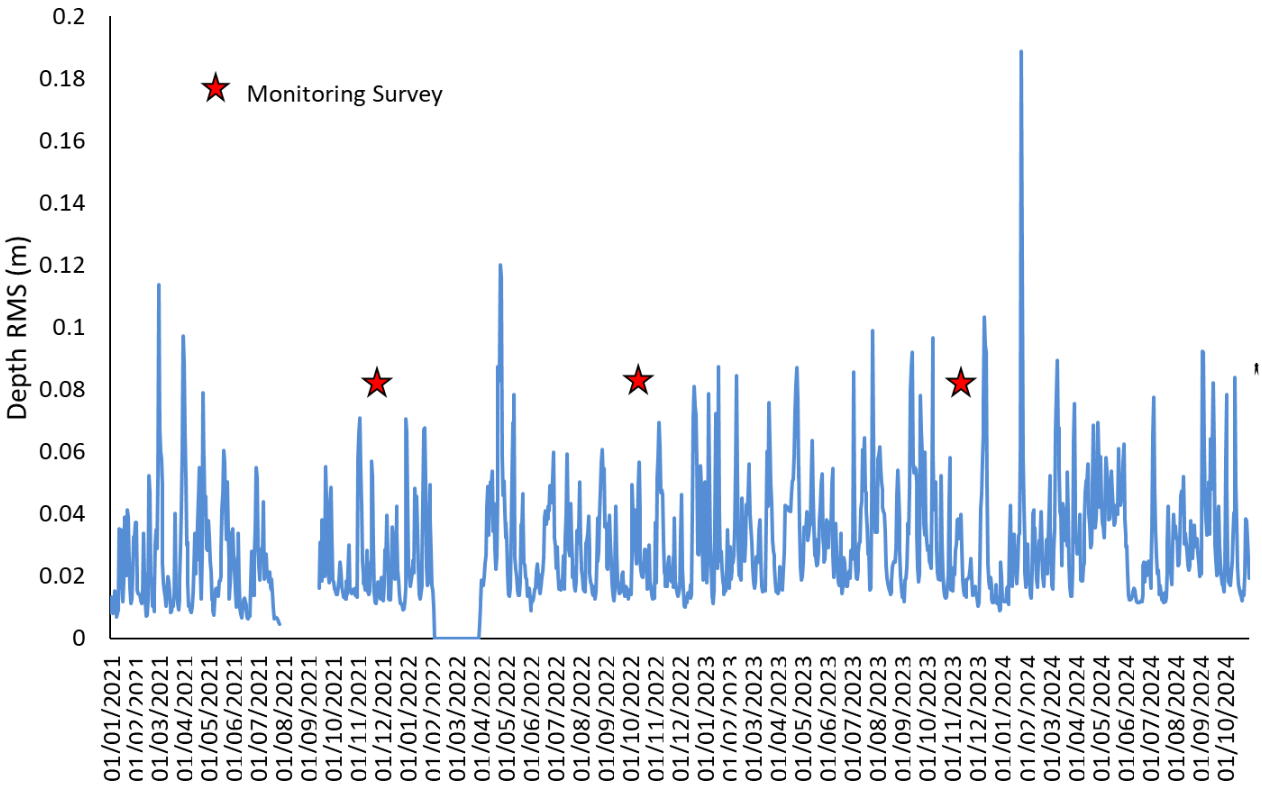

Figure 20a. Daily RMS depth measured at AMB1 July 2020 – October 2024 (data provided by TropWATER Water Quality team).

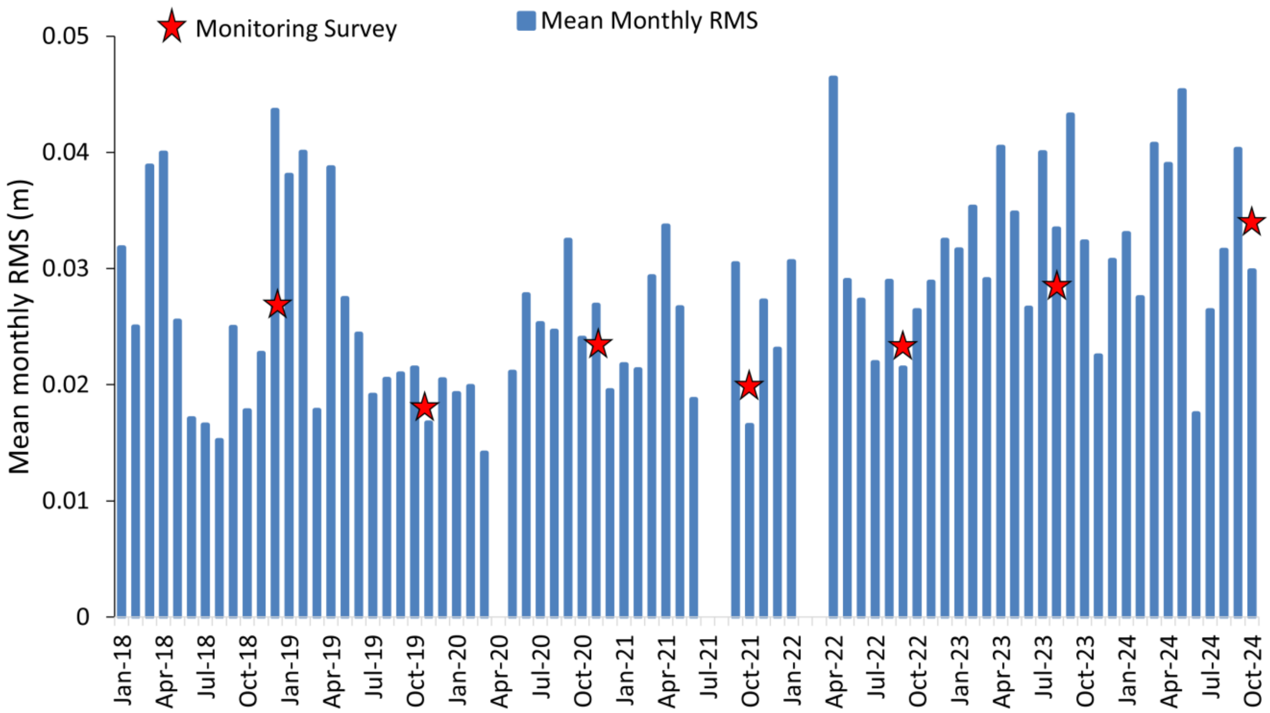

Figure 20b. Monthly mean RMS depth and long-term monthly average measured at AMB1 January 2018 – October 2024 (data provided by TropWATER Water Quality team).

5.3.4 Rainfall

Total annual rainfall in the 12 months prior to the 2024 survey was 558 mm and below the long-term average for the first time in the past six years (Figure 21a). In 2024, monthly rainfall was above-average in February, June, August, and after the monitoring survey in November 2024 (Figure 21b).

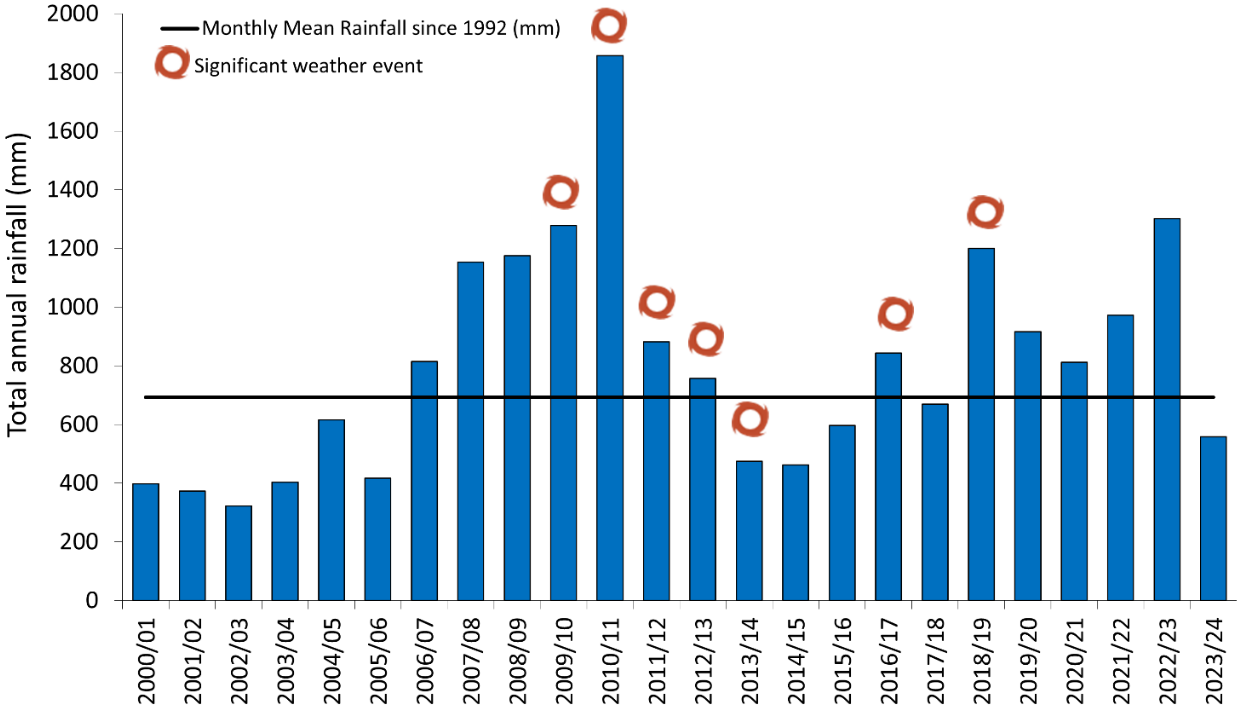

Figure 21a. Total annual rainfall (mm) recorded at Guthalungra, 2000/01-2023/24. Year represented in columns is twelve months prior to the survey.

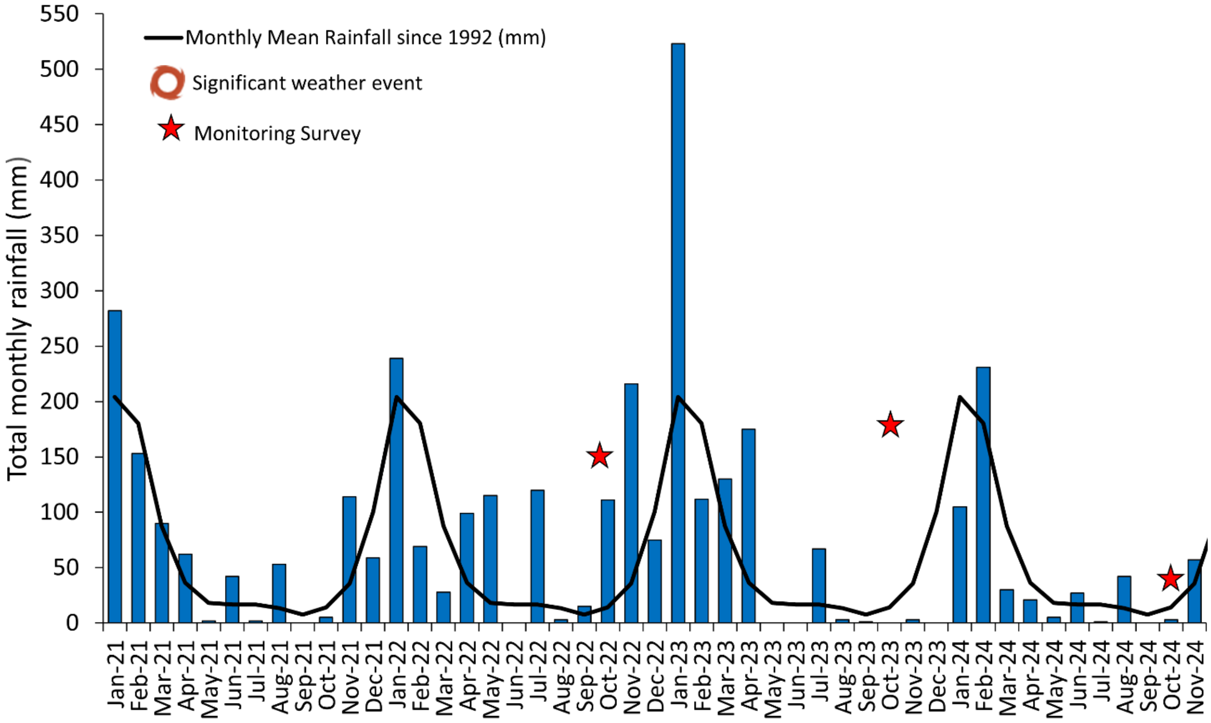

Figure 21b. Total monthly rainfall (mm) recorded at Guthalungra, January 2021 – November 2024.

5.3.5 River flow - Elliot River

River flow for the Elliot River was below the long-term annual mean in the twelve months before the annual seagrass survey (Figure 22a). River flow was below the long-term monthly average throughout the 12 months leading up to the seagrass monitoring survey (Figure 22b).

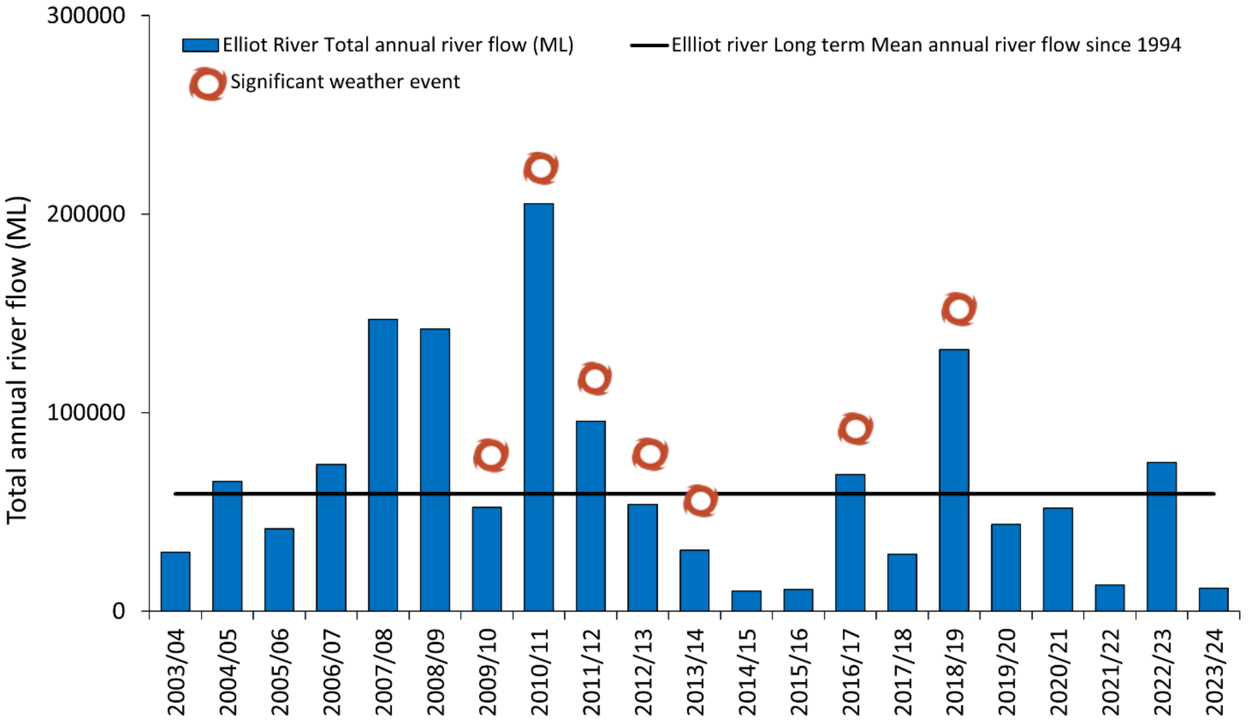

Figure 22a. Total annual river discharge of the Elliot River from 2003/04 to 2023/24. The year represented in columns is twelve months prior to the survey.

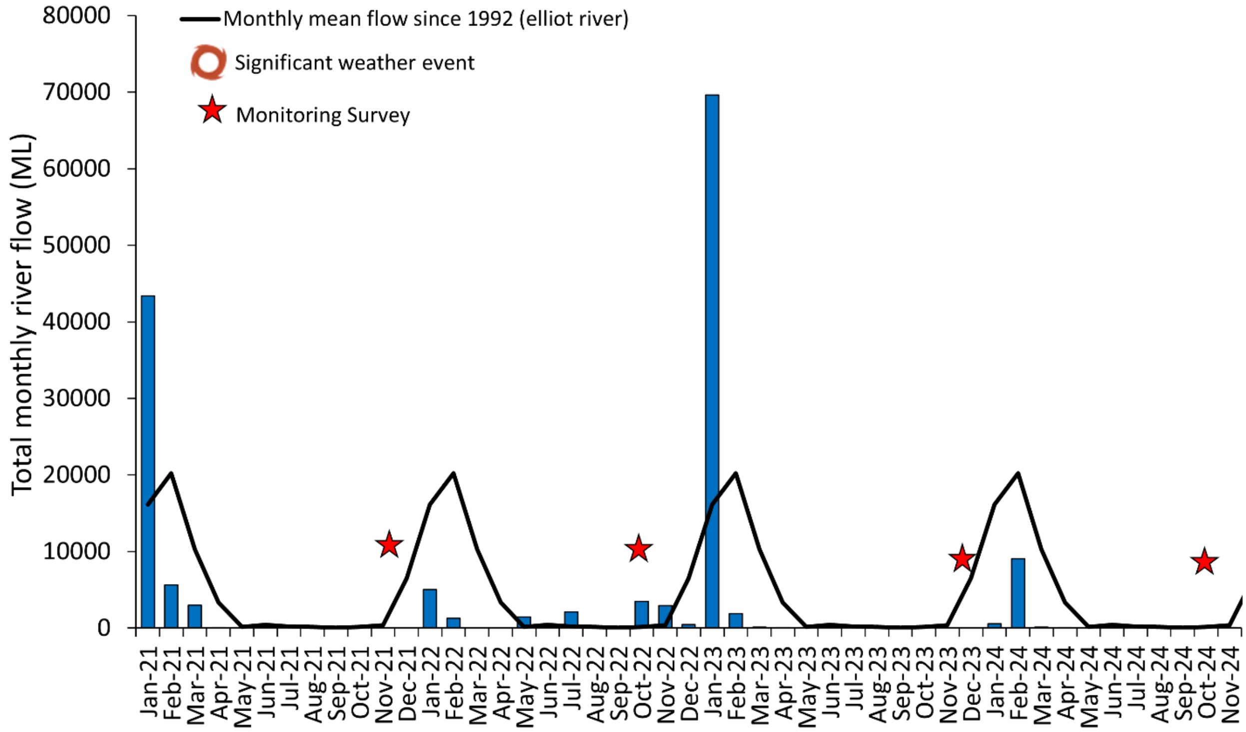

Figure 22b. Total monthly river discharge of the Elliot River from January 2021 to November 2024.

6 DISCUSSION

Seagrass meadows around Abbot Point were in an overall satisfactory condition at the end of 2024. All individual seagrass monitoring meadows maintained an area and species composition above their baseline and were classified as good or very good for these indicators. For the two coastal meadows to the south of Abbot Point, biomass was also in a good condition. Two meadows received an overall poor condition, the coastal meadow west of Abbot Point and the large offshore meadow, due to declines in seagrass biomass. The biomass declines were likely driven by poor benthic light associated with high wind/ wave action and rainfall events leading up to the monitoring survey.

It is likely the changes observed in seagrass biomass for the coastal meadow to the west of Abbot Point wharf (Meadow 9) were linked to benthic light (PAR) falling below seagrass growth requirements for the months leading up to the seagrass monitoring survey. PAR recorded at the monitoring station within this meadow was below the locally derived threshold for the key species *Halodule uninervis* (McKenna et al. 2015), for much of the three months leading up to the survey. This PAR reduction occurred despite most climate conditions seeming to be favourable for seagrass growth with annual rainfall and river flows below average. However, examined on a month-by-month basis, there was uncharacteristically high rainfall during August 2024 and from July to September 2024 wave heights and sediment shear stress were substantially above average likely leading to sediment resuspension and low light in this shallow meadow. Despite the biomass declines the spatial footprint of the meadow remained across much of its historical extent and the key species, *Halodule uninervis* remained throughout. A good indicator that a rapid recovery is possible should PAR be more favourable during 2025.

The offshore meadow (Meadow 19) is primarily formed by deepwater *Halophila* species, which have much lower light thresholds than *H. uninervis* (1.5 mol m^{-2} day^{-1} and 3.5 mol m^{-2} day^{-1}, respectively; McKenna et al. 2015). These deepwater species are considered to be colonisers (Kilminster et al. 2015) and have a high degree of year-to-year and seasonal variability (York et al. 2015). As such large changes in meadow condition are expected to occur. As colonising species, they have a low resistance to unfavourable conditions including light below their growth requirements. There was evidence of PAR below their thresholds at periods during 2024 which may explain the lower biomass recorded for this meadow at the time of the survey. In addition, there was a notable change in species composition between 2023 and 2024 with a reduction in the presence of the higher light requiring, larger growing, species *Halodule uninervis.* Due to the colonising nature of the deep water *Halophila* species they are generally quick to recover and re-establish with favourable environmental conditions and previous work at Abbot Point has shown that they form seed banks in the sediments that can drive this recovery (Rasheed et al. 2014).

In the shallower coastal seagrass meadows, to the south of Abbot Point, there were positive signs of improved seagrass condition. In the shallowest of these, the Euri Creek meadow, saw an increase in the abundance of the indicator species *Zostera muelleri*. This likely also contributed to observed biomass increases, as this species is larger growing than the *Halodule uninervis*. The increase in this relatively high light requiring species (Collier et al. 2016) may indicate that light conditions here were not impacted the same way as at the coastal meadow to the west of Abbot Point, although no PAR monitoring occurs at this site to confirm this.

Seagrass meadows around Abbot Point were in an overall satisfactory condition at the end of 2023. While biomass for two meadows was below baseline levels and may mean they are more susceptible to future pressures, their good spatial coverage, and maintenance of foundation species indicates they have levels of resilience, and a capacity to return to better overall meadow condition if favourable environmental conditions are present through 2025.

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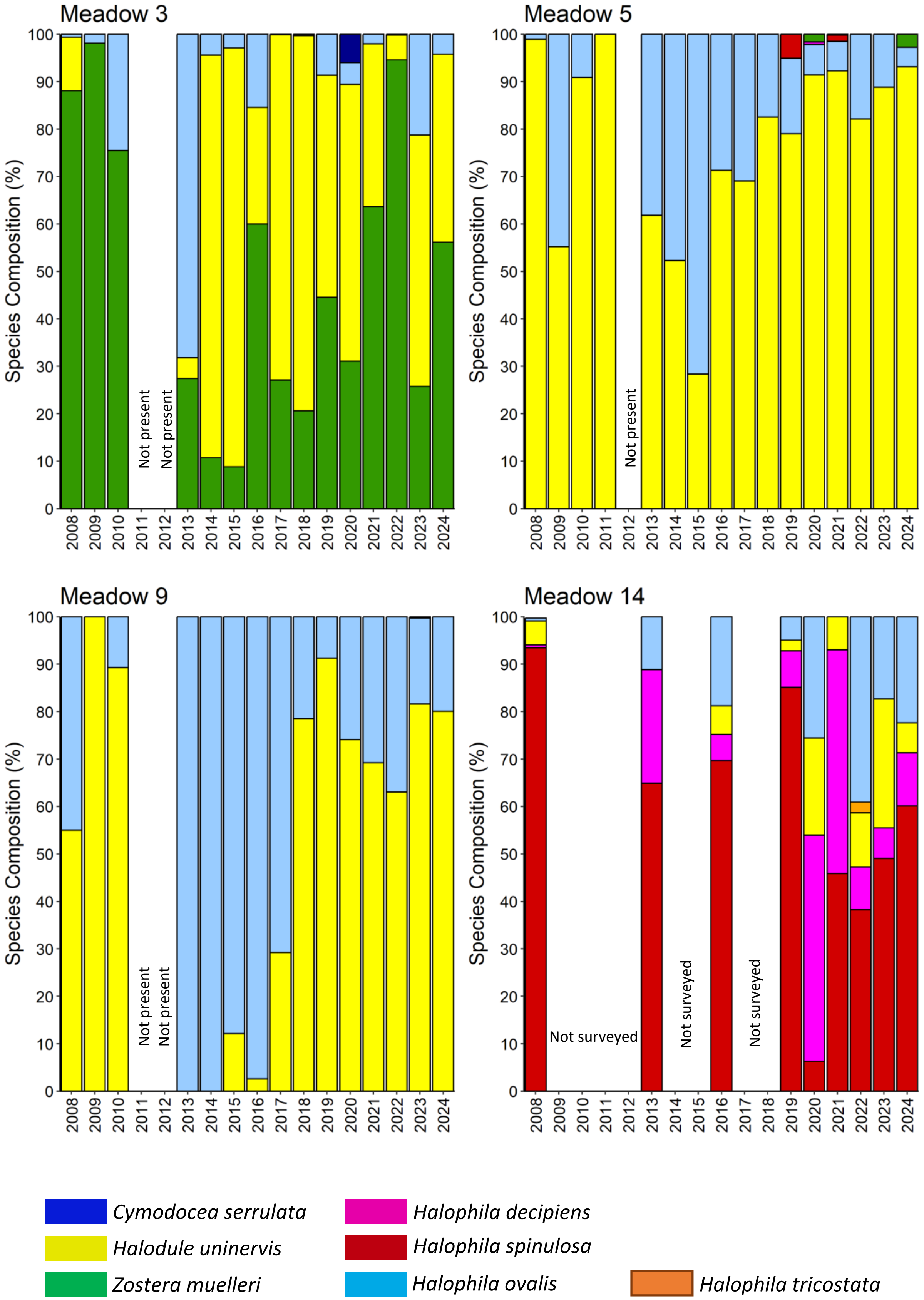
8 APPENDICES

8.1 Species composition of inshore and offshore monitoring meadows



8.2 Biomass and area of annual monitoring meadows

8.2.1 Mean biomass of monitoring meadows in the Abbot Point region

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)
2022	6.25 ± 1.03 (10)	2.42 ± 0.31 (27)	2.09 ± 0.35 (18)	1.86 ± 0.33 (25)
2023	1.74 ± 0.57 (5)	1.65 ± 1.49 (12)	1.19 ± 0.91 (19)	1.29 ± 0.28 (12)
2024	3.64 ± 0.94 (6)	1.92 ± 0.58 (13)	0.48 ± 0.11 (19)	0.42 ± 0.18 (12)

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, 2022, 2023. Offshore meadow 14 has was added to the long-term monitoring program in 2020.)

8.2.2 Area (ha) of monitoring meadows in the Abbot Point region

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
2022	23.22 ± 8.10	477.32 ± 55.27	266.85 ± 30.91	5555.54 ± 489.35
2023	32.41 ± 4.58	226.52 ± 22.33	181.55 ± 14.72	4386.31 ± 285.31
2024	55.04 ± 11.01	215.1 ± 31.81	245.69 ± 33.78	4709.35 ± 327.34

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, 2022, 2023. Offshore meadow 14 has was added to the long-term monitoring program in 2020.)