Port of Weipa Long-Term Seagrass Monitoring Program 2024

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Authored by: Reason, C. L., McKenna, S., & Rasheed, M.A.

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Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) James Cook University

Townsville Phone: (07) 4781 4262

Email: TropWATER@jcu.edu.au

Web: www.jcu.edu.au/tropwater/

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Contacts
For more information contact: michael.rasheed@jcu.edu.au

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

CONTENTS

1 KEY FINDINGS

Seagrass condition 2024

Good

Likely causes of seagrass condition:

↑ *Return of H. uninervis in A3 meadow.*

↓↑ *Moderate wet season resulting in a shorter period of unfavourable light conditions*

↑ *Good light conditions for the rest of the year.*

- Seagrasses in the Port of Weipa were in an overall good condition in 2024. An improvement from a satisfactory condition in 2023.
- The return of *Halodule uninervis* to areas where it was absent in 2023, including monitoring meadow A3 in the Hey River, was the driver of the overall condition improvement.
- The other four monitoring meadows were all in good condition in 2024, an improvement from the previous two years.
- Sediment grabs in the A3 and A5 meadows revealed that a *H. uninervis* seed bank was present in the A5 meadow, but no seeds were found in the A3 meadow.
- Seagrass meadow area in the Intensive Monitoring Area (IMA) has declined over the past three years, however remained around the long-term average and has been either on par or above the long-term average for the past nine years.
- In the broader port area (Pine River Bay, Embley, Hey and Mission Rivers), seagrass condition also improved from 2023. Aerial observations noted meadows previously absent (some since 2001) had re-established.
- Dugong feeding trails were observed throughout the IMA and in the broader port area in 2024.
- A relatively benign wet season, compared to the previous two years, may have provided conditions for seagrasses to replenish reserves and offer a period suited for optimal seagrass growth. This has likely left seagrasses in an improved condition to withstand any potential unfavourable conditions leading into the next wet season.

2 IN BRIEF

Seagrasses have been monitored annually in the port of Weipa since 2000. Each year all seagrasses within the Intensive Monitoring Area (IMA) around the major areas of port activity are mapped. Five core seagrass meadows within the IMA representing the range of different seagrass community types found in Weipa are assessed for changes in biomass, area, and species composition (condition indicators). Changes to these metrics are then used to develop a seagrass condition grade (see section 4.3).

In 2024 the Port of Weipa seagrasses were in an overall good condition. All five core monitoring meadows were relatively stable and in good condition compared to their long-term baselines (Figure 1). Of note was the return of foundation species *H. uninervis* in meadow (A3) and also to some other areas around Weipa after being absent in 2023. This is the ninth consecutive year that the total extent of seagrass in the IMA was at or above the long-term average (Figure 2).

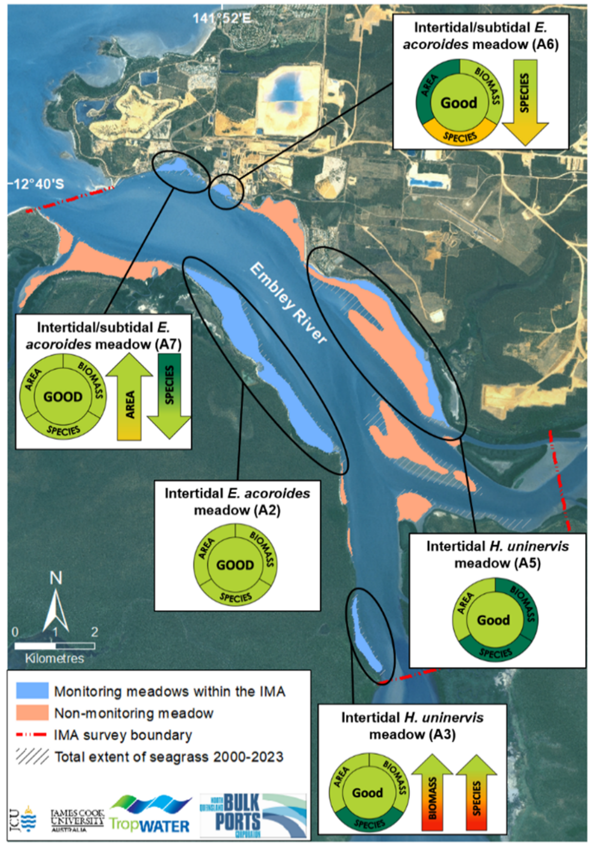


Figure 1. Seagrass meadow condition in the Port of Weipa 2024.

Seagrasses outside the IMA (Pine River Bay, Mission River and upstream Hey and Embley Rivers) were also inspected in 2024 to provide an update on seagrass condition in the broader area. Additional meadows were observed with the majority last seen in 2020 however some of these meadows had not been recorded as far back as 2001.

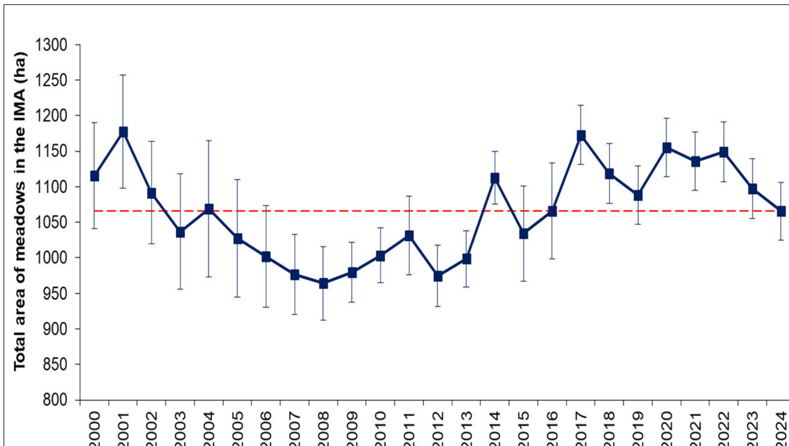


Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2024. (Error bars = "R" reliability estimate). Red dashed line indicates 20-year mean of total meadow area.

Climate conditions in 2024 saw a reduction in rainfall with a more benign 2023/24 wet season compared to the previous year (Figure 3). The duration at which light fell below maintenance and growing thresholds for seagrass was also much reduced throughout 2024 compared with recent years. This reprieve has likely facilitated seagrass growth and increased plant reserves, particularly for *H. uninervis*. Weather events that bring intense rainfall, associated catchment and river flows, and flooding can physically impact seagrass through removal and burial and reduce growth and survivorship due to reductions in light. While tidal exposure to air for seagrass meadows was above average for the year it was below average in the months leading up to the survey, protecting seagrasses from the stresses associated with drying at low tide. Sediment grabs confirmed a *H. uninervis* seed bank was present in the A5 meadow and offered a likely mechanism for *H. uninervis* re-growth in 2024.

The good condition of Weipa seagrass in 2024 should put seagrasses in a good position to have some resilience going into the 2024/25 wet season. The return of *H. uninervis* as well as the presence of a sediment seed bank, is evidence of the resilience built up from the continued good condition of Weipa seagrasses since 2017.

The Weipa seagrass monitoring program forms part of a program that examines seagrasses in most Queensland commercial ports and other areas where seagrasses face the highest levels of cumulative risk. It also forms a component of James Cook University's broader seagrass assessment and research program (see www.tropwater.com).

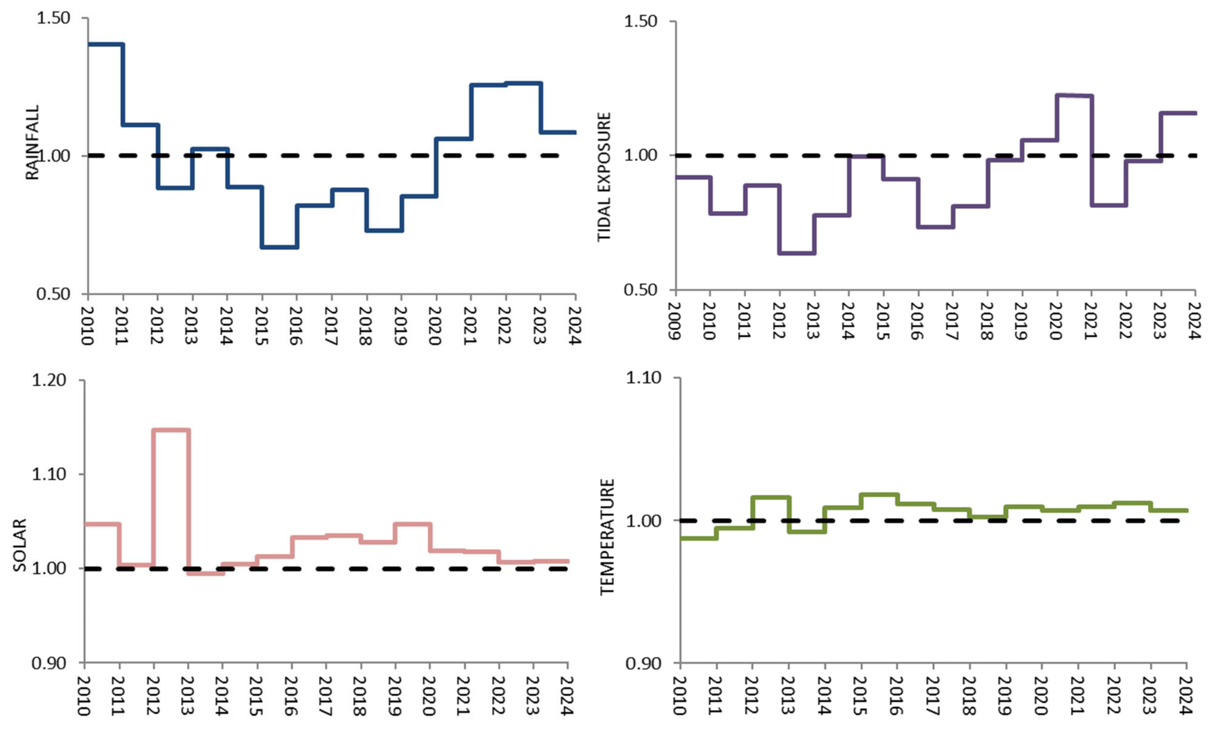


Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average. (See section 5.4 for detailed climate data).

3 INTRODUCTION

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

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009; Dunic et al. 2021). 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; Scott et al. 2021). 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. 2012). These hot spots arise because 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 is established in most Queensland commercial ports. The program was developed by James Cook University's Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. While each location is funded separately, a common methodology and rationale is used providing a network of seagrass monitoring locations throughout Queensland (Figure 4).

Figure 4. Location of Queensland Port seagrass assessment sites.

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

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

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

3.2 Weipa Seagrass Monitoring Program

Diverse and productive seagrass meadows occur in the Port of Weipa. North Queensland Bulk Ports (NQBP) commissioned JCU's Seagrass Ecology Group to establish a long-term seagrass monitoring program for Weipa's port in 2000 (Roelofs et al. 2001; 2003; 2005). The first three years (2000 to 2002) of the seagrass monitoring program provided important information on the distribution, abundance, and seasonality of seagrasses within the greater port limits. Due to the large area of the port, the approach for long term monitoring has been to focus monitoring efforts on seagrass meadows located near the port and shipping infrastructure and activities. This area is known as the Intensive Monitoring Area (IMA; Figure 5). Meadows within the IMA represent the range of seagrass meadow communities identified in the greater Weipa region. Every three years seagrass monitoring surveys are expanded to include a greater area of the Weipa port limits (i.e., Pine River Bay, Mission River, Embley River and Hey River), with a focus on mapping seagrass meadow distribution, meadow cover type and species composition in these areas (the last broadscale survey being conducted in 2023) (Figure 5).

Results from seagrass monitoring surveys are used by NQBP to assess the health of the port marine environment and help identify any possible detrimental effects of port operations (e.g., dredging) and other activity on seagrass meadows. Seagrass monitoring surveys satisfy environmental monitoring requirements as part of the port's Long-Term Dredge Management Plan and are used by management agencies to assess the status and condition of seagrass resources in the region.

As part of the seagrass monitoring program in Weipa, light (Photosynthetically Active Radiation (PAR)) and temperature conditions within the seagrass canopy have been assessed since September 2010.

This report presents the results of the long-term seagrass monitoring assessments conducted in August 2024. The objectives were to:

1. Map seagrass distribution and determine meadow biomass, and species composition in core monitoring meadows inside the IMA.
2. Map seagrass distribution and characterise non-monitoring meadows within the IMA.
3. Briefly assess seagrass meadows outside the IMA to record any significant changes in seagrass condition in the broader port limits.
4. Assess changes in seagrass meadows compared with previous monitoring surveys.
5. Assess light and temperature conditions in core seagrass meadows.
6. Incorporate the results into the Geographic Information System (GIS) database for the Port of Weipa.

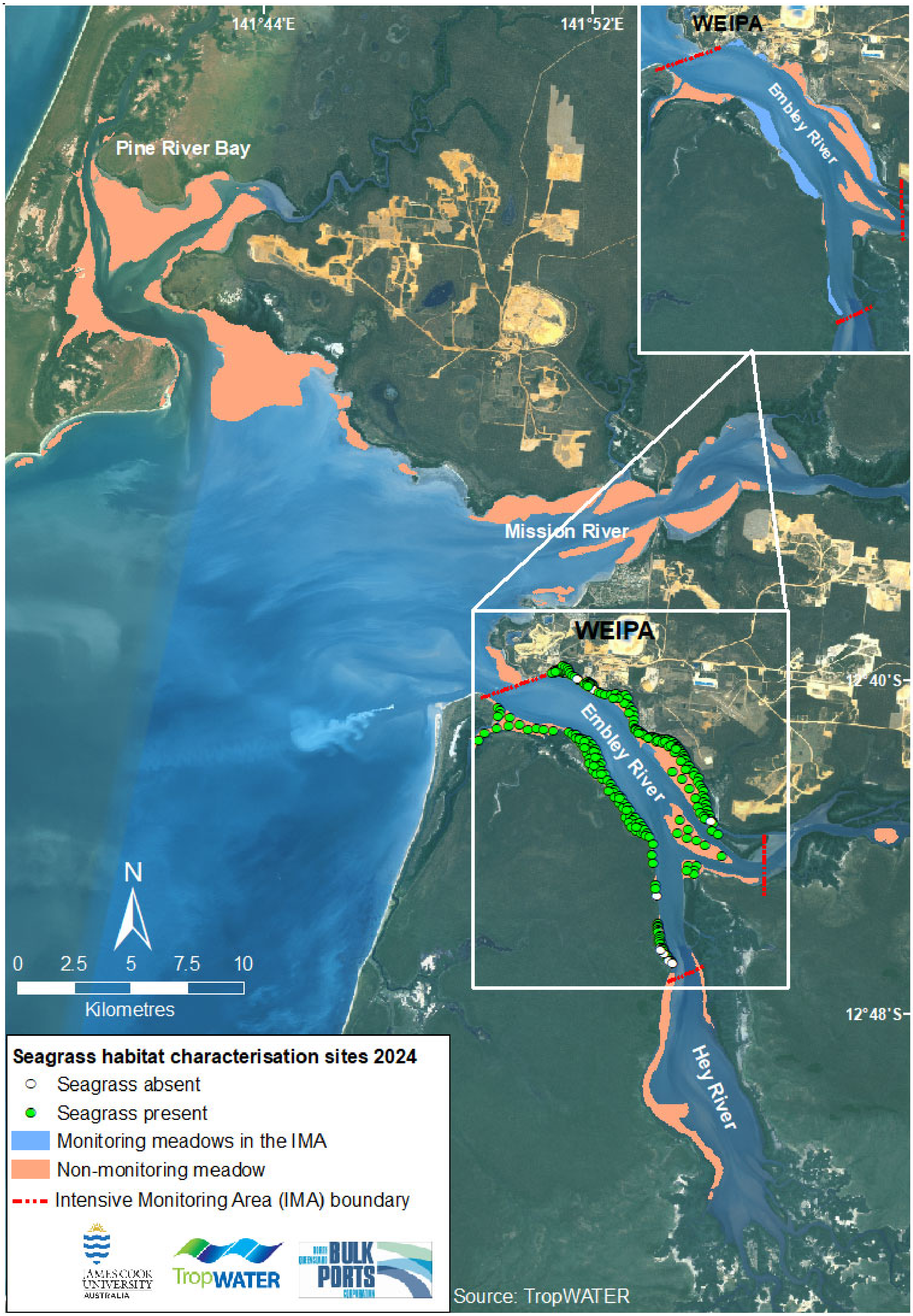


Figure 5. Location of 2024 seagrass survey sites and seagrass meadows in the Port of Weipa IMA. Meadows outside the IMA were mapped in 2023.

4 METHODS

4.1 Sampling approach

Annual monitoring focuses on five core monitoring meadows within the Intensive Monitoring Area (IMA) (Figure 5 and 10) (Roelofs et al. 2001). These meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in the baseline surveys, and because they were in areas likely to be vulnerable to impacts from port operations and developments.

Results from original baseline surveys identified that for some meadows - those where *Enhalus acoroides* was present but not dominant - mean meadow biomass had to be calculated without the biomass of the larger *E. acoroides* contributing to the overall meadow mean biomass (Roelofs et al. 2003). The dry weight biomass for *E. acoroides* is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Isolated *E. acoroides* plants occurring within the *Halodule* dominated meadows A3 and A5 (Figure 1) are excluded from all meadow biomass and species composition analyses to track the dynamics of the morphologically smaller *Halodule* species that is dominant in these two meadows.

4.2 Sampling methods

Survey and monitoring methods for assessing seagrass in the Weipa region follow those of the established techniques for Weipa and JCU, TropWATER's Queensland-wide seagrass monitoring programs. The application of standardised methods at Weipa 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 levels of sampling were used in the 2024 survey:

- Assess and map seagrass distribution, species composition and biomass in the five core monitoring meadows within the IMA (A2, A3, A5, A6, and A7; Figure 10).
- Map seagrass distribution and species composition in non-core meadows within the IMA and in the broader port area conduct aerial observational checks to determine large scale changes from the previous survey (Pine River Bay, Mission River, Hey River and Embley River; Figure 22 - 25).

Seagrass meadows were surveyed using a combination of helicopter aerial assessments and boat-based underwater camera surveys (Figure 6). At each site surveyed seagrass meadow characteristics including seagrass species composition, above-ground biomass, seagrass and algal percent cover, sediment type, position fixes (GPS; ±5m) and depth below mean sea level for subtidal sites were recorded. A detailed outline of these methods can be found in Roelofs et al. (2001).

Figure 6. Seagrass methods using (A) helicopter aerial surveillance, and (B, C) boat-based camera surveillance.

At sites where seagrass was present, seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (as described by Mellors 1991; Kirkman 1978).

In response to the disappearance of *Halodule uninervis* in monitoring meadows in 2023 additional reconnaissance sampling for seeds stored in the sediments (seed bank) was conducted in meadows A3 and A5 using the van veen sediment grab. 6 grabs were collected in each meadow with the sediments sieved and any seeds were identified and counted.

4.3 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition ('seagrass indicators') relative to a 10-year baseline (see Carter et al. 2023 for a full description on the development of the condition index). 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% (Carter et al. 2023).

4.4 Habitat mapping and Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.8®. Three seagrass GIS layers (shapefiles) were created to describe spatial features of the region:

- *Point (site) layer:* Contains data collected at each assessment site, including:
    - Site number
    - Temporal details – survey date and time.
    - Spatial details – latitude and 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); percent cover of seagrass, algae, and open substrate; presence/absence of DFTs.
    - Sampling method and any relevant comments.

- *Polygon (meadow) layer:* Provides summary information for all sites within each meadow, including:
    - Temporal details – survey date.
    - Habitat information – depth category (intertidal/subtidal), mean meadow biomass + standard error (SE), meadow area (hectares) + reliability estimate (R), number of sites within the meadow, seagrass species present, meadow density and community type, meadow landscape category (Figure 7).
    - Meadow identification number – a unique number assigned to each monitoring meadow to allow comparisons among surveys.
    - Sampling method and any relevant comments.

- *Raster (biomass interpolation) 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.

Seagrass meadows were described using a standard nomenclature system. Seagrass community type is defined using the dominant species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Community density is based on mean biomass and the dominant species within the meadow (Table 2).

Table 1. Seagrass meadow community types.

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. Seagrass meadow density categories.

Density	Mean above ground-biomass (grams dry weight per metre square (g DW m^{-2}))				
	***H. uninervis* (narrow)**	***H. ovalis* *H. decipiens***	***S. isoetifolium***	***T. hemprichii***	***E. acoroides***
Light	< 1	< 1	< 5	< 15	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	40 - 100
Dense	> 4	> 5	> 25	> 35	> 100

Isolated seagrass patches

Most of the 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

Most of the meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

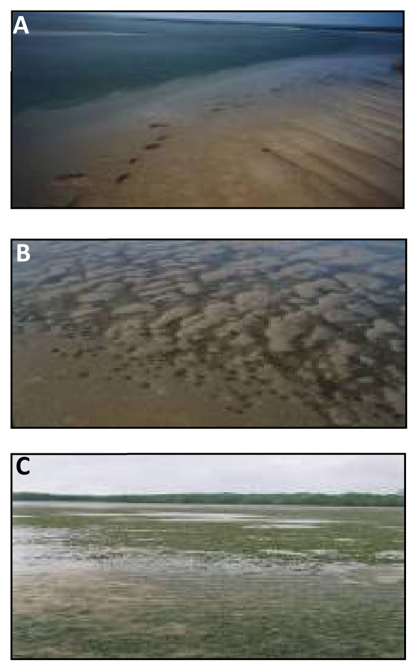


Figure 7. Seagrass meadow landscape categories: (A) isolated seagrass patches, (B) aggregated seagrass patches, (C) continuous seagrass cover.

Seagrass meadow boundaries were constructed using seagrass presence/absence site data, field notes, GPS marked meadow boundaries, colour satellite imagery of the survey region (Source: ESRI; Google Earth), and aerial photographs taken during helicopter surveys.

Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were also 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 methods for seagrass meadows in the Port of Weipa.

Mapping precision	Mapping method
≤5m	• Meadow boundaries determined from helicopter and camera/grab surveys. • Inshore boundaries mapped from helicopter. • Offshore boundaries interpreted from survey sites and recent satellite imagery. • Relatively high density of mapping and survey sites. • Recent satellite imagery aided in mapping.

4.5 Environmental data

Environmental data was collated for the twelve months preceding the survey. Tidal data was provided by Queensland Government (Maritime Safety Queensland). Total daily rainfall (mm) and global solar exposure was obtained for the nearest weather station from the Australian Bureau of Meteorology (Weipa Airport station #027045; http://www.bom.gov.au/climate/data/).

Light (Photosynthetically Active Radiation (PAR) mol photons m^{-2} day^{-1}) conditions and temperature within the seagrass canopy is assessed in the intertidal A2 meadow, and in the subtidal/intertidal A7 and A6 meadows (Figure 10), using custom built benthic data logging stations (Figure 8). A PAR logger has also been placed on land at the NQBP work shed which acts as a control logger. Each independent logging station within the meadows consists of two π cosine-corrected irradiance loggers (Submersible Odyssey Photosynthetic Irradiance Recording Systems) with supporting electronic wiper units. Loggers were calibrated using a cosine corrected Li-Cor underwater quantum sensor (LI-190SA; Li-Cor Inc., Lincoln, Nebraska USA) and data was 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 were deployed with each of these units, recording seabed temperature every 30 minutes.

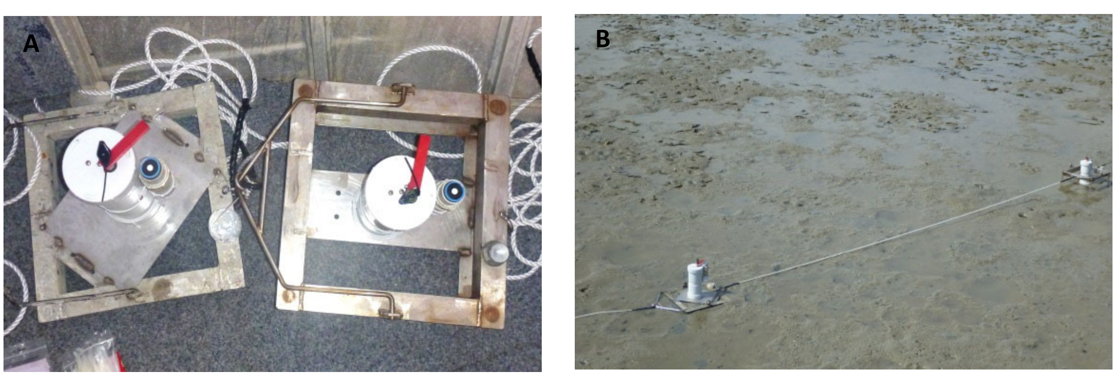


Figure 8. (A) Logging station consisting of a stainless-steel frame with PAR loggers, temperature loggers and wiper units attached. (B) Deployment of logging stations on the A2 meadow.

5 RESULTS

5.1 Seagrass presence and species throughout Weipa

Annual monitoring of seagrass within the port of Weipa was conducted between 19th and 21st August 2024. A total of 306 sites across 14 meadows were assessed within the IMA. Seagrass was present at 94% of the assessment sites (Figure 5). Four species of seagrass was found in the IMA (Figure 9). *Syringodium isoetifolium* was absent in 2024 after previously being observed in the Pine River Bay since 2020. The total seagrass meadow area within the IMA was close to the long-term average at 1065 ± 40 ha (Figure 11). This is the third consecutive year that meadow area has declined, however has remined above the long-term average for the eighth year in a row. *Enhalus acoroides* is a large and persistent species and was present in low density cover across 11 of the 14 meadows (Figure 10). The other three meadows were dominated by *T. hemprichii* and *H. uninervis* (Figure 10).

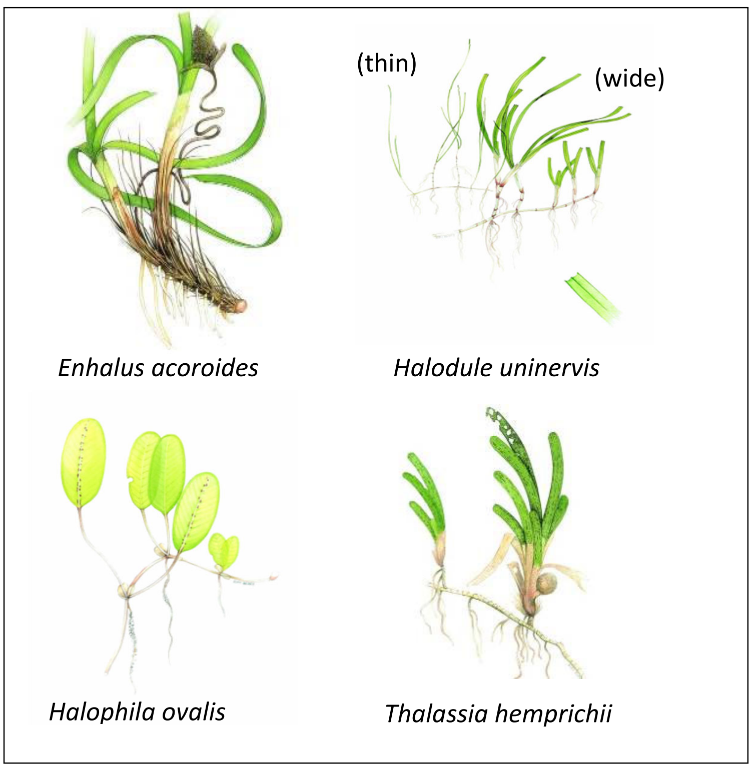


Figure 9. Seagrass species present in the Port of Weipa 2024. Pictures are not to scale.

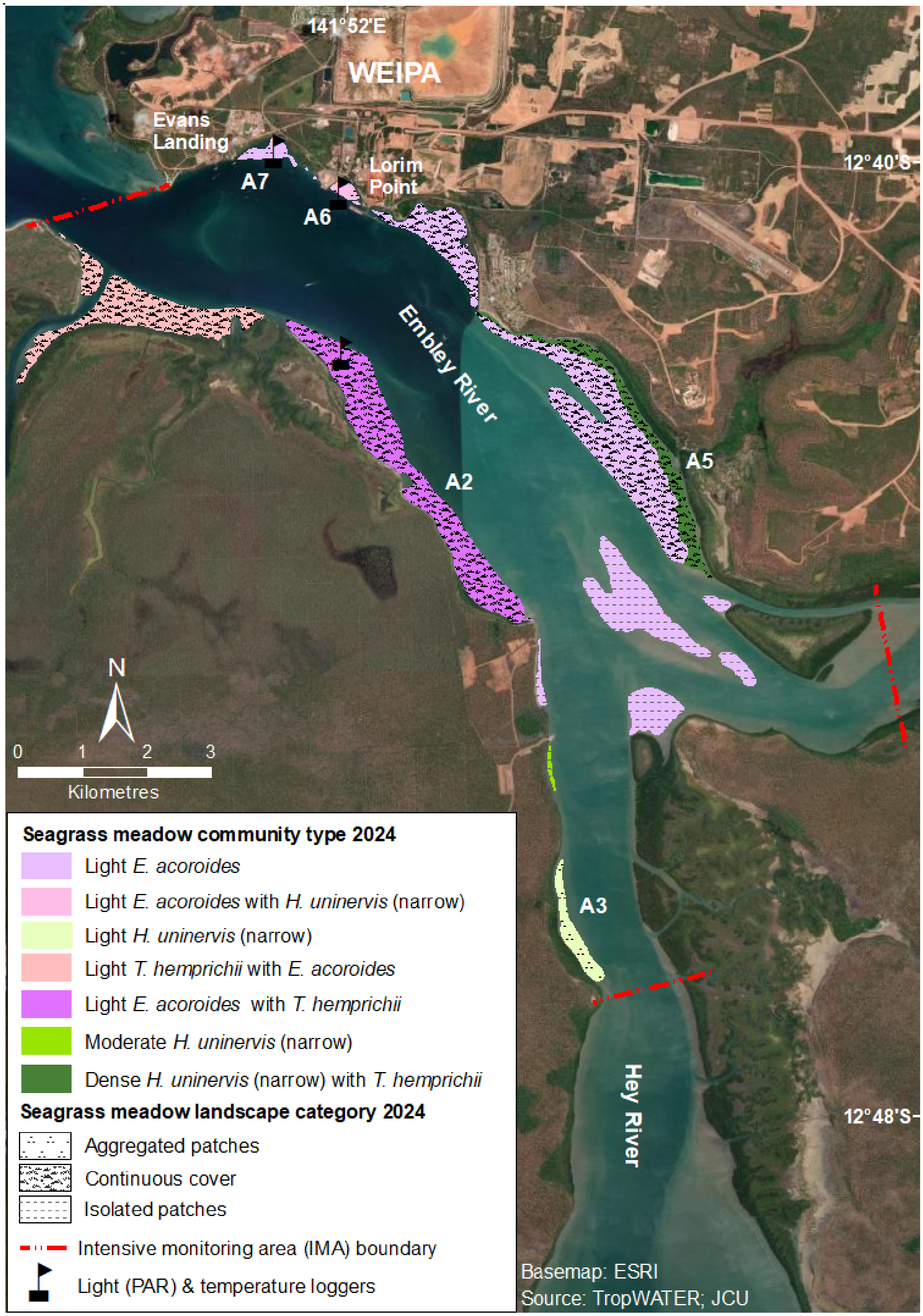


Figure 10. Meadow community type and landscape category for seagrass within the Intensive Monitoring Area 2024.

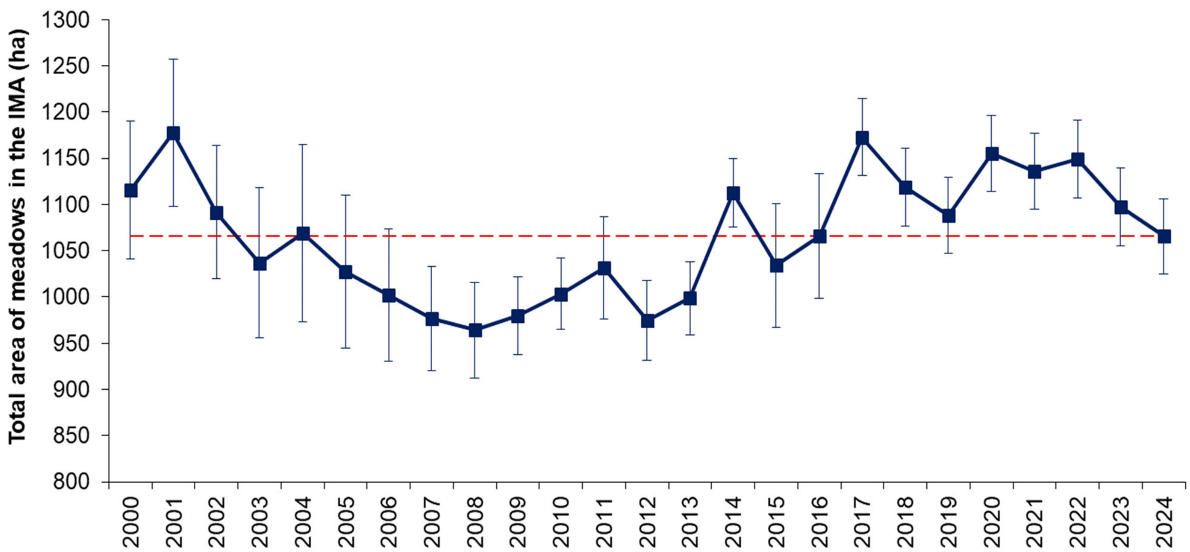


Figure 11. Total area of seagrass within the Intensive Monitoring Area from 2000 to 2024 (error bars = "R" reliability estimate). Red dashed line indicates 24-year mean of total meadow area.

5.2 Seagrass condition in the core annual monitoring meadows within the IMA

The Weipa monitoring meadows were in an overall good condition in 2024 (Table 4). The most notable change in 2024 was the return of *H. uninervis* in the A3 monitoring meadow. This species was absent in the meadow in 2023 and is the species that is 'tracked' for the condition indicators. The overall the condition of seagrass in the core monitoring meadows has been satisfactory or better over the last seven years, with the exception of meadow A3 last year (Table 4).

Table 4. Grades and scores for seagrass indicators for 2024 in the port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.82	0.77	0.65	0.71
A3	0.67	0.72	0.99	0.67
A5	1.00	0.72	0.99	0.72
A6	0.78	0.97	0.55	0.67
A7	0.73	0.73	0.84	0.73
Overall Score for the Port of Weipa				**0.70**

= very good condition = good condition = satisfactory condition
= poor condition = very poor condition

5.2.1 *Enhalus acoroides* dominated monitoring meadows (Meadows A2, A6, A7).

All *Enhalus* monitoring meadows were in a good condition in 2024. These meadows continued to be dominated by *E. acoroides* and also include other species such as *H. uninervis*, *H. ovalis* and *T. hemprichii* (Appendix 8.1). Seagrass cover in these meadows was similar to last year; the Lorim Point meadow (A6) and the A2 meadow (on the western side of the Embley River) had a continuous cover of seagrass, while A7 had aggregated and isolated patches of seagrass (Figure 10).

Meadow A2: In 2024 seagrass condition was good with no change in the overall condition from last year (Table 4; Figure 14). Meadow biomass remained in a good condition in 2024 and did increase slightly from the previous year. This is the eighth consecutive year seagrass biomass has been at or above the long-term average. The extent of this meadow has also been at or above the long-term average for the last twelve years and in 2024 remained in good condition (Figure 14). This meadow had a moderate amount of burning observed on *E. acoroides* leaves throughout the footprint.

Meadow A6: The overall meadow condition was good with a decline in one condition indicator in 2024 (Table 4; Figure 17). Species composition declined from good condition in 2023 to satisfactory condition in 2024 due to a reduction in *E. acoroides* in the overall meadow composition. From 2017 onwards there has been a trend of reduced composition of *E. acoroides* compared to previous history for the meadow. Despite these changes to species composition seagrass biomass remained in a good condition and did increase slightly to be above the long-term average. The area of seagrass in meadow A6 was above the baseline mean for the eighth year in a row.

Meadow A7: The overall meadow condition was good in 2024 (Table 4; Figure 18). Seagrass area improved from a satisfactory to good condition in 2024 and was just below the long-term average. This meadow was made up of aggregated patches of seagrass that formed seagrass density 'hot spots' (areas of higher biomass). These 'hot spots' occurred in the middle section of the meadow (Figure 18). The western and eastern ends of the meadow had a low biomass of seagrass and was very patchy (Figure 18).

5.2.2 *Halodule uninervis* dominated monitoring meadows (Meadows A3, A5).

The *H. uninervis dominated* monitoring meadows were in a good condition in 2024. The most notable change was the return of foundation species *H. uninervis* in the A3 meadow, after being absent in 2023. Areas outside of the IMA upstream in the Hey and Embley Rivers also saw a return of *H. uninervis*, indicating favourable growing conditions for this species throughout 2024. The A3 meadow had a light cover of seagrass and was made up of aggregated patches, while the A5 meadow had a dense, mostly continuous cover of seagrass.

Meadow A3: Overall meadow condition improved in 2024. This was due to the return of foundation species *H. uninervis* in the meadow and surrounding area. Both area and biomass were in a good condition while species composition was in a very good condition. The extent of this meadow did decline slightly below the long-term average for the first time in seven years, however remained in a good condition (Table 4; Figure 15; Appendix 8.1). Biomass was also below the long-term average, however, was in a good condition overall.

Meadow A5: The overall meadow condition has remained the same since 2019; good overall condition (Table 4; Figure 16; Appendix 8.1). Meadow biomass increased from the previous year and remained in a very good condition in 2024. The footprint of this meadow was just below the long-term average, however remained in a good condition overall. The species composition of this meadow is dominated by *H. uninervis*, with *Thalassia hemprichii* making up a significant proportion of the rest of the biomass in this meadow.

Due to the absence of *H. uninervis* in 2023 sediment grabs were collected in meadow A3 and the northern half of meadow A5 in order to determine whether a *H. uninervis* seed bank was present. Evidence of a seed bank was found in meadow A5 with 6 *H. uninervis* seeds present in one of the 6 grabs collected near the Napranum boat ramp. No seeds were found in the 6 grabs collected in Meadow A3.

In 2024 burning on the tips of leaves was observed at 17% of sites in the IMA. This was an increase compared to the previous year (Figure 12). The browning of *E. acoroides* leaves is known as burning and indicates stress associated with high temperatures and desiccation when exposed at low tide which may lead to the death of seagrass leaves (Unsworth et al. 2012). Tidal exposure was above average in 2024 (Figure 21a) which increased the total amount of seagrass exposure to air and sunlight and therefore the burning of seagrass leaves.

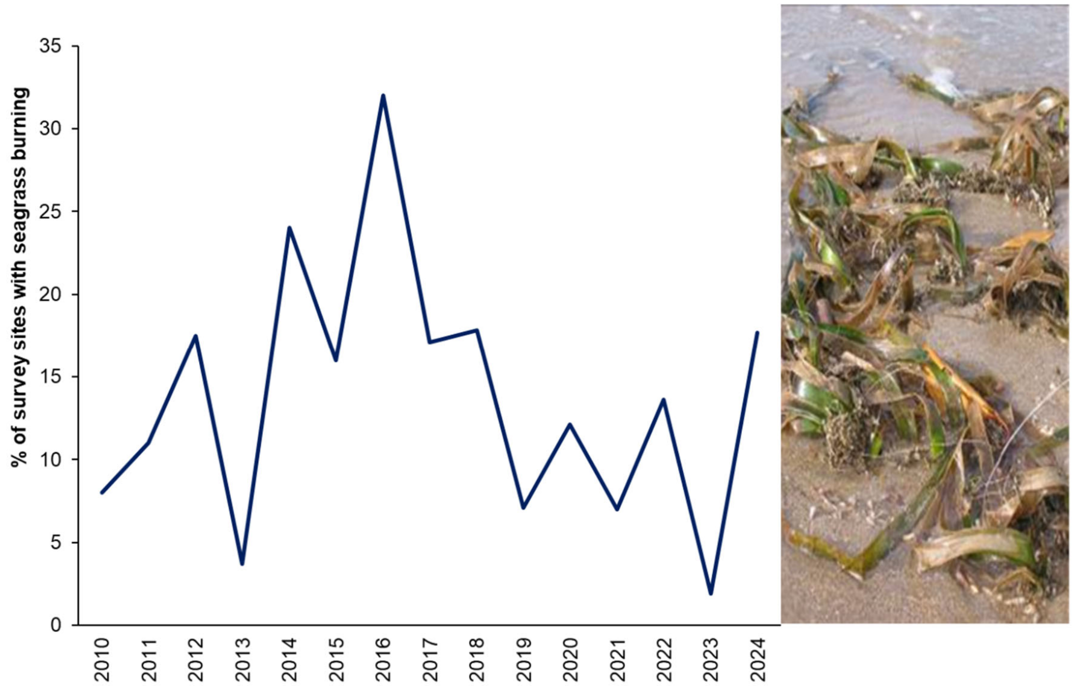


Figure 12. Percentage of sites within the IMA that had evidence of *Enhalus acoroides* leaf burning.

Dugong feeding trails were recorded in the *H. ovalis* and *H. uninervis* patches in the A5 monitoring meadow on the eastern side of the Embley River. Additionally, dugong feeding trails were observed upstream in the Hey River, upstream in the Embley River, Pine River Bay, and also in the Mission River.

Figure 13. Dugong feeding trails (meandering lines over the mud bank) in Pine River Bay and the A5 Weipa monitoring meadow in 2024.

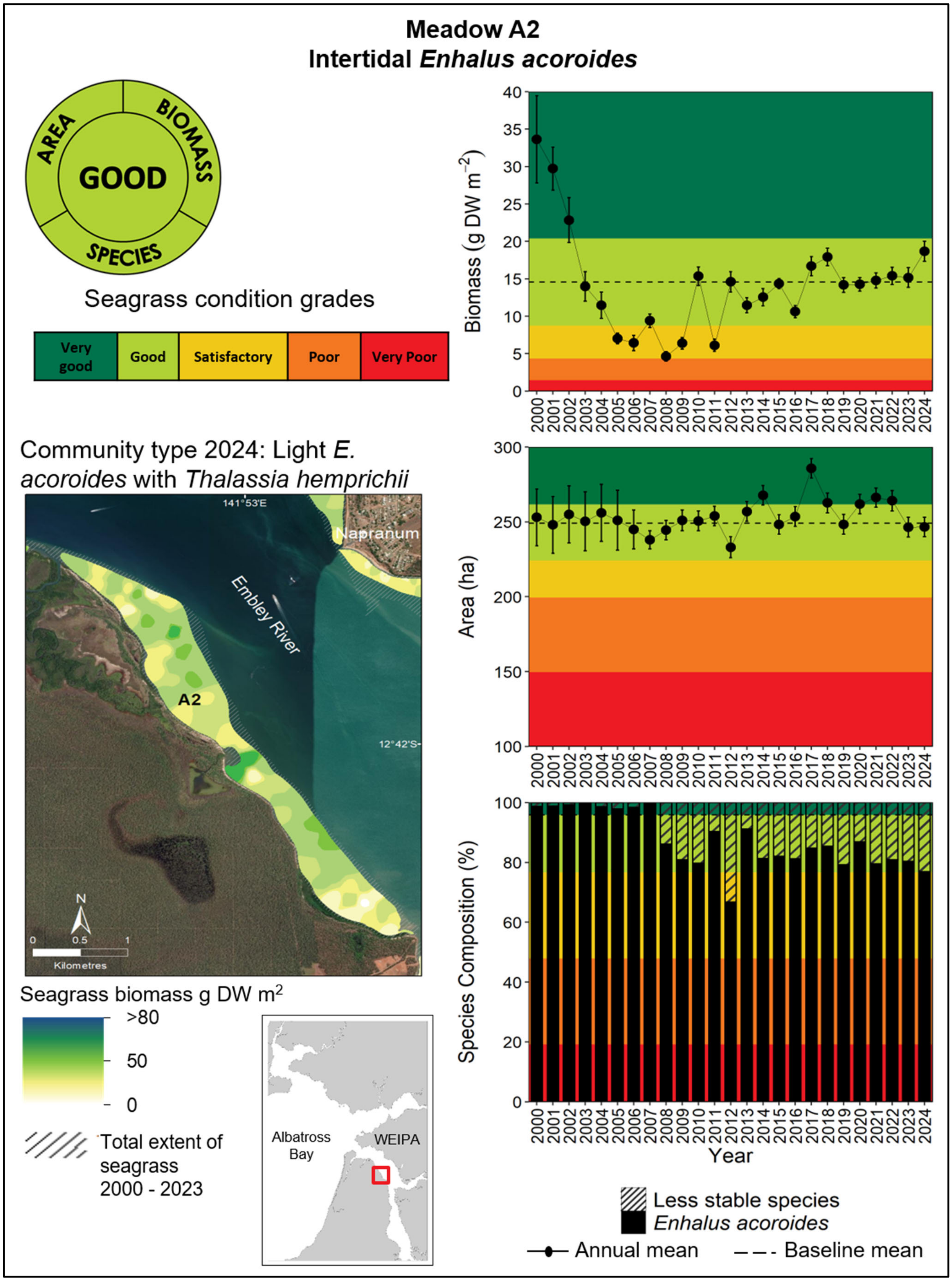


Figure 14. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa; 2000 to 2024 (biomass error bars = SE; area error bars "R").

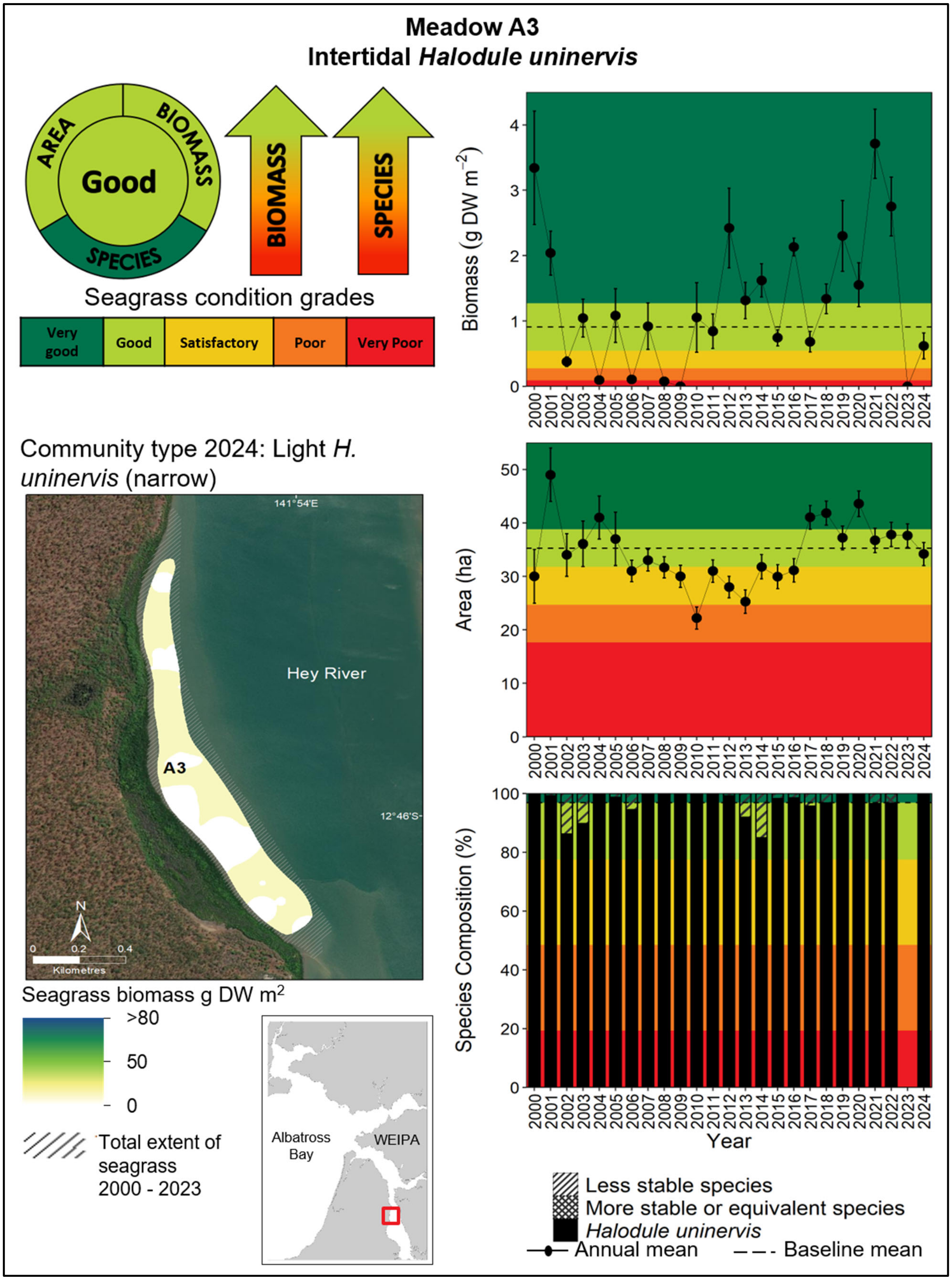


Figure 15. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa; 2000 to 2024 (biomass error bars = SE; area error bars "R"). *The area of meadow A3 is based on the presence of *E. acoroides* in the meadow not *H. uninervis* – *H. uninervis* is the species that is 'tracked', monitored and grades based upon.

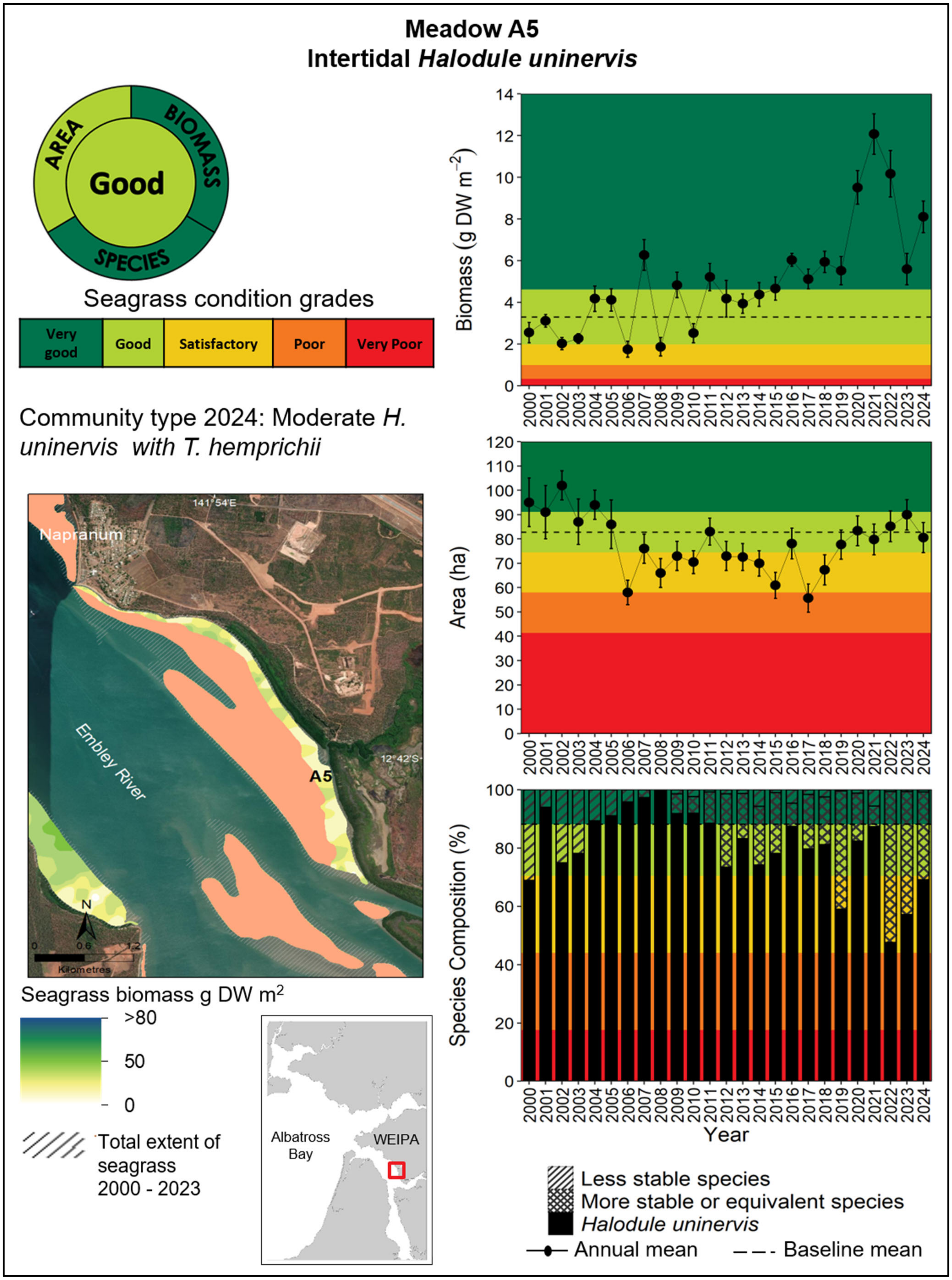


Figure 16. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa; 2000 to 2024 (biomass error bars = SE; area error bars "R").

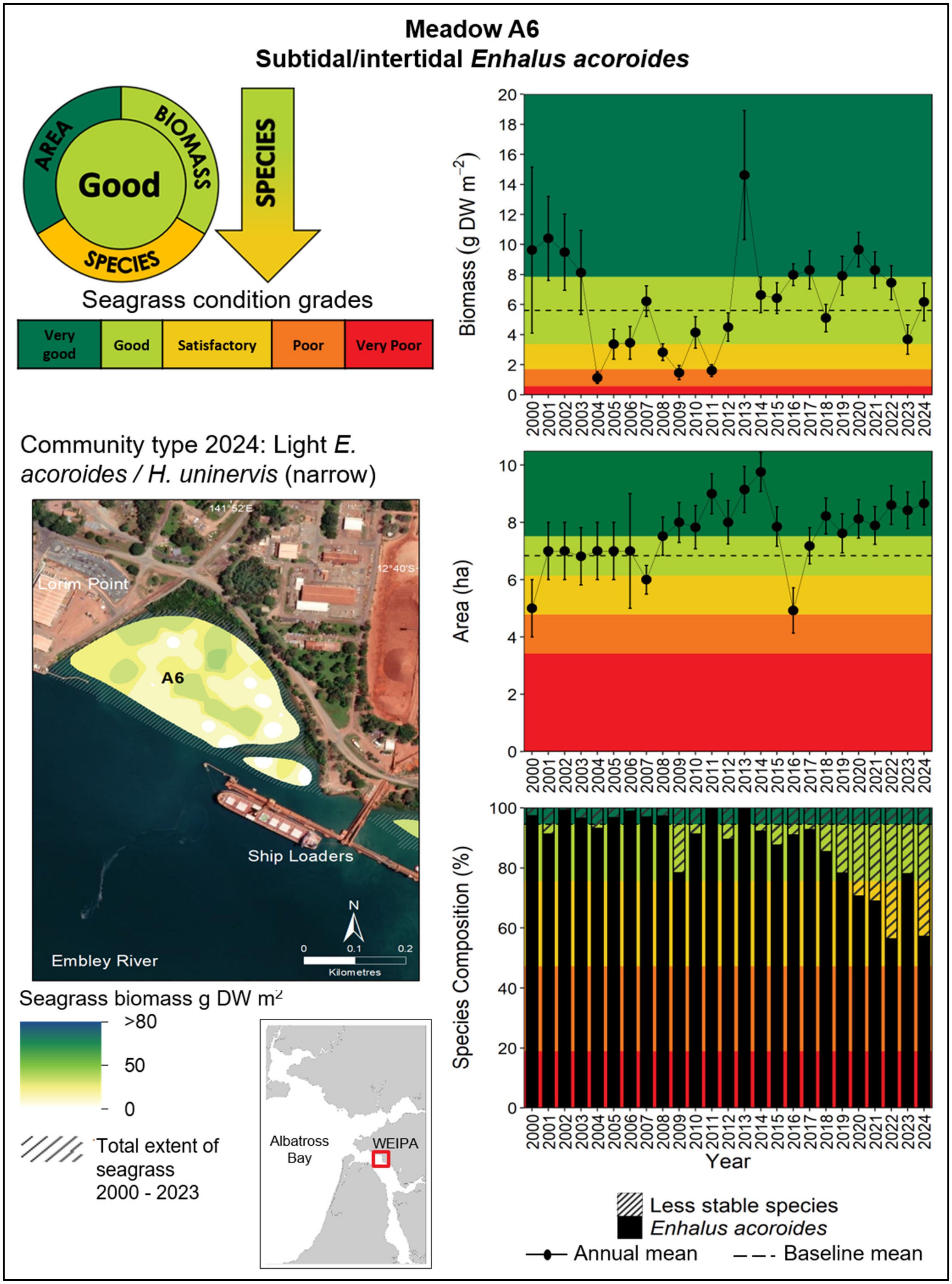


Figure 17. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa; 2000 to 2024 (biomass error bars = SE; area error bars “R”).

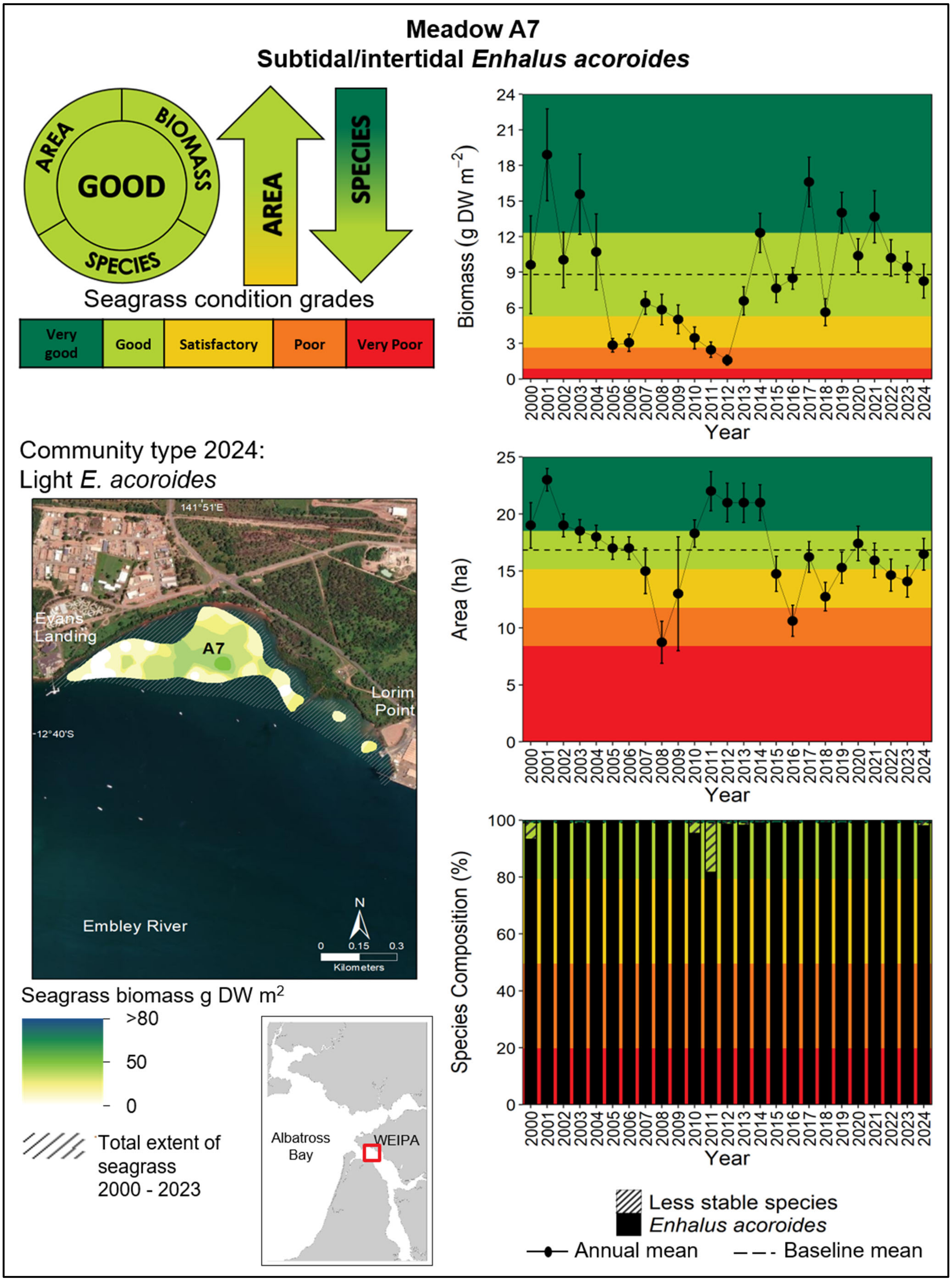


Figure 18. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa; 2000 to 2024 (biomass error bars = SE; area error bars “R”).

5.3 Seagrass condition in the broader Port of Weipa

The last broadscale survey in 2023 mapped seagrasses across the wider port region to give an updated understanding of seagrasses in the broader port limits. In 2024, the footprint and species composition were inspected, and improvements were found. Additional meadows, some that haven't been recorded since 2002 had appeared in each broadscale region (Figure 19).

In the Mission River some small *H. ovalis*, *H. uninervis*, and *E. acoroides* meadows reappeared, last mapped in 2002 and 2011. The Pine River Bay area also recorded an additional patch of *H. ovalis* which was last seen in the 2020 broadscale survey. An abundance of dugong feeding trails were observed in Pine River Bay in many of the *H. uninervis* meadows and upstream in the *T. hemprichii* patches. The Hey River meadows also showed improvements with additional patches of *H. uninervis* mapped, and similar to what was seen in 2020. Some patches had very long blades (30cm+) of grass and included dugong feeding trials. The Embley River *H. uninervis* meadows returned after being absent in 2023. Dugong feeding trails were recorded in the *H. uninervis* meadows in all of the broader harbour meadows.

Figure 19. *E. acoroides* and *T. hemprichii* meadows in Pine River Bay and the Mission River 2024.

5.4 Weipa climate conditions

5.4.1 Rainfall

Rainfall in Weipa in the twelve months prior to the 2024 survey was less than the past two years however still above average for the fourth year in a row (2122mm) (Figure 20a). The wet season started later than previous years with above average monthly rainfall recorded during the months of December 2023 to April 2024 except for February which was below average (Figure 20b).

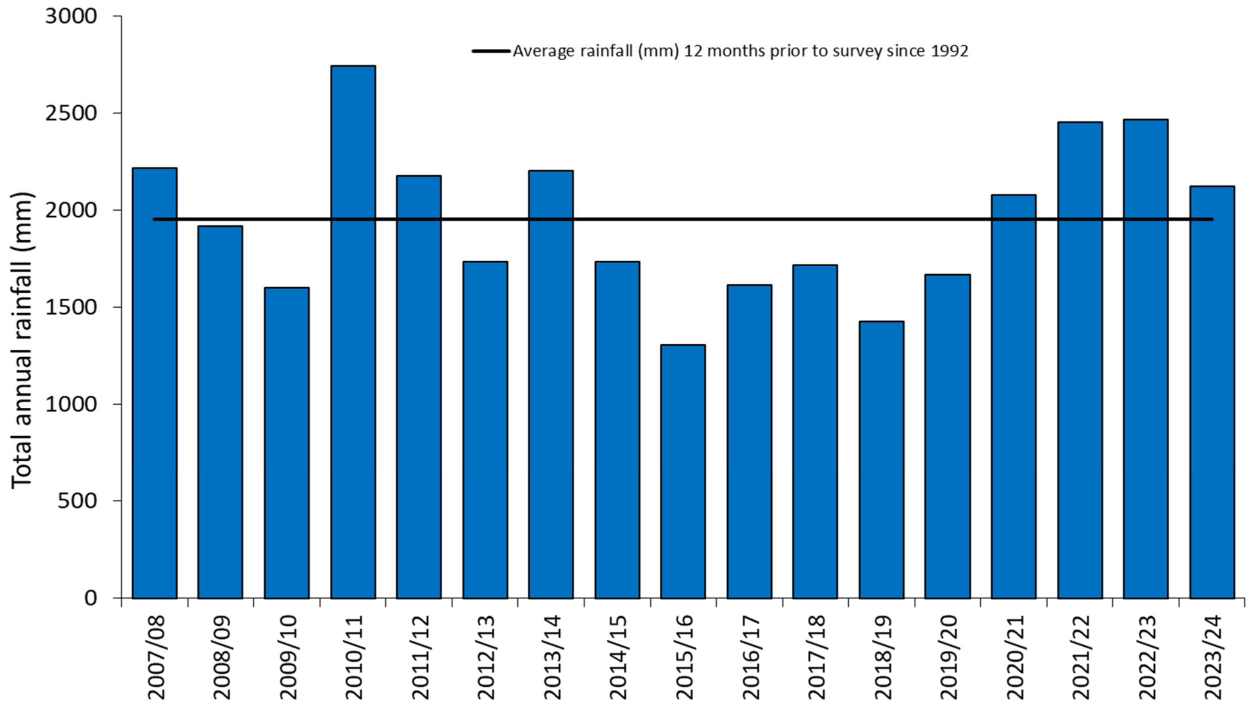


Figure 20a. Total annual rainfall recorded at Weipa Airport in the 12 months prior to each survey; 2007-2024.

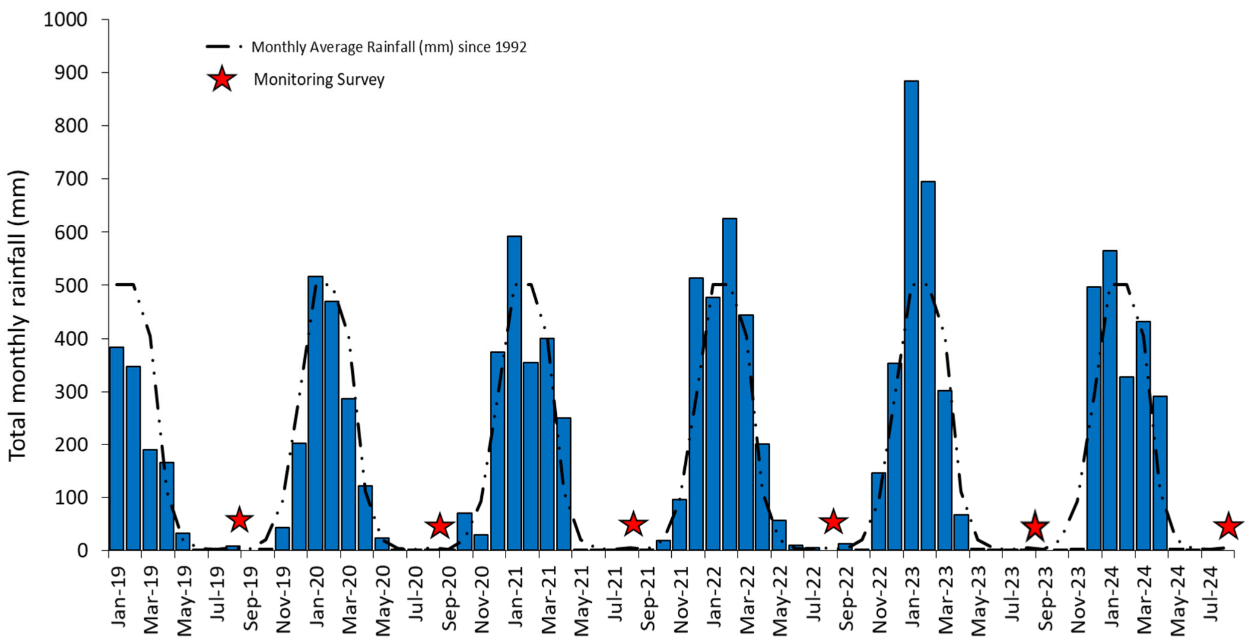


Figure 20b. Total monthly rainfall (mm); January 2019 – November 2024.

5.4.2 Daytime Tidal Exposure

The intertidal meadows in Weipa were exposed to daytime air for 457 hours in the twelve months prior to the 2024 survey. This was above the long-term average of 395 hours (Figure 21a). Daytime tidal exposure was below average for the two months prior to the survey, while for the rest of the year exposure was above average (Figure 21b). Intertidal seagrass meadows are subjected to a greater amount of daytime exposure during the winter/dry season months and minimal to no exposure during the summer/wet season months (Figure 21b).

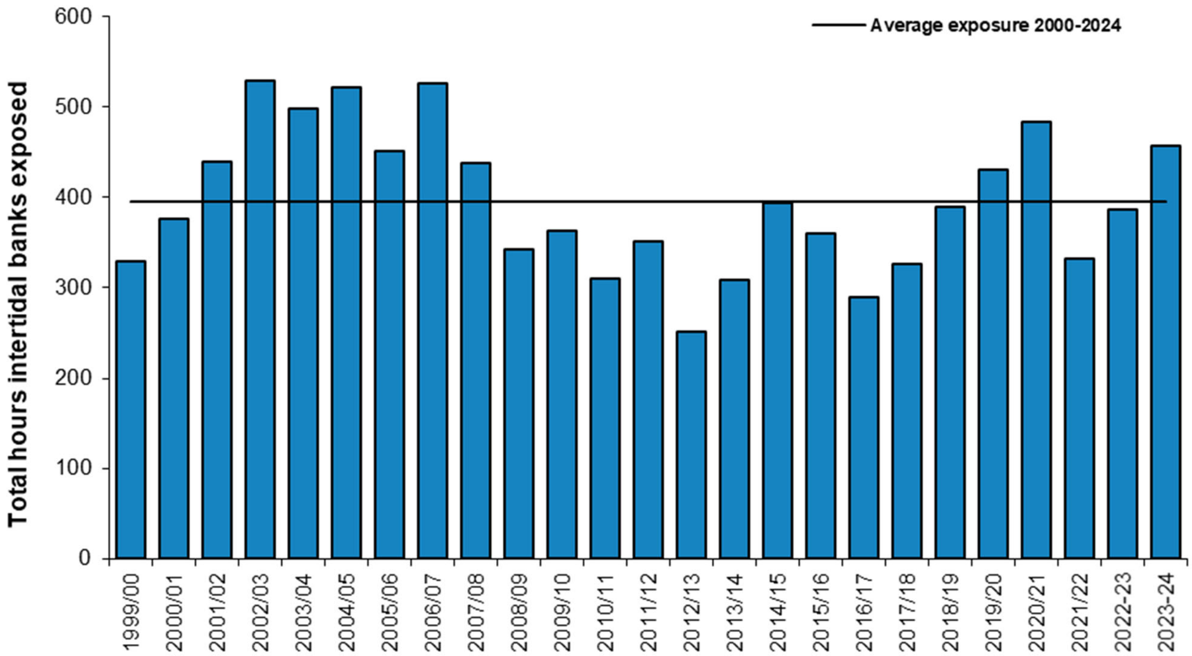


Figure 21a. Total daily tidal exposure to air 1999/00 -2023/24. Data is twelve months prior to survey.

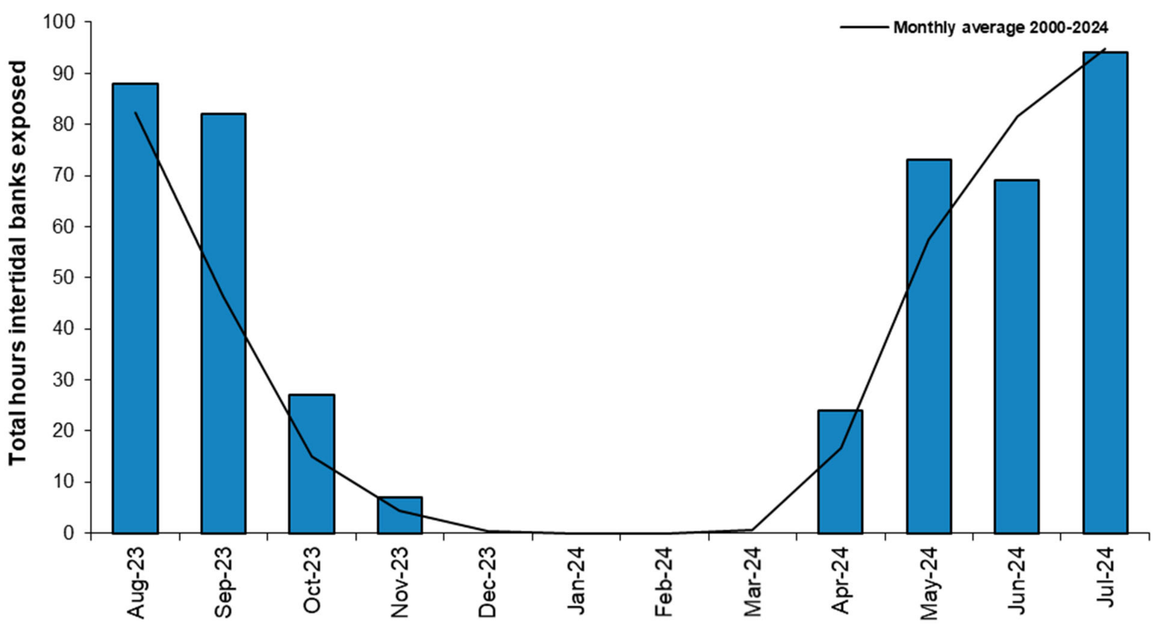


Figure 21b. Monthly total daytime tidal exposure to air (hours; ≤0.9m tidal height); August 2023 – July 2024.

5.4.3 Photosynthetically Active Radiation (PAR (light))

The quantity of light reaching the seabed is a limiting factor and critical to the persistence and growth of seagrass. Monitoring PAR helps us understand seagrass change and potential causes of any observed change. The wet season months of December to March is usually when PAR is typically below ideal growing and maintenance thresholds for most seagrass species.

Biologically relevant thresholds (Collier *et al*. 2016) for seagrasses in Weipa are:

- Seagrass meadows dominated by *Halophila* – 2.5 mol/m^2/day; 7 day rolling average, 28 consecutive days below threshold before impact.
- Seagrass meadows dominated by *Halodule uninervis* - 5 mol/m^2/day; 14 day rolling average, 40 consecutive days below threshold before impact.
- Seagrass meadows dominated by *Cymodocea*, *Thalassia hemprichii*, *Enhalus acoroides* - 5 mol/m^2/day; 14 day rolling average, 28 - 50 consecutive days below threshold before impact

Above average rainfall in December 2024 and January 2025 saw PAR drop below thresholds at all logger sites, however the duration was shorter compared to previous years indicating a mild wet season. The range of PAR in the deeper A6 and A7 meadows was less than previous years (2023: 0.46-27.10 mol m^{-2} day^{-1}) (Figure 22a). Additionally, the PAR in meadow A2 also had a shorter period of light below thresholds compared to 2023 (Figure 22b). Overall, the longer duration of ideal light may have been enough to sustain healthy seagrass growth in all meadows during 2024.

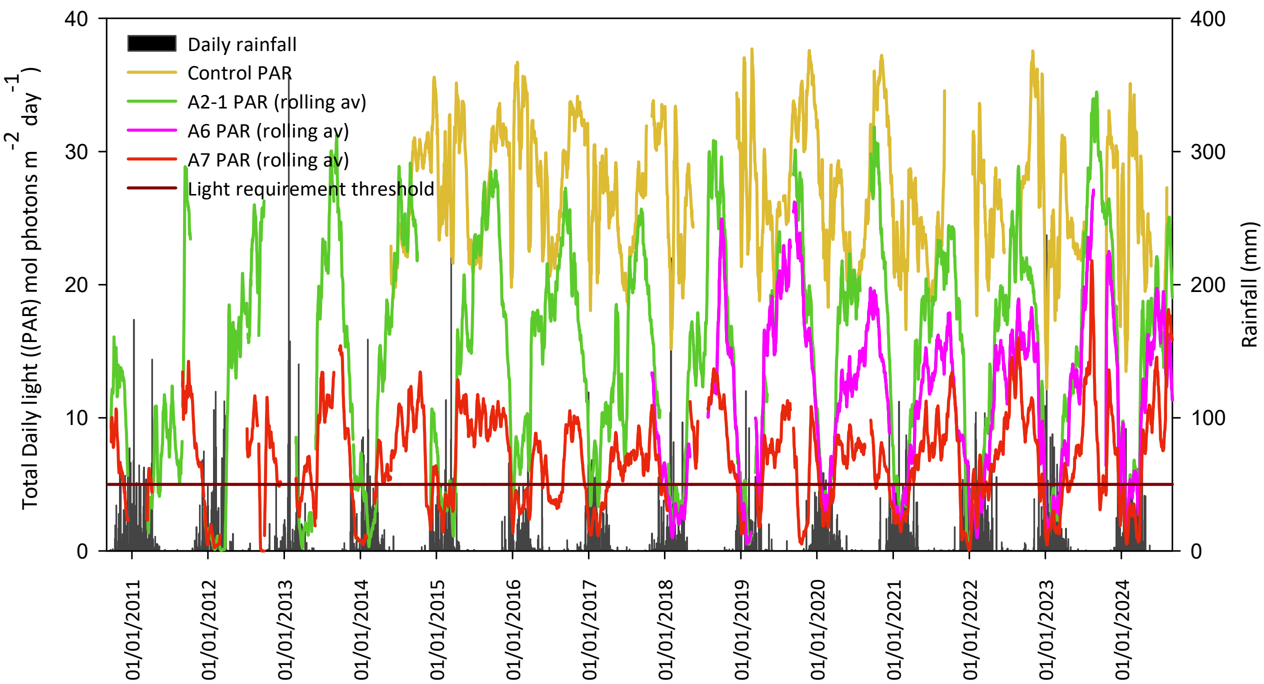
PAR was lower in the deeper meadows (A6 and A7) than the shallower A2 meadow as expected due to greater light attenuation with depth of water and shorter periods of low tide exposure to air. In the twelve months prior to the seagrass survey PAR ranged from (see Figure 22a):

- Control logger (above water): 5.9 – 35.09 mol m^{-2} day^{-1}.
- A2 intertidal meadow: 0.98 – 26.44 mol m^{-2} day^{-1}.
- A6 intertidal/subtidal meadows: 0.97 – 22.49 mol m^{-2} day^{-1}.
- A7 intertidal/subtidal meadows: 0.50 – 18.12 mol m^{-2} day^{-1}.

The longest continuous period that PAR remained below the 14 day rolling average threshold for Weipa seagrass species (5 mol m^{-2} day^{-1}) during 2023/2024 at each site meadow was (Figure 22b):

- A2: 23 days below threshold January 2024 – February 2024.
- A6: 27 days below threshold January 2024 – February 2024.
- A7: 108 days below threshold December 2023 – April 2024.

a)



*A6 PAR site established late 2017

b)

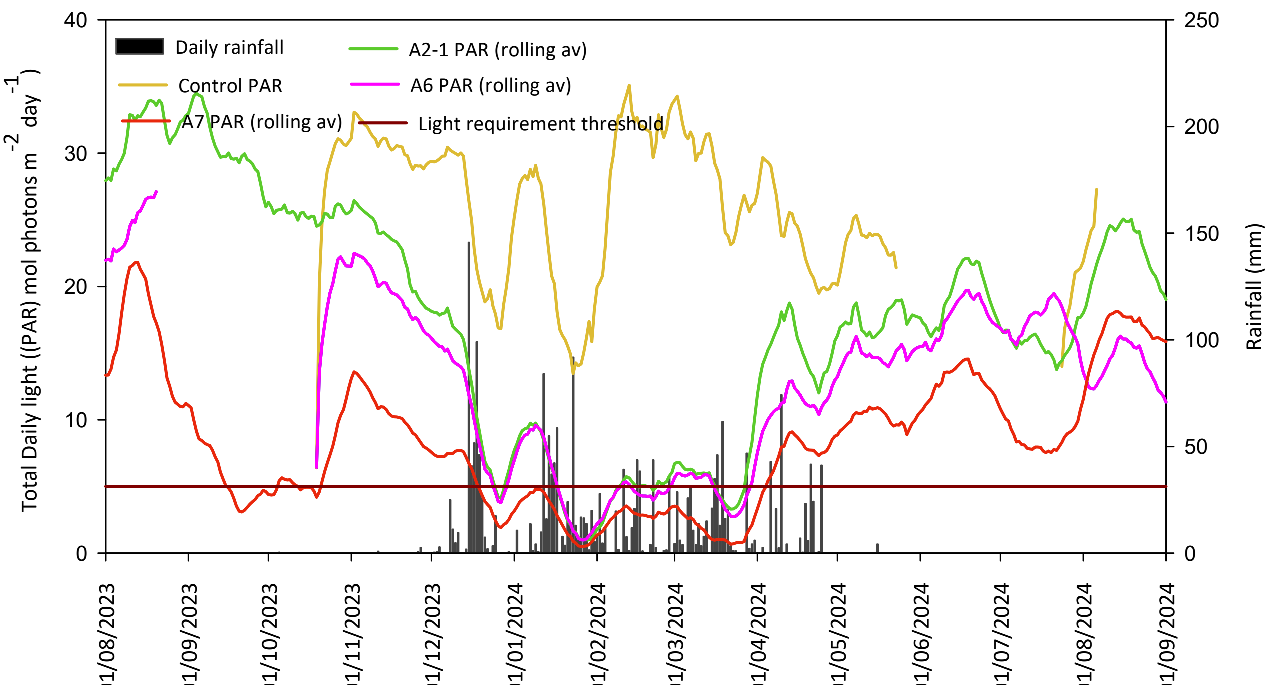


Figure 22 (a) Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa; January 2011 – September 2024. **(b)** Period of low light over the 2023-2024 wet season.

6 DISCUSSION

Seagrasses in the Port of Weipa were in an overall good condition in 2024. Meadow area and biomass were in good condition for all monitoring meadows and 2024 saw the return of *Halodule uninervis* to meadows (A3) and along the banks of the Hey River after being absent in 2023. Seagrasses in the broader survey area (outside of the IMA) including Pine River Bay, Mission River, Hey River and Embley River improved in their overall footprint since 2023, with additional meadows recorded, some that were last seen in 2002 and 2011. Significant numbers of dugong feeding trails were observed in monitoring meadow A5, Pine River Bay, and Mission River and reconnaissance sampling saw the evidence of seagrass seed banks for some meadows.

The return of above-ground biomass for *H. uninervis* in the A3 monitoring meadow and in other areas outside of the IMA was a good sign of seagrass resilience in the Port of Weipa in 2024. In 2023 scouring and sediment deposition as a result of the intense 2022/23 wet season was noted as the likely cause of the loss of *H. uninervis* (Reason *et al*. 2024). In 2023 some meadows had below-ground structures (rhizomes) of *H. uninervis*, however no above-ground biomass present. Weather events that bring intense rainfall, associated catchment and river flows, flooding, and wind-driven re-suspension of sediment, can have a negative physical effect on seagrass through direct removal and burial, as well as physiological impacts due to changes in water quality and benthic light (Cabaco et al. 2008, Sim Ooi et al. 2011). The fact that *H. uninervis* was able to return within 12 months shows the meadows and species have good longer-term resilience. *H. uninervis* can produce long-lived seeds that may lay dormant in the sediment for several years and these can offer a means of recovery when the adult population is lost (Birch and Birch 1984; Inglis 2000; Preen et al. 1995;). Seed bank sampling has not previously been conducted in Weipa and our reconnaissance sampling in meadows during 2024 found some seeds in meadow A5, indicating the presence of a seed bank and a mechanism for the observed recovery. It is possible that meadow A3 also had a seed bank and the seagrass found here in 2024 was due to their germination. The lack of seeds found there could be due to them all germinating to replenish the meadow or possibly went undetected due to the relatively low number of samples collected. Full scale sampling would be required to quantify the seed bank with confidence.

The 2023/24 wet season was relatively benign compared to the previous year, leading to favourable growing conditions allowing *H. uninervis* to recover. Favourable light conditions (i.e., shorter durations that PAR fell below critical growing and maintenance thresholds) are also likely to have provided better growing conditions for all seagrasses in Weipa, helping existing below-ground seagrass structures re-shoot.

Seagrass monitoring is conducted in other parts of Queensland including Thursday Island in Torres Strait to the north of Weipa, and Karumba in the southern Gulf of Carpentaria. Thursday Island has similar species compositions to Weipa including *E. acoroides*, *H. uninervis, T. hemprichii* and *H. ovalis* (Scott *et al.* 2023). Seagrass was in an overall satisfactory condition around Thursday Island in 2024 with some declines in the *Enhalus* meadows possibly due to high rainfall in the months leading up to the survey (Scott *et al.* 2024). Seagrass meadows in Karumba are dominated by *H. uninervis* and were in a poor condition with a reduction in biomass and area in 2024 also due to cumulative stressors from the 2022/23 wet season (Scott and Rasheed 2025).

The good condition of seagrass meadows in Weipa in 2024, especially the return of *H. uninervis* indicate that seagrass meadows should have a good level of resilience to natural or anthropogenic disturbances going into 2025.

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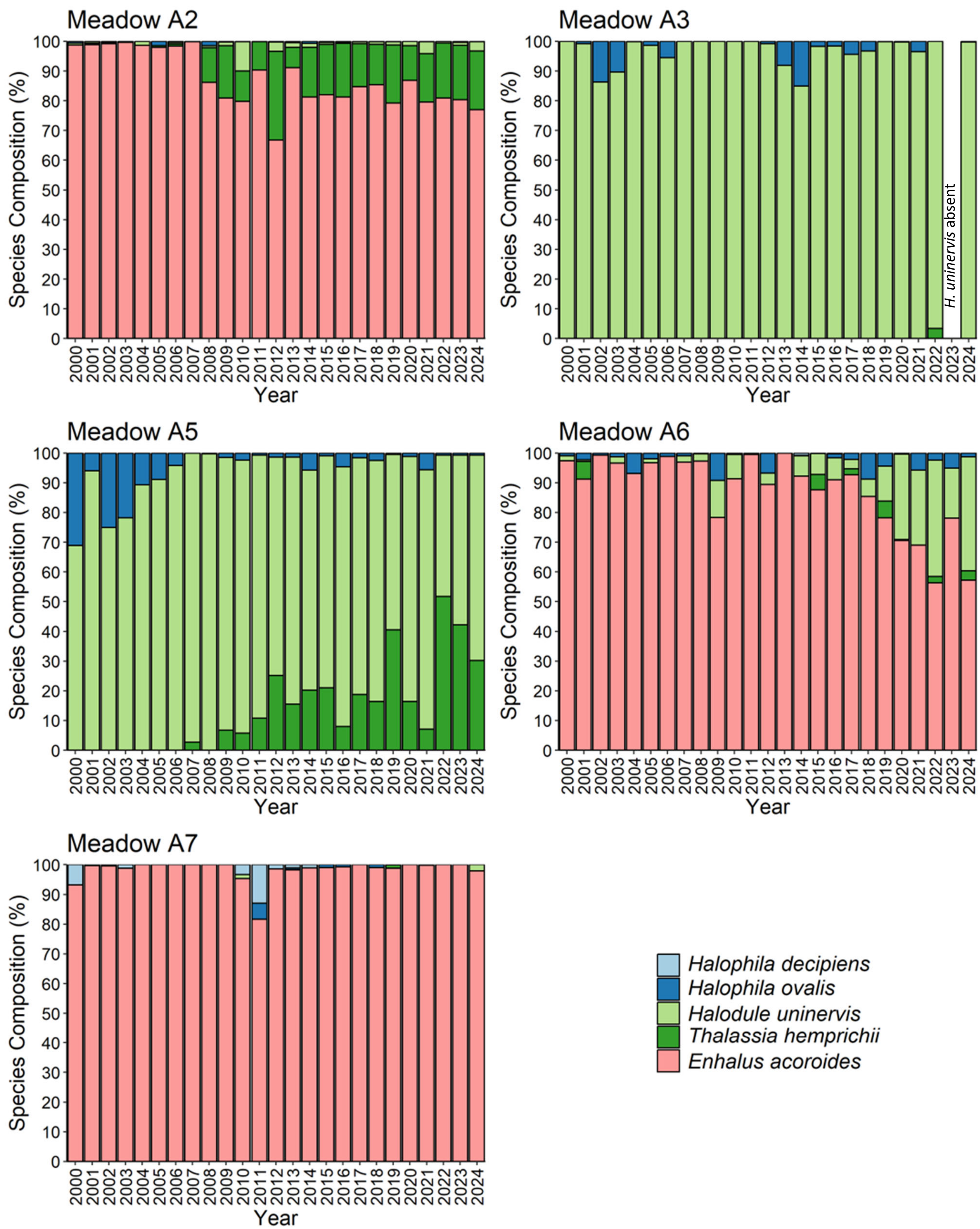
8 APPENDICES

8.1 Detailed meadow species composition; 2000 – 2024



8.2 Meadow above-ground biomass and area

Mean above-ground seagrass biomass (g DW m^{-2}) ± standard error and number of biomass sampling sites (in brackets) for each core monitoring meadow within the Port of Weipa, 2000 – 2024.

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)																								
	Sep 00	**Sep 01**	**Sep 02**	**Sep 03**	**Aug 04**	**Aug 05**	**Aug 06**	**Sep 07**	**Sep 08**	**Sep 09**	**Sep 10**	**Aug 11**	**Aug 12**	**Sep 13**	**Aug 14**	**Sep 15**	**Aug 16**	**Aug 17**	**Sep 18**	**Sep 19**	**Aug 20**	**Aug 21**	**Aug 22**	**Aug 23**	**Aug 24**
A2 Intertidal *Enhalus* dominated	33.63 ± 5.82 (17)	29.73 ± 2.88 (51)	22.84 ± 2.99 (50)	13.99 ± 1.96 (54)	11.47 ± 1.77 (51)	7.04 ± 0.72 (51)	6.43 ± 1.03 (54)	9.40 ± 0.90 (46)	4.65 ± 0.63 (48)	6.39 ± 0.77 (70)	15.36 ± 1.23 (52)	6.13 ± 0.82 (51)	14.60 ± 1.36 (65)	11.47 ± 1.01 (76)	12.55 ± 1.15 (81)	14.37 ± 0.66 (91)	10.62 ± 1.13 (66)	16.70 ± 1.28 (72)	17.92 ± 1.18 (68)	14.19 ± 0.98 (62)	14.27 ± 0.89 (64)	14.78 ± 0.99 (74)	15.40 ± 1.14 (76)	15.18 ± 1.32 (73)	18.68 ± 1.32 (73)
A3 Intertidal *Halodule* dominated	3.34 ± 0.87 (11)	2.04 ± 0.33 (26)	0.38 ± 0.07 (30)	1.04 ± 0.29 (26)	0.10 ± 0.04 (26)	1.08 ± 0.41 (25)	0.11 ± 0.05 (31)	0.92 ± 0.36 (31)	0.08 ± 0.05 (28)	0.0002 ± 0.0001 (31)	1.05 ± 0.53 (26)	0.84 ± 0.26 (44)	2.42 ± 0.61 (34)	1.31 ± 0.28 (69)	1.62 ± 0.25 (71)	0.74 ± 0.12 (77)	2.13 + 0.19 (42)	0.68 ± 0.16 (71)	1.34 ± 0.23 (56)	2.30 ± 0.54 (45)	1.55 ± 0.33 (42)	3.71 ± 0.53 (58)	2.75 ± 0.45 (51)	0	0.61 ± 0.19 (34)
A5 Intertidal *Halodule* dominated	2.55 ± 0.49 (9)	3.11 ± 0.31 (51)	2.03 ± 0.29 (51)	2.26 ± 0.23 (49)	4.18 ± 0.61 (50)	4.11 ± 0.54 (50)	1.75 ± 0.38 (57)	6.27 ± 0.74 (48)	1.87 ± 0.45 (48)	4.83 ± 0.61 (76)	2.52 ± 0.46 (62)	5.21 ± 0.66 (78)	4.17 ± 0.88 (60)	3.94 ± 0.47 (70)	4.38 ± 0.57 (67)	4.66 ± 0.55 (67)	6.03 + 0.44 (95)	5.12 ± 0.47 (69)	5.94 ± 0.51 (91)	5.52 ± 0.67 (60)	9.51 ± 0.81 (58)	12.07 ± 0.98 (57)	10.17 ± 1.11 (53)	5.60 ± 0.75 (56)	8.09 ± 0.76 (58)
A6 Intertidal/ subtidal *Enhalus* dominated	9.63 ±5.52 (9)	10.4 ±2.79 (26)	9.5 ±2.54 (25)	8.13 ±2.90 (25)	1.14 ±0.40 (26)	3.37 ±1.00 (26)	3.45 ±1.09 (26)	6.22 ±1.01 (31)	2.83 ±0.55 (25)	1.47 ±0.47 (29)	4.14 ±1.04 (25)	1.61 ±0.41 (49)	4.49 ±0.94 (28)	14.61 ± 4.29 (32)	6.64 ±1.19 (32)	6.43 ±1.03 (32)	7.99 +1.05 (19)	8.30 ±1.26 (32)	5.1 ±0.91 (33)	7.91 ±1.30 (40)	9.67 ±1.1 (33)	8.30 ±0.1.2 (33)	7.45 ±1.14 (32)	3.70 ±1.0 (31)	6.18 ±1.2 (31)
A7 Intertidal/ subtidal *Enhalus* dominated	9.63 ±4.12 (14)	18.89 ± 3.88 (30)	10.03 ± 2.34 (33)	15.57 ± 3.39 (31)	10.71 ± 3.19 (24)	2.84 ±0.58 (30)	3.06 ±0.73 (33)	6.41 ±0.97 (33)	5.85 ±1.28 (21)	5.03 ±1.22 (24)	3.46 ±0.92 (21)	2.47 ±0.65 (35)	1.58 ±0.42 (36)	6.58 ±1.20 (45)	12.31 ± 1.65 (39)	7.64 ±1.20 (34)	8.48 +0.91 (28)	16.61 ± 2.08 (30)	5.63 ±1.13 (28)	12.99 ± 1.82 (38)	10.01 ± 1.25 (41)	13.66 ± 2.19 (41)	10.2 ±1.52 (40)	9.43 ±1.30 (48)	8.24 ±1.42 (38)

8.3 Meadow above-ground biomass and area

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2024.

Monitoring Meadow	**Total meadow area ± R (ha)**												
	Sep 00	**Sep 01**	**Sep 02**	**Sep 03**	**Aug 04**	**Aug 05**	**Aug 06**	**Sep 07**	**Sep 08**	**Sep 09**	**Sep 10**	**Aug 11**	**Aug 12**
A2 Intertidal *Enhalus* dominated	253.0 ±19.0	248.0 ±19.0	255.0 ±19.0	250.4 ±19.7	256.0 ±19.0	251.0 ±20.0	245.0 ±13.0	238.0 ± 6.0	244.5 ± 6.6	251.0 ± 7.0	250.7 ± 6.5	254.0 ± 6.5	233.0 ± 7.0
A3 Intertidal *Halodule* dominated	30.0 ±5.0	49.0 ±5.0	34.0 ±4.0	36.1 ±4.3	41.0 ±4.0	37.0 ±5.0	31.0 ±2.0	33.0 ±2.0	31.7 ±2.0	30.0 ±2.1	22.2 ±2.1	31.0 ±2.1	28.0 ±2.0
A5 Intertidal *Halodule* dominated	95.0 ± 0.0	91.0 ±11.0	102.0 ±6.0	87.0 ±9.3	94.0 ±6.0	86.0 ±10.0	58.0 ±5.0	76.0 ±6.0	66.0 ±6.0	73.0 ±6.0	70.5 ±4.7	83.0 ±5.5	73.0 ±6.0
A6 Intertidal/ subtidal *Enhalus* dominated	5.0 ±1.0	7.0 ±1.0	7.0 ±1.0	6.8 ±1.0	7.0 ±1.0	7.0 ±1.0	7.0 ±2.0	6.0 ±0.5	7.5 ±0.7	8.0 ±0.7	7.8 ±0.8	9.0 ±0.7	8.0 ±3.0
A7 Intertidal/ subtidal *Enhalus* dominated	19.0 ±2.0	23.0 ±1.0	19.0 ±1.0	18.5 ±1.0	18.0 ±1.0	17.0 ±1.0	17.0 ±1.0	15.0 ±2.0	8.7 ±1.9	13.0 ±5.0	18.3 ±1.2	22.0 ±3.4	21.0 ±7.0
Total	**402.0 ±37.0**	**418.0 ±37.0**	**417.0 ±31.0**	**398.8 ±35.3**	**416.0 ±31.0**	**398.0 ±37.0**	**358.0 ±23.0**	**368.0 ±16.5**	**358.4 ±17.0**	**375.0 ±20.8**	**369.4 ±15.3**	**399.0 ±18.2**	**363.0 ±25.0**

Monitoring Meadow	**Total meadow area ± R (ha)**											
	Sep 13	**Aug 14**	**Sep 15**	**Aug 16**	**Aug 17**	**Sept 18**	**Sep 19**	**Aug 20**	**Aug 21**	**Aug 22**	**Aug 23**	**Aug 24**
A2 Intertidal *Enhalus* dominated	256.9 ± 6.6	267.7 ± 6.5	248.3 ± 6.5	253.59 ± 6.56	285.82 ± 6.51	262.63 ± 6.62	248.32 ± 6.61	261.85 ± 6.49	266.27 ± 6.39	264.14 ± 6.80	246.44 ± 6.62	246.58 ± 6.59
A3 Intertidal *Halodule* dominated	25.3 ±2.2	31.8 ±2.3	30.0 ±2.2	31.11 ± 2.2	41.04 ± 2.22	41.82 ± 2.22	37.21 ± 2.22	45.57 ± 2.37	36.73 ± 2.27	37.83 ± 2.26	37.64 ± 2.19	37.18 ± 2.15
A5 Intertidal *Halodule* dominated	72.6 ±5.5	69.9 ±5.3	60.9 ±10.8	78.06 ± 6.34	55.63 ± 5.82	67.26 ± 6.19	77.67 ± 6.03	83.33 ± 6.14	79.76 ± 6.28	85.20 ± 6.36	89.94 ± 6.26	80.53 ± 6.20
A6 Intertidal/ subtidal *Enhalus* dominated	9.2 ±1.6	9.8 ±1.4	7.9 ±1.4	4.92 ±3.34	7.19 ±2.61	8.22 ±2.61	7.62 ±0.68	8.13 ±0.67	7.89 ±0.66	8.60 ± 0.68	8.42 ± 0.64	8.66 ± 0.75
A7 Intertidal/ subtidal *Enhalus* dominated	21.0 ±3.5	21.0 ±6.4	14.7 ±6.0	10.62 ± 5.53	16.23 ± 5.56	12.74 ± 1.26	15.28 ± 1.37	15.69 ± 1.12	15.93 ± 1.51	14.63 ± 1.41	14.08 ± 1.37	16.47 ± 1.38
Total	**384.9 ±19.4**	**400.1 ±21.8**	**361.8 ±27.0**	**378.31 ±23.97**	**405.91 ± 2.72**	**392.67 ± 6.92**	**386.09 ± 5.00**	**412.58 ±16.79**	**406.58 ±17.11**	**410.41 ±17.50**	**396.52 ±17.08**	**386.44 ±17.10**