Port of Weipa Long-Term Seagrass Monitoring Program 2025

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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 2025

Good

Likely causes of seagrass condition:

Continued growth and condition improvements of H. uninervis in A3 meadow.

Favourable environmental conditions with near average wet season and below average tidal exposure.

Favourable light conditions during the dry season enabling seagrasses to build and improve condition.

- Seagrasses in the Port of Weipa maintained an overall good condition in 2025, for the second consecutive year.
- Two of the five monitoring meadows were in a very good condition with the remaining three in a good condition.
- The A3 *Halodule uninervis* meadow was the only meadow to reach a very good condition across all 3 condition grades in 2025, a notable improvement from being absent in 2023.
- Biomass improved to a very good condition across four of the five monitoring meadows indicating a good growing year for seagrass in the Port of Weipa.
- Seagrass area in the Intensive Monitoring Area (IMA) also improved and was well above the long-term average, with the largest area recorded since 2017.
- Aerial reconnaissance in the broader port area (Pine River Bay, Embley, Hey and Mission Rivers), noted meadows had persisted from the previous year and some meadows showed signs of further expansion.
- An abundance of dugong feeding trails were observed throughout the IMA and in the broader port area in 2025.
- Average rainfall and high levels of benthic light in the 5 months leading up to the survey, likely provided optimal seagrass growing conditions. The good overall condition of seagrasses leading into the next wet season means they were likely to have a high level of resilience to any unfavourable conditions in 2026.

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 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).

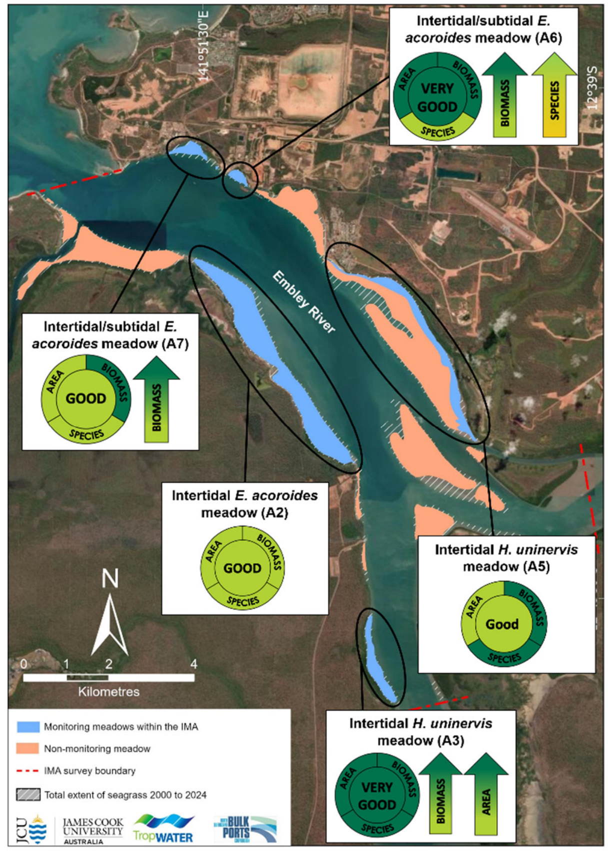


Figure 1. Seagrass meadow condition in the Port of Weipa 2025.

In 2025 the Port of Weipa seagrasses were in an overall good condition. Two of the five monitoring meadows were in a very good condition with the remainder in good condition compared to their long-term baselines (Figure 1). The *H. uninervis* meadow (A3) achieved very good scores across all 3 grades, a notable improvement after being absent in 2023. The total extent of seagrass also improved to well above the long-term average and with the largest area mapped since 2017 (Figure 2).

Seagrasses outside the IMA (Pine River Bay, Mission River and upstream Hey and Embley Rivers) were also inspected in 2025 to provide an update on seagrass condition in the broader area. Meadows were observed to be in similar condition to the previous year with some meadows showing signs of further expansion.

Climate conditions in 2025 were favourable for seagrass growth, with reduced rainfall and an average wet season (Figure 3). Tidal exposure to air was below average during the year and in the months preceding the survey, likely reducing physiological stress associated with desiccation and heat damage during low tide. The wet season lacked the intensity required to generate prolonged high river discharge or flooding, thereby limiting turbidity-driven light reduction and the physical disturbance associated with sediment erosion or burial.

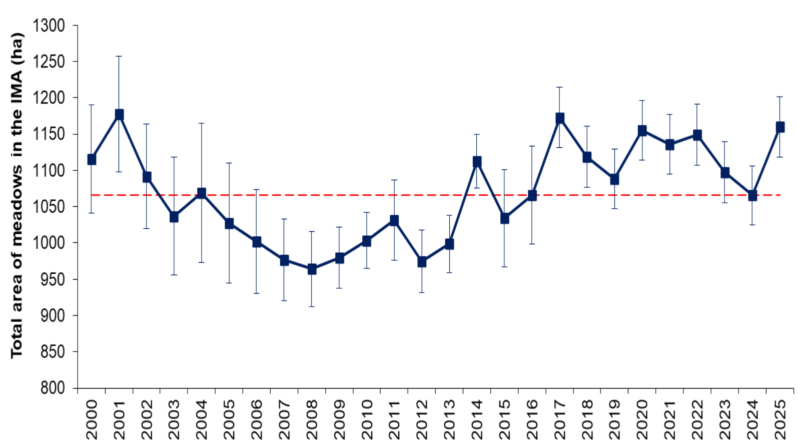


Figure 2. Total area of seagrass within the Weipa Intensive Monitoring Area from 2000 to 2025. (Error bars = "R" reliability estimate). Red dashed line indicates 24-year mean of total meadow area.

The duration of benthic light below seagrass maintenance and growth thresholds during the wet season was higher than previous years, but light during the dry season months leading up to the survey was higher. Although reductions in benthic light typically have negative effects on seagrass growth, the periods of ideal light during the dry season were enough to support continued seagrass growth and recovery and replenishment from any negative impacts during the wet season.

Weipa seagrasses were in a good position to be resilient to stresses and impacts going into the 2025/26 wet season, due to their high biomass and area in 2025.

The Weipa seagrass monitoring 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). Seagrasses to the south in Karumba were in a poor conditon due to continued high rainfall and flooding of local rivers in 2025 (Scott and Rasheed 2026) similarly many areas on the east coast such as Cairns, Mourilyan and Townsville had climate related losses of seagrasses in 2025 (JCU in prep).

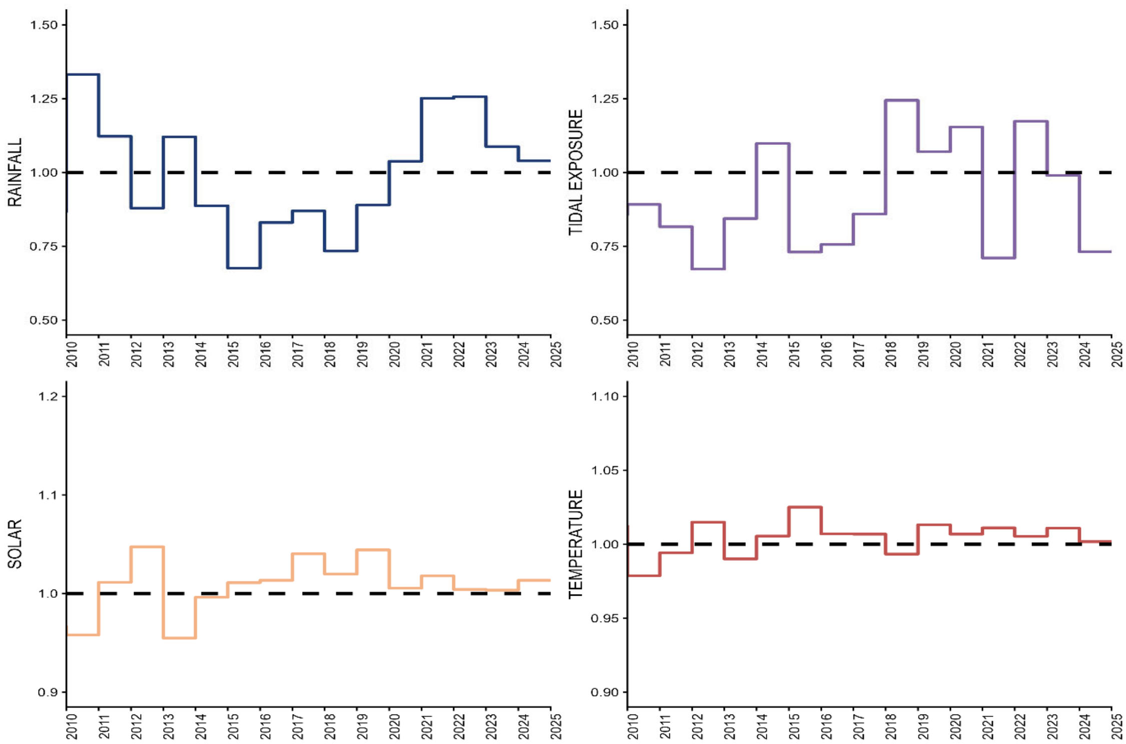


Figure 3. Recent climate trends in Weipa: Change in climate variables as a proportion of the long-term average. (See section 5.4 for detailed climate data).

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 (Azizova et al. 2025).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009; Dunic et al. 2021). Causes 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).

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.

Figure 4. Location of Queensland Port seagrass assessment sites.

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 2025. 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.

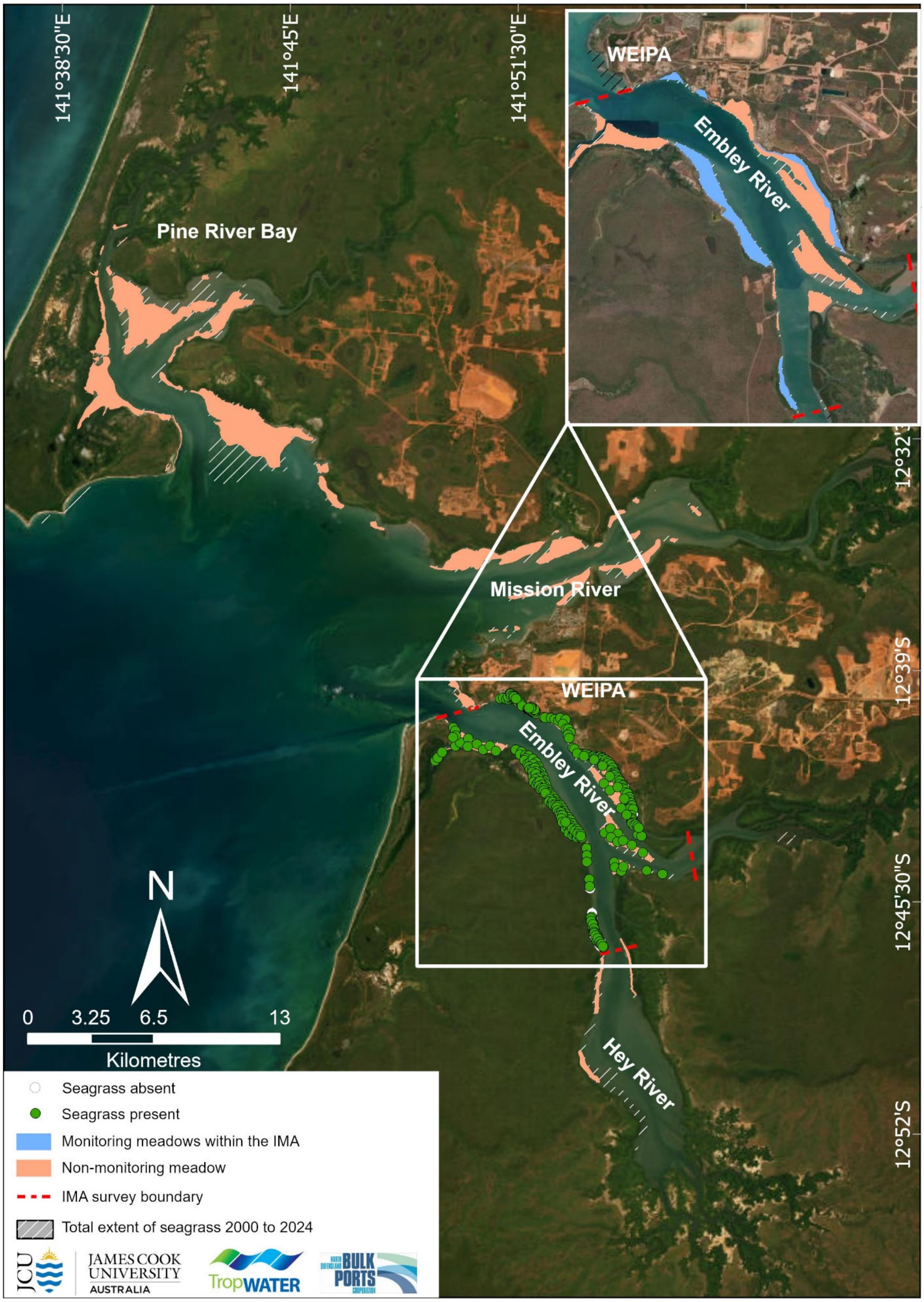


Figure 5. Location of 2025 seagrass survey sites and seagrass meadows in the Port of Weipa IMA. Meadows outside the IMA were mapped in 2023.

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 2025 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 by mapping meadow edges directly from the helicopter and 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.

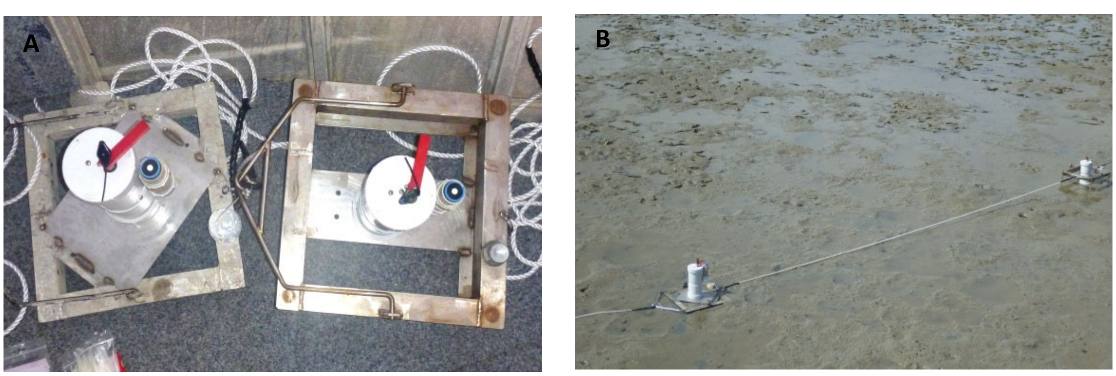


Figure 8. (A) Logging station consisting of a stainless-steel frame with PAR loggers, temperature loggers and wiper units attached. (B) Deployment of logging stations on the A2 meadow.

5 RESULTS

5.1 Seagrass presence and species throughout Weipa

Annual monitoring of seagrass within the port of Weipa was conducted between 20th and 21st August 2025. Seagrass was present at 94% of assessment sites within the IMA, with 340 sites across 14 meadows surveyed. Total seagrass meadow area within the IMA was above the long-term average at 1,160 ± 41 ha (Figure 11). This represents an increase from the previous year and is the highest recorded over the past seven years (the previous highest was in 2017 at 1,172 ± 41 ha). Four species of seagrass was found in the IMA (Figure 9). *Enhalus acoroides* is a large and persistent species and was present in low density cover across 9 of the 14 meadows (Figure 10). The remaining five meadows were dominated by *T. hemprichii* and *H. uninervis* (Figure 10).

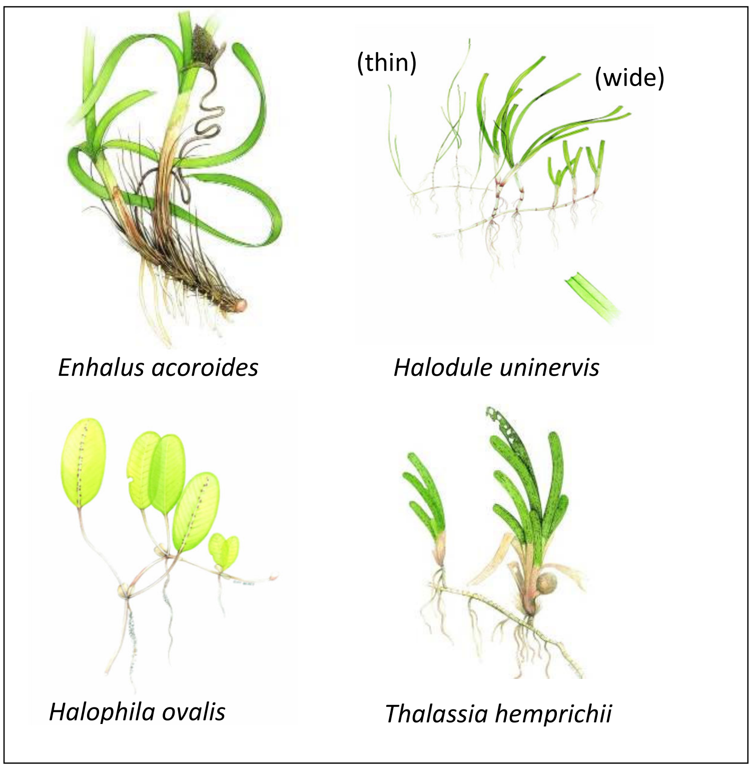


Figure 9. Seagrass species present in the Port of Weipa 2025. Pictures are not to scale.

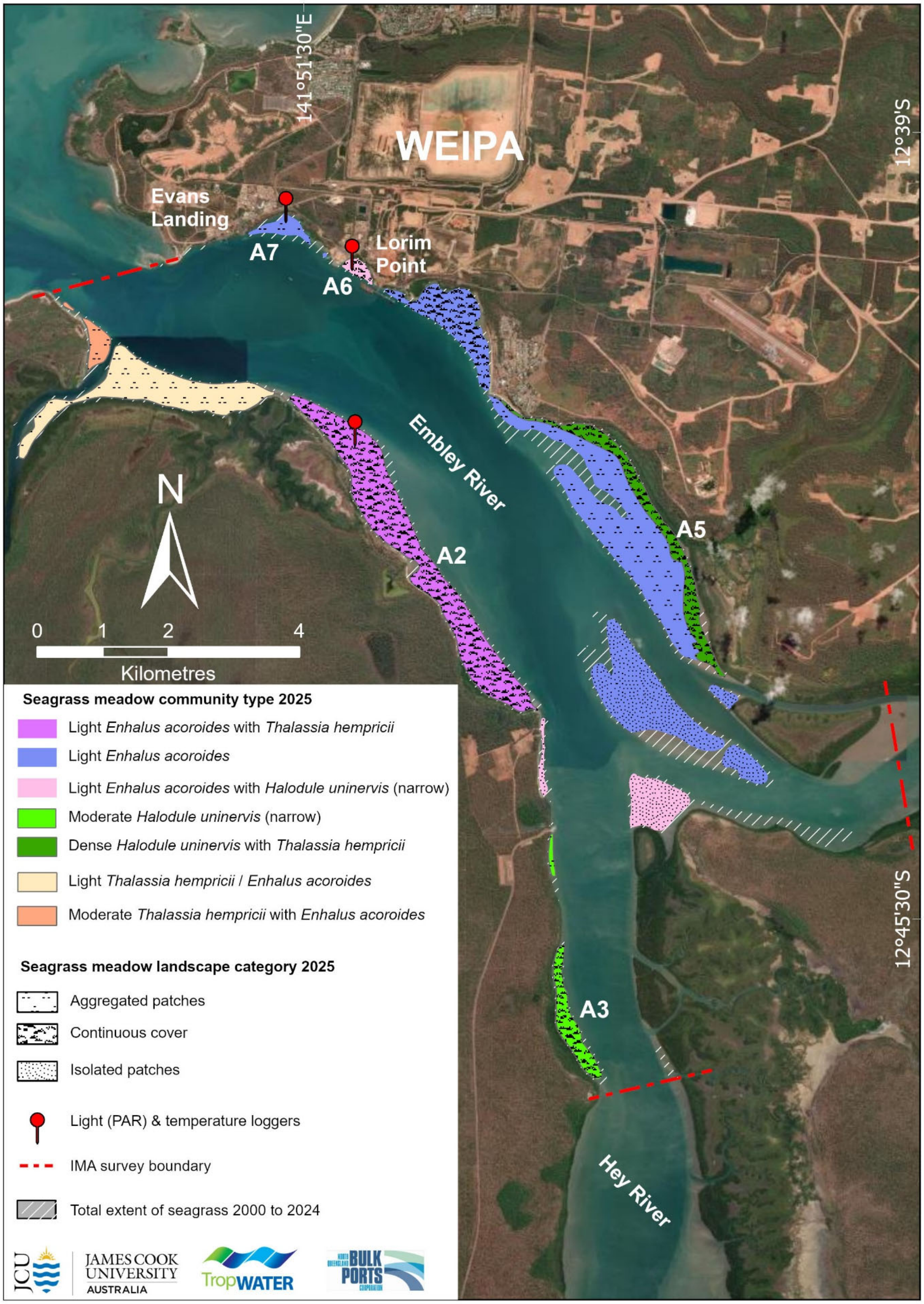


Figure 10. Meadow community type and landscape category for seagrass within the Intensive Monitoring Area 2025.

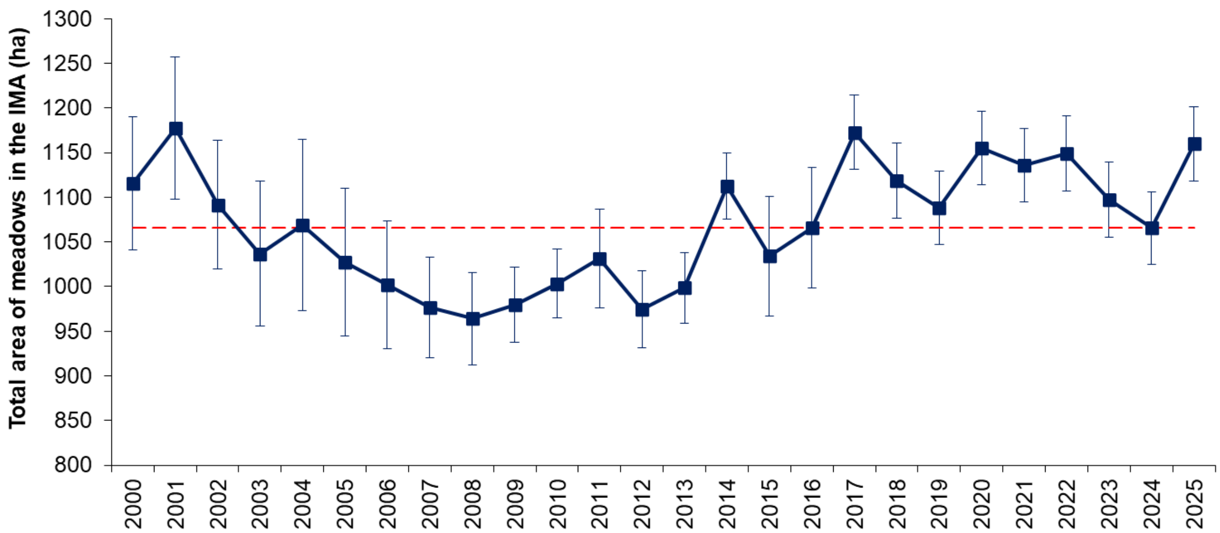


Figure 11. Total area of seagrass within the Intensive Monitoring Area from 2000 to 2025 (error bars = "R" reliability estimate). Red dashed line indicates 24-year mean of total meadow area.

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

The Weipa monitoring meadows were in an overall good condition in 2025 (Table 4). The overall condition of seagrass in the core monitoring meadows has been satisfactory or better over the last seven years, with the exception of meadow A3 in 2023 in which was very poor due to absence of *H. uninervis* that year (Table 4).

Table 4. Grades and scores for seagrass indicators for 2025 in the port of Weipa.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
A2	0.78	0.83	0.70	0.74
A3	0.86	0.87	0.96	0.86
A5	1.00	0.77	0.97	0.77
A6	1	1	0.73	0.86
A7	1	0.75	0.85	0.75
Overall Score for the Port of Weipa				**0.79**

= 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 or very good condition in 2025. 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 2025 seagrass condition was good with no change in the overall condition from last year (Table 4; Figure 14). Meadow biomass did decrease slightly from the previous year, however remained in a good condition in 2025. This is the ninth consecutive year seagrass biomass has been at or above the long-term average. Meadow extent has been at or above the long-term average for the last thirteen years (Figure 14). This meadow had a low to moderate amount of burning observed on *E. acoroides* leaves throughout the footprint.

Meadow A6: Overall meadow condition was rated very good, improving from good in the previous year (Table 4; Figure 17). All three indicators recorded improvements, with biomass showing the most notable change and was the highest recorded since monitoring began in 2000 (Figure 17). There was also a shift in species composition, with *E. acoroides* becoming more dominant, particularly along the northern waterline of the meadow where it occurred at higher densities than previous years (Figure 17). The area of seagrass in Meadow A6 remained above the baseline mean for the ninth consecutive year.

Meadow A7: The overall meadow condition was good in 2025 (Table 4; Figure 18). Seagrass biomass increased from last year and was the highest recorded since monitoring began with 31.5 ± 3.8 g DW m^{-2} (Figure 18). This was due to the increase in density of *E. acoroides* throughout the meadow with the aggregated patches expanding their density 'hot spots' (areas of higher biomass). The area of this meadow was on par with the long-term average at 16.81 ± 1.3 ha in 2025. The species composition of this meadow has remained consistently dominated by *E. acoroides* and contains smaller patches of *H. ovalis* and *H. uninervis* (narrow).

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

The *H. uninervis dominated* monitoring meadows were in a very good and good condition in 2025. The A3 meadow had a continuous cover of seagrass, while the A5 meadow had a dense, mostly continuous cover of seagrass.

Meadow A3: All 3 condition indicators improved which resulted in overall meadow condition being very good in 2025. Biomass has continued to improve since its absence in 2023, due to the return of foundation species *H. uninervis* in the meadow and surrounding area. The footprint of this meadow is the largest since 2021, and above the long-term average (35 ha) with 41 ± 2.3 ha in 2025 (Table 4; Figure 15; Appendix 8.1).

Meadow A5: For the past seven years the overall meadow condition has remained in good condition (Table 4; Figure 16; Appendix 8.1). Meadow biomass remained in a very good condition in 2025. The area of this meadow increased slightly and remains in a good condition. The species composition of this meadow is dominated by *H. uninervis* (60%), with *Thalassia hemprichii* making up a significant proportion (36%) of the rest of the biomass.

The browning of *E. acoroides* leaves is known as burning and indicates stress associated with high temperatures and desiccation when exposed to air at low tide which may lead to the death of seagrass leaves (Unsworth et al. 2012). In 2025 burning on the tips of leaves was observed at 12.5% of sites in the IMA (Figure 12). This was a decrease compared to the previous year most likely due to the reduction in the total amount of hours of seagrass was exposed to air and sunlight (Figure 21a).

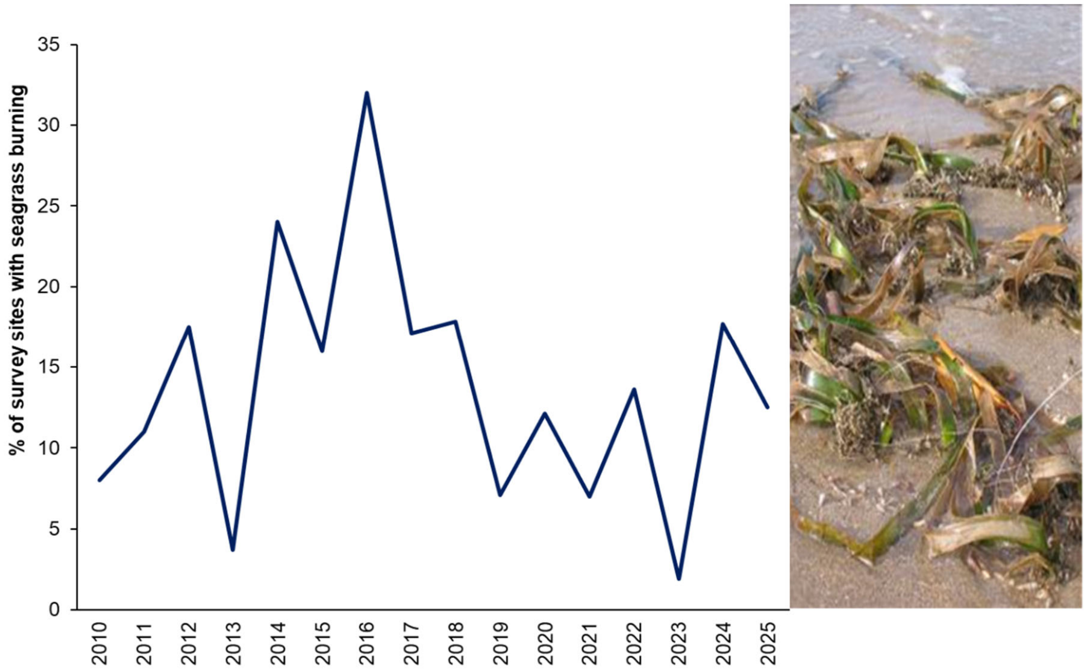


Figure 12. Percentage of sites within the IMA that had evidence of *Enhalus acoroides* leaf burning.

Dugong feeding trails were recorded in the *H. ovalis* and *H. uninervis* patches in the A5 and A2 monitoring meadow on the eastern and western 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 2025.

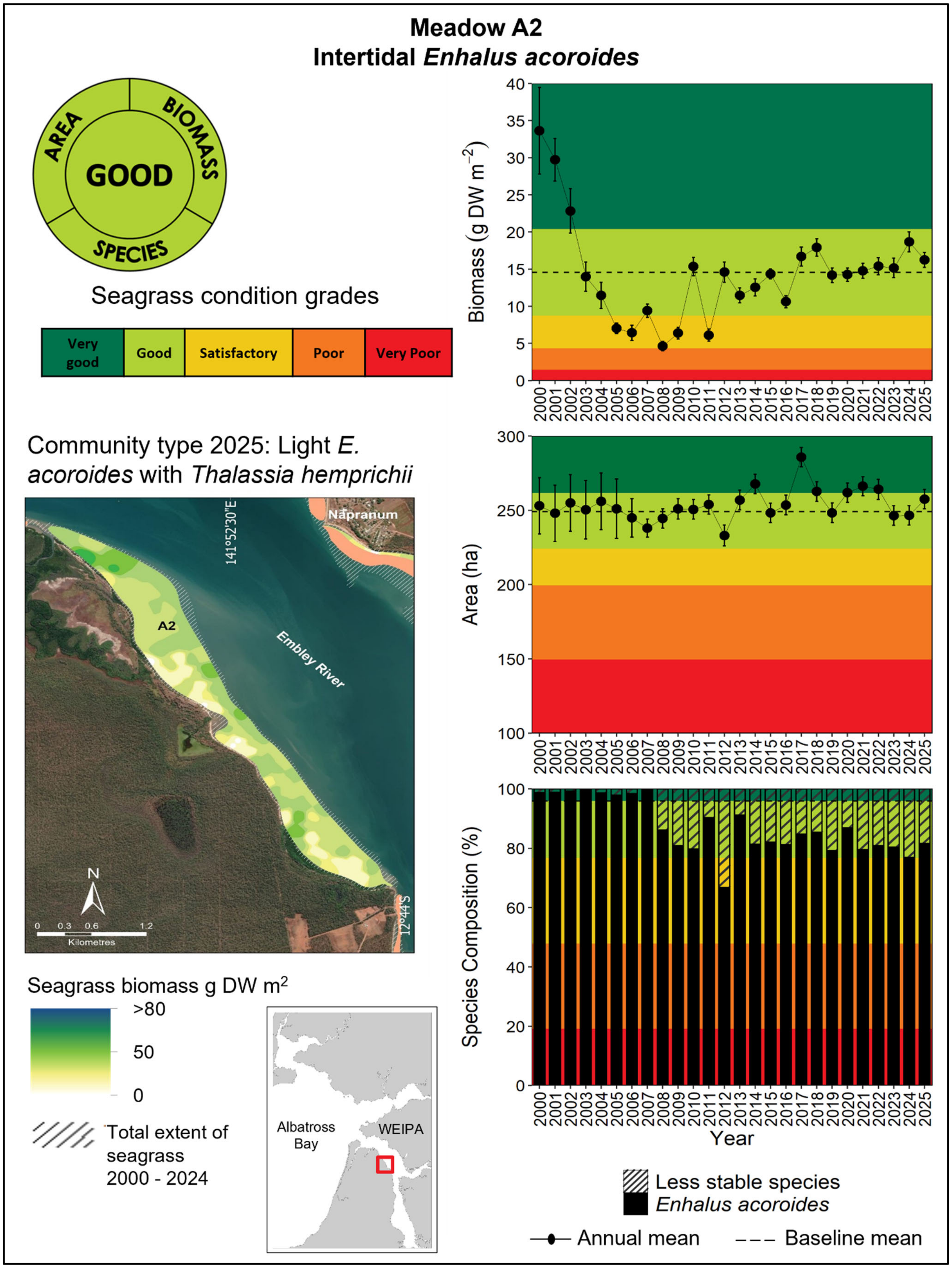


Figure 14. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A2 in Weipa; 2000 to 2025 (biomass error bars = SE; area error bars "R").

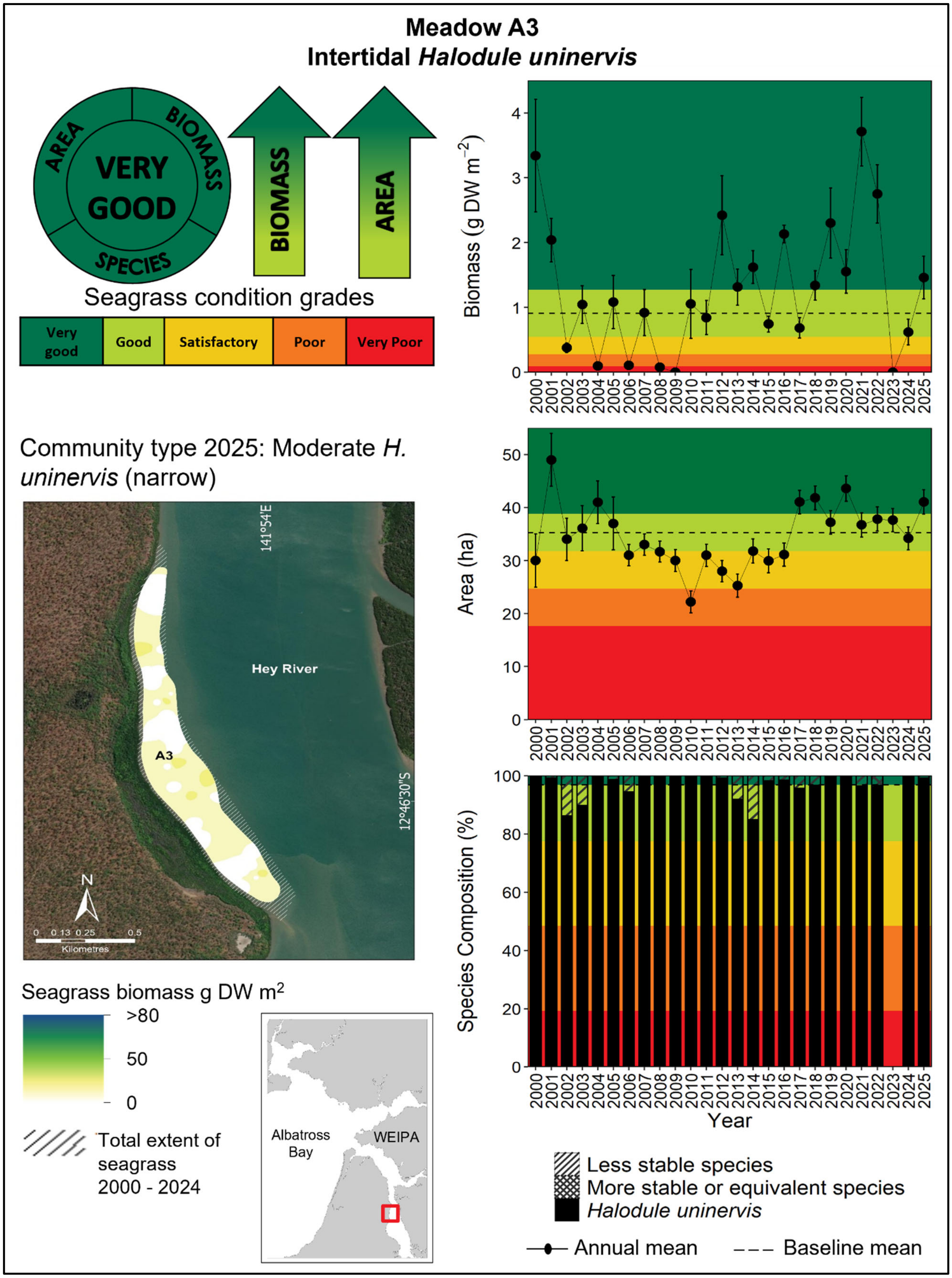


Figure 15. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A3 in Weipa; 2000 to 2025 (biomass error bars = SE; area error bars "R"). *The area of meadow A3 is based on the presence of *E. acoroides* in the meadow not *H. uninervis* – *H. uninervis* is the species that is 'tracked', monitored and grades based upon.

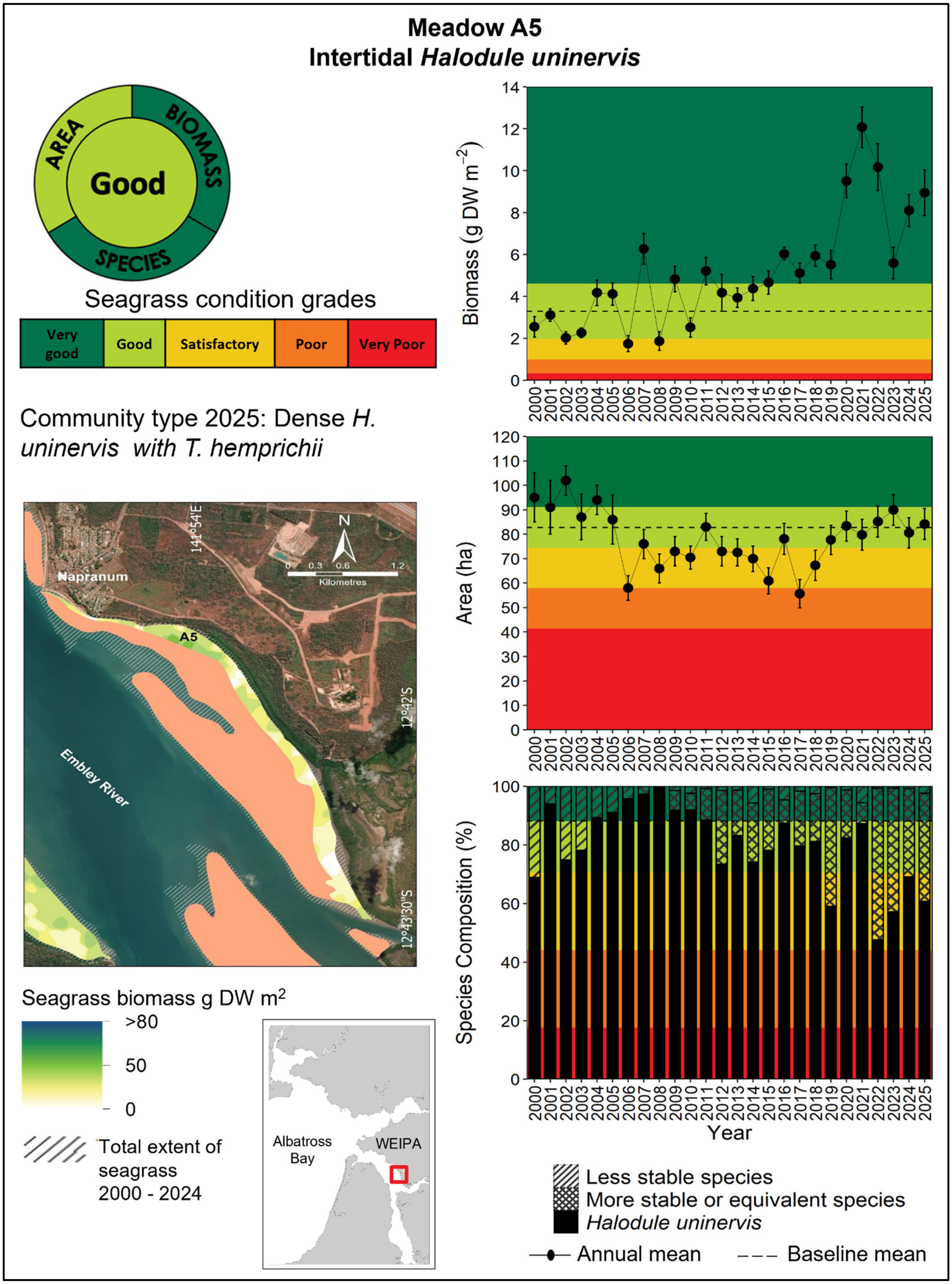


Figure 16. Changes in biomass, area and species composition for the *H. uninervis* dominated core monitoring meadow A5 in Weipa; 2000 to 2025 (biomass error bars = SE; area error bars "R").

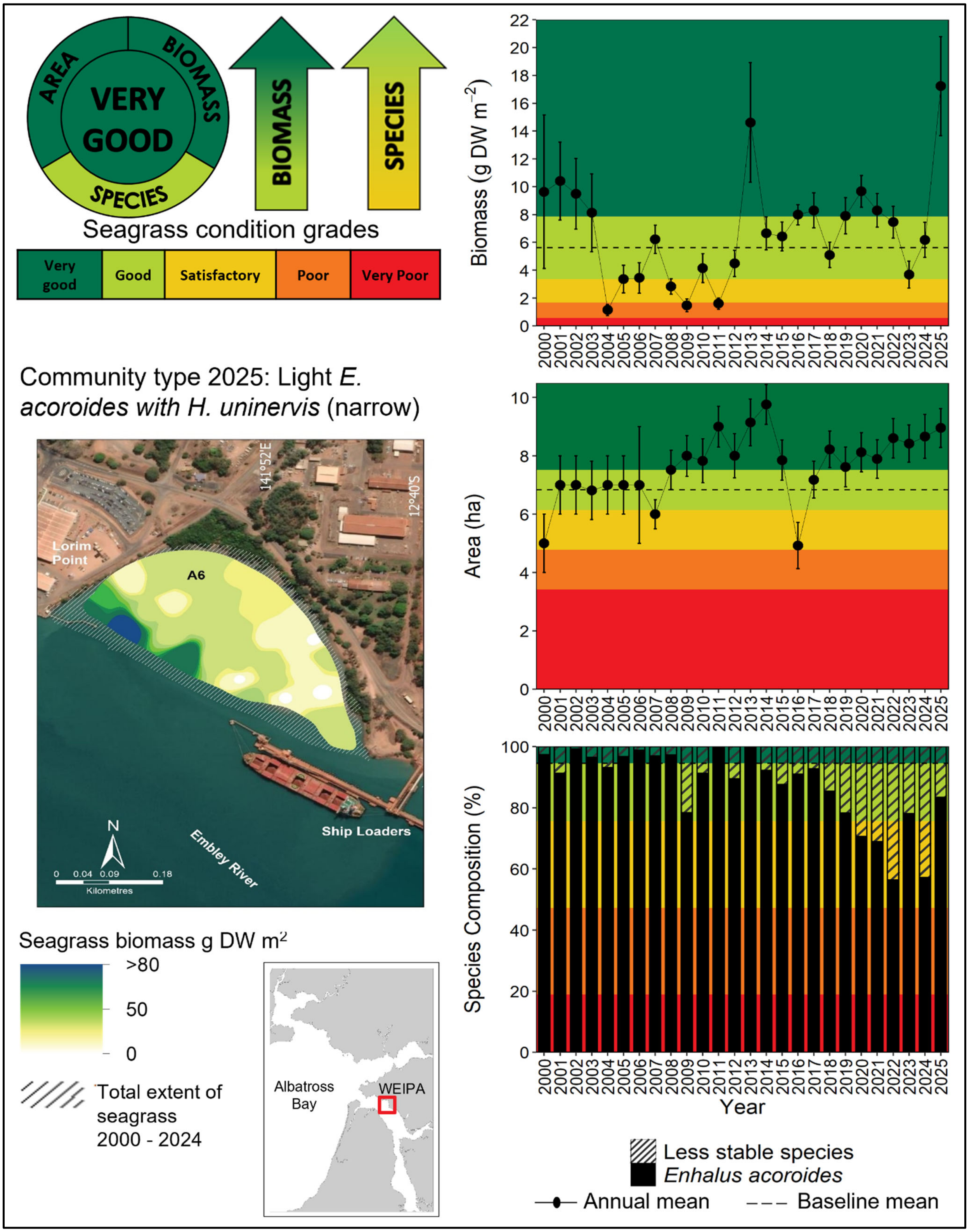


Figure 17. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A6 in Weipa; 2000 to 2025 (biomass error bars = SE; area error bars "R").

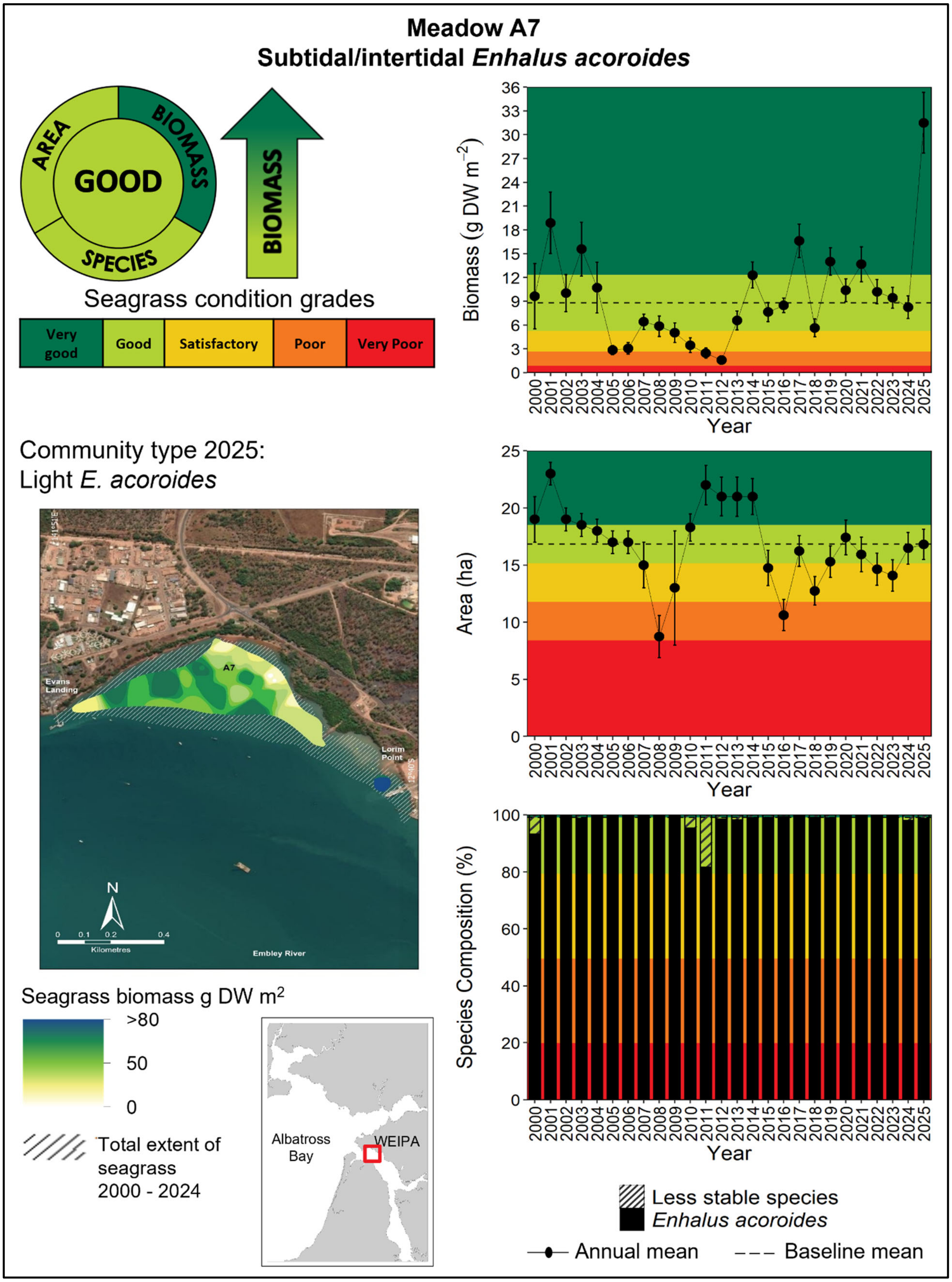


Figure 18. Changes in biomass, area and species composition for the *E. acoroides* dominated core monitoring meadow A7 in Weipa; 2000 to 2025 (biomass error bars = SE; area error bars "R").

5.3 Seagrass condition in the broader Port of Weipa

In 2025 a reconnaissance of seagrasses in the broader port limits was conducted to provide an update on seagrass condition since the last full broadscale survey in 2023. In 2025, the footprint and species composition of meadows were observed to be similar to the previous year. Some meadows that had reappeared in 2024 after being last seen in 2002, persisted in 2025 and in some cases showed further expansion (Figure 19).

In the Mission River the small *H. ovalis*, *H. uninervis*, and *E. acoroides* meadows that reappeared in 2024 remained present in 2025. The Pine River Bay meadows also persisted with some expansion along the narrow banks to join up with other patches that were observed in 2024. 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 (Figure 19). The Hey River meadows also increased in size with patches of *H. uninervis* joining up to form a longer continuous meadow, similar to what was recorded in the 2020 survey and also included dugong feeding trials. In the Embley River *H. uninervis* persisted in small, aggregated patches within the pools on the bank. Similar to last year dugong feeding trails were recorded in the *H. uninervis* meadows in all the broader harbour meadows (Figure 19). These areas will be formally mapped and assessed in the next annual survey in 2026 as part of the established three year cycle.

Figure 19. *E. acoroides* and *T. hemprichii* meadows in Pine River Bay and the Mission River, Dugong feeding trails in the H. uninervis meadows in the broader harbour meadows 2025.

5.4 Weipa climate conditions

5.4.1 Rainfall

Annual rainfall in Weipa was lower than in the previous two years (2,028 mm) and was close to the long-term average of 1,893 mm in 2024/2025 (Figure 20a). In the three months leading up to the August survey, monthly rainfall was below average, while above-average rainfall occurred in February 2025, around six months prior to the survey (Figure 20b).

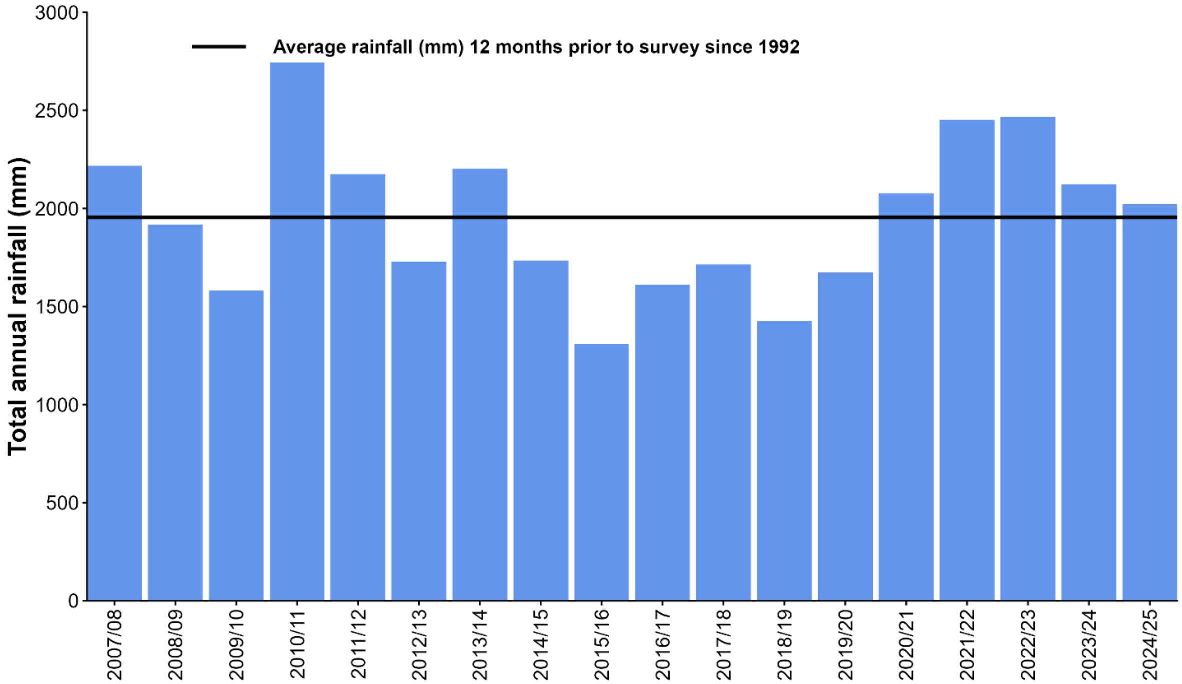


Figure 20a. Total annual rainfall recorded at Weipa Airport in the 12 months prior to each survey (November to October *standardised across all monitoring locations to capture the same wet season months); 2007-2025.

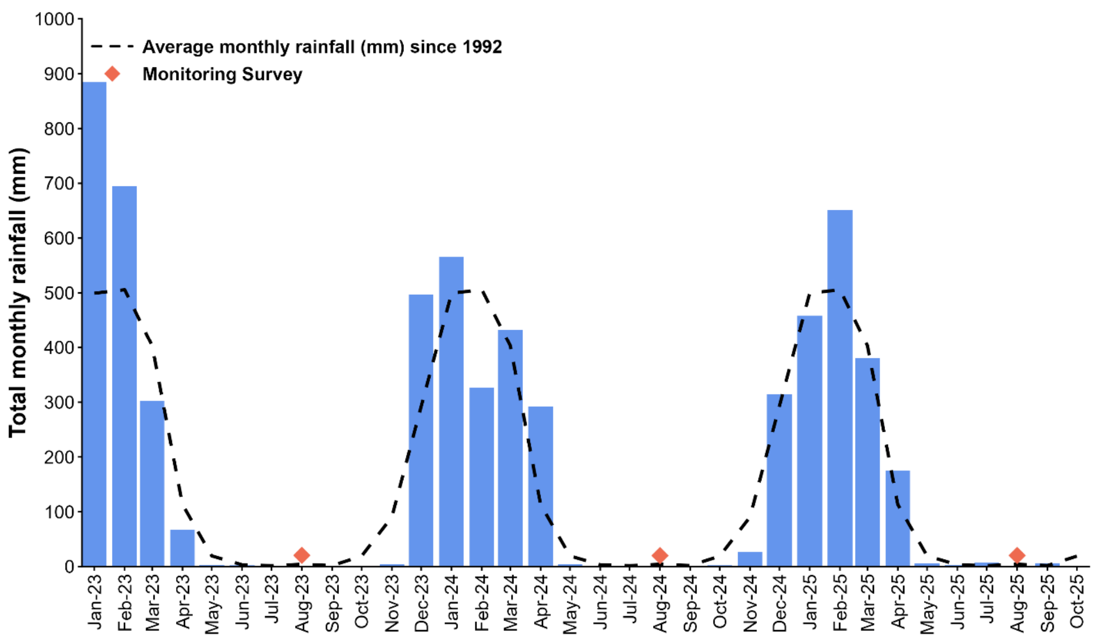


Figure 20b. Total monthly rainfall (mm); January 2023 – October 2025.

5.4.2 Daytime Tidal Exposure

Intertidal meadows in Weipa were exposed to daytime air for 290 hours in the twelve months prior to the 2025 survey, which is below the long-term average of 395 hours (Figure 21a). Daytime tidal exposure was below average in the month prior to the survey, and also for the preceding two months (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).

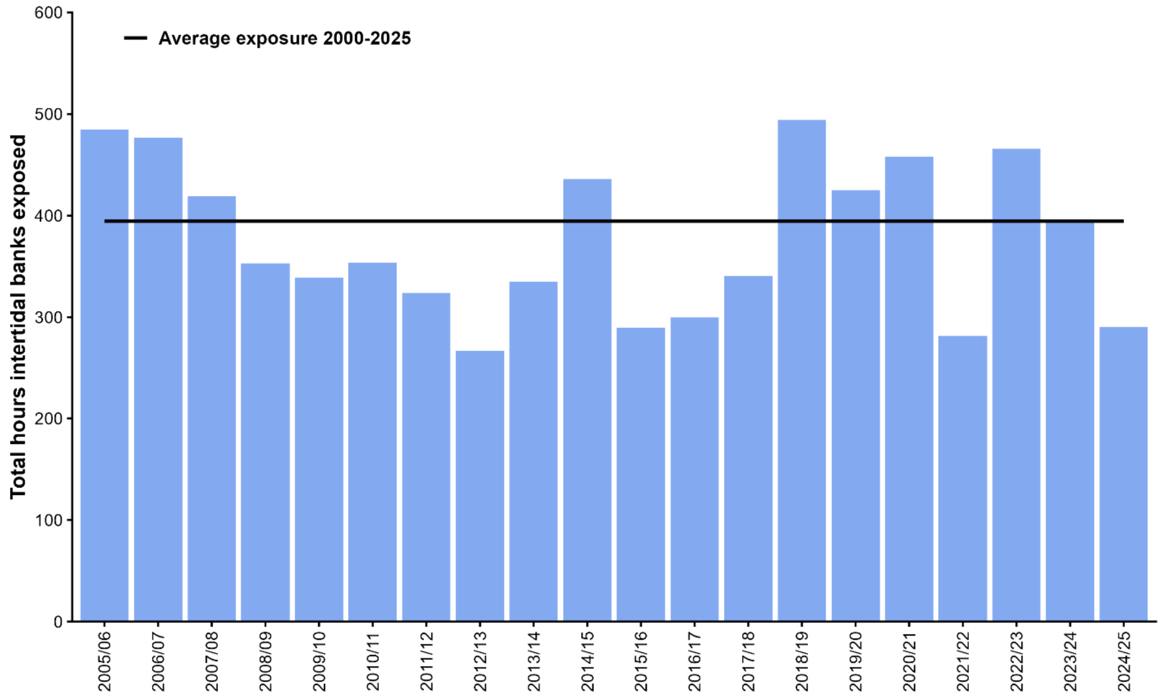


Figure 21a. Total daily tidal exposure to air 2005/06 -2024/25. Data is twelve months prior to survey (November to October *standardised across all monitoring locations to capture the same wet season months).

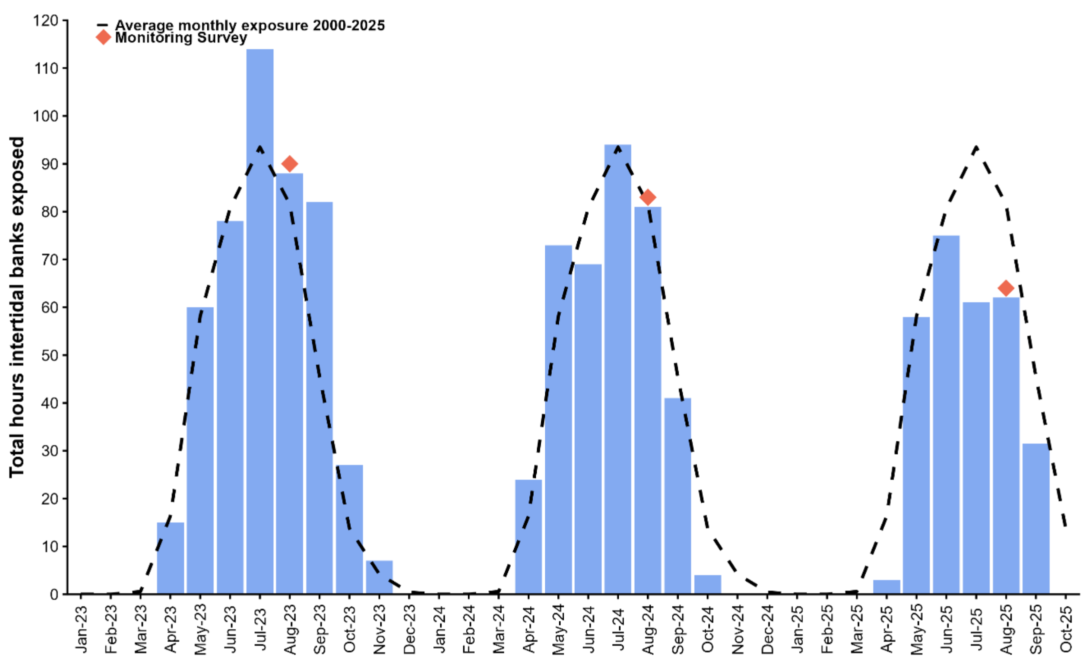


Figure 21b. Monthly total daytime tidal exposure to air (hours; ≤0.9m tidal height); January 2023–October 2025.

5.4.3 Photosynthetically Active Radiation (PAR (light))

In Weipa, the wet season (December to March) brings higher rainfall, increased cloud cover, and elevated river flows, resulting in benthic light levels (PAR) that are typically below the ideal growing thresholds for most seagrass species. Total daily PAR is measured in the shallow intertidal meadow on the south-western bank of the Embley River (A2), and in the deeper meadows between Evans Landing and Lorim Point (meadows A6 and A7) (Figure 10).

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

PAR dropped below the thresholds at all logger sites from January to February 2025 which coincided with above average rainfall in those months (Figure 22b). The durations of low light at these meadows differed, with the A2 meadow experiencing low light for a shorter period of 42 days, while meadow A6 and A7 had low light for up to 140 days, which is a longer duration than the previous year (23 days in A2; 108 days in A7) (Figure 22b). The range of PAR in the deeper A6 and A7 meadows was greater than previous years with 0.01 – 31.50 mol m^{-2} day^{-1} in 2025 (2024: 0.50-22.49 mol m^{-2} day^{-1}) (Figure 22a). Overall, the duration of light below the threshold was longer and the range of par readings was greater with both the lower and upper ranges in 2025. In the months leading up to the 2025 monitoring survey PAR was substantially above minimum requirements at all sites and substantially higher than the equivalent period of time in the previous year, likely providing ideal growing conditions for seagrasses.

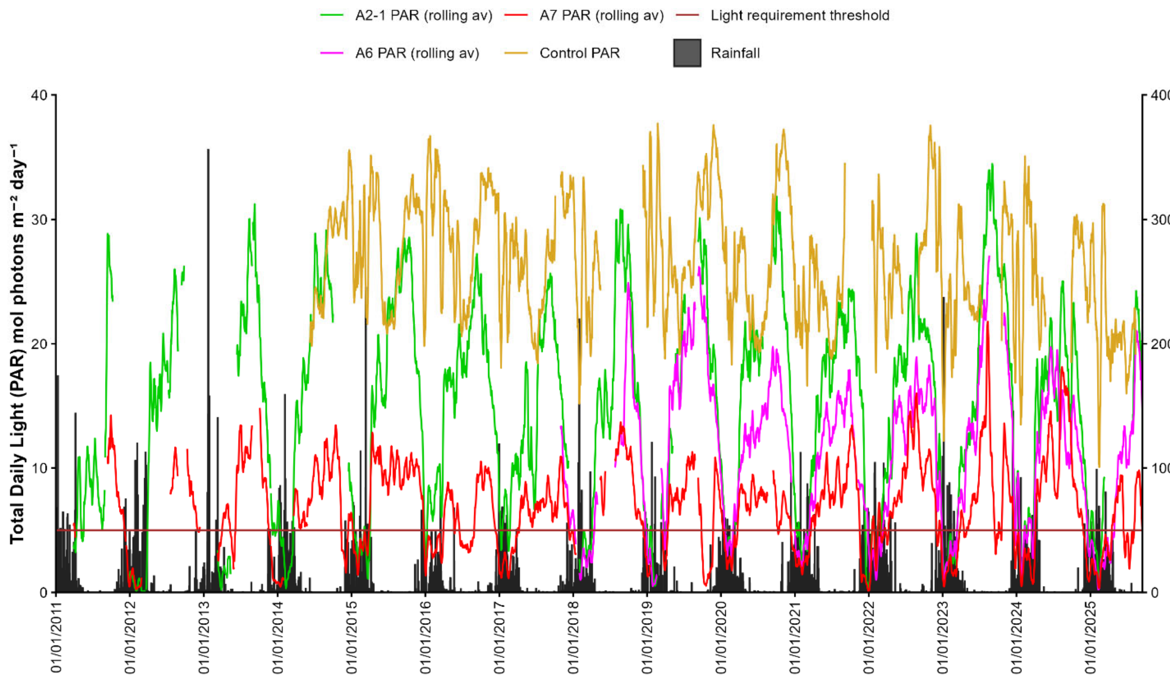
PAR is normally lower in the deeper meadows (A6 and A7) than the shallower A2 meadow, due to greater light attenuation with depth of water and shorter periods of low tide exposure to air. However, in the twelve months prior to the seagrass survey PAR ranged from (see Figure 22a):

- Control logger (above water): 2.48 – 44.65 mol m^{-2} day^{-1}.
- A2 intertidal meadow: 0.13 – 30.71 mol m^{-2} day^{-1}.
- A6 intertidal/subtidal meadows: 0.01 – 31.50 mol m^{-2} day^{-1}.
- A7 intertidal/subtidal meadows: 0.01 – 23.34 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 2024/2025 at each site meadow was (Figure 22b):

- A2: 42 days below threshold January 2025 – February 2025.
- A6: 134 days below threshold December 2024 – April 2025.
- A7: 140 days below threshold November 2024 – April 2025.

a)



*A6 PAR site established late 2017

b)

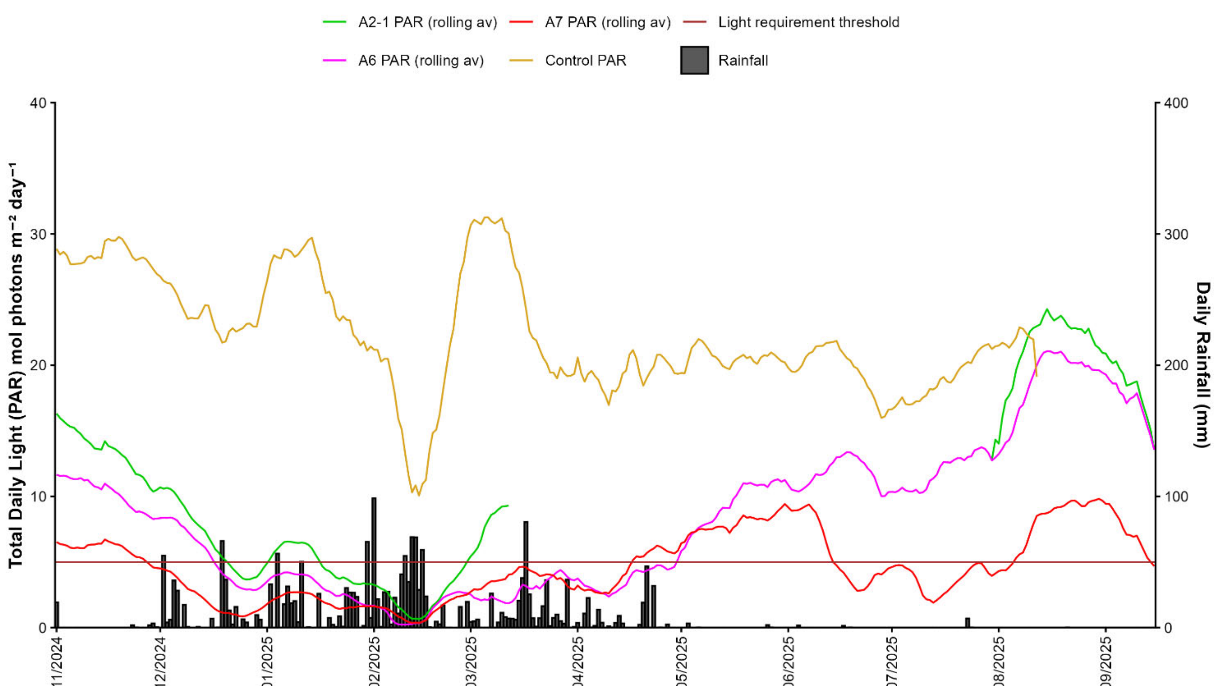


Figure 22 (a) Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) and total daily rainfall (mm) at Weipa; January 2011 – August 2025. **(b)** Period of low light over the 2024-2025 wet season. Note: Between March and August 2025, A2 logger was fouled upon retrieval and therefore was unable to record PAR during deployment.

6 DISCUSSION

Seagrasses in the Port of Weipa were in an overall good condition in 2025. Meadow area and biomass were in good condition or better for all monitoring meadows, with the (A3) *Halodule uninervis* meadow achieving very good grades for all three condition indicators. Seagrasses also retained or improved condition in the broader survey area (outside of the IMA) including Pine River Bay, Mission River, Hey River and Embley River. Significant numbers of dugong feeding trails were observed in monitoring meadows, as well as in the broader port limit areas including Pine River Bay, Mission River and Hey River.

Four of the five monitoring meadows in the Port of Weipa had very good condition for biomass which indicates favourable growing conditions in 2025. The *H. uninervis* monitoring meadow A3 saw further improvements in biomass which attributed an overall very good condition for the first time since 2020. This is a notable improvement after *H. uninervis* was absent in this meadow in 2023. Both the *E. acoroides* meadows A6 and A7, recorded the highest biomass since monitoring began in 2000, with long leaf blades estimated to be up to 1 meter long.

A second consecutive year of near-average wet season conditions likely created a favourable growing environment, enabling *H. uninervis* to recover further and *E. acoroides* to improve in density. Only one month of above-average rainfall (February 2025) occurred in the 12 months preceding the survey, compared to four months in the previous year. Additionally, the number of hours that intertidal meadows were exposed to air was well below average in 2025, resulting in fewer observations of burnt leaf tips and a likely reduction in exposure related stress to seagrasses (Unsworth et al 2012).

These improvements occurred despite benthic light (PAR) being below seagrass growth requirements for an extended period of time during the wet season months. This occurs every year in Weipa and while the longest continuous duration of below ideal PAR was more than it was for 2024, seagrasses had improved by August 2025 over the previous year's results. This suggests that light reductions were not prolonged enough to substantially impact *E. acoroides* in the long-term. It is possible that the long (up to 1 m) leaf blades of *Enhalus acoroides* were able to float at or near the water surface, thereby maintaining photosynthetic function even when benthic light conditions were sub-optimal (Duarte, 1991, Larkum *et al*. 2018). In addition, PAR post the wet season was substantially higher than in previous recent years providing ideal growing conditions for seagrass to recover from any wet season impacts and restore resilience by the time of the survey in August. This persistent species stores large carbohydrate reserves within below-ground structures (Kilminster et al. 2015), which likely supports resilience during periods of reduced light.

Seagrass monitoring is also conducted elsewhere in 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.* 2025). Seagrass was in an overall good condition around Thursday Island in 2025 with improvements also noted in the *Enhalus* meadows due to improved climate conditions in the months leading up to the survey (Scott *et al.* 2025). However, the condition of seagrasses to the south in Karumba differ and were in a poor condition with a reduction in biomass and area in 2025, due to cumulative stressors from the past few wet seasons and consecutive years of flooding from local rivers (Scott and Rasheed 2026). The Kurumba meadow is dominated by *H. uninervis* the same as the A3 and A5 meadows in Weipa. Declines in *H. uninervis* meadows in Karumba but not Weipa demonstrate how local conditions and cumulative climate impacts can reduce seagrass condition. In Kurumba there was a extended presence of a turbid plume over the meadows, unlike Weipa where this didn't occur. Many areas on the east coast of Queensland such as Cairns, Mourilyan and Townsville also had climate related losses of seagrasses in 2025 (Scott *et al.* 2026, Shepherd et al. 2026, Tol *et al.* 2026).

Overall, the good condition of seagrass meadows in Weipa in 2025 indicate that these systems should have a good level of resilience to natural or anthropogenic disturbances going into 2026. The high biomass and stable meadow extent in 2025 suggest these habitats are well positioned to continue to support key ecosystem functions. If favourable environmental conditions persist, these meadows are likely to maintain adequate energy reserves and reproductive capacity, supporting their longer-term persistence within the Port of Weipa.

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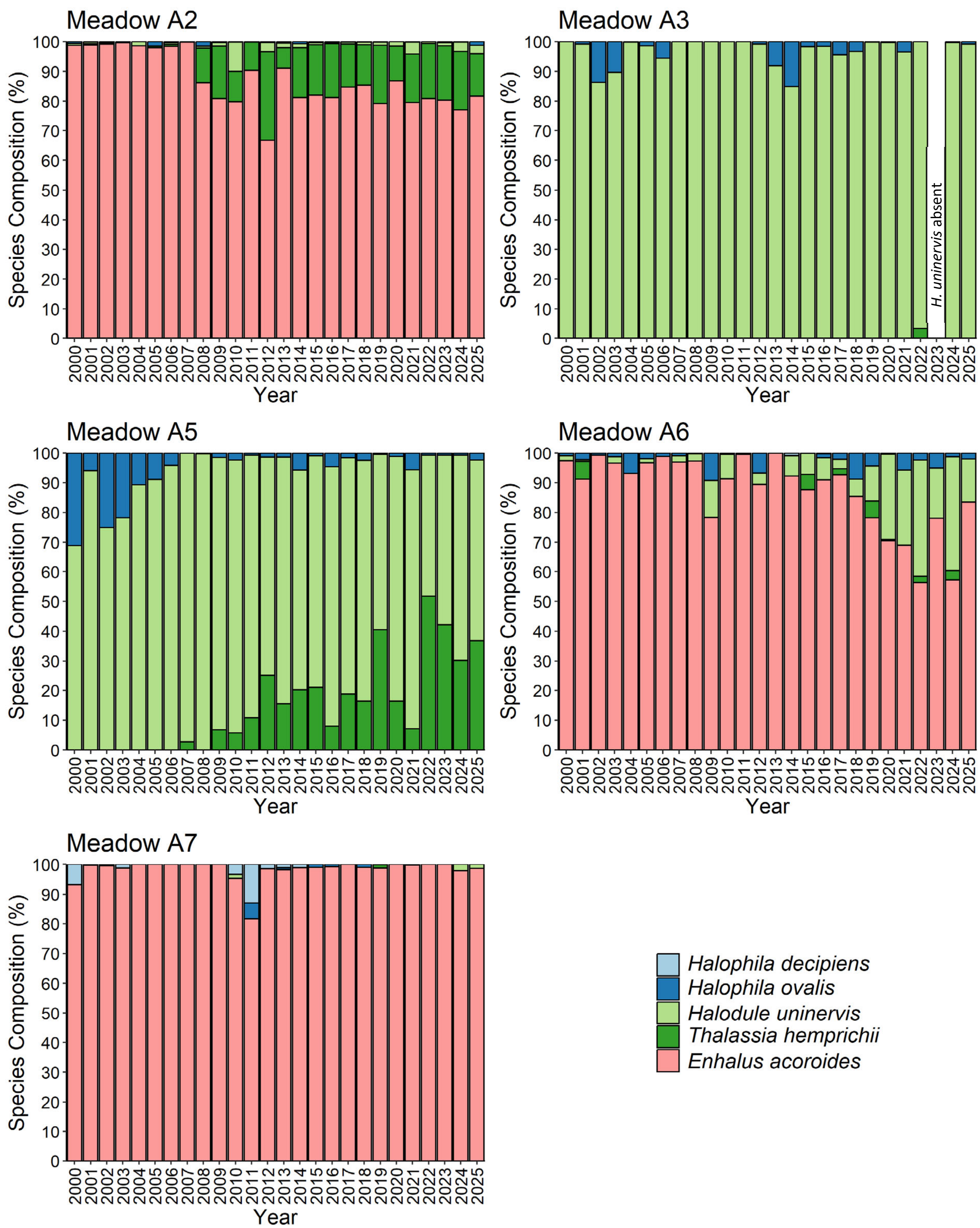
8 APPENDICES

8.1 Detailed meadow species composition; 2000 – 2025



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 – 2025.

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**
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)
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)
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)
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)
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)

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)												
	Sep 13	**Aug 14**	**Sep 15**	**Aug 16**	**Aug 17**	**Sep 18**	**Sep 19**	**Aug 20**	**Aug 21**	**Aug 22**	**Aug 23**	**Aug 24**	**Aug 25**
A2 Intertidal *Enhalus* dominated	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)	16.24 ± 1.02 (104)
A3 Intertidal *Halodule* dominated	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)	1.46 ± 0.33 (44)
A5 Intertidal *Halodule* dominated	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)	8.94 ± 1.08 (56)
A6 Intertidal/ subtidal *Enhalus* dominated	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)	17.22 ± 3.56 (35)
A7 Intertidal/ subtidal *Enhalus* dominated	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)	31.50 ± 3.82 (39)

8.3 Meadow above-ground biomass and area

Total meadow area + R (ha) for each core monitoring meadow within the Port of Weipa, 2000 – 2025.

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	Sep 13	Aug 14	Sep 15	Aug 16	Aug 17	Sept 18	Sep 19	Aug 20	Aug 21	Aug 22	Aug 23	Aug 24	Aug 25
A2 Intertidal *Enhalus* dominated	253 ± 19.0	248 ± 19.0	255 ± 19.0	250 ± 19.7	256 ± 19.0	251 ± 20.0	245 ± 13.0	238 ± 6.0	244.5 ± 6.6	251 ± 7.0	250.7 ± 6.5	254 ± 6.5	233 ± 7.0	256.9 ± 6.6	267.7 ± 6.5	248.3 ± 6.5	253.6 ± 6.56	285.8 ± 6.51	262.6 ± 6.62	248.3 ± 6.61	261.9 ± 6.49	266.3 ± 6.39	264.1 ± 6.80	246.4 ± 6.62	246.6 ± 6.59	257.5 ± 6.53
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	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	41 ± 2.3
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	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	84.2 ± 6.3
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	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	8.96 ± 0.66
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	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	16.8 ± 1.32
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**	**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**	**408.47 ± 17.10**