Seagrass Habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2024

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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

Cairns Harbour
Seagrass condition
2024

Satisfactory

Trinity Inlet
Seagrass condition
2024

Poor

- This report presents results of the 24th annual survey for the long-term Seagrass Monitoring Program and the eighth whole of port survey for Cairns Harbour and Trinity Inlet.
- This survey occurred 8 months after Tropical Cyclone Jasper and the associated record flooding which significantly impacted on coastal marine habitats in the region.
- While seagrasses declined in 2024, the major meadows within Cairns Harbour remained largely intact with good coverage and biomass of the key species.
- The smaller highly variable meadows in Trinity Inlet collectively remained in a poor condition in 2024, with declines in area and the complete loss of the small *Zostera muelleri* Redbank Meadow (Meadow 20).
- Outside of the 6 annually monitored meadows, the whole of port survey mapped 9 additional meadows with total seagrass area of 1,297ha, a 13% reduction since last whole of port survey in 2021.
- Record rainfall and flooding in the region due to Cyclone Jasper in December 2023, was likely to have had a major impact on seagrasses creating unfavourable conditions for seagrass growth.
- Low light (PAR) associated with these events was likely the primary driver of seagrass declines in the Trinity Inlet meadows with benthic light below the minimum requirements for *Z. muelleri* for extended periods.
- In Cairns Harbour light conditions were better, with seagrasses receiving light above their thresholds on the Esplanade and were only below growth requirements for sub-tidal Bessie Point meadows for short periods of time around the floods.
- Seed banks remained for meadows in Cairns Harbour, although density and viability of *Z. muelleri* seeds remained low and *Halodule uninervis* seed density declined in 2024.
- The satisfactory condition of the Harbour meadows indicates they are well placed to continue to build resilience with favourable growing conditions in the year ahead and were likely to remain resilient to planned annual maintenance dredging and port activity. The Trintiy Inlet meadows are variable from year to year and have proven quick to recover once growing conditions improve.

2. IN BRIEF

Seagrasses have been monitored annually in Cairns Harbour and Trinity Inlet since 2001. Each year six seagrass monitoring meadows representing the range of different seagrass community types found in Cairns are mapped and assessed for changes in area, biomass, and species composition. These metrics are then used to develop a seagrass condition index from very poor to very good (Figure 1). All seagrasses within the port limits are also remapped every three years as part of the long-term monitoring program.

Annual assessments of the seagrass seed bank density and viability are also conducted in the Esplanade and Bessie Point meadows. Benthic light and temperature (continuously logged) is also monitored in these meadows (Site E and B; Figure1) as well as at Trinity Inlet adjacent to the Redbank Creek meadow (Site R; Figure 1).

Despite the record flooding from Cyclone Jasper in December 2023, the large coastal meadows in Cairns Harbour were in an overall satisfactory condition in 2024, a decline from good condition in 2023. The meadows declined in both area and biomass however overall area remained above the long-term average (Figure 2).

The Bessie Point monitoring meadows (11 & 13) and the large Esplanade meadow (34) were all in an overall satisfactory condition, with all three condition indicators varying from satisfactory to very good (Figure 1).

The three smaller Trinity Inlet estuarine monitoring meadows remained in an overall poor condition in 2024. Area declined for the two highly variable *Halophila* meadows (19 & 33), but species composition remained in good or very good condition (Figure 1). The small Redbank *Z. muelleri* meadow (20) was absent in 2024.

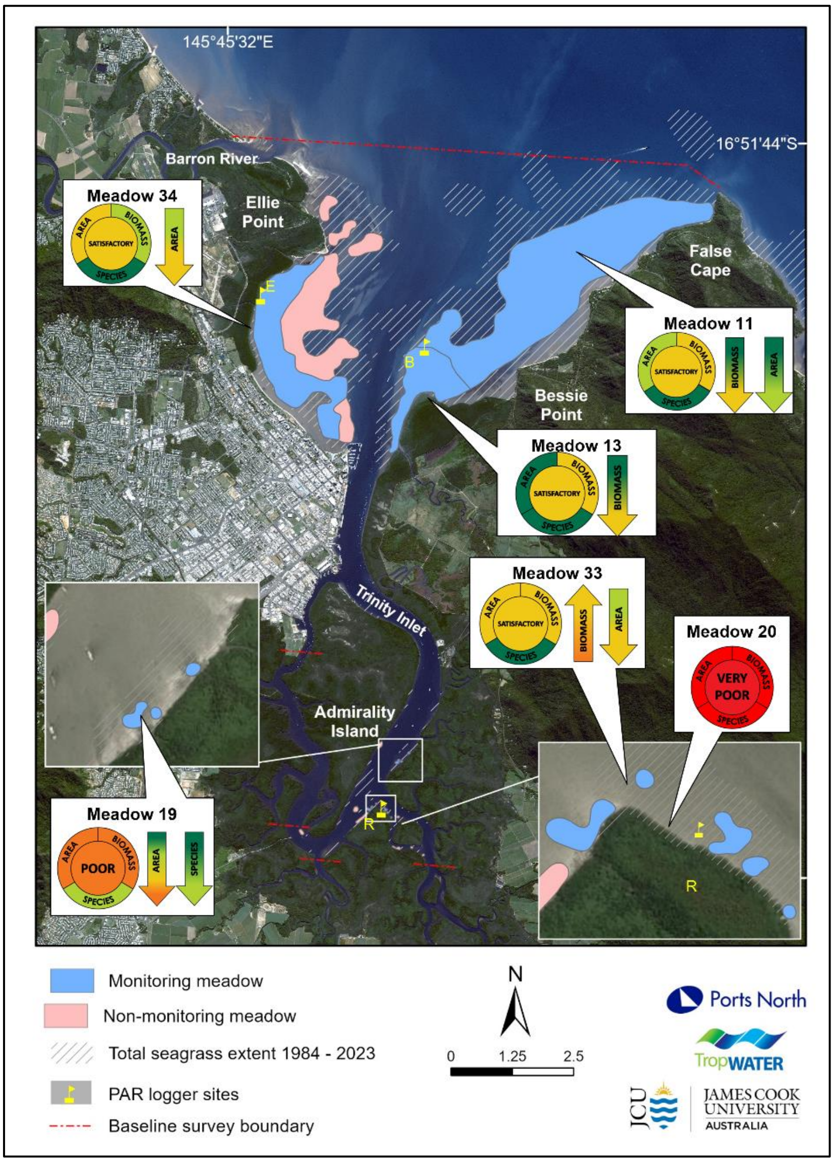


Figure 1. Seagrass monitoring meadow condition in Cairns Harbour and Trinity Inlet, 2024.

Sustained periods of low benthic light (PAR) during 2024 were the likely causes of seagrass declines in the Trinity Inlet meadows. Record river flow and above average rainfall due to Cyclone Jasper in December 2023 were a major contributor to the low light (PAR) levels recorded (Figure 3). For much of the year benthic PAR was well below the growth requirements for seagrasses in Trinity Inlet. In Cairns Harbour where seagrasses were in satisfactory condition, benthic PAR remained above seagrass growth requirements in the Esplanade meadow throughout 2024 and was only below requirements at Bessie Point for a shorter period in the months following the cyclone.

In 2024 seed banks remained in both of the meadows assessed. However, *H. uninervis* seeds were present only in the Bessie point meadow after consistently being recorded in both meadows over the past five years. *Z. muelleri* seeds were again present in the Esplanade meadow, but as with the past couple of years, were at very low density, and none of the seeds collected since 2020 have been viable.

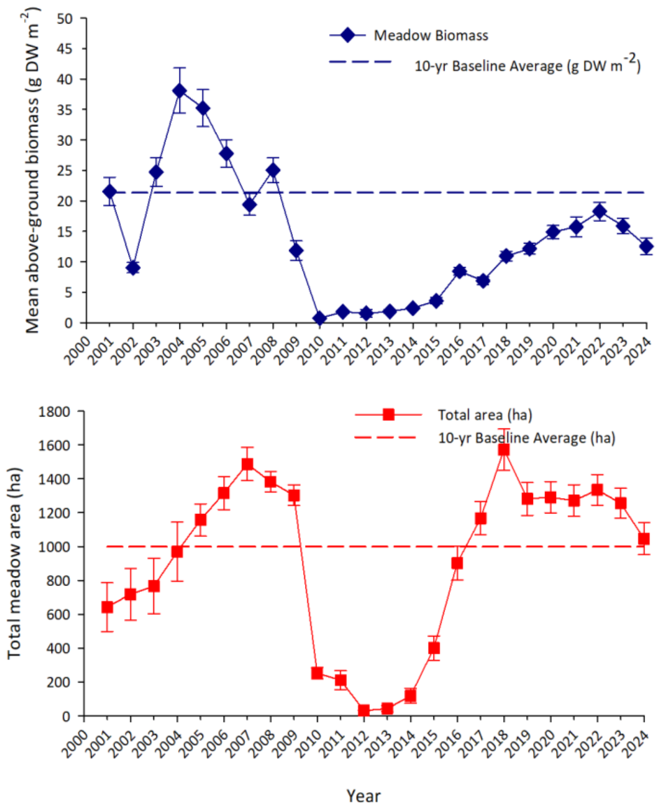


Figure 2. Total a) biomass and b) area of seagrass within all Cairns monitoring meadows from 2001 to 2024. Dotted line indicates 10-year (2001 – 2010) baseline mean.

Although there were overall declines in seagrass biomass and area during 2024, the continued presence of persistent seagrass species and maintenance of area above the long term average for the larger Cairns Harbour meadows has likely maintained the key seagrass ecosystem services. These include food for dugong and green turtles, nursery habitat for juvenile fish and prawns, improved water quality through the trapping of suspended sediments and the capture and storage of carbon and nitrogen in plant tissues and sediments.

The ability for seagrasses in the harbour to maintain a satisfactory condition despite the major floods associated with Cyclone Jasper was likely due to the high levels of resilience that have built up over the last 7 years. It is likely that these meadows will further increase with favourable weather conditions and that they should remain resilient to planned annual maintenance dredging.

The Cairns Harbour and Trinity Inlet seagrass monitoring forms part of a broader program that examines condition of seagrasses in most Queensland commercial ports and areas of high cumulative anthropogenic risk. In Mourilyan Harbour, the nearest monitoring site to Cairns, seagrass has not recovered from the widespread losses between 2009 and 2011, largely due to the complete loss of the foundation species *Z. muelleri* (Shepherd et al. 2025). Across the wider Queensland seagrass monitoring network, seagrass condition has varied, with some areas showing signs of recovery while others declined. In general, these reflected local climate and weather conditions, similar to observations in Cairns. Seagrass in the Gulf of Carpentaria were in a good condition in Weipa with favourable climate and poor in Karumba where flooding locally impacted seagrasses (Reason et al. 2025a; Scott and Rasheed 2025). On the east coast, Townsville seagrass was in a poor condition due to a range of unfavourable weather conditions over the past six years (McKenna et al. 2025a) and in Gladstone seagrasses were in good condition reflecting favourable growing conditions (Reason et al. 2025b).

For full details of the Queensland ports seagrass monitoring program see
https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

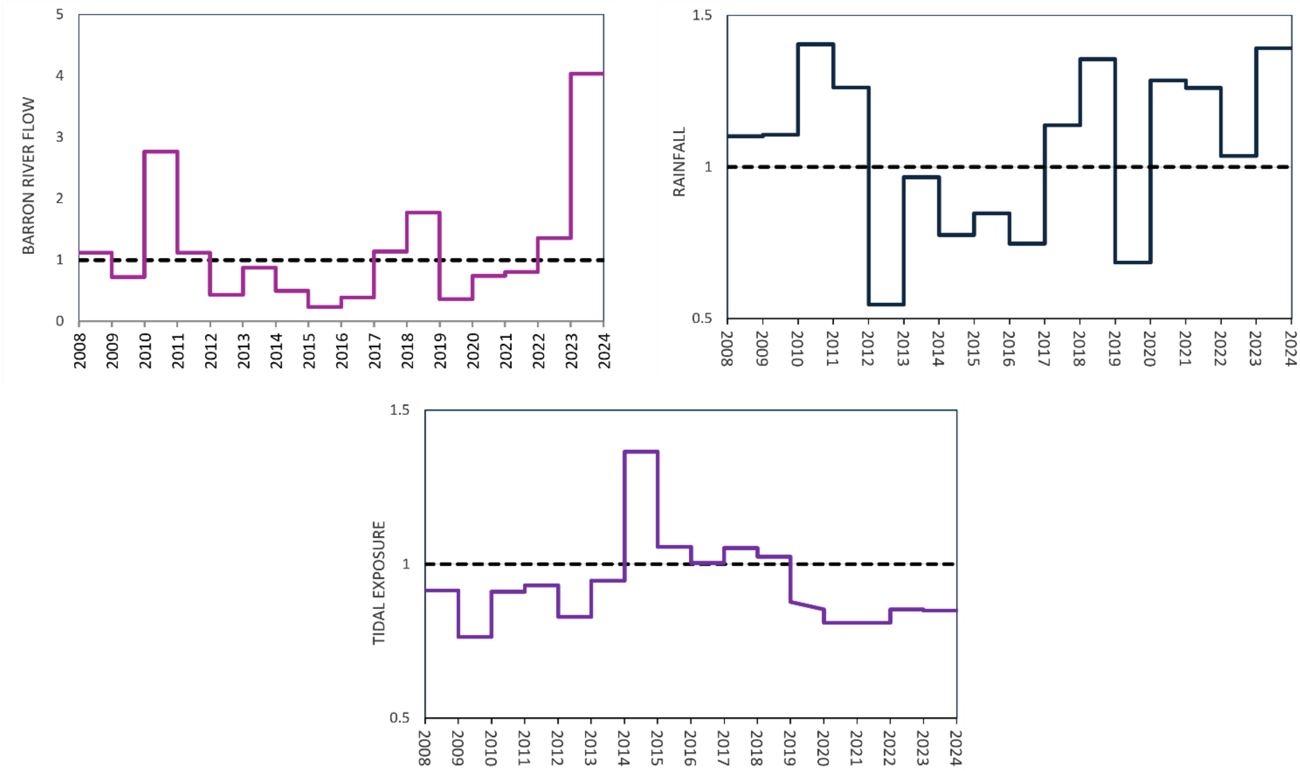


Figure 3. Climate trends in Cairns: Change in climate variables as a proportion of the long-term average.

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 (Costanza et al. 2014). These services include the provision of nursery habitat for economically important fish and crustaceans (Heck et al. 2003; Coles et al. 1993), and food for grazing mega herbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018; Scott et al. 2020). Further, seagrasses play a major role in the cycling of nutrients (McMahon and Walker 1998), stabilisation of sediments (Christianen et al. 2013), improving of water quality (McGlathery et al. 2007) and studies suggest they are one of the most efficient and powerful carbon sinks in the marine realm (Fourqurean et al. 2012; Pendleton et al. 2012, York et al. 2018).

Globally, seagrasses have been declining at ever increasing rates due to both natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores as well as anthropogenic stresses including direct disturbance from coastal development, dredging, and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution, and eutrophication (Short and Wyllie-Echeverria 1996). In the tropical Indo-Pacific region industrial and urban run-off, port development, and dredging have all been identified as threats to seagrass (Grech et al. 2012). Locally in the Great Barrier Reef (GBR) coastal region, the highest threat areas for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot spots arise as seagrasses preferentially occur in the same sheltered coastal locations that 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 and ensure impacts are minimised (Coles et al. 2015).

3.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in most Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & 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).

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

Figure 4. Location of Queensland Port Seagrass assessment sites (red – long-term monitoring and baseline mapping; blue - baseline mapping only).

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses and an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

3.2 Port of Cairns Seagrass Monitoring Program

The Port of Cairns is located within Trinity Bay and Trinity Inlet and operated by Ports North. It is one of Queensland's busiest ports and handles bulk and general cargo, cruise ships, fishing fleets and passenger ferries. Existing port infrastructure includes twelve operational wharves, commercial fishing bases, a barge ramp, marina and mooring facilities, swing basins and a 10km long channel which is subject to annual maintenance dredging.

Ports North have recognised that seagrasses make up an ecologically important and environmentally sensitive habitat in the Port of Cairns and recognise their value as a tool for monitoring water quality and the marine environmental health of the port.

In partnership with the James Cook University - Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) and following the baseline survey conducted in 2001 (Campbell et al. 2002), Ports North established an annual seagrass monitoring program which helped define the natural variation for seagrass communities and some of the links between seagrass change and climate. The annual monitoring program conducted between October and December each year provides a regular update of the marine environmental health of Trinity Bay (Cairns Harbour) and Trinity Inlet and an assessment of seagrass condition and resilience to inform port management. As the annual monitoring program only examines a sub-set of representative seagrass meadows, an updated baseline survey of all of the seagrass in the system is conducted every 3 years. Annual assessments of the seagrass seed bank and the viability of buried seeds are conducted for the two main seagrass meadows in Cairns Harbour as a measure of the resilience to future impacts in March of each year.

In addition to the annual seagrass monitoring, benthic light (Photosynthetically Active Radiation (PAR) and temperature (continuously logged) data are recorded at three sites (Figure 1) to help assess the condition and resilience of seagrass and their associated benthic light (PAR) levels.

The overall objectives of the 2024 annual seagrass monitoring were to:

1. Map and quantify the distribution, abundance and species composition of the selected long-term seagrass monitoring meadows.
2. Map and quantify the distribution and abundance of all seagrasses in Trinity Bay and Trinity Inlet to provide an update on the whole of port assessment.
3. Compare monitoring results with previous seagrass surveys and assess changes in relation to natural events, port and catchment activities.
4. Assess seagrass condition and examine seagrass change in relation to light (Photosynthetic Active Radiation (PAR)), and reproductive effort (seed banks).

4. METHODS

4.1 Sampling Approach

Survey and monitoring methods followed the established techniques for TropWATER's Queensland-wide seagrass monitoring programs. The application of standardised methods in Cairns and throughout Queensland allows for direct comparison of local seagrass dynamics with other seagrass monitoring programs in the broader Queensland region.

The annual seagrass survey was conducted during the seasonal peak of seagrass condition from September to December 2024.

Queensland seagrass communities are seasonal, with maximum distribution and abundance usually occurring in late spring/early summer.

4.2 Sampling Methods

Intertidal meadows were sampled at low tide using a helicopter. GPS was used to map the position of meadow boundaries and sites were scattered haphazardly within each meadow. Sites were surveyed as the helicopter hovered less than one metre above the substrate (Figure 5). Shallow subtidal meadows were sampled by boat using camera drops and van Veen grab (Figure 5). A Van Veen sediment grab (grab area 0.0625 m^{-2}) was used where required at each camera site to confirm sediment type and species viewed on the video screen. Subtidal sites were positioned at approximately 50 to 100 m intervals running perpendicular from the shoreline, or where major changes in bottom topography occurred. Transects continued to at least the seaward edge of any seagrass meadows that were encountered. Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (see Mellors 1991; Kirkman 1978).

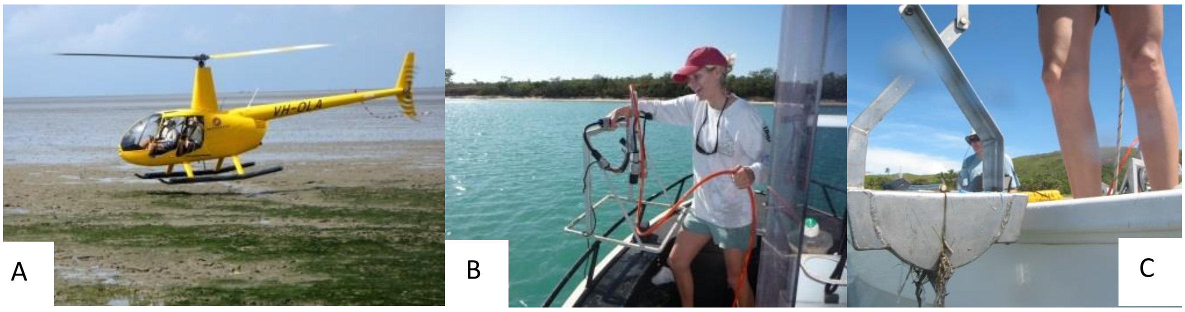


Figure 5. Seagrass monitoring methods in 2023. (a) helicopter survey of intertidal seagrass, (b and c) boat-based camera drops and van Veen grab for subtidal seagrass.

Seagrass meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcPro 3.4.0®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 1). Mapping precision ranged from 1 m for intertidal seagrass meadows with boundaries mapped by helicopter to ± 50 m for subtidal meadows with boundaries mapped by distance between sites with and without seagrass. 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.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 2). Community density was based on mean biomass of the dominant species within the meadow (Table 3). Seagrass meadows were also described using 'landscape categories' (Figure 6). Seagrass meadows were classified from meadows that contained isolated patches, through to meadows that had a continuous cover of seagrass.

Table 1. Mapping precision and methodology for seagrass meadows in Cairns Harbour and Trinity Inlet.

Mapping precision	Mapping methodology
1-10 m	• Meadow boundaries determined from a combination of helicopter and camera/grab surveys. • Exposed inshore boundaries mapped from helicopter. • Offshore boundaries interpreted from subtidal survey sites. • Relatively high density of mapping and survey sites. • Small subtidal meadows in Trinity Inlet.
10-50 m	• Subtidal meadow boundaries determined from camera/grab surveys only. • All meadows subtidal. • Patchy cover of seagrass throughout meadow. • Moderate density of survey sites. • Recent aerial photography aided in mapping.

Table 2. Nomenclature for seagrass community types in Cairns Harbour and Trinity Inlet.

Community type	**Species composition**
Species A	Species A is >90-100% of composition
Species A with Species B (2 species present) Species A with mixed species (>2 species)	Species A is >60-90% of composition
Species A/Species B	Species A is 40-60% of composition

Table 3. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density Cairns Harbour and Trinity Inlet.

Density	Mean above ground biomass (g DW m^{-2})				
	H. uninervis (narrow)	*H. ovalis H. decipiens*	*H. uninervis (wide) C. serrulata/rotundata*	*H. spinulosa*	*Z. muelleri*
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

Isolated seagrass patches

The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches

The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

Continuous seagrass cover

The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

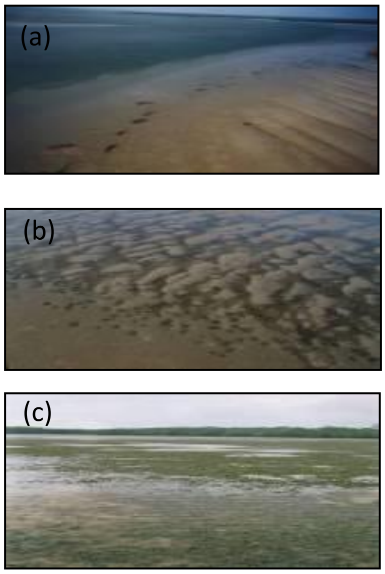


Figure 6. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

4.3 Seagrass Meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in the key indicators: mean above-ground biomass, total meadow area and species composition, relative to a long-term baseline (see Carter et al. 2023 for full details). Seagrass condition for each indicator in monitoring meadows 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 Seed bank assessment & seed viability

Seed-bank density for *Zostera muelleri* and *Halodule uninervis* is quantified around March each year for the two main seagrass meadows in Cairns Harbour (Bessie Point and Esplanade meadows). This timing is likely to capture a representative sample of the total pool of seeds in the sediment from the previous fruiting season that are available for germination in the subsequent growing season.

Approximately 30 sediment cores measuring 50mm in diameter and 100 mm in depth were taken randomly within the boundary of each meadow (Figure 7). Samples were separated into three depth categories (0 – 20 mm, 20 – 50 mm and 50 – 100 mm) then sieved with fresh water to separate out seagrass seeds from the sediment. For all cores, the 710 µm to 1 mm fraction of the sediment was inspected for *H. uninervis* and *Z. muelleri* seeds using a dissecting microscope. Seed density data were delineated by species and reported as mean number of seeds per m^{-2} per site.

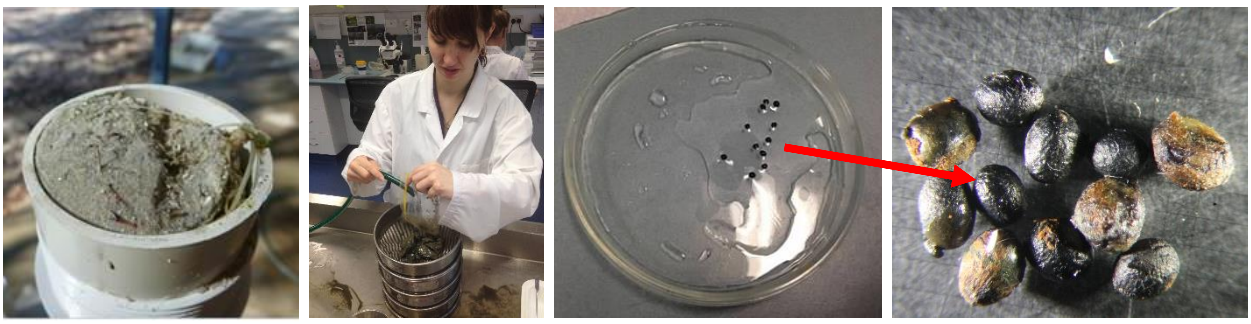
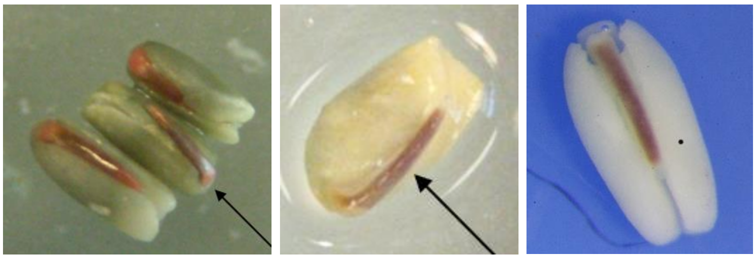


Figure 7. Sediment seed bank cores, sieving cores in the lab and *Halodule uninervis* seeds found in the sieved material.

Once identified, collected, and recorded all seeds were stored in scintillation vials with mesh screening (<0.1mm diameter) in 37 L tanks containing oxygenated salt water collected from Cairns Harbour at 8-10 °C until processing (Marion and Orth 2010). All intact seeds were tested for viability using tetrazolium chloride (Jarvis et al. 2021; Conacher et al. 1994) within 1 week of collection. Tetrazolium chloride was used due to increased accuracy and greater time efficiency compared to traditional germination tests (Jarvis and Moore 2010; Conacher et al. 1994). Seed embryos were removed from their seed coats and soaked in a 0.5 % tetrazolium chloride solution for 48 hours before examination on a dissecting microscope at 10 x magnification (Jarvis et al. 2021). Seeds with a red to brown stained cotyledon and axial hypocotyl were considered viable (Jarvis et al. 2021; Conacher et al. 1994; Harrison 1993) (Figure 8). Viability data were separated by species and reported as mean number of viable seeds per m^{-2} per site. Seed bank sampling reported here was conducted in March 2023.



Viable seagrass seeds (various shades of red/brown cotyledons)

Non-viable seagrass seeds (white cotyledons)

Figure 8. Examples of stained viable and non-viable *Zostera muelleri* seeds using tetrazolium chloride.

4.5 Habitat mapping and Geographic Information System

All survey data was entered into a Geographic Information System (GIS) using ArcPro 3.4.0®. Satellite imagery of the Cairns area with information recorded during the monitoring surveys was combined to assist with mapping seagrass meadows. Three seagrass GIS layers were created:

4.5.1 Seagrass site layer

The seagrass site (point) layer contains data collected at each site, including:

- Unique identifier
- Temporal details – Survey date and time.
- Spatial details – Latitude/longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
- Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE).
- Sampling method and any relevant comments.
- Comments (e.g., dugong feeding trail (DFT) presence/absence.

4.5.2 Seagrass meadow layer

The meadow (polygon) layer provides summary information for all sites within each meadow, including:

- Meadow unique identifier – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass + standard error (SE), meadow area (hectares) + reliability estimate (R) (Table 4), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 2, 3), meadow landscape category (Figure 6).
- Sampling method
- Comments (e.g., dugong feeding trails present in meadow).

4.5.3 Seagrass biomass interpolation layer

The interpolation (raster) layer describes spatial variation in seagrass biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

4.6 Temperature and Light PAR Loggers

Light (Photosynthetically Active Radiation or PAR) and temperature are monitored continuously at three sites: The Esplanade/Ellie Point (Site E), Bessie Point (Site B) and Redbank (Site R) (Figure 1). Monitoring of within seagrass canopy temperature (°C) was recorded every 15 minutes using autonomous iBTag submersible temperature loggers. Temperature loggers were replaced at each location quarterly. Submersible OdysseyTM photosynthetic irradiance autonomous loggers (light loggers) were also deployed to assess PAR. Continuous measurements were conducted and recorded by the logger every 15 minutes. Automatic wiper brushes cleaned the optical surface of the sensor every 15 minutes to prevent marine organisms fouling the sensors. Light loggers were replaced and downloaded quarterly.

5. RESULTS

5.1 Seagrass presence and species in monitoring meadows

A total of 691 habitat characterisation sites were assessed across the whole of port and annual monitoring survey in 2024 (Figure 9). Seagrass was present at 36% of sites and a total seagrass area of 1,297 ± 120 ha was mapped. Within the total mapped area, 1,046 ± 94 ha was mapped in the annually assessed long-term monitoring meadows leaving 251 ± 25 ha mapped outside of these meadows (Figure 10a and 10b).

Five species of seagrass were found in the monitoring meadows, a similar composition to previous years (Table 4). *Thalassia hemprichii* has only occasionally been recorded in Cairns Harbour and was not recorded for the second year in a row in the annual monitoring meadows in 2024.

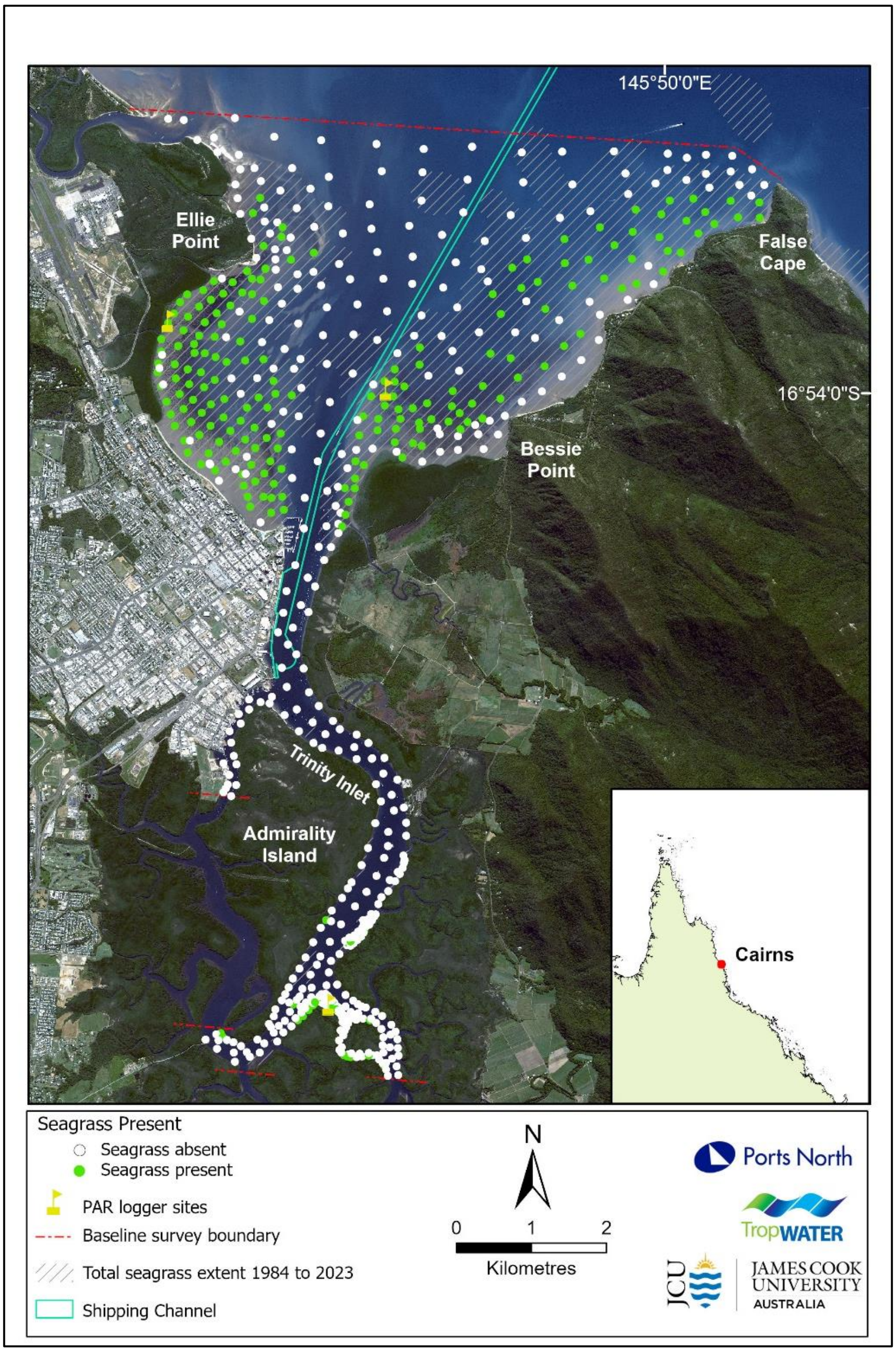


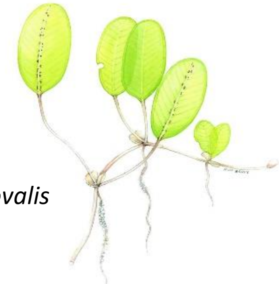
Figure 9. Seagrass presence/absence at sites surveyed within the Cairns survey area, 2024.

Table 4. Seagrass species present in Cairns Harbour and Trinity Inlet monitoring meadows in 2024. Pictures are not to scale.

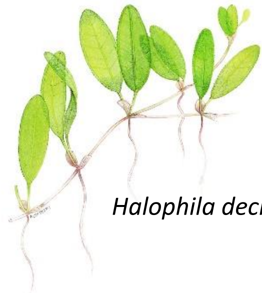
Cymodocea serrulata

Halodule uninervis (narrow & wide form)

Zostera muelleri



Halophila ovalis



Halophila decipiens

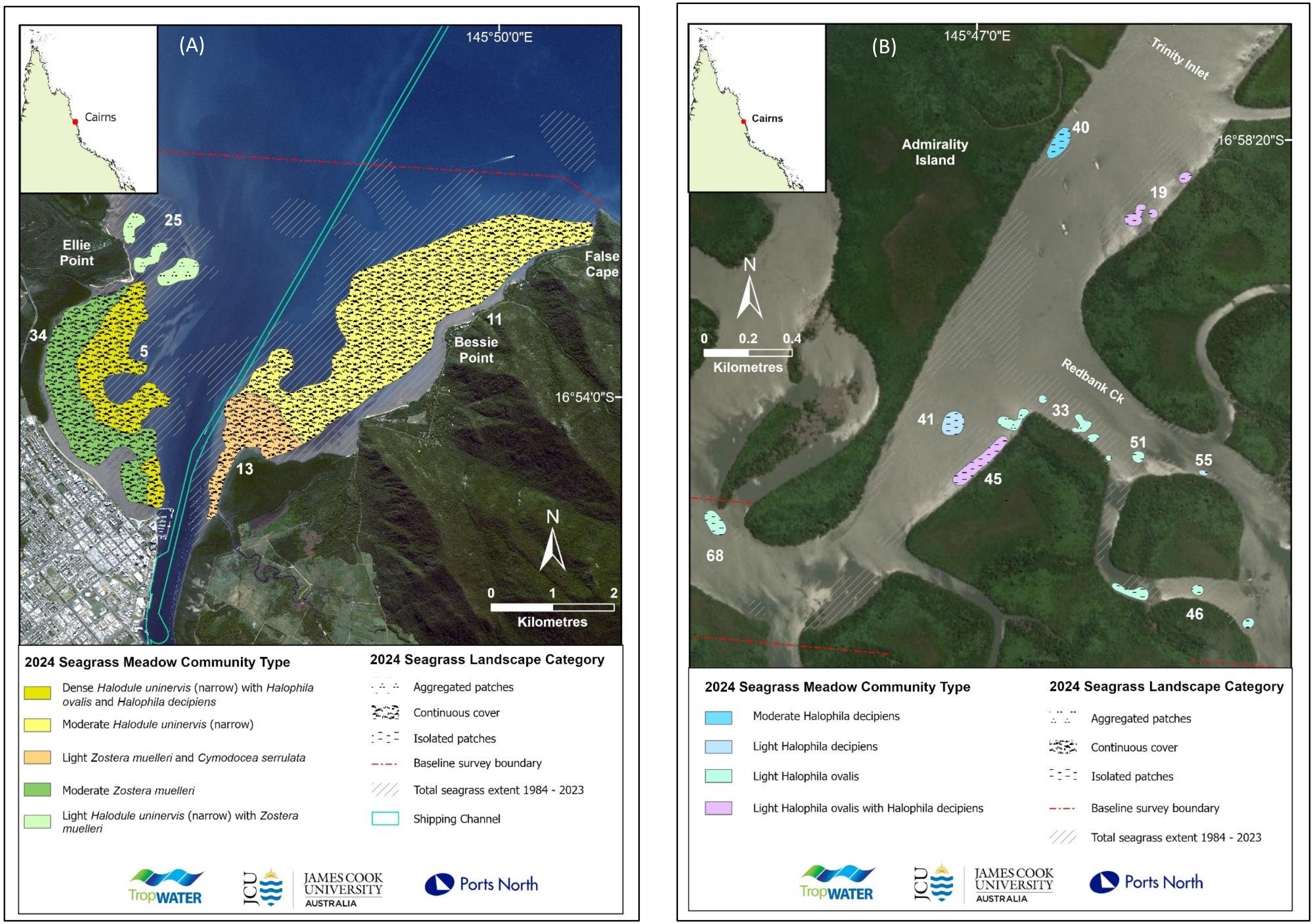


Figure 10: (A) Cairns Harbour monitoring meadows and (B) Trinity Inlet monitoring meadow distribution and community type in 2024.

5.2 Seagrass condition in monitoring meadows

In 2024, the three large Cairns Harbour monitoring meadows (Meadows 11, 13 and 34) were collectively in a satisfactory condition (Figure 10a; Table 5; Figures 13-15), a decline from a good overall condition the previous year. All three meadows had declines in either area or biomass while the species composition remained unchanged and in a very good condition (Table 5).

The three small Trinity Inlet meadows (Meadows 19, 20 and 33) remained in a poor overall condition driven by declines in biomass, area and species composition (Figure 10b; Table 5; Figures 16-18). In 2024 the small intertidal Redbank Creek meadow (20) was absent with no *Z. muelleri* recorded (Figure 10b; Table 5). The subtidal Trinity Inlet meadow (19) remained in a poor condition with declines in area and species composition (Table 5; Figure 16). In contrast, the Redbank subtidal meadow (33) was the only one to show improvement, with its overall condition upgraded to satisfactory (Table 5; Figure 18).

The overall mean biomass of the six long-term monitoring meadows in 2024 was 12.5 ± 1.4 g DW m^{-2}, a 20% decline from the previous year (Figure 11). While biomass steadily increased from 2010 to 2022, this marks the third consecutive year of decline, with current levels remaining below the long-term average of 21.3 g DW m^{-2} (Figure 11). While the total area (1,046 ± 95 ha) of monitoring meadows did decline in 2024, it remains above the long-term average of 999 ± 108 ha for the eighth consecutive year (Figure 12).

Table 5. Grades and scores for seagrass indicators (biomass, area, and species composition) for the long-term monitoring meadows in Cairns; September/December 2024 survey.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
Cairns Harbour Meadows				
Esplanade to Ellie Pt. (34)	0.68	0.55	0.89	0.55
Bessie Point (11)	0.55	0.81	1	0.55
South Bessie Pt (13)	0.50	0.87	0.96	0.50
Overall Score for Cairns Harbour				0.53
Trinity Inlet Meadows				
Inlet (19)	0.41	0.33	0.83	0.33
Redbank Intertidal (20)	0.0	0.0	0.0	0.0
Redbank Subtidal (33)	0.57	0.52	1.00	0.52
Overall Score for Trinity Inlet				0.28

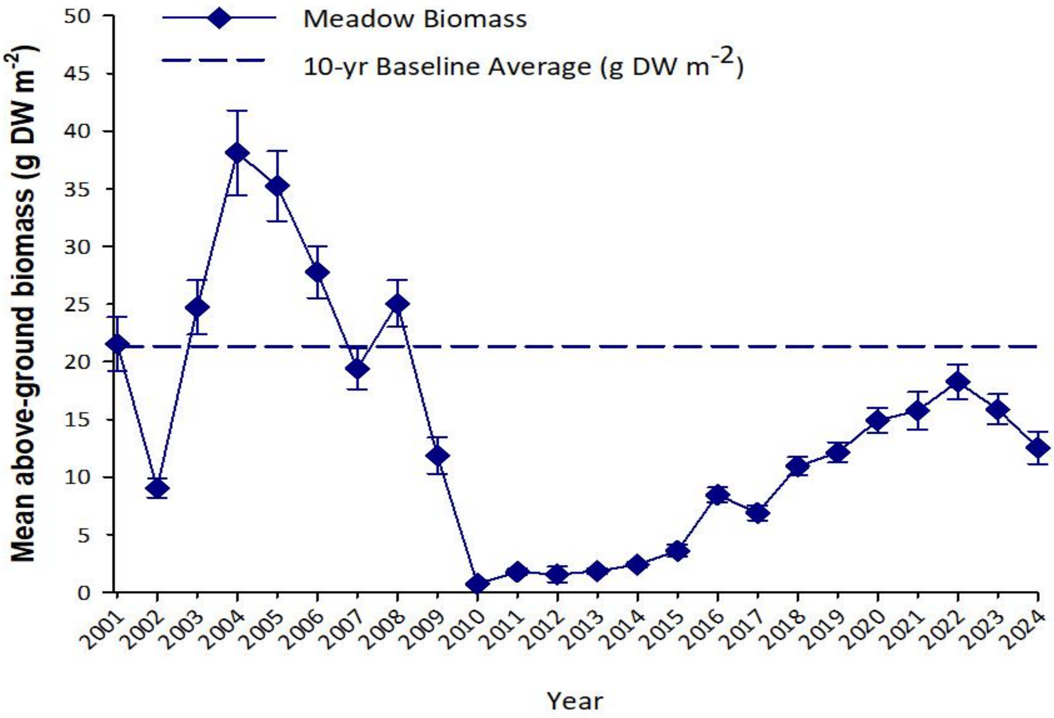


Figure 11. Mean above-ground biomass (g DW m-2) of all Cairns long-term monitoring meadows combined from 2001 – 2024 (error bars – standard error). Dotted blue line indicates 10-year (2001 – 2010) baseline mean of meadow biomass.

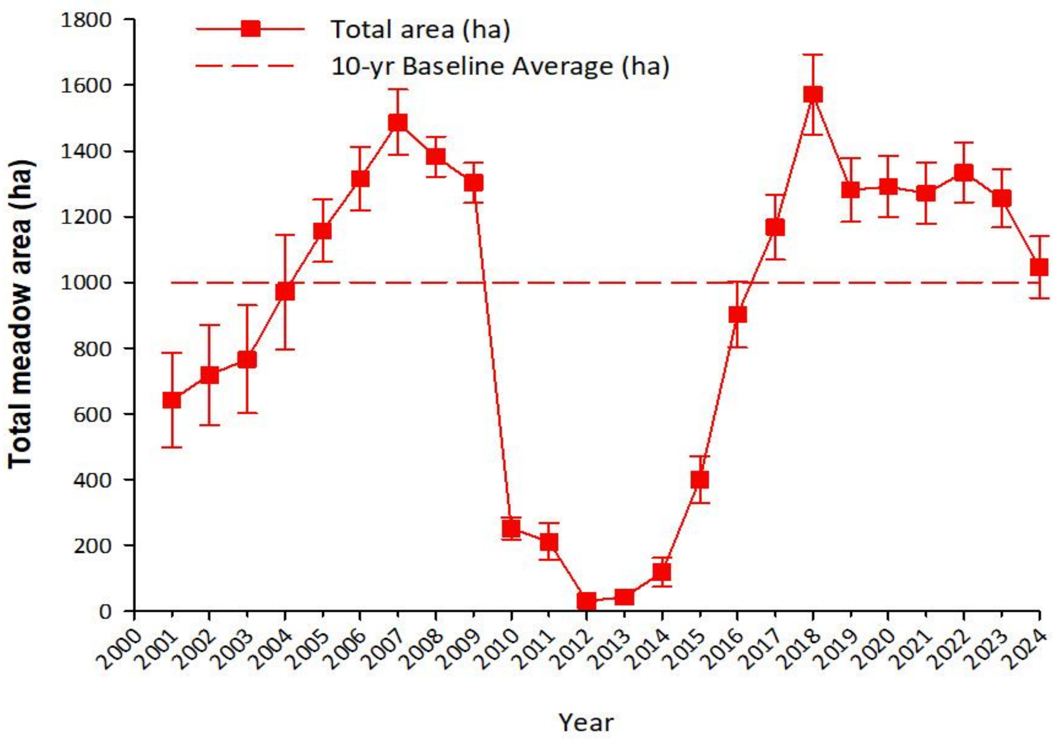


Figure 12. Total area of all Cairns monitoring meadows combined from 2001 – 2024 (error bars – "R" reliability estimated). Dotted red line indicates 10-year (2001 – 2010) baseline mean of total meadow area.

5.2.1 Coastal Cairns Harbour Meadows

The three larger monitoring meadows in Cairns Harbour were all in a satisfactory condition in 2024. This group of coastal meadows include the Esplanade to Ellie Point meadow (34), Bessie Point (11) and South Bessie Point (13).

The Esplanade meadow (34) was in a satisfactory overall condition in 2024, a decline from a good condition the previous year (Figure 13 & 19). While the condition indicators of biomass and species composition remained the same as the previous year, there was a decline in area, particularly in the deeper offshore edge of the meadow, which was the main driver behind the condition downgrade (Table 5; Figure 13). Biomass remained in a good condition at 27.6 ± 2.7 g DW m^{-2} and was 28% below the long-term average of 38 g DW m^{-2} (Figure 13). This meadow is categorised as a moderate density *Z. muelleri* meadow made up of continuous cover of seagrass (Figure 10A) with seagrass biomass 'hotspots' more widespread across the meadow now compared to previous years (Figure 19). In 2024, the species composition of this meadow remained in a very good condition with an increase in the amount of *Z. muelleri* in the meadow making up 93% of the species contribution (Figure 13; Appendix 8.1). The footprint of this meadow declined 23% from the previous year to 236 ± 5.8 ha in 2024 and was below the long-term baseline average (308 ha) (Figure 13 and 19).

The subtidal Bessie Point meadow (11) declined to a satisfactory condition in 2024 (Figure 14). Species composition remained stable and in a very good condition, while declines were found in both area and biomass (Figure 14). Biomass declined from very good condition (9.8 ± 0.8 g DW m^{-2}) the previous year to satisfactory (2.7 ± 0.4 g DW m^{-2}) in 2024 (Figure 14). This is the first time in six years that biomass has been below the long-term baseline average (6.8 ± 0.8 g DW m^{-2}) (Figure 14). The density and cover of the meadow remains high enough for the meadow to be categorised as a moderate *H. uninervis* meadow with a continuous cover of seagrass across the meadow (Figure 10A). The footprint of this large Bessie Point meadow declined slightly by 13% to 687 ± 85 ha in 2024, however, remained in a good condition and above the baseline average (619 ha) (Figure 14 & 20). Species composition remained in a very good condition with the meadow dominated by *H. uninervis* (Figure 14; Appendix 8.1).

The intertidal meadow at South Bessie Point (13) was also in a satisfactory condition (Figure 15). While the biomass condition was downgraded, both area and species composition conditions remained unchanged and in a very good condition (Figure 15 & 20; Appendix 8.1 & 8.2). Biomass declined 80% from the previous year and was 5.2 ± 1.4 g DW m^{-2} in 2024, the first time in 4 years it's fallen below the long-term average of 17.2 g DW m^{-2} (Figure 15; Appendix 8.3). Species composition has remained in a very good condition for the sixth consecutive year, dominated by *Z. muelleri* alongside the larger-leaved *C. serrulata*, which accounted for 83% of the species composition in 2024 (Figure 15; Appendix 8.1). This Bessie Point meadow is made up of continuous cover of seagrass and is light in density for its species mix (Figure 10A).

5.2.2. Trinity Inlet Estuarine Meadows

In 2024, the three small monitoring meadows in Trinity Inlet were collectively assessed as being in poor overall condition (Table 5; Figures 16 – 18). These meadows include the Trinity Inlet meadow (19), the intertidal Redbank Creek meadow (20), and the subtidal Redbank Creek meadow (33) (Figure 10B and 21). Characterised by their high year-to-year variability, these small meadows are patchy and typically consist of moderate to light-density seagrass cover (Figures 10B, 16–18 and 21). Due to their small size and variability, even relatively minor changes in any of the three condition indicators biomass, area, and species composition can result in a shift in overall condition grade.

The Trinity Inlet meadow (19) remained in a poor overall condition in 2024 (Figure 16). The decline in area and species composition was the main driver of the condition downgrade from the previous year (Figure 16). While biomass remained in a poor condition in 2024, this meadow is highly variable between years with biomass oscillating above and below the long-term average over the course of the program. However, it has remained below the long-term average for the past four consecutive years (Figure 16). The footprint of this meadow declined to a poor condition in 2024 after being at or above the long-term average for seven consecutive years (Figure 16). Species composition was in good condition despite some reduction of *H. ovalis* dominance and increases in *H. decipiens* in this meadow.

The intertidal Redbank Creek *Z. muelleri* meadow (20) was absent in 2024 (Figure 17). This meadow inhabits a narrow strip along the edge of the mangroves and traditionally joins the subtidal Meadow 33. Historically, this meadow has shown substantial variability and was previously absent between 2011-2014 and again in 2016 (Figure 17 and 21).

The subtidal Redbank Creek meadow (33) improved in condition in 2024 with an upgrade to satisfactory due to an increase in biomass (Table 5; Figure 18). Despite the increases in biomass, area declined from the previous year and this meadow has now fragmented to five aggregated patches (Figure 18; Figure 21).

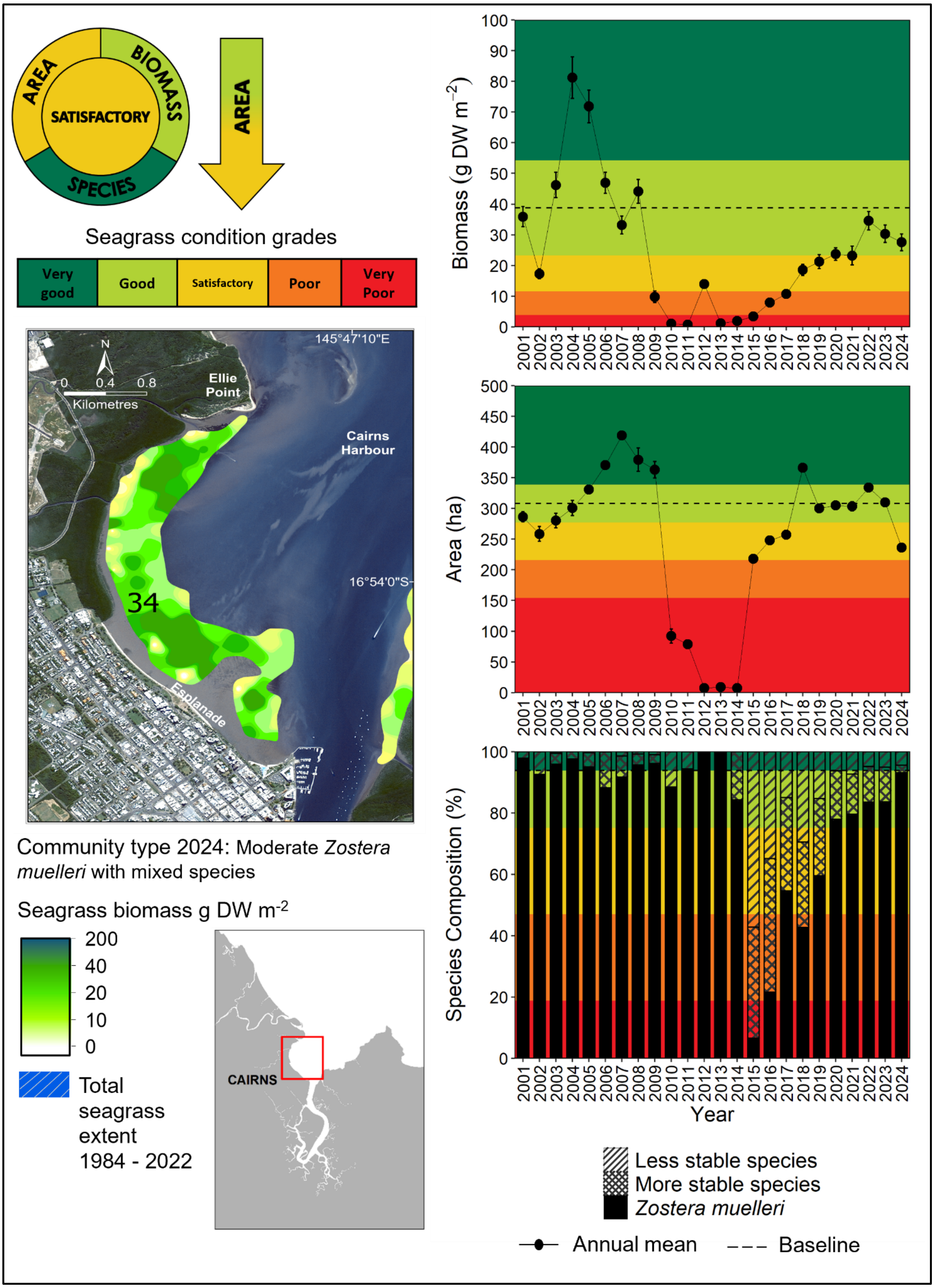


Figure 13. Changes in biomass, area and species composition for the Esplanade meadow (meadow no. 34) from 2001 – 2024 (biomass error bars = SE; area error bars = "R" reliability estimate).

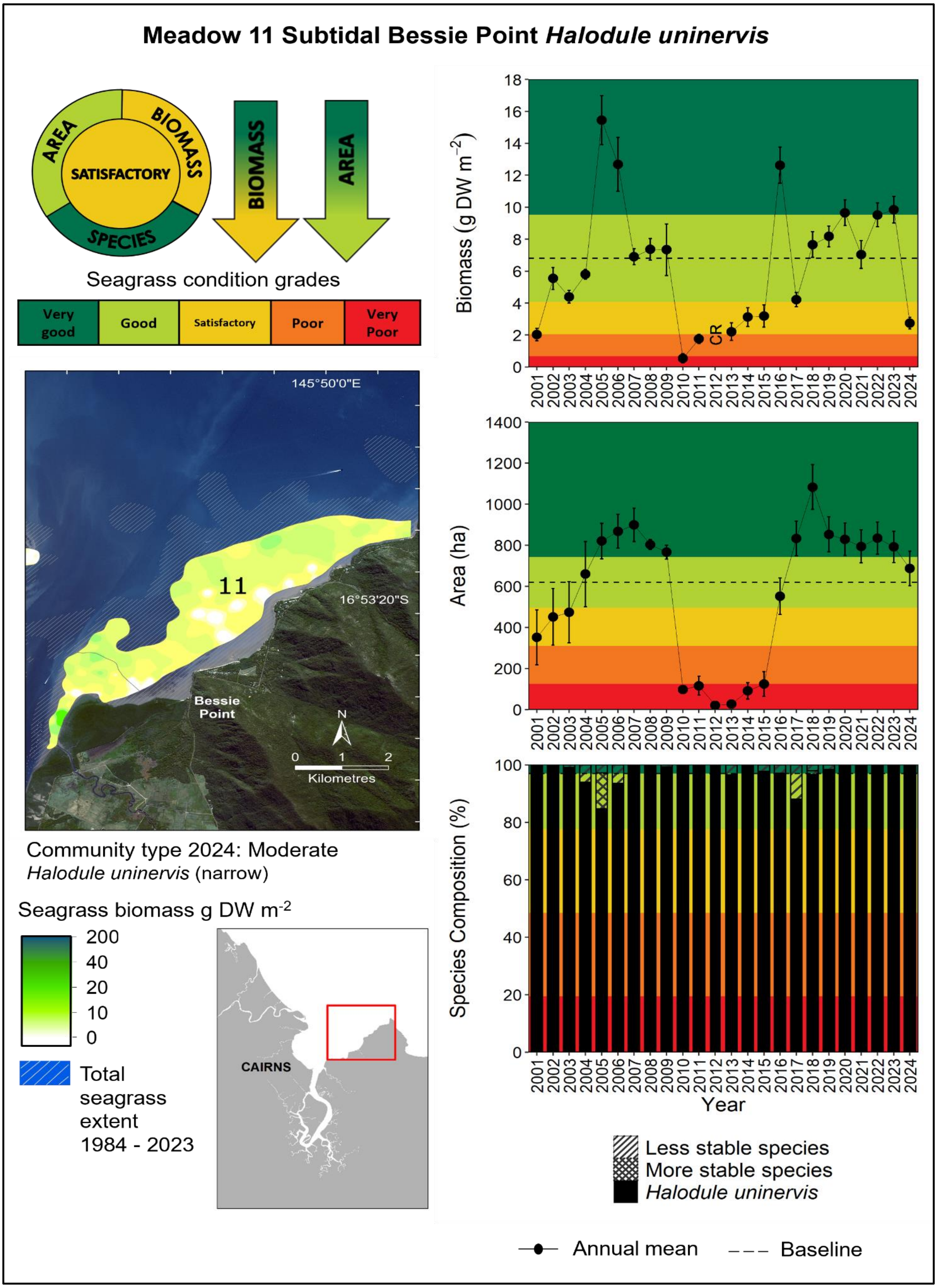


Figure 14. Changes in biomass, area and species composition for the Bessie Point (meadow no. 11) meadow from 2001 – 2024 (biomass error bars = SE; area error bars = "R" reliability estimate).

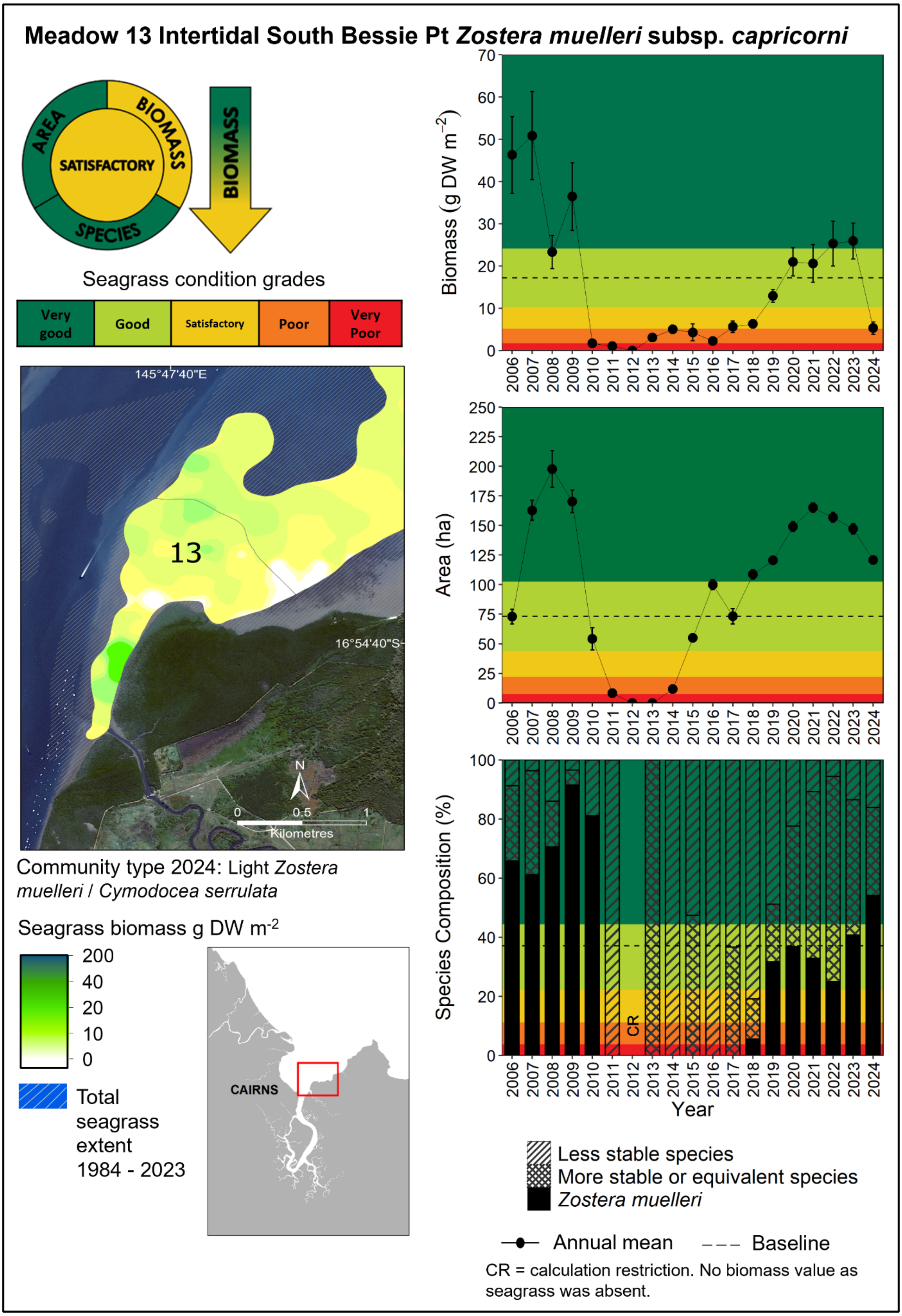


Figure 15. Changes in biomass, area and species composition for the South Bessie Point (meadow no. 13) meadow from 2006 – 2024 (biomass error bars = SE; area error bars = "R" reliability estimate).

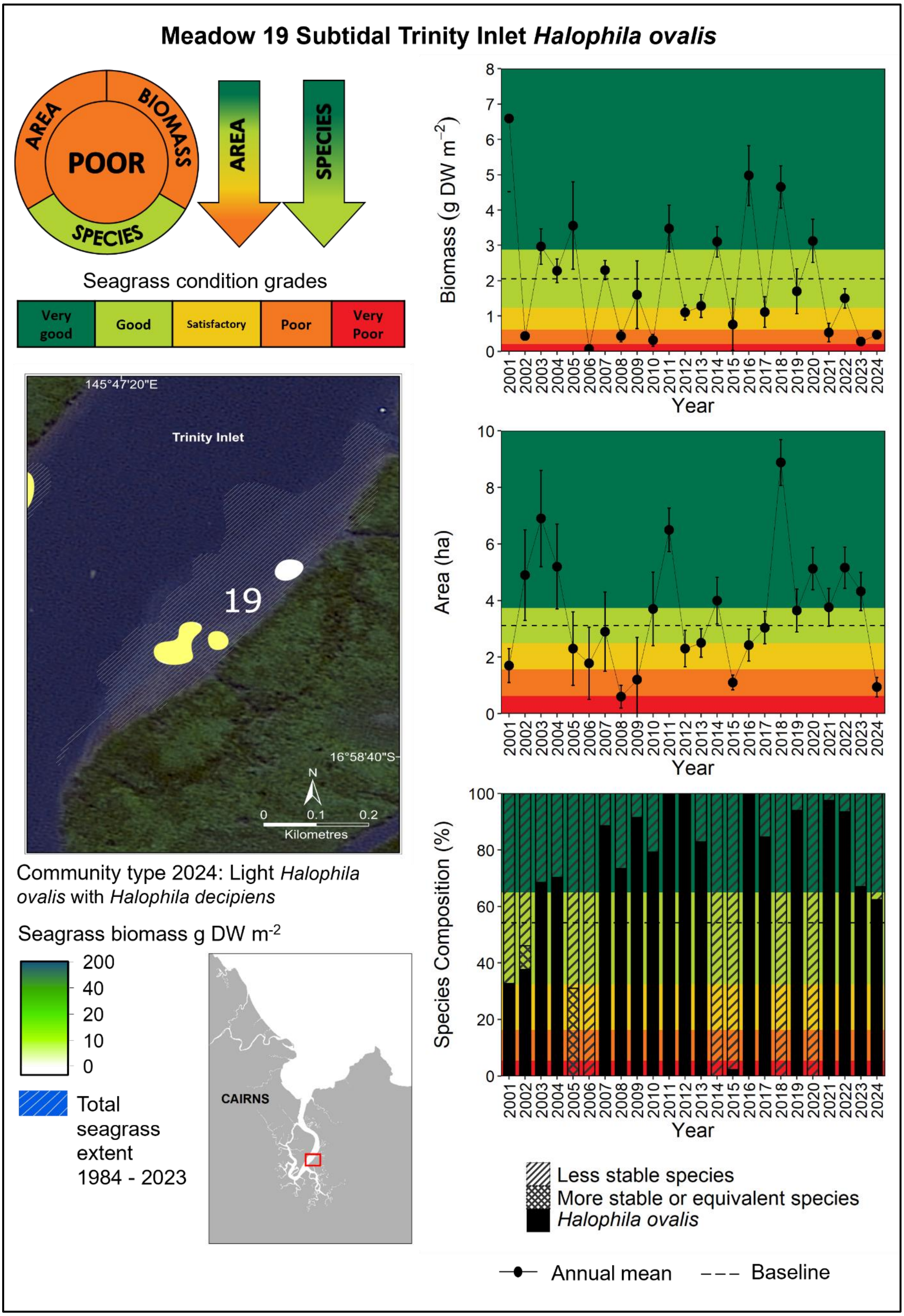


Figure 16. Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow no. 19) from 2001 – 2024 (biomass error bars = SE; area error bars = "R" reliability estimate).

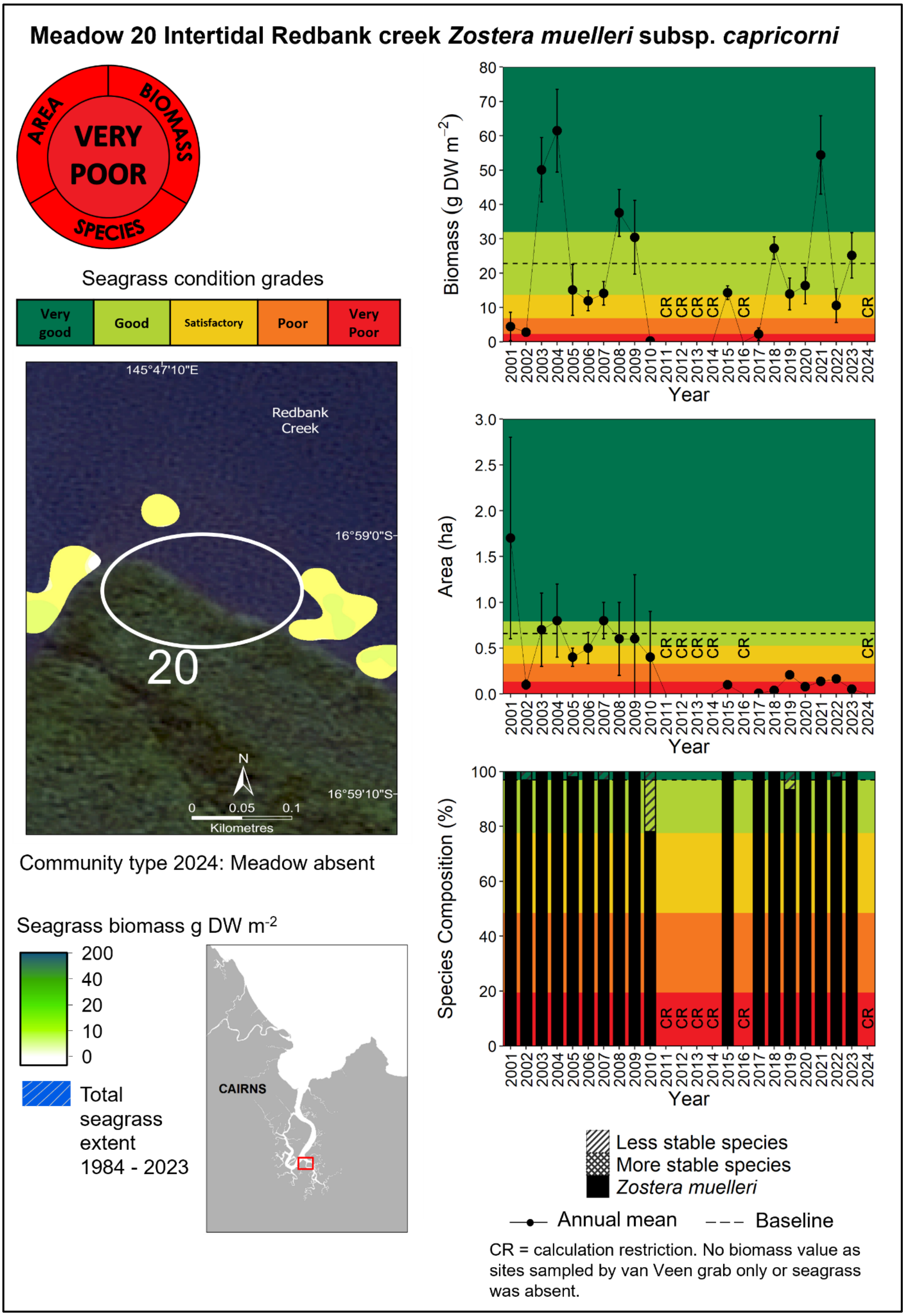


Figure 17. Changes in biomass, area and species composition for the Trinity Inlet Zostera meadow (meadow no. 20) from 2001 – 2024 (biomass error bars = SE; area error bars = "R" reliability estimate).

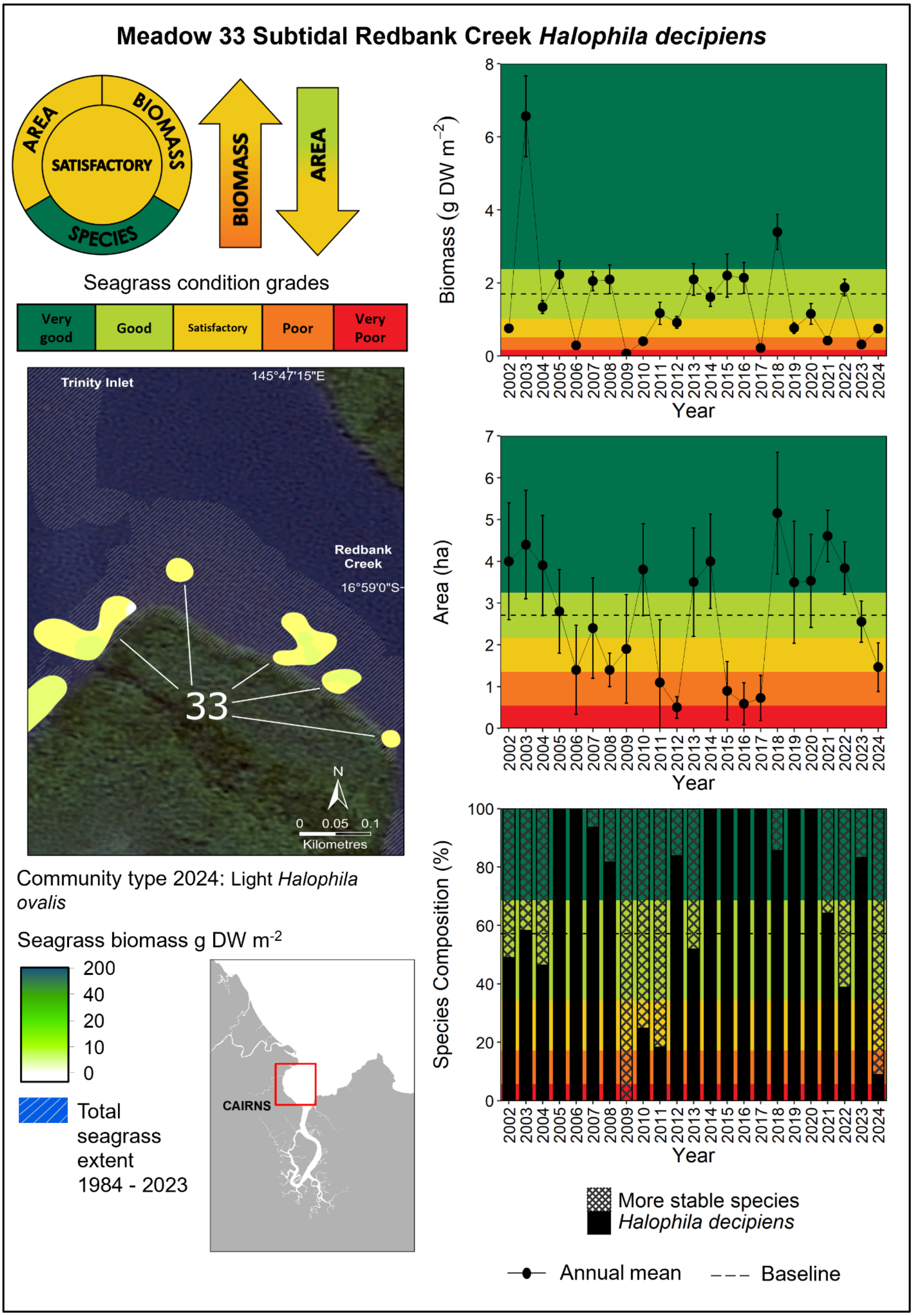


Figure 18. Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow 33) from 2002 – 2024 (biomass error bars = SE; area error bars = “R” reliability estimate).

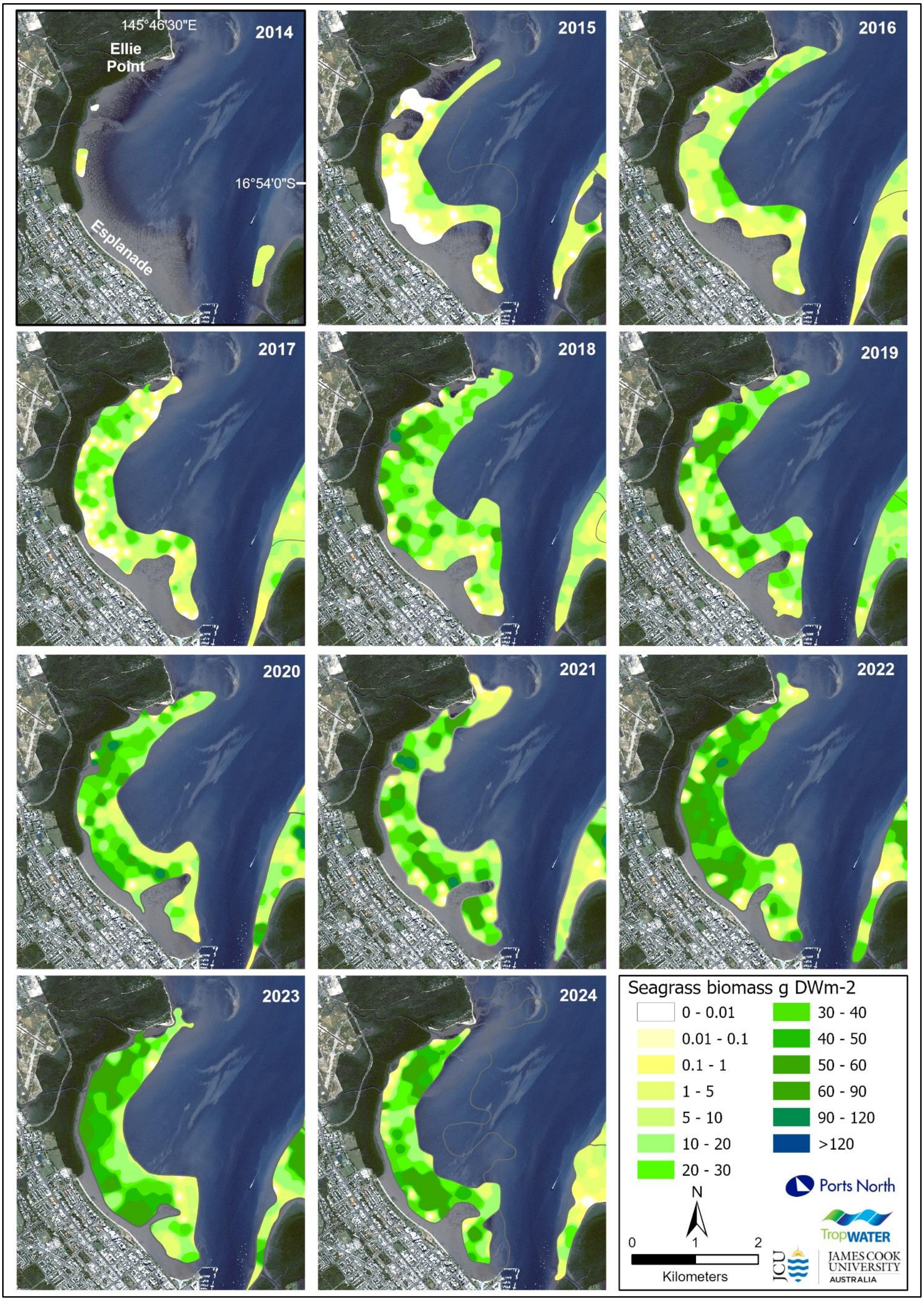


Figure 19. Esplanade to Ellie Point seagrass monitoring meadows from 2014 to 2024.

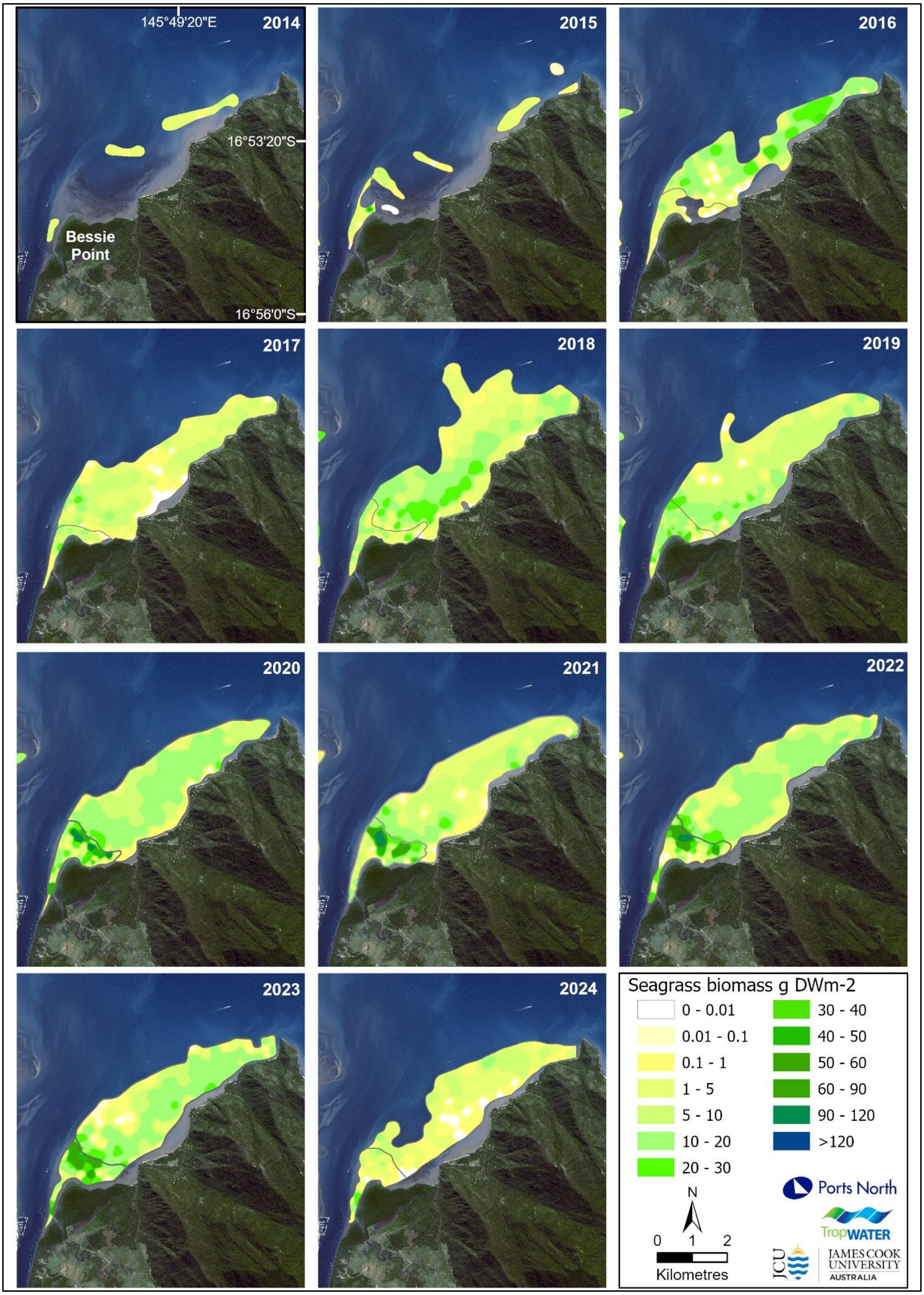


Figure 20. Bessie Point and South Bessie Point seagrass monitoring meadows from 2014 to 2024.

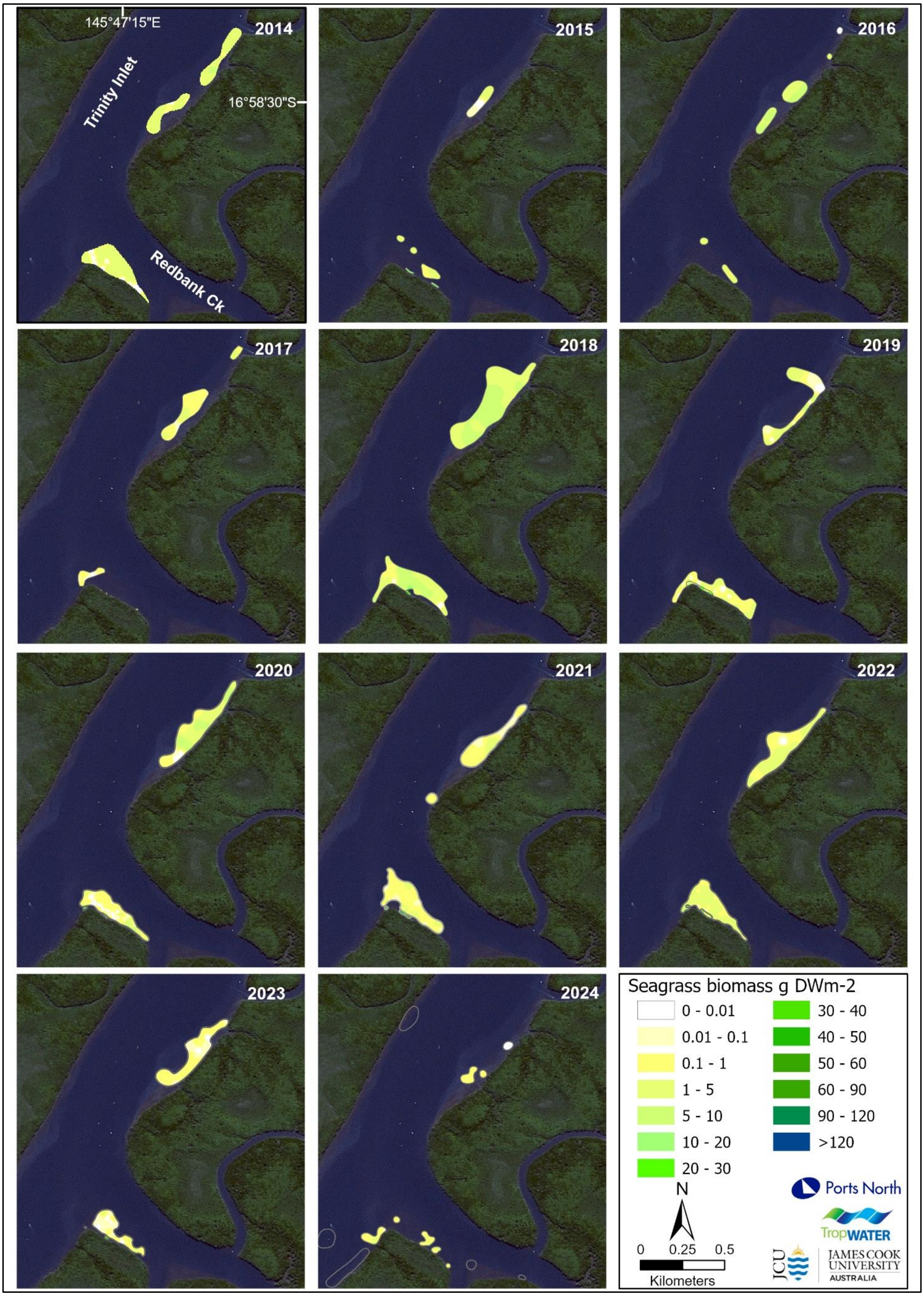


Figure 21. Trinity Inlet seagrass monitoring meadows from 2014 to 2024.

5.2.3. Seagrasses in the broader Cairns area

In 2024, total seagrass area within the broader Cairns region was 1,297 ha, a 13% decline compared to the last whole of port survey in 2021 (Figure 20). While the 2024 area was well below the peak of 1,960 ha recorded in 2018, the current footprint remains within the upper range of historical values observed over the past 5 years (Figure 20).

In addition to the six long-term monitoring meadows, nine additional seagrass meadows were mapped in 2024 across the broader Cairns Harbour and Trinity Inlet region. These included two meadows in the Cairns Harbour area and seven small meadows in Trinity Inlet (Maps 10A and 10B; Table 8).

In Cairns Harbour, the larger of the two meadows (Meadow 5) was a deeper, subtidal meadow dominated by *H. uninervis*, located adjacent to the Esplanade Meadow (Meadow 34). The second, smaller subtidal meadow (Meadow 25) consisted of aggregated patches and was dominated by *H. uninervis* and *Z. muelleri* (Map 10A; Table 8).

The seven smaller meadows in Trinity Inlet were composed of isolated patches dominated by the colonising species *H. decipiens* and *H. ovalis* (Map 10B; Table 8). Notably, the isolated patches of *Z. muelleri* previously observed on the western bank of Admiralty Island were absent in 2024, after being present for the past three whole of port surveys (Map 10B; Table 8).

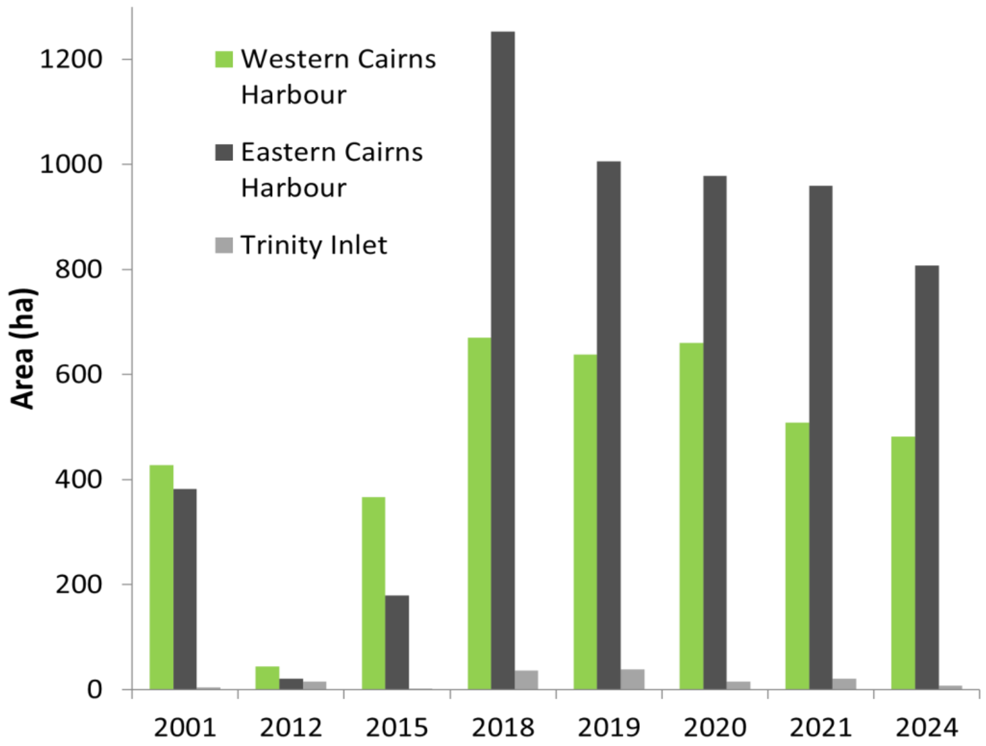


Figure 20: Comparison of total seagrass area (hectares) in the broader Cairns region, for western and eastern Cairns Harbour and Trinity Inlet in 2001, 2012, 2015, 2018, 2019, 2020, 2021 and 2024.

Table 6: Description of Cairns Harbour and Trinity Inlet seagrass whole of port non-monitoring meadows in 2024.

Meadow		Location	Meadow ID	Number of Sites	Meadow Area (ha) ± (R)	Habitat Type	Meadow Cover	Meadow Description
Baseline Non-Monitoring Meadows	**Esplanade - Ellie Point**	Cairns Harbour	5	36	200.73 ± 22.52	Subtidal	Continuous cover	Dense *Halodule uninervis* (narrow) with *Halophila ovalis* and *Halophila decipiens*
	Ellie Point Inlet	Cairns Harbour	25	7	44.86 ± 2.54	Subtidal	Aggregated patches	Light *Halodule uninervis* (narrow) with *Zostera muelleri*
	Inlet 1	Trinity Inlet	40	1	0.93 ± 0.04	Intertidal to Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 2	Trinity Inlet	41	1	0.91 ± 0.03	Subtidal	Isolated patches	Light *Halophila decipiens*
	Inlet 3	Trinity Inlet	45	3	1.61 ± 0.35	Subtidal	Isolated patches	Light *Halophila ovalis* with *Halophila decipiens*
	Inlet 4	Trinity Inlet	46	6	1.08 ± 0.07	Intertidal to Subtidal	Isolated patches	Light *Halophila ovalis*
	Inlet 5	Trinity Inlet	51	1	0.24 ± 0.01	Subtidal	Isolated patches	Light *Halophila ovalis*
	Inlet 6	Trinity Inlet	55	1	0.08 ± 0.01	Subtidal	Isolated patches	Light *Halophila decipiens*
	Inlet 7	Trinity Inlet	68	32	0.76 ± 0.03	Subtidal	Isolated patches	Light *Halophila decipiens*

5.3 Seagrass Seed Banks

This is the sixth consecutive year seed bank assessments were conducted at meadow scale in the two larger meadows, Esplanade (34) and Bessie Point (11) (Table 7; Figure 22). In 2024, *H. uninervis* seeds were present in only the Bessie Point meadow after being in both meadows the previous 5 years (Table 7; Figure 22). *Z. muelleri* seeds have only been found on the Esplanade side of the Harbour (Table 7; Figure 22). Seed densities in the meadows have ranged from 0 (2017) to 153 (2023) seeds per metre square across both species (see Reason et al. 2023 for historical seagrass seed densities).

In March 2024 the Esplanade meadow (34) had a 14% decline in *Z. muelleri* seeds with 7.59 ± 2.39 seeds m^{-2} and no viable seeds found (Table 7). This is the fourth year in a row that there have been no viable *Z. muelleri* seeds found in this meadow. Except for April 2021 with 27.86 ± 7.39 seeds m^{-2}, seed density has been consistently lower than the density of seeds first recorded at the meadow scale in 2013 (24 ± 4 seeds m^{-2}).

The Bessie Point meadow (Meadow 11) had a 50% decline of *H. uninervis* seed numbers in 2024 to 75.23 ± 18.87 seeds m^{-2} (Table 7; Figure 22). *H. uninervis* seeds had consistently been present in both meadows until this year where they were only found in the Bessie Point meadow (Table 7; Figure 22).

Table 7. Cairns Harbour 2013/2019-2024 mean *Zostera muelleri* and *Halodule uninervis* seed bank density at the meadow scale in the Esplanade meadow (34) and Bessie Point meadow (11). *Data from Jarvis et al. 2021 for comparison.

Sampling Date	Esplanade *Zostera muelleri* mean total seeds m^{-2}	Esplanade *Zostera muelleri* mean viable seeds m^{-2}	Esplanade *Halodule uninervis* mean total seeds m^{-2}	Bessie Point *Halodule uninervis* mean total seeds m^{-2}
July 2013*	24 ± 4	5 ± 1	8 ± 2	13 ± 3
April 2019	9.81 ± 4.72	0	10.76 ± 10.9	105.1 ± 27.42
April 2020	3.80 ± 1.73	0.65 ± 0.65	4.58 ± 2.24	73.92 ± 21.12
April 2021	27.86 ± 7.39	0	15.05 ± 9.3	87.66 ± 23.76
March 2022	9.81 ± 3.39	0	3.17 ± 1.6	141.1 ± 34.39
March 2023	8.86 ± 3.85	0	7.85 ± 6.56	153.1 ± 38.04
March 2024	7.59 ± 2.39	0	0	75.23 ± 18.87

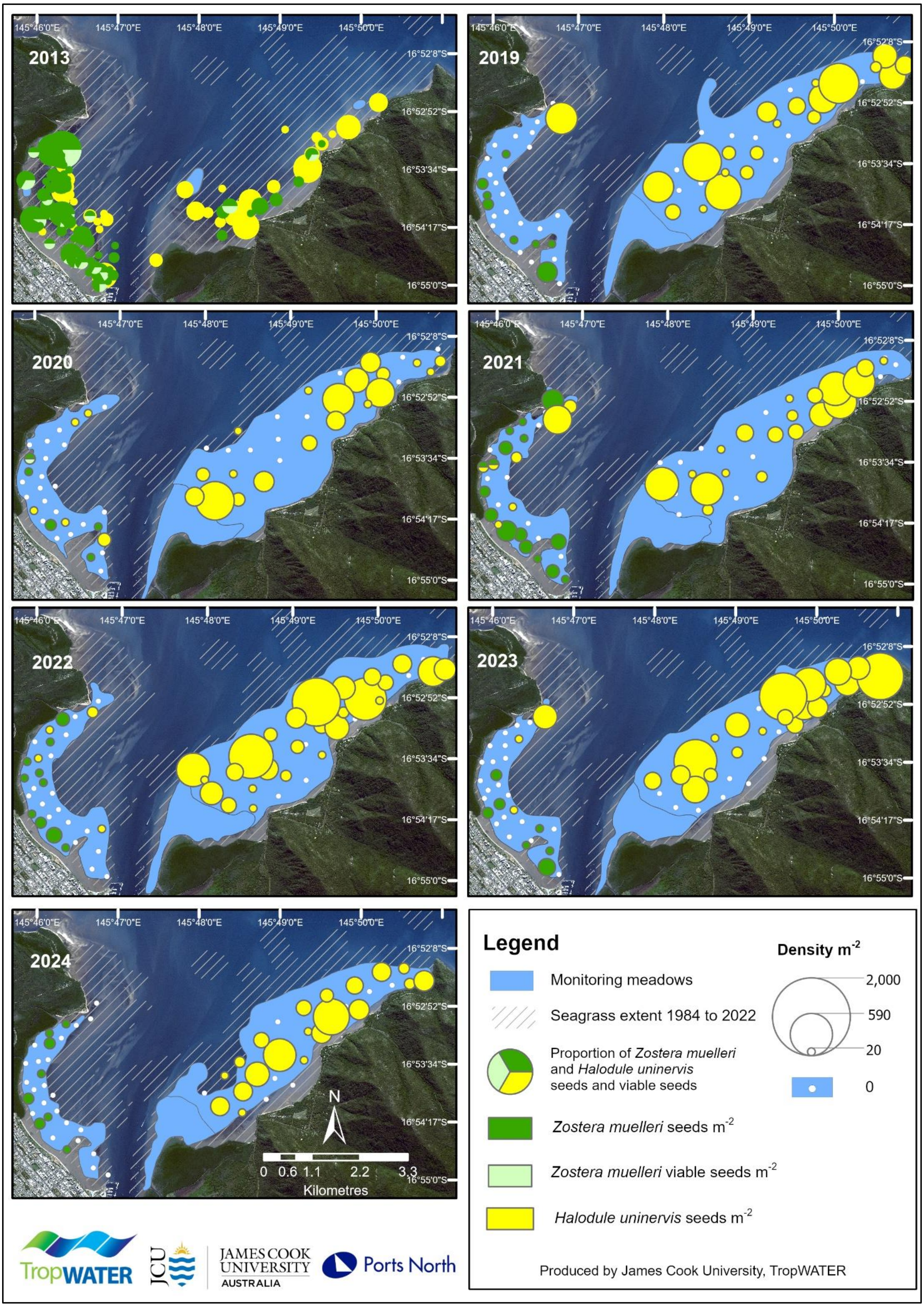


Figure 22. Mean *Zostera muelleri* seed density and viable seed density at each site in the Esplanade (34) meadow and mean *Halodule uninervis* seed information in both Cairns Harbour meadows from 2019 to 2024. 2013 Seed data presented for comparison, Source: Jarvis et al. 2021.

5.5 Cairns environmental conditions

5.5.1 Light (PAR) and Temperature Assessment

The quantity and quality 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. Benthic light (PAR) and temperature within the seagrass canopy is collected at three sites in the Cairns meadows; the Esplanade/Ellie Point (Site E), Bessie Point (Site B) and Redbank (Site R) (Figure 1). Published light requirement thresholds for seagrass species (i.e., Chartrand et al. 2016) are used to help understand the drivers of seagrass habitat change and condition. For the species found in Cairns, biologically relevant seagrass thresholds suggested in the literature include:

- Seagrass meadows dominated by *Zostera muelleri* and *Halodule uninervis* – 5-6 mol/m^2/day; 14 day rolling average; 28 consecutive days below threshold before impact.
- Seagrass meadows dominated by *Halophila* – 2.5 mol/m^2/day; 7 day rolling average; 28 consecutive days below threshold before impact.

In Cairns, benthic light (PAR) generally drops below the thresholds for periods of time during the summer months usually coinciding with high rainfall. For example, at Bessie Point PAR was below the *H. uninervis* threshold during the months of December 2023, and again in October 2024 (Figure 23). This location also sustained additional low light periods during high rainfall events during the year in February, April and May 2024 (Figure 23). The Ellie Point site (Esplanade meadow 34), experienced light conditions above the *Z. muelleri* threshold for the duration of the year (Figure 23). Notably, this site had maintained optimal light conditions for nearly 20 consecutive months, with the previous dip below the threshold occurring in February 2023 (Figure 23).

PAR levels at the Redbank Creek site remained below the *Z. muelleri* light threshold for most of the year, with only brief periods of sufficient light in June, October, and November 2024 (Figure 23). Additionally, PAR levels fell below the suggested *Halophila* threshold during the summer wet season from February to April 2024, before returning to sufficient levels for the remainder of the year (Figure 23).

The maximum benthic water temperatures were variable between sites with a peak in temperature of 38.9^{o}C in December at the Ellie Point site and a minimum of 19.7^{o}C in July at the same site (Figure 23).

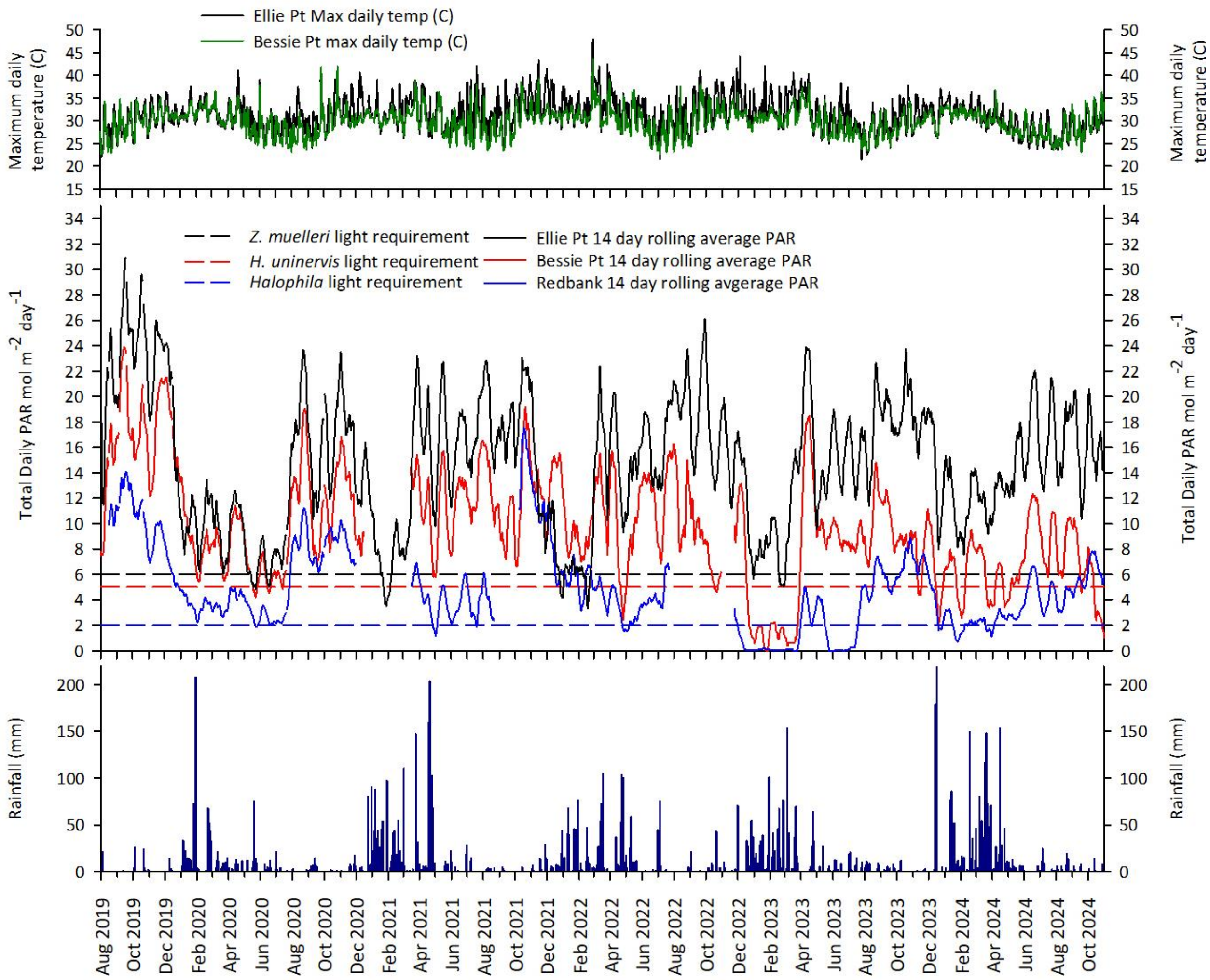


Figure 23. Maximum temperatures (°C), Total Daily PAR (mol m^{-2} day^{-1}) displayed as rolling averages, seagrass light threshold and rainfall (mm), August 2019 – December 2024.

5.5.2 Rainfall

The Cairns region recorded a total annual rainfall of 2799mm in 2024, well above the long-term average (2011 mm) and the highest since 2010/2011 (2824 mm) (Figure 24). In the months leading up to the survey rainfall was above the long-term average in March / April, and July / August (Figure 25).

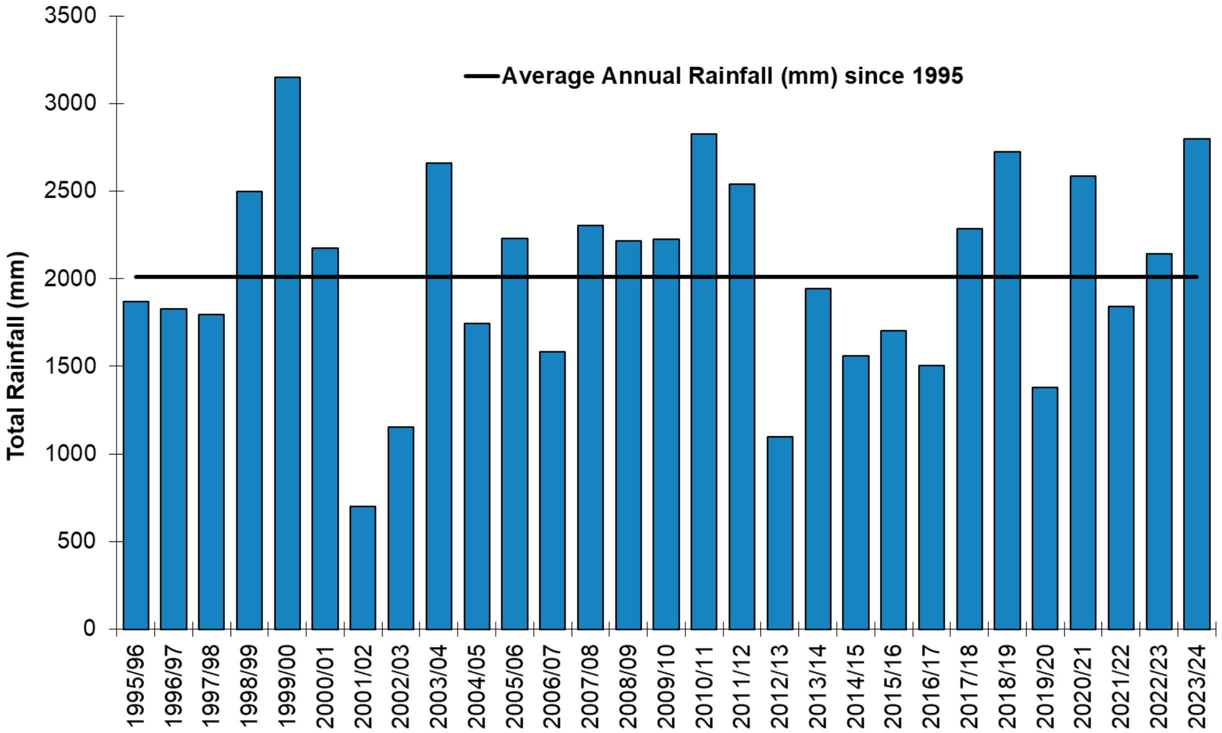


Figure 24. Total annual rainfall (mm) recorded at Cairns Airport, 1995 – 2024 Twelve month year (2023/2024 is 12 months prior to survey. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

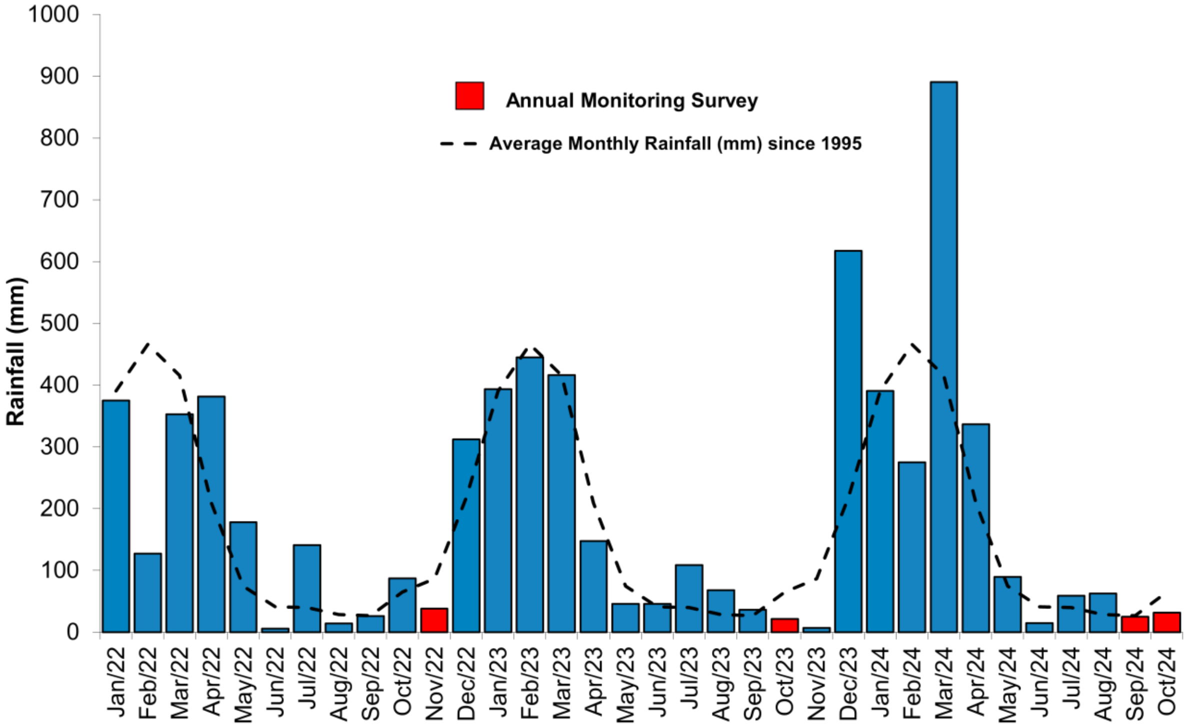


Figure 25. Total monthly rainfall (mm) recorded at Cairns Airport, Jan 2022 – October 2024. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

5.5.3 River Flow (Barron River)

River flow in the Barron River reached 2,788,303 ML in 2023/2024, 4 times higher than the long-term average of 691,118 ML (Figure 26). December 2023 recorded the highest monthly flow, significantly exceeding the long-term monthly average. Most months throughout the year experienced above-average flows, with the exceptions of February 2024 and the survey months from September to November 2024, which were below average (Figure 27).

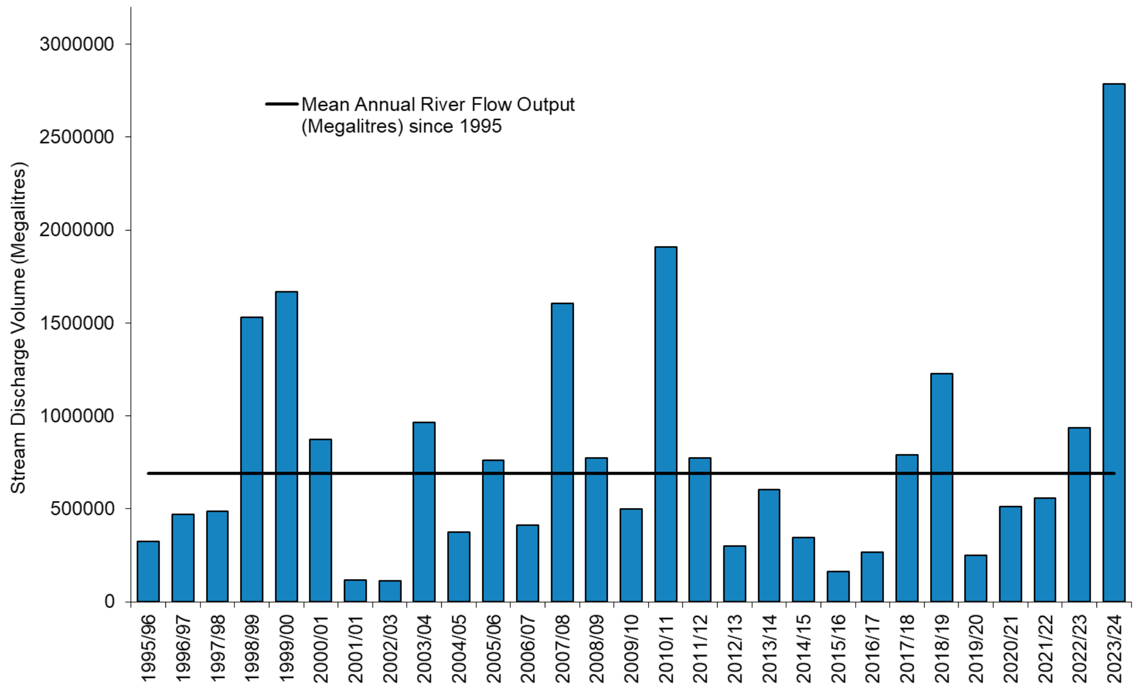


Figure 26. Annual water flow (mega litres) for the Barron River recorded at Myola, 1995 – 2024. Twelve month year (2022/23) is 12 months prior to survey. Source: Queensland Department of Environment and Resource Management, Station 110001D, available at: http://watermonitoring.derm.qld.gov.au/host.htm

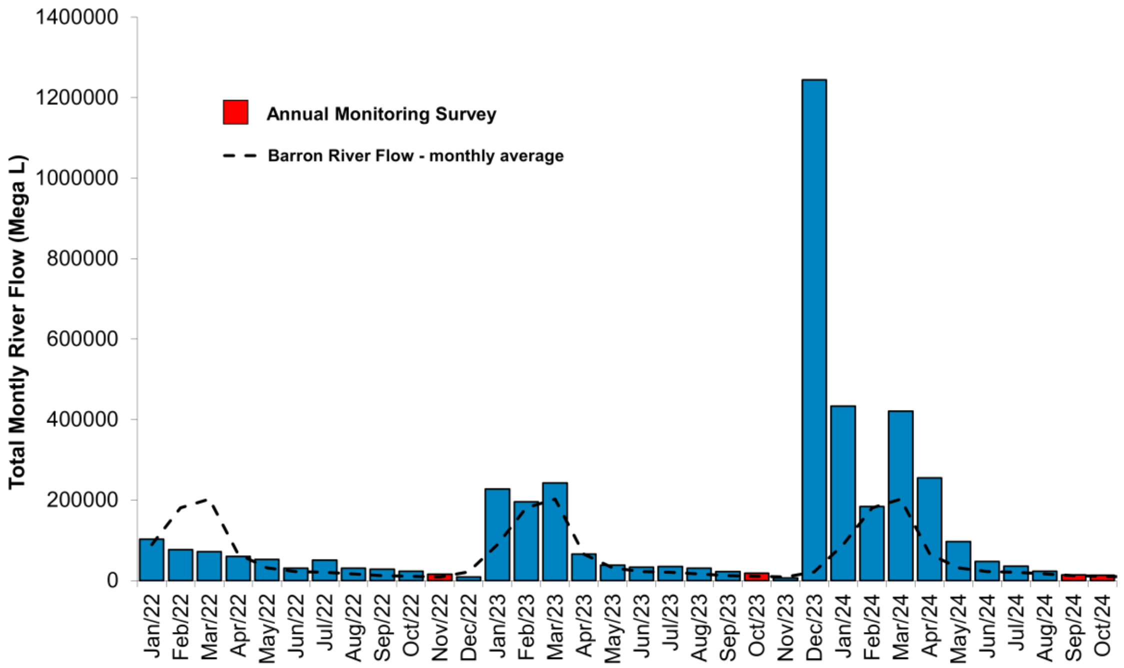


Figure 27. Monthly water flow (mega litres) for the Barron River recorded at Myola, January 2022 to October 2024. Source: Queensland Department of Environment and Resource Management, Station 110001D, available at: http://watermonitoring.derm.qld.gov.au/host.htm

5.5.4 Air Temperature

The annual maximum daily air temperature recorded at Cairns Airport in 2023/2024 was 29.92°C, an increase from the previous year and remaining above the long-term average (29.48°C) (Figure 28a). Monthly maximum air temperatures were above the long-term average from November 2023 to February 2024, as well as in April, while the remaining months recorded below-average temperatures (Figure 28b).

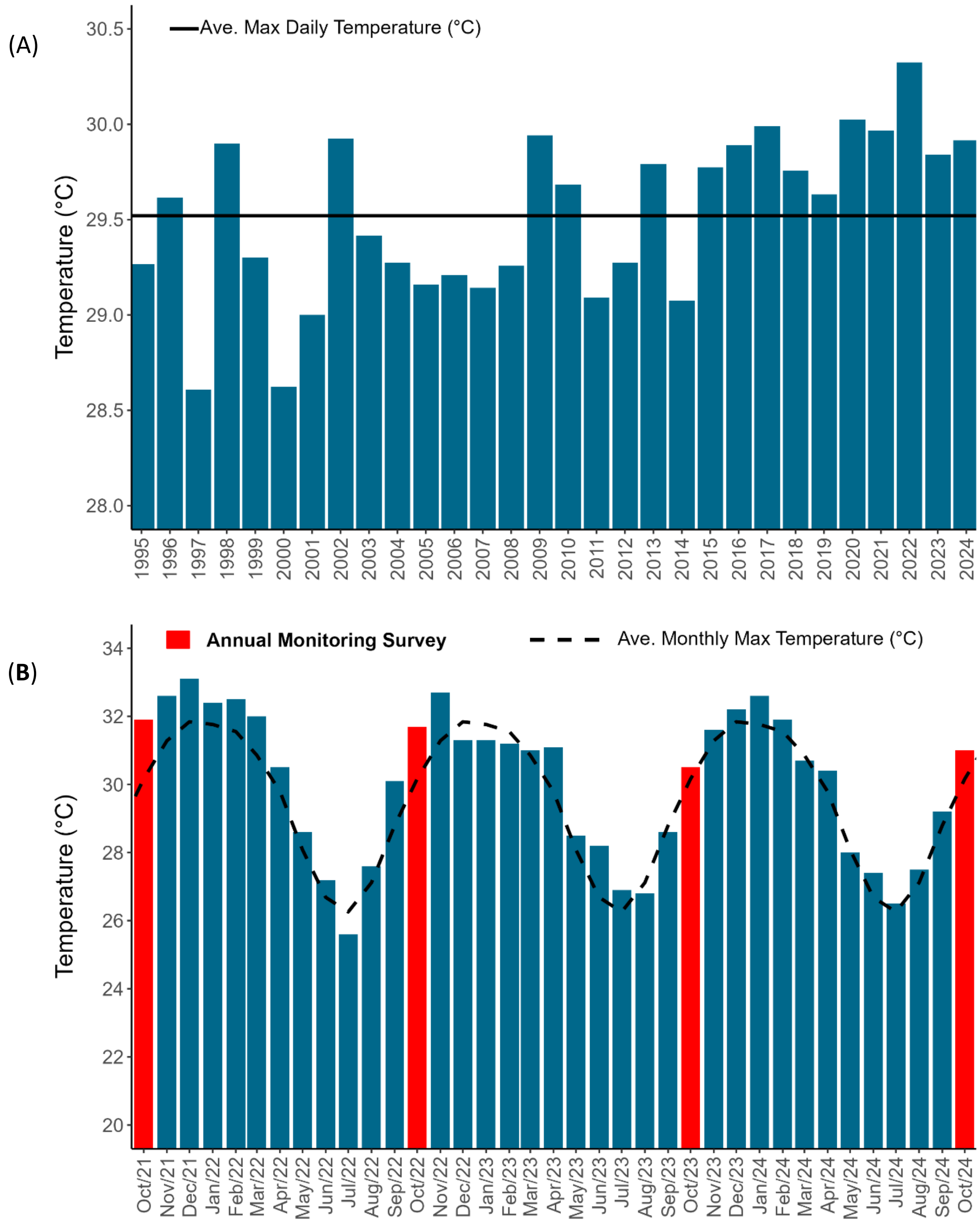


Figure 28. (A) Mean annual maximum daily air temperature (°C) recorded at Cairns Airport, 1995 – 2024. Twelve month year (2023/24) is 12 months prior to survey. (B) Monthly mean maximum daily air temperature (°C) recorded at Cairns Airport, October 2021 – October 2024. Source: Bureau of Meteorology, Station 031011, available at: www.bom.gov.au.

5.5.5 Tidal Exposure of Seagrass Meadows

In 2023/2024, intertidal seagrass meadows were exposed to air for a total of 209 hours, marking the fifth consecutive year of below-average annual exposure compared to the long-term average of 246 hours (Figure 30). While monthly exposure exceeded the long-term average in January and June 2024, all other months remained below average (Figure 31).

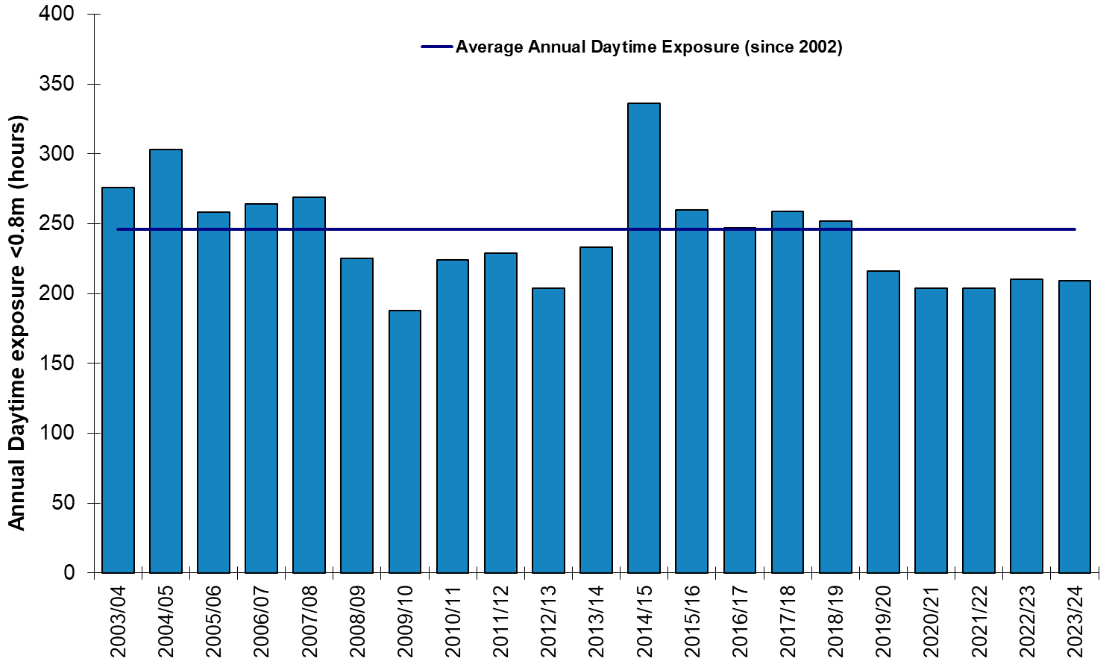


Figure 30. Total annual daytime tidal exposure of seagrass meadows in Cairns Harbour*; 2003 - 2024. Twelve month year is 12 months prior to survey. Source: Maritime Safety Queensland, 2024. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

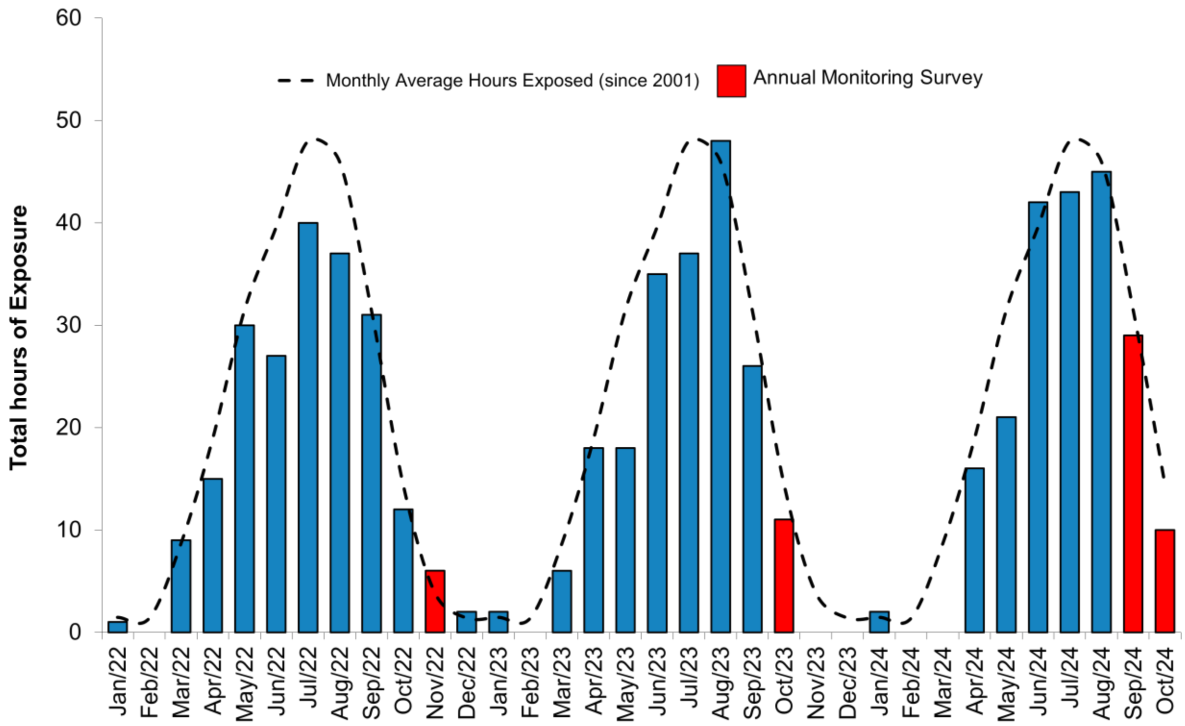


Figure 31. Total monthly daytime tidal exposure of seagrass meadows in Cairns Harbour*; January 2022 – October 2024. Source: Maritime Safety Queensland, 2024. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

6. DISCUSSION

The 2024 annual seagrass monitoring in Cairns occurred eight months following one of the largest flooding events on record for the region. The floods, associated with Tropical Cyclone Jasper in December 2023, led to large impacts on water quality along the Wet Tropics coastline. Despite these conditions, by September 2024, seagrasses in Cairns Harbour were in a satisfactory condition. While there were declines from the previous year, seagrasses remained across most of their historical footprint with area remaining above the long-term average and foundation species occurring throughout the meadows. Biomass of seagrass within the Cairns Harbour meadows, while reduced, was still within the range rated as satisfactory against their long-term baseline. The small variable meadows in the estuary of Trinity Inlet were more affected, with declines in area and biomass meaning they remained in poor condition in 2024.

In addition to the annually monitored meadows, seagrasses across the larger port limits area were surveyed in 2024, with an additional nine seagrass meadows mapped and total area of 1,297 ha recorded across the whole of port survey. As with the annually monitored meadows, seagrasses in Cairns Harbour were similar to previous extents, but in the Inlet, the small patches of *Zostera muelleri,* that had previously occurred, were absent in 2024. Previous whole of port surveys (2021) mapped aggregated patches of *Z. muelleri* on the bank on Admiralty Island, however, in 2024 these patches were also absent (Reason et al. 2022).

The better-than-expected outcome for seagrasses in Cairns Harbour was likely related to several factors. Firstly prior to 2023, seagrasses had been on 13 consecutive years of an upward trend of biomass, area and species composition and were in good to very good condition. This meant they had likely built-up substantial resilience to potential impacts, with extensive footprints, high biomass and good energy stores. Additionally, the Cyclone Jasper impacts, and wet season of 2023/24 represented a single year with poor growing conditions. Previous large-scale losses to seagrasses in Cairns resulted from multiple consecutive years of La Nina conditions between 2009-2011 resulting in poor light conditions rather than a response to a single event (McKenna et al. 2015). Seagrasses rely on an adequate benthic light environment for growth and population maintenance, and light is the main limiting factor for many coastal seagrasses (Waycott et al. 2005). The floods in late 2023 and early 2024, while having an impact on light available to seagrasses did not result in intertidal seagrasses receiving light lower than their growth requirements, and for the shallow sub-tidal seagrasses only having light below their thresholds for relatively short periods of time. This was different for the small meadows further up the Inlet where light was below growing requirements for extended periods, particularly for the higher light requiring species *Zostera muelleri* (Chartrand et al. 2016). These Inlet meadows were also in a poor condition prior to Cyclone Jasper so did not have the same levels of resilience as the Cairns Harbour meadows, explaining their comparatively poor result.

While the declines of Trinity Inlet meadows, and in particular the complete loss of the Redbank *Z. muelleri* meadow (20), are noteworthy, these meadows have a history of very high variability. The meadows are all very small in area and low in biomass, so it only takes a small change to register a large loss. The Redbank *Z. muelleri* meadow has a history of complete loss, having been absent in the monitoring program for multiple years between 2011 and 2016. This indicates that in this location *Z. muelleri* is likely growing at the limits of its requirements. The other two Inlet monitoring meadows are dominated by ephemeral species that display large interannual fluctuations in condition. The two species occurring in here (*H. ovalis* and *H. decipiens*) have similar morphology, life history strategies and ecological function, and are capable of growing in lower light environments than most other seagrass species (Chartrand et al. 2016, Josselyn et al. 1986, Erftemeijer and Stapel 1999). The small colonising *Halophila* species have relatively small energy reserves and decline rapidly (in the order of days to a week) when light is limiting compared to the larger species that occur elsewhere in Cairns. They are also very quick to colonise and increase when light windows become available (Kenworthy 2000).

Maintaining a seed-bank in the sediments is another key aspect of seagrass meadow resilience. While the results from seed-bank assessments in 2024 found seed banks were present in the two Cairns Harbour meadows assessed, the density of seeds was lower for both species. For *Z. muelleri* none of the seeds collected remained viable for the fourth consecutive year (no viability testing is conducted for *H. uninervis* seeds). These results suggest that *H. uninervis* may have maintained its long-term resilience, supported by a relatively dense and persistent seed bank. In contrast, full meadow resilience for *Z. muelleri* may not yet be achieved. The low density of *Z. muelleri* seeds may be because many of the seeds produced by plants had already germinated prior to sampling, leaving only older, less viable seeds. If this is the case the newly recruited seedlings are likely contributing to the continued expansion of the meadows in the harbour and their increasing biomass. Alternatively, low seed numbers may indicate a lack of a successful flowering/fruiting, however, observations in the field during the year, suggest that *Z. muelleri* did produce substantial numbers of reproductive shoots (T. Smith personal observation).

The fact that the vast majority of seagrasses in Cairns Harbour had their spatial footprint intact with foundation species present and for the largest meadows, biomass maintained in at least satisfactory condition, meant that they were likely continuing to support key ecosystem services. These large meadows provide habitats that deliver important ecosystem services such as food sources for herbivores like dugongs and green turtles, nursery habitat for juvenile fish and prawns, improved water quality through the trapping of suspended sediments and the capture and storage of carbon and nitrogen in plant tissues and sediments (Orth et al. 2020; Lefcheck et al. 2021).

Seagrass condition was variable in the broader long-term monitoring network in other parts of Queensland, and like Cairns were related to local weather and climate conditions. In Mourilyan Harbour, the closest monitoring location to Cairns Harbour, seagrass has remained in a very poor condition for the last few years and continues an 8-year run of poor-very poor condition with seagrasses having failed to recover from complete meadow losses leading up to 2010 (Shepherd et al. 2025). Seagrass in Townsville declined driven by multiple years of unfavourable climate conditions (McKenna et al. 2025a). Seagrass condition further to the south at Abbot Point has also reported declines in biomass and area associated with weather events (McKenna et al. 2025b). In the Gulf of Carpentaria, seagrass in Weipa were in good condition linked to favourable weather but declined in Karumba related to high rainfall and flooding (Reason et al. 2025a; Scott and Rasheed 2025).

Seagrass meadows in Cairns Harbour in 2024 maintained a large spatial footprint and continued to increase in the dominance of larger growing foundation species such as *Z. muelleri* and *C. serrulata*. The satisfactory condition of the Harbour meadows indicate that the Port of Cairns seagrass meadows are well placed to continue to build resilience with favourable growing conditions in the year ahead and were likely to remain resilient to planned annual maintenance dredging and port activity. In contrast, the Trinity Inlet meadows were impacted by major flooding following Cyclone Jasper, resulting in poor condition and a reduced footprint. However, these meadows are naturally highly variable and are expected to recover as benthic light conditions improve.

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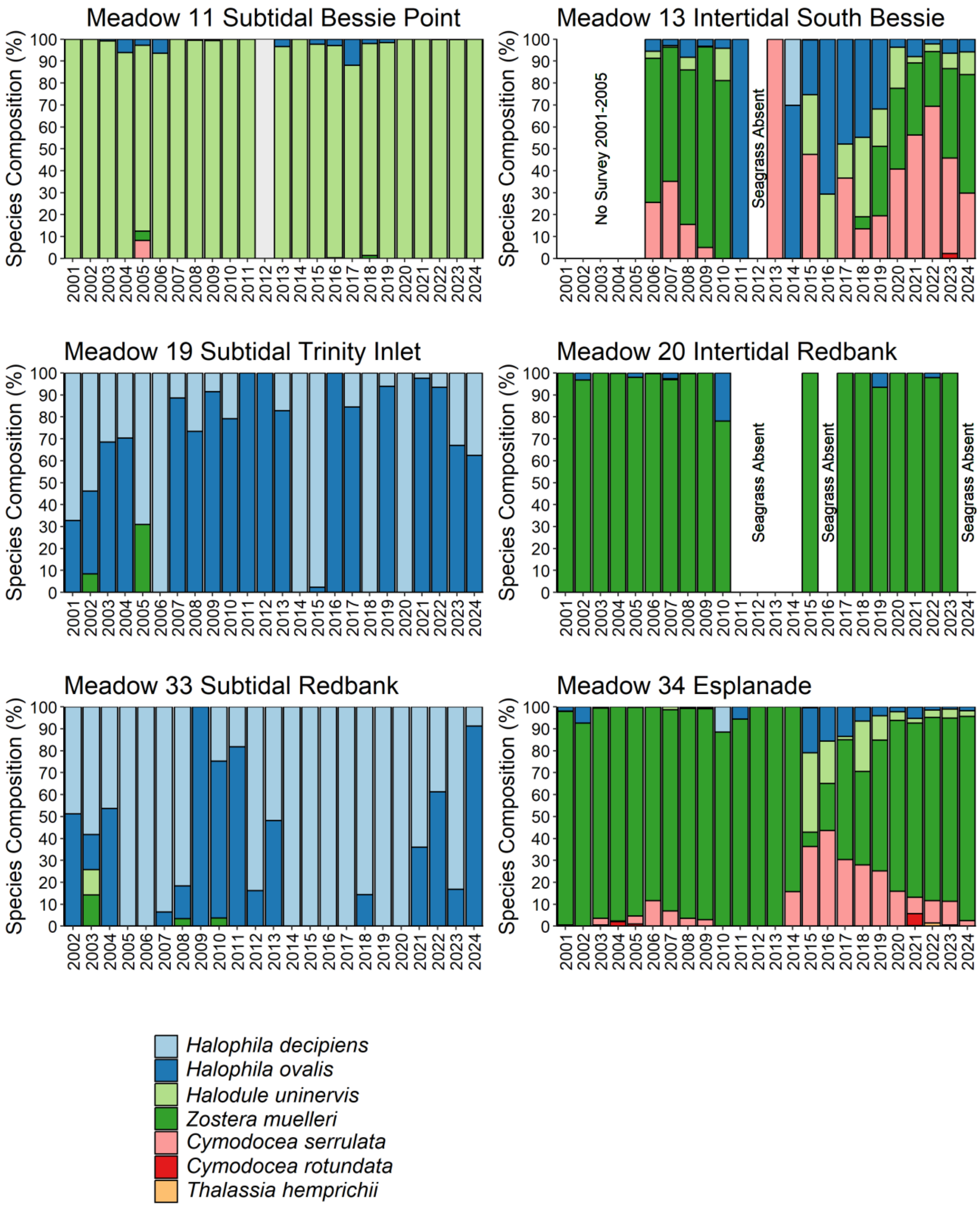
8. APPENDICIES: SPECIES COMPOSITION, AREA AND ABOVE-GROUND BIOMASS

8.1 Species Composition changes: 2001 – 2024.



8.2 Seagrass monitoring meadow area (ha) in Cairns Harbour and Trinity Inlet, 2001-2024; ± R = reliability estimate.

Meadow	Area (ha) ± (R)																							
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Esplanade to Ellie Pt. (34)	286.4 ± 8.2	258.5 ± 12.2	280.4 ± 11.7	300.8 ± 12.3	330.9 ± 6.5	370.8 ± 6.5	418.9 ± 6.4	379.3 ± 19.2	362.9 ± 13.4	92.1 ± 11.5	78.6 ± 37.9	7.4 ± 0.4	9.0 ± 1.0	7.3 ± 1.5	218.1 ± 6.9	247.8 ± 6.7	257.2 ± 11.90	366.3 ± 6.8	300.1 ± 6.8	304.9 ± 7.1	303.3 ± 7.5	334 ± 6.6	310 ± 6.5	235 ± 5.8
Bessie Pt. (11)	351.8 ± 133.9	451.2 ± 137.3	473.2 ± 148.8	659.3 ± 158.5	820.4 ± 86.6	868.1 ± 81.6	899.7 ± 81.3	803.3 ± 25.0	766.2 ± 34.1	97.2 ± 9.3	116.1 ± 46.5	20.7± 0.5	27.1 ± 15.1	90.6 ± 40.2	124.2 ± 60.7	551.0 ± 88.9	833.2 ± 84.4	1083.1 ± 108.8	853.1 ± 84.8	828.74 ± 78.9	794 ± 80.7	834 ± 78.6	792 ± 76	687 ± 85
South Bessie Pt. (13)	NA	NA	NA	NA	NA	73.0 ± 6.3	162.8 ± 8.4	197.7 ± 15.4	170.3 ± 9.6	54.2 ± 9.4	8.3 ± 3.4	NP	0.03 ± 0.02	11.8 ± 8.9	55.0 ± 3.3	100.0 ± 4.3	73.2 ± 6.4	108.7 ± 4.1	120.6 ± 3.9	149 ± 4.2	165.2 ± 4.0	156.9 ± 4.1	147 ± 4.3	121 ± 3.2
Inlet (19)	1.7 ± 0.6	4.9 ± 1.6	6.9 ± 1.7	5.2 ± 1.5	2.3 ± 1.3	1. 8 ± 1.3	2.9 ± 1.4	0.6 ± 0.4	1.2 ± 1.5	3.7 ± 1.3	6.5 ± 3.2	2.3 ± 1.3	2.5 ± 2.2	4.0 ± 3.5	1.1 ± 0.5	2.4 ± 1.2	3.0 ± 3.9	8.88 ± 0.8	3.6 ± 0.7	5.12 ± 0.7	3.8 ± 0.7	5.16 ± 0.7	4.3 ± 0.7	0.94 ± 0.3
Redbank (Zm) (20)	1.7 ± 1.1	0.1 ± 0.05	0.7 ± 0.4	0.8 ± 0.4	0.4 ± 0.1	0.5 ± 0.2	0.8 ± 0.2	0.6 ± 0.4	0.6 ± 0.7	0.4 ± 0.5	NP	NP	NP	NP	0.1 ± 0.1	NP	0.008 ± 0.006	0.04 ± 0.01	0.2 ± 0.03	0.07 ± 0.01	0.14 ± 0.02	0.16 ± 0.02	0.05 ± 0.01	NP
Redbank (Ho) (33)	NA	4.0 ± 1.4	4.4 ± 1.3	3.9 ± 1.2	2.8 ± 1.0	1.4 ± 1.1	2.4 ± 1.2	1.4 ± 0.4	1.9 ± 1.3	3.8 ± 1.1	1.1 ± 1.5	0.5 ± 0.3	3.5 ± 2.7	4.0 ± 2.3	0.9 ± 0.7	0.6 ± 0.5	0.7 ± 1.1	5.15 ± 1.5	3.5 ± 1.5	3.5 ± 1.1	4.6 ± 0.6	3.83 ± 0.6	2.55 ± 0.5	1.47 ± 0.6
TOTAL (monitoring meadows only)	641.6 ± 143.9	718.9 ± 152.6	765 ± 163.9	970 ± 173.9	1156.8 ± 95.5	1315.6 ± 96.9	1487.5 ± 98.9	1382.9 ± 60.8	1303.1 ± 60.6	251.4 ± 33.1	210.6 ± 55.8	30.9 ± 1.8	42.1 ± 17.9	117.7 ± 44.5	399.4 ± 71.8	901.8 ± 100.9	1167.5 ± 98	1572.2 ± 121.9	1281.2 ± 97	1291.4 ± 92	1271 ± 93.4	1334.44 ± 90.7	1255.8 ± 88.1	1046.3 ± 94.6

NA = meadow not assessed, NP = meadow not present

8.3 Mean above ground biomass (g DW m^2) of seagrass for monitoring meadows in Cairns Harbour and Trinity Inlet, 2001-2024.

Meadow	Mean biomass ± SE (g DW m^{-2})																							
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Esplanade to Ellie Pt. (34)	5.9 ± 3.3	17.3 ± 1.6	46.2 ± 4.1	81.2 ± 6.8	71.8 ± 5.3	46.9 ± 3.4	33.2 ± 2.9	44.1 ± 3.8	9.8 ± 1.9	1.1 ± 0.4	0.7 ± 0.2	NA	1.2 ± 0.9	2.0 ± 0.9	3.4 ± 0.7	7.9 ± 0.7	10.7 ± 1.3	18.5 ± 1.8	21.2 ± 2.3	23.7 ± 2.0	3.2 ± 3.1	34.5 ± 3	30.3 ± 2.8	27.6 ± 2.7
Bessie Pt. (11)	2.0 ± 0.4	5.5 ± 0.7	4.4 ± 0.4	5.8 ± 0.3^	15.5 ± 1.5	12.7 ± 1.7	6.9 ± 0.5	7.4 ± 0.7	7.3 ± 1.6	0.5 ± 0.3	1.8 ± 0.3	NA	2.2 ± 0.6	3.1 ± 0.6	3.2 ± 0.7	12.6 ± 1.1	4.2 ± 0.4	7.6 ± 0.7	8.2 ± 0.6	9.6 ± 0.8	7.0 ± 0.9	9.5 ± 0.7	9.8 ± 0.8	2.7 ± 0.4
South Bessie Pt. (13)	NA	NA	NA	NA	NA	46.3 ± 9.1	50.9 ± 10.4	23.3 ± 3.9	36.5 ± 8.0	1.7 ± 0.8^	1.1 ± 0.4	NP	3.1 ± 0.0	5.1 ± 0.3	4.3 ± 2.0	2.3 ± 0.5	5.6 ± 1.3	6.2 ± 0.1	12.9 ± 1.5	20.9 ± 3.3	20.6 ± 4.8	25.3 ± 5.3	25.9 ± 4.2	5.3 ± 1.4
Trinity Inlet (19)	6.6 ± 2.1	0.4 ± 0.1	3.0 ± 0.5	2.3 ± 0.3	3.6 ± 1.2	0.1 ± 0.02	2.3 ± 0.3	0.4 ± 0.2	1.6 ± 1.0	0.3 ± 0.2	3.5 ± 0.7	1.1 ± 0.2	1.3 ± 0.3	3.1 ± 0.4	0.8 ± 0.7	5.0 ± 0.8	1.1 ± 0.4	4.6 ± 0.6	1.7 ± 0.6	3.1 ± 0.6	0.53 ± 0.3	1.49 ± 0.3	0.28 ± 0.06	0.47 ± 0.10
Redbank (Ho)* (33)	NA	0.8 ± 0.1	6.6 ± 1.1	1.3 ± 0.2	2.2 ± 0.4	0.3 ± 0.04	2.0 ± 0.3	2.1 ± 0.4	0.1 ± 0.1	0.4 ± 0.1	1.2 ± 0.3	0.9 ± 0.2	2.1 ± 0.4	1.6 ± 0.3	2.2 ± 0.6	2.1 ± 0.4	0.2 ± 0.02	3.4 ± 0.4	0.8 ± 0.1	1.1 ± 0.3	0.4 ± 0.1	1.87 ± 0.2	0.31 ± 0.1	0.75 ± 0.1
Redbank (Zm) (20)	4.5 ± 4.1	2.8 ± 0.6	50.1 ± 9.4	61.5 ± 12.1	15.1 ± 7.4	11.9 ± 2.9	14.1± 3.1	37.5 ± 6.8	0.2 ± 0.02	30.4 ± 10.7	NP	NP	NP	NP	14.3 ± 2.0	NP	2.2 ± 1.8	27.2 ± 3.3	13.9 ± 4.5	16.4 ± 5.3	54.4 ± 11.4	10.54 ± 4.9	25.13 ± 6.6	NP

^ The one site containing *Cymodocea serrulata* was omitted from Bessie Point biomass analysis and *Cymodocea rotunda* was omitted from South Bessie Point biomass analysis.
NP = meadow not present
NA = biomass values not available due to insufficient biomass samples
(Ho = *Halophila ovalis*; Zm = *Zostera muelleri*)