

Seagrass Habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2022

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Seagrass Habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2022

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KEY FINDINGS

**Cairns Harbour
Coastal Seagrass
condition 2022**



Good

**Trinity Inlet
Estuarine Seagrass
condition 2022**

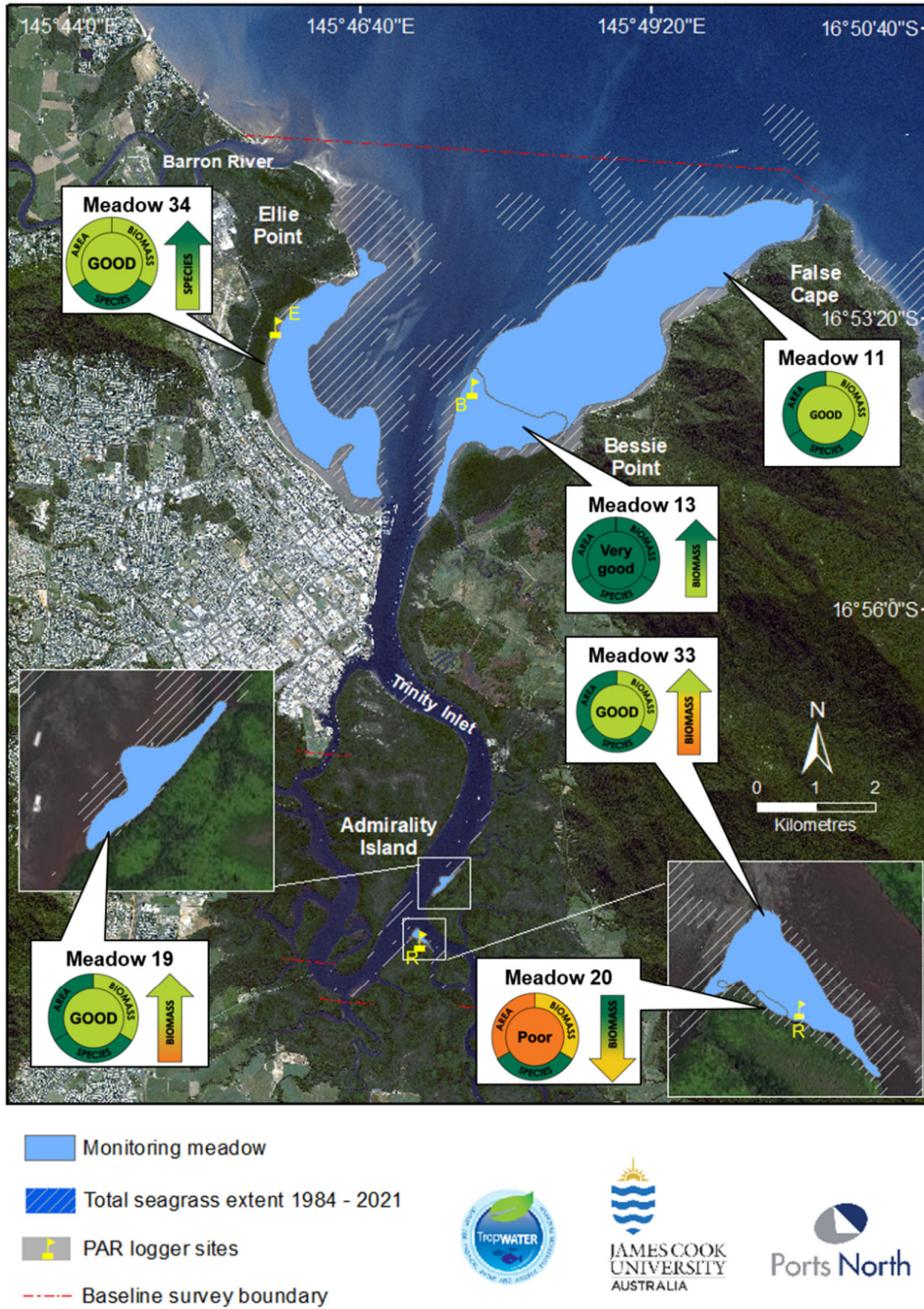


Satisfactory

1. Cairns seagrass meadows are monitored annually to assess the condition of three key indicators; biomass, area and species composition as a measure of marine habitat health.
2. The large coastal meadows in Cairns Harbour showed continued improvements in biomass and species composition within individual meadows and remained in an overall good condition for the fourth consecutive year. With these improvements they have now effectively returned to the state they were before the large disturbance events from 2009-2011.
3. The smaller meadows in Trinity Inlet improved from a poor to a satisfactory condition in 2022. This was driven by an increase in the biomass of the highly variable *Halophila* dominated meadows, although there was a concurrent decline in the biomass of the small *Zostera muelleri* meadow.
4. For the sixth year in a row the area of the monitoring meadows is above the baseline average while the average seagrass biomass per site continued its annual improvement and is now approaching the 10 year baseline.
5. The stable condition of the Harbour meadows combined with the improvements in the Inlet meadows indicate that the Port of Cairns seagrass meadows are well placed to thrive with the continuation of favourable growing conditions.

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 (Map 1). All seagrasses within the port limits are also remapped every 3 years as part of the long-term monitoring program. In addition to the established annual monitoring program, regular assessments of the seagrass seed bank density and viability (annually), and benthic light (continuously logged) are conducted at Ellie Point to the Esplanade (site E; Map 1), and the Bessie Point intertidal meadow (Site B, Map 1) and light is also monitored in the Inlet adjacent to the Redbank Creek meadow (Site R, Map 1).

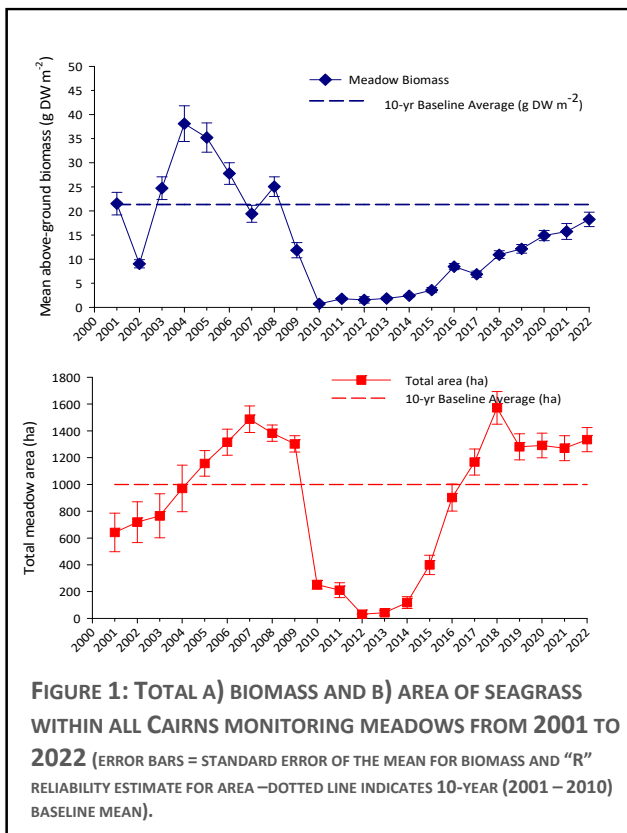


MAP 1. SEAGRASS MONITORING MEADOW CONDITION IN CAIRNS HARBOUR, 2022.

In 2022 overall biomass in the six long-term monitoring meadows continued its decade-long upward trajectory and is now only slightly below the long-term average (Figure 1; Map 1). The area of the long-term monitoring meadows also increased slightly in 2022 and remained well above the long-term average for the sixth consecutive year (Map 1; Figure 1). Continued improvement of the biomass and area of seagrass is likely due to the favourable environmental conditions in 2022. These consisted of below average river flow (despite above average rainfall for the area) and the combination of low tidal exposure and above average solar radiation which contributed to continuous seagrass growth (Figure 2).

The Cairns Harbour meadows remained in good condition overall, with improvements in species composition and biomass in some meadows. This effectively signals the return of meadows to the condition they were in prior to the major disturbances of 2009-2011 that led to almost complete meadow collapse. The intertidal meadow at Bessie Point reached a very good condition across all three condition indicators due to an improvement in the biomass of the seagrass present in this meadow. Additionally, species composition in the large meadow along the Esplanade improved to a very good condition, however the overall condition of this meadow remained in a good condition for the third year in a row.

The three smaller Trinity Inlet estuarine monitoring meadows collectively improved to a satisfactory condition, however, some meadow condition indices improved while others declined. Biomass condition increased for the two highly variable *Halophila* meadows and declined in the *Zostera* meadow. Species composition remained in a very good condition for all three meadows.



The recovery of the seagrass meadows to pre-disturbance levels over the last decade has likely also facilitated the return of the important ecosystem services these habitats provide. These include food sources 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 Cairns Harbour and Trinity Inlet seagrass monitoring forms part of a broader program that examines condition of seagrasses in the majority of Queensland commercial ports and areas of high cumulative anthropogenic risk. In Mourilyan Harbour, the closest monitoring location to Cairns Harbour, seagrass has failed to recover from the losses experienced in 2009 – 2011 mostly due to the complete loss of the foundation species *Z. muelleri*. In the broader Queensland monitoring network, seagrass condition has mostly shown similar trends of improved condition as seen in Cairns. Seagrass in the Gulf of Carpentaria (Weipa and Karumba) were in a good and very good condition due to favourable

climate conditions. On the east coast, Townsville seagrass were also in a good condition due to stable climate conditions over the past two years (McKenna et al. 2023).

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

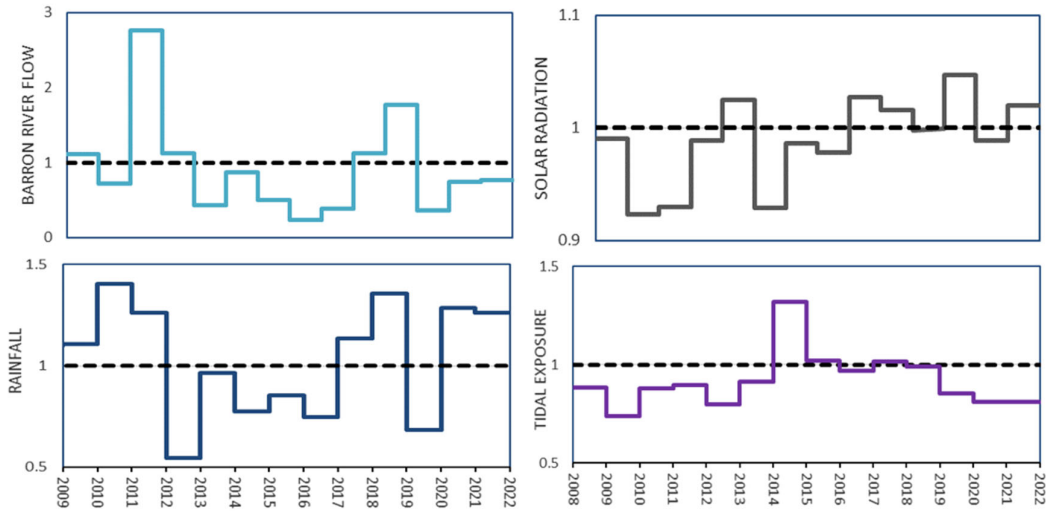


FIGURE 2: RECENT CLIMATE TRENDS IN CAIRNS: CHANGE IN CLIMATE VARIABLES AS A PROPORTION OF THE LONG-TERM AVERAGE.

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1 INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services worth substantial economic value (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 recent 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).

1.1 QUEENSLAND PORTS SEAGRASS MONITORING PROGRAM

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with 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 (Map 2).

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.

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/>

1.2 CAIRNS HARBOUR AND TRINITY INLET SEAGRASSES

The first surveys of seagrass distribution, species diversity and abundance in Cairns Harbour were undertaken as part of a broad scale statewide seagrass survey in 1984 (Coles et al. 1985). In 1988 and 1993, Cairns Harbour and Trinity Inlet seagrasses were re-surveyed (Lee Long et al. 1996; Coles et al. 1993) and subsequent detailed mapping of Ellie Point seagrasses occurred in December 1996 (Rasheed and Roelofs 1996). The State of Trinity Inlet Report (WBM 1997) recognised seagrasses as crucial to maintaining biodiversity and fisheries productivity in the Inlet and identified seagrasses as a key habitat type for long-term monitoring. As seagrasses show measurable responses to changes in water quality, they can also be used as an effective tool to monitor marine environmental health (e.g. Dennison et al. 1993). In response, the Trinity Inlet Management Program commissioned a baseline survey of seagrass in the region in 2001 (Campbell et al. 2002) from which the current annual seagrass monitoring program was established. Over 800 hectares of seagrass habitat was mapped in these surveys with meadows representing the only major coastal seagrass resource between Hinchinbrook Island and Cooktown (Campbell et al. 2003; Campbell et al. 2002; Lee Long et al. 1996; Lee Long et al. 1993).



1.3 PORT OF CAIRNS

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 2023).

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.

1.4 SEAGRASS MONITORING PROGRAM

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 monitoring, Ports North established quarterly monitoring surveys at a site representing a key intertidal seagrass meadow type found in Cairns Harbour at the Esplanade in 2014 (Site E - Map 1) and expanded that to include an additional site on the opposite side of the harbour near Bessie Point in 2018 (Site B -Map 1). At these sites regular (quarterly) assessments of seagrass condition were conducted through to December 2019 and benthic light and temperature (continuously logged) are recorded to assess the condition and resilience of seagrass and their associated benthic light (PAR) levels. In 2019 a third benthic PAR and temperature logger was added at the Redbank Creek seagrass meadow. Queensland seagrass communities are seasonal, with maximum distribution and abundance usually occurring in late spring/early summer.

The overall objectives of the 2022 annual seagrass monitoring were to:

1. Map and quantify the distribution, abundance and species composition of the selected long-term seagrass monitoring meadows;
2. Compare monitoring results with previous seagrass surveys and assess changes in relation to natural events, port and catchment activities;
3. Assess seagrass condition and examine seagrass change in relation to light (Photosynthetic Active Radiation (PAR)), and reproductive effort (seed banks).

2 METHODS

2.1 SAMPLING APPROACH

Survey and monitoring methods followed the established techniques for TropWATER's Queensland-wide seagrass monitoring programs. The annual seagrass survey was conducted on 6th and 18th October and 24th November 2022 during seasonal peak of seagrass condition. The survey involved mapping and assessing the six long-term monitoring meadows assessed annually within the Cairns Harbour and Trinity Inlet monitoring area.

For more details see: <https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/>

2.2 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 3). Shallow subtidal meadows were sampled by boat using camera drops and van Veen grab (Figure 3). A Van Veen sediment grab (grab area 0.0625 m²) was used where required at each camera site to confirm sediment type and species viewed on the video screen (Figure 3). 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.

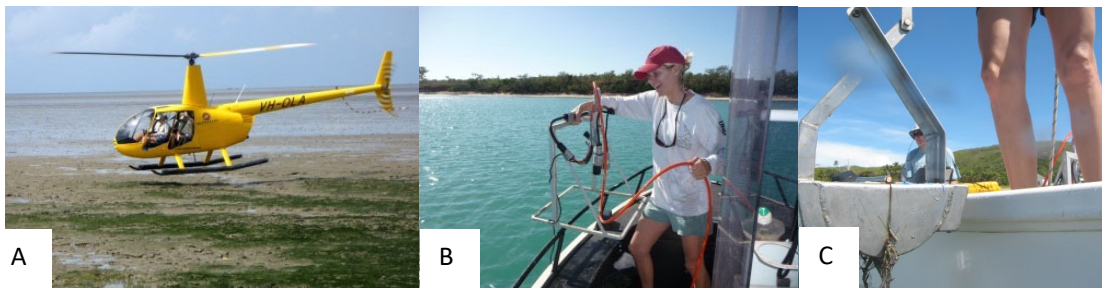


FIGURE 3: SEAGRASS MONITORING METHODS IN 2018. (A) HELICOPTER SURVEY OF INTERTIDAL SEAGRASS, (B AND C) BOAT-BASED CAMERA DROPS AND VAN VEEN GRAB FOR SUBTIDAL SEAGRASS.

2.2.1 SEAGRASS BIOMASS

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (Mellors 1991; Kirkman 1978). At each site a 0.25 m² quadrat was placed randomly three times. An observer assigned a biomass rank to each quadrat while referencing a series of quadrat photographs of similar seagrass habitats where the above-ground biomass had previously been measured. Two separate ranges were used - low biomass and high biomass. The percentage contribution of each species to each quadrat’s biomass also was recorded.

At the survey’s completion, each observer ranked a series of calibration quadrat photographs representative of the range of seagrass biomass and species composition observed during the survey. These calibration quadrats had previously been harvested and the above-ground biomass weighed in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks recorded in the field. Field biomass ranks were converted into above-ground biomass in grams dry weight per square metre (g DW m⁻²) for each of the three replicate quadrats per site. Total seagrass biomass at each site, and the biomass of each species, is the mean of the three replicates. Seagrass biomass could not be determined from sites sampled only by van Veen grab.

2.3 GEOGRAPHIC INFORMATION SYSTEM

All survey data was entered into a Geographic Information System (GIS) using ArcGIS 10.8.2[®]. 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:

2.3.1 SITE LAYER

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

- Site number
- Temporal details – Survey date and time.
- Spatial details – Latitude, longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
- Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail (DFT) presence/absence.
- Sampling method and any relevant comments.

2.3.2 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.

2.3.3 MEADOW LAYER

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

- Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass + standard error (SE), meadow area (hectares) + reliability estimate (R) (Table 4), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 2, 3), meadow landscape category (Figure 5).
- Sampling method and any relevant comments.

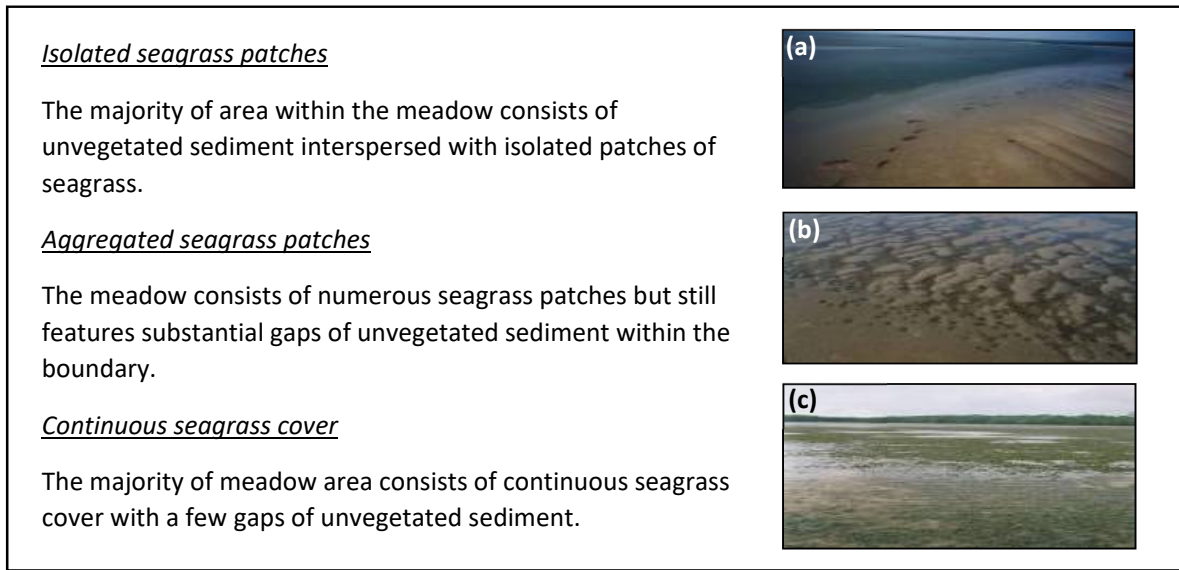


FIGURE 4: SEAGRASS MEADOW LANDSCAPE CATEGORIES: (A) ISOLATED SEAGRASS PATCHES, (B) AGGREGATED SEAGRASS PATCHES, (C) CONTINUOUS SEAGRASS COVER.

TABLE 1: NOMENCLATURE FOR SEAGRASS COMMUNITY TYPES 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 is >60-90% of composition
Species A with mixed species (>2 species)	
Species A/Species B	Species A is 40-60% of composition

TABLE 2: DENSITY CATEGORIES AND MEAN ABOVE-GROUND BIOMASS RANGES FOR EACH SPECIES USED IN DETERMINING SEAGRASS COMMUNITY DENSITY CAIRNS HARBOUR AND TRINITY INLET.

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

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 ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 4). 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).

TABLE 3: MAPPING PRECISION AND METHODOLOGY FOR SEAGRASS MEADOWS IN CAIRNS HARBOUR AND TRINITY INLET.

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

2.4 SEED BANK ASSESSMENT

Seed-bank density for *Zostera muelleri* subsp. *capricorni* and *Halodule uninervis* seeds is quantified around March each year for the two main seagrass meadows in Cairns Harbour (Bessie Point and Esplanade). This 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. Samples were separated into three depth categories (0 – 20 mm, 20 – 50 mm and 50 – 100 mm) then run through a series of test sieves 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* subsp. *capricorni* seeds using a dissecting microscope. Seed density data were delineated by species and reported as mean number of seeds per m⁻² per site.

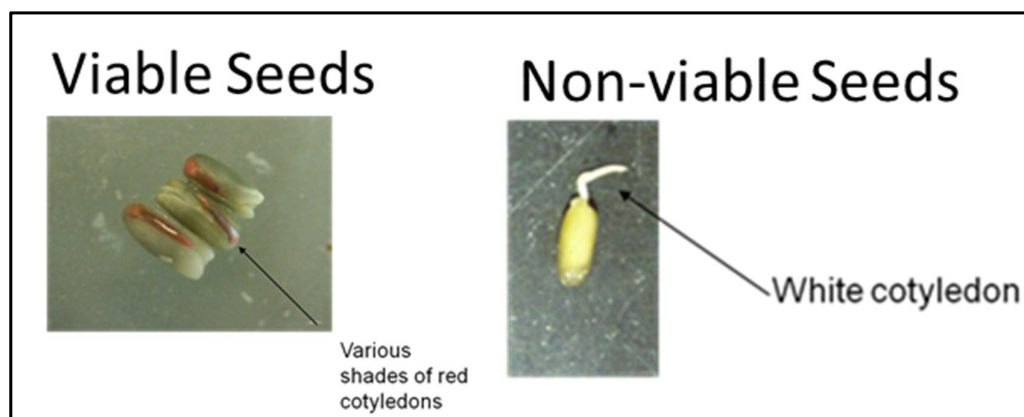


FIGURE 5: HELICOPTER SURVEY, SEDIMENT SEED BANK CORES, AND PAR LOGGERS AT CAIRNS HARBOUR QUARTERLY MONITORING SITE E.

2.4.1 SEED VIABILITY

Seed viability is tested annually at the end of the seed producing period. Once identified 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. 1994a) 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. 1994a). 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 pink to brown stained cotyledon and axial hypocotyl were considered viable (Jarvis et al. 2021, Conacher et al. 1994a; Harrison 1993) (Figure 7). 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 April 2021 and is scheduled to occur next in March 2022.

FIGURE 6: EXAMPLES OF STAINED VIABLE AND NON-VIABLE *ZOSTERA* SEEDS USING TETRAZOLIUM CHLORIDE.



2.5 TEMPERATURE AND LIGHT PAR LOGGERS

Light (Photosynthetically Active Radiation or PAR) and temperature are monitored continuously at three sites, The Esplanade (site E), Bessie Point (Site B) and Redbank (Site R) (Map 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 Odyssey™ 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.

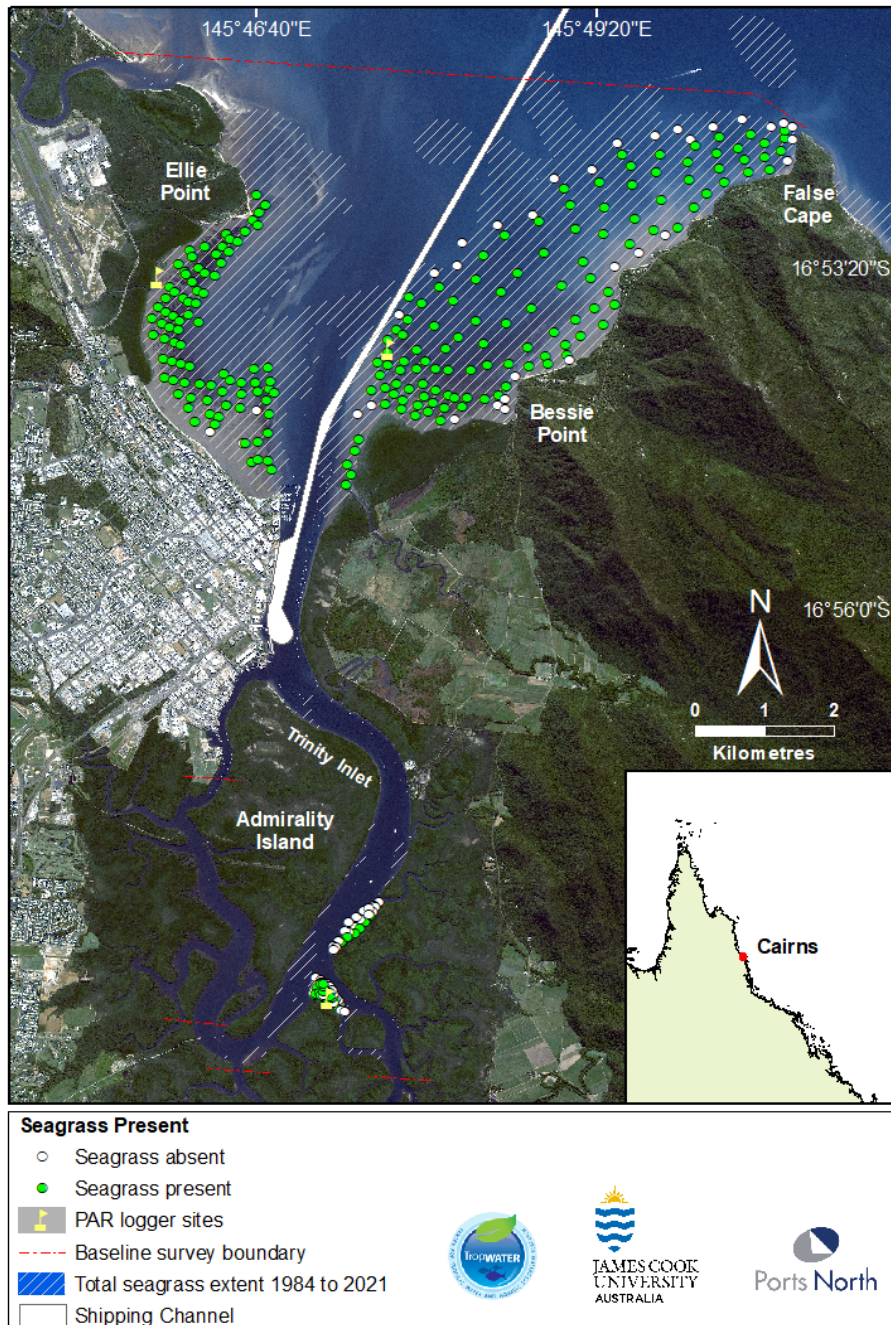
2.6 SEAGRASS CONDITION INDEX

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

3 RESULTS






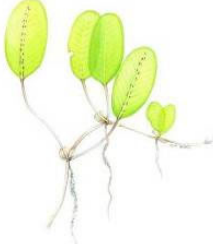
3.1 SEAGRASS SPECIES

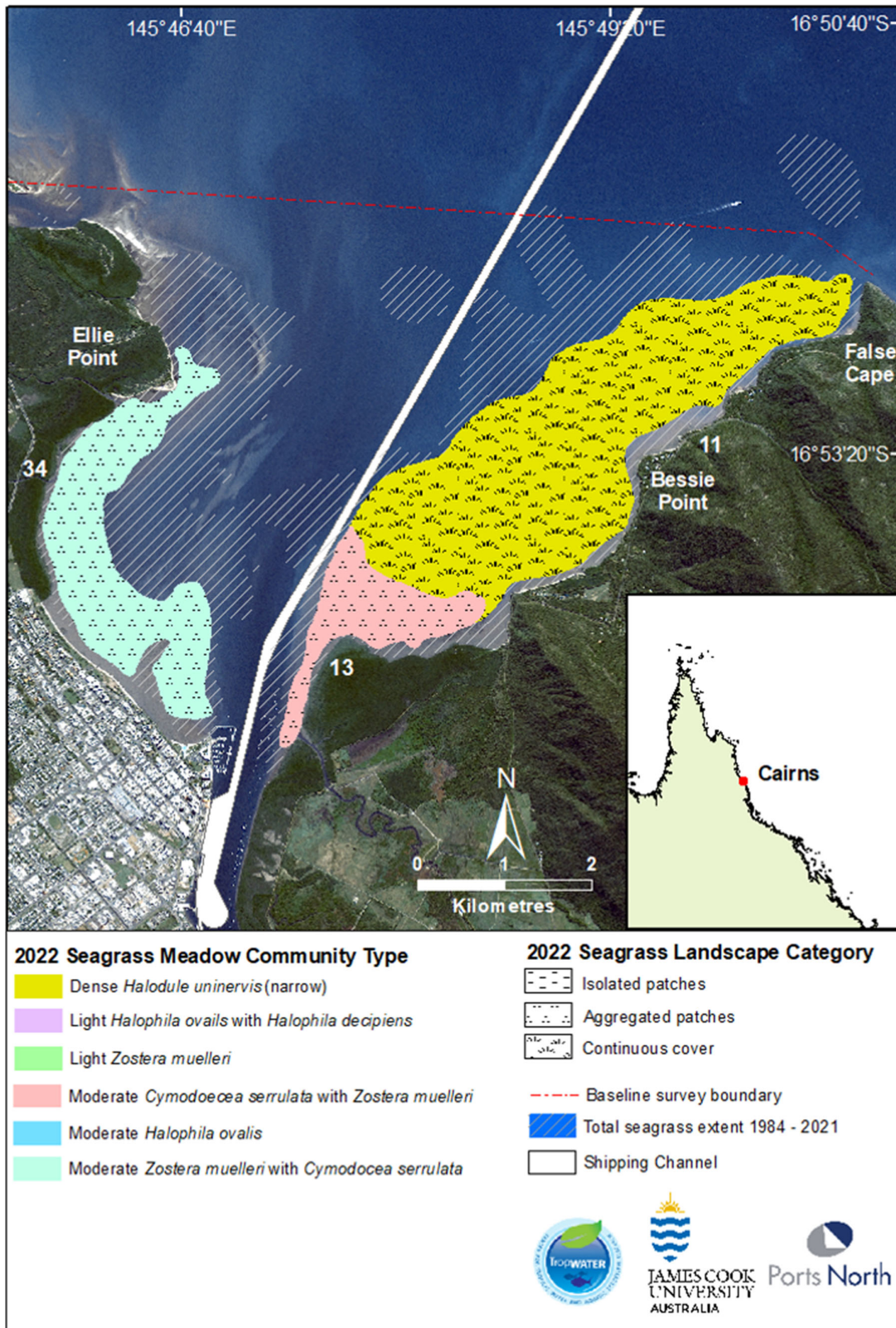
In 2022 the annual seagrass monitoring survey assessed a total of 338 habitat characterisation sites with seagrass present at 75% of the sites (Map 3). The six long-term monitoring meadows were mapped with a total area of $1,334 \pm 90$ ha in 2022 (Map 4a; 4b). Six species of seagrass was found in these meadows, the same as the previous year (Table 4). *Thalassia hemprichii* has only occasionally been recorded in Cairns Harbour and this is the second year in a row it has been found within the annual monitoring meadows.



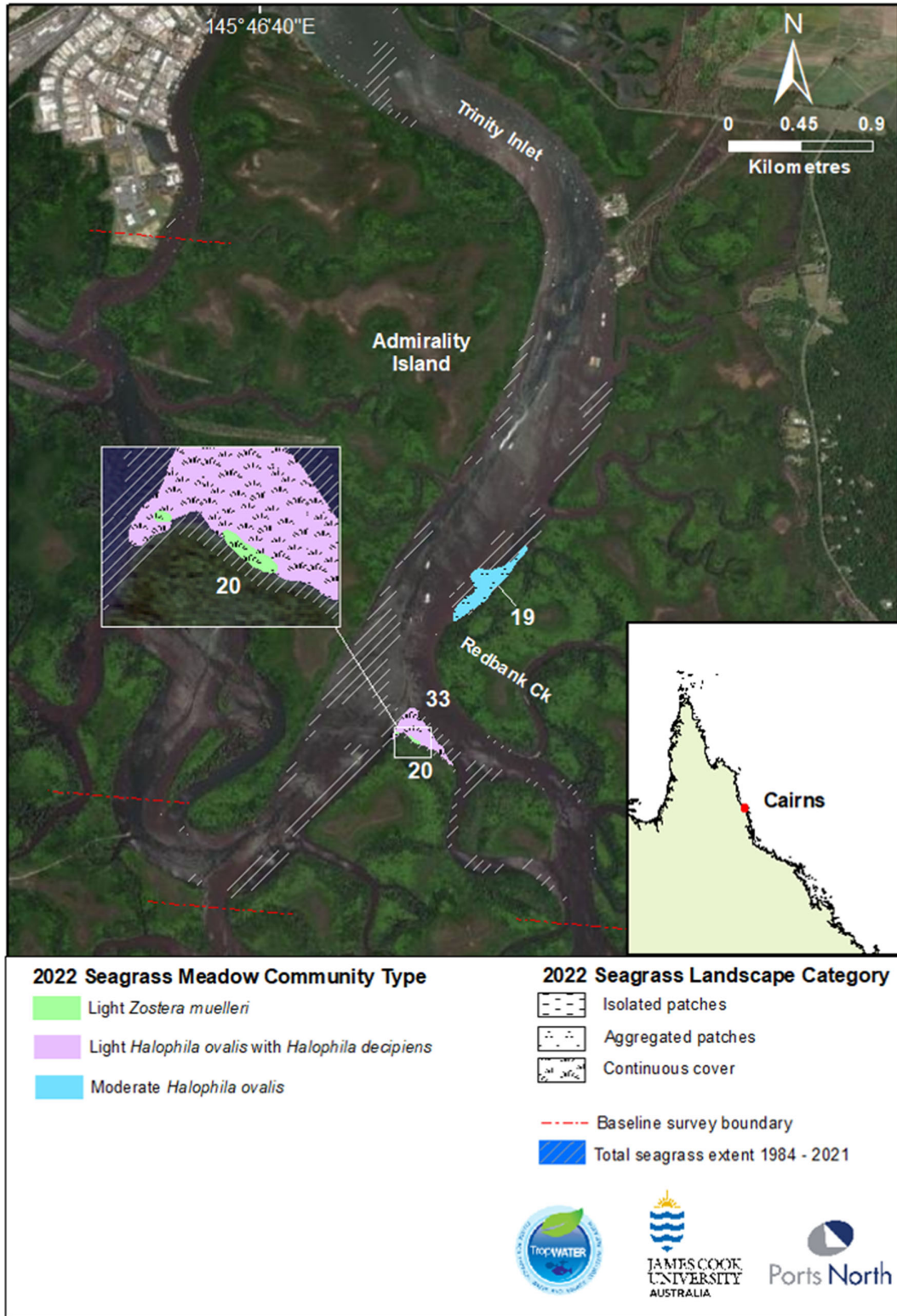
MAP 3: SEAGRASS PRESENCE/ABSENCE AT SITES SURVEYED WITHIN THE CAIRNS SURVEY AREA, 2022.

TABLE 3: SEAGRASS SPECIES PRESENT IN CAIRNS HARBOUR AND TRINITY INLET MONITORING MEADOWS IN 2022.

Family	Species	
CYMODOCEACEAE Taylor	<p>(narrow)</p> <p><i>Halodule uninervis</i> (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier</p>  <p>(wide)</p>	<p><i>Cymodocea serrulata</i> (R.Br.) Aschers and Magnus</p> 
ZOSTERACEAE Drummortier	<p><i>Zostera muelleri</i> Aschers.</p> 	<p>* Note <i>Zostera capricorni</i> has been re-classified as a sub-species of <i>Zostera muelleri</i></p>
HYDROCHARITACEAE Jussieu	<p><i>Halophila decipiens</i></p>  <p><i>Thalassia hemprichii</i></p> 	<p><i>Halophila ovalis</i></p> 



MAP 4A: COASTAL CAIRNS HARBOUR DISTRIBUTION AND COMMUNITY TYPE FOR SEAGRASS MEADOWS IN 2022.



MAP 4B: ESTUARINE TRINITY INLET DISTRIBUTION AND COMMUNITY TYPE FOR SEAGRASS MEADOWS IN 2022.

3.2 SEAGRASS CONDITION FOR LONG-TERM MONITORING MEADOWS

The six long-term monitoring meadows increased overall mean biomass to 18.3 ± 1.5 g DW m⁻², and remains the highest recorded since 2008. Biomass has been steadily improving since 2010, however is still below the long-term average of 21.3 g DW m⁻² (Table 4; Figure 8). The overall area of monitoring meadows in 2022 was 1334 ± 91 ha, the sixth year in a row it is above the long-term average (999 ± 108 ha) (Table 4; Figure 9).

The three large coastal Cairns Harbour meadows (Meadows 11, 13 and 34) were collectively in a good condition in 2022 (Map 1; Figure 4). The Esplanade meadow (34) remained in overall good condition. Species composition improved to very good in 2022, while the condition indicators of biomass and area stayed the same as the previous year (Table 4; Figure 10). The Bessie Point intertidal meadow (13) improved to a very good condition in 2022, while the subtidal Bessie Point meadow (11) remained stable across all three condition indicators (Table 4; Figure 11 and 12). In 2022 biomass values for the intertidal meadow (13) have further improved and is above the long-term average for the third year in a row (Table 4; Figure 12).

The small highly variable Trinity Inlet meadows (Meadows 19, 20 and 33) have seen some condition improvements in 2022 (Map 1; Table 4). The subtidal Trinity Inlet meadow (19) improved to a good condition with biomass increasing to a new condition grade (Table 4; Figure 13). The small intertidal Redbank Creek meadow (20) remains in a poor condition in 2022 due to a reduction in biomass to a satisfactory condition (Table 4; Figure 14). The Subtidal Redbank meadow (33) improved to a good condition due to an increase in biomass to just above the long-term average, while the area and species composition both remained very good (Table 4; Figure 15).

TABLE 4: GRADES AND SCORES FOR SEAGRASS INDICATORS (BIOMASS, AREA AND SPECIES COMPOSITION) FOR CAIRNS HARBOUR AND TRINITY INLET SEAGRASS MONITORING MEADOWS. OVERALL MEADOW SCORE IS THE LOWEST OF THE BIOMASS OR AREA SCORES, OR WHERE SPECIES COMPOSITION IS THE LOWEST SCORE IT MAKES UP 50% OF THE SCORE WITH THE OTHER 50% FROM THE NEXT LOWEST INDICATOR (SEE APPENDIX 1 AND TABLE A3 FOR A FULL DESCRIPTION OF SCORES AND GRADES). *ACTUAL VALUE IS 0.849 WHICH IS TRUE VALUE FOR THE GOOD CATEGORY.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
Coastal Cairns Harbour Meadows				
Esplanade to Ellie Pt. (34)	0.72	0.83	0.88	0.72
Bessie Point (11)	0.84*	0.91	0.99	0.84*
South Bessie Pt (13)	0.85	0.92	0.98	0.85
Overall Score for Cairns Harbour				0.80
Estuarine Trinity Inlet Meadows				
Inlet (19)	0.68	0.89	0.97	0.68
Redbank Intertidal (20)	0.58	0.29	0.90	0.29
Redbank Subtidal (33)	0.78	0.89	1.00	0.78
Overall Score for Trinity Inlet				0.58

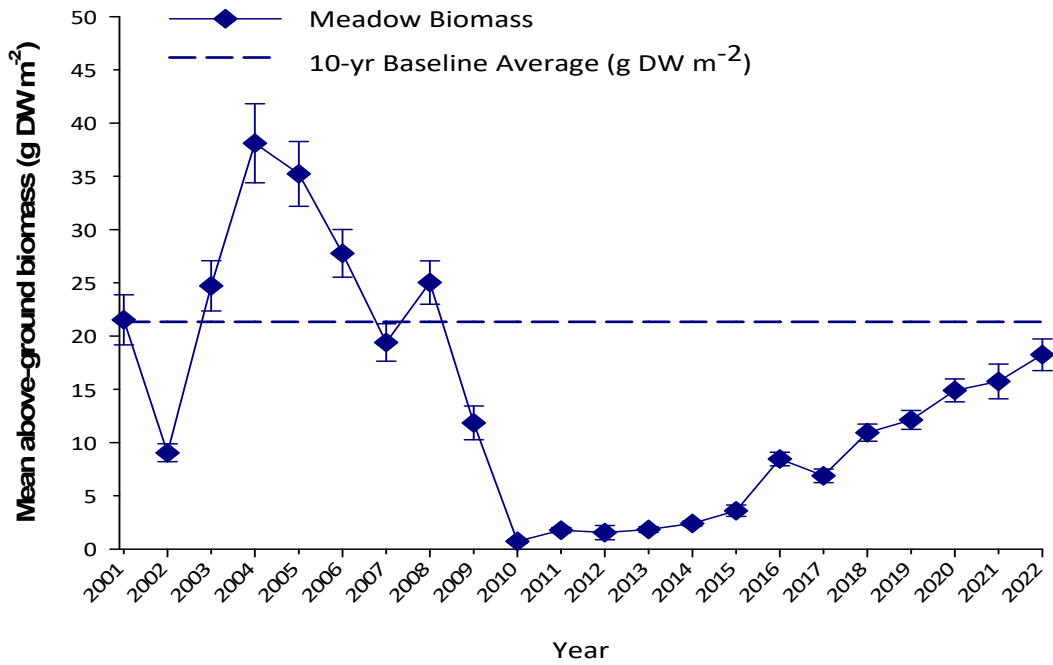


FIGURE 8: MEAN ABOVE-GROUND BIOMASS (G DW M⁻²) OF ALL MONITORING MEADOWS COMBINED IN CAIRNS HARBOUR AND TRINITY INLET FROM 2001 – 2022 (ERROR BARS – STANDARD ERROR). DOTTED BLUE LINE INDICATES 10-YEAR (2001 – 2010) BASELINE MEAN OF MEADOW BIOMASS.

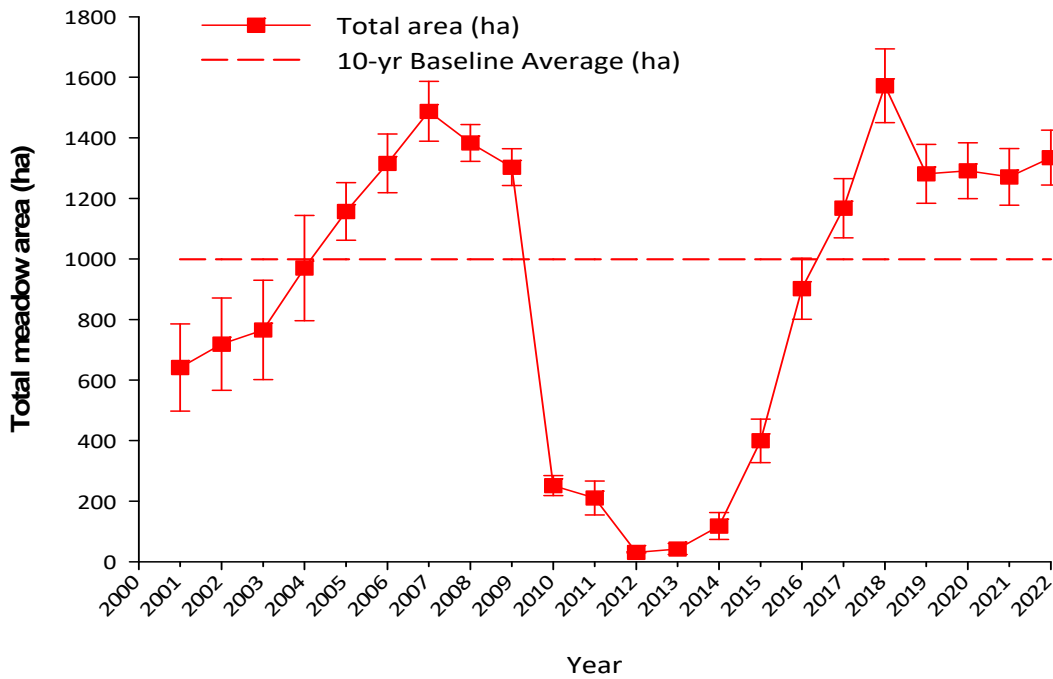


FIGURE 9: TOTAL AREA OF ALL MONITORING MEADOWS COMBINED IN CAIRNS HARBOUR AND TRINITY INLET FROM 2001 – 2022 (ERROR BARS – “R” RELIABILITY ESTIMATED). DOTTED RED LINE INDICATES 10-YEAR (2001 – 2010) BASELINE MEAN OF TOTAL MEADOW AREA.

3.2.1 COASTAL CAIRNS HARBOUR MEADOWS

The coastal group of monitoring meadows in Cairns Harbour all stabilised to a good condition in 2022 and consist of the larger Esplanade to Ellie Point meadow (34), Bessie Point (11) and South Bessie Point (13) meadows.

The Esplanade meadow (34) remained stable and in a good condition overall for the third year in a row (Figure 10; Map 5; Appendix 1). Species composition improved to a very good condition with the indicator species *Zostera muelleri* increasing in this meadow (Figure 10). Additionally, an increase in the more persistent species *Cymodocea serrulata* and a small patch of *Thalassia hemprichii* remaining for the second year in a row, further enhanced the species composition condition of this meadow. Improvements in area (333 ± 6 ha) to above the long-term baseline average (308 ha) has enabled this meadow to stabilise in a good condition (Figure 10). Biomass also remained in a good condition at 34 ± 3 g DW m⁻², and is the highest recorded since 2008, however is still below the long-term average of 38 g DW m⁻² (Figure 10).

The Bessie Point meadow (11) remained stable and in a good condition in 2022 (Figure 11). Biomass (9.5 ± 0.7 g DW m⁻²) improved since last year and for the 5th year in a row and remains above the long-term baseline average (6.8 ± 0.8 g DW m⁻²) (Figure 11; Appendix 1). This is the largest meadow in the Harbour group and meadow area (834.4 ± 78 ha) remained in a very good condition and well above the long-term average in 2022 (Figure 11; Map 6). Species composition remained dominated by *Halodule uninervis* and continues to be in a very good condition (Figure 11; Appendix 1).

The intertidal meadow at South Bessie Point (13) was the only meadow to reach very good overall condition grade in 2022 (Figure 12). Improvements in biomass to the highest recorded since 2009 (25 ± 5.3 g DW m⁻²), enabled this meadow to attain a very good condition (Figure 12; Appendix 1). Area (156 ± 4 ha) were also at the highest levels recorded since 2009 and well above the long-term average baseline conditions (Figure 12, Map 6, Appendix 1). *Cymodocea serrulata*, a large persistent species increased its presence in this meadow and combined with the presence of *Zostera muelleri* these dominant species ensured a very good species condition in 2022 (Figure 16; Appendix 1).

3.2.2 TRINITY INLET ESTUARINE MEADOWS

The three smaller monitoring meadows in the Trinity Inlet consist of Trinity Inlet (M19), Intertidal Redbank Creek (M20) and Subtidal Redbank Creek (33) (Map 8). The predominantly subtidal meadows collectively improved to a satisfactory condition in 2022 (Table 4).

The Trinity Inlet meadow (19) improved to an overall satisfactory condition in 2022 (Figure 13). The main driver of improvement in this meadow is the increase in biomass of *Halophila ovalis* (Figure 13). Species composition also remained in a very good condition with the dominance of *Halophila ovalis* over the past two years. The footprint of this meadow has remained in a very good condition and above the long-term average for the fifth year in a row (Figure 13). This meadow has been highly variable across all three condition indexes over the years, but looks to be stable in 2022 (Map 8).

The subtidal Redbank Creek meadow (33) also improved to an overall good condition due to improvement in biomass in 2022 (Figure 15). Area and species composition remained in a very good condition in 2022, with more persistent species *Halophila ovalis* dominating the meadow for the second year in a row (Figure 15). While this meadow has been variable, its presence has been consistent through time (Figure 15; Map 8).

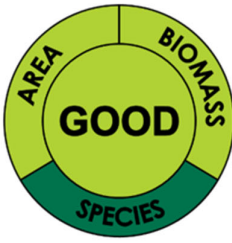
The adjoining intertidal Redbank Creek *Zostera muelleri* meadow (20) has maintained an overall poor condition due to its small area and a decline in biomass to below the long-term average (Figure 14). This meadow consists of larger growing *Z. muelleri* and following its complete loss between 2010 and 2015 has shown improvements from very poor to a poor condition due to increases in biomass, area and species composition and has been variable over the last few years (Table 4; Figure 14).

TABLE 5: MAXIMUM DEPTH PENETRATION (DEPTH BELOW MEAN SEA LEVEL) OF MONITORING MEADOWS IN CAIRNS HARBOUR AND TRINITY INLET, 2001 –2022.

Meadow location and ID number	Maximum Depth (depth below mean sea level (m))																					
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Esplanade to Ellie Pt. (34)	NA	NA	NA	NA	NA	NA	NA	1.7	1.5	NA	NA	NA	NA	NA	NA	NA	1.9	2.1	1.55	2.26	1.52	1.62
Bessie Point (11)	3.7	3.7	4	4.1	4	4.3	4.2	4.2	3.1	4.2	1.8	NA	2.1	2.9	4.1	3.8	5.3	5.7	4.38	7.70	4.11	4.07
South Bessie Point (13)	-	-	-	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.07
Inlet (19)	-	3.2	3.4	3.8	2.9	3.3	3.3	4.4	3.8	2.6	5.1	5.6	3	3.4	2.3	2.1	3.2	3.5	4.57	3.37	1.87	4.70
Redbank Intertidal (20)	1.3	1.1	1.5	1.6	1.2	1.1	2	1.6	2.4	1.5	NP	NP	NP	NP	NA	NP	1.1	1.8	NA	1.32	NA	1.7
Redbank Subtidal (33)	NA	3.4	3.2	3.2	2.9	2.4	3	1.8	4.8	3.8	3.3	2.9	2.5	2.5	2.3	2.1	2.6	3.5	4.58	3.01	3.87	3.10

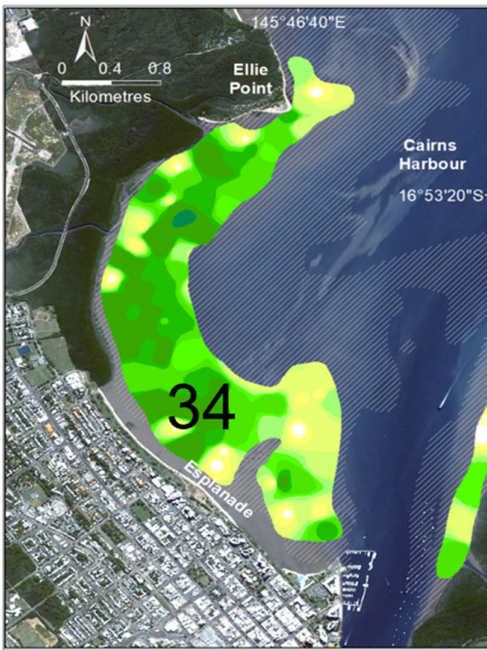
NP – No seagrass present; NA – Not applicable (meadow exposed at spring low tide)

Meadow 34 Intertidal Ellie Point to Esplanade *Zostera muelleri* subsp. *capricorni*



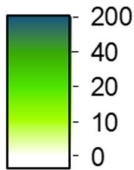
Seagrass condition grades

Very good	Good	Satisfactory	Poor	Very Poor
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Community type 2022: Moderate *Zostera muelleri* with mixed species

Seagrass biomass g DW m⁻²



Total seagrass extent 1984 - 2021

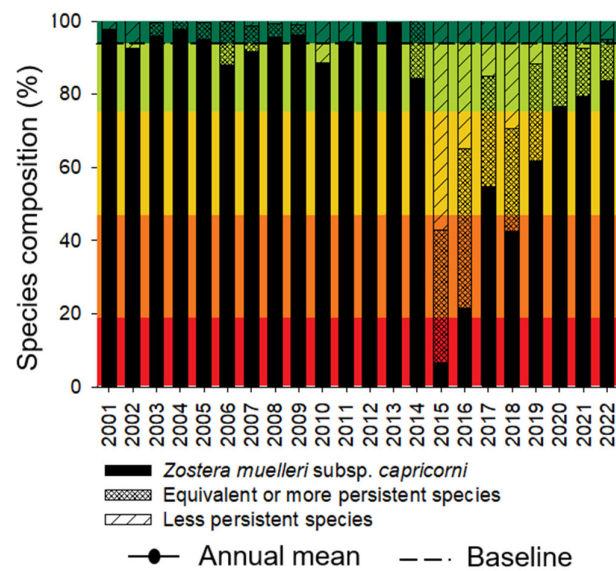
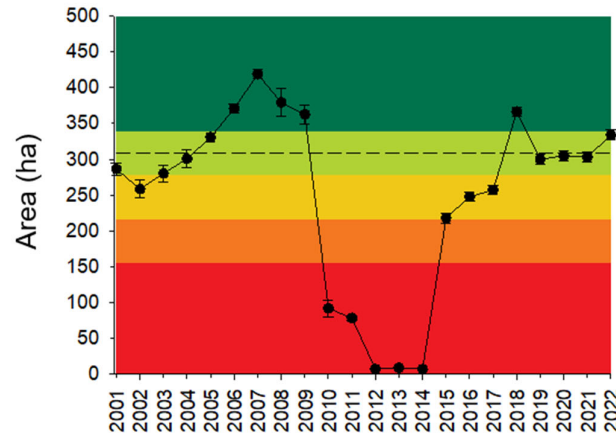
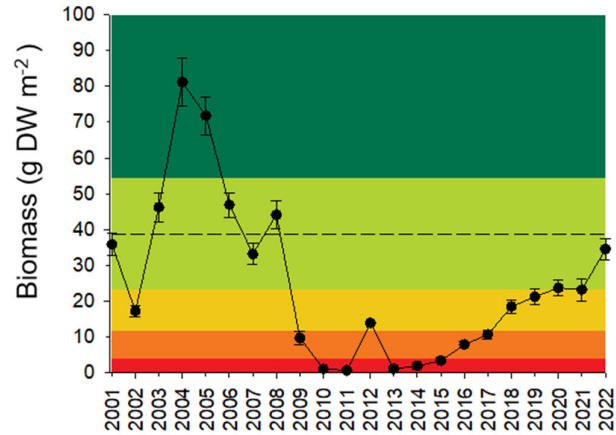
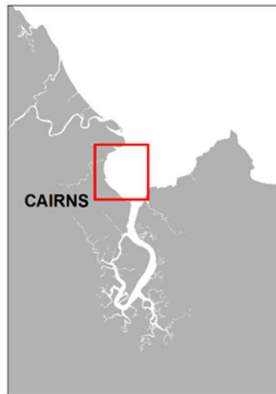


FIGURE 10: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE ESPLANADE MEADOW (MEADOW NO. 34) FROM 2001 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).

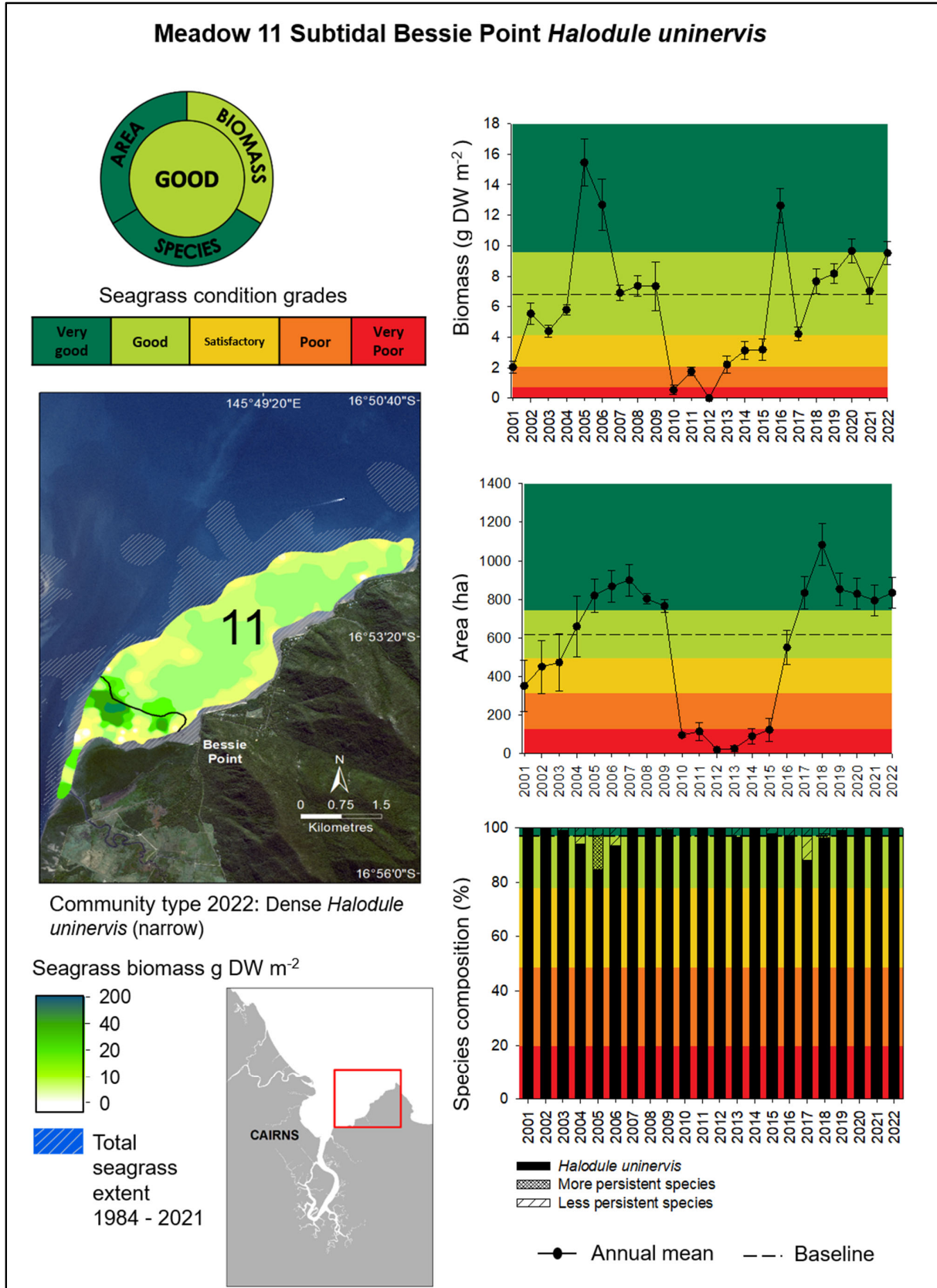


FIGURE 11: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE BESSIE POINT (MEADOW NO. 11) MEADOW FROM 2001 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).

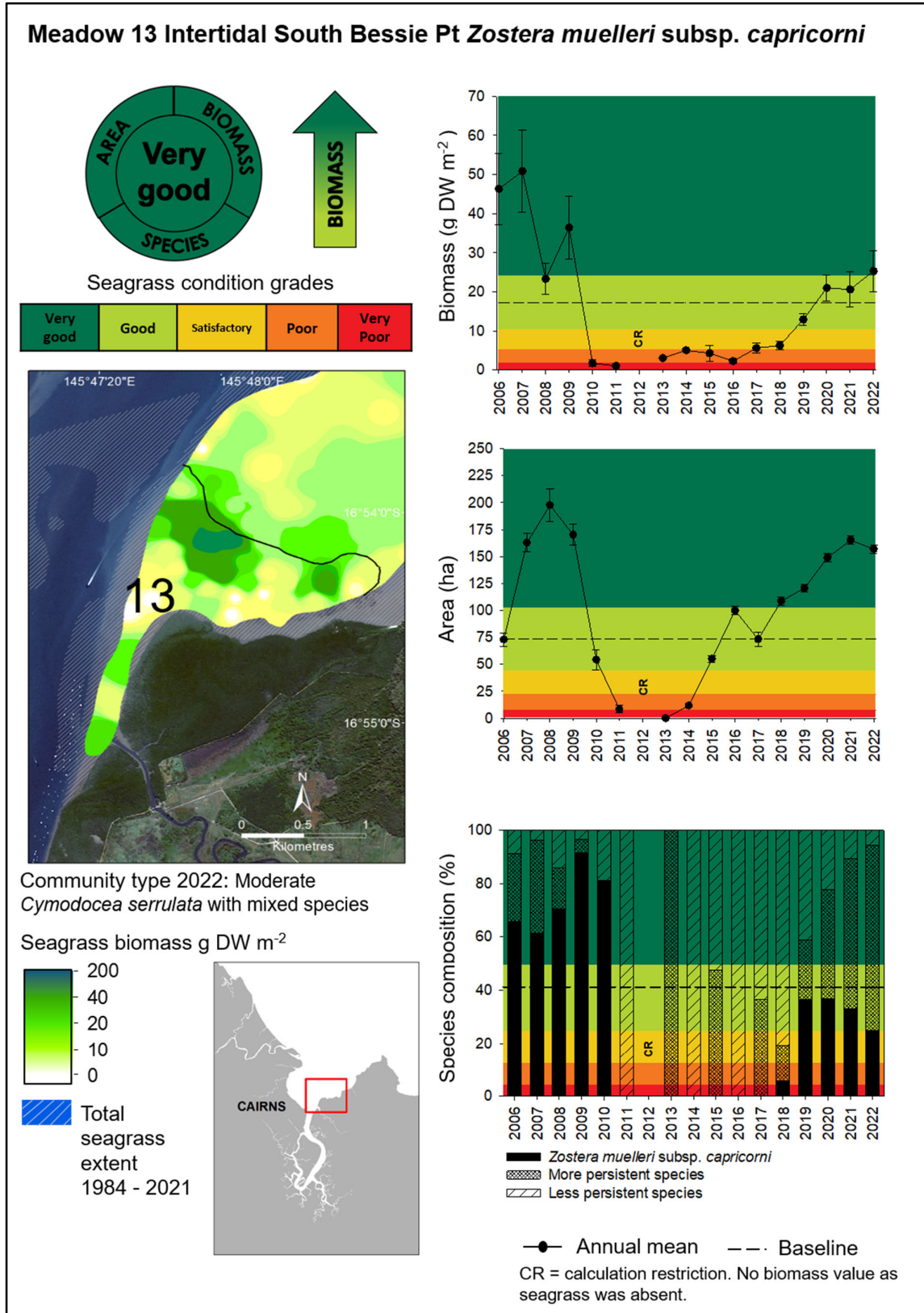


FIGURE 12: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE SOUTH BESSIE POINT (MEADOW NO. 13) MEADOW FROM 2006 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).

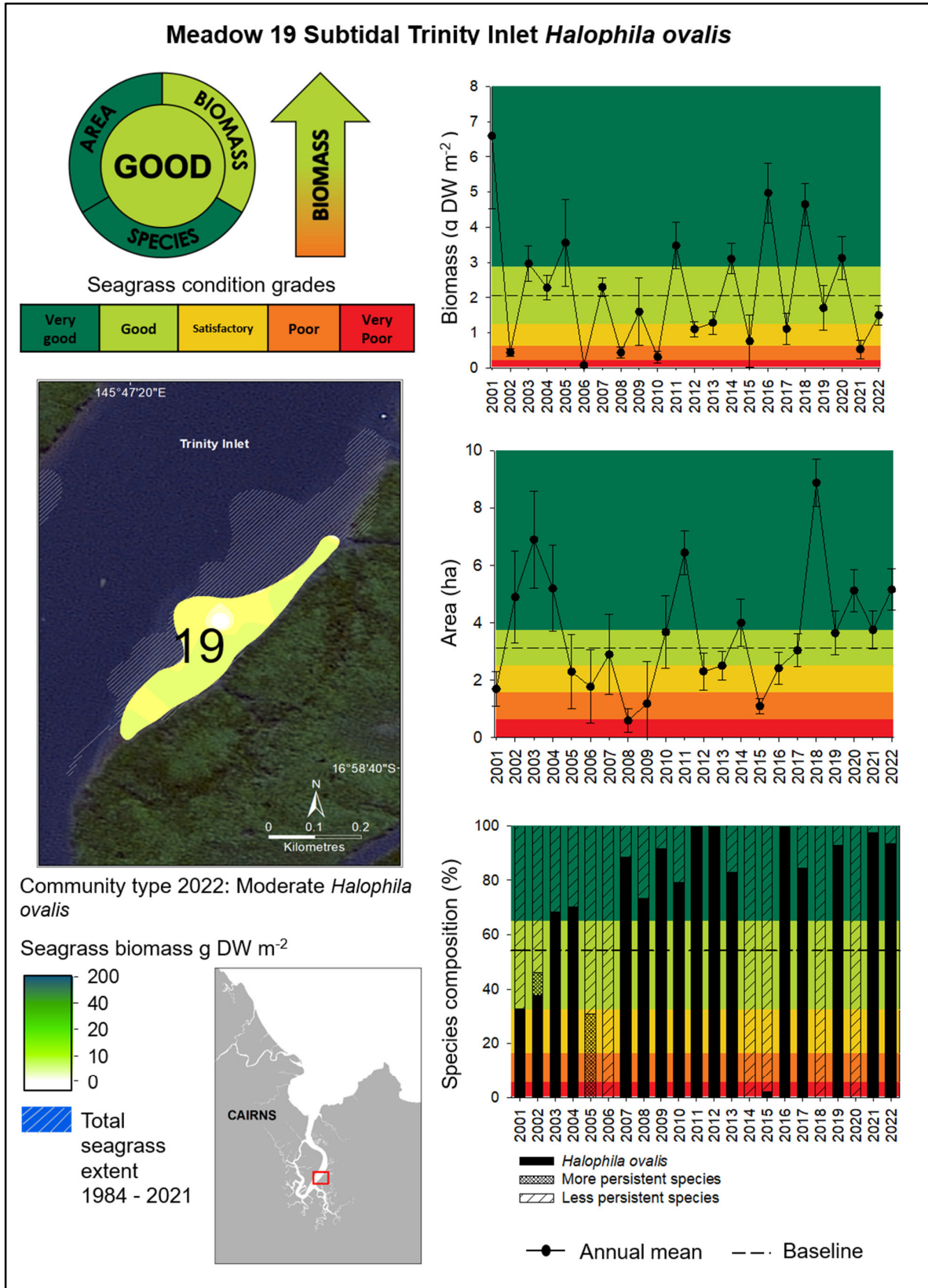


FIGURE 13: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE TRINITY INLET *HALOPHILA* MEADOW (MEADOW 19) FROM 2001 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).

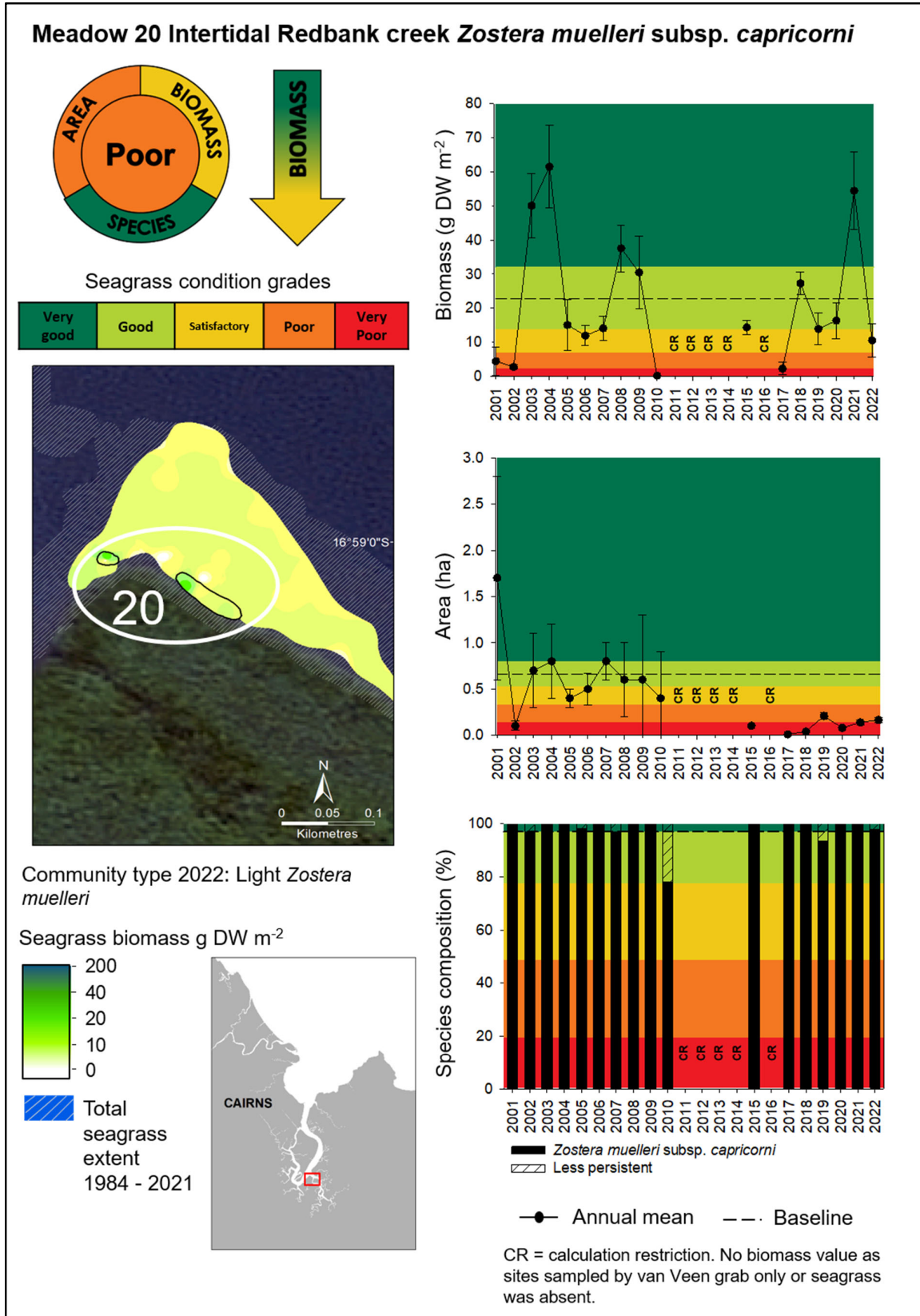


FIGURE 14: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE TRINITY INLET *ZOSTERA* MEADOW (MEADOW NO. 20) FROM 2001 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).

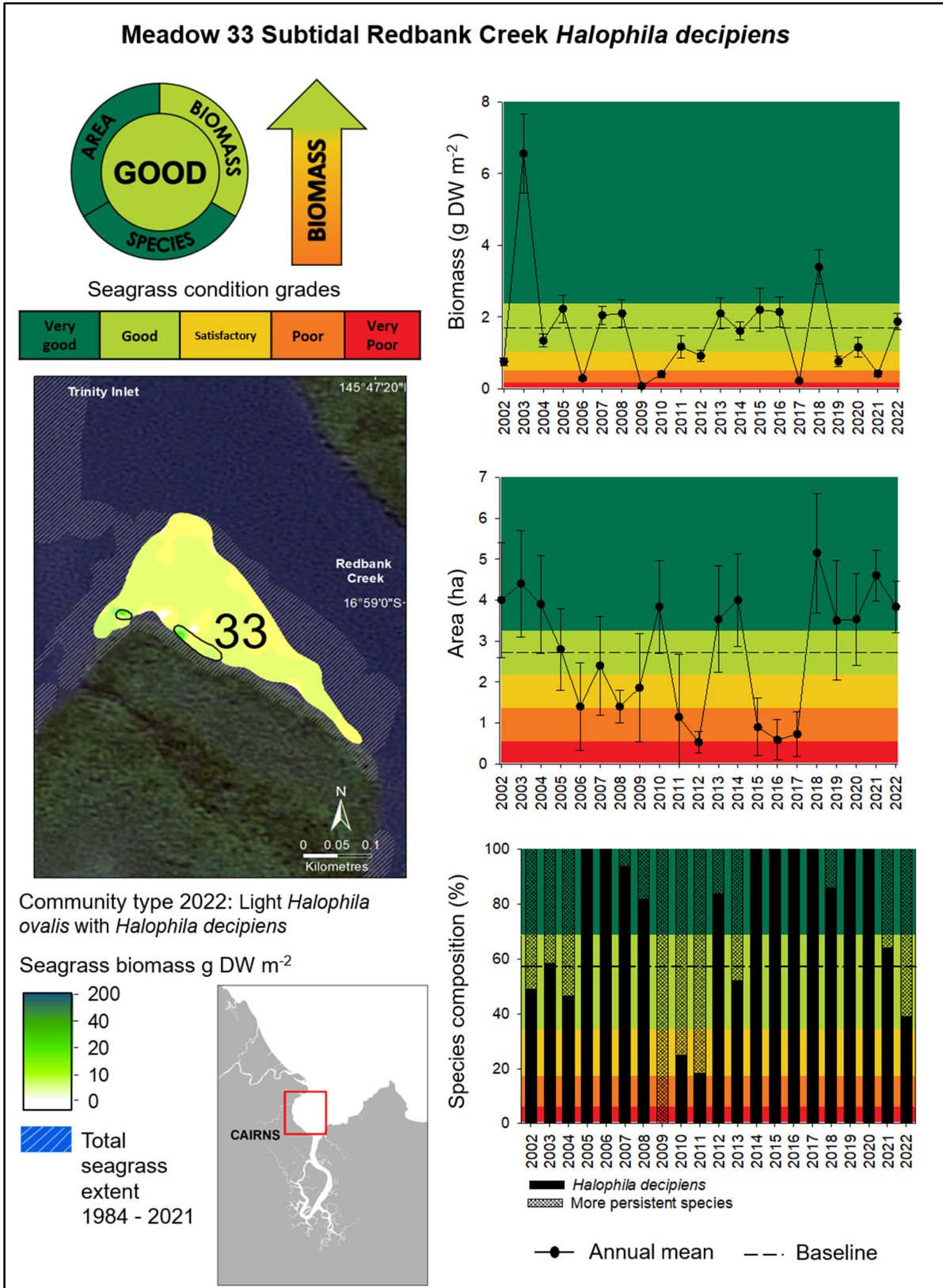
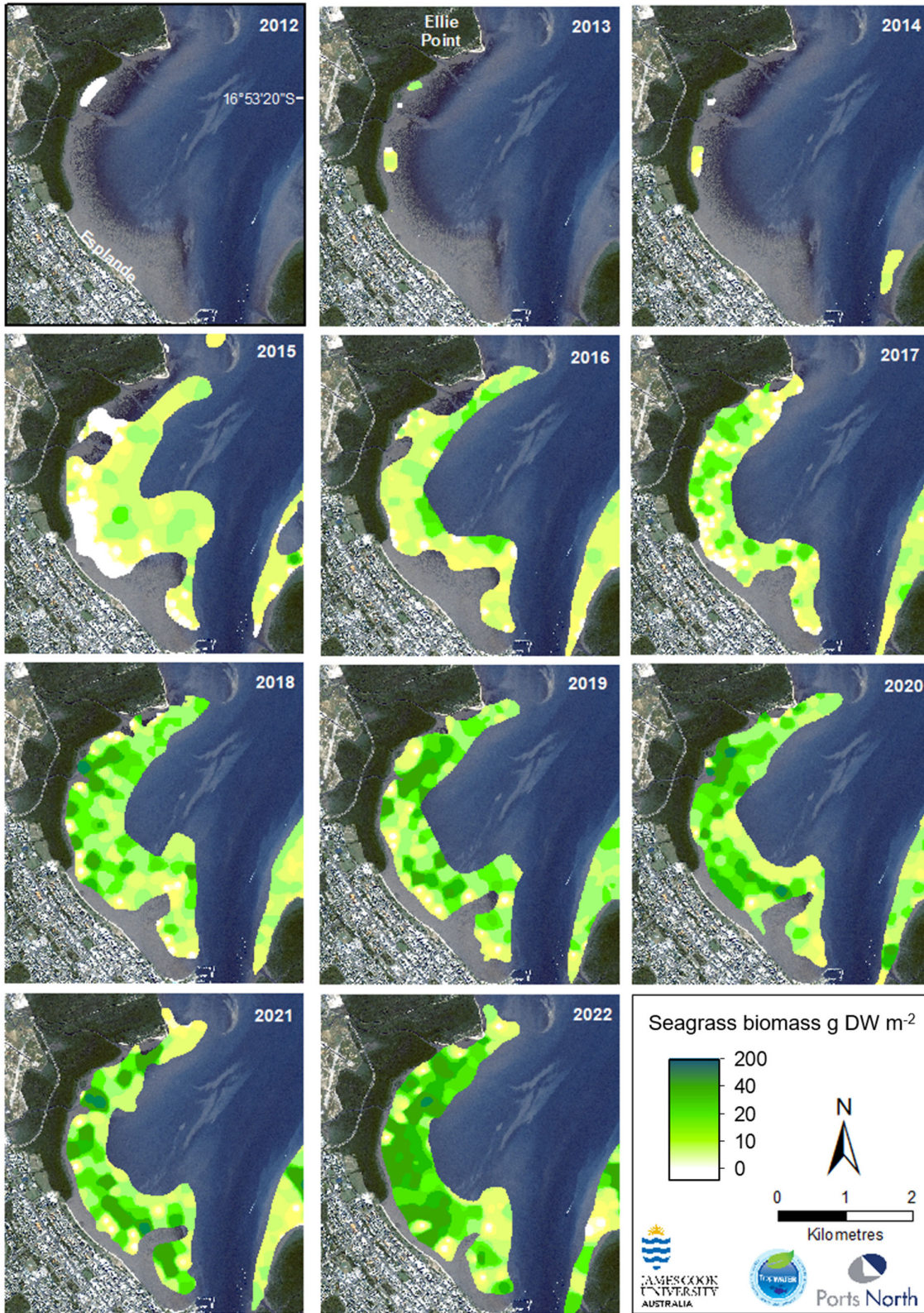
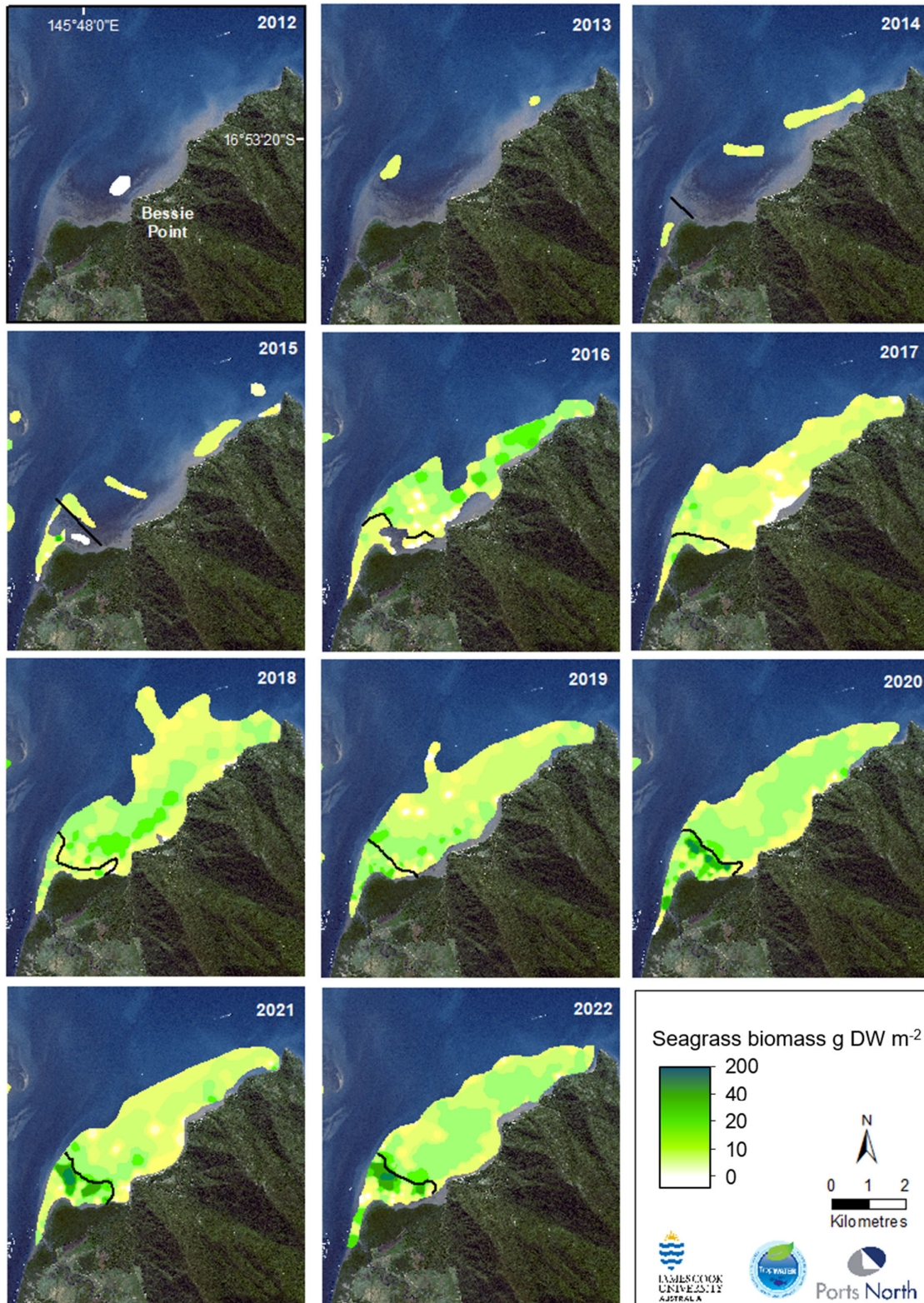


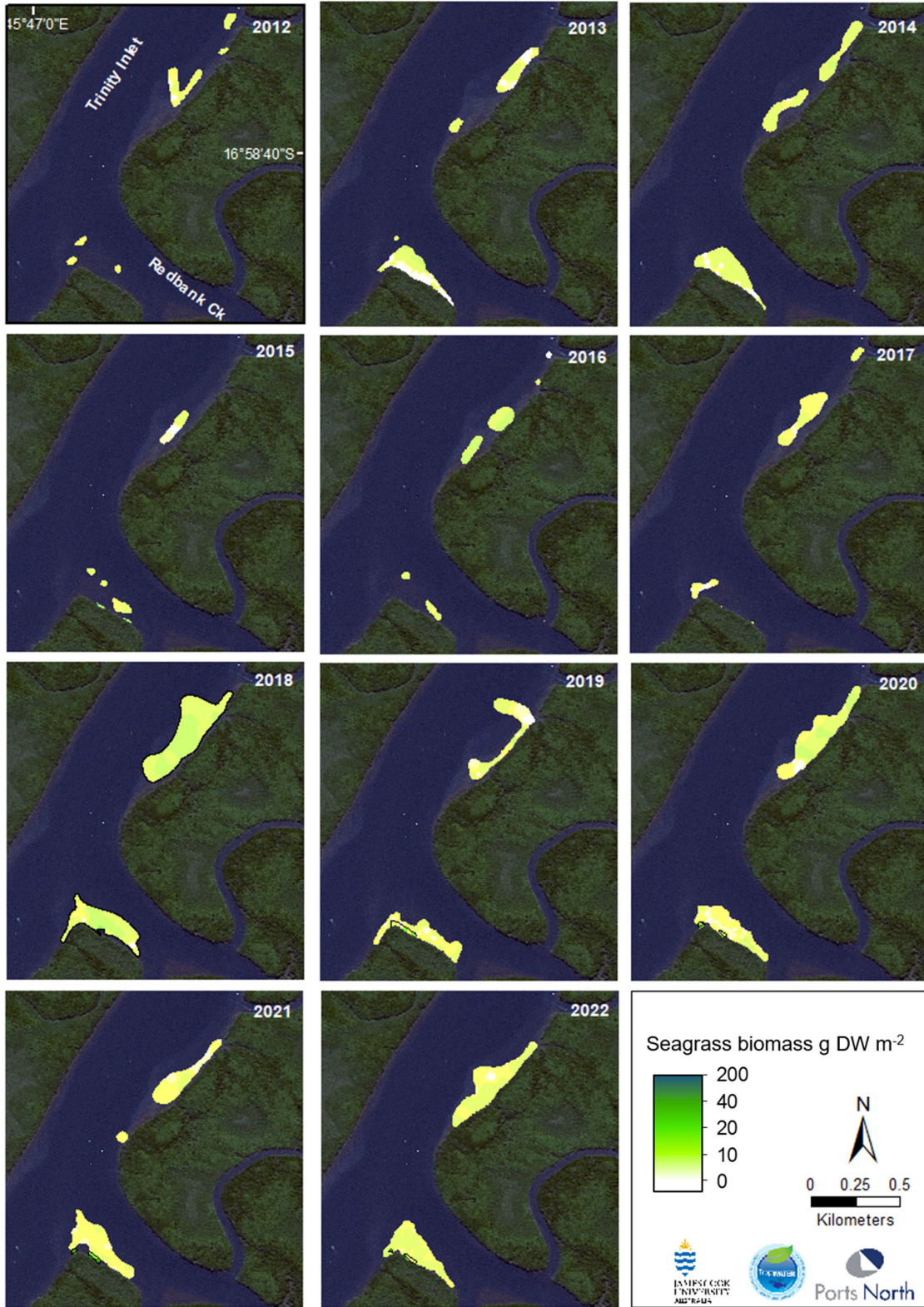
FIGURE 15: CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE TRINITY INLET *HALOPHILA* MEADOW (MEADOW 33) FROM 2002 – 2022 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = “R” RELIABILITY ESTIMATE).



MAP 5: ESPLANADE TO ELLIE POINT SEAGRASS MONITORING MEADOWS FROM 2009 TO 2022.



MAP 6: BESSIE POINT AND SOUTH BESSIE POINT SEAGRASS MONITORING MEADOWS FROM 2009 TO 2022.



MAP 8: TRINITY INLET SEAGRASS MONITORING MEADOWS FROM 2009 TO 2022.

3.3 SEAGRASS REPRODUCTIVE CAPACITY

In March 2022, 9.81 ± 3.38 *Zostera muelleri* seeds m^{-2} were found in the Esplanade meadow, however, when tested with tetrazolium stain none of these were viable (Table 7). This was the fourth year that seeds have been sampled at the meadow scale and density was lower than the highest density of seeds recorded in April 2018 (28.8 ± 7.4 seeds m^{-2}) which was recorded at the smaller 50 x 50m Site E (Table 6).

Over the past four years the results for the seed bank assessment in the two larger meadows Esplanade (34) and Bessie Point (11) show that *Halodule uninervis* seeds are present in both meadows, while *Zostera muelleri* seeds are only found on the Esplanade side of the Harbour (Table 7). The *Halodule uninervis* seed numbers increased in the Bessie point meadow in 2022 and declined in the Esplanade meadow (Table 7).

TABLE 6: MEAN CAIRNS HARBOUR 2014-2018 ZOSTERA MUELLERI SEED BANK DENSITY AND VIABILITY (SEEDS M-2) PER MONTH AT SITE E. SAMPLING SCALE ASSESSMENTS AT 50 X 50M IN BLOCK E ON THE ESPLANADE MEADOW.

Month	Mean Total seeds m^{-2}	Viable seeds m^{-2}
June 2014	26.17 ± 6.82	0
September 2014	20.93 ± 9.08	1.31 ± 1.31
December 2014	10.47 ± 3.77	1.31 ± 1.31
February 2015	18.32 ± 4.48	0
June 2015	9.15 ± 5.37	1.31 ± 1.31
October 2015	5.23 ± 2.31	N/A
January 2016	9.81 ± 3.10	0
March 2016	6.54 ± 2.47	N/A
June 2016	2.62 ± 1.78	N/A
August 2016	15.70 ± 5.81	N/A
November 2016	6.54 ± 4.14	N/A
March 2017	0	0
June 2017	0	N/A
November 2017	9.15 ± 6.59	N/A
April 2018	28.78 ± 7.38	14.39 ± 7.02

NA = not assessed.

TABLE 7: MEAN CAIRNS HARBOUR 2013/2019-2022 ZOSTERA MUERLLI AND HALODULE UNINERVIS SEED BANK DENSITY AT THE MEADOW SCALE ON THE ESPLANADE MEADOW (34) AND BESSIE POINT MEADOW (11).

Sampling Date	Esplanade <i>Zostera muelleri</i> Mean Total seeds m ⁻²	Esplanade <i>Zostera muelleri</i> Mean Viable seeds m ⁻²	Esplanade <i>Halodule uninervis</i> Mean Total seeds m ⁻²	Bessie Point <i>Halodule uninervis</i> 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

*Data from Jarvis et al. 2021 for comparison.

3.4 LIGHT (PAR) AND TEMPERATURE ASSESSMENT

The benthic light (PAR) level has generally been maintained above the likely growth threshold for *Zostera muelleri* subsp. *capricorni* ($6 \text{ mol m}^{-2} \text{ day}^{-1}$ over a 2 week average; Chartrand et al. 2016) since continuous logging began at the Esplanade site E in June 2014 (Figure 17). During January and February in 2022 light dropped below the *Zostera muelleri* threshold for a brief period before returning to above threshold levels (Figure 17). Annual monitoring of the Esplanade meadow (34) shows an increase in biomass from the previous 2 years, a sign that light conditions were favourable for seagrass growth (Figure 17). In 2022 the maximum benthic water temperatures were variable with a peak in temperature of 44°C occurring in February and a minimum of 28°C in July (Figure 17).

The Esplanade site E light logging site showed PAR dip below seagrass growth thresholds in January and February 2022 but then remain above the threshold providing ideal light conditions for the rest of the year (Figure 18). Similarly, the Bessie Point PAR site remained above thresholds for most of the year with a dip below ideal light conditions for a short time in April and October 2022 (Figure 22). The Redbank Creek PAR site has shown light is consistently below growth thresholds for higher light requiring species for most of the year but sufficient for low light requiring species such as *Halophila decipiens* (Figure 18).

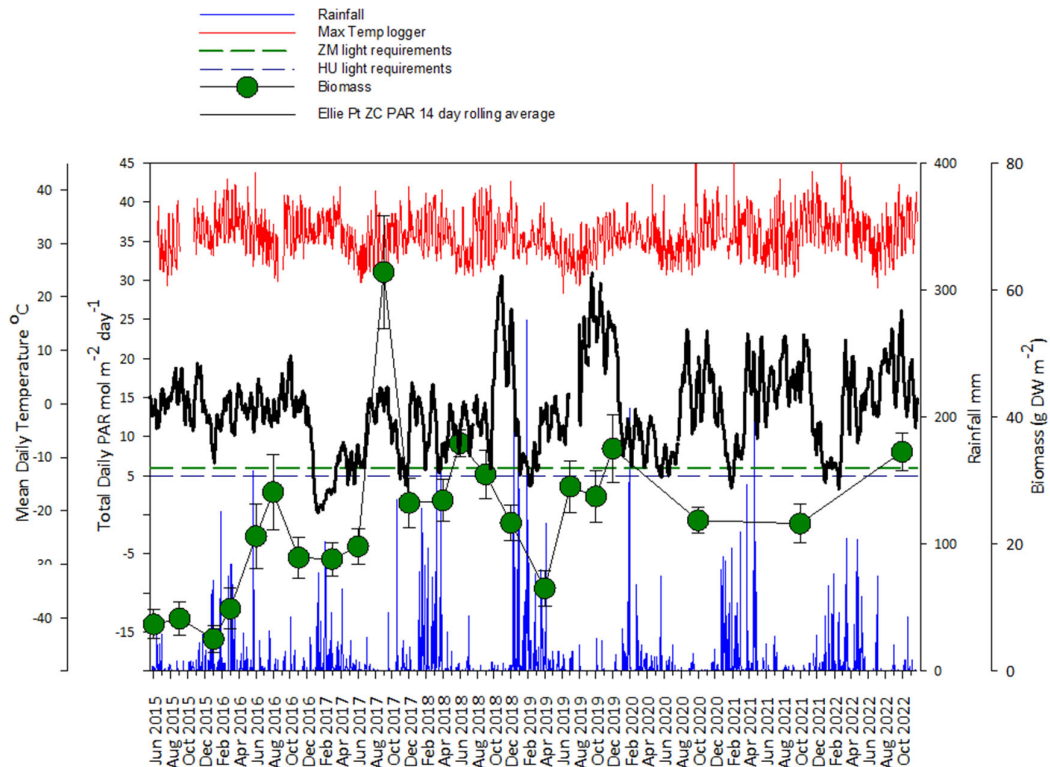


FIGURE 17: TOTAL DAILY IRRADIANCE (MOL M-2 DAY-1), MEAN DAILY TEMPERATURE ($^{\circ}\text{C}$), AND TOTAL DAILY RAINFALL (MM) AND BIOMASS (G DW M-2) FOR THE INTERTIDAL CAIRNS HARBOUR QUARTERLY MONITORING SITE E, OCTOBER 2022 BIOMASS IS MEADOW 34. ALL DATA IS FROM JUNE 2015 TO OCTOBER 2022. DAILY RAINFALL DATA SOURCE: BUREAU OF METEOROLOGY, STATION 31011, AVAILABLE AT: WWW.BOM.GOV.AU.

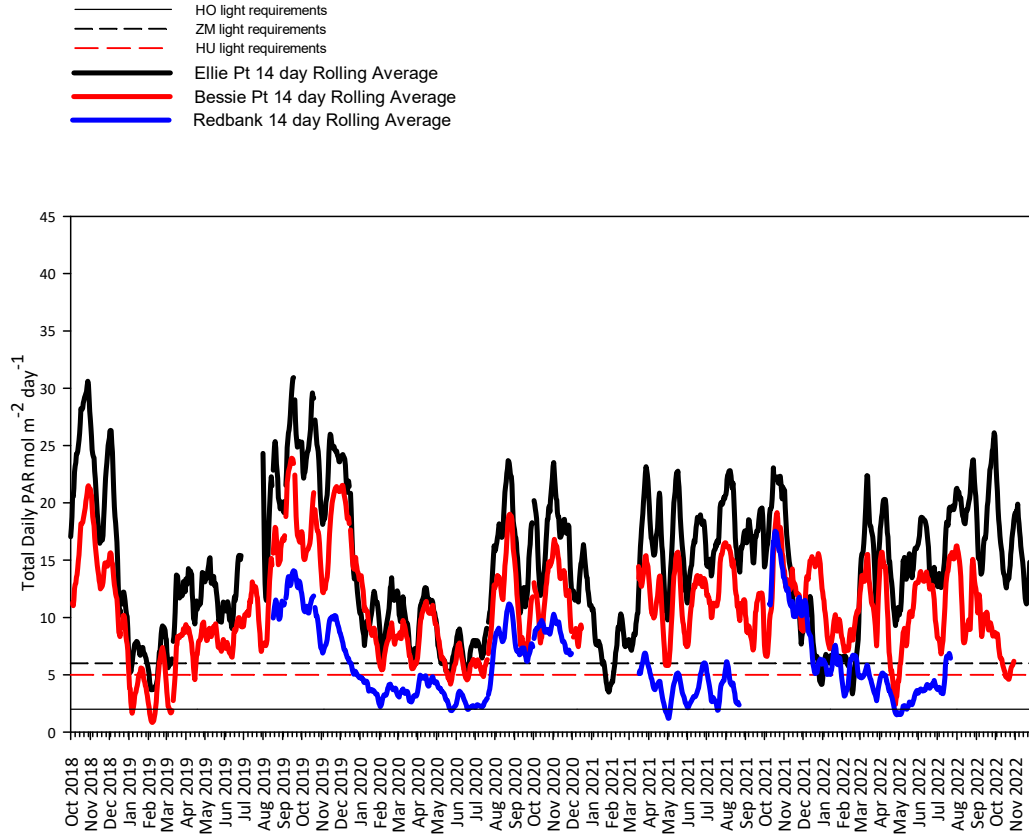


FIGURE 18: 14 DAY ROLLING AVERAGE OF TOTAL DAILY PAR (MOL M⁻² DAY⁻¹), FOR THE THREE PAR MONITORING STATIONS IN CAIRNS HARBOUR AND TRINITY INLET IN RELATION TO SEAGRASS LIGHT THRESHOLDS FROM OCTOBER 2018 TO DECEMBER 2022.

3.5 CAIRNS ENVIRONMENTAL CONDITIONS

3.5.1 RAINFALL

The total annual rainfall in the Cairns region was above the long-term average (2012 mm) recording 2535 mm in 2022 (Figure 19). Rainfall was above average in April and May, July and October and remained below average for the rest of the year (Figure 20). The two months prior to the survey showed minimal rainfall (Figure 20).

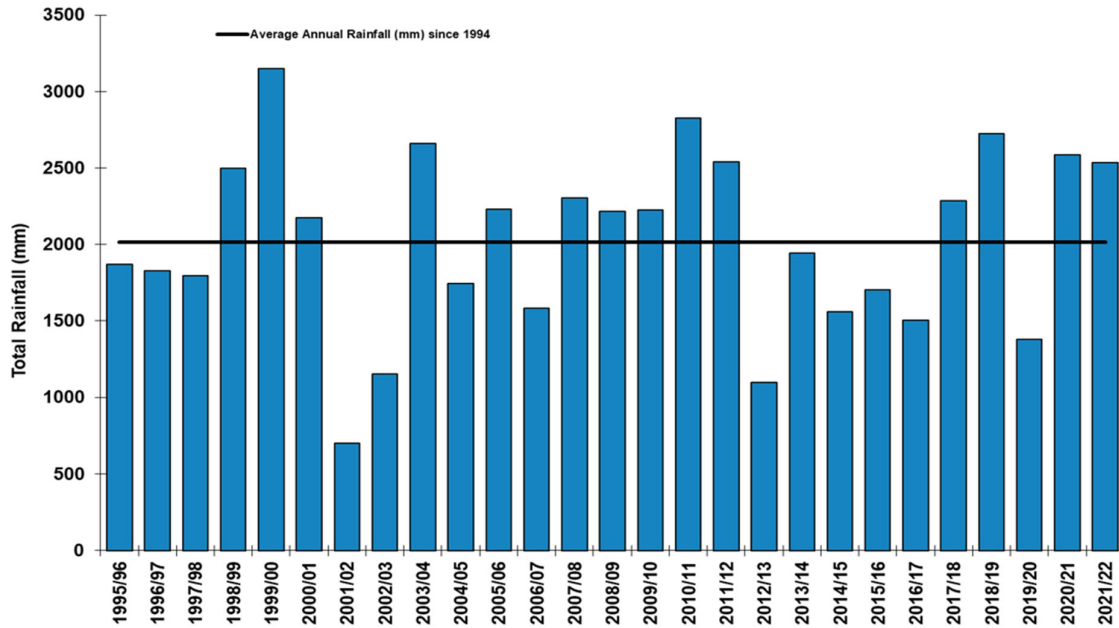


FIGURE 19: TOTAL ANNUAL RAINFALL (MM) RECORDED AT CAIRNS AIRPORT, 1995 – 2022. TWELVE MONTH YEAR (2021/22) IS 12 MONTHS PRIOR TO SURVEY. SOURCE: BUREAU OF METEOROLOGY, STATION 31011, AVAILABLE AT: WWW.BOM.GOV.AU.

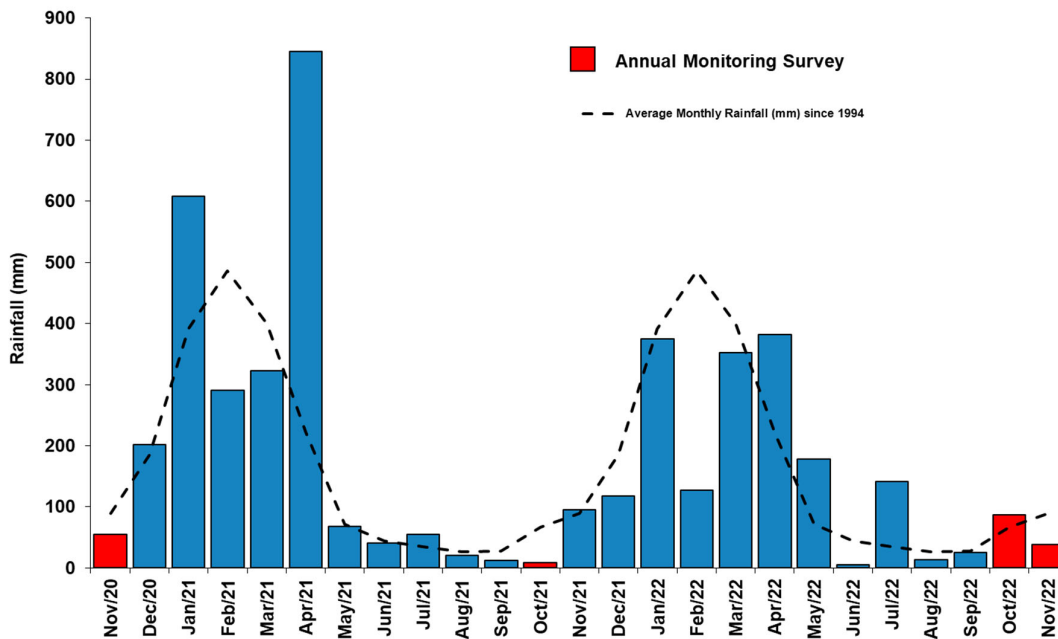


FIGURE 20: TOTAL MONTHLY RAINFALL (MM) RECORDED AT CAIRNS AIRPORT, NOVEMBER 2020 – NOVEMBER 2022. SOURCE: BUREAU OF METEOROLOGY, STATION 31011, AVAILABLE AT: WWW.BOM.GOV.AU.

3.5.2 RIVER FLOW (BARRON RIVER)

River flow of the Barron River was below the long-term average (686,000 ML) for the third year in a row with 528,388 ML in 2021/2022 (Figure 21). River flow was below average for most of the year in 2021 with a few above average flows in April, July and August (Figure 22). In 2022 above average river flow was experienced for most of the year from May, (apart from no river flow recorded in June due to logger error), including the two months prior to the survey (Figure 22).

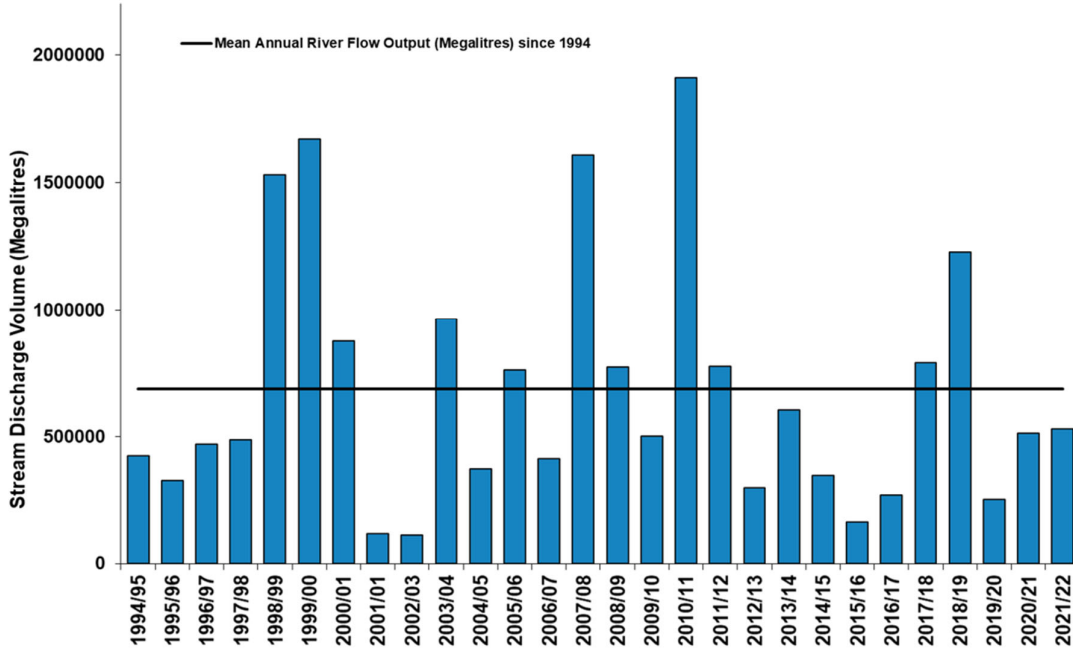


FIGURE 21: ANNUAL WATER FLOW (MEGA LITRES) FOR THE BARRON RIVER RECORDED AT MYOLA, 1995 – 2022. TWELVE MONTH YEAR (2021/22) IS 12 MONTHS PRIOR TO SURVEY. SOURCE: QUEENSLAND DEPARTMENT OF ENVIRONMENT AND RESOURCE MANAGEMENT, STATION 110001D, AVAILABLE AT: [HTTP://WATERMONITORING.DERM.QLD.GOV.AU/HOST.HTM](http://watermonitoring.derm.qld.gov.au/host.htm)

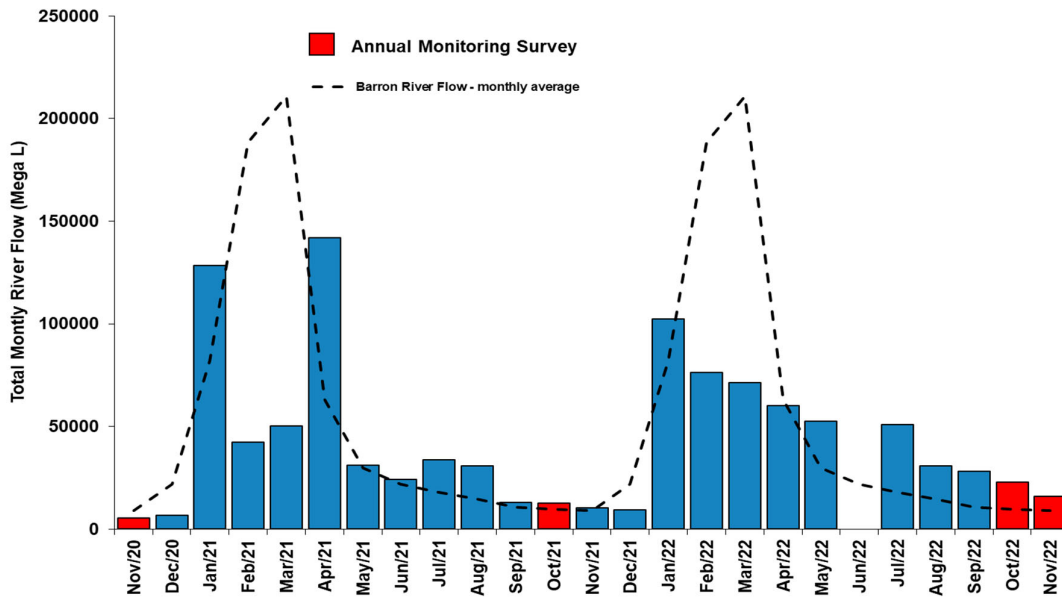


FIGURE 22: MONTHLY WATER FLOW (MEGA LITRES) FOR THE BARRON RIVER RECORDED AT MYOLA, NOVEMBER 2020 TO NOVEMBER 2022. SOURCE: QUEENSLAND DEPARTMENT OF ENVIRONMENT AND RESOURCE MANAGEMENT, STATION 110001D, AVAILABLE AT: [HTTP://WATERMONITORING.DERM.QLD.GOV.AU/HOST.HTM](http://watermonitoring.derm.qld.gov.au/host.htm)

3.5.3 AIR TEMPERATURE

Annual maximum daily air temperature recorded at Cairns Airport was almost 1°C above the long-term average (29.4°C) (Figure 23). In 2022, most of the year experienced temperatures above the long-term average monthly maximum air temperature, including the 2 months prior to the survey (Figure 24).

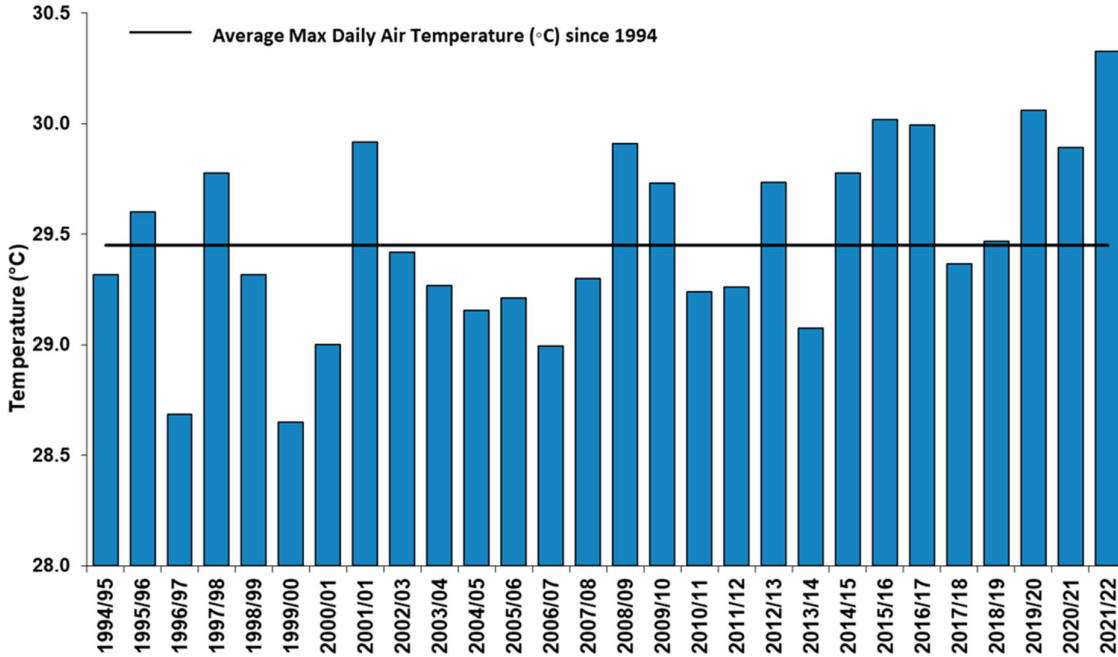


FIGURE 23: MEAN ANNUAL MAXIMUM DAILY AIR TEMPERATURE (°C) RECORDED AT CAIRNS AIRPORT, 1994 – 2022. TWELVE MONTH YEAR (2021/22) IS 12 MONTHS PRIOR TO SURVEY. SOURCE: BUREAU OF METEOROLOGY, STATION 031011, AVAILABLE AT: WWW.BOM.GOV.AU.

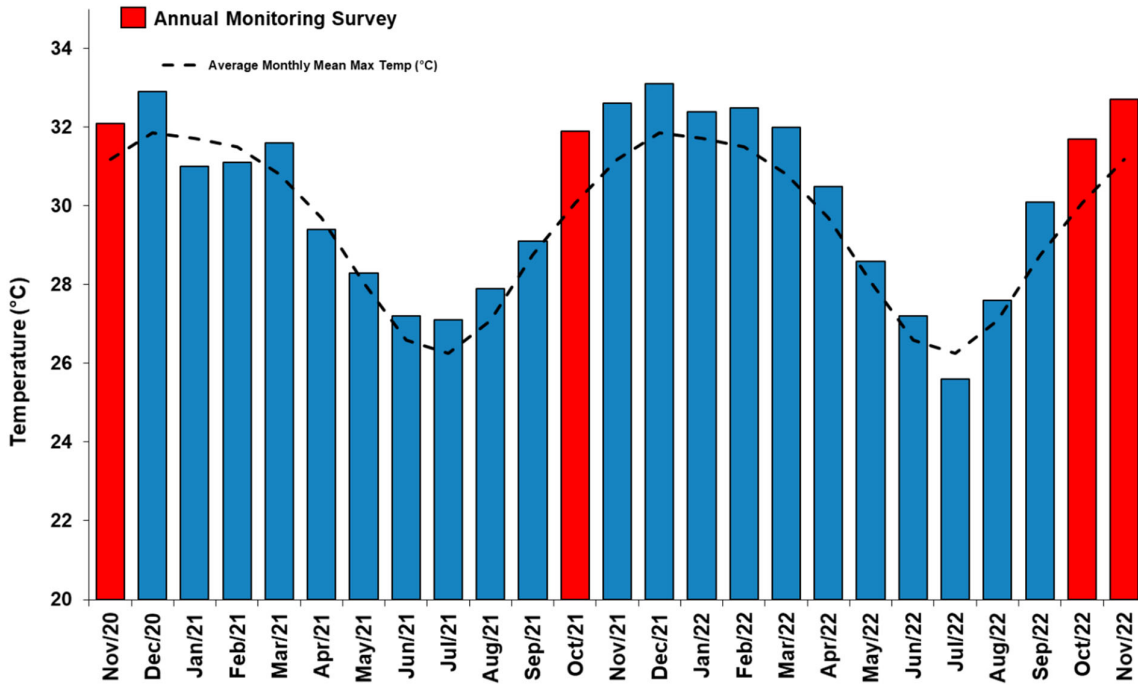


FIGURE 24: MONTHLY MEAN MAXIMUM DAILY AIR TEMPERATURE (°C) RECORDED AT CAIRNS AIRPORT, NOVEMBER 2020 – NOVEMBER 2022. SOURCE: BUREAU OF METEOROLOGY, STATION 31011, AVAILABLE AT: WWW.BOM.GOV.AU.

3.5.4 TIDAL EXPOSURE OF SEAGRASS MEADOWS

In 2022 annual daytime tidal air exposure of intertidal meadows was below the long-term average (252 hrs), for the third year in a row (Figure 25). All months in 2022 were below the long-term average of hours exposed, including the 2 months prior to the survey (Figure 26).

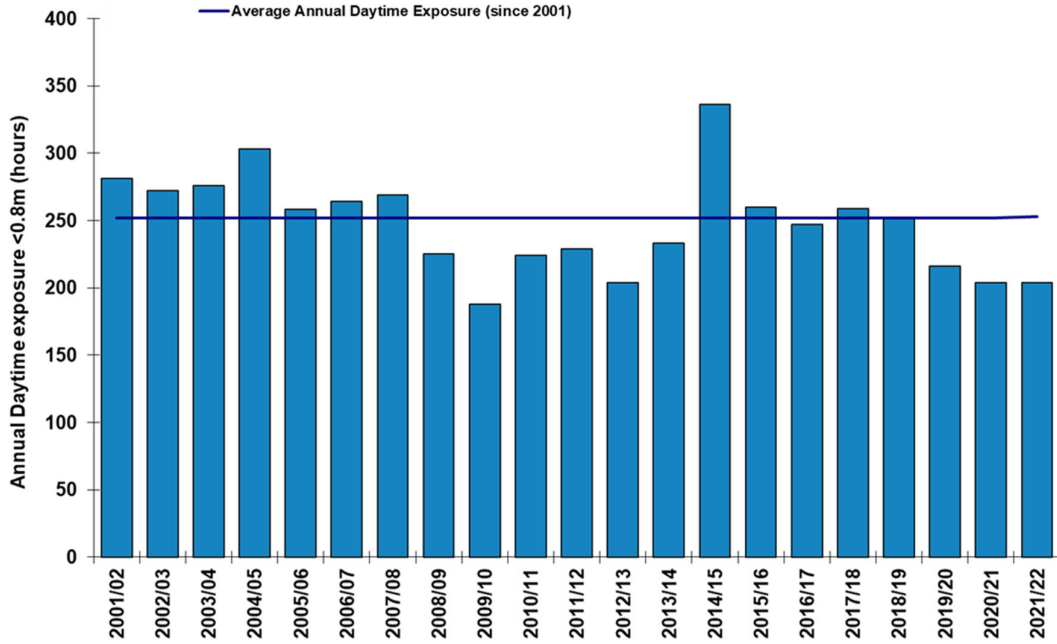


FIGURE 25: ANNUAL DAYTIME TIDAL EXPOSURE (TOTAL HOURS)* OF SEAGRASS MEADOWS IN CAIRNS HARBOUR; 2001 - 2022. TWELVE MONTH YEAR IS 12 MONTHS PRIOR TO SURVEY. SOURCE: MARITIME SAFETY QUEENSLAND, 2022. * ASSUMES INTERTIDAL BANKS BECOME EXPOSED AT A TIDE HEIGHT OF 0.8M ABOVE LOWEST ASTRONOMICAL TIDE.

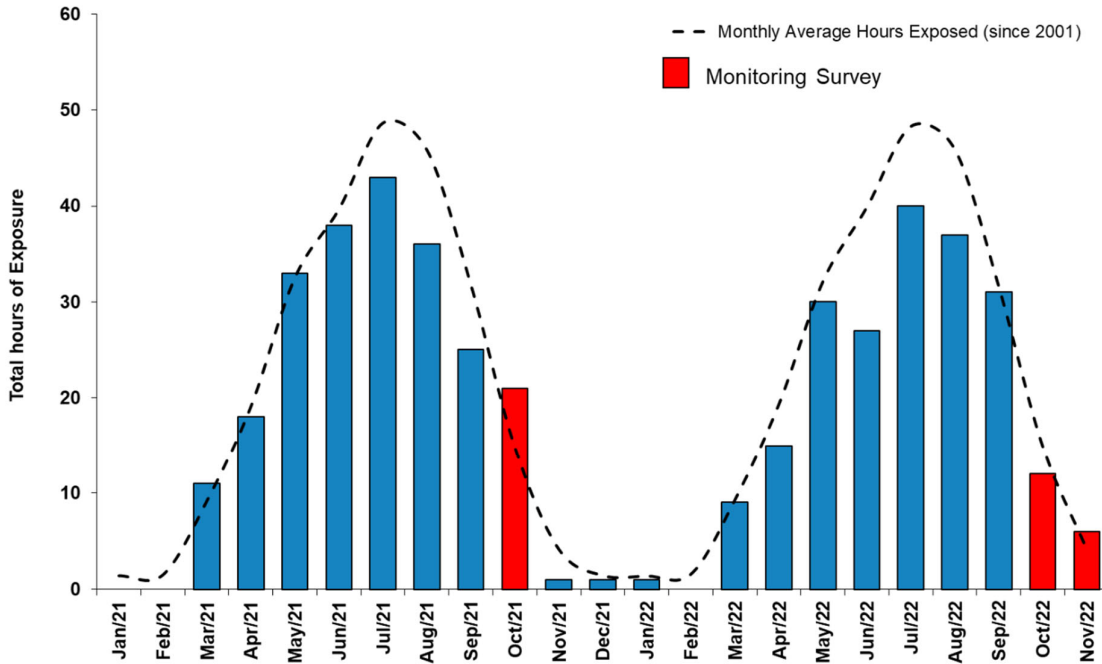


FIGURE 26: TOTAL MONTHLY DAYTIME TIDAL EXPOSURE (TOTAL HOURS)* IN CAIRNS HARBOUR; JANUARY 2021 – NOVEMBER 2022. SOURCE: MARITIME SAFETY QUEENSLAND, 2022. * ASSUMES INTERTIDAL BANKS BECOME EXPOSED AT A TIDE HEIGHT OF 0.8M ABOVE LOWEST ASTRONOMICAL TIDE.

4 DISCUSSION

The past few years have seen an improving trend in seagrass indices with seagrass biomass increasing for the last 5 years and the area of the meadows consistently above the long-term average along with an increase in foundation species in the large intertidal meadow off the Esplanade. Overall condition of the coastal Cairns Harbour meadows maintained a good condition for the fifth straight year and improvements in mean biomass and species composition effectively signals the return of meadows to the condition they were in prior to the major disturbances of 2009-2011 that lead to an almost complete meadow collapse. These large meadows have seen further increases in the dominance of the large, more persistent species, particularly *Z. muelleri* in the Ellie Point to Esplanade intertidal meadow (34) and *C. serrulata* in the South Bessie Point intertidal meadow (13) and all are in a very good condition for the species composition index. The biomass condition has also increased in all the Cairns Harbour meadows and area has increased in two of the three meadows with meadow 13 showing a slight decline in footprint in 2022. The recovery of the seagrass meadows to pre-disturbance levels over the last decade has likely also facilitated the return of the important ecosystem services these habitats provide such as food sources for herbivores like 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 (Lefcheck et al. 2020).

The much smaller Trinity Inlet meadows improved to a satisfactory condition. These meadows are more variable than those in Cairns Harbour with two meadows dominated by ephemeral species that display large interannual fluctuations in condition. The two subtidal monitoring meadows consist of colonising *Halophila* species that are adapted to the low light environment occurring in these upstream habitats. The two species occurring here (*H. ovalis* and *H. decipiens*) have similar morphology, life history strategies and ecological function with *H. decipiens* being able to withstand lower light environments (Josselyn et al. 1986, Ertemeijer and Stapel 1999). In 2022 the increase in *H. ovalis* dominance potentially indicates improved light conditions, as there was a significant increase in biomass compared to the previous year. However, the light monitoring at the Redbank Creek PAR station indicates that the light environment was poorer in 2022 during the period leading up to the surveys. 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). The inlet *Z. muelleri* meadow (20) had a biomass below the long-term average in 2022 however this shallow intertidal meadow is one of the few small niches in the inlet where larger persistent species exist, and the local conditions experienced through 2022 must have been favourable for its perseverance. Its persistence over the past four years is significant given it was completely lost and absent between 2010 and 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). PAR (light) has now been monitored at the Redbank subtidal meadow in the inlet for four years and shows that the rolling average of light here is regularly below optimal growing requirements for larger more persistent species (*Z. muelleri* and *H. uninervis*) but high enough to support *Halophila* species that exist here (Chartrand et al. 2016). In contrast, benthic PAR at the two Cairns Harbour monitoring locations was generally well above requirements for positive seagrass growth of these larger species (see Chartrand et al. 2016; Collier et al. 2016). This provides strong evidence that light is one of the main factors driving differences in species composition between Cairns Harbour and Trinity Inlet. In 2022, Cairns received above average rainfall with most of this occurring during April, May and July and this coincides with when the benthic PAR values dropped below optimal growing requirements in the Redbank meadows.

Stored seed reserves add an important element of seagrass resilience by providing an ability for meadows to recover from large-scale losses that may occur in the future (Rasheed et al. 2014). In the last four years seed bank sampling has expanded to encompass the entirety of the two major seagrass meadows (34) and (11) in the Harbour, after previously being conducted at a small (50 x 50m) area of the Esplanade meadow between 2014 and 2018. The smaller scale sampling found seed numbers peaked in 2018 following very low numbers of seeds after the seagrass losses in 2009-2011. The seed bank began to re-establish between 2017 and 2018 as meadows recovered. Sampling over a larger meadow-scale has showed a variation in seed-bank density, with 2022 seed density below the previous year and no viable *Zostera muelleri* seeds found. This may be because many of the seeds produced had already germinated prior to sampling and the seeds remaining were older than 12 months and exhibited reduced viability. 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/fruited season and recruitment of new seeds in late 2022. Whichever the explanation, the continued long-term resilience of seagrass meadows in Cairns Harbour is not currently being strengthened by a large, viable and persistent seed bank should another catastrophic loss of seagrass occur in the near future.

The seagrass condition observed in 2022 for Cairns Harbour highlights a continued trend of recovery and the re-establishment of much of their natural resilience following the dramatic losses that occurred due to La Niña climate events between 2009 and 2011. These include the continued increase in the dominance of larger growing foundation species such as *Zostera muelleri*, overall increases in biomass, and maintenance of a large spatial footprint of meadows compared with their long-term history. In Mourilyan Harbour, the closest monitoring location to Cairns Harbour, seagrass has remained in a very poor condition for the past couple of years (2020, 2021) and continues a 7 year run of poor-very poor status. Mourilyan Harbour seagrass has failed to recover from the losses experienced in 2009 – 2011 mostly due to the complete loss of the foundation species *Z. muelleri* including the seed bank (Reason et al. 2022). In the broader Queensland monitoring network, seagrass condition has mostly shown similar trends of improved condition as seen in Cairns. Seagrass in the Gulf of Carpentaria (Weipa and Karumba) were in a good and very good condition due to favourable climate conditions (Reason et al. 2022; Scott et al. 2023). On the east coast, Townsville seagrass were also in a good condition due to stable climate conditions over the past two years (McKenna et al. 2023).

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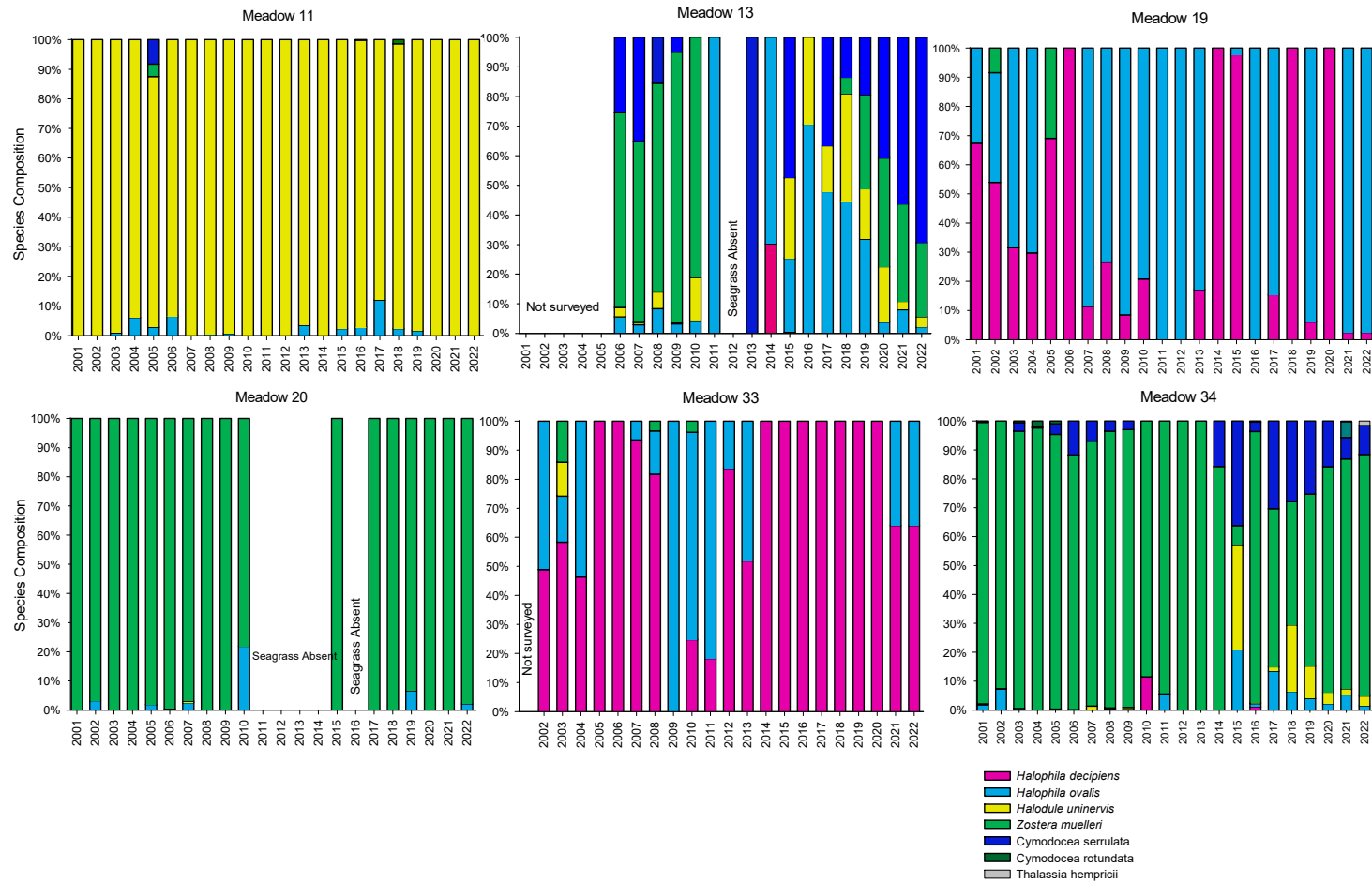
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6 APPENDICES

6.1 APPENDIX: SPECIES COMPOSITION, ABOVE-GROUND BIOMASS AND AREA CHANGES: 2001 – 2022.

6.1.1.1 CAIRNS HARBOUR HISTORICAL SEAGRASS MONITORING MEADOW SPECIES COMPOSITION 2001-2022



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6.1.1.2 SEAGRASS MONITORING MEADOW AREA (HA) IN CAIRNS HARBOUR AND TRINITY INLET, 2001-2022; ± R = RELIABILITY ESTIMATE.

NA = meadow not assessed, NP = meadow not present

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
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
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
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
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
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
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
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

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6.1.1.3 MEAN ABOVE GROUND BIOMASS (G DW M²) OF SEAGRASS FOR MONITORING MEADOWS IN CAIRNS HARBOUR AND TRINITY INLET, 2001-2022.

^ The one site containing *Cymodocea serrulata* was omitted from Bessie Point biomass analysis and *Cymodocea rotunda* was omitted from South Bessie Point biomass analysis.

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
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	23.2 ± 3.1	34.5 ± 3
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
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
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
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
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

NP = meadow not present

NA = biomass values not available due to insufficient biomass samples

(Ho = *Halophila ovalis*; Zm = *Zostera muelleri*)