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JAMES COOK UNIVERSITY
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SEAGRASS HABITAT OF CAIRNS HARBOUR AND TRINITY INLET:

Annual Monitoring Report
And
Cairns Shipping Development Project
Monitoring Report 2021

Reason CL, York PH & Rasheed MA

Report No. 22/03
March 2022

SEAGRASS HABITAT OF CAIRNS HARBOUR AND TRINITY INLET

Annual Monitoring Report

And

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Monitoring Report 2021

A Report for Far North Queensland Ports Corporation Limited
(Ports North)

Report No. 22/03

March 2022

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KEY FINDINGS

Cairns Harbour
Coastal Seagrass
condition 2021

Good

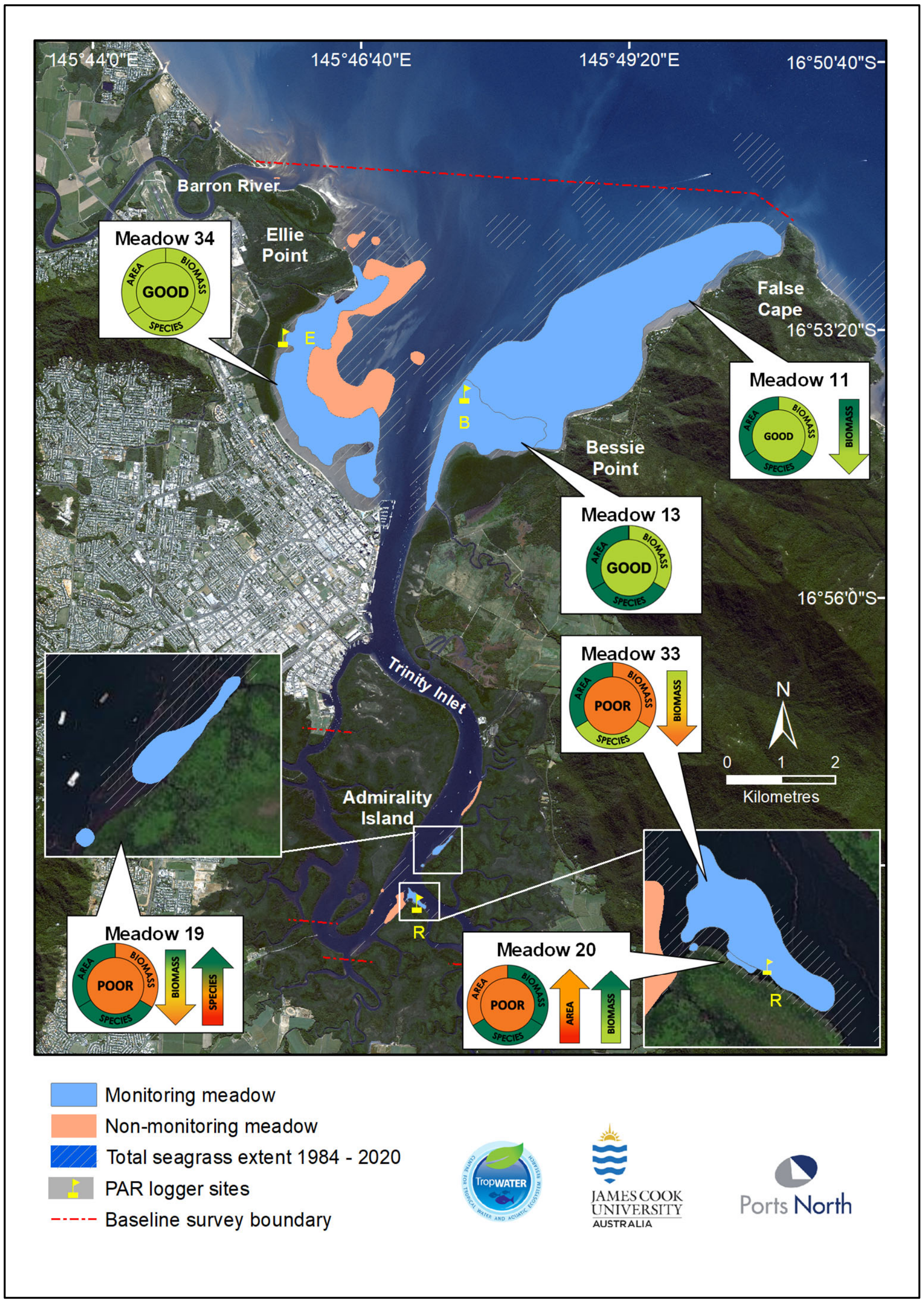
Trinity Inlet
Estuarine Seagrass
condition 2021

Poor

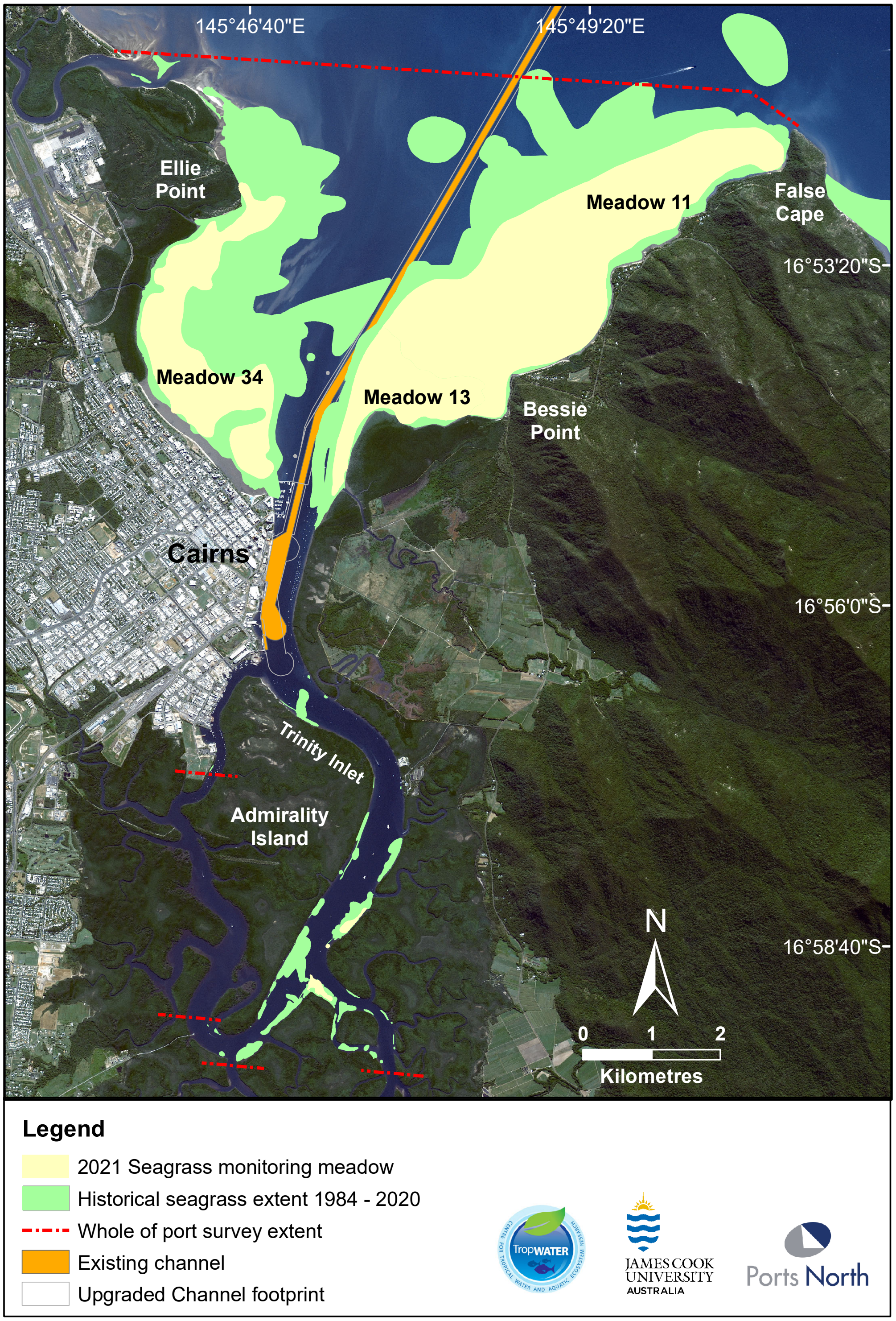
- Seagrass meadows in Cairns Harbour and Trinity Inlet are monitored annually to assess their condition and as an indicator of marine environmental health in the Port of Cairns.
- The three large meadows in Cairns Harbour were in a good condition and remained stable in 2021.
- Due to reductions in area and or biomass the three smaller Estuarine Trinity Inlet monitoring meadows were collectively in a poor condition.
    - Two of these small meadows consist of ephemeral species and are highly variable in density and distribution each year.
    - The third meadow of larger growing species has improved in condition over the last two years following its complete loss between 2010 and 2015.
- The whole of port assessment in 2021 mapped 1,488 ha of seagrass, the fourth year in a row recording some of largest areas of seagrass in the Cairns region, but a slight reduction compared to the past 3 years.
- Two years after completion of the Cairns Shipping Development Project (CSDP) there were no signs of impacts on the extensive seagrass monitoring meadows adjacent to the harbour works.
- The meadows closest to the dredge operation remained in a good condition and both area and biomass have been stable since the CSDP works were completed.

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). In addition to this annual long-term seagrass monitoring program, an intensive quarterly monitoring of meadows adjacent to the shipping channel was conducted between October 2018 and December 2019 associated with the Cairns Shipping Development Project (CSDP) (Map 2). All seagrasses within the port limits are also remapped every 3 years as part of the long term monitoring program but this has been increased to annually through to 2021 as part of conditions for the CSDP project. 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.



Map 1: Seagrass monitoring meadow condition in Cairns Harbour, 2021.



Map 2: Location of Cairns seagrass meadows 1984 – 2021 and the three large monitoring meadows adjacent to the shipping channel that were the focus of intensive monitoring during the CSDP capital works.

The three intensive seagrass monitoring meadows beside the CSDP showed no signs of impact in the two years since dredging works were completed. The two Bessie point meadows (11 & 13) continue to have biomass and area values above the long-term average while the Esplanade meadow values have stabilised in 2021 (Figure 1, 9, 15, 16).

Overall biomass in the long-term monitoring meadows was still below the long-term average, however improvements are in an upward trajectory with 2021 having the highest biomass since 2008 (Figure 2; Map 1). The total area of seagrass in the six long-term monitoring meadows remained well above the long-term average for the fifth year in a row (Map 1; Figure 2).

During 2021, seagrass in the three large long-term annual monitoring meadows in Cairns Harbour were in a good condition. Meadows on the eastern side of the harbour between Bessie Point and False Cape had very good biomass and species composition. Biomass, area and species composition in the large meadow along the Esplanade are stable and in good condition for the second year in a row.

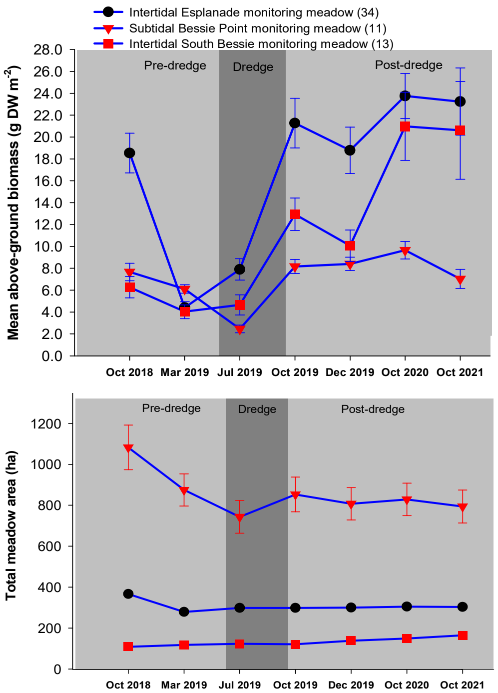


Figure 1: Quarterly and annual assessments of the three seagrass meadows adjacent to shipping channel (a) biomass and (b) area, pre, during and post CSDP dredging.

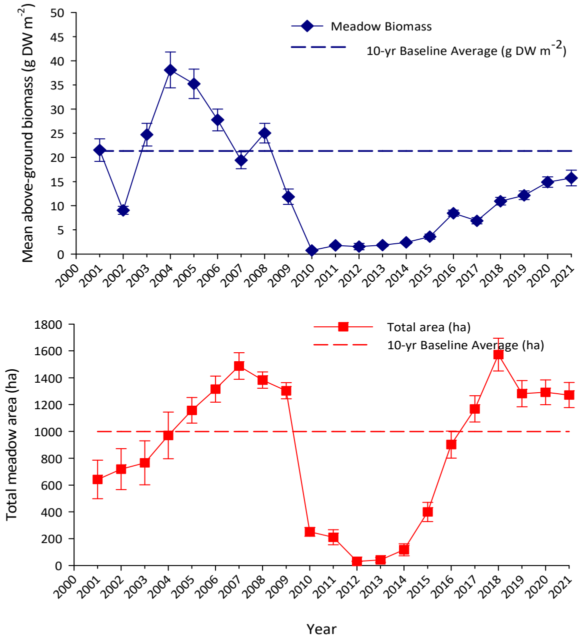


Figure 2: Total a) biomass and b) area of seagrass within all Cairns monitoring meadows from 2001 to 2021 (error bars = standard error of the mean for biomass and "R" reliability estimate for area –dotted line indicates 10-year (2001 – 2010) baseline mean).

Similar to last year, the three smaller Trinity Inlet estuarine seagrass monitoring meadows were collectively in a poor condition with some meadow conditions improving and some declining. Species composition improved for all three meadows to very good. The inlet meadows are made up of highly variable colonising species and tend to fluctuate substantially from year to year.

For the fourth year in a row the extended survey of the entire port region mapped some of largest areas of seagrass recorded for the Cairns region. During 2021, combined below average river flow, solar radiation and tidal exposure led to favourable conditions for seagrass growth (Figure 3).

The improvements in the species composition in 2021 for Cairns Harbour seagrasses mean they have re-established their natural resilience following the dramatic losses that occurred due to La Niña climate events between 2009 and 2011. The continued increase in the larger growing foundation species *Zostera muelleri*, the large spatial footprint of meadows compared with their long-term history and the presence of a seed bank are all signs of improving resilience.

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, as well as a component of JCU's broader seagrass assessment and research. On the east coast of Queensland where seagrasses were broadly impacted by climate and storms leading up to 2011, seagrass condition and the trajectory of recovery has varied between locations. These variations were mainly due to more localised recent weather events such as cyclones or heavy rainfall combined with the degree to which meadows were initially impacted by the 2011 events. In Mourilyan where foundation meadows were completely lost prior to 2011 little recovery has occurred, whereas seagrasses further south in Townsville had fully recovered in 2014 (Reason et al. 2021, Davies et al. 2015). The current condition of seagrasses in the Cairns region was one of the better outcomes for coastal seagrasses that are monitored in the wet tropics region. For full details of the Queensland ports seagrass monitoring program see https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

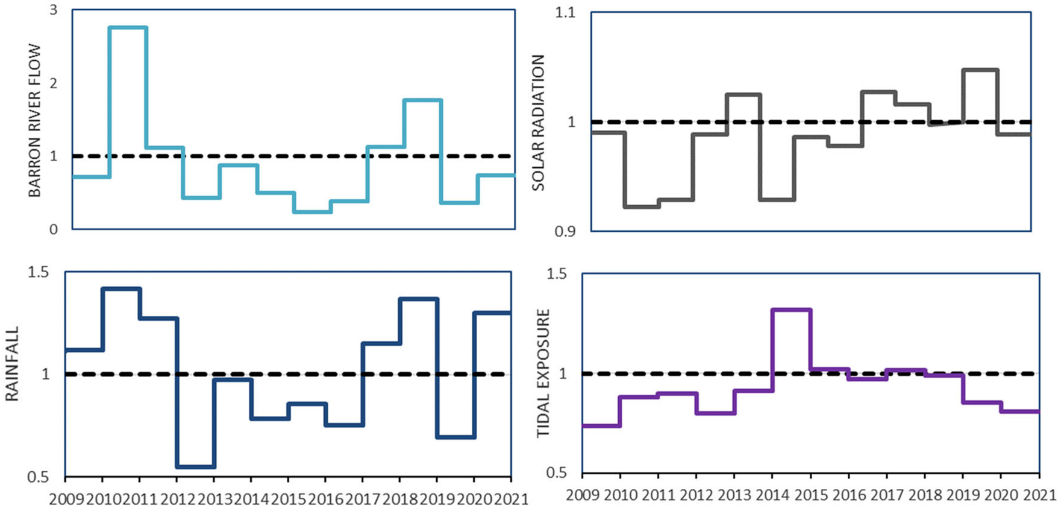


Figure 3: Recent climate trends in Cairns: Change in climate variables as a proportion of the long-term average.

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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 (Madsen et al. 2001), 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 3).

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.

Map 3: 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/

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 2022).

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.

1.4 Cairns Shipping Development Project Monitoring Program

From October 2018 to December 2019 as part of the Cairns Shipping Development Project (CSDP) an increased intensity of monitoring occurred for seagrass adjacent to the shipping channel where capital works were conducted. The focus of the intensive monitoring program has been the large intertidal/subtidal meadows to the east and west of the channel (Map 2). In addition, the whole of port scale assessments have been increased from once every 3 years to annual assessments through to 2021. The quarterly CSDP seagrass monitoring program builds on the long-term seagrass monitoring (see above).

The objectives of the CSDP seagrass monitoring program were to:

- Monitor seagrass presence/absence, density and distribution, (light) PAR and temperature adjacent to the proposed channel expansion footprint before, during and after capital works (completed December 2019);
- Monitor seagrass presence/absence, density and distribution after capital works for at least 2 years – ongoing to 2021;
- Provide information to inform the Reactive Management Programs (RMP) related to water quality and seagrass habitat during capital works.

This report presents the findings of the 2021 whole of port mapping, annual monitoring surveys, and the assessment of meadows adjacent to the shipping channel for the CSDP.

The overall objectives of the 2021 annual and quarterly seagrass monitoring were to:

1. Map and quantify the distribution and abundance of all seagrass in Trinity Bay and Trinity Inlet to provide an updated whole of port assessment;
2. Map and quantify the distribution and abundance of the selected long term seagrass monitoring meadows;
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)), seed banks and reproductive effort.

This monitoring program forms part of the dredge management plan and is one of the key monitoring requirements under approval conditions for the CSDP.

2 METHODS

2.1 Long Term Seagrass Monitoring Program

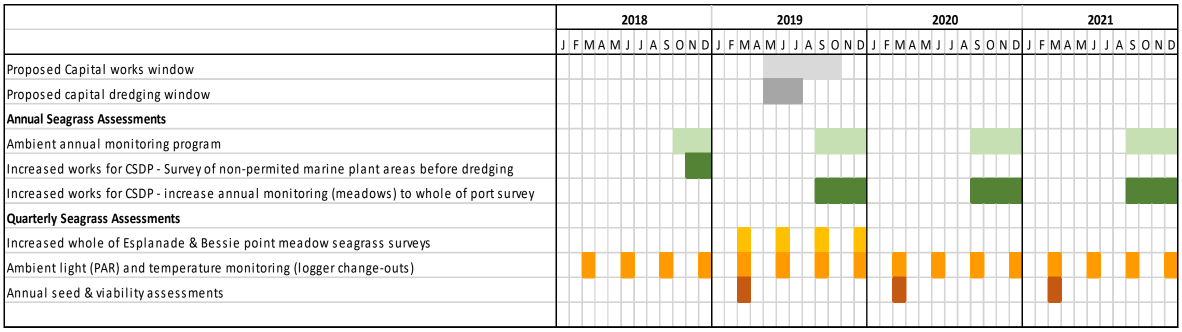
Survey and monitoring methods followed the established techniques for TropWATER's Queensland-wide seagrass monitoring programs. The annual seagrass survey was conducted in October 2021 during seasonal peak of seagrass condition. In addition to the annual monitoring survey, mapping was extended to update the regional distribution of Cairns seagrasses. The survey involved mapping and assessing:

- The six long-term monitoring meadows assessed annually within the Cairns Harbour and Trinity Inlet monitoring area.
- All intertidal and subtidal areas extending from the Barron River mouth across to False Cape, and south to Redbank Creek in Trinity Inlet (Map 1), as part of the extended survey normally conducted every 3 years but increased to annual to 2021 as part of expanded CSDP monitoring.

2.2 Cairns Shipping Development Project Intensive monitoring meadows

In addition to the annual monitoring scope, seagrass was assessed at the three major meadows adjacent to the shipping channel at increased frequency from October 2018 to December 2019 as part of the CSDP seagrass program. The Esplanade meadow (34) represents key *Zostera muelleri* subsp. *capricorni* and the Bessie point meadows (11) and (13) represents the key *Halodule uninervis, Zostera muelleri and Cymodocea serrulata* meadows closest to the dredging program operations. These meadows were assessed quarterly, during the months of October 2018, March 2019, July 2019, October 2019, and December 2019. The full range and timing of the various seagrass monitoring components including the expanded monitoring for the CSDP are summarised in Table 1.

Table 1. Monitoring schedule for tasks associated with seagrass long-term monitoring program and expanded monitoring for the CSDP between 2018 and 2021.



	2018												2019												2020												2021											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Proposed Capital works window																	▒	▒	▒	▒	▒	▒																										
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Increased works for CSDP - Survey of non-permited marine plant areas before dredging											🟩	🟩																																				
Increased works for CSDP - increase annual monitoring (meadows) to whole of port survey																					🟩	🟩	🟩	🟩									🟩	🟩	🟩	🟩									🟩	🟩	🟩	🟩
Quarterly Seagrass Assessments																																																
Increased whole of Esplanade & Bessie point meadow seagrass surveys															🟨			🟨			🟨			🟨																								
Ambient light (PAR) and temperature monitoring (logger change-outs)			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧			🟧
Annual seed & viability assessments															🟫												🟫												🟫									

2.3 General 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 4). Shallow subtidal meadows were sampled by boat using camera drops and van Veen grab (Figure 4). 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 (Figure 4). 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.

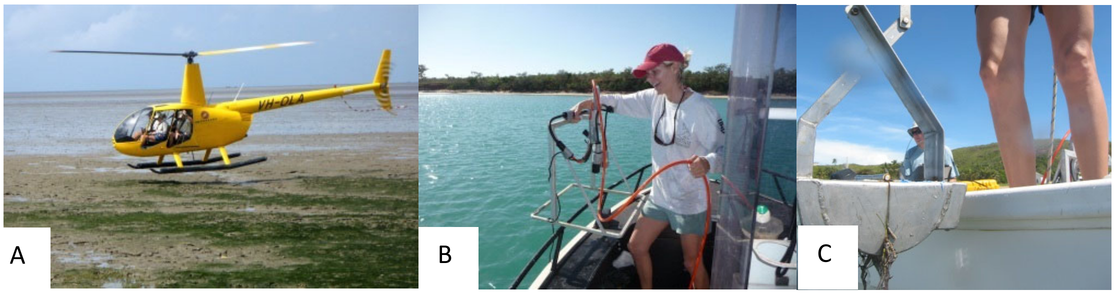


Figure 4: Seagrass monitoring methods in 2018. (a) helicopter survey of intertidal seagrass, (b, c) boat-based camera drops and van Veen grab for subtidal seagrass.

2.3.1 Seagrass biomass estimates

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (Mellors 1991; Kirkman 1978). At each site a 0.25 m^2 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.

2.3.2 Geographic Information System

All survey data was entered into a Geographic Information System (GIS) using ArcGIS 10.8®. 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:

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.

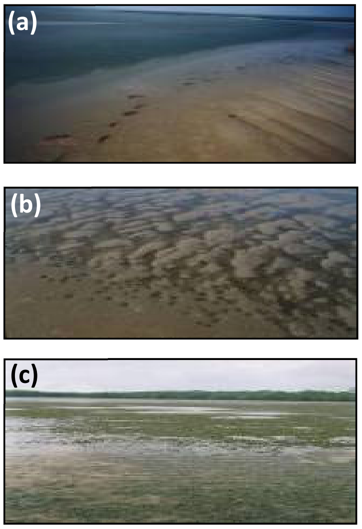
Interpolation layer

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.

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.



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

Table 2. 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 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

Meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, colour satellite imagery of the survey region (Source: Landsat 2018, courtesy ESRI), 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 $\leq$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 4: Mapping precision and methodology for seagrass meadows 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; Patchy cover of seagrass throughout meadow; 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.

2.3.3 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 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. Density data were separated by species and reported as total number of seeds m^{-2} and mean number of seeds per m^{-2} per site (Figure 6).

Figure 6: Helicopter survey, sediment seed bank cores, and PAR loggers at Cairns Harbour quarterly monitoring site E.

2.2.3 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 and Moore 2010; Conacher et al. 1994a) within 3 weeks 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 (Conacher et al. 1994a). Seeds with a pink to brown stained cotyledon and axial hypocotyl were considered viable (Conacher et al. 1994a; Harrison 1993) (Figure 7). Viability data were separated by species and reported as total number of viable seeds m^{-2}, mean number of viable seeds per m^{-2} per site, and as the percentage of viable seeds per sampling site. Seed bank sampling reported here was conducted in April 2021 and is scheduled to occur next in March 2022.

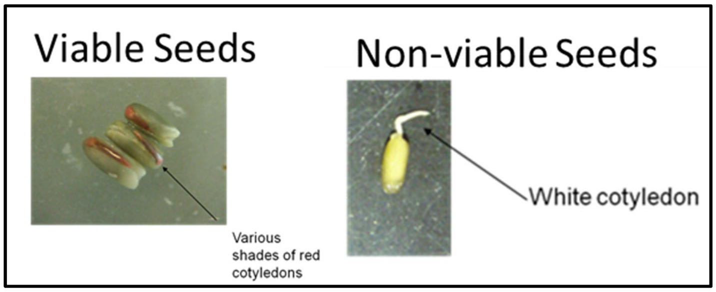


Figure 7: Examples of stained viable and non-viable *Zostera* seeds using tetrazolium chloride

2.3.4 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 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.

2.4 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. 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%. The flow chart in Figure 8 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.

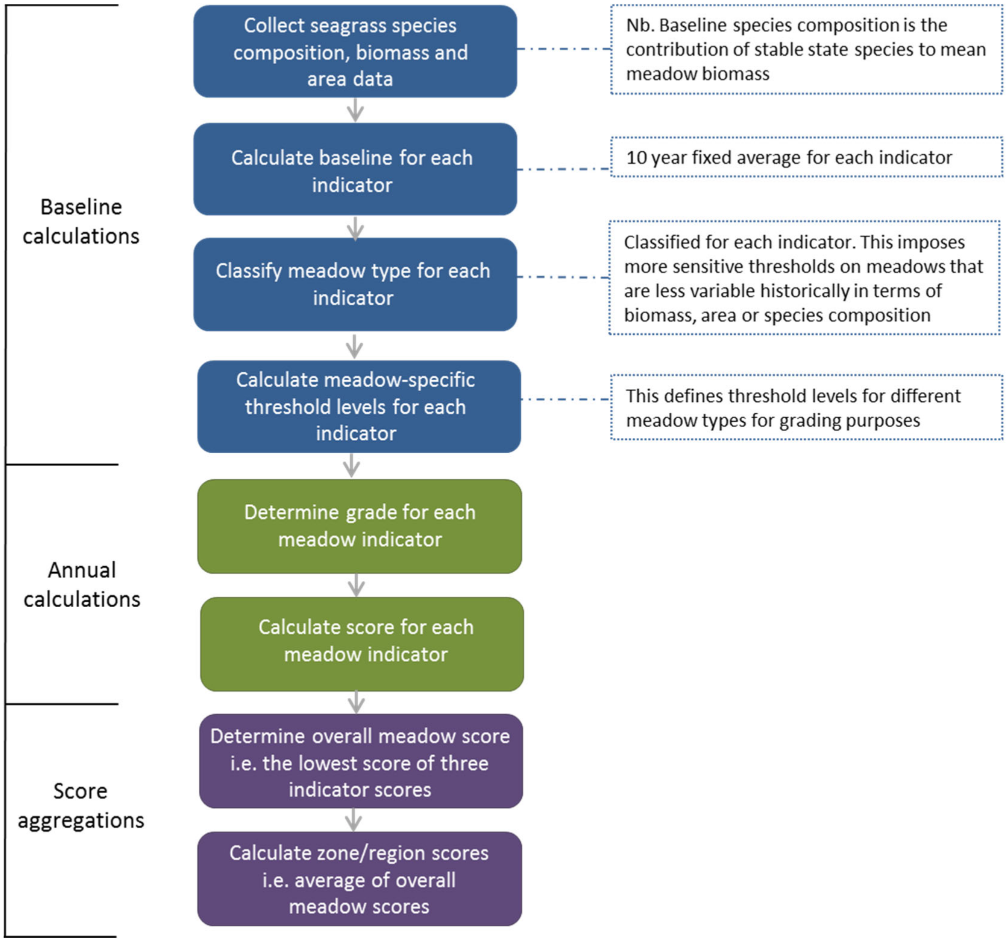


Figure 8. Flow chart to develop Cairns Harbour grades and scores.

3 RESULTS

3.1 Cairns Shipping Development Project intensive monitoring meadows

In the 2 years post CSDP operations there are no signs of impact on the meadows adjacent to the works. The distribution and density of seagrass in the three largest Harbour monitoring meadows adjacent to the main shipping channel; Esplanade (34), Bessie (11) and South Bessie (13), have remained healthy since the completion of the capital dredging program and are within the range of historical records (Figure 9, Map 4 & 5). Total meadow area has been relatively stable since October 2018 (Figure 10) and biomass of meadows was similar in 2021 and higher than the pre-dredge and dredge sampling (Figure 11).

3.1.1 Esplanade monitoring meadow (34)

According to the seagrass condition index developed for the long-term monitoring program, the Esplanade meadow has stabilised over the past 2 years to a good condition (Figures 9 & 14). This is the largest intertidal monitoring meadow on the western side of the shipping channel and is dominated by the foundation species *Zostera muelleri* (Table 4; Figure 10 & 11; Map 2). The footprint of this meadow has been stable since October 2019 at around its long-term average (308 ± 6.8 ha) with an area of 303 ± 7 ha in October 2021 (Figure 9). Biomass of seagrass in this meadow 2 years post dredge has continued to stabilise in a good condition and is the same as last year with 23 ± 3 g DW m^{-2} in October 2021 (Figure 9).

Six species of seagrass occurred in this meadow during the 2021 survey period; *Z. muelleri*, *Cymodocea serrulata*, *Thalassia hempricii*, *Halodule uninervis*, *Halophila ovalis,* and *Halophila decipiens* (Table 5). The meadow has been steadily increasing in its dominance of the more persistent, larger-growing species since the major climate related seagrass losses that occurred leading up to 2011. This trend continued during 2021 with species composition remaining in a good condition with *Z. muelleri* and *Cymodocea serrulata* continuing to increase their presence and the new addition of *Thalassia hemprichii* in this meadow (Figure 14, Appendix 3.1).

3.1.2 Bessie point monitoring meadows (11 &13)

The Bessie Point meadows on the eastern side of the shipping channel comprise an intertidal ‘south Bessie Point’ meadow (13) and a subtidal ‘north Bessie Point’ meadow (11) (Map 2).

The subtidal Bessie Point meadow (11) is dominated by *H. uninervis* and is the largest meadow in the harbour group (794 ± 80.6 ha October 2021) (Figures 9, 10, 15). The annual monitoring overall condition index is good for this meadow (Figure 15), and while the October 2021 survey saw a slight decline in biomass and area, both are above the long term average for this meadow (Figures 9, 11 & 15).

The south Bessie Point intertidal meadow (13) is continuing to return to its historical species composition following meadow loss in 2011 with increased proportion of the morphologically larger species *Z. muelleri* and *C. serrulata.* The seagrass condition index for biomass has remained good and species composition remained very good for the past two years (Figures 9 & 16). The footprint of this meadow has remained above the long-term average for the fourth year in a row and was at a 12-year peak of 165 ± 3.9 ha (Figure 9, 10 & 16).

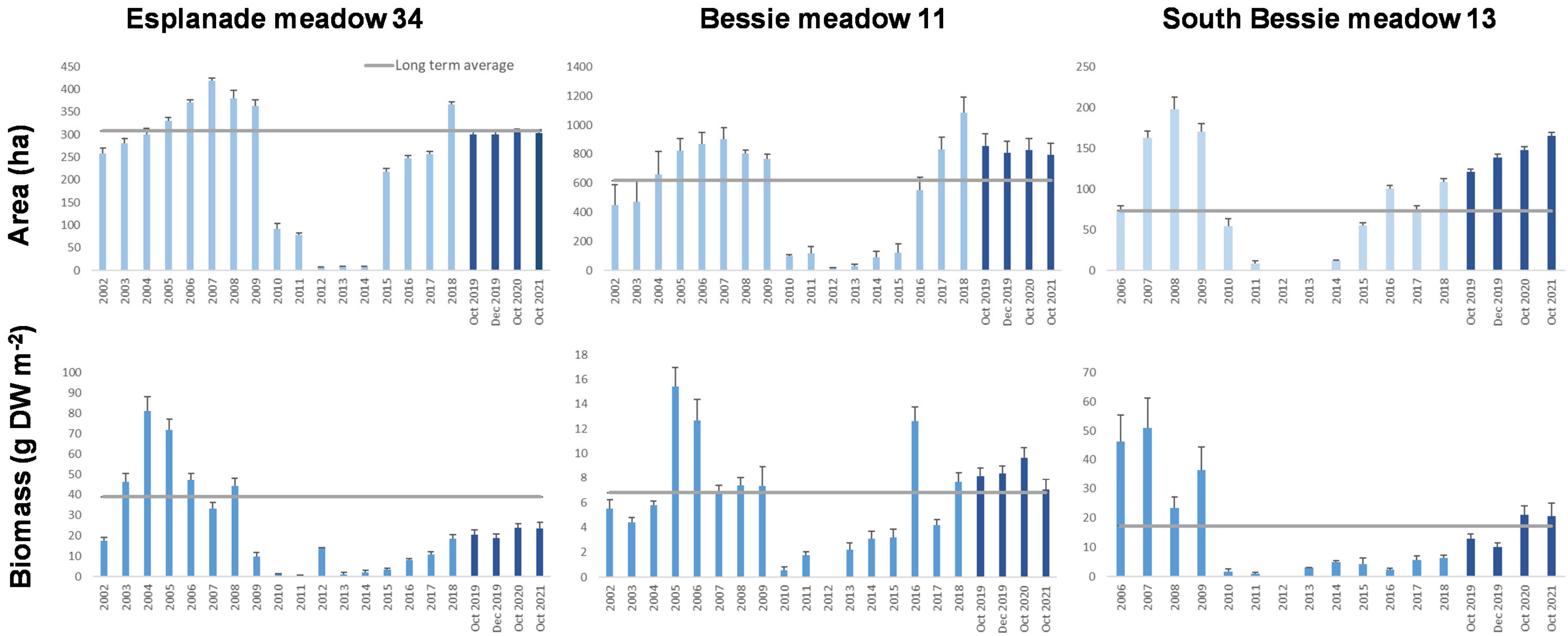


Figure 9. Biomass (g DW m^{-2}) and area (ha) of the three seagrass meadows monitored for the CSDP in comparison with long term annual monitoring surveys, from 2002 to 2021. Post Dredge values were collected in October and December 2019 and October 2020 and 2021 and are dark blue bars. Previous year's data collected at peak of growth season between September and November (Biomass error bars– standard error, Area error bars – "R" reliability estimates, long term average is the 10-year (2001 – 2010) baseline mean of meadow biomass and area).

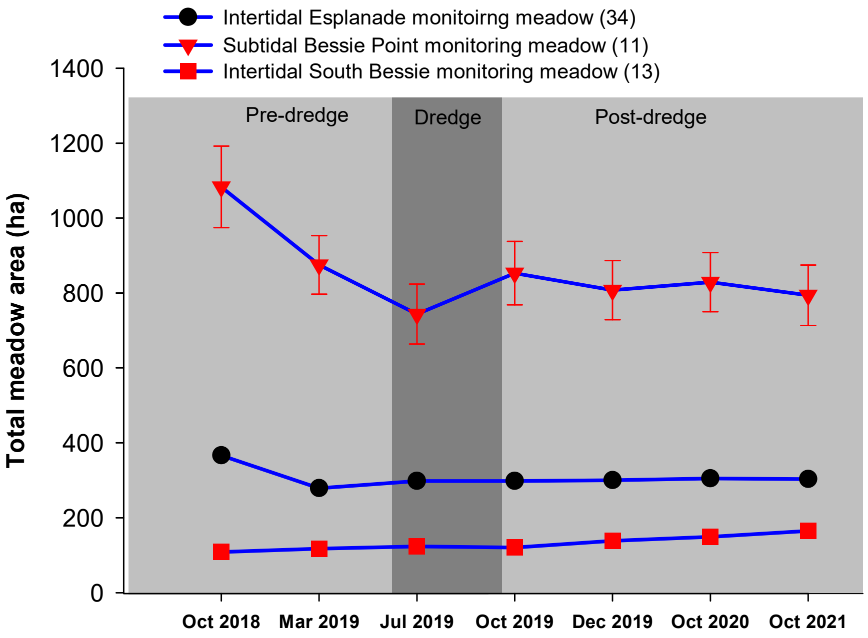


Figure 10. Area (ha) of the three seagrass meadows monitored for the CSDP program between October 2018 and October 2021.

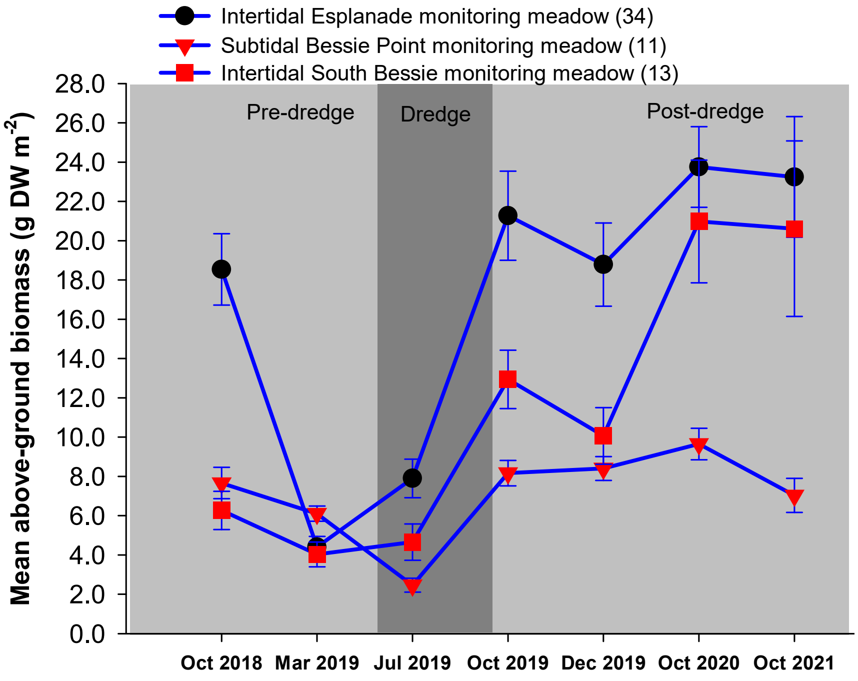
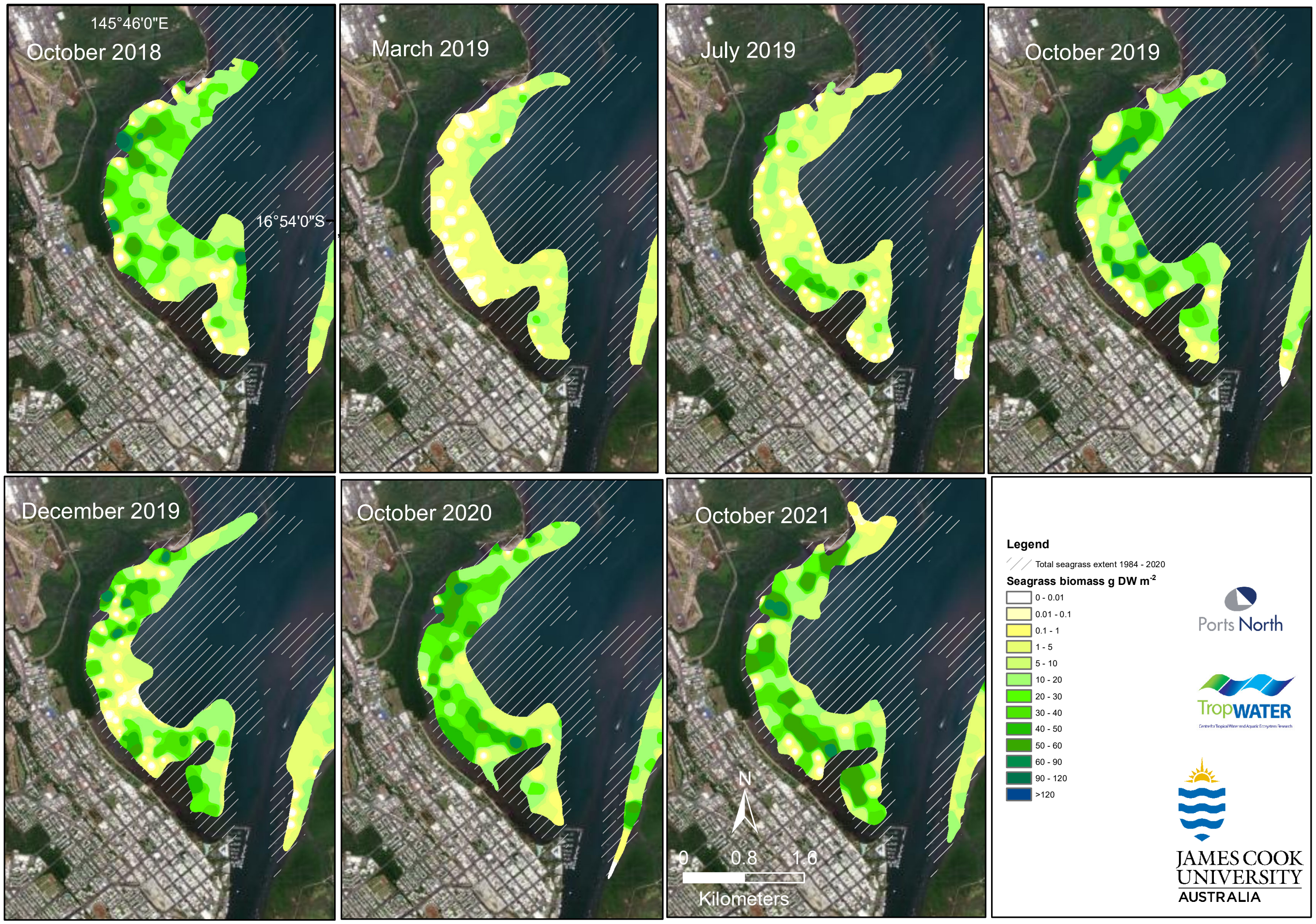
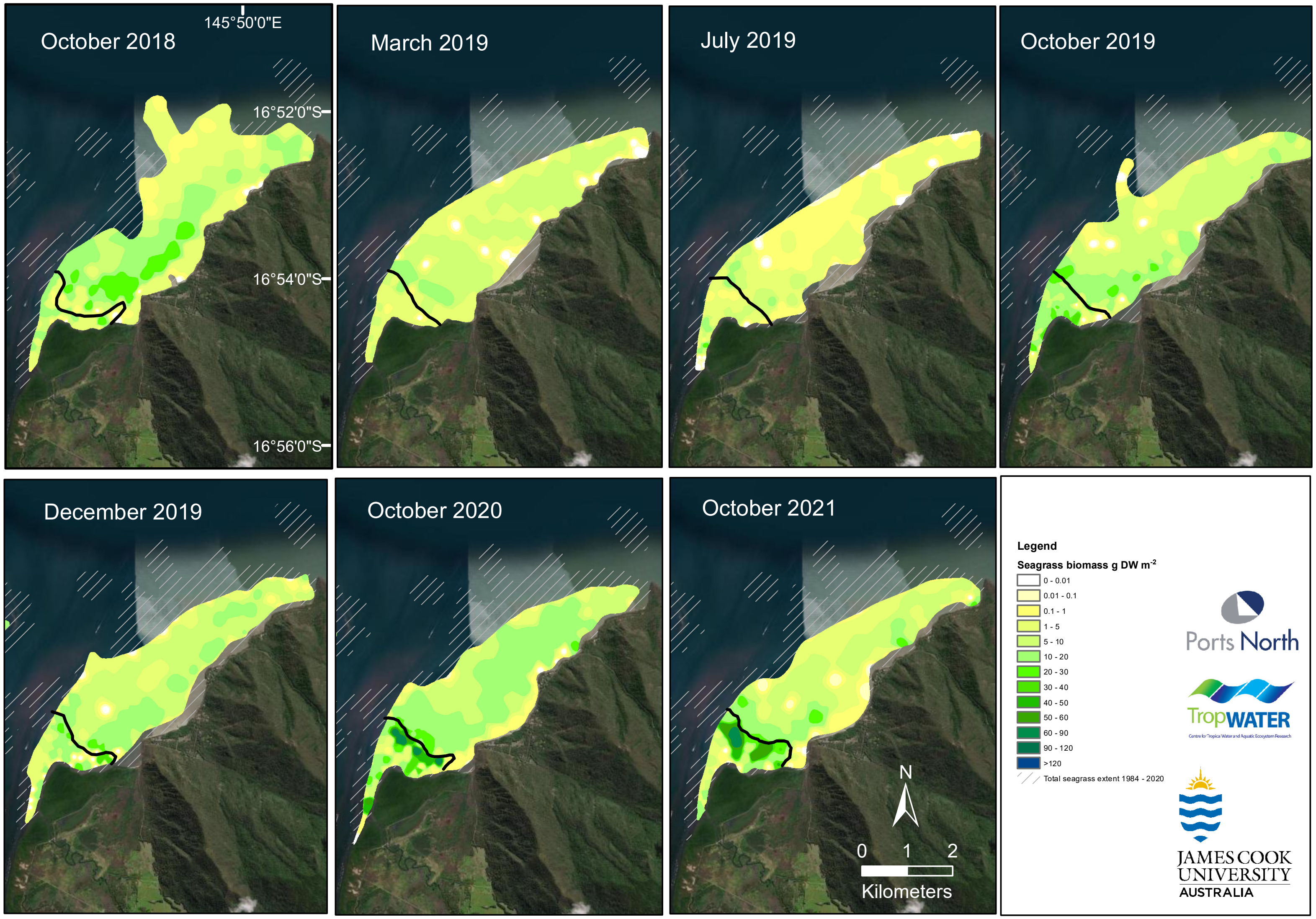


Figure 11. Mean above-ground biomass (g DW m^{-2}) of the three seagrass meadows monitored for the CSDP program between October 2018 and October 2021.



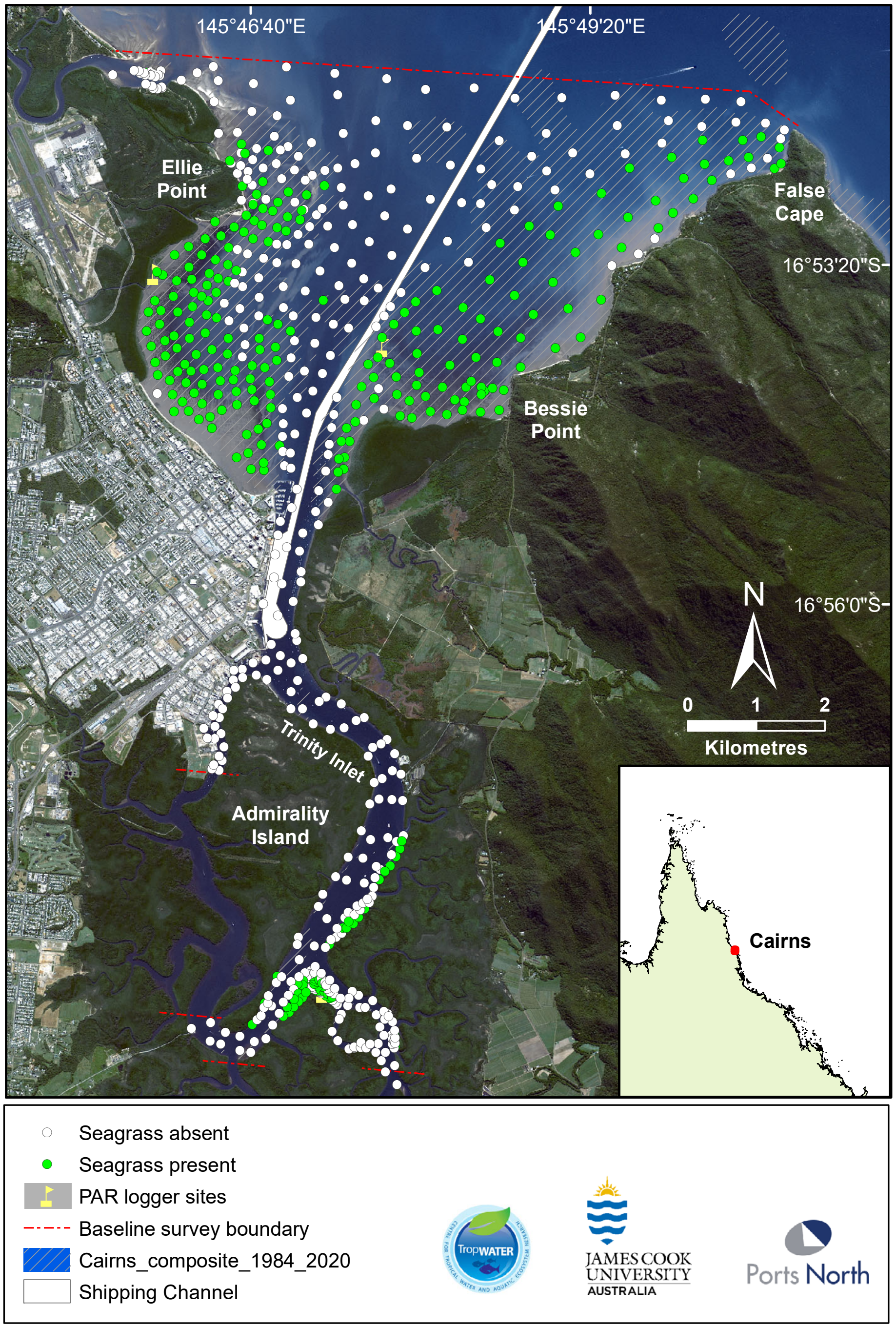
Map 4. Interpolation maps of seagrass distribution and density (g DW m^{-2}) of the Esplanade monitoring meadow between October 2018 and October 2021.



Map 5. Interpolation maps of seagrass distribution and density (g DW m^{-2}) of the Bessie Point monitoring meadows between October 2018 and October 2021.

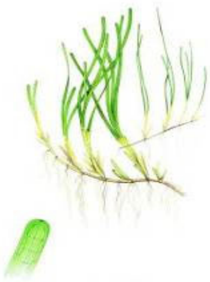
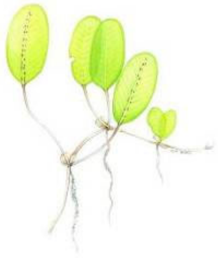
3.2 Annual Monitoring of Seagrasses in Cairns Harbour and Trinity Inlet

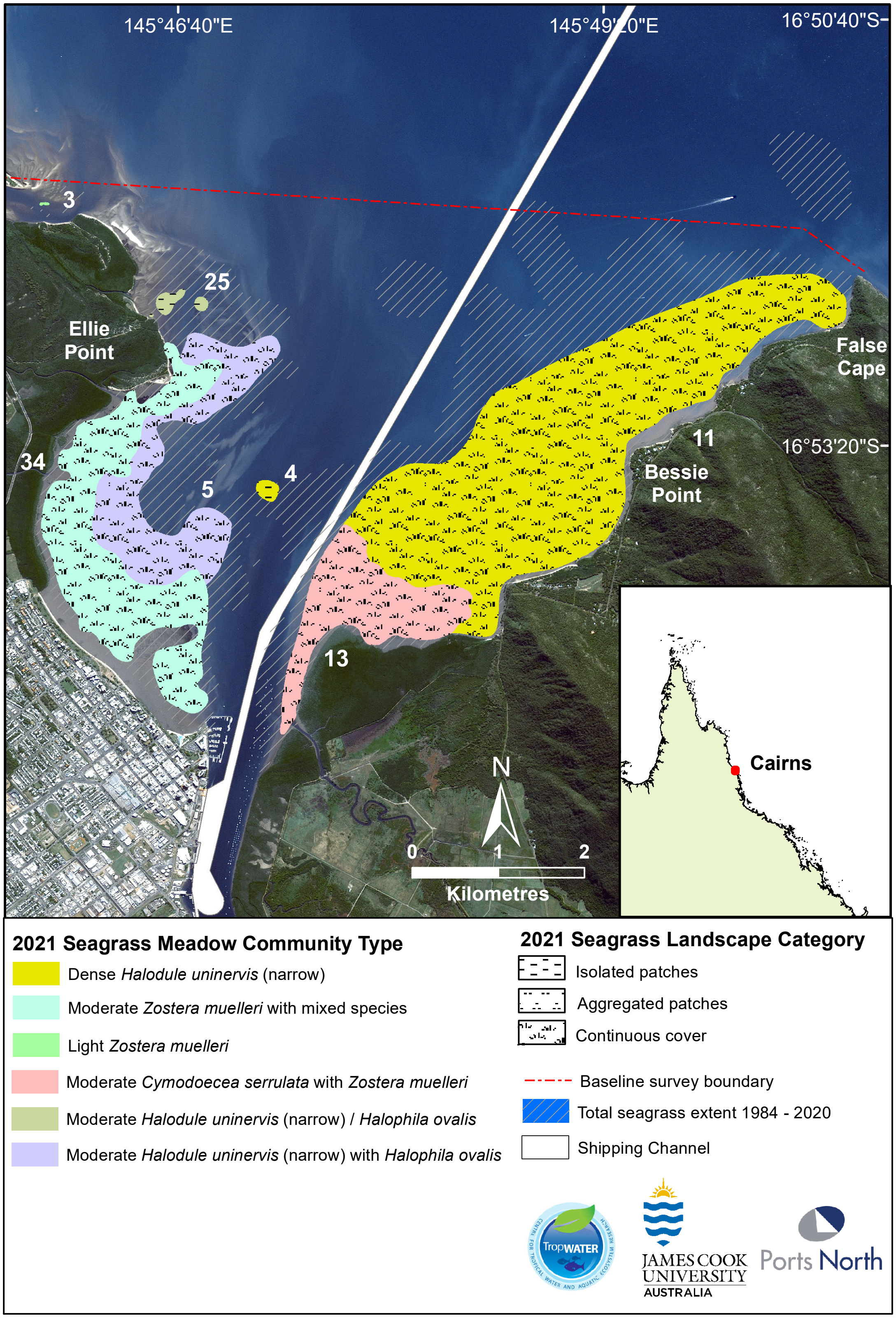
A total of 679 habitat characterisation sites were surveyed with seagrass present at 40% of sites in the 2021 whole of port and annual seagrass monitoring survey (Map 6). A total seagrass area of 1,488 ha was mapped in the whole of port survey region consisting of 1,270 ± 93 ha in the annually assessed long-term monitoring meadows, and an additional 217 ± 27 ha of seagrass habitat outside of these meadows (Map 7a; 7b). In 2021 an additional species, *Thalassia hemprichii*, was found along with the same five species as previous years within the annually monitored meadows (Table 5). *T. hemprichii* has only occasionally been recorded in Cairns Harbour and generally not found within the annual monitoring meadows.



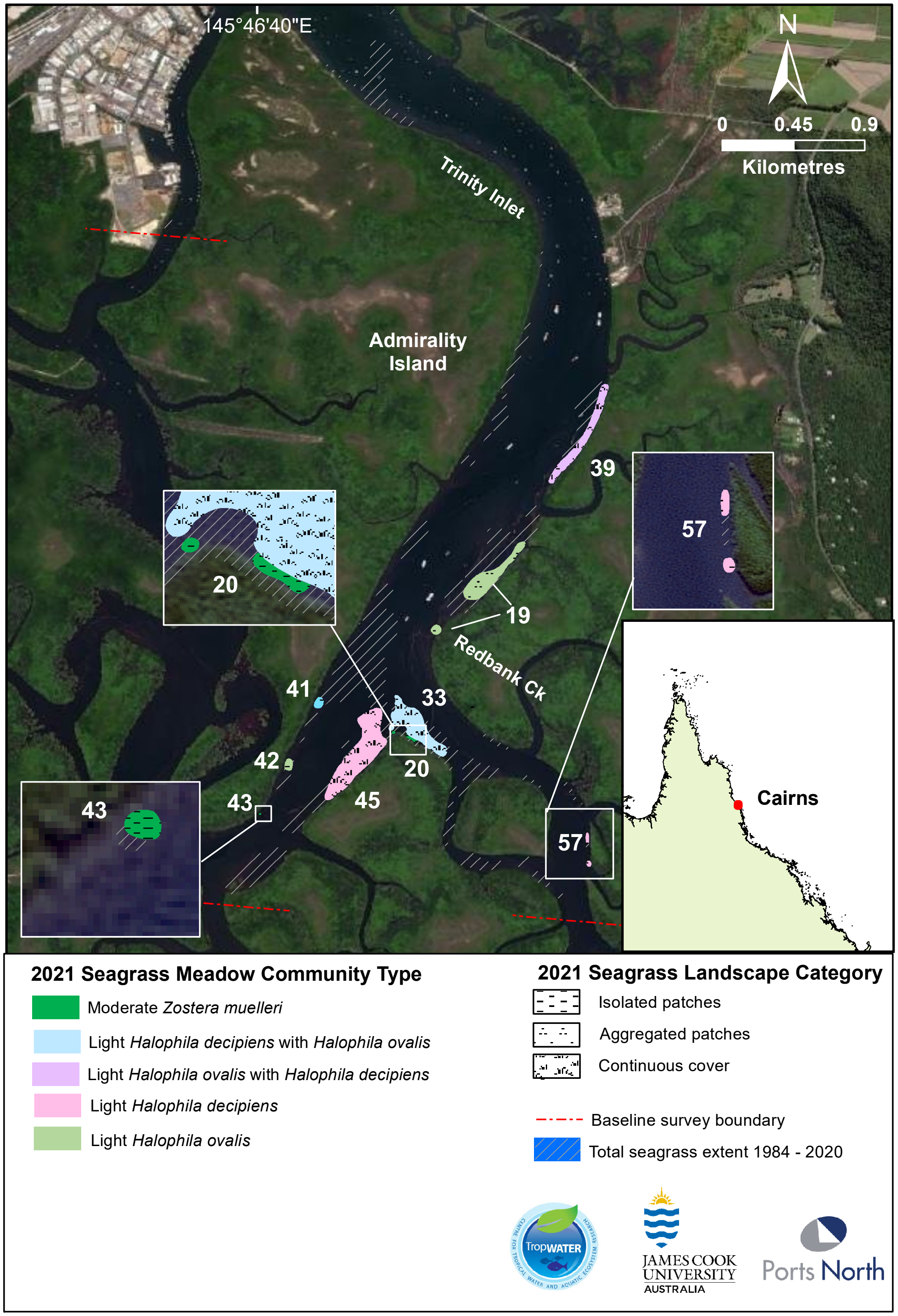
Map 6: Seagrass presence/absence at sites surveyed within the Cairns survey area, 2021.

Table 5: Seagrass species present in Cairns Harbour and Trinity Inlet monitoring meadows in 2021.

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



Map 7a: Coastal Cairns Harbour distribution and community type for seagrass meadows in 2021.



Map 7b: Estuarine Trinity Inlet distribution and community type for seagrass meadows in 2021.

3.2.1 Seagrass condition for long-term monitoring meadows

The overall mean biomass for all six long-term monitoring meadows increased to 15.7 ± 1.63 g DW m^{-2}, the highest recorded since 2008. Biomass has been steadily increasing in upward trajectory since 2010 however is still below the long-term average of 21.33 g DW m^{-2} (Table 6; Figure 12). The overall area of monitoring meadows in 2021 was 1270.97 ± 93 ha, well above the long-term average (999 ± 108 ha) (Table 6; Figure 13).

The condition of the three large coastal Cairns Harbour meadows (Meadows 11, 13 and 34) were collectively in a good condition. The Esplanade meadow (34) remained in good condition in 2021, with all three condition indicators of biomass, area, and species staying the same as 2020 (Table 6; Figure 14). Both the Bessie Point subtidal (11) and intertidal (13) meadow had biomass and area values above the long-term average for the second year in a row and species composition was in a very good condition in 2021 (Table 6; Figure 15 and 16). While the small highly variable estuarine Trinity Inlet meadows (Meadows 19, 20 and 33) collectively remained in a poor condition in 2021 (Map 1; Table 6). The subtidal Trinity Inlet meadow (19) remained in poor condition even though the species shifted back to *Halophila ovalis* (Table 6; Figure 17). While area and species composition was very good, the low biomass gave the overall condition of poor (Table 6; Figure 14). The Subtidal Redbank meadow (33) also remained in a poor condition due to low biomass, while the area and species composition were both very good (Table 6; Figure 19). The small intertidal Redbank Creek meadow (20) consists of larger growing *Z. muelleri* and following its complete loss between 2010 and 2015 has shown recent improvements from very poor to a poor condition due to increases in biomass, area and improved species composition over the last two years (Table 6; Figure 18).

Table 6: 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).

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
Coastal Cairns Harbour Meadows				
Esplanade to Ellie Pt. (34)	0.65	0.73	0.84	0.65
Bessie Point (11)	0.76	0.88	1.00	0.76
South Bessie Pt (13)	0.80	0.93	1.00	0.80
Overall Score for Cairns Harbour				**0.77**
Estuarine Trinity Inlet Meadows				
Inlet (19)	0.45	0.85	0.99	0.45
Redbank Intertidal (20)	0.93	0.26	1.00	0.26
Redbank Subtidal (33)	0.44	0.93	1.00	0.44
Overall Score for Trinity Inlet				**0.37**

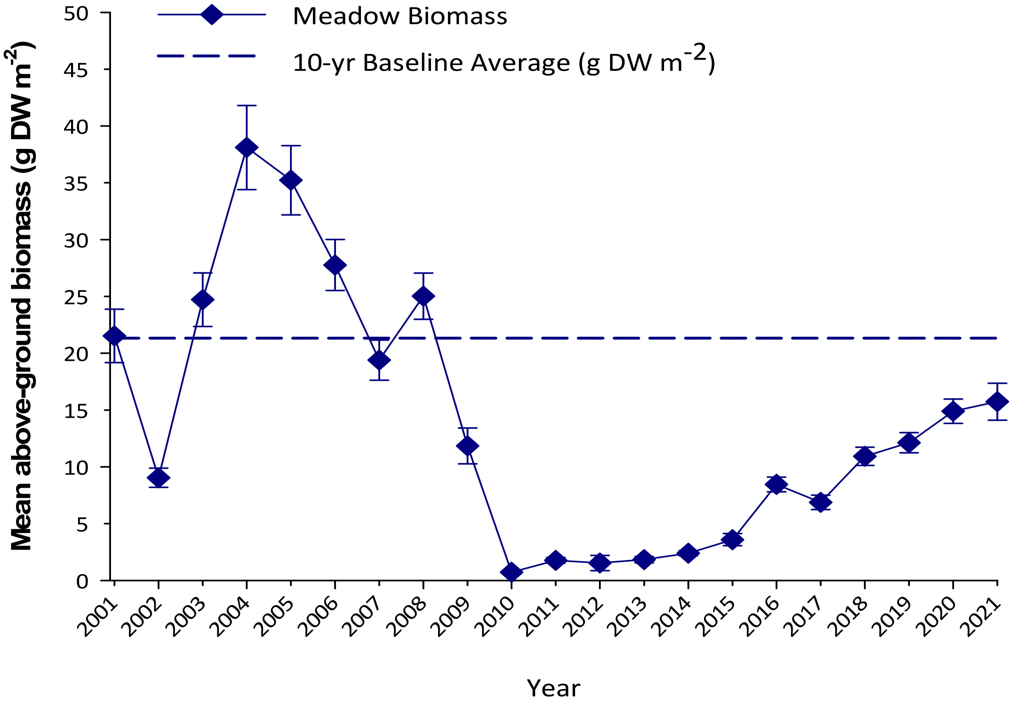


Figure 12: Mean above-ground biomass (g DW m^{-2}) of all monitoring meadows combined in Cairns Harbour and Trinity Inlet from 2001 – 2021 (error bars – standard error). Dotted blue line indicates 10-year (2001 – 2010) baseline mean of meadow biomass.

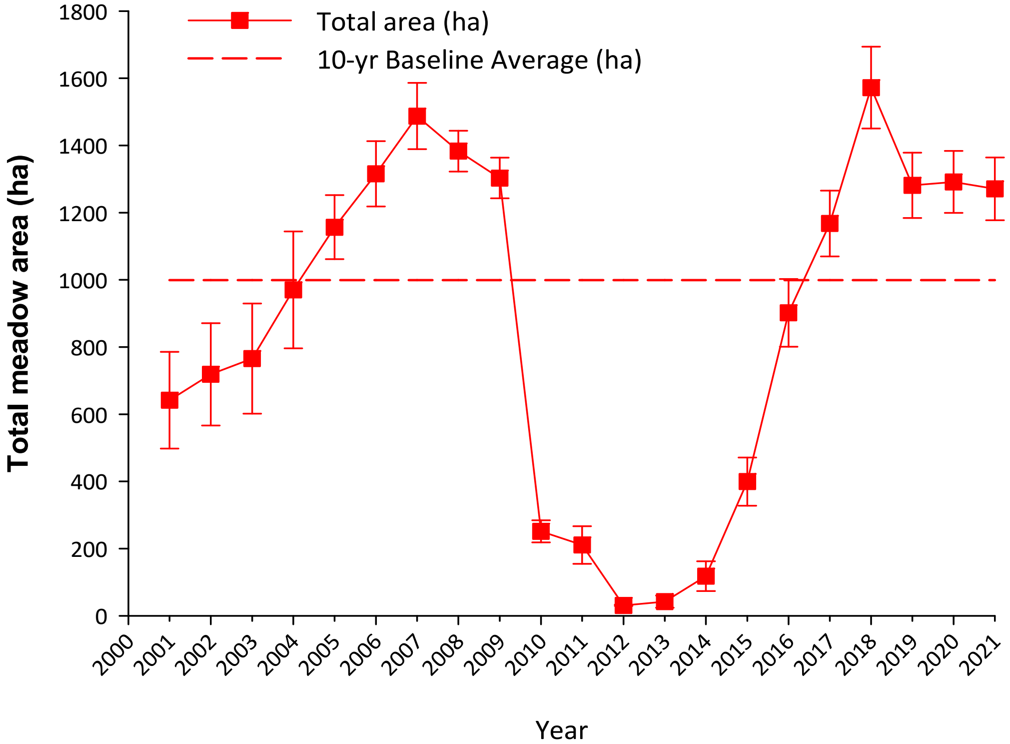


Figure 13: Total area of all monitoring meadows combined in Cairns Harbour and Trinity Inlet from 2001 – 2021 (error bars – “R” reliability estimated). Dotted red line indicates 10-year (2001 – 2010) baseline mean of total meadow area.

3.2.2 Coastal Cairns Harbour Meadows

The three largest monitoring meadows in the coastal Cairns Harbour group all stabilised to a good condition in 2021 and consist of the Esplanade to Ellie point meadow (34), Bessie Point (11) and South Bessie Point (13) meadows.

In 2021, all three condition indicators in the Esplanade meadow (34) stabilised at a good condition for the second year in a row. Area (303 ± 7 ha) is on par with the long-term baseline average (308 ha) and has remained stable over the past three years (Figure 14). Biomass remained in a good condition at 23 ± 3 g DW m^{-2}, however is still below the long term average of 38 g DW m^{-2} (Figure 14). Indicator species *Zostera muelleri* continued to increase in this meadow and a small patch of *Thalassia hemprichii* recorded for the first time since the monitoring program began (Figure 14; Map 8; Appendix 3).

The Bessie Point meadow (11) declined from very good to good condition in 2021 due to a decline in biomass (Figure 15). While biomass declined from a peak in 2020 to 7 ± 0.8 g DW m^{-2} in 2021, it is still above the long-term baseline average of 6.8 ± 0.8 g DW m^{-2} (Figure 15; Map 9; Appendix 3). Meadow area also remained well above the long-term average and rated as being in a very good condition for the 5th year in a row (Figure 15). Species composition remained dominated by *Halodule uninervis* (Figure 15; Appendix 3).

Biomass, area and species composition were stable compared with 2020 levels in the subtidal monitoring meadow at South Bessie Point (13) and remained in a good condition in 2021. Both biomass (20 ± 4.4 g DW m^{-2}) and area (165 ± 3.9 ha) were at the highest levels recorded since 2009 and well above the long-term average baseline conditions (Figure 16, Map 9, Appendix 3). There was a continued increase in the more persistent species *Cymodocea serrulata* in 2021, along with a good presence of indicator species *Zostera muelleri* remaining dominant in the meadow (Figure 16; Appendix 3).

3.2.3 Trinity Inlet Estuarine Meadows

The three smaller, predominantly subtidal, meadows in Trinity Inlet are historically highly variable across all indicators and were collectively in a poor condition in 2021. The monitoring meadows consist of Trinity Inlet (M19), Intertidal Redbank Creek (M20) and Subtidal Redbank Creek (33).

The subtidal Trinity Inlet meadow (19) stabilised to a poor overall condition in 2021 (Figure 17). Biomass declined from very good to satisfactory, a trend that seems to alternate back and forth over the past 8 years (Figure 17). The species composition improved to very good as the dominant species shifted back to *Halophila ovalis*, the indicator species (Figure 17). While area declined, it has remained above the long-term average and in a very good condition (Figure 17). This meadow is also highly variable from year to year in both biomass and area (Map 10).

A decline in the subtidal Redbank Creek meadow (33) from good to poor was a result of lower biomass surveyed in 2021 (Figure 19). Area and species composition remained in a very good condition in 2021, with an increase in a more persistent species *Halophila ovalis* (Figure 19). While this meadow is the most variable of all the monitoring meadows in the program, its presence has been consistent through time (Figure 19; Map 10).

The adjoining intertidal Redbank Creek *Zostera muelleri* meadow (20) has improved in condition to poor, due to an increase in the footprint of this meadow, however it is still considerably below the long-term average (Figure 18). Biomass (54 ± 11 g DW m^{-2}) in this meadow has improved and is the second highest ever recorded for this meadow since monitoring began in 2001 (Figure 18, Map 10, Appendix 3). Species composition was dominated by *Zostera muelleri* and while this meadow disappeared between 2010 and 2015 it has since reappeared as small patches, in a narrow footprint adjacent to the mangroves (Figure 18).

Table 7: Maximum depth penetration (depth below mean sea level) of monitoring meadows in Cairns Harbour and Trinity Inlet, 2001 –2021.

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**
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
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
South Bessie Point (13)	-	-	-	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
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
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
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

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

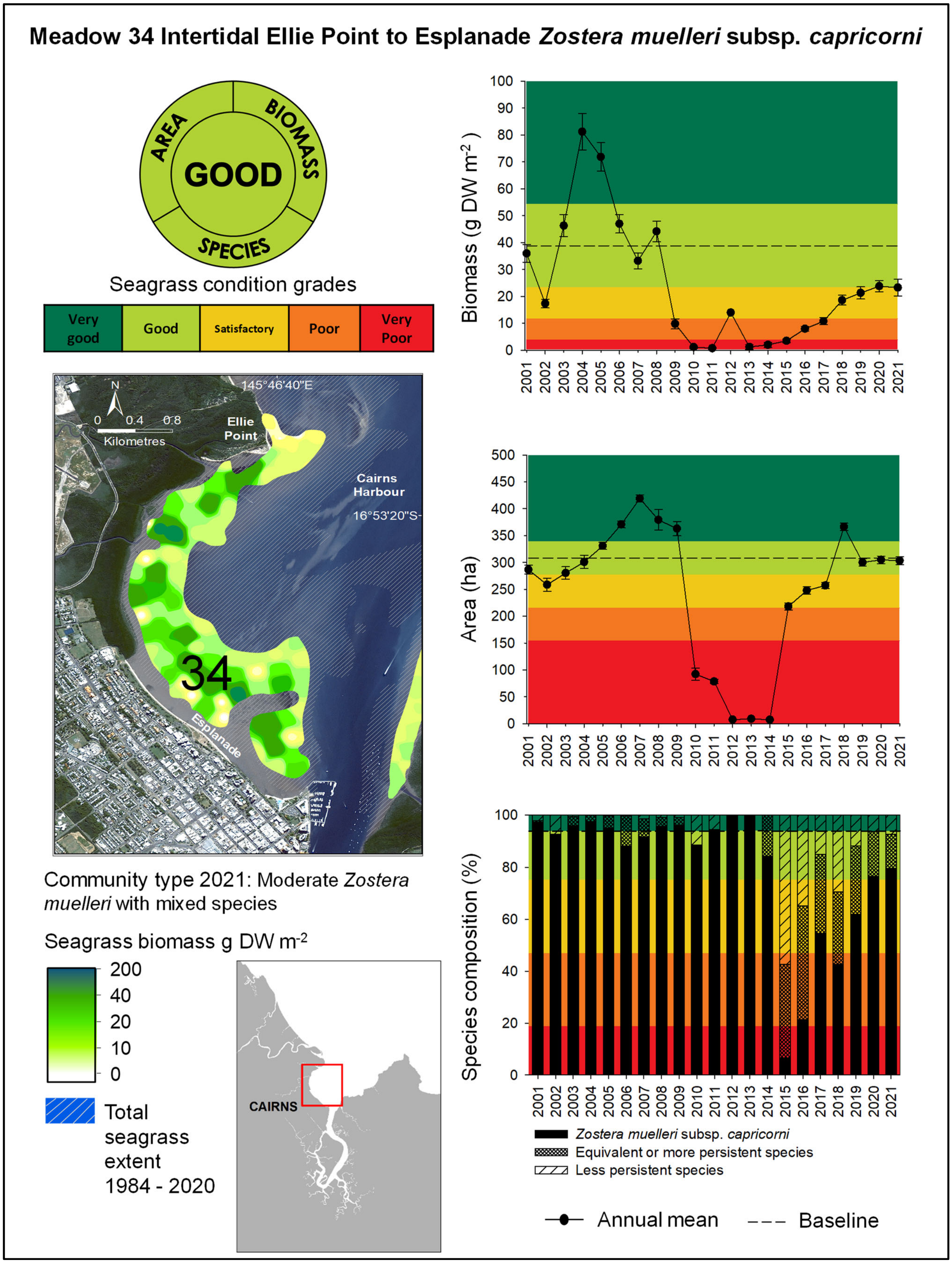


Figure 14: Changes in biomass, area and species composition for the Esplanade meadow (meadow no. 34) from 2001 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

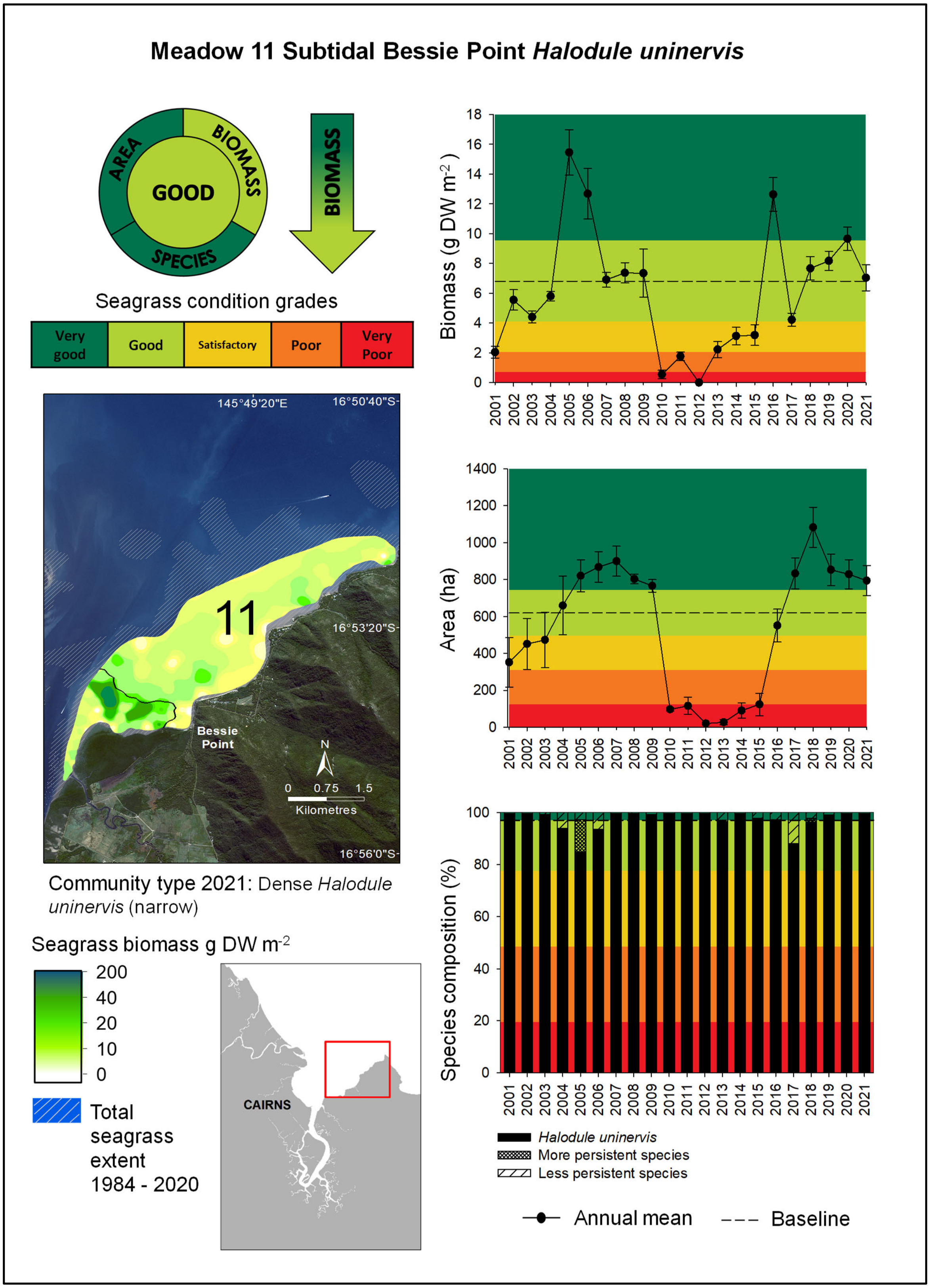


Figure 15: Changes in biomass, area and species composition for the Bessie Point (meadow no. 11) meadow from 2001 – 2021 (biomass error bars = SE; area error bars = “R” reliability estimate).

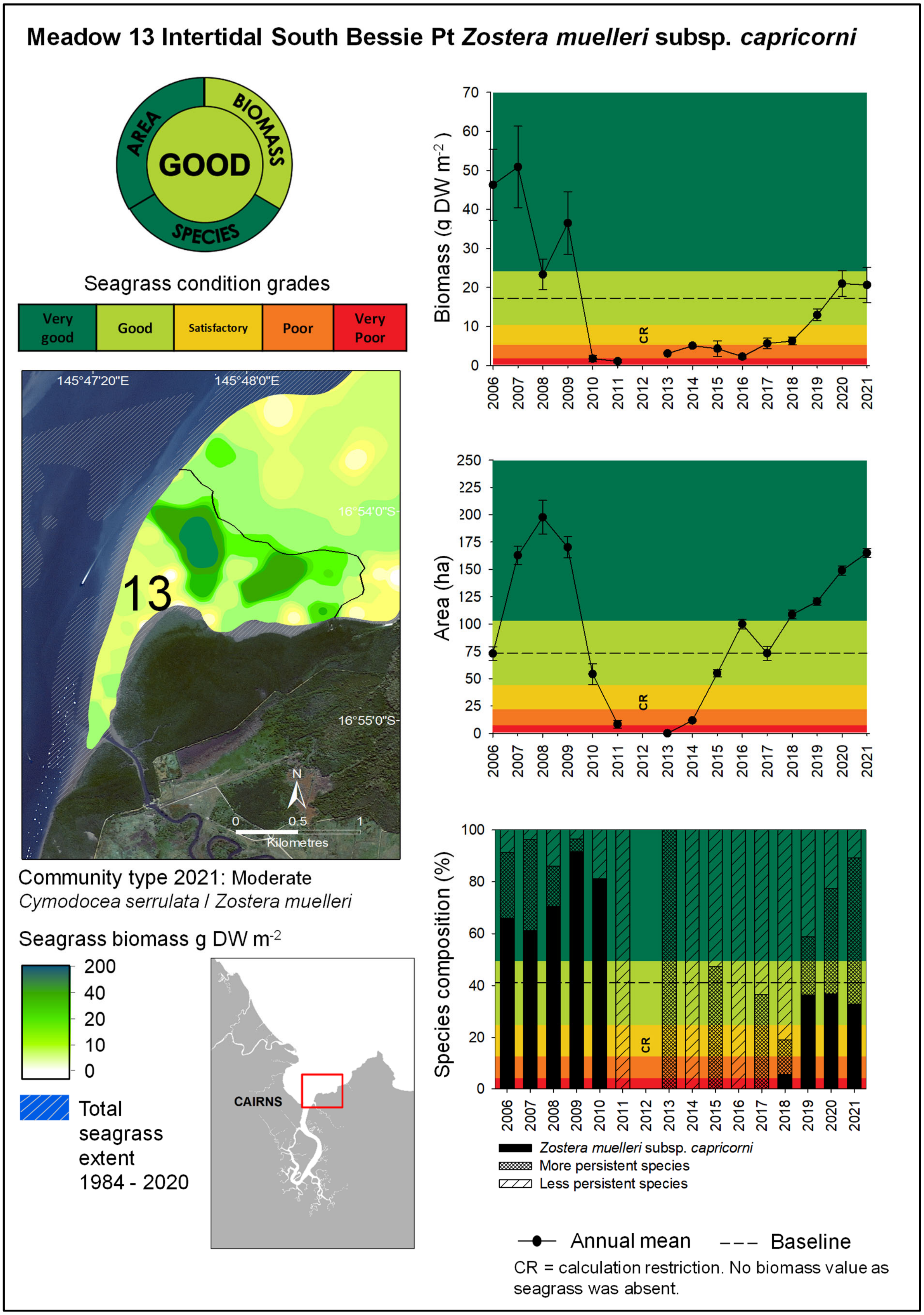


Figure 16: Changes in biomass, area and species composition for the South Bessie Point (meadow no. 13) meadow from 2006 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

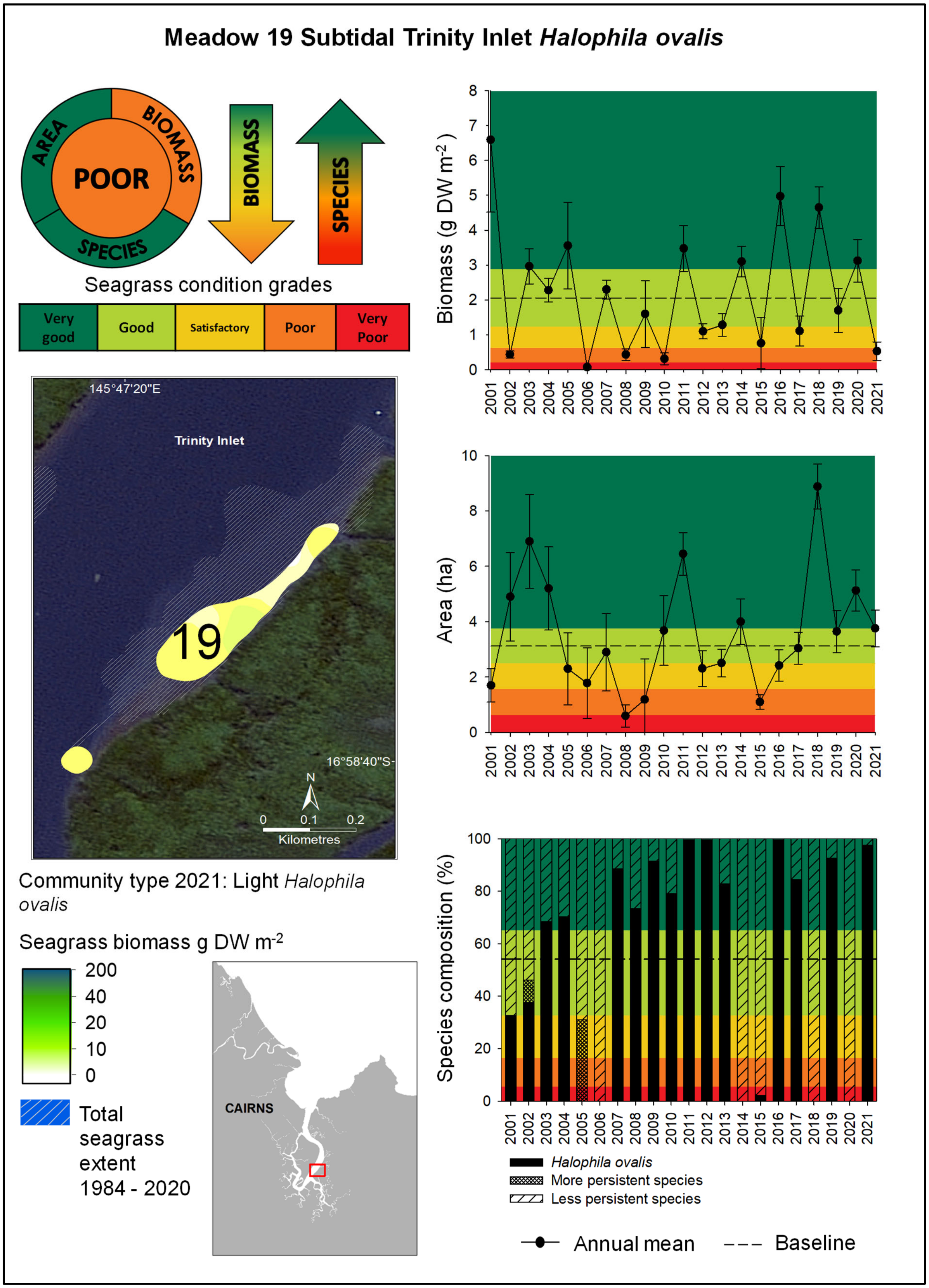


Figure 17: Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow 19) from 2001 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

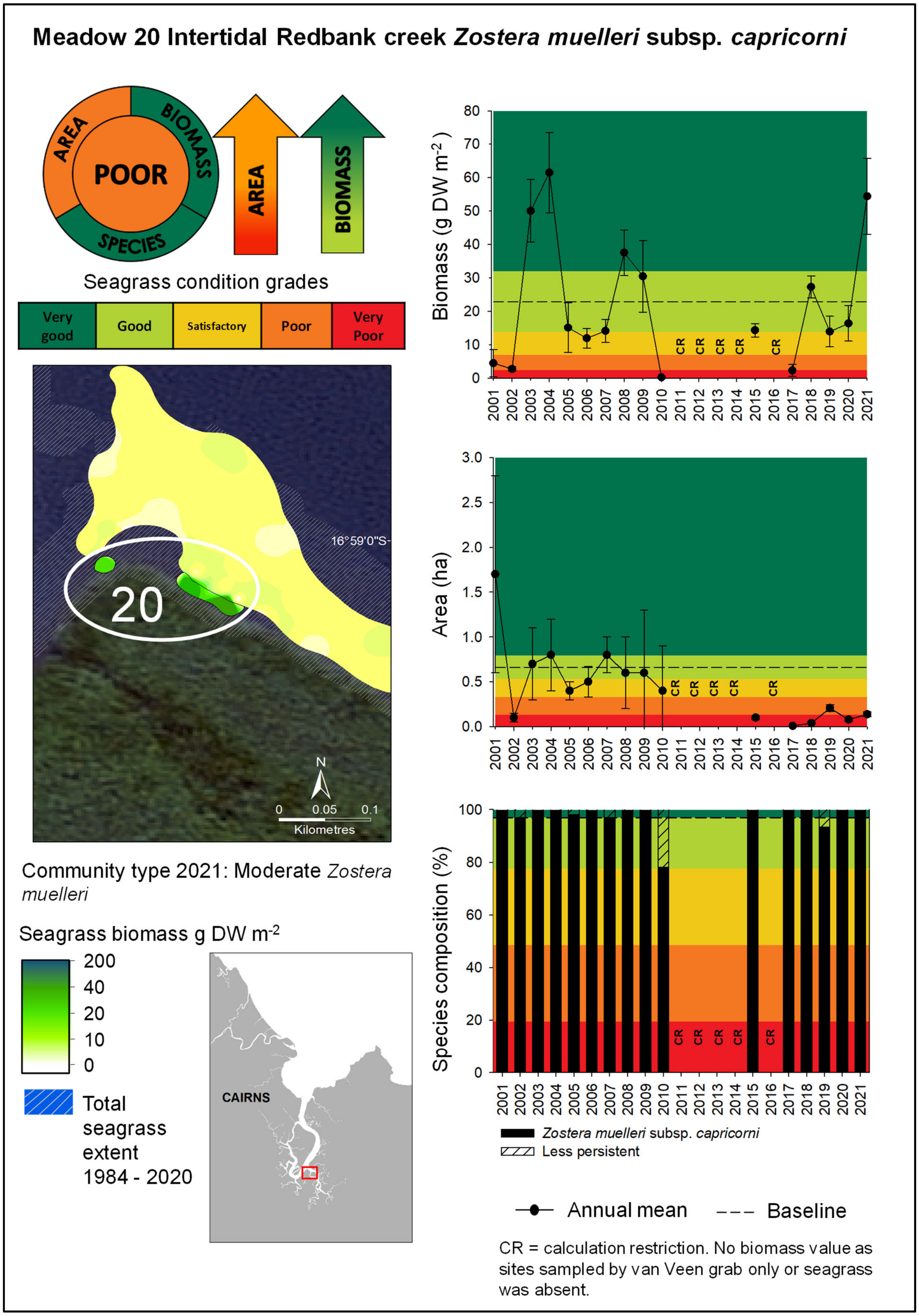


Figure 18: Changes in biomass, area and species composition for the Trinity Inlet *Zostera* meadow (meadow no. 20) from 2001 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

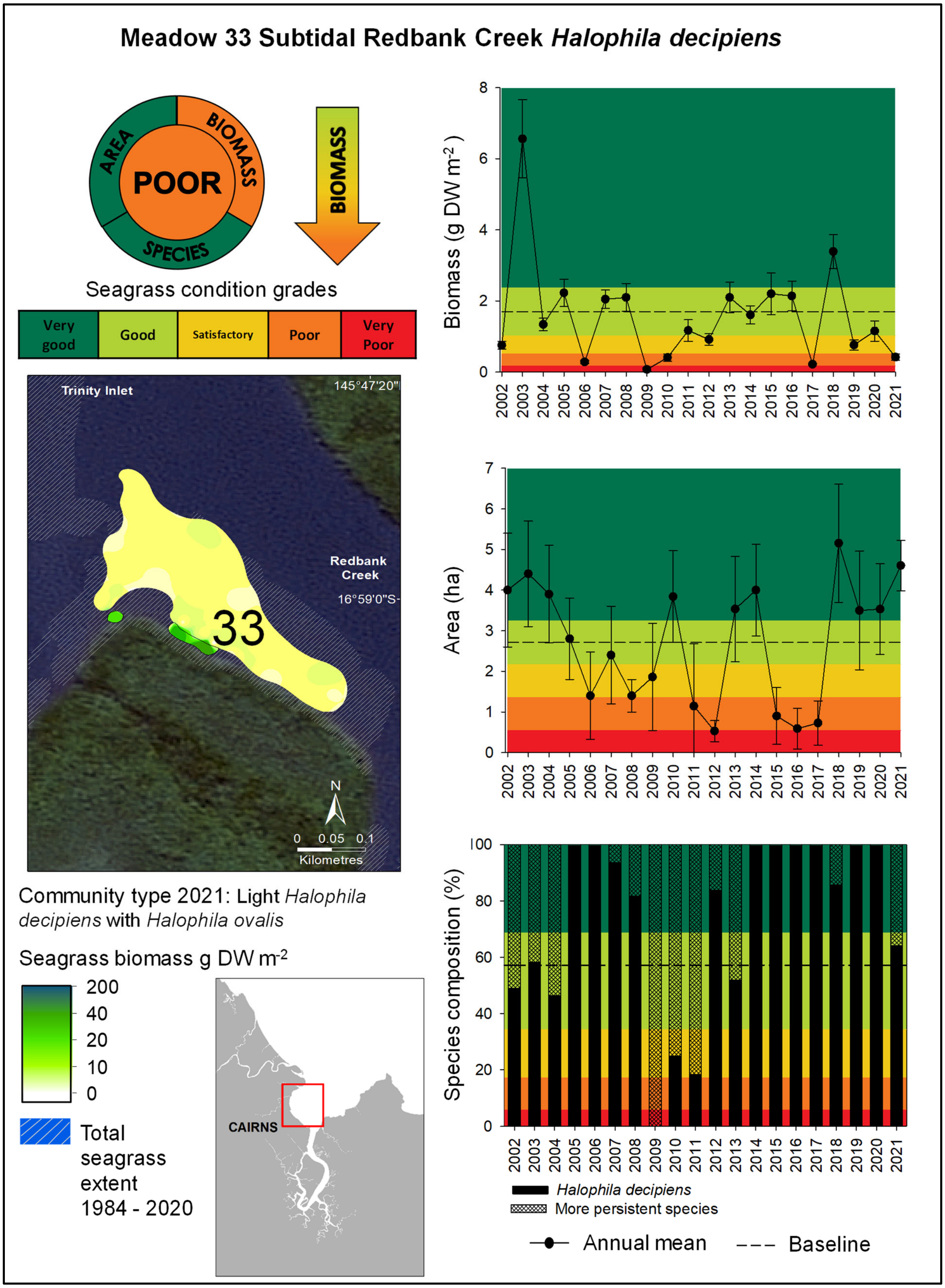
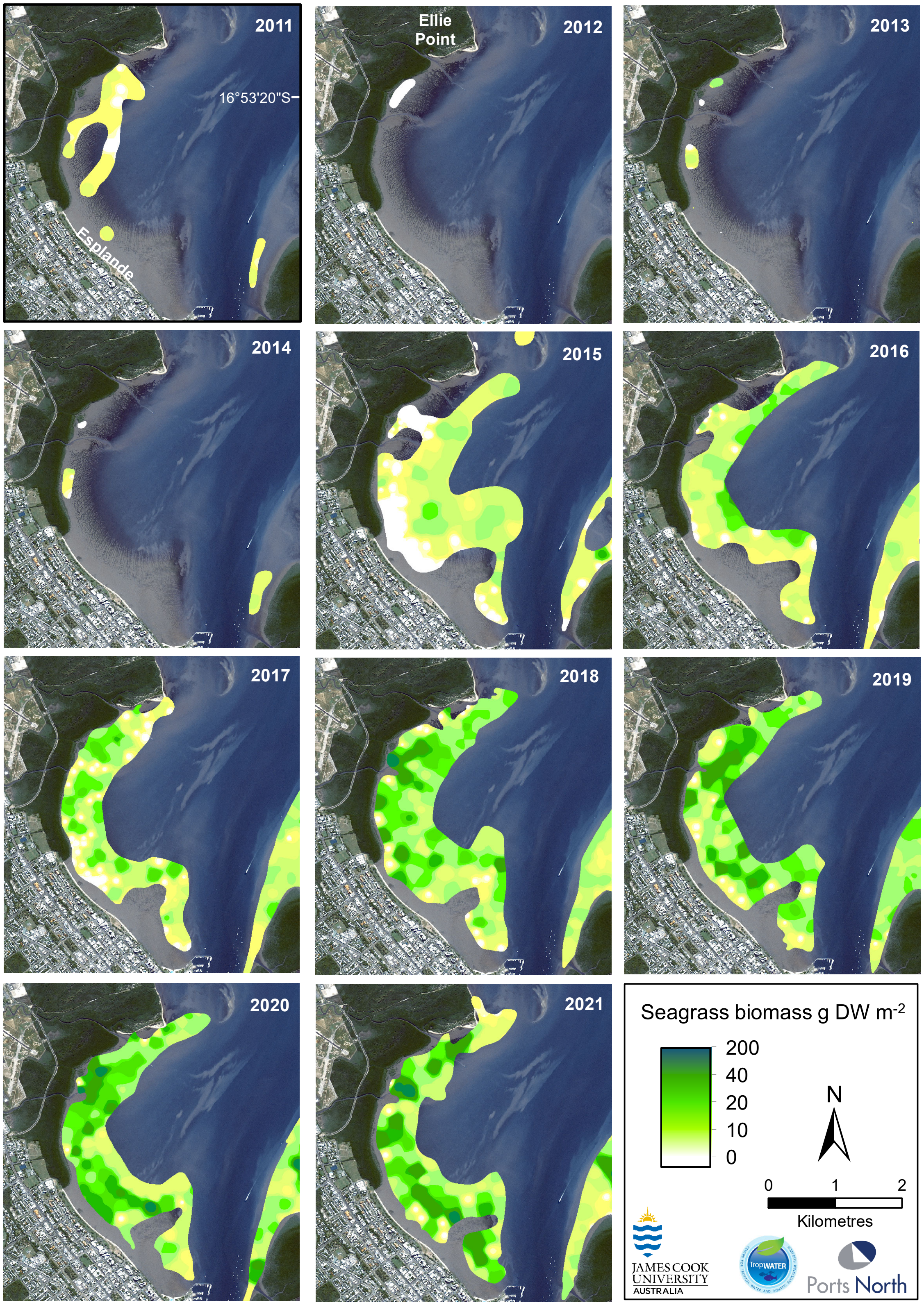
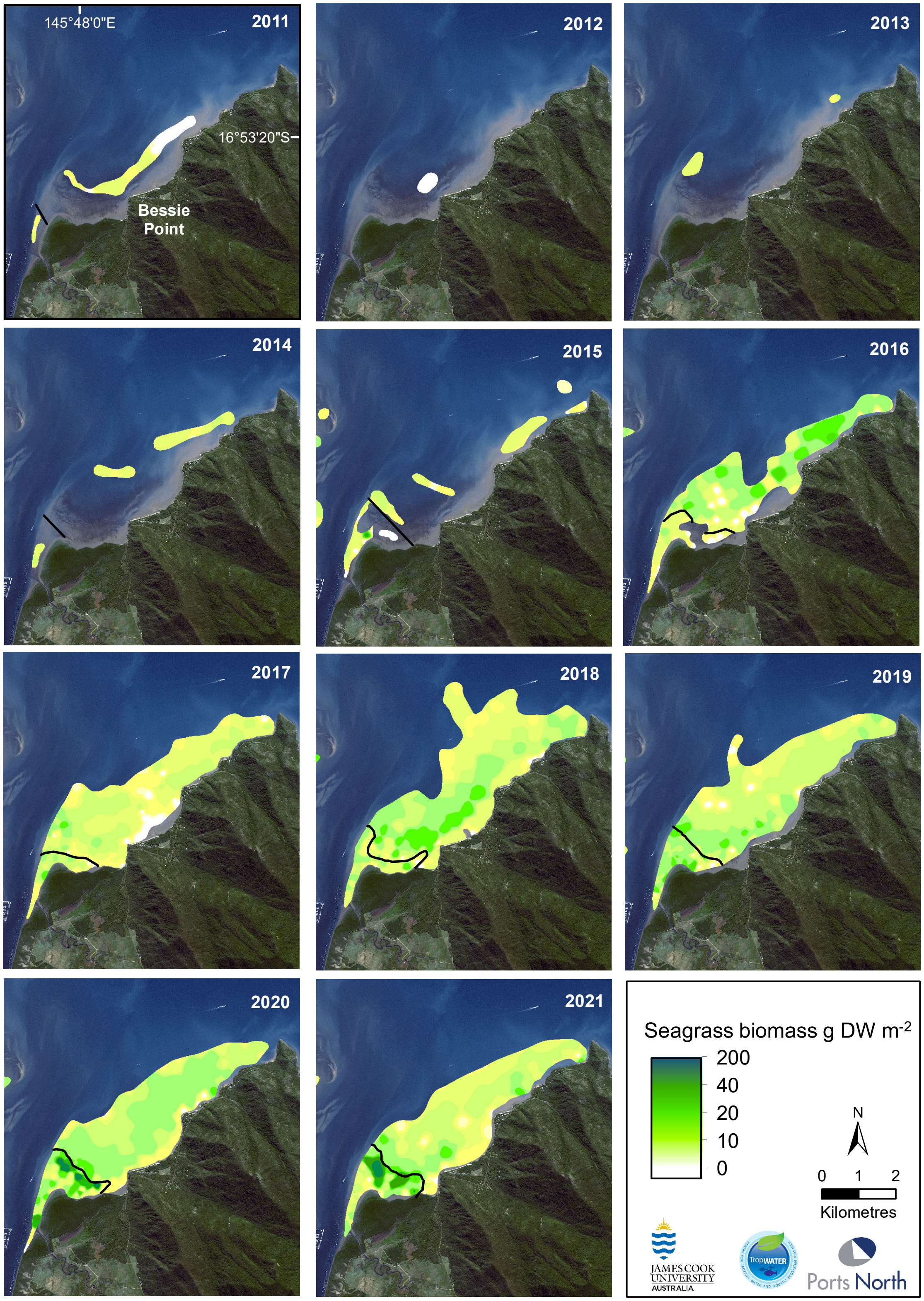


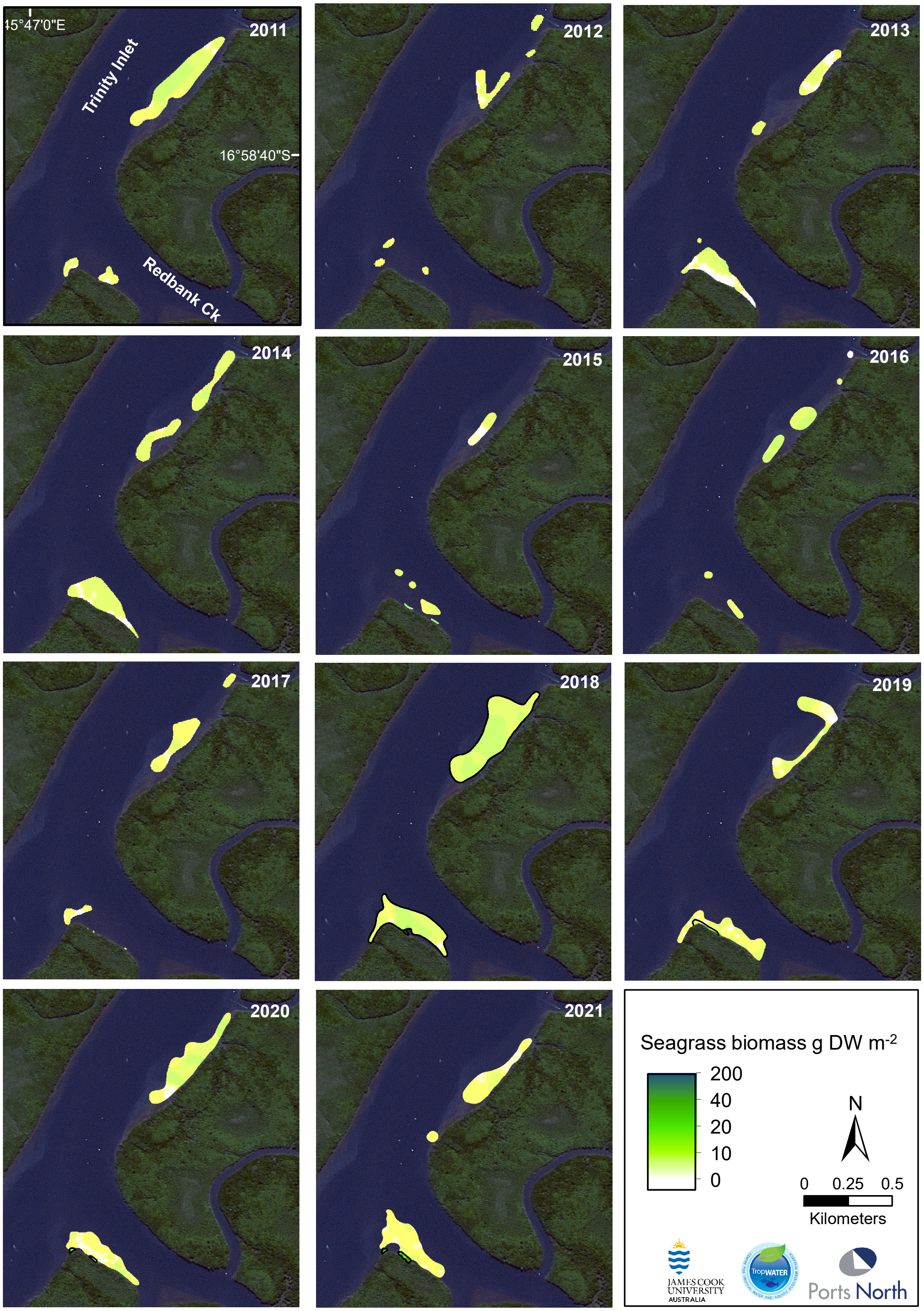
Figure 19: Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow 33) from 2002 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).



Map 8: Esplanade to Ellie Point seagrass monitoring meadows from 2009 to 2021.



Map 9: Bessie Point and South Bessie Point seagrass monitoring meadows from 2009 to 2021.



Map 10: Trinity Inlet seagrass monitoring meadows from 2009 to 2021.

3.2.4 Seagrasses in the broader Cairns area

In 2021, total seagrass area within the broader Cairns region declined slightly to 1,488 ha (Figure 20). The highest recorded area for whole of port was 1,960 ha in 2018 and while the footprint in 2021 is lower it remains has remained in the upper range of historical values over the past 4 years (Figure 20).
An additional 10 seagrass meadows were mapped outside of the six regular annually assessed long-term monitoring meadows in the broader Cairns Harbour and Trinity Inlet region. These comprised three meadows in the Cairns Harbour region and six small meadows in the Trinity Inlet region (Map 7a and 7b; Table 8).

The larger meadow on the western side of the Cairns Harbour (Meadow 5) was a deeper, subtidal, *Halodule uninervis* dominant meadow adjacent to the Esplanade Meadow (34). There were three other smaller subtidal meadows, two of which (Meadow 4) and (Meadow 25) were also dominated by *Halodule uninervis*, and (Meadow 3) in the mouth of the Barron river with isolated patches of *Zostera muelleri* (Map7a; Table 8).

There were five smaller meadows in the Trinity Inlet consisting of isolated patches of colonising species *Halophila decipiens* and *Halophila ovalis* (Map7b; Table 8). The isolated patch of *Zostera muelleri* on the western bank of Admiralty Island remained intact for the third year in a row (Meadow 43) (Map7b; Table 8).

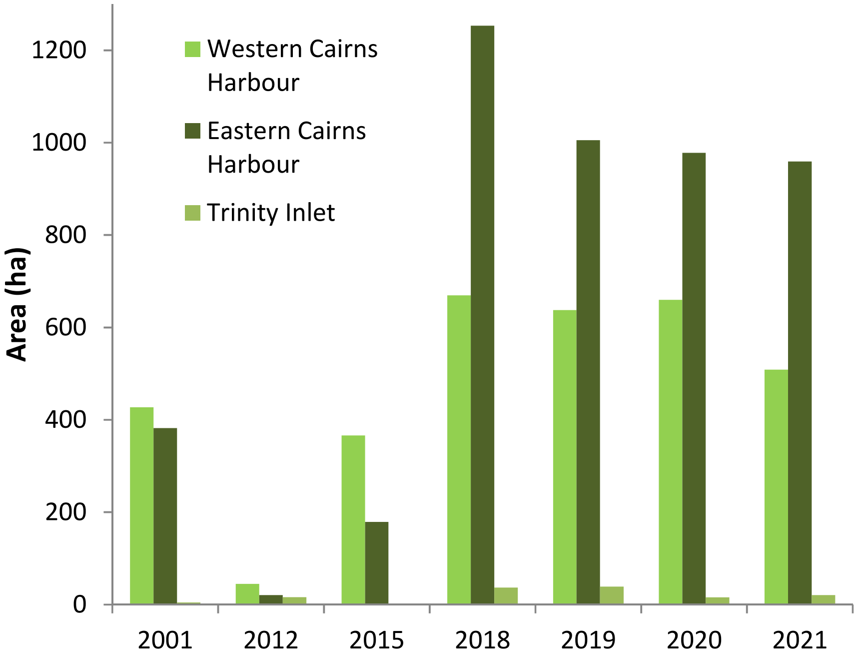


Figure 20: Comparison of total seagrass area (hectares) in the broader Cairns region, for western and eastern Cairns Harbour and Trinity Inlet in 2001, 2012, 2015, 2018, 2019, 2020 and 2021.

Table 8: Description of Cairns Harbour and Trinity Inlet seagrass baseline non-monitoring meadows in 2021.

Meadow		**Location**	**Meadow ID**	**Number of Sites**	**Meadow Area (ha) ± (R)**	**Habitat Type**	**Meadow Cover**	**Meadow Description**
Baseline Non-Monitoring Meadows	**Barron River Mouth**	Cairns Harbour	3	2	0.34 ± 0.05	Subtidal	Isolated patches	Light *Zostera muelleri*
	Harbour	Cairns Harbour	4	1	4.85 ± 0.83	Subtidal	Isolated patches	Dense *Halodule uninervis*
	Esplanade - Ellie Point	Cairns Harbour	5	45	192.43 ± 23.33	Intertidal to Subtidal	Continuous cover	Moderate *Halodule uninervis* (narrow) with *Halophila ovalis*
	Ellie Point Inlet	Cairns Harbour	25	5	7.70 ± 0.85	Subtidal	Isolated patches	Moderate *Halodule uninervis* (narrow) / *Halophila ovalis*
	Inlet 1	Trinity Inlet	39	6	3.26 ± 0.76	Intertidal to Subtidal	Continuous cover	Light *Halophila ovalis* with *Halophila decipiens*
	Inlet 2	Trinity Inlet	41	1	0.33 ± 0.11	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 3	Trinity Inlet	42	1	0.34 ± 0.02	Subtidal	Isolated patches	Light *Halophila decipiens*
	Inlet 4	Trinity Inlet	43	1	0.02 ± 0.005	Intertidal to Subtidal	Isolated patches	Moderate *Zostera muelleri*
	Inlet 5	Trinity Inlet	45	13	7.93 ± 1.54	Subtidal	Continuous cover	Light *Halophila decipiens*
	Inlet 6	Trinity Inlet	57	3	0.23 ± 0.03	Subtidal	Isolated patches	Light *Halophila decipiens*

3.3 Seed bank assessment

In April 2021, no viable *Zostera muelleri* seeds were found in Cairns Harbour, however 27.60 ± 7.27 seeds m^{-2} were found, a significant increase on last year (Table 9). This was third year that seeds have been sampled at the more expansive meadow scale, and is only slightly lower than the highest density of seeds recorded at the smaller 50 x 50m Site E of 28.8 ± 7.4 seeds m^{-2} in April 2018 (Table 9).

Over the past three 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 10). The *Halodule uninervis* seed numbers increased in both meadows between 2020 and 2021 (Table 10).

Table 9: Mean Cairns Harbour and Trinity Inlet 2014-2021 *Zostera muelleri* seed bank density and viability (seeds m^{-2}) per month at Site E.

Sampling Scale	Month	Mean Total seeds m^{-2}	Viable seeds m^{-2}
Assessments at 50 x 50m Esplanade "Block E"	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
Assessments at meadow scale	April 2019	9.81 ± 4.79	0
	April 2020	3.68 ± 1.71	0.63 ± 0.64
	April 2021	27.60 ± 7.27	0

NA = not assessed.

Table 10: Mean Cairns Harbour 2019-2021 *Zostera muelleri* and *Halodule uninervis* seed bank density at the Esplanade meadow (34) and Bessie Point (11).

Month	Location	***Zostera muelleri*** **Mean Total seeds m^{-2}**	***Halodule uninervis*** **Mean Total seeds m^{-2}**
April 2019	Esplanade meadow	9.81 ± 4.79	10.8 ± 4.79
	Bessie Point Meadow	0	105.1 ± 27.87
April 2020	Esplanade meadow	3.68 ± 1.71	4.43 ± 2.21
	Bessie Point Meadow	0	71.54 ± 20.9
April 2021	Esplanade meadow	27.60 ± 7.27	18.36 ± 9.74
	Bessie Point Meadow	0	84.83 ± 23.54

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 mol m^{-2} day^{-1} over a 2 week average; Chartrand et al. 2016) since continuous logging began at the Esplanade site E in June 2014 (Figure 21). During January in 2021 light dropped below the *Zostera muelleri* threshold for a brief period before returning to above threshold levels. Since completion of the dredging phase of the CSDP, monitoring of the Esplanade meadow (34) has returned from quarterly to annual assessments and is what is displayed as an indicator of seagrass condition on the below plot (Figure 21). In 2021 the maximum benthic water temperatures were cooler than the previous year with a peak in temperature of 42^{o}C occurring in July (Figure 21).

In parallel with this long term monitoring program, Ports North enacted a Dredge Management Plan for the CSDP capital dredging work, which included a reactive monitoring program where both water quality and light triggers and limits were in place to protect seagrasses during the June to September 2019 works period. Throughout that period, the project maintained light above the compliance levels, and achieved suitable benthic light environment for local seagrasses and the continued good to very good condition of the CSDP seagrass meadows.

The Esplanade site E light logging site showed PAR dip below seagrass growth thresholds in January 2021 but then remain above the threshold providing ideal light conditions for the rest of the year. 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 May 2021 (Figure 22). The Redbank Creek PAR site has shown light is consistently below growth thresholds for higher light requiring species 6 months from March to August but probably sufficient for low light requiring species such as *Halophila decipiens* (Figure 22).

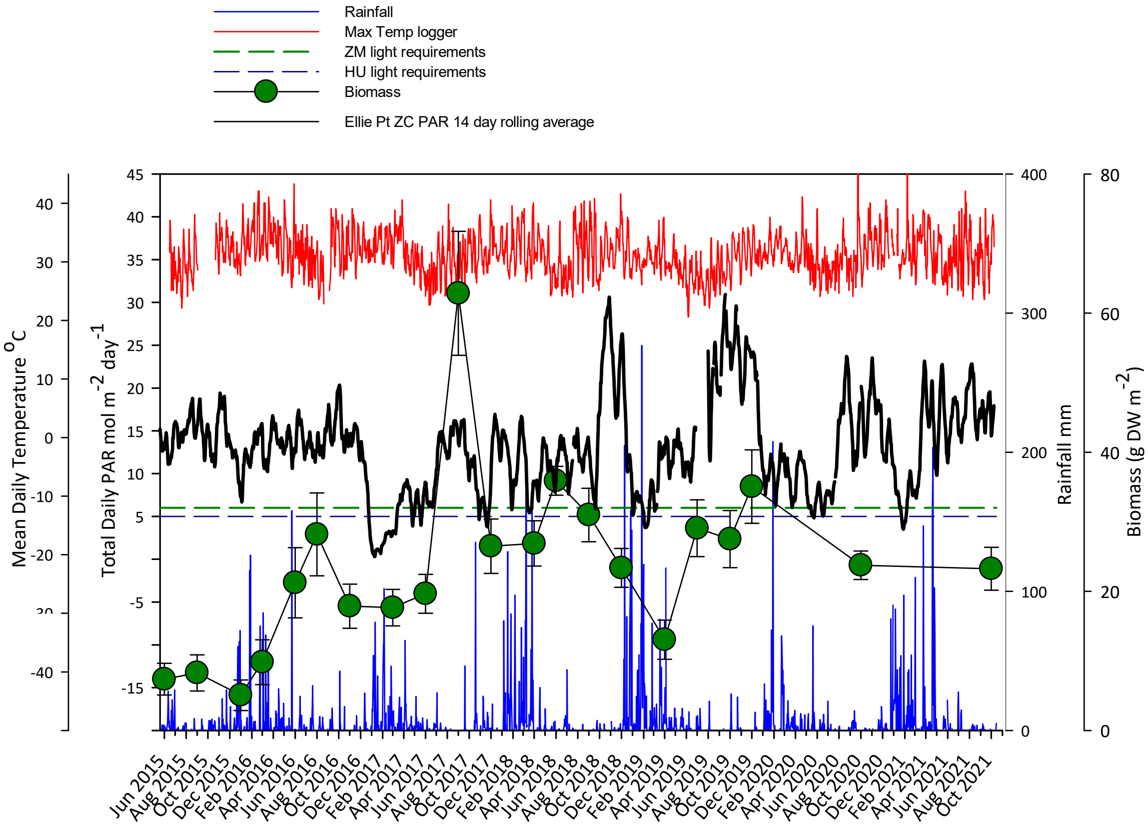


Figure 21: Total daily irradiance (mol m^{-2} day^{-1}), mean daily temperature (° C), and total daily rainfall (mm) and biomass (g DW m^{-2}) for the intertidal Cairns Harbour quarterly monitoring Site E, October 2021 biomass is Meadow 34. All data is from June 2015 to December 2021. Daily rainfall data source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

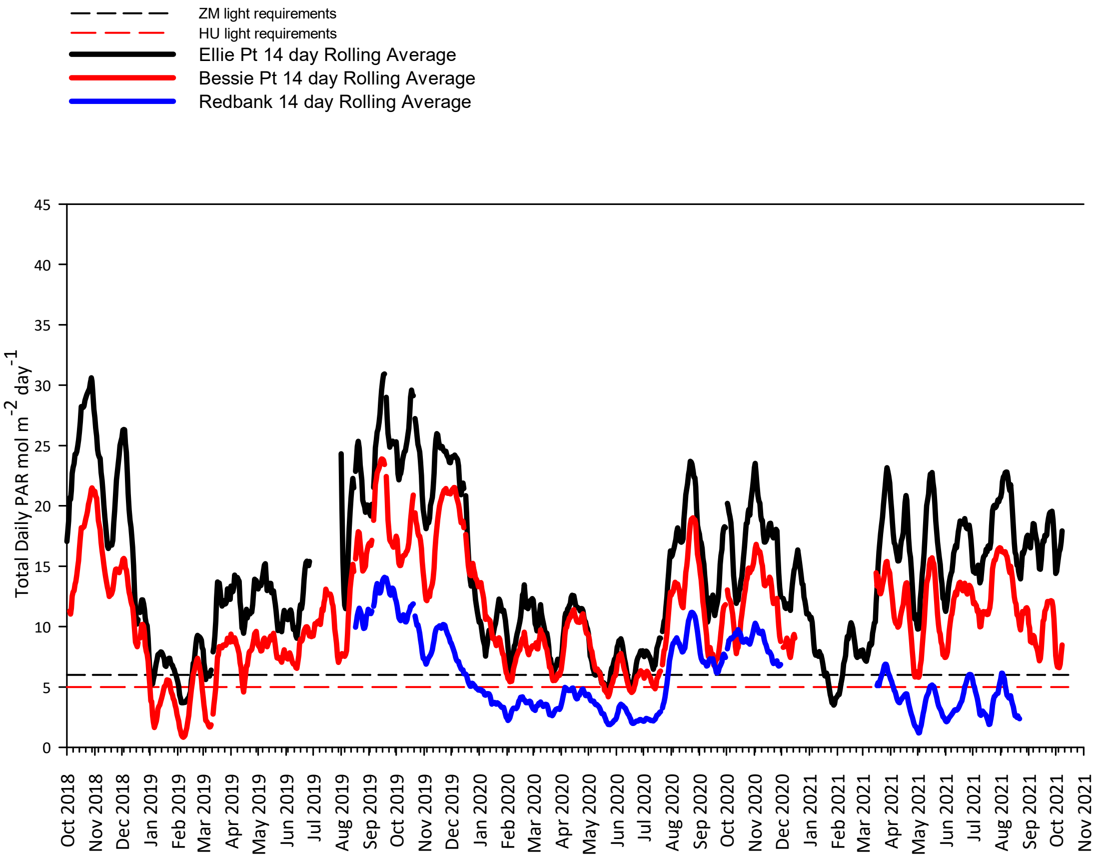


Figure 22: 14 day rolling average of total daily PAR (mol m^{-2} day^{-1}), for the three PAR monitoring stations in Cairns Harbour and Trinity Inlet in relation to seagrass light thresholds from October 2018 to December 2021.

3.5 Cairns environmental conditions

3.5.1 Rainfall

In 2021 the total annual rainfall in the Cairns region was 2586 mm, significantly above the long-term average (1990 mm) (Figure 23). Rainfall was below average for most of the year apart from a large peak in April and smaller peaks in January and July (Figure 23). The months leading up to the survey showed minimal rainfall two months prior to the survey (Figure 23).

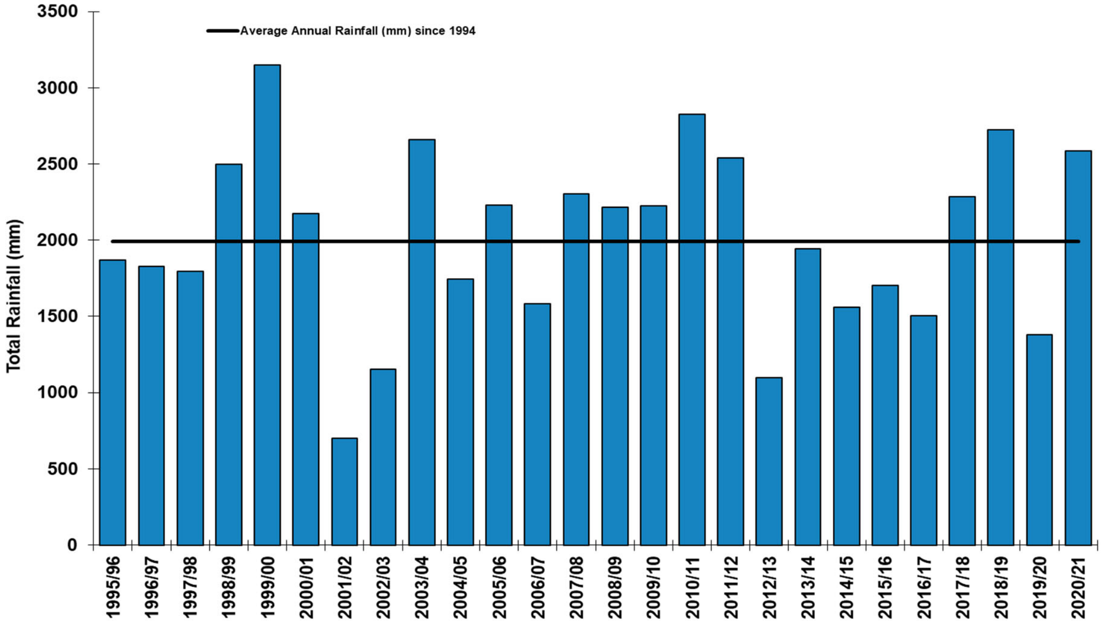


Figure 23: Total annual rainfall (mm) recorded at Cairns Airport, 1995 – 2021. Twelve month year (2020/21) is 12 months prior to survey. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

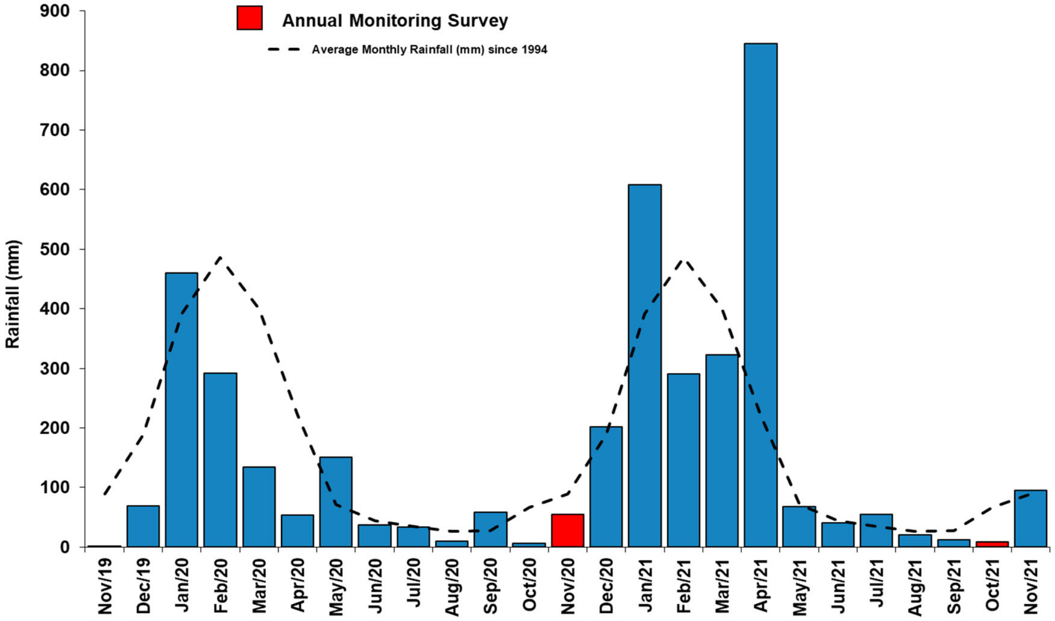


Figure 24: Total monthly rainfall (mm) recorded at Cairns Airport, November 2020 – November 2021. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

3.5.2 River Flow (Barron River)

River flow of the Barron River in 2020/2021 (513,281 ML) was below the long-term average of approximately 693,000 ML (Figure 25). River flow was below average for the entire year in 2020, while in April 2021, it was more than double the monthly average and the two months prior to the 2021 survey river flow was also above the long-term average (Figure 26).

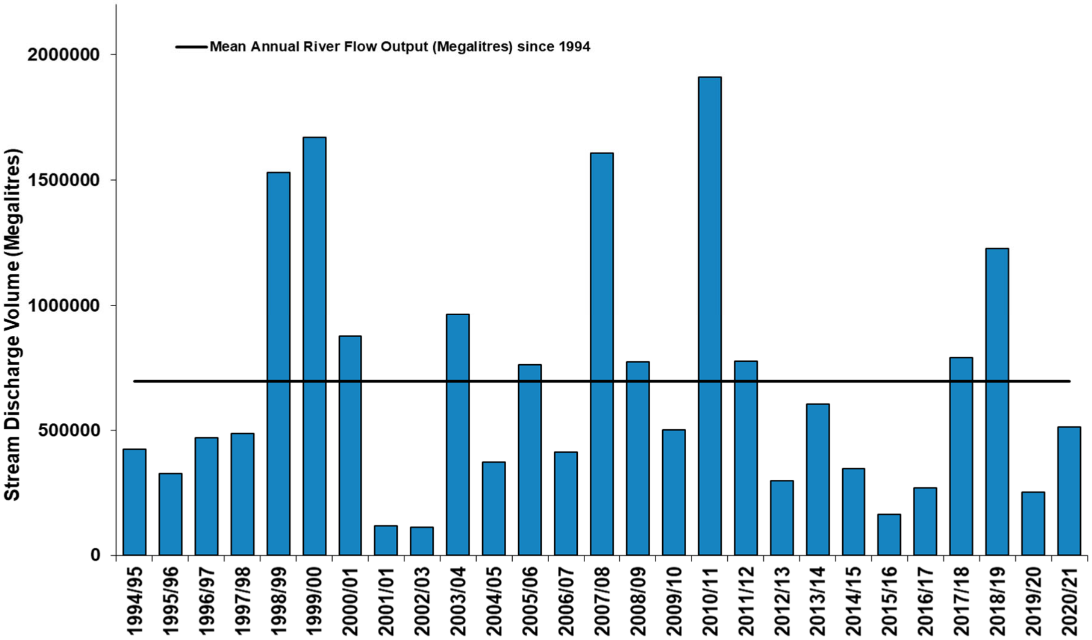


Figure 25: Annual water flow (mega litres) for the Barron River recorded at Myola, 1995 – 2021. Twelve month year (2020/21) is 12 months prior to survey. Source: Queensland Department of Environment and Resource Management, Station 110001D, available at: http://watermonitoring.derm.qld.gov.au/host.htm

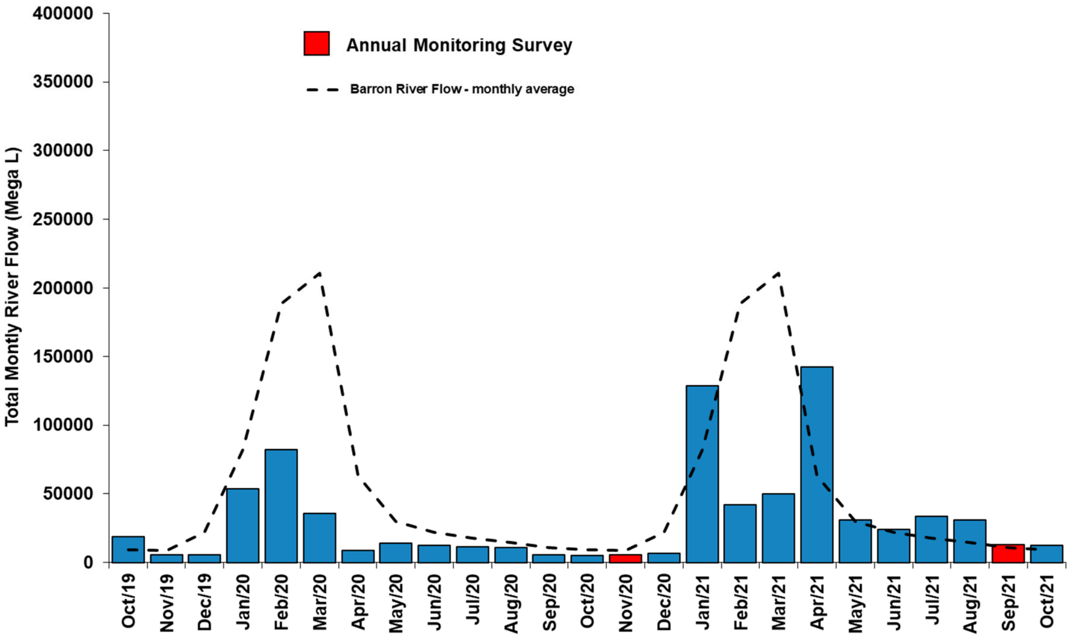


Figure 26. Monthly water flow (mega litres) for the Barron River recorded at Myola, October 2019 to December 2021. Source: Queensland Department of Environment and Resource Management, Station 110001D, available at: http://watermonitoring.derm.qld.gov.au/host.htm

3.5.3 Air Temperature

Annual maximum daily air temperature recorded at Cairns Airport was approximately 0.5°C above the long-term average (29.4°C) (Figure 27). In 2021, the 4 months prior to the survey were above the long-term average monthly maximum air temperature (Figure 28).

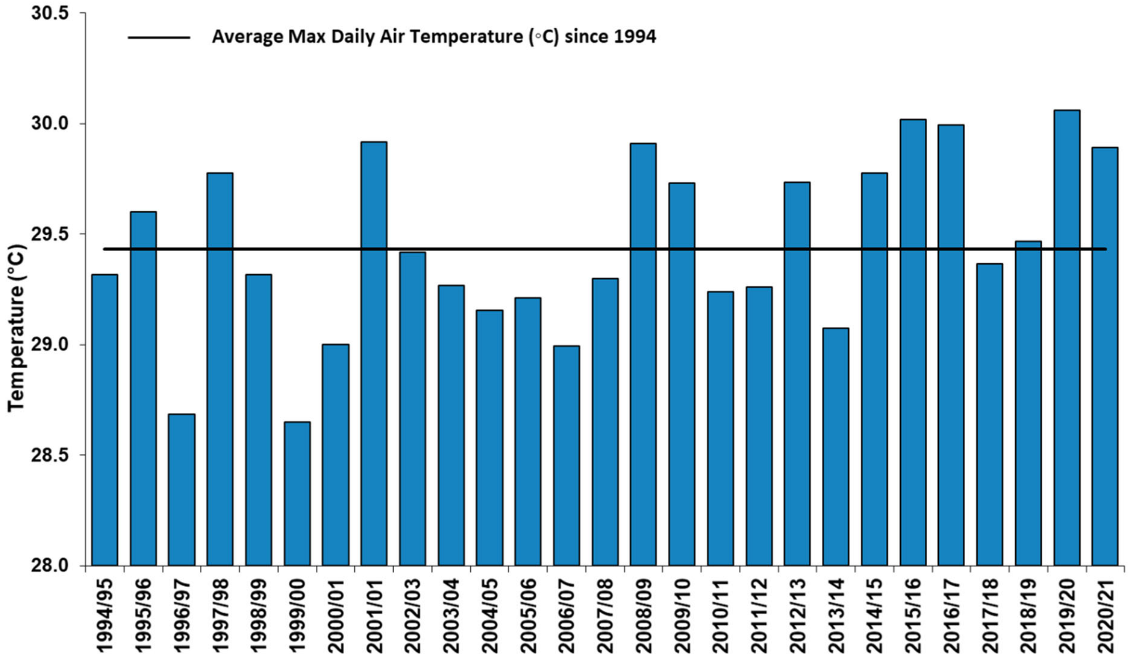


Figure 27: Mean annual maximum daily air temperature (°C) recorded at Cairns Airport, 1994 – 2021. Twelve month year (2020/21) is 12 months prior to survey. Source: Bureau of Meteorology, Station 031011, available at: www.bom.gov.au.

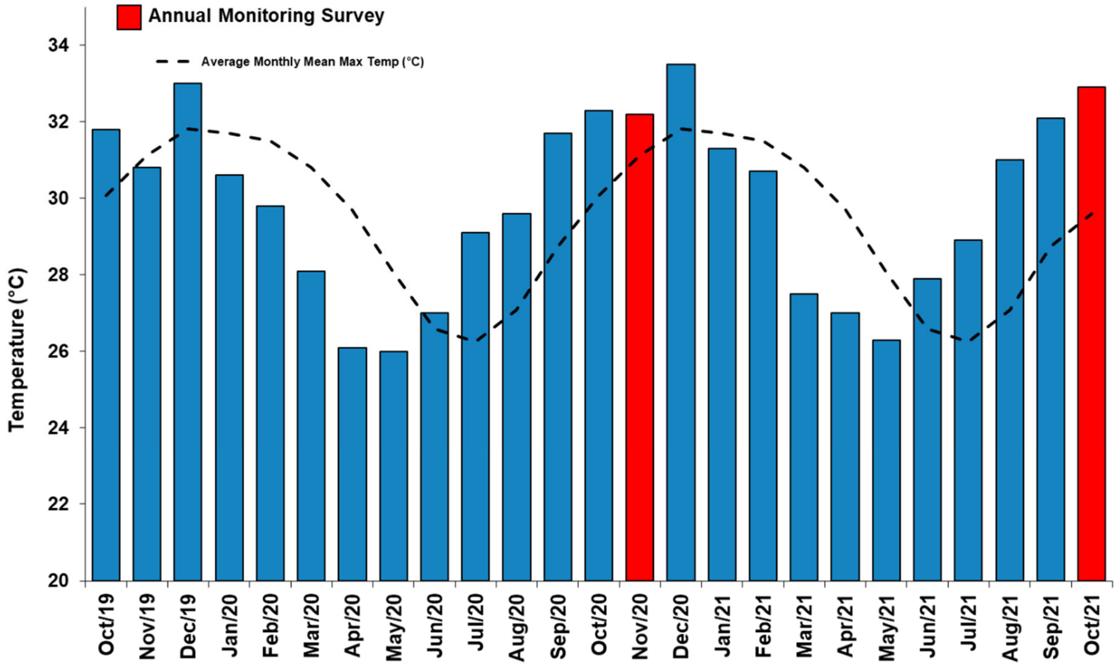


Figure 28: Monthly mean maximum daily air temperature (°C) recorded at Cairns Airport, October 2019 – October 2021. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

3.5.5 Tidal Exposure of Seagrass Meadows

Annual daytime tidal air exposure of intertidal meadows was the lowest in 7 years and below the average recorded (252 hrs) (Figure 29). October, the survey month, was the only month during 2021 that the intertidal areas in Cairns Harbour were exposed above the monthly average (Figure 30).

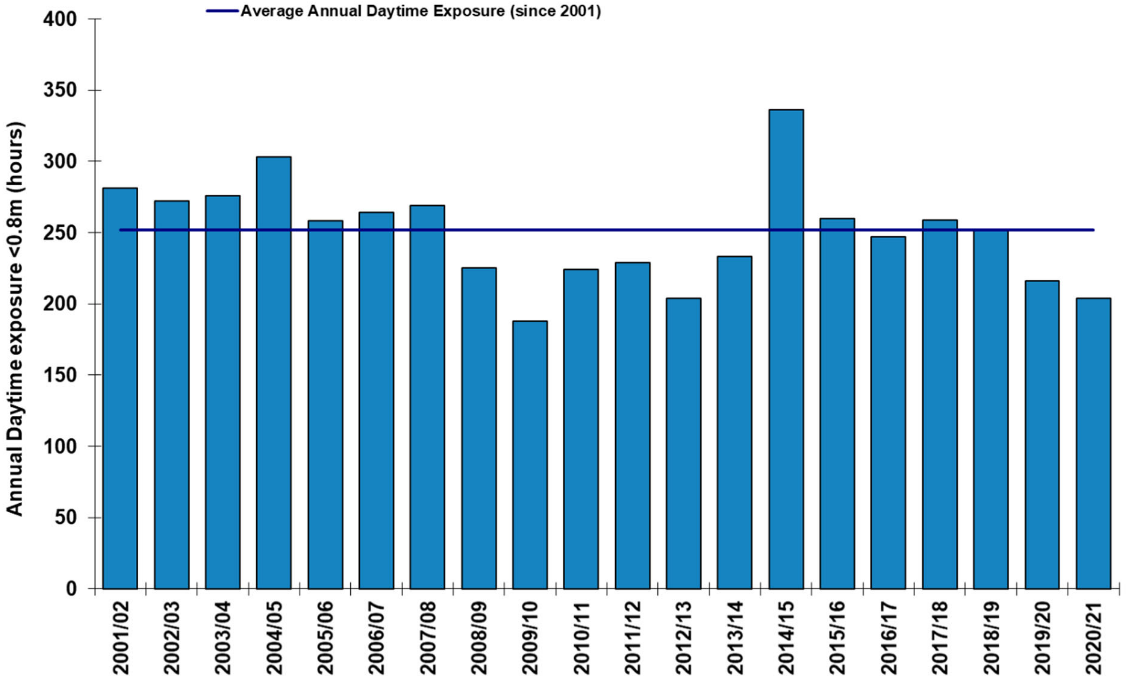


Figure 29: Annual daytime tidal exposure (total hours)* of seagrass meadows in Cairns Harbour; 2001 - 2021. Twelve month year is 12 months prior to survey. Source: Maritime Safety Queensland, 2020. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

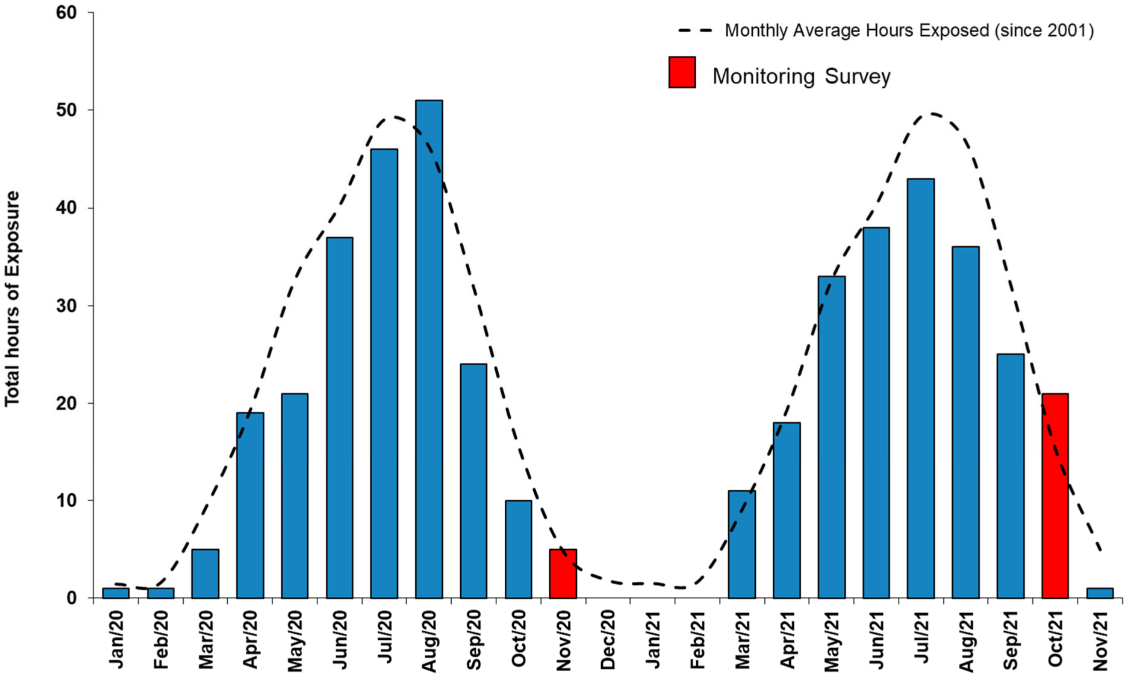


Figure 30: Total monthly daytime tidal exposure (total hours)* in Cairns Harbour; January 2018 – December 2021. Source: Maritime Safety Queensland, 2019. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

4 DISCUSSION

The seagrass meadows in Cairns Harbour and Trinity Inlet have continued their long trajectory of recovery following catastrophic climate related losses over a decade ago. This steady recovery of seagrass habitats in the area is no doubt contributing to a return of the important ecosystem services they provide such as fisheries habitat, carbon storage and coastal protection. In 2021, seagrasses in the Cairns region were generally in a robust or improving condition. The footprint of the monitoring meadows has stabilised over the past 3 years and remains well above the long-term average. Overall biomass of the monitoring meadows is still below the long-term baseline average, but there has been a continued upward trend each year since 2017. Looking more closely, the large meadows in Cairns Harbour were all in a good and stable condition. The much smaller Trinity Inlet meadows are more variable with the two dominated by ephemeral species having a large year to year variation and the intertidal meadow of larger growing species showing good signs of improvement following its complete absence between 2010 and 2015. Two years post the CSDP operation there have been no negative impacts on the adjacent intensive monitoring meadows. The broader port wide seagrass assessments mapped 1,488 ha of seagrass maintaining a substantial footprint of seagrasses within the greater port limits. The seed bank in the harbour meadows increased in 2021, however none of the seeds tested were viable.

All three monitoring meadows in Cairns Harbour were rated as good in 2021 due to healthy scores across all condition indicators. The Cairns Harbour meadows have shown continual improvement over the last 10 years and the strongest indicator of this is the very good condition for area and species in the meadows on the eastern side of the harbour. All meadows are now dominated by large, more persistent species traditionally found in each meadow (*Z. muelleri*, *C. serrulata*, *H. uninervis* depending on the meadow).

The smaller Trinity Inlet meadows have been far more variable over time and are collectively rated as poor in 2021. While the *Z. muelleri* meadow (20) had a footprint below its long-term average in 2021, the biomass was well above the long-term average and the highest recorded since 2004. 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 2021 must have been favourable for its growth. Its improvement over the past two years is significant given it was completely lost and absent between 2010 and 2015. The two subtidal monitoring meadows in the inlet 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. A shift in species in 2021 with *H. ovalis* increasing in dominance potentially indicates improved light conditions, however there was a significant reduction in biomass compared to the previous year. The light monitoring at the Redbank Creek PAR station indicates that the light environment was much better in 2020 during the period leading up to the surveys than in 2021 possibly explaining this difference. 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.

Regional and local climate conditions are strong drivers of seagrass condition in tropical North Queensland (McKenna et al. 2015; Rasheed et al. 2014). 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 has now been monitored at the Redbank subtidal meadow in the inlet for 24 months 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;* 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 species (see Chartrand et al. 2016; Collier et al. 2016). This confirms light as one of the main factors driving differences in species composition between Cairns Harbour and Trinity inlet. In 2021, Cairns received above average rainfall, however, most of this occurred during a short period in April and didn't extend long enough for a prolonged decline in the light environment. This provided favourable growing conditions which is reflected in the increased seagrass biomass, area and presence of larger higher light requiring species such as *Z. muelleri* and *C. serrulata*.

In the last three 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. The shift to sampling over larger meadow scale showed a reduction in seed-bank density initially, however in 2021 seed density increased to be close to that seen in 2018 and was comparable to meadows of the same species in southern Queensland (Conacher et al. 1994a; Conacher et al. 1994b). While seed numbers had improved, none of the *Zostera muelleri* seeds tested in 2021 were in a viable condition. It is unclear at this stage the reason for this. Potentially the seeds were older than 12 months and may indicate a lack of a successful flowering/fruiting season in late 2020. Alternatively, environmental conditions may have led to rapid deterioration of seed condition. 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).

This monitoring campaign and report marks the completion of the post CSDP annual and whole of port scale monitoring assessments of key seagrass meadows, however these meadows remain part of the long-term seagrass monitoring strategy for Cairns and therefore revert back to being included in the regular monitoring cycle from 2022 onwards. The potential for delayed impacts to seagrass from the CSDP is now highly unlikely, due to the actions implemented as part of the dredge management plan to ensure PAR and water quality more than met growing requirements of seagrasses. The fact that seagrasses were in the best condition of the past decade at the end of the dredging activity and have remained in a good condition two years later indicates they were resilient to the CSDP activities and are well placed to continue to thrive with the continuation of favourable growing conditions.

In the broader Queensland monitoring network, seagrass condition has mostly shown similar trends of improved condition. Seagrass in the Gulf of Carpentaria in Weipa and Karumba were in a good and very good condition due to favourable climate conditions (McKenna et al. 2021; Scott et al. 2022). 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. 2022). However, Mourilyan Harbour, the closest monitoring location to Cairns Harbour, has remained in a very poor condition for the second year in a row 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). The seagrass condition observed in 2021 for Cairns Harbour highlights a continued trajectory 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.

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6 APPENDICES

Appendix 1. Seagrass Condition Index

Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (2001–2011). This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014). The 2001–2011 period incorporates a range of conditions present in Cairns Harbour, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events (Carter et al. 2015a). In some cases less than 10 years of data were available, or species composition data were unavailable for years where no seagrass was present. In this instance the baseline was calculated over the longest available time period excluding the year of interest (i.e. November 2015 data). Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments. This will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Grade and Score Calculations section and Figure A1).

Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass and species composition were classified as either stable or variable (Table A1). Meadow area was classified as either highly stable, stable, variable, or highly variable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table A1. Coefficient of variation (CV; %) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

Indicator	**Class**			
	Highly stable	**Stable**	**Variable**	**Highly variable**
Biomass	-	< 40%	≥ 40%	-
Area	< 10%	≥ 10, < 40%	≥ 40, <80%	≥ 80%
Species composition	-	< 40%	≥ 40%	-

Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).

Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass	Stable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area	Highly stable	>5% above	5% above - 10% below	10-20% below	20-40% below	>40% below
	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Highly variable	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species composition	Stable and variable; Single species dominated	>0% above	0-20% below	20-50% below	50-80% below	>80% below
	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable; Mixed species	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below
	Increase above threshold from previous year		↑ BIOMASS	Decrease below threshold from previous year		↓ BIOMASS

Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows, Cairns Harbour Zones, and for the Cairns Harbour region (Table A3; see Carter et al. 2016; Carter et al. 2015b for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year (see Baseline Calculations section), allocating a grade for each indicator by comparing 2019 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.

An example of calculating a meadow score for biomass in satisfactory condition is provided in Appendix 2.

Table A3. Score range and grading colours used in the Cairns Harbour report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥0.25	<0.50
E	Very poor	0.00	<0.25

Where species composition was determined to be anything less than in “perfect” condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure A1). If this was the case then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure A1).

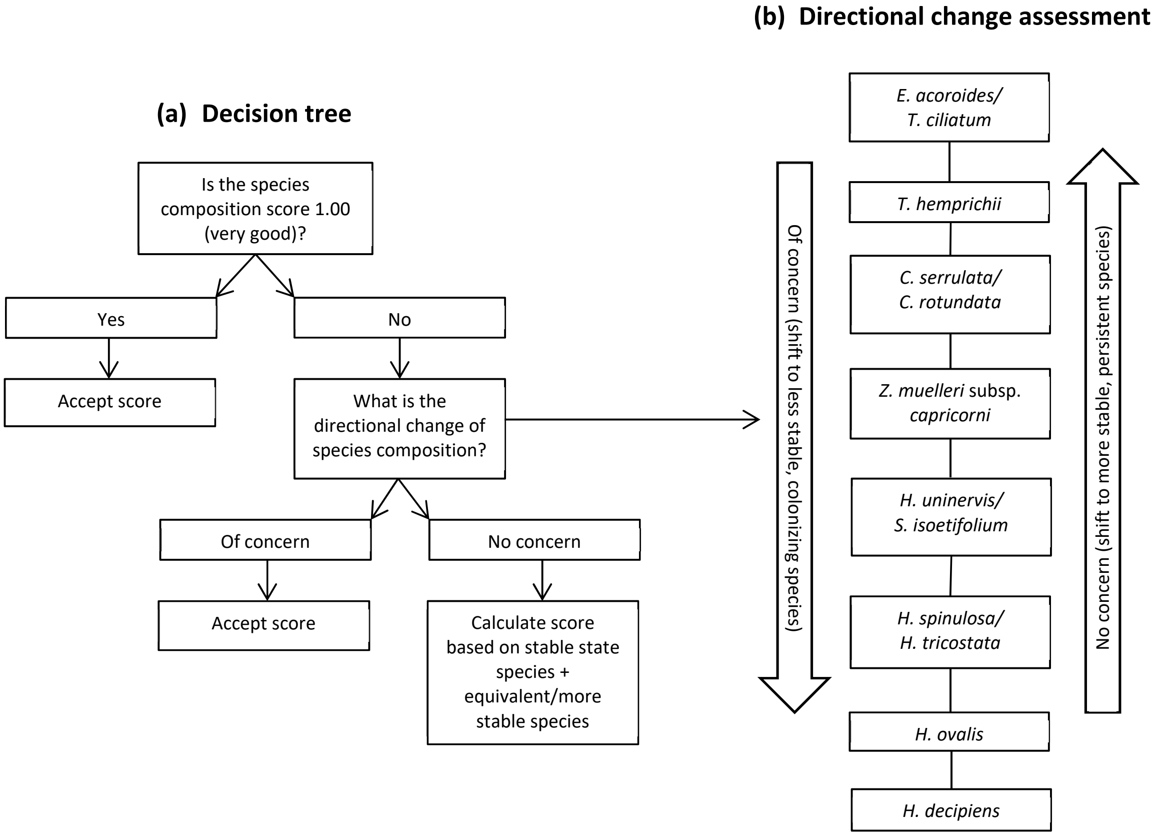


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Cairns.

Score Aggregation

Each overall meadow grade/score was defined as the lowest grade/score of the three condition indicators within that meadow. The lowest score, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these three fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014). In cases where species composition was the lowest score, an average of both the species composition score and the next lowest score is used to determine the overall meadow score. This is to prevent a case where a meadow may have a spatial footprint and seagrass biomass but a score of zero due to changes in species composition.

Cairns Harbour grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the harbour, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the harbour, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Harbour grades are therefore more sensitive to changes in stable than variable meadows.

Appendix 2. Example of calculations meadow condition scores

An example of calculating a meadow score for biomass in satisfactory condition in 2018.

1. Determine the grade for the 2018 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in biomass (B_{diff}) between the 2018 biomass value (B_{2018}) and the area value of the lower threshold boundary for the satisfactory grade ($B_{satisfactory}$):

$$\mathrm{B_{diff} = B_{2018} - B_{satisfactory}}$$

Where $B_{satisfactory}$ or any other threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (highly stable [area only], stable, variable, highly variable [area only]), and whether the meadow is dominated by a single species or mixed species.

3. Calculate the range for biomass values (B_{range}) in that grade:

$$\mathrm{B_{range} = B_{good} - B_{satisfactory}}$$

Where $B_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.
Note: For species composition, the upper limit for the very good grade is set as 100%. For area and biomass, the upper limit for the very good grade is set as the maximum value of the mean plus the standard error (i.e. the top of the error bar) for a given year during the baseline period for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (B_{prop}) that B_{2018} takes up:

$$\mathrm{B_{prop} = \frac{B_{diff}}{B_{range}}}$$

5. Determine the biomass score for 2018 ($Score_{2018}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

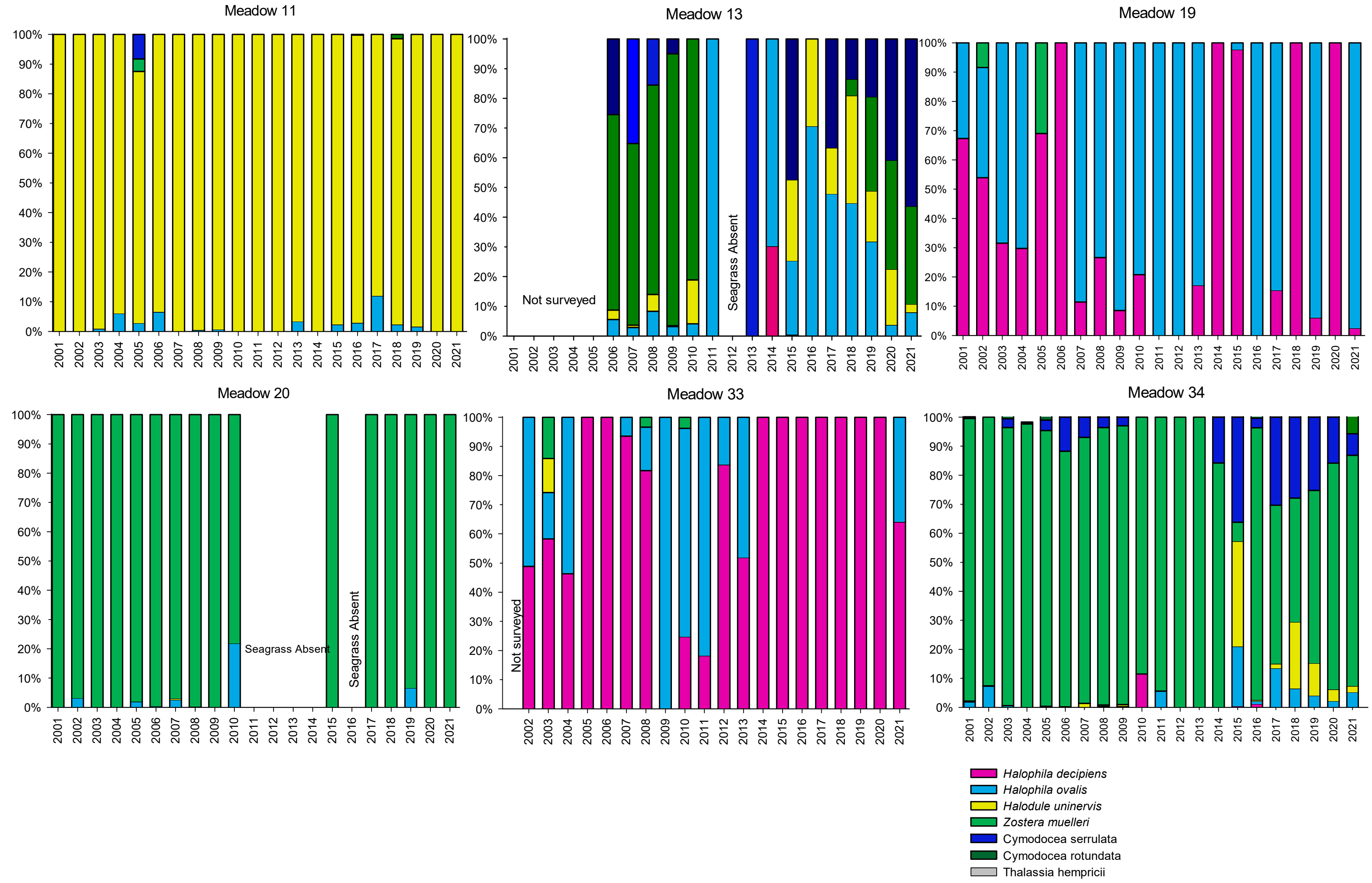
$$\mathrm{Score_{2018} = LB_{satisfactory} + (B_{prop} \times SR_{satisfactory})}$$

Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

Appendix 3: Species Composition, Above-Ground Biomass and Area changes: 2001 – 2021

Appendix 3.1: Cairns Harbour historical seagrass monitoring meadow species composition.

Species composition of monitoring meadows in Cairns Harbour and Trinity Inlet; 2001 – 2021



Appendix 3.2: Cairns Harbour historical seagrass monitoring meadow area.

Seagrass monitoring meadow area (ha) in Cairns Harbour and Trinity Inlet, 2001-2021; ± 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**
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
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
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
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
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
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
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**

NA = meadow not assessed
NP = meadow not present

Appendix 3.3: Cairns Harbour historical seagrass monitoring meadow biomass.

Mean above-ground biomass (g DW m^2) of seagrass for monitoring meadows in Cairns Harbour and Trinity Inlet, 2001-2021.

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**
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
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
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
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
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
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

^ 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*)