

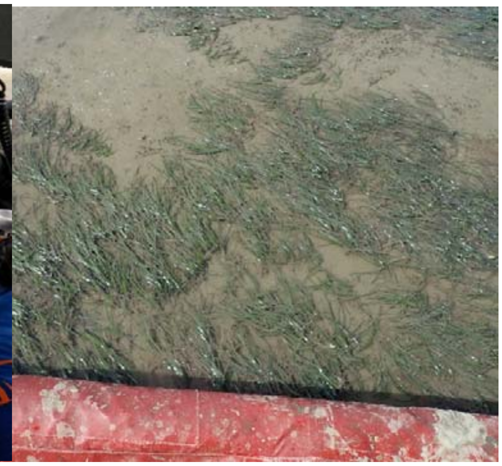

SEAGRASS HABITAT OF CAIRNS HARBOUR AND TRINITY INLET:

Annual Monitoring Report

And

Cairns Shipping Development Project

Monitoring Report 2020

Reason CL, Smith TM & Rasheed MA

Report No. 21/09

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SEAGRASS HABITAT OF CAIRNS HARBOUR AND TRINITY INLET

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

Report No. 21/09

March 2021

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KEY FINDINGS

Cairns Harbour Coastal Seagrass condition 2020

Good

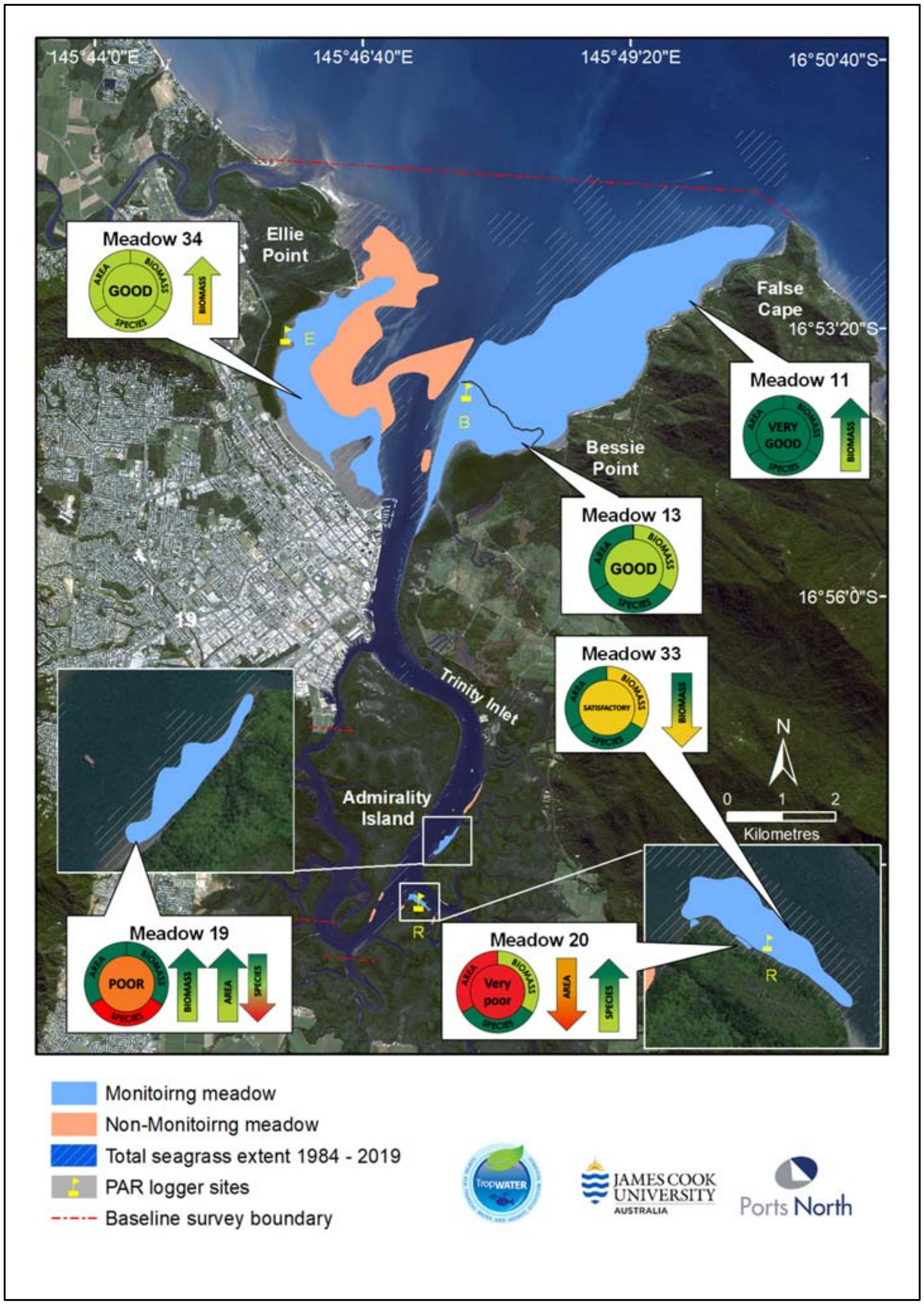
Trinity Inlet Estuarine Seagrass condition 2020

Poor

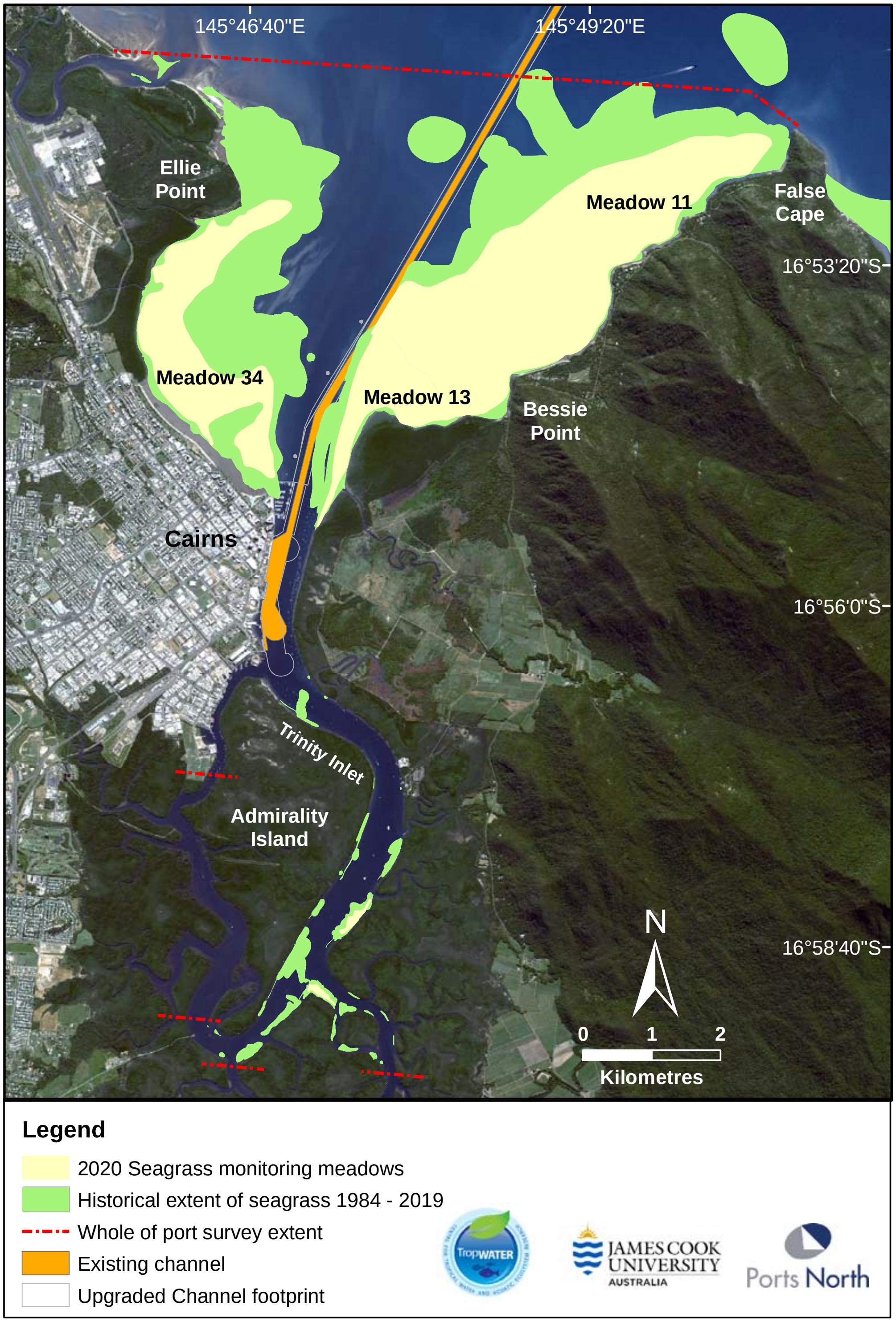
- In 2020 the large seagrass meadows of Cairns Harbour were in their best condition since declines associated with La Niña climate events between 2009 and 2011. All of the harbour monitoring meadows were rated as being in good or better condition for the first time since 2008.
- The three smaller Trinity Inlet estuarine seagrass monitoring meadows were collectively in a poor condition due to reductions in area and a shift in species composition; These small meadows consist of highly ephemeral species and have been highly variable over time.
- Assessment of the larger port limits area in 2020 mapped 1,659 ha of seagrass, maintaining a relatively stable area since 2018.
- 14 months after completion of the Cairns Shipping Development Project (CSDP) there were no signs of impacts on the intensive seagrass monitoring meadows adjacent to the harbour works.
- Area and biomass of the meadows closest to the dredging operation have continued to improve since the CSDP works and are in good and very good conditions.
- The continued improvement of Cairns Harbour seagrasses indicates they have re-established their natural resilience following the dramatic losses that occurred due to La Niña climate events between 2009 and 2011.

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, 2020.



Map 2: Location of Cairns seagrass meadows 1984 – 2020 and the three large monitoring meadows adjacent to the shipping channel that were the focus of intensive monitoring during the CSDP capital works.

Since the completion of the CSDP operations 14 months ago, seagrass in the Cairns Shipping Development intensive monitoring meadows showed no signs of impact from the CSDP operations. Area and biomass of the meadows closest to the dredging operation have continued to improve, with two of the three meadows reaching values above the long-term average (Figure 1 & 11).

In 2020, the total area of seagrass in the six long term monitoring meadows remained well above the long-term average for the fourth year in a row (Map 1; Figure 2).

Seagrass biomass continued to increase in most meadows in 2020, however overall biomass was still below the long-term average. This was principally due to the slower return of the larger growing foundation species to many of the meadows following the large climate related declines that occurred leading up to 2011 (Figure 2; Map 1).

During 2020, improvements were observed in seagrass in the three large long-term annual monitoring meadows in Cairns Harbour. Meadows on the eastern side of the harbour between Bessie Point and False Cape were in good to very good condition. Biomass in the large meadow along the Esplanade has continued to improve and was rated as good for the first time since 2008.

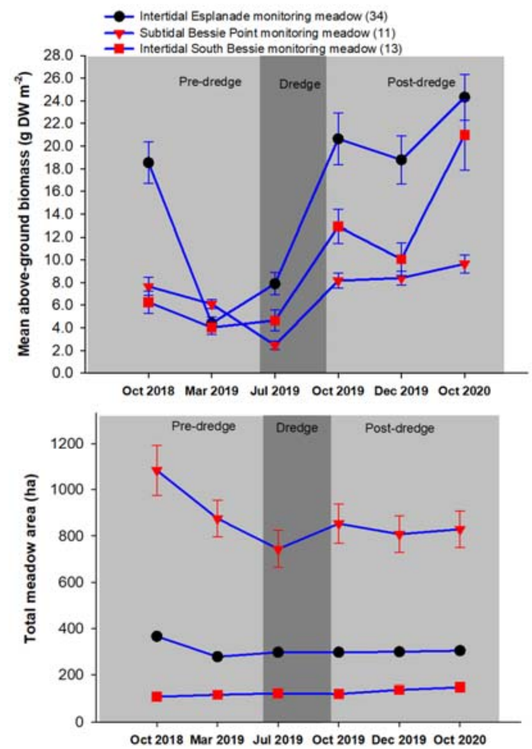


Figure 1: Quarterly and annual assessments of the three seagrass meadows adjacent to shipping channel (a) biomass and (b) area, pre, during and post CSDP dredging

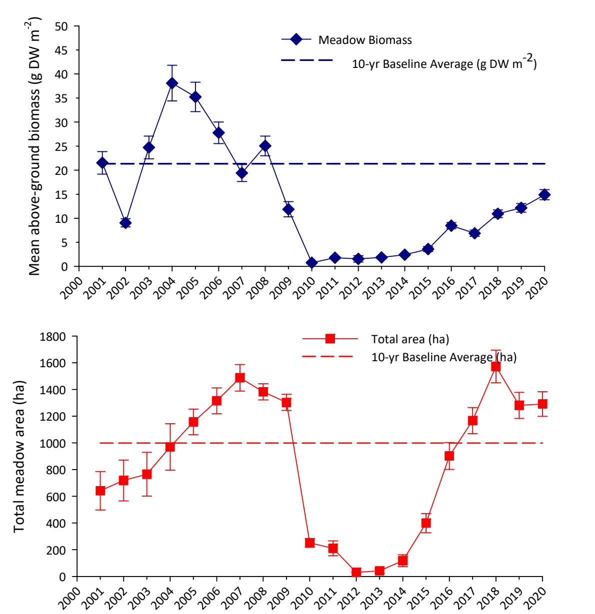


Figure 2: Total a) biomass and b) area of seagrass within all Cairns monitoring meadows from 2001 to 2020 (error bars = standard error of the mean for biomass and "R" reliability estimate for area –dotted line indicates 10-year (2001 – 2010) baseline mean).

The three smaller Trinity Inlet estuarine seagrass monitoring meadows were collectively in a poor condition with some meadows improved and some declined. While biomass improved in all three meadows the decline in area and a shift in species composition to more colonising species was the driver for the overall condition downgrade. The inlet meadows are made up of highly variable colonising species and tend to fluctuate substantially from year to year.

For the third 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 2020, below average rainfall, riverflow and tidal exposure led to favourable conditions for seagrass growth (Figure 3).

The improvements observed in 2020 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. These include the continued increase in the larger growing foundation species *Zostera muelleri*, above average biomass, the large spatial footprint meadows compared with their long-term history and the presence of a seed bank.

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 2018. 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/

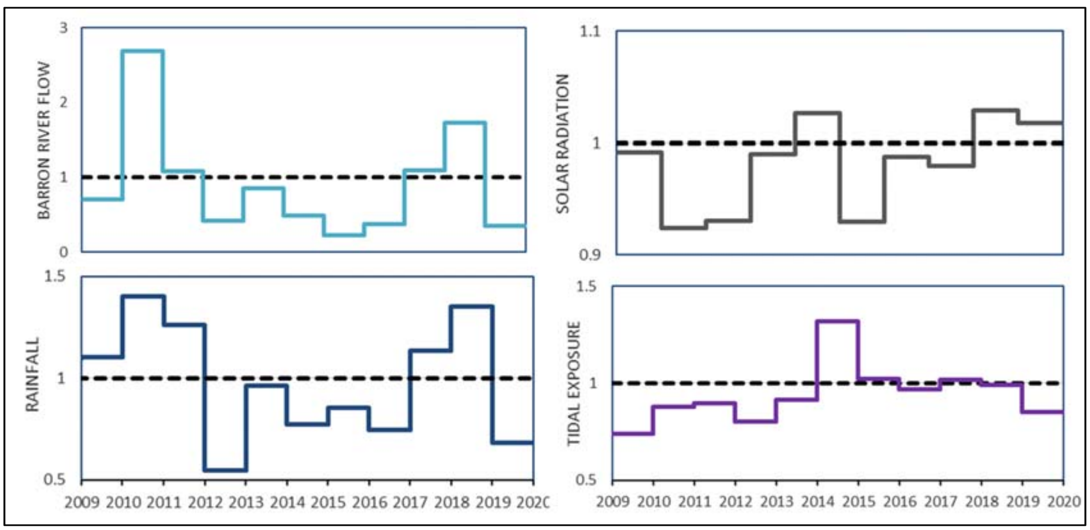


Figure 3: Recent climate trends in Cairns: Change in climate variables as a proportion of the long-term average.

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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 (Unsworth and Cullen 2010; Heck et al. 2008). 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 (Lavery et al. 2013; Fourqurean et al. 2012; Pendleton et al. 2012).

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).

Map 3: Location of Queensland Port Seagrass assessment sites (red – long-term monitoring and baseline mapping; blue - baseline mapping only)

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

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

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

1.2 Cairns Harbour and Trinity Inlet Seagrasses

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

1.3 Port of Cairns

The Port of Cairns is located within Trinity Bay and Trinity Inlet, and operated by Ports North. It is one of Queensland's busiest ports and handles bulk and general cargo, cruise ships, fishing fleets and passenger ferries. Existing port infrastructure includes twelve operational wharves, commercial fishing bases, a barge ramp, marina and mooring facilities, swing basins and a 10km long channel which is subject to annual maintenance dredging (Ports North 2019).

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 is 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 2020 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 2020 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 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 between October and November 2020 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																	X	X	X	X	X	X																										
Proposed capital dredging window																	X	X	X																													
Annual Seagrass Assessments																																																
Ambient annual monitoring program										X	X	X									X	X	X	X									X	X	X	X									X	X	X	X
Increased works for CSDP - Survey of non-permited marine plant areas before dredging											X	X																																				
Increased works for CSDP - increase annual monitoring (meadows) to whole of port survey																					X	X	X	X									X	X	X	X									X	X	X	X
Quarterly Seagrass Assessments																																																
Increased whole of Esplanade & Bessie point meadow seagrass surveys															X			X			X			X																								
Ambient light (PAR) and temperature monitoring (logger change-outs)			X			X			X			X			X			X			X			X			X			X			X			X			X			X			X			X
Annual seed & viability assessments															X												X												X									

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 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.

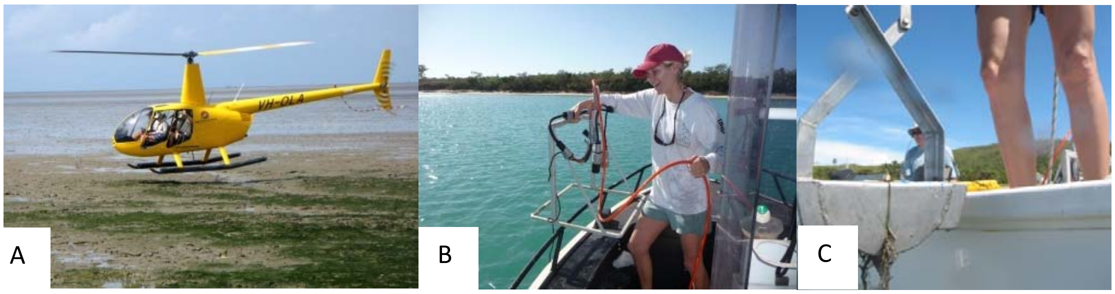


Figure 4: Seagrass monitoring methods in 2018. (a) helicopter survey of intertidal seagrass, (b, c) boat-based camera drops and van Veen grab for subtidal seagrass.

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. Site biomass, 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 ≤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 2 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 was conducted in March 2019 and is scheduled to occur in early April 2020.

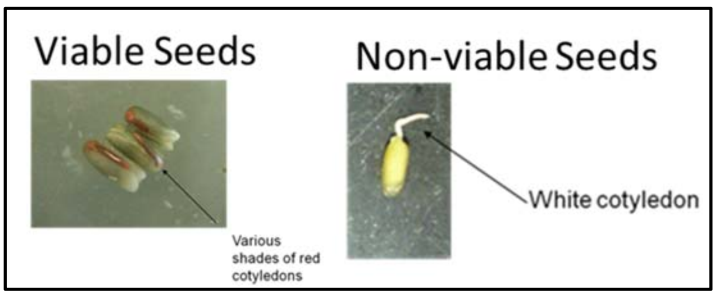


Figure 7: Examples of stained viable and non-viable *Zostera* seeds using tetrazolium chloride

2.3.4 Temperature and Light PAR Loggers

Light (Photosynthetically Active Radiation or PAR) and temperature are monitored continuously at 3 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

The CSDP operations that occurred during 2019 show no signs of impacts on the adjacent meadows 14 months post works. 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 with the density and distribution of seagrass within the range of historical records (Figure 11, Map 4 & 5). The total meadow area has been relatively stable since October 2018 (Figure 9) and the biomass of meadows continued on their improving trajectory post-dredging works (Figure 10).

3.1.1 Esplanade monitoring meadow (34)

The large intertidal Esplanade monitoring meadow on the western side of the shipping channel is dominated by *Zostera muelleri* (Table 4; Figure 9 & 10; Map 2). Biomass of seagrass in this meadow 14 months post dredge has continued to improve and is the highest recorded 23.75 ± 2.31 g DW m^{-2} since 2008 (Figure 11). According to the seagrass condition index developed for the long-term monitoring program, biomass for the past two surveys post dredge improved from satisfactory to good condition, which is higher than the 11 previous years of monitoring (Figures 11 & 14). 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 304 ± 7 ha in October 2020 (Figure 11). The seagrass condition index for area in the past two surveys post dredge both remain in a good condition (Figure 14). The meadow has been recovering since large climate related declines occurred leading up to 2011 and this recovery has continued post the CSDP project.

The meadow has been steadily increasing in its dominance of the larger growing species since the major seagrass losses that occurred leading up to 2011. This trend continued during 2020 with *Z. muelleri* and *Cymodocea serrulata* continuing to increase their presence in the meadow and species composition rated as good post dredging (Figure 14). Four species of seagrass occurred in this meadow during the 2020 survey period; *Z. muelleri*, *Cymodocea serrulata*, *Halodule uninervis*, *Halophila ovalis* (Table 4).

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). South Bessie Point (13) has historically been dominated by *Z. muelleri* and *C. serrulata*, while the subtidal north Bessie Point meadow (11) is dominated by *H. uninervis*. The biomass for both meadows have improved since the completion of the dredging works 14 months ago and are now above the long-term average, while their footprint remains well above the long term average (Figure 9, 10, 11).

In the south Bessie Point intertidal meadow (13) the seagrass condition index for biomass remained good for the past two surveys with a peak in 2020 of 20.97 ± 3.31 g DW m^{-2}, the highest in 12 years (Figure 11 & 16). The morphologically larger species *Z. muelleri* and *C. serrulata* continued to dominate this meadow in 2020 which contributed to the peak in biomass (Figure 16). The footprint of this meadow has remained relatively stable since 2018 (Figure 9), however continues to gradually improve with the largest area recorded in 11 years 149 ± 4.2 ha, well above the long term average (Figure 11, 16)

The subtidal Bessie Point meadow (11) showed a gradual improvement in biomass since the completion of the dredging works and remains above the long term average with a peak of 9.65 ± 0.8 g DW m^{-2} in October 2020 (Figure 10, 11, 15). The annual monitoring condition index is very good for this meadow (Figure 15). *Halodule uninervis* remained the dominant species in this meadow during 2020 (Figure 15). The Bessie Point meadow (11) is the largest meadow in the harbour group, and while it remains above the long term average since completion of the CSDP, it has decreased slightly since 2019 from 853 ± 84.8 ha to 828.74 ± 78.9 ha in October 2020 (Figure 9, 11, 15).

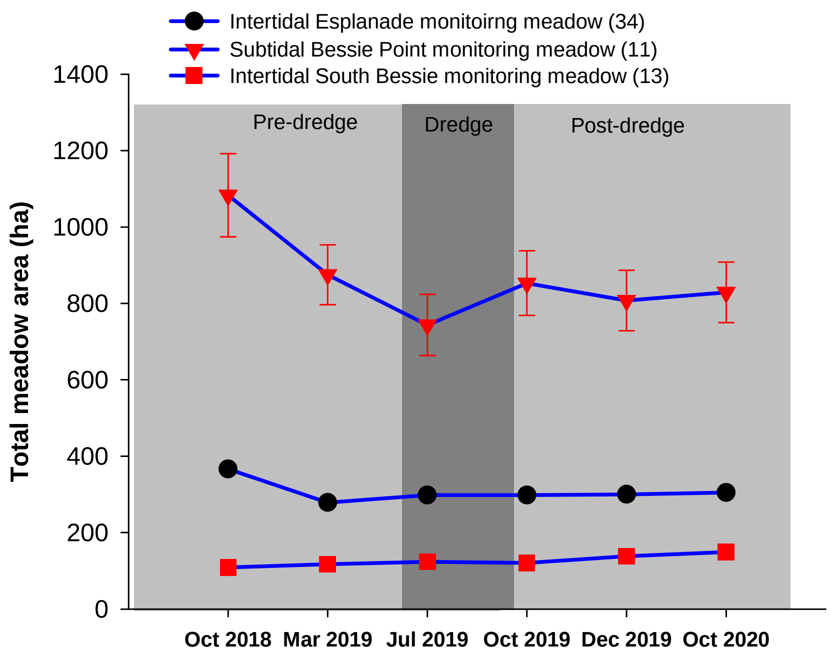


Figure 9. Area (ha) of the three seagrass meadows monitored for the CSDP program between October 2018 and October 2020.

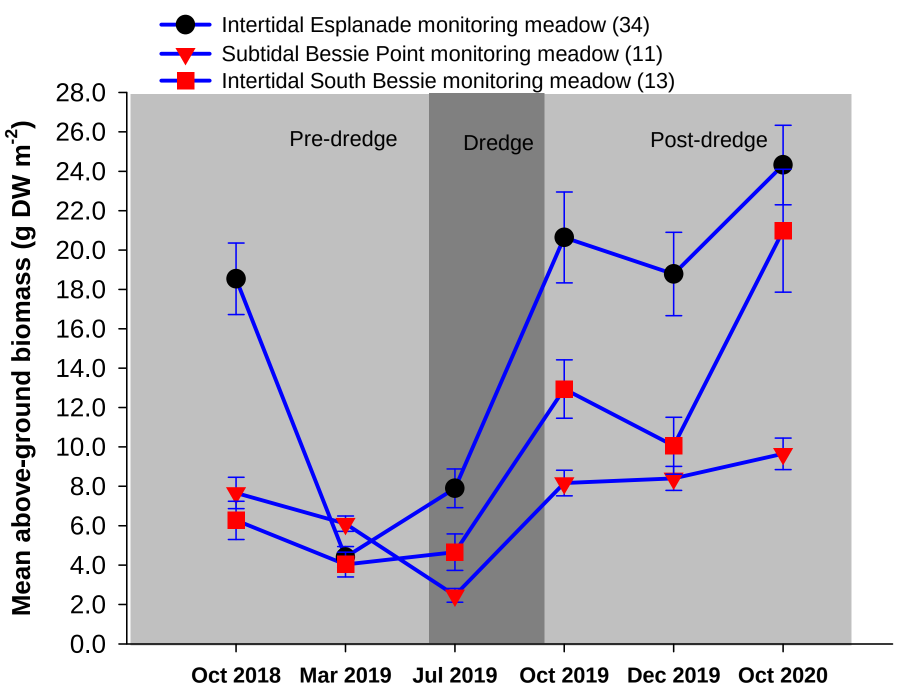


Figure 10. Mean above-ground biomass (g DW m^{-2}) of the three seagrass meadows monitored for the CSDP program between October 2018 and October 2020.

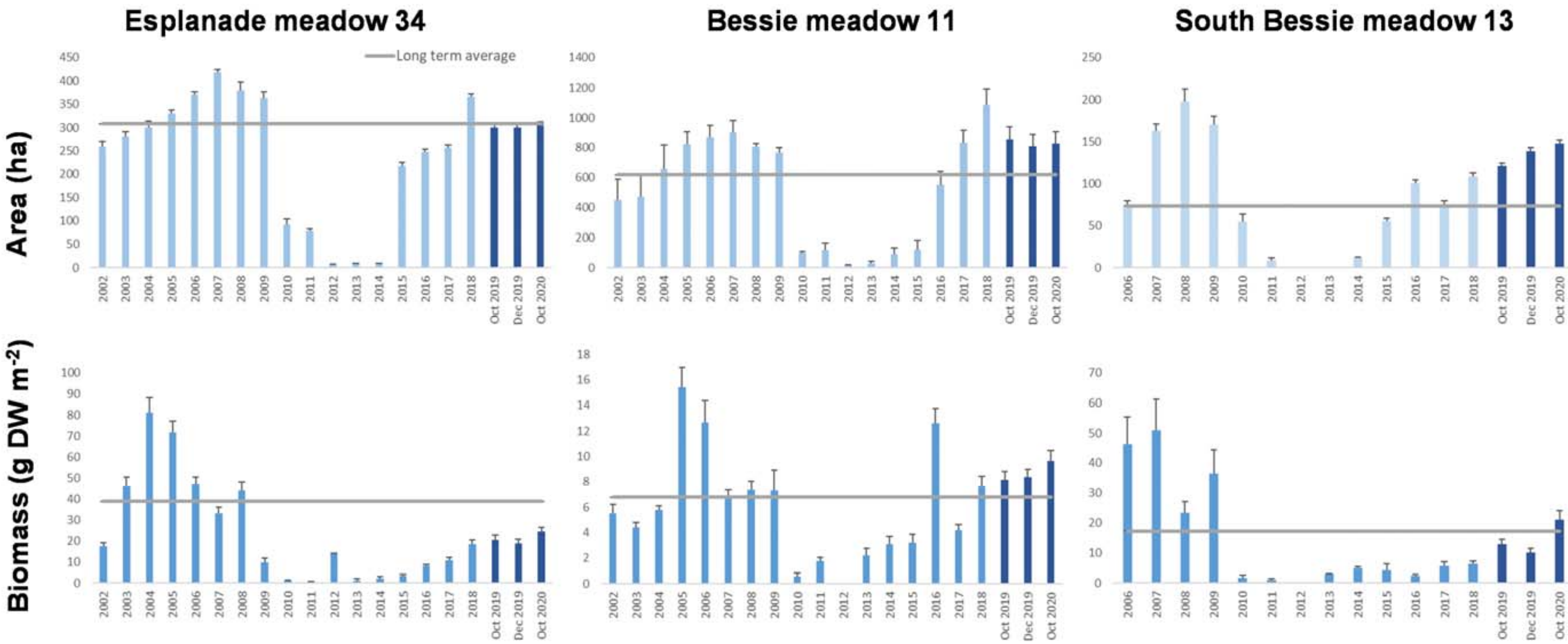
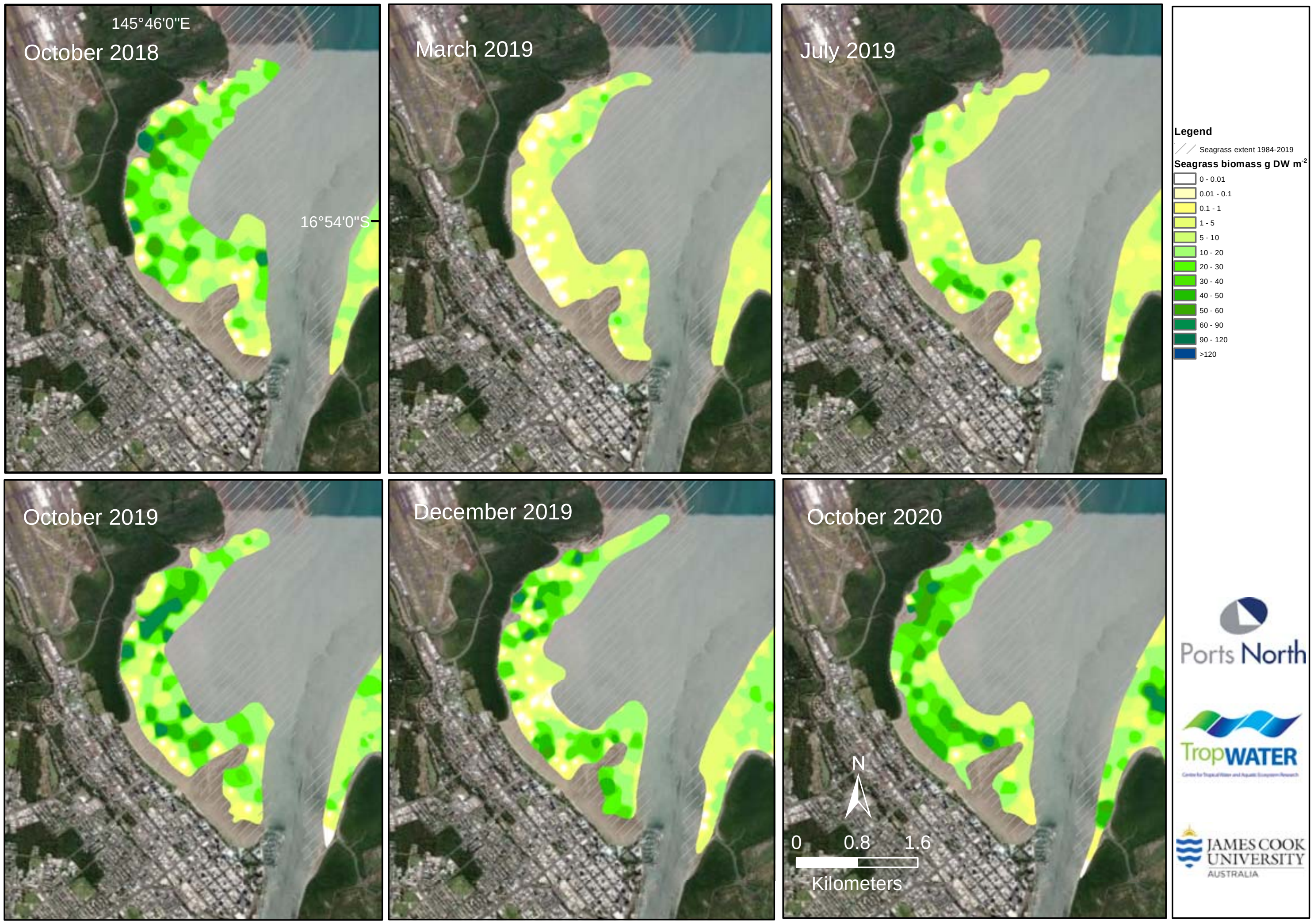
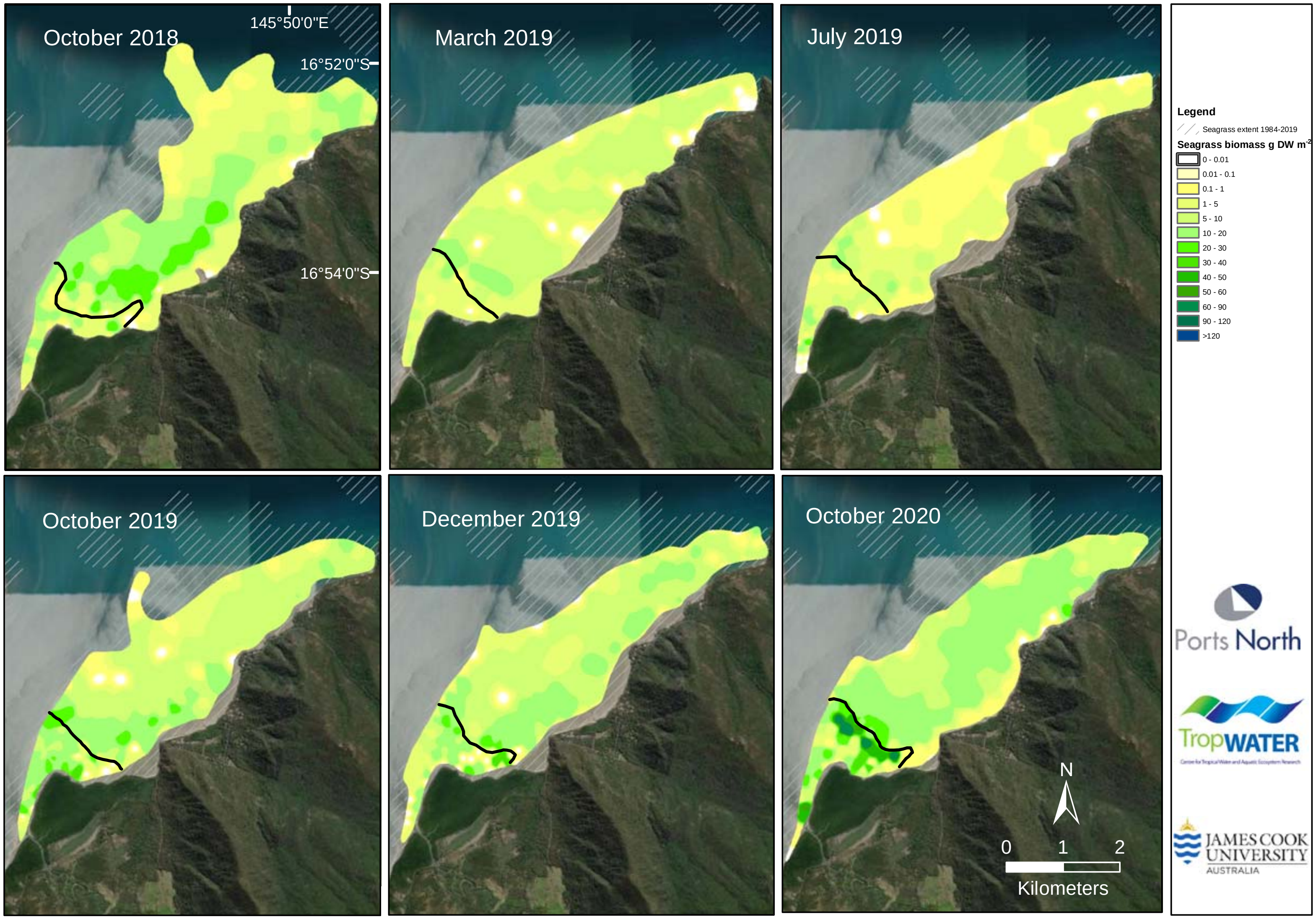


Figure 11. Biomass (g DW m-2) and area (ha) of the three seagrass meadows monitored for the CSDP in comparison with long term annual monitoring surveys, from 2002 to 2020. Post Dredge values were collected in October and December 2019 and October 2020 and are dark blue bars. Previous years data collected 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).



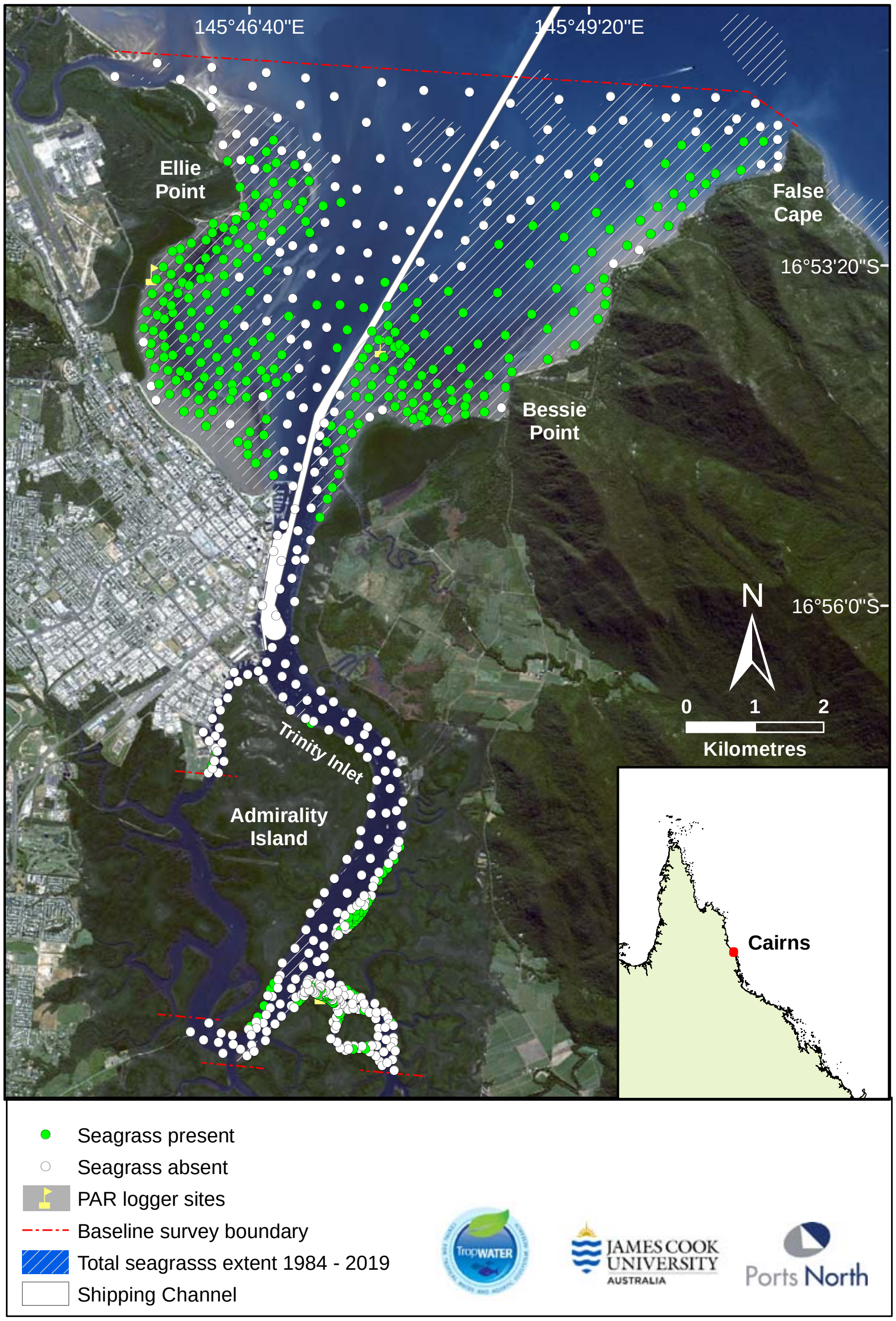
Map 4. Seagrass area (ha) and density (g DW m^{-2}) distribution of the Esplanade monitoring meadow between October 2018 and October 2020.



Map 5. Seagrass area (ha) and density (g DW m^{-2}) distribution of the Bessie Point monitoring meadows between October 2018 and October 2020.

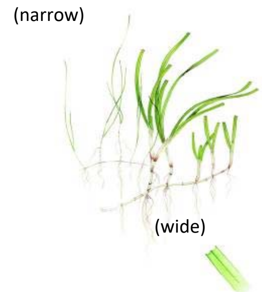
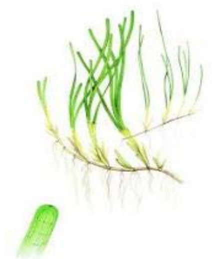
3.2 Annual Monitoring of Seagrasses in Cairns Harbour and Trinity Inlet

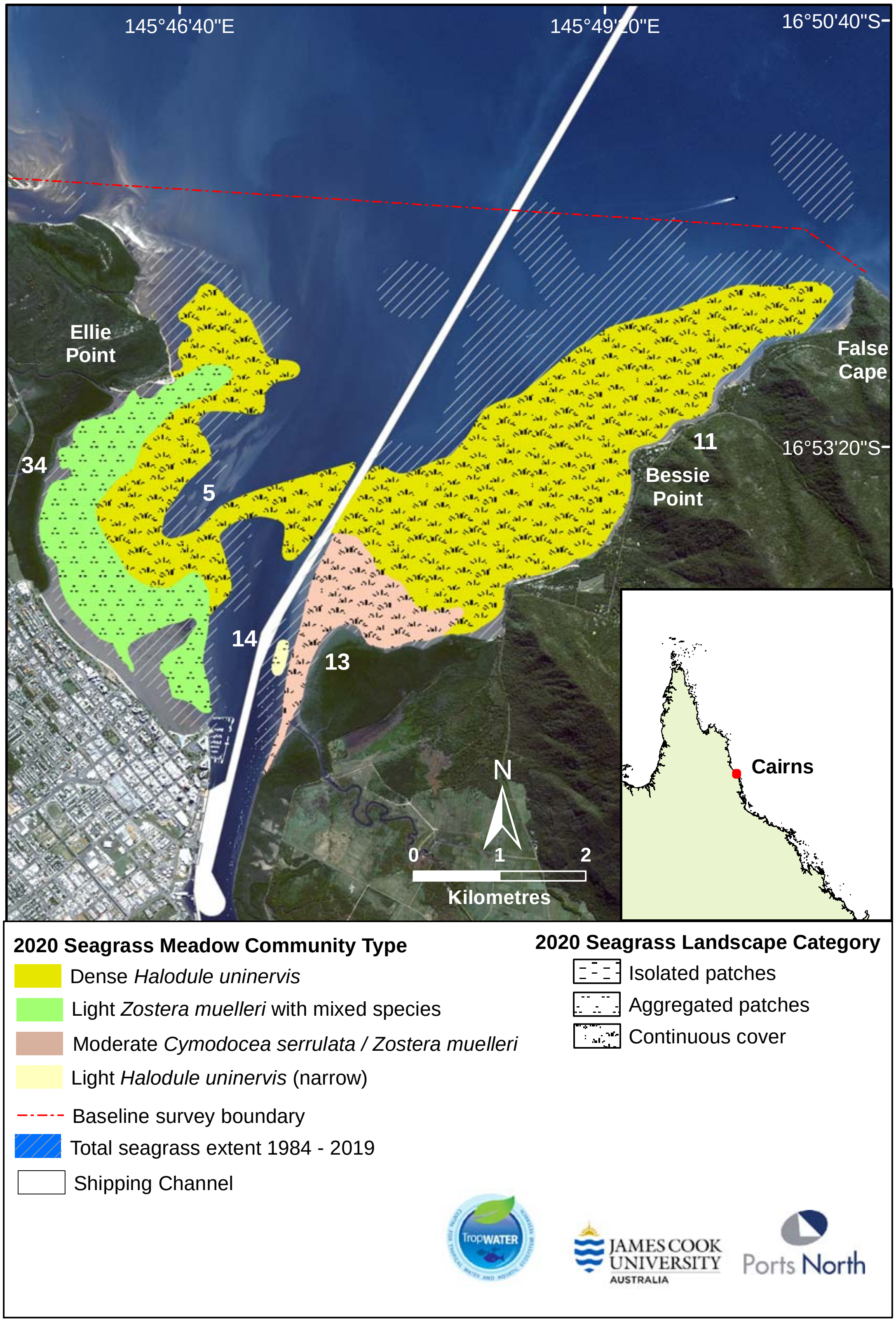
A total of 731 habitat characterisation sites were surveyed in the 2020 annual seagrass monitoring survey, with seagrass present at 45% of sites (Map 6). The same five species were recorded in the 2020 survey as the previous year (Table 5). A total seagrass area of 1,659 ha was mapped in the whole of port survey region consisting of 1,291 ± 92 ha in the annually assessed long-term monitoring meadows, and an additional 367 ± 39 ha of seagrass habitat outside of these meadows (Map 7a; 7b).



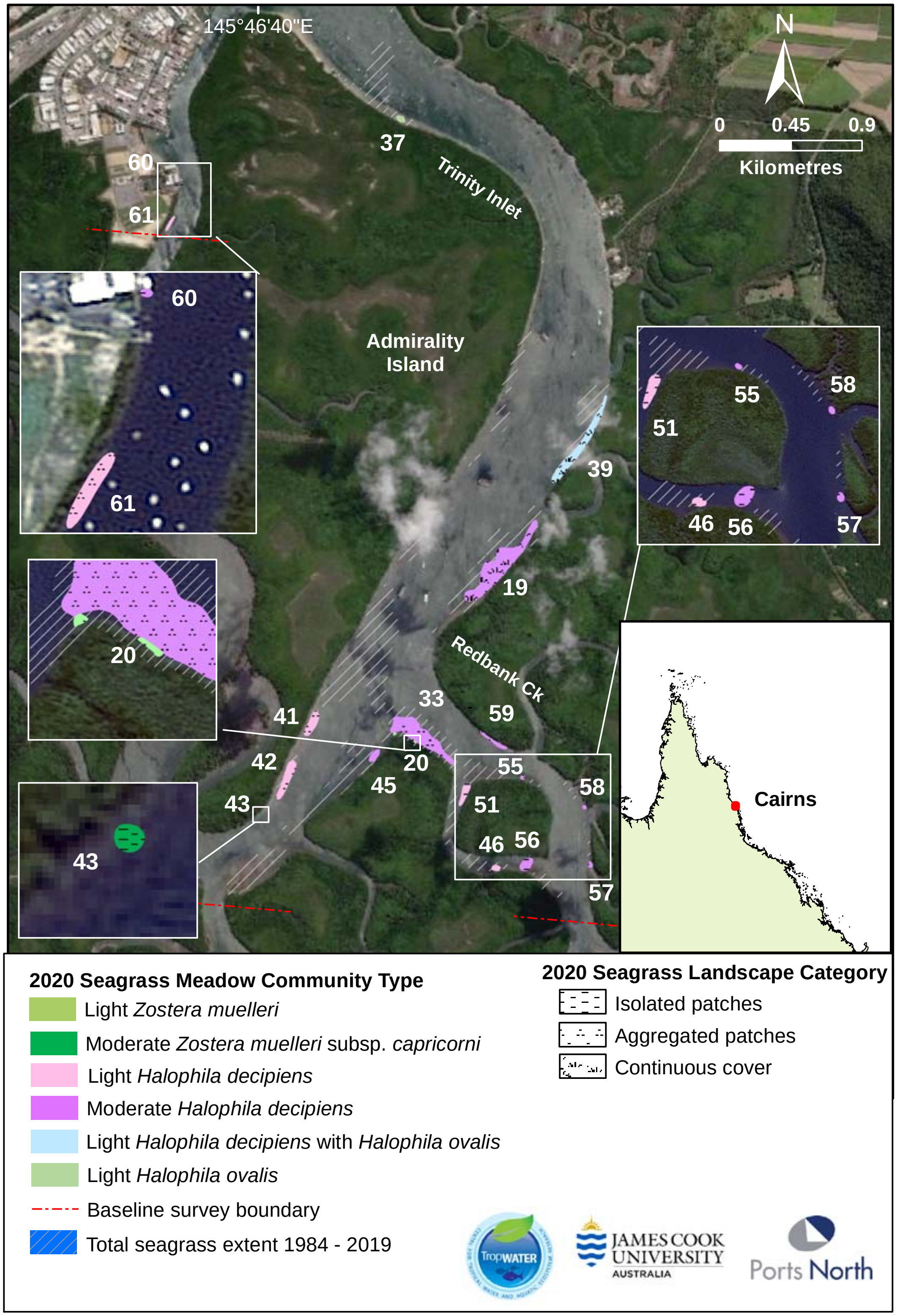
Map 6: Seagrass presence/absence at sites surveyed within the Cairns survey area, 2020.

Table 5: Seagrass species present in Cairns Harbour and Trinity Inlet monitoring meadows in 2020.

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* (R. Br.) Hook. F.	



Map 7a: Coastal Cairns Harbour distribution and community type for seagrass meadows in 2020.



Map 7b: Estuarine Trinity Inlet distribution and community type for seagrass meadows in 2020.

3.2.1 Seagrass condition for long-term monitoring meadows

Collectively the mean biomass for long-term monitoring meadows increased to 14.9 ± 1.06 g DW m^{-2}, the highest since 2008. Biomass has been steadily increasing since 2012 however is was still below the long-term average of 21.33 g DW m^{-2} (Table 6; Figure 12). The overall area of the monitoring meadows in 2020 was 1291.43 ± 92 ha, well above the long-term average (999 ± 108 ha) (Table 6; Figure 13).

The collective condition of the three large coastal Cairns Harbour meadows (Meadows 11, 13 and 34) was rated as being in good condition. The small highly variable estuarine Trinity Inlet meadows on the other hand (Meadows 19, 20 and 33) collectively declined from a satisfactory condition to poor condition in 2020 (Map 1; Table 6).

For Cairns Harbour monitoring meadows condition of the Bessie Point meadows was maintained with biomass, area and species composition at South Bessie (13) remaining in a good condition and North Bessie (11) improving to a very good condition. The biggest change occurred for the Esplanade meadow (34) improving from satisfactory to a good condition in 2020, due to an increase in biomass (Table 6; Figure 14).

The collective mean scores for the Trinity Inlet meadows declined from satisfactory in 2019 to a poor condition in 2020. The intertidal Redbank Creek meadow (20) was the main driver behind the decline due to the reduction in area in 2020. This meadow has been variable in biomass and area since its return in 2017, and while it is still present in a smaller footprint, improvements in biomass and species condition to good and very good are promising signs that this meadow will persist. The Subtidal Redbank meadow (33) improved from satisfactory to good in 2020 with the main improvements in the condition of biomass. The subtidal Trinity Inlet meadow (19) declined to poor in 2020, due to the species shift to a less persistent species *Halophila decipiens*.

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)	0.66	0.74	0.85	0.66
Bessie Point (11)	0.85	0.90	1.00	0.85
South Bessie Pt (13)	0.8	0.91	0.94	0.80
Overall Score for Cairns Harbour				**0.77**
Estuarine Trinity Inlet Meadows				
Inlet (19)	0.86	0.89	0	0.43
Redbank Intertidal (20)	0.68	0.15	1.00	0.15
Redbank Subtidal (33)	0.67	0.87	1.00	0.67
Overall Score for Trinity Inlet				**0.41**

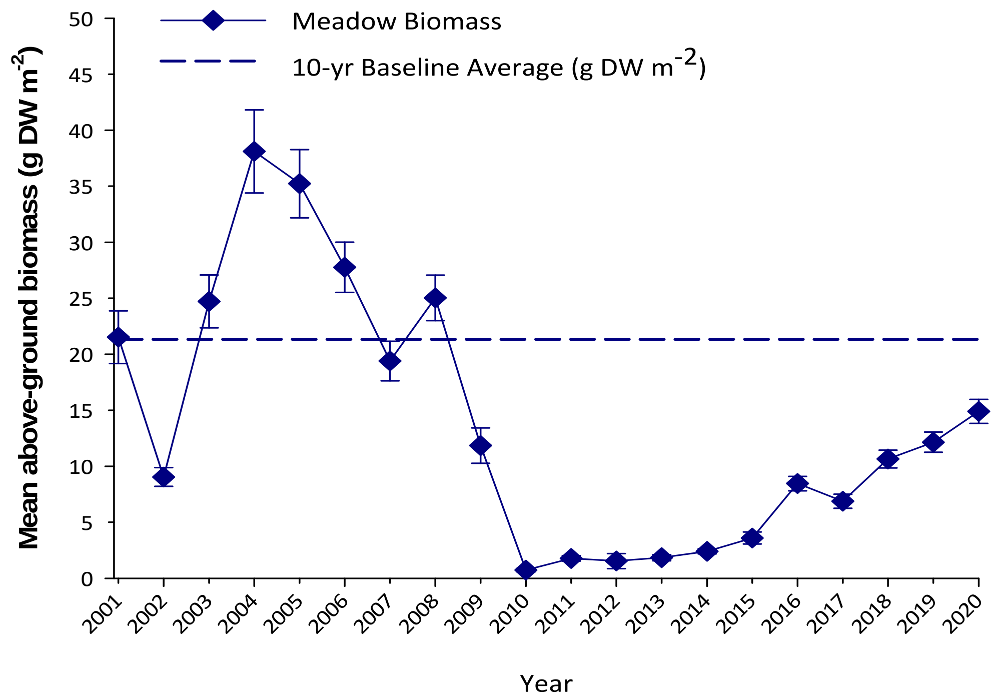


Figure 12: Mean above-ground biomass (g DW m^{-2}) of all monitoring meadows combined in Cairns Harbour and Trinity Inlet from 2001 – 2020 (error bars – standard error). Dotted blue line indicates 10-year (2001 – 2010) baseline mean of meadow biomass.

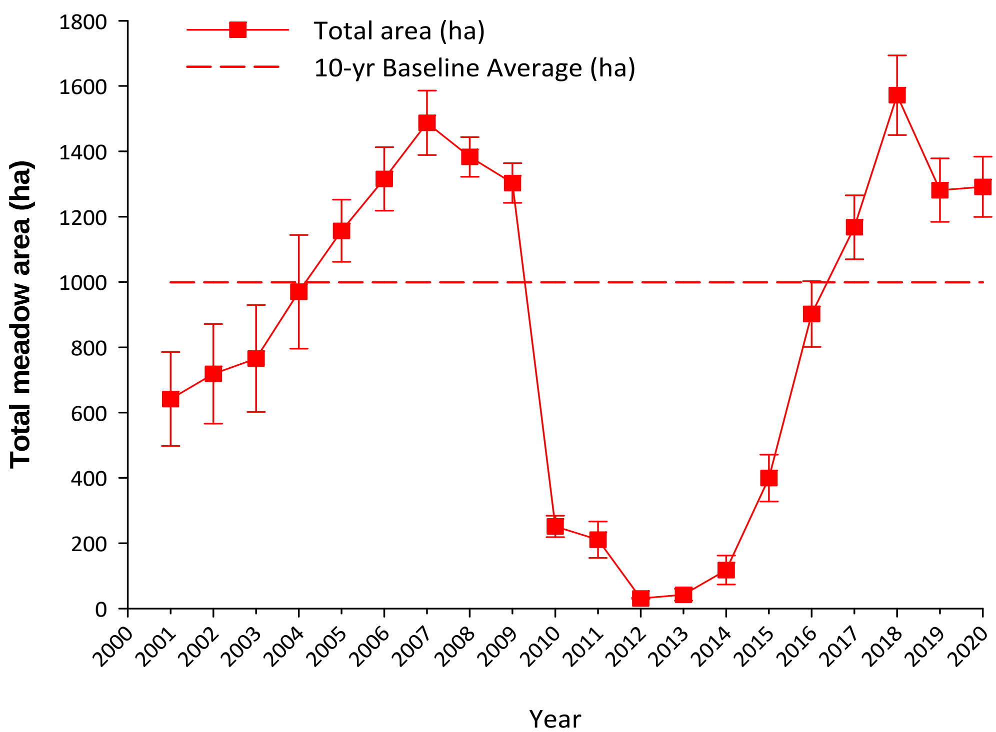


Figure 13: Total area of all monitoring meadows combined in Cairns Harbour and Trinity Inlet from 2001 – 2020 (error bars – "R" reliability estimated). Dotted red line indicates 10-year (2001 – 2010) baseline mean of total meadow area.

3.2.2 Coastal Cairns Harbour Meadows

The coastal Cairns Harbour meadows consist of the larger Esplanade to Ellie point meadow (34), Bessie Point (11) and South Bessie Point (13) meadows, which all improved in 2020.

The Esplanade meadow (34) increased in biomass to a good condition, the best it has been in since 2008. The area of this meadow remained in good condition at 304.9 ± 7 ha, close to the long-term baseline average of 308 ha (Figure 14). Species composition was also good with the proportion of *Zostera muelleri* continuing its increasing trend of recent years (Figure 14; Map 8; Appendix 3).

The Bessie Point meadow (11) was in very good condition for all three indicators measured (biomass, area, and species composition). Biomass was 9.6 ± 0.6 g DW m^{-2} in 2020 substantially above the long term average (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 4th year in a row (Figure 15). Species composition remained dominated by *Halodule uninervis* (Figure 15; Appendix 3).

The subtidal monitoring meadow at South Bessie Point (13) remained in a good condition in 2020. Both biomass (20.97 ± 3.3 g DW m^{-2}) and area (149 ± 4.2 ha) were at their highest level since 2009 and well above the long-term average baseline condition (Figure 16, Map 9, Appendix 3). Larger growing more persistent species *Zostera muelleri* and *Cymodocea serrulata* continued the trend of recent years increasing their dominance in the meadow (Figure 16; Appendix 3).

3.2.3 Trinity Inlet Estuarine Meadows

The Trinity Inlet long-term monitoring meadows consist of three smaller predominantly subtidal meadows, Trinity Inlet (M19), Intertidal Redbank Creek (M20) and Subtidal Redbank Creek (33), these small meadows are much more variable from year to year than those in the harbour and results for meadows and indicators was mixed in 2020.

The subtidal Redbank Creek meadow (33) improved in condition from satisfactory to good in 2020 (Figure 19). An increase in biomass drove the grade improvement. Area and species composition remained in a very good condition in 2020, and while this meadow is the most variable of all the monitoring meadows in the program, it remains persistent (Map 10).

The adjoining intertidal Redbank Creek *Zostera muelleri* meadow (20) has declined in condition to very poor overall (Figure 18). Even though biomass for this meadow improved to a good condition with 16.35 ± 5.3 g DW m^{-2} and very good species composition due to a dominance in *Zosteria muelleri*, the main driver for the decline was the reduction in area in 2020 (Figure 18, Map 10, Appendix 3). This meadow disappeared between 2010 and 2015 and since has reappeared as small patches, in a narrow footprint adjacent to the mangroves (Figure 18).

The subtidal Trinity Inlet meadow (19) declined to a poor overall condition in 2020 (Figure 17). While both biomass and area were in very good condition and have improved since last year, there was a shift in species composition from *Halophila ovalis* to less persistent species *Halophila decipiens* (Figure 17). This meadow is also highly variable from year to year in both biomass and area (Map 10).

Table 7: Maximum depth penetration (depth below mean sea level) of monitoring meadows in Cairns Harbour and Trinity Inlet, 2001 –2020

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

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
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
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
South Bessie Point (13)	-	-	-	-	-	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
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
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

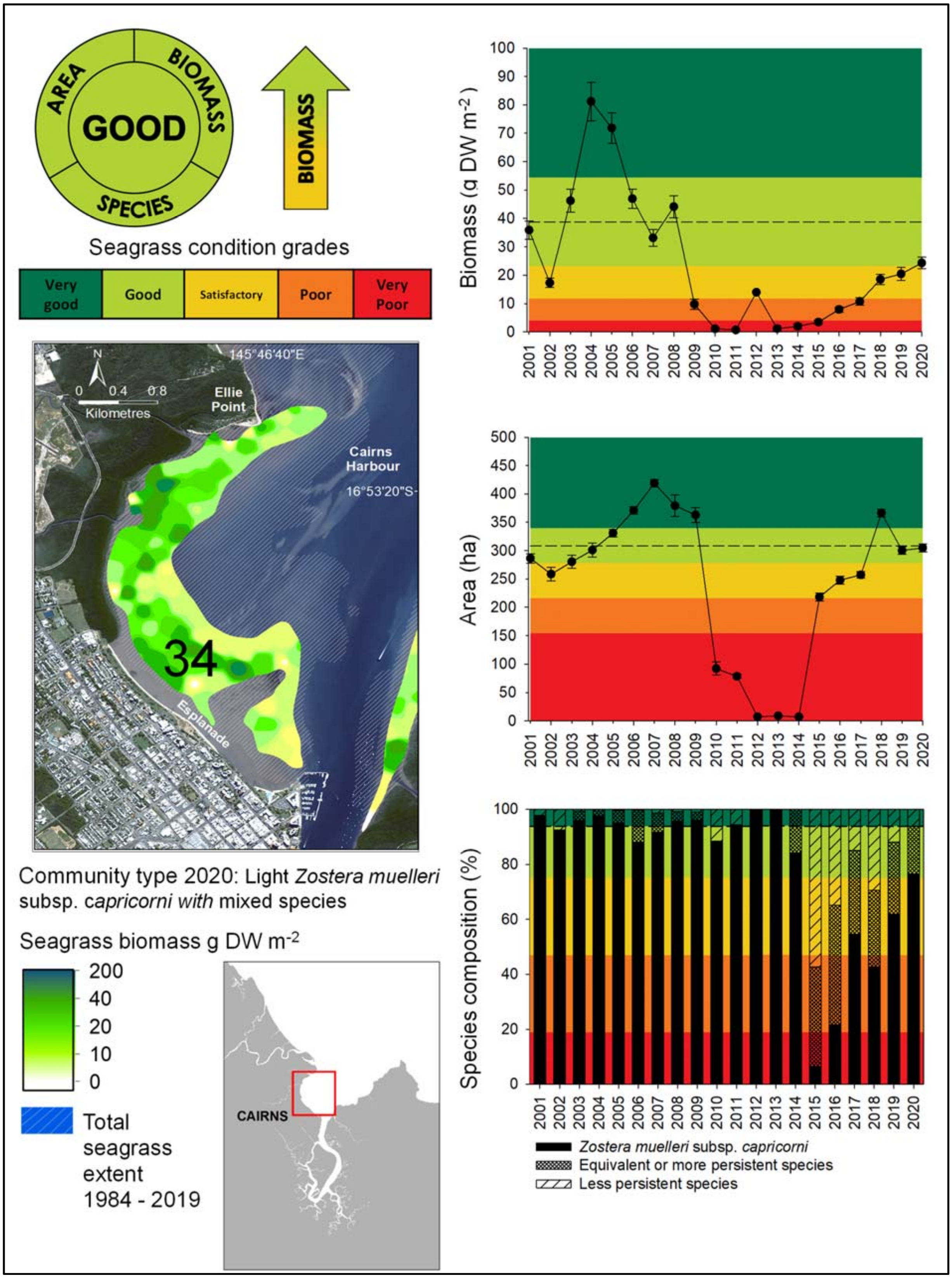


Figure 14: Changes in biomass, area and species composition for the Esplanade meadow (meadow no. 34) from 2001 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).

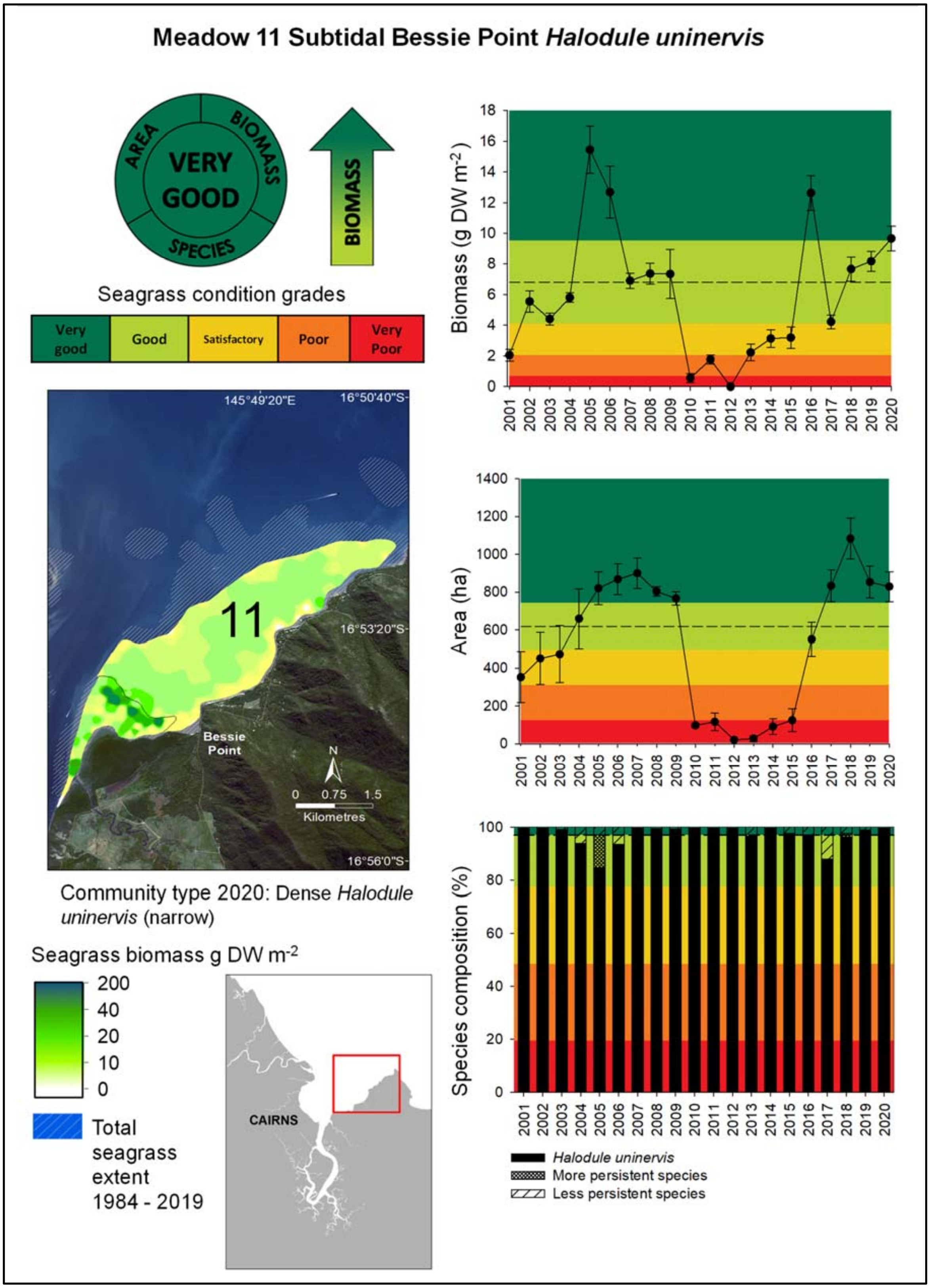


Figure 15: Changes in biomass, area and species composition for the Bessie Point (meadow no. 11) meadow from 2001 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).

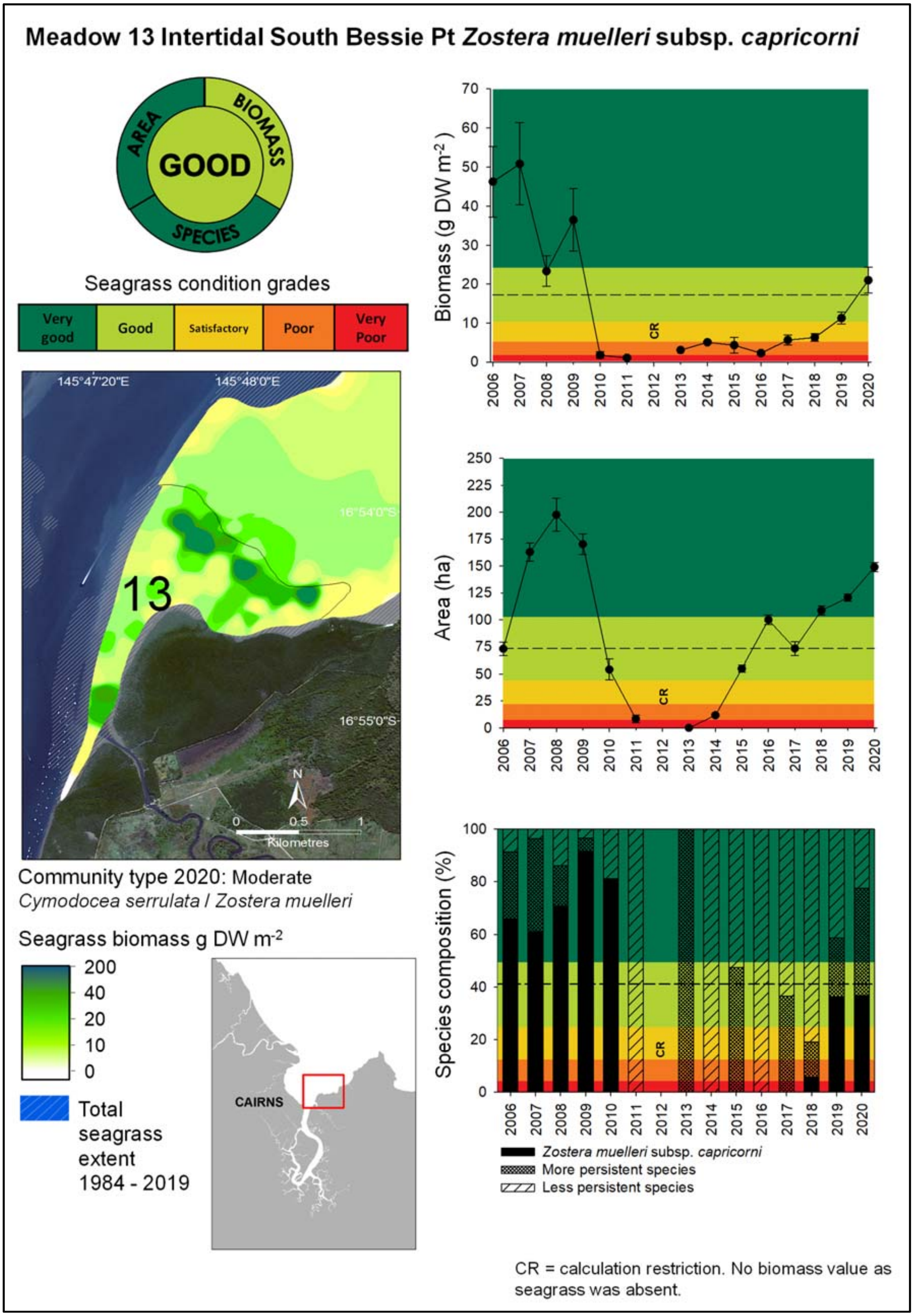


Figure 16: Changes in biomass, area and species composition for the South Bessie Point (meadow no. 13) meadow from 2006 – 2020 (biomass error bars = SE; area error bars = “R” reliability estimate).

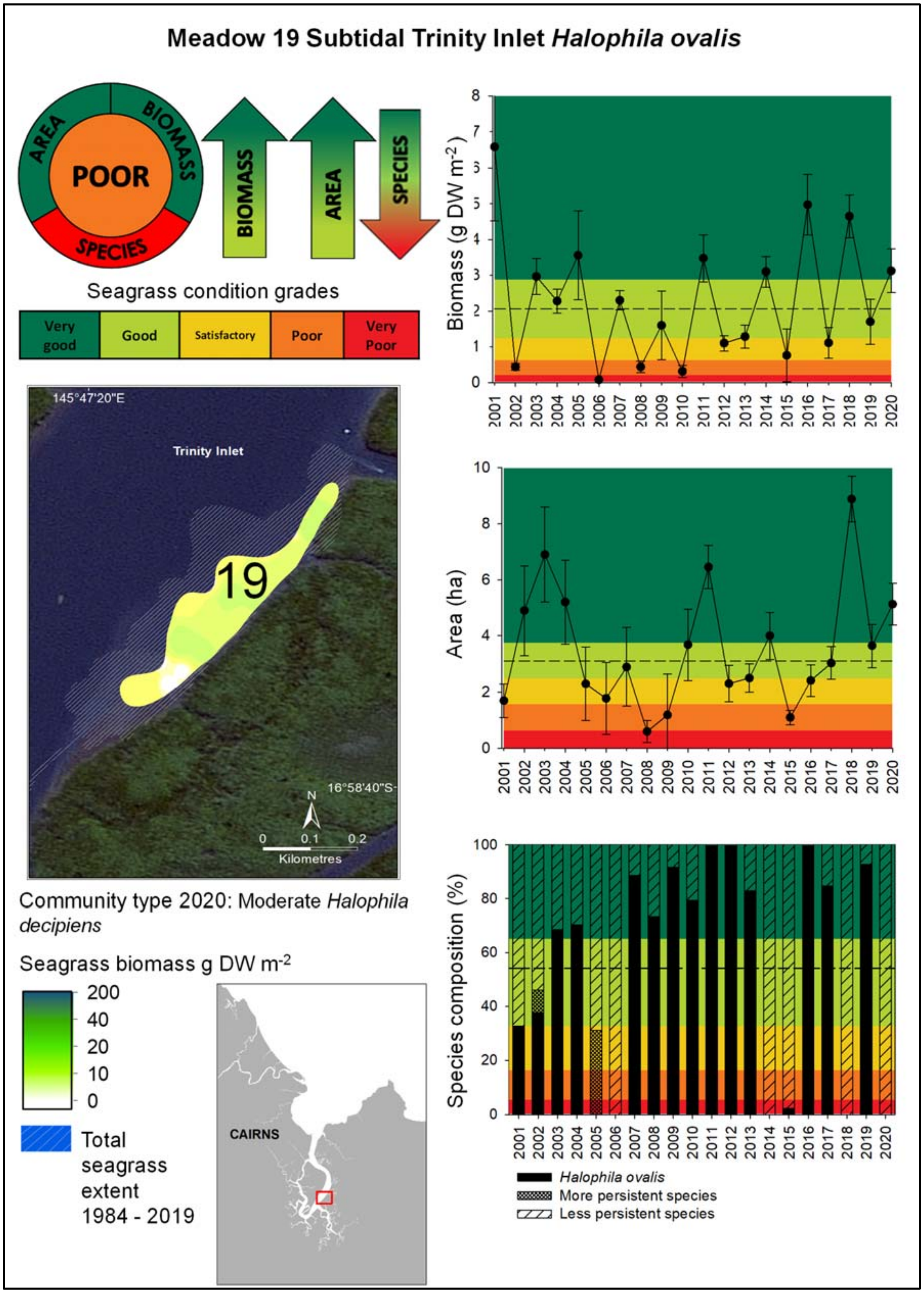


Figure 17: Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow 19) from 2001 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).

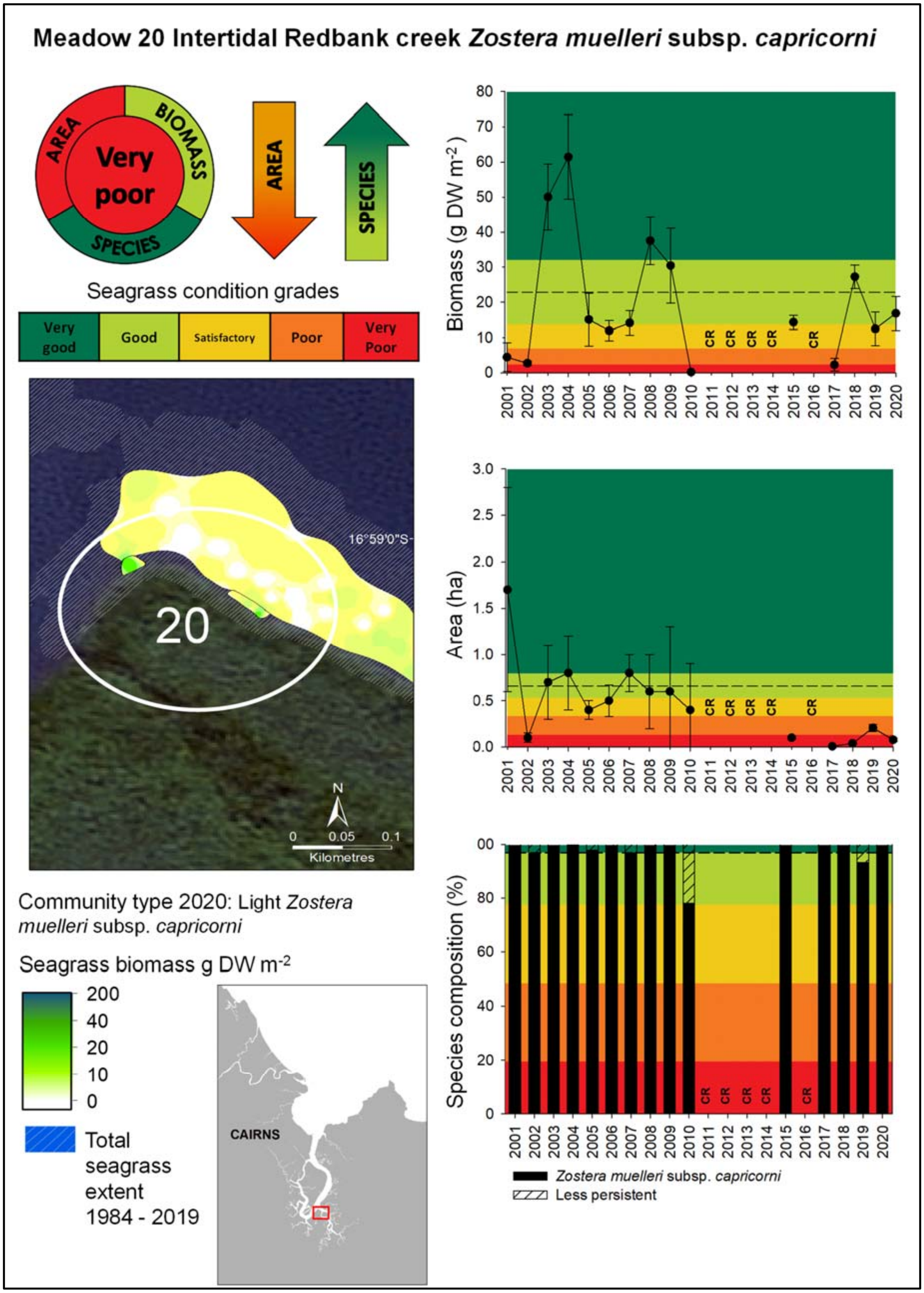


Figure 18: Changes in biomass, area and species composition for the Trinity Inlet *Zostera* meadow (meadow no. 20) from 2001 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).

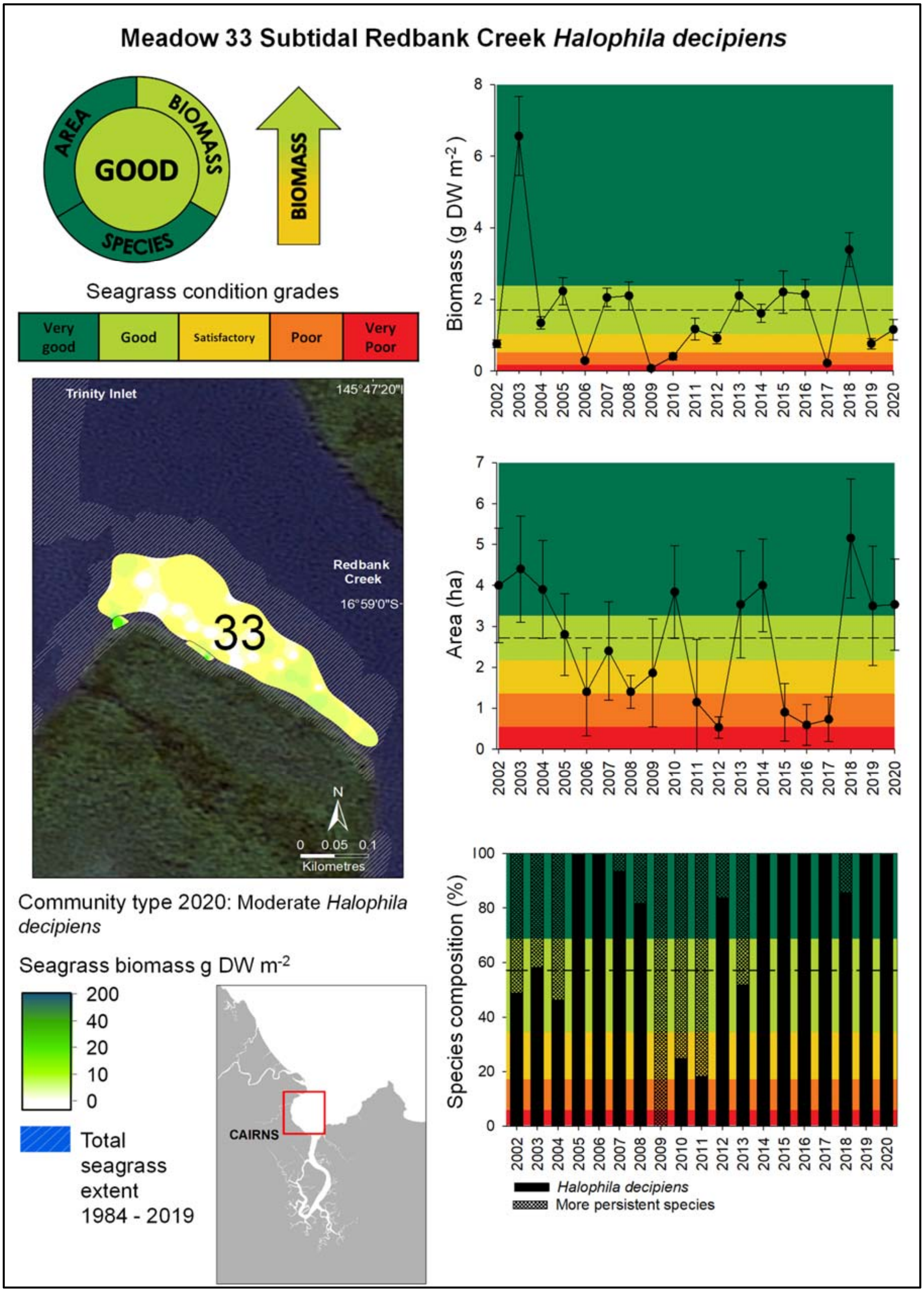
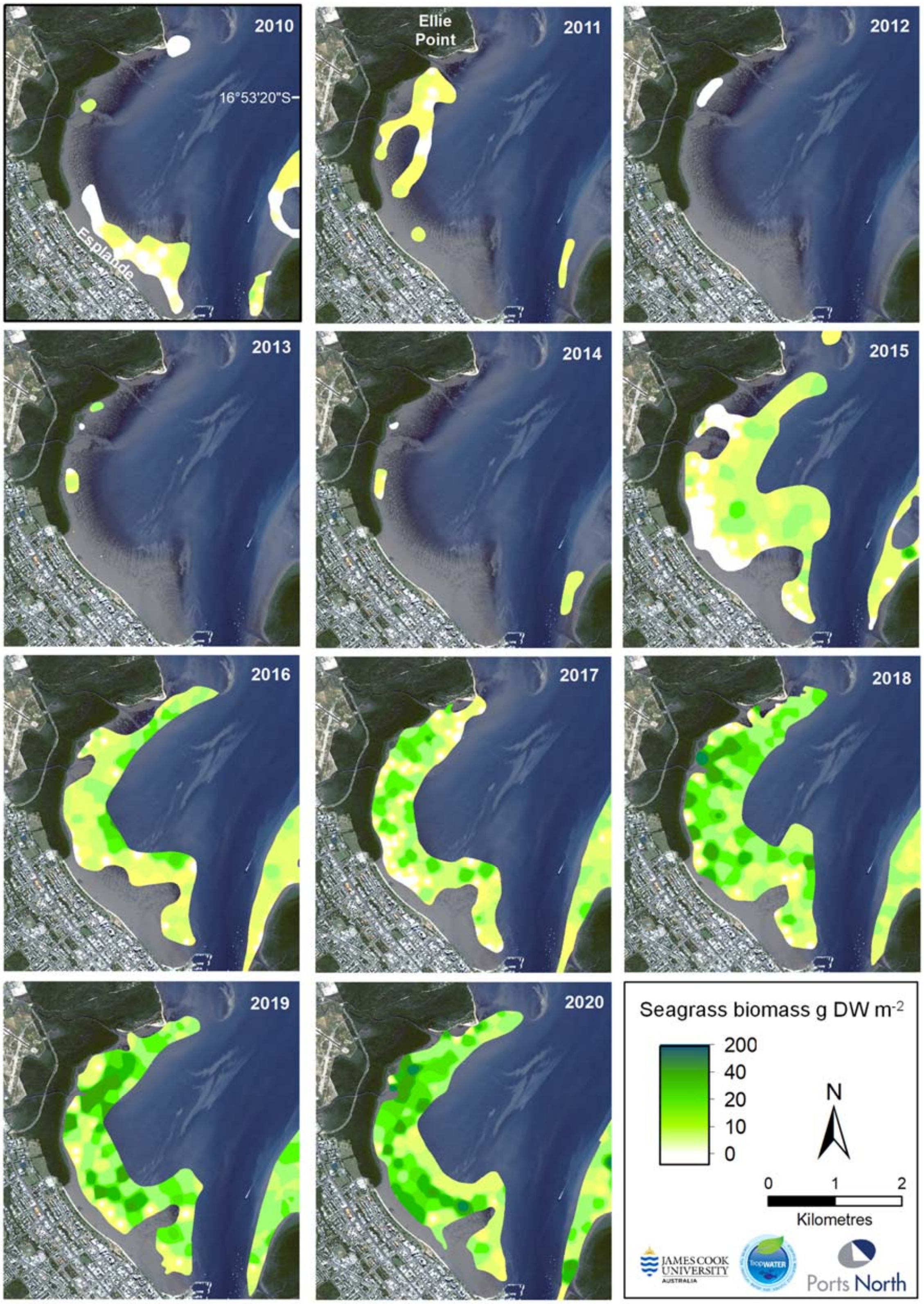
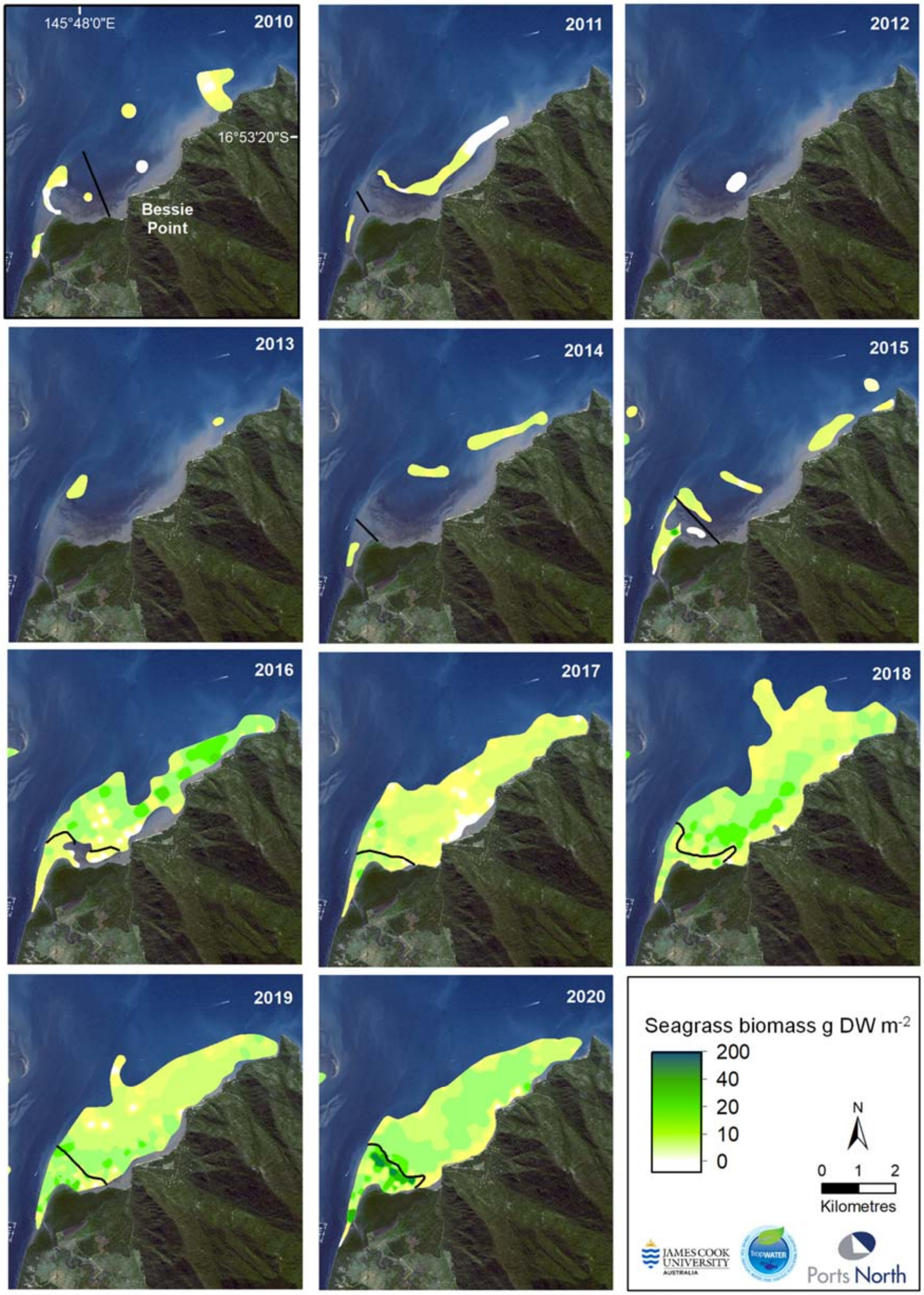


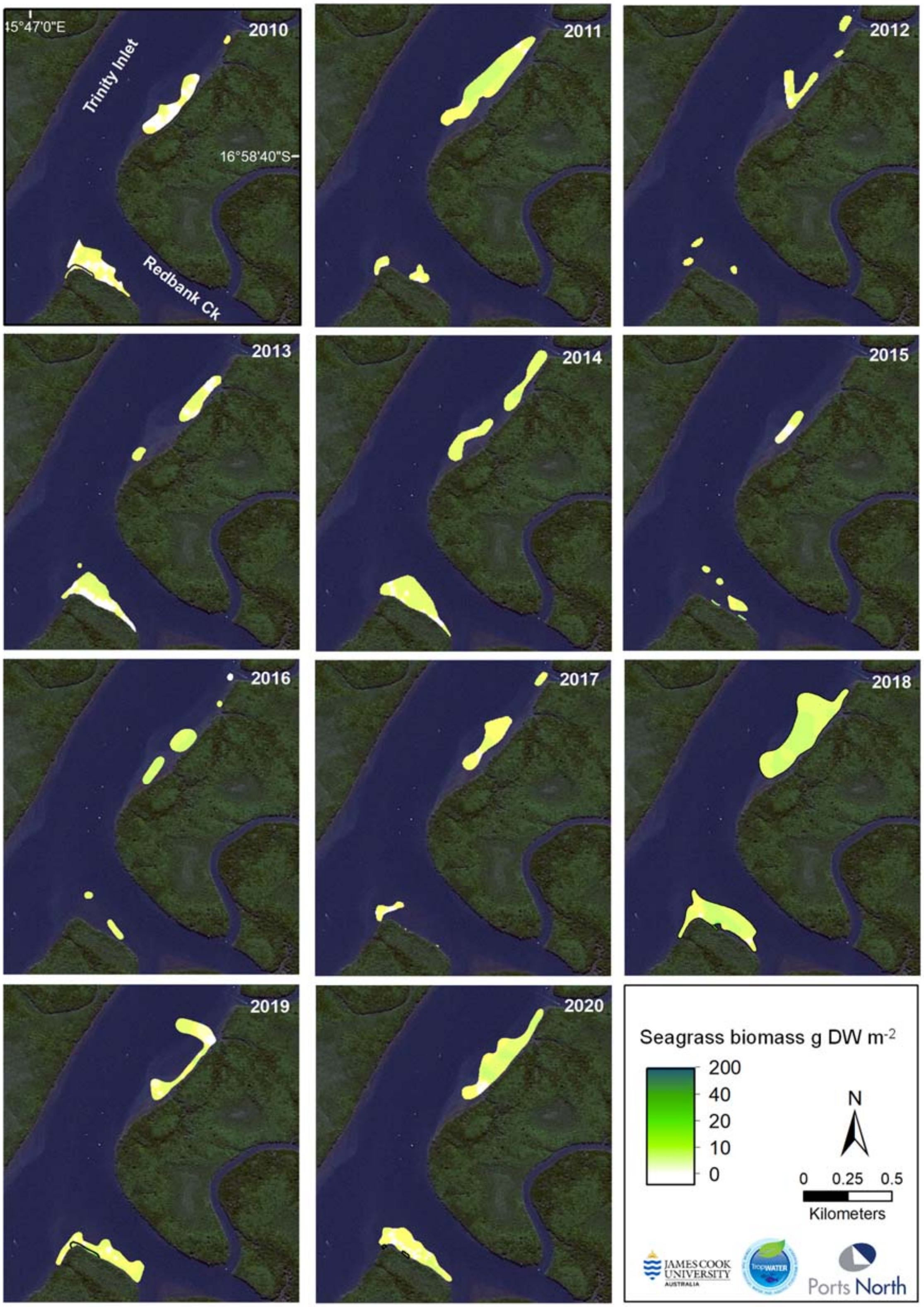
Figure 19: Changes in biomass, area and species composition for the Trinity Inlet *Halophila* meadow (meadow 33) from 2002 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).



Map 8: Esplanade to Ellie Point seagrass monitoring meadows from 2009 to 2020.



Map 9: Bessie Point and South Bessie Point seagrass monitoring meadows from 2009 to 2020.



Map 10: Trinity Inlet seagrass monitoring meadows from 2009 to 2020.

3.2.4 Seagrasses in the broader Cairns area

In 2020, there were an additional 17 seagrass meadows mapped outside of the six regular annually assessed long-term monitoring meadows in the broader Cairns Harbour and Trinity Inlet region. These comprised two meadows in the Cairns Harbour region and 15 small meadows in the Trinity Inlet region (Map 7a and 7b, Table 8). Total seagrass area within the broader Cairns region was similar to last year covering 1,653 ha (Figure 20), but lower than the highest recorded area in 2018 which was 1,960 ha (Figure 20).

The additional meadow on the western side of the Cairns Harbour (Meadow 5) was a large deeper subtidal *Halodule uninervis* meadow adjacent to the Esplanade Meadow (34). On the eastern side of the Harbour an additional deeper subtidal meadow of *Halodule uninervis* (Meadow 14) occurred adjacent to the Bessie Point long-term monitoring Meadow (13) (Map7a; Table 8).

Seagrass in the Trinity inlet region consisted of smaller isolated patches of colonising species *Halophila decipiens* and *Halophila ovalis*. Notably, there was also a small isolated patch of *Zostera muelleri* on the western bank of Admiralty Island (Meadow 43) (Map7b; Table 8).

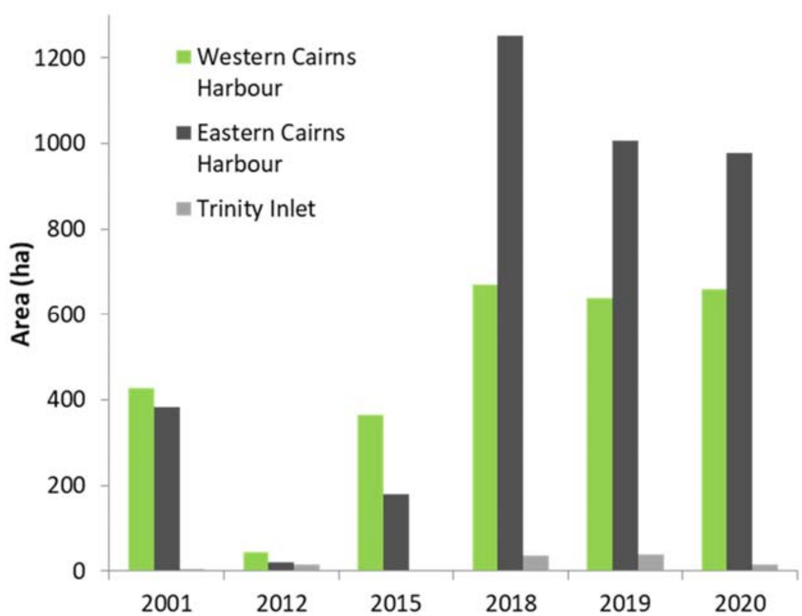


Figure 20: Comparison of total seagrass area (hectares) in the broader Cairns region, for western and eastern Cairns Harbour and Trinity Inlet in 2001, 2012, 2015, 2018, 2019 and 2020.

Table 8: Description of Cairns Harbour and Trinity Inlet seagrass baseline non-monitoring meadows in 2020.

Meadow		Location	Meadow ID	Number of Sites	Habitat Type	Meadow Cover	Meadow Description
Baseline Non-Monitoring Meadows	**Esplanade - Ellie Point**	Cairns Harbour	5	61	Intertidal to subtidal	Continuous cover	Dense *Halodule uninervis*
	South Bessie Inlet	Cairns Harbour	14	2	Subtidal	Aggregated patches	Light *Halodule uninervis*
	Inlet 1	Trinity Inlet	37	1	Subtidal	Isolated patches	Light *Halophila ovalis*
	Inlet 2	Trinity Inlet	39	5	Subtidal	Continuous cover	Light *Halophila decipiens with Halophila ovalis*
	Inlet 3	Trinity Inlet	41	2	Subtidal	Aggregated patches	Light *Halophila decipiens*
	Inlet 4	Trinity Inlet	42	2	Subtidal	Aggregated patches	Light *Halophila decipiens*
	Inlet 5	Trinity Inlet	43	1	Intertidal to Subtidal	Isolated patches	Moderate *Zostera muelleri*
	Inlet 6	Trinity Inlet	45	2	Subtidal	Aggregated patches	Moderate *Halophila decipiens*
	Inlet 7	Trinity Inlet	46	1	Subtidal	Isolated patches	Light *Halophila decipiens*
	Inlet 8	Trinity Inlet	51	3	Subtidal	Isolated patches	Light *Halophila decipiens*
	Inlet 9	Trinity Inlet	55	1	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 10	Trinity Inlet	56	2	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 11	Trinity Inlet	57	1	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 12	Trinity Inlet	58	1	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 13	Trinity Inlet	59	3	Subtidal	Aggregated patches	Moderate *Halophila decipiens*
	Inlet 14	Trinity Inlet	60	1	Subtidal	Isolated patches	Moderate *Halophila decipiens*
	Inlet 15	Trinity Inlet	61	2	Subtidal	Aggregated patches	Light *Halophila decipiens*

3.3 Seed bank assessment

In April 2020, *Zostera muelleri* seeds in Cairns Harbour declined from the previous year to 3.68 ± 1.71 seeds m^{-2} with 0.63 seeds m^{-2} being viable (Table 9). This was only the second year that seeds have been sampled at the more expansive meadow scale, however this was also substantially 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). The results for the seed bank assessment in the two larger meadows Esplanade (34) and Bessie Point (11) over the past two years 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 declined in both meadows between 2019 and 2020 (Table 10).

Table 9: Mean Cairns Harbour and Trinity Inlet 2014-2020 *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

NA = not assessed.

Table 10: Mean Cairns Harbour 2019-2020 *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}**	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

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 May and June in 2020 light dropped below the *Zostera muelleri* threshold for brief periods intermittently 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 2020 the maximum benthic water temperatures were warmer than 2019 with some peaks occurring during October (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 Bessie Point light logging site showed PAR similar to the Esplanade site E with some dips below seagrass growth thresholds during the summer months of February and March and the winter months of May, June and July (Figure 22). The Redbank Creek PAR site has shown light is consistently below growth thresholds for 7 months from January to August, however improves for the growing summer months (Figure 22).

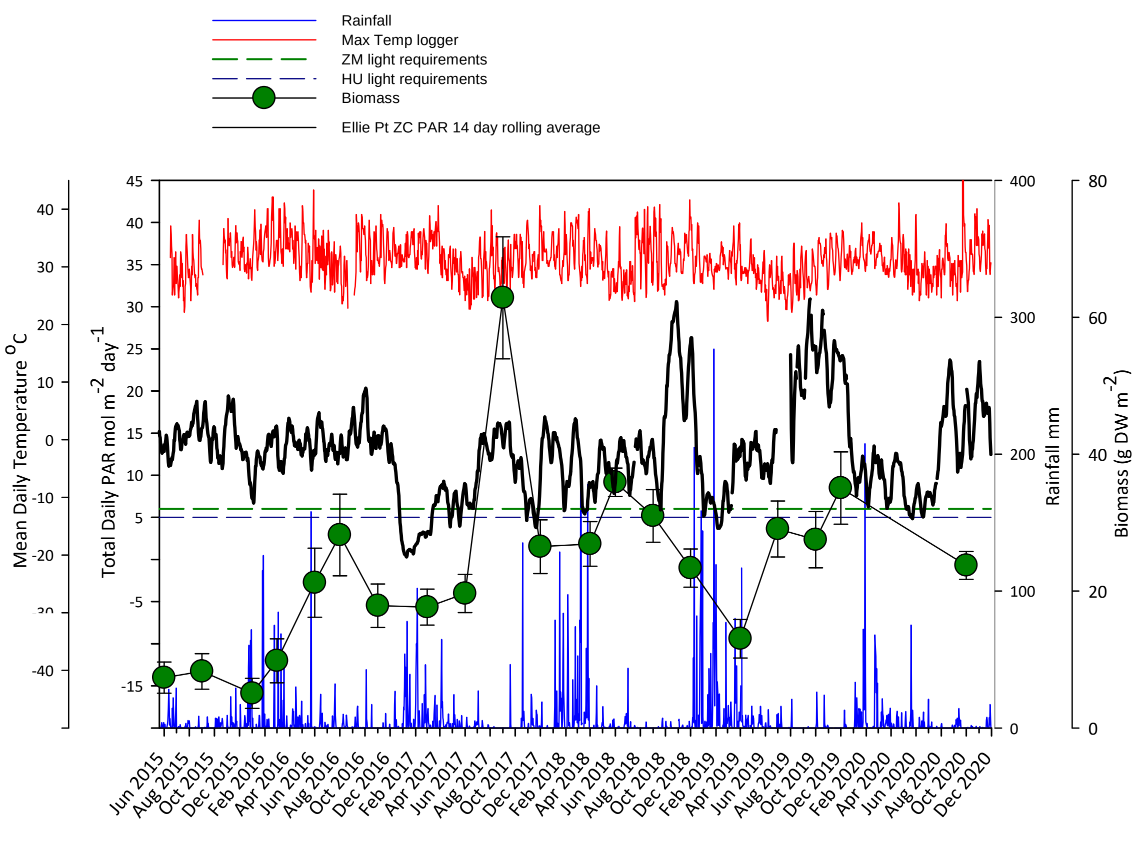


Figure 21: Total daily irradiance (mol m^{-2} day^{-1}), mean daily temperature (° C), and total daily rainfall (mm) and biomass (g DW m^{-2}) for the intertidal Cairns Harbour quarterly monitoring Site E, October 2020 biomass is Meadow 34. All data is from June 2015 to December 2020. Daily rainfall data source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

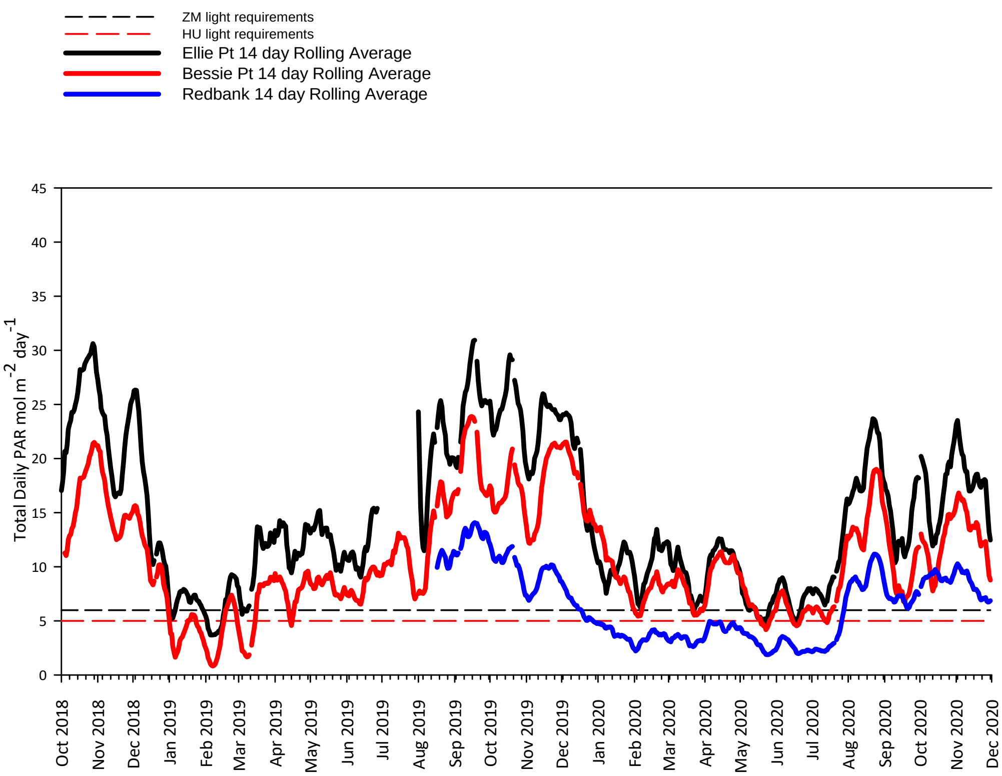


Figure 22: 14 day rolling average of total daily PAR (mol m^{-2} day^{-1}), for the three PAR monitoring stations in Cairns Harbour and Trinity Inlet in relation to seagrass light thresholds from October 2018 to December 2020.

3.5 Cairns environmental conditions

3.5.1 Rainfall

In 2020 the total annual rainfall in the Cairns region was below the long-term average (2015.14 mm) and at a six year low (Figure 23). Rainfall was below average for most of the year apart from some peaks in January, May and September (Figure 23). The months leading up to the survey showed mixed totals of above and below average, with minimal rainfall the month before the survey (Figure 23).

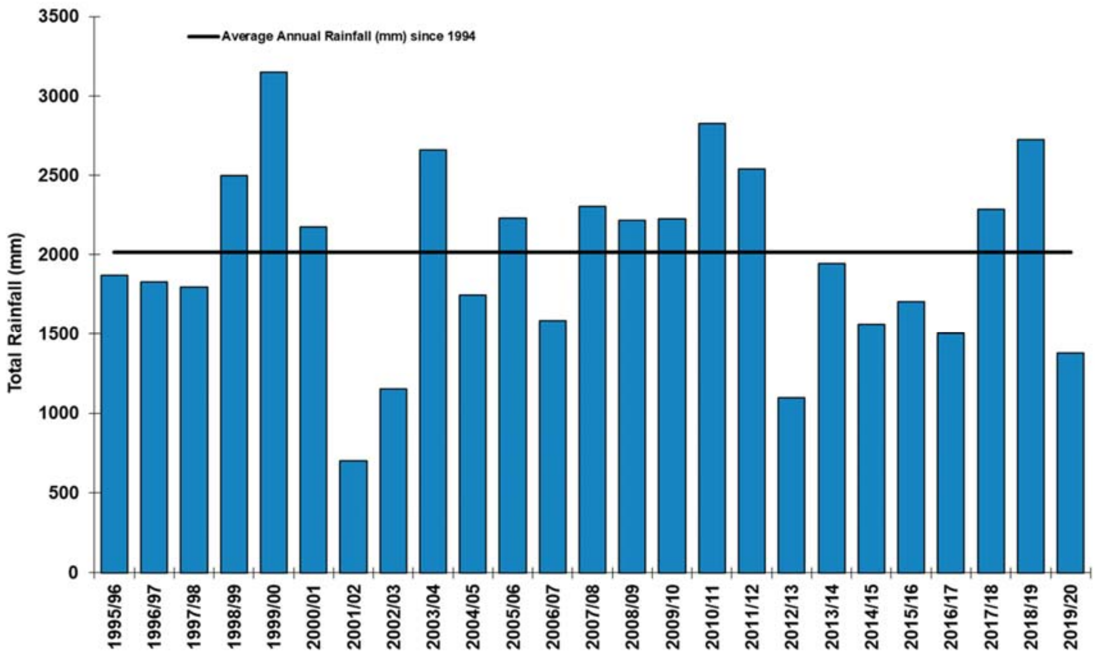


Figure 23: Total annual rainfall (mm) recorded at Cairns Airport, 1995 – 2020. Twelve month year (2019/20) is 12 months prior to survey. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

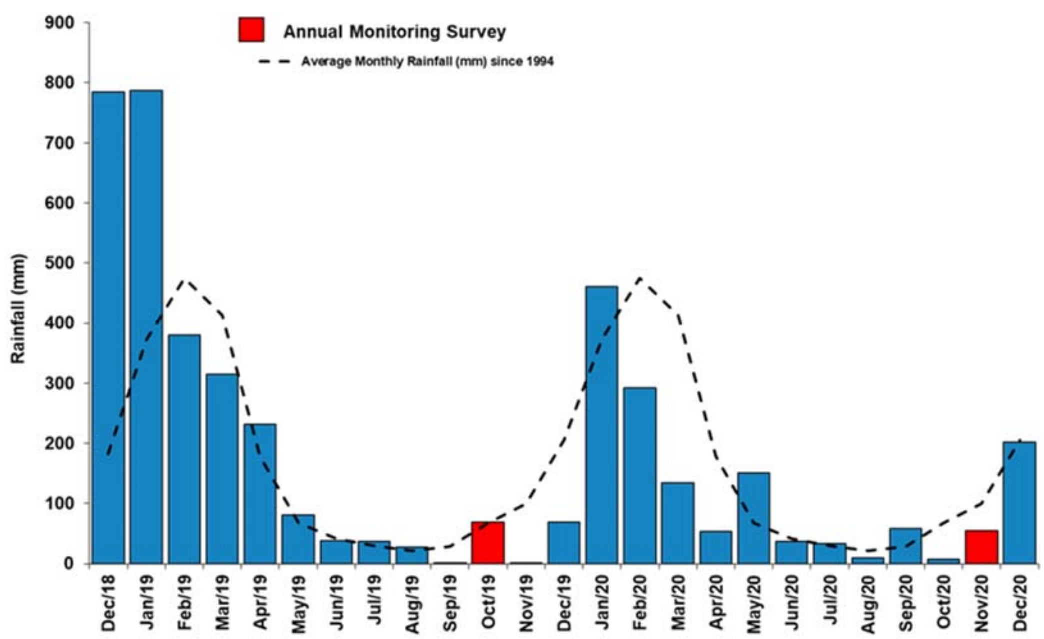


Figure 24: Total monthly rainfall (mm) recorded at Cairns Airport, December 2018 – December 2020. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

3.5.2 River Flow (Barron River)

River flow of the Barron River in 2019/2020 (251,740 ML) was below the long-term average of 711,304 ML (Figure 25), and the lowest recorded since 2015/2016. During December 2019 to March 2020, the summer months, river flow was well below average, while the three months prior to the 2020 survey river flow was closer yet still below the long-term average (Figure 26).

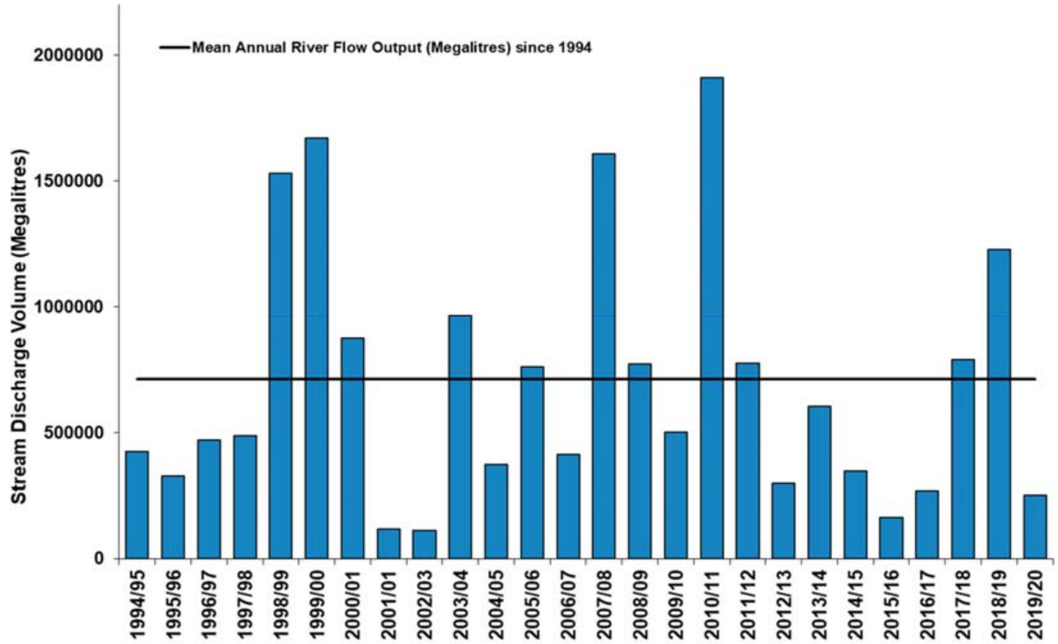


Figure 25: Annual water flow (mega litres) for the Barron River recorded at Myola, 1995 – 2020. Twelve month year (2019/20) is 12 months prior to survey. Source: Queensland Department of Environment and Resource Management, Station 110001D, available at: http://watermonitoring.derm.qld.gov.au/host.htm

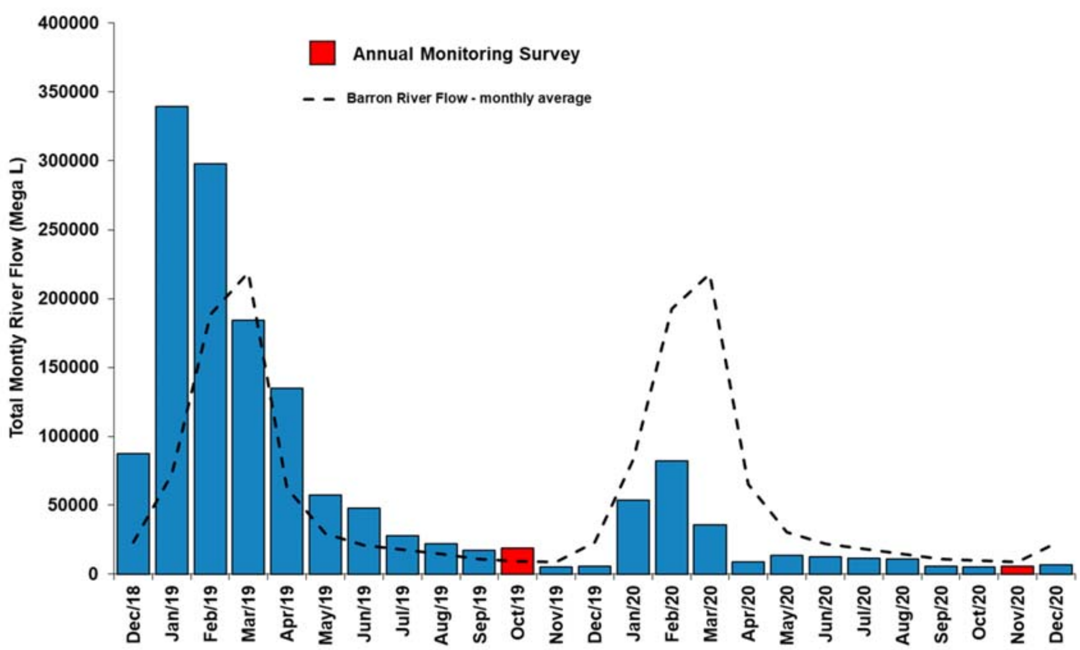


Figure 26. Monthly water flow (mega litres) for the Barron River recorded at Myola, December 2018 to December 2020. Source: Queensland Department of Environment and Resource Management, Station 916001B, available at: http://watermonitoring.derm.qld.gov.au/host.htm

3.5.3 Air Temperature

Annual maximum daily air temperature recorded at Cairns Airport in 2019-2020 (30.3°C) was above the long-term mean (29.4°C) (Figure 27). Every month in 2020, apart from May, was above the long-term average monthly maximum air temperature, including the 3 months prior to the survey (Figure 28).

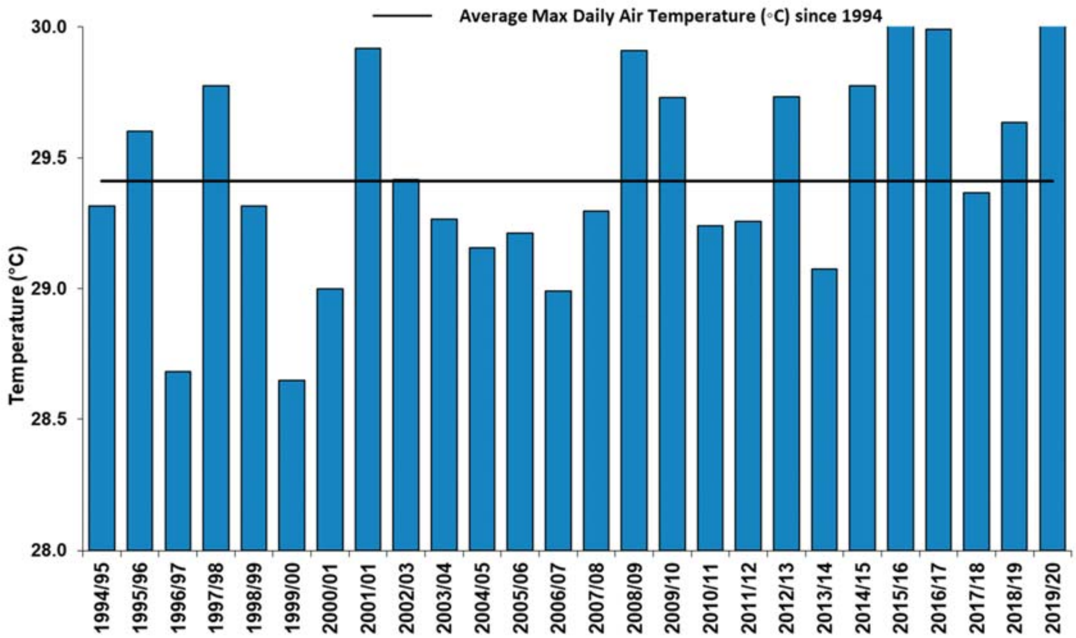


Figure 27: Mean annual maximum daily air temperature (°C) recorded at Cairns Airport, 1994 – 2020. Twelve month year (2019/20) is 12 months prior to survey. Source: Bureau of Meteorology, Station 031011, available at: www.bom.gov.au.

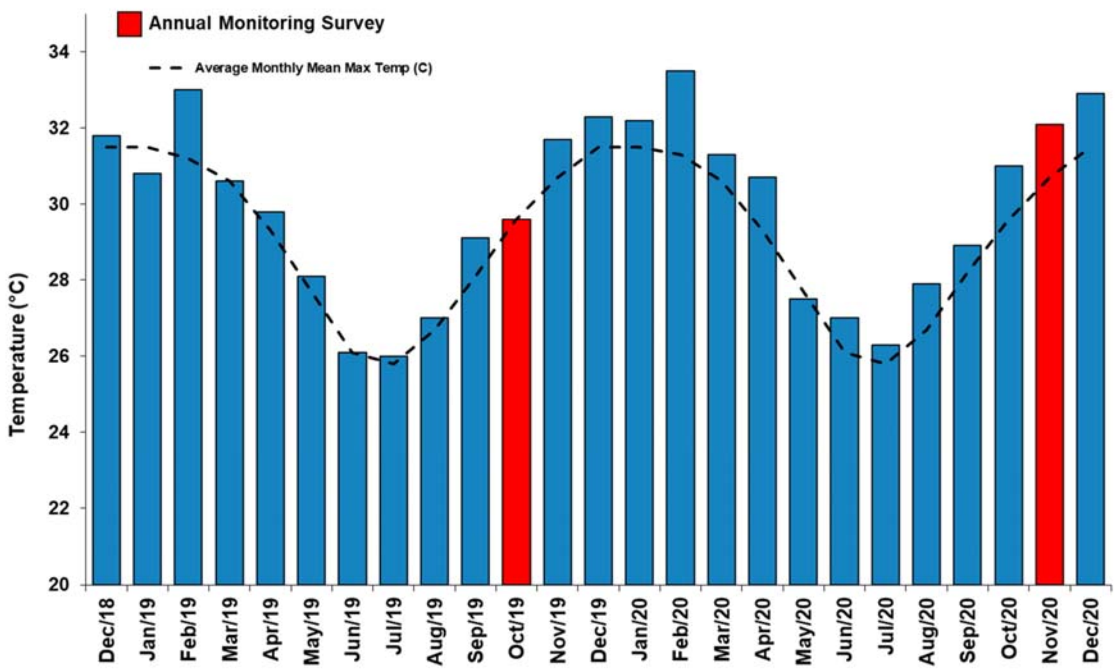


Figure 28: Monthly mean maximum daily air temperature (°C) recorded at Cairns Airport, December 2018 – December 2020. Source: Bureau of Meteorology, Station 31011, available at: www.bom.gov.au.

3.5.5 Tidal Exposure of Seagrass Meadows

Annual daytime tidal air exposure of intertidal meadows was the lowest in 6 years and below the average recorded (216 hrs) over the 17 year duration of the seagrass monitoring program (Figure 29). August was the only month during 2020 that the intertidal areas in Cairns Harbour were exposed for the longest daytime period (Figure 30).

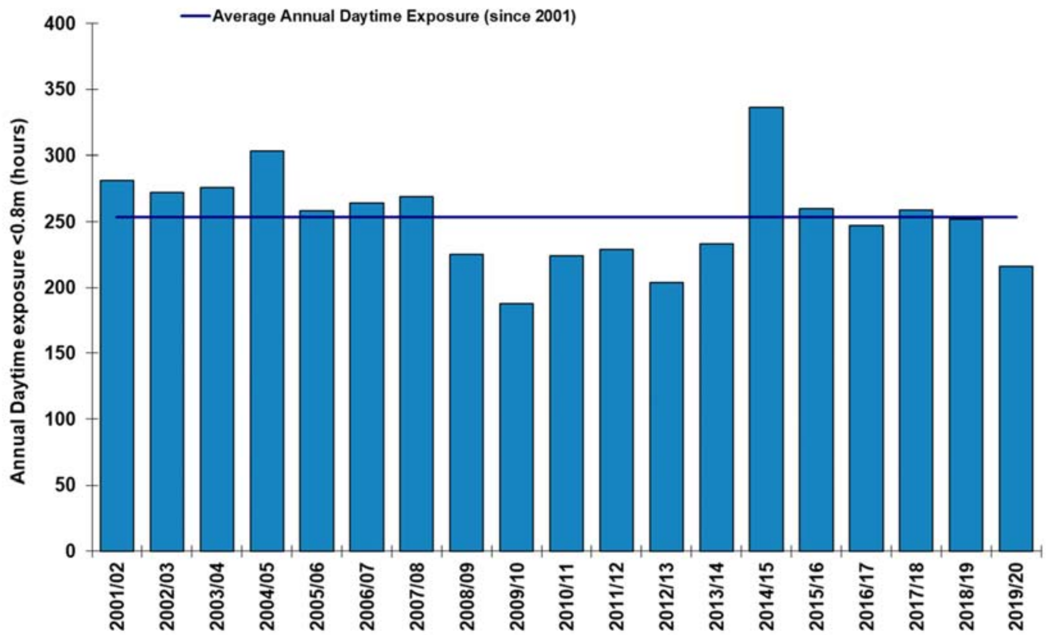


Figure 29: Annual daytime tidal exposure (total hours)* of seagrass meadows in Cairns Harbour; 2001 - 2020. Twelve month year is 12 months prior to survey. Source: Maritime Safety Queensland, 2020. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

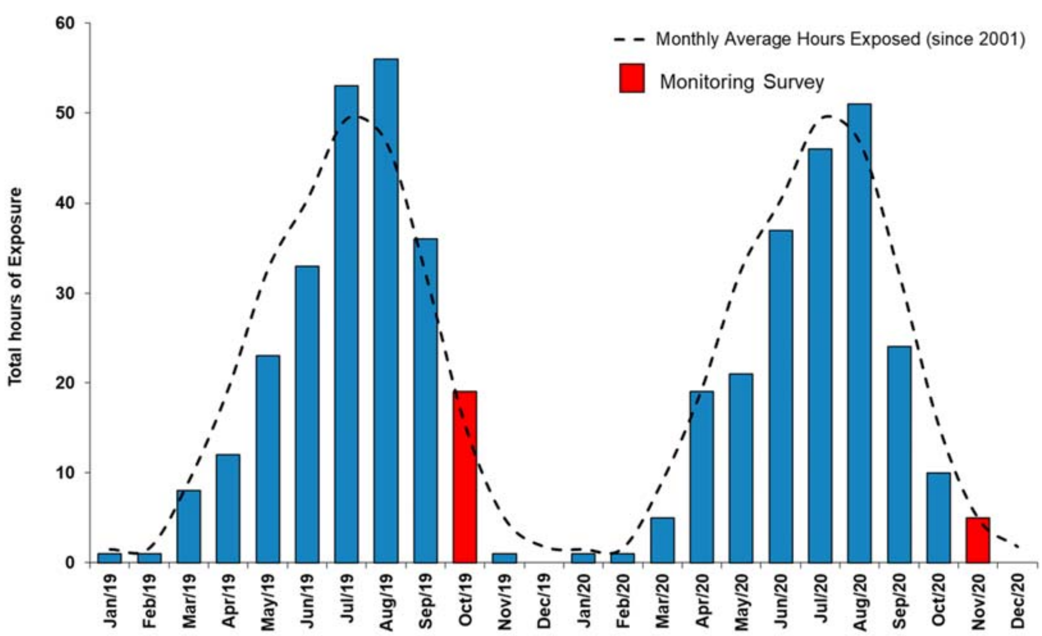


Figure 30: Total monthly daytime tidal exposure (total hours)* in Cairns Harbour; January 2018 – December 2020. Source: Maritime Safety Queensland, 2019. *Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

4 DISCUSSION

Seagrasses in Cairns Harbour and Trinity inlet have continued to improve in area biomass and species composition since large climate related declines that occurred leading up to 2011. In 2020 long-term seagrass monitoring meadows in Cairns Harbour and Trinity Inlet were collectively in a satisfactory condition with the largest meadows in Cairns Harbour all in good to very good condition and fully recovered from the 2009-2011 declines. Seagrass meadows maintained a viable seed-bank in 2020 although numbers had declined from the previous year. The intensive monitoring meadows adjacent to the CSDP operation have improved in both biomass and area during the dredging and in the 14 months post works. The broader port wide seagrass assessments mapped 1,659 ha of seagrass maintaining a substantial footprint of seagrasses within the greater port limits.

The Cairns Harbour meadows have shown continual improvement over the last 10 years and are now considered in good condition. All three monitoring meadows in Cairns Harbour were rated as good or very good as biomass and species composition have improved. All meadows are now dominated by large persistent species traditionally found in each meadow (*Z. muelleri* or *H. uninervis* depending on the meadow). The Esplanade *Z. muelleri* meadow has been the slowest to recover but in 2020 biomass improvements here, would suggest that Cairns harbour meadows can be considered as having fully recovered from the 2009-2011 large scale declines (McKenna et al. 2015).

The smaller Trinity Inlet meadows have been far more variable than the substantive areas of seagrass in Cairns Harbour. While collectively rated as being in poor condition this was really down to a shift in species from *Halophila ovalis* to *Halophila decipiens* in one meadow and a loss of area for the small patches of *Z. muelleri* in the Redbank Creek meadow. All meadows maintained a relatively high biomass (compared with their baseline state). Both of these changes are good indicators of a reduced light environment, with a shift to a lower light requiring colonising species in one meadow (Chartrand et al 2018) and a reduction in the presence of the higher light requiring *Z. muelleri* in the other (Chartrand et al 2016). The results from light monitoring at the Redbank Creek PAR monitoring support this, with light consistently below the growing requirement for *Z. muelleri* for 7 months from January to August 2020, only a couple of months prior to the survey. As PAR has only been monitored at this site for 12 months, it is difficult to know if this reflects a typical annual cycle of PAR here. The fact that biomass remained good for all meadows and all the relevant species remained present, means they should have the capacity to bounce back with the return of more favourable light conditions. For meadow 19 both of the *Halophila* species have similar morphology, life history strategies and ecological function being fast growing colonising species and composition has alternated between the two species over the years (8 of the 20 years *Halophila decipiens* has been dominant). While the *Z. muelleri* meadow (20) had an area below its expected baseline average in 2020, it was the second highest recorded since 2011.

Unlike the Inlet, Benthic PAR at the two Cairns Harbour monitoring locations was generally well above requirements for positive seagrass growth (see Chartrand et al 2016; Collier et al 2016). The effects of rainfall events in the wet season can be seen in the light (PAR) levels briefly falling below seagrass light requirement following these events (Figures 21 & 22) however, unlike the Inlet site these brief periods were not long enough to reach the point where they would result in loss of seagrass (Collier et al 2016).

Regional and local climate conditions have generally been the major determinant of seagrass condition in tropical North Queensland in recent years (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). High rainfall and associated flooding events degrade the light environment by increasing suspended particles in the water column associated with sediment laden flood plumes from river runoff. Between 2009 and 2011 seagrasses across North Queensland including Cairns Harbour suffered major losses associated with multiple years of La Niña climate conditions (McKenna et al. 2015). These declines were part of regional climate impacts that affected the majority of seagrasses along Queensland's developed east coast (Rasheed et al. 2014; Coles et al. 2015). In 2020, Cairns received below average rainfall, river flow and tidal exposure providing light conditions that allow seagrass to grow rapidly reflected in the increased seagrass biomass, area and presence of larger higher light requiring species such as *Z. muelleri* and *C. serrulata*.

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). Seed bank monitoring has been conducted at a small (50 x 50m) area of the Esplanade meadow between 2014 and 2018 but in the last two years that sampling has expanded to encompass the entirety of the two major seagrass meadows in the Harbour. 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 2019 as meadows recovered. With the shift to sampling over larger meadow scale there has been a reduction in seed-bank density and between 2019 and 2020 a reduction in both the total numbers and the proportion of seeds that were determined to be viable. There could be a range of reasons for this including, poor flowering conditions limiting seed production or potentially high levels of germination facilitating the observed expansion of seagrass meadows during 2020. Optimal flowering conditions and cues in seagrasses are poorly understood but thought to relate to water temperature and day length (York et al. 2017, Qin et al. 2019; Smith et al. 2016). In 2020 there remained a viable seed bank but total seed numbers were low compared to other similar meadows that have been assessed (Conacher et al. 1994a; Conacher et al. 1994b).

The potential for delayed impacts to seagrass from the CSDP is 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 remained in a good condition 14 months later means they were well placed to continue to thrive. To ensure this is the case Ports North have engaged JCU to continue the expanded whole of port scale seagrass assessments until the end 2021 and the key CSDP seagrass meadows remain part of the long-term seagrass monitoring strategy for Cairns beyond 2021.

The improvements observed in 2020 for Cairns Harbour seagrasses mean they have re-established 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 larger growing foundation species *Zostera muelleri*, above average biomass, the large spatial footprint of meadows compared with their long-term history and the continued presence of a seed bank.

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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			Decrease below threshold from previous year		

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).

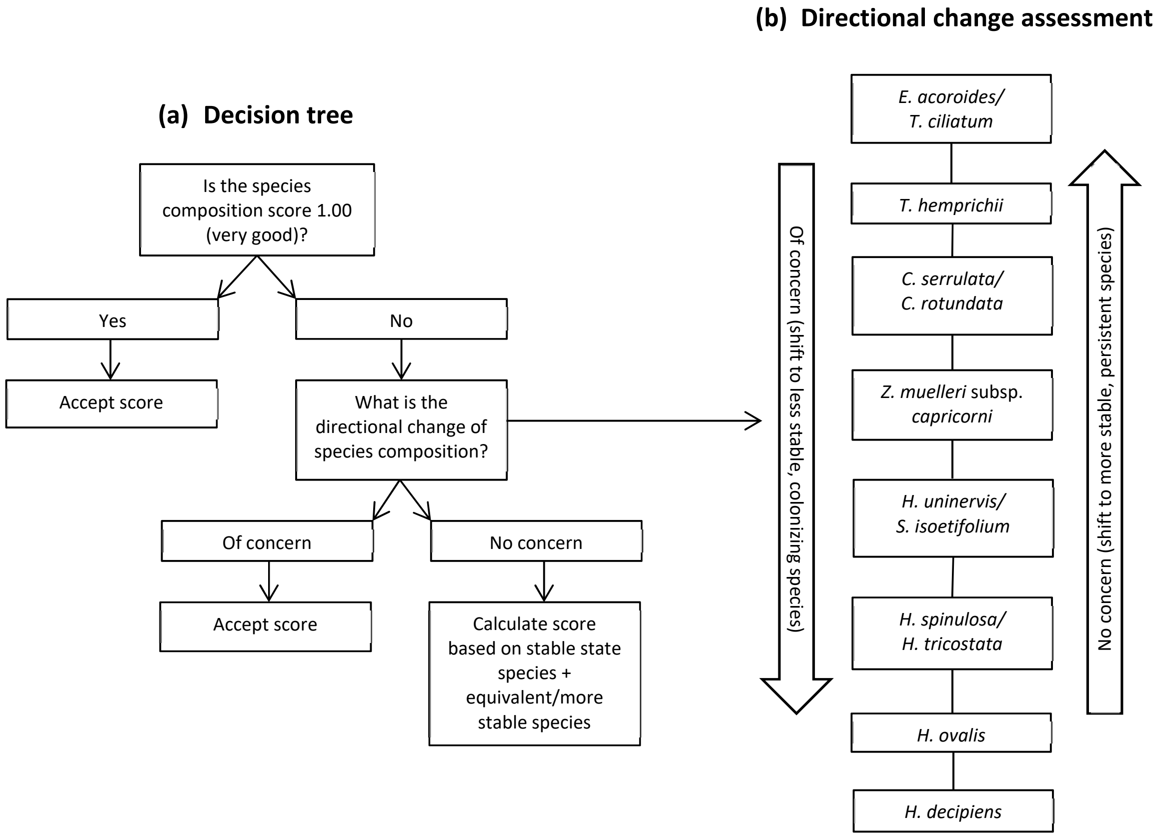


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Cairns.

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 ($B_{satisfactory}$):

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

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:

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

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:

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

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:

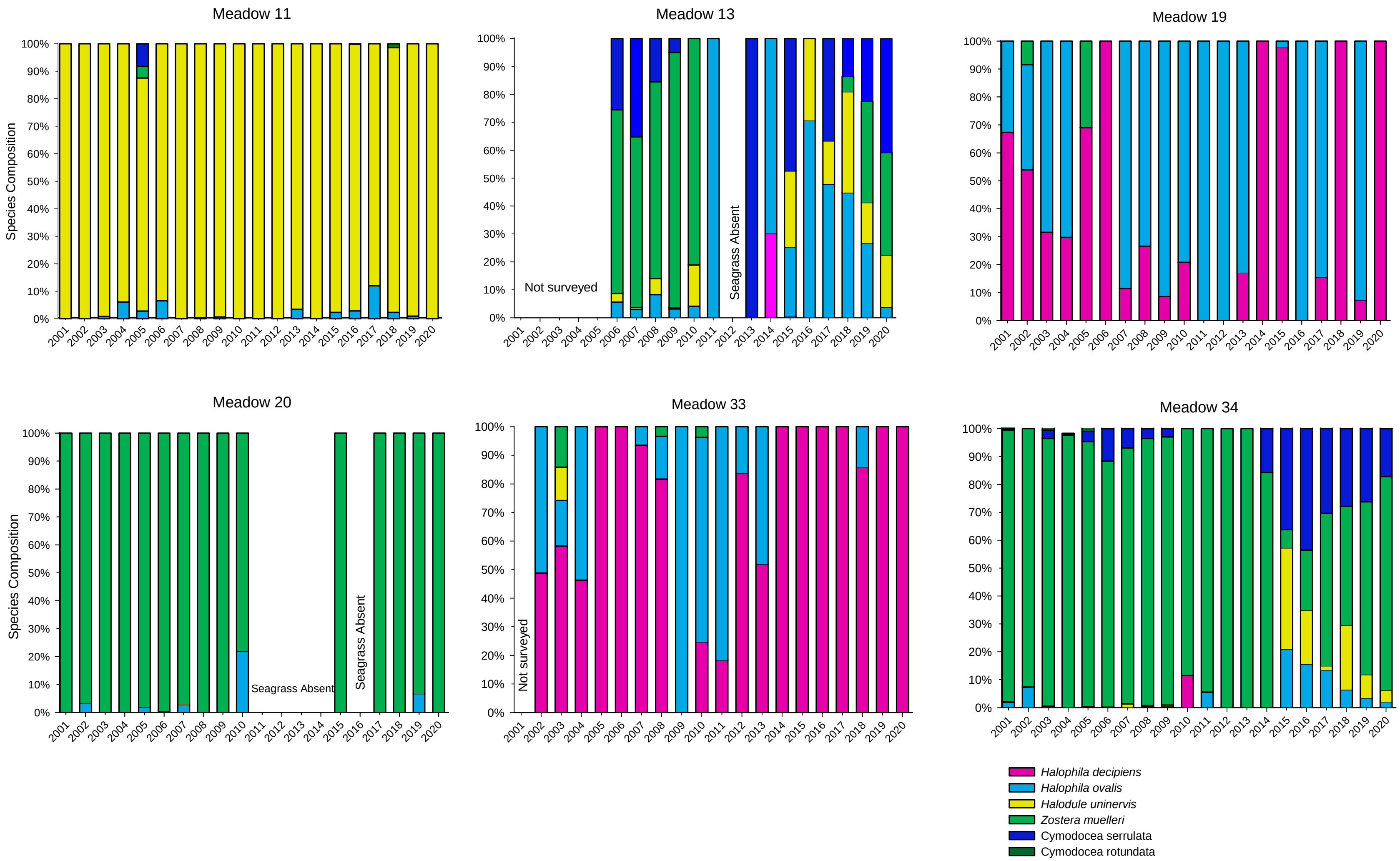
$$\mathrm{Score_{2018}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

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 – 2020

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

Species composition of monitoring meadows in Cairns Harbour and Trinity Inlet; 2001 – 2020



Appendix 3.2: Cairns Harbour historical seagrass monitoring meadow area.

Seagrass monitoring meadow area (ha) in Cairns Harbour and Trinity Inlet, 2001-2020; ± 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**
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
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
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
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
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
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
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**

NP = meadow not present
NA = meadow not assessed

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, 2001-2020.

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**
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
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
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
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
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
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

^ 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*)