SEAGRASS HABITAT IN THE PORT OF THURSDAY ISLAND:

Annual Monitoring Report 2022

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Seagrass Habitat in the Port of Thursday Island: Annual Monitoring Report 2022

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Seagrass Condition 2022

Good

KEY FINDINGS

- Aerial and boat surveys of seagrass monitoring meadows and a whole of port survey were conducted between 23rd - 28th March 2022.
- The overall condition of the annual monitoring meadows in the Port of Thursday Island remained in good condition in 2022 with all meadows in good or very good condition.
- The combined area of annual monitoring meadows was the highest recorded in the program in 2022.
- Many of the intertidal meadows continued to shift towards larger growing more stable seagrass species.
- Climate conditions were favourable for seagrass growth in 2022.
- There were declines in the overall seagrass area in the whole of port survey, driven by declines in deep-water species also doumented in other areas.
- In the intertidal and shallow subtidal whole of port meadows, area remained stable overall and there were large increases in seagrass biomass which were driven by a shift towards higher biomass species.
- These results point to a healthy and resilient seagrass community in the Port of Thursday Island, and a key indicator of a healthy marine environment in the port in 2022.

IN BRIEF

Seagrasses have been monitored in the Port of Thursday Island biennially since 2002 and annually since 2016. Nine seagrass meadows representing the range of different seagrass community types found in the Thursday Island region are monitored and assessed for changes in area, biomass, and species composition. These indicators are used to develop a seagrass condition index (see section 2.3 of this report for further details). In addition, every three years all seagrasses within the greater port limits are mapped and assessed, this was also conducted in March 2022

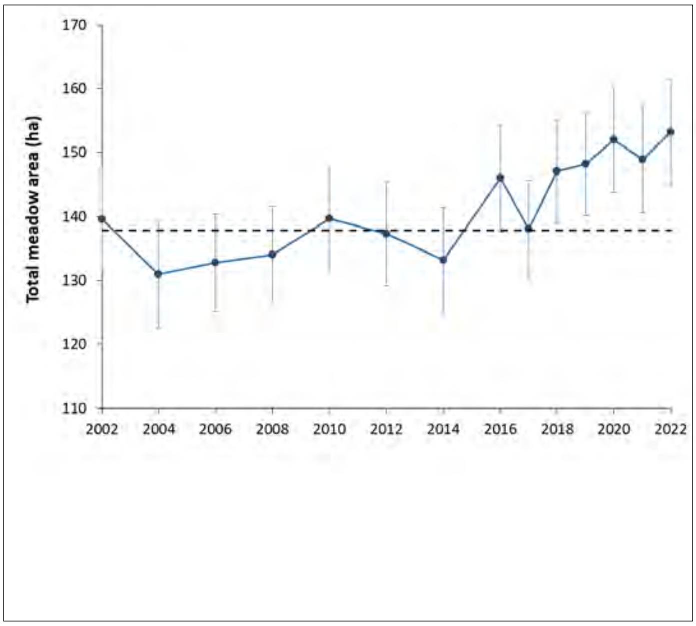


Figure 1. Total area of seagrass within the Thursday Island monitoring meadows from 2002 to 2022 (error bars = "R" reliability estimate). Dashed line indicates long-term average of meadow area.

In March 2022 the overall condition of seagrass in the Port of Thursday Island annual monitoring meadows was good and all meadows were in good or very good condition. The total area of 153 ± 8 ha of seagrass habitat mapped within the nine monitoring meadows in 2022 was the largest recorded since monitoring began in 2002 (Figure 1).

All meadow indicators in monitoring meadows remained in good or very good condition in 2022.

There was a decline in meadow area in the whole of port survey compared with the two previous port limits surveys (2019; 2002), concentrated in the deep-water meadows (Figure 2).

Climate conditions were favorable leading up to the March 2022 survey with no major storms or cyclones affecting the area. Air temperature, solar radiation, rainfall and exposure were above average in 2021/22 (Figure 3). As a consequence seagrass condition in the monitoring meadows remained stable and in good to very good condition, with a record high area, and some meadows having the highest biomass recorded in the program. Declines in the deeper water seagrass meadows compared with three years prior, in the whole of port area are consistent with other areas in Torres Strait, and these regional declines are a cause for concern, however there were also increases in area and large biomass increases in the shallower non-monitoring meadows.

All of these results point to a healthy and resilient seagrass community in the Port of Thursday Island and a key indicator of a healthy marine environment in the port in 2022. This is in contrast to other seagrass meadows in the Torres Strait particularly in the Central and Western Cluster areas where declines in seagrasses have been observed in 2021. At Weipa, the next closest seagrass long-term monitoring location to Thursday Island (Figure 4), seagrasses were similarly in a good condition. For full details of the Queensland ports seagrass monitoring program see: https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

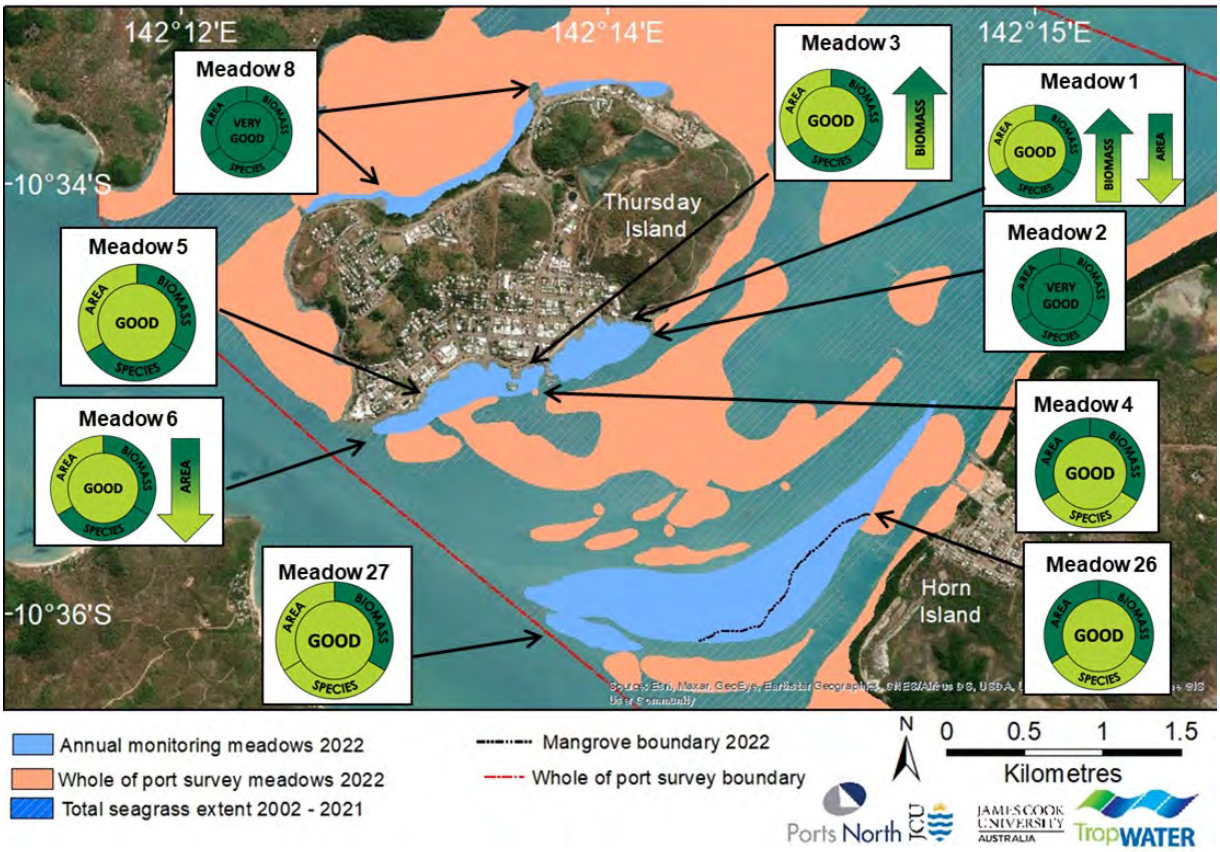


Figure 2. Seagrass condition for Port of Thursday Island annual monitoring meadows in 2022.

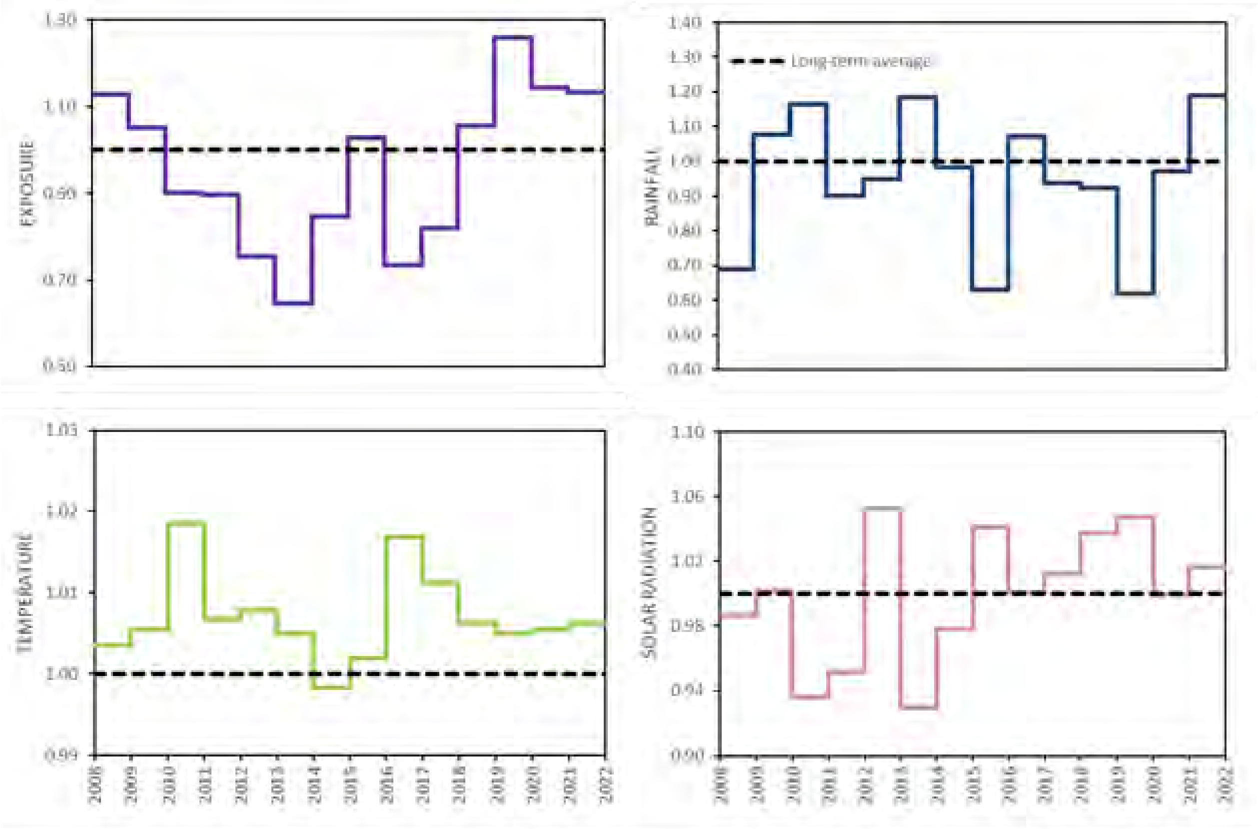


Figure 3. Diagrammatic summary of climate trends in Thursday Island: changes in climate variables as a proportion of the long-term average. See Section 3.4 for detailed climate data.

Contents

1 INTRODUCTION

Seagrasses are one of the most productive marine habitats 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 (Scott et al. 2018; Heck et al. 2008). Seagrasses play a major role in the cycling of nutrients (McMahon and Walker 1998), stabilisation of sediments (Madsen et al. 2001), improving 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).

1.1 Queensland Ports Seagrass Monitoring Program

The majority of Queensland's commercial ports have a long-term seagrass monitoring and assessment program. The program was developed by the Seagrass Ecology Group at James Cook University's (JCU) Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with Queensland port authorities. A common program methods and rationale provides a network of seagrass monitoring locations comparable across the State (Figure 4).

A strategic long-term assessment and monitoring program for seagrass provides port managers and regulators with key information to ensure effective management of seagrass habitat. This information is central to planning and implementing port development and maintenance programs that ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass. The program also has provided significant advances in the science and knowledge of tropical seagrass ecology. This includes the development of tools, indicators, and thresholds for the protection and management of seagrass, and an understanding of the drivers of seagrass change.

Figure 4. Location of Queensland Port seagrass assessment sites.

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

1.2 Seagrass Monitoring Program

Torres Strait Island communities rely on coastal marine habitats for subsistence, and have strong cultural and spiritual links to these environments. Due to the high reliance on fishing in the Thursday Island area, habitats that support commercial and traditional fisheries, such as seagrasses, are of critical importance to the region. The loss of seagrass habitat in Torres Strait would have detrimental effects on the species reliant on seagrass, and local island communities. For example, substantial seagrass diebacks (up to 60%) have been documented twice in central Torres Strait and linked to dramatic increases in local dugong mortality (Marsh et al. 2004; Long and Skewes 1996). Threats to seagrass in the region include shipping-related oil spills and structural habitat damage, climate change (Carter et al. 2014) and seagrass diebacks. Torres Strait seagrass distribution, density and species composition also varies significantly seasonally and annually, with change largely driven by environmental conditions (Carter et al. 2014; Mellors et al. 2008).

Following a fine-scale baseline survey of seagrass habitat conducted at the port in March 2002, an annual seagrass monitoring program was established consisting of a subset of nine representative meadows in the port (annual monitoring meadows). The monitoring meadows represent the range of seagrass species, habitat types (intertidal and subtidal) and meadow community types identified within the port limits. The results from the program inform an evaluation of the health of the port marine environment and help identify possible detrimental effects of port operations on seagrass meadows. The program also provides an assessment of climate-related influences on seagrass meadows, and acts as a reference tool for other organisations involved in management of community use of the inshore area. Results of this program also form a critical component of the Torres Strait wide regional assessment and reporting on seagrass condition to aid in management of the Torres Strait seagrass resources and their reliant fish and animal communities (see Carter et al. 2020).

This report presents results of the March 2022 annual seagrass monitoring and the updated whole of port survey, including:

- Maps of seagrass distribution, abundance and species composition within the long-term annual monitoring meadows and within the whole of port area;
- Assessments of seagrass condition in the monitoring meadows within the context of historical seagrass conditions and discussion of the observed changes in a regional and state-wide context;
- Comparison with the previous whole of port surveys of the extent and composition of seagrass meadows not included in annual monitoring meadows;
- Discussion of the implications of monitoring results in relation to the overall health of the marine environment in the port.

2 METHODS

2.1 Field surveys

Survey and monitoring methods followed the established techniques for JCU's Queensland-wide seagrass monitoring programs. The annual seagrass monitoring surveys of the nine long-term monitoring meadows (Figure 2) were conducted on 23 – 28th March 2022. In addition to the annual monitoring survey, mapping was extended to update the distribution of seagrasses within the whole of port limits area which was last conducted in 2019, this involved mapping and assessing all intertidal areas surrounding Thursday Island between Hammond to Horn Islands (Figure 8).

Intertidal meadows were sampled at low tide using a helicopter. GPS was used to map the position of meadow boundaries and sites for assessment were scattered haphazardly within each meadow. Sites were assessed as the helicopter hovered less than one metre above the substrate (Figure 5 A). Shallow subtidal meadows were sampled by boat using camera drops and van Veen grab (Figure 5 B, C). A Van Veen sediment grab (grab area 0.0625 m^{-2}) was used to confirm sediment type and seagrass species. Subtidal sites were positioned at approximately 50 to 100 m intervals on a transect 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 5. Seagrass monitoring methods. (A) helicopter aerial surveillance, (B, C) boat-based camera drops.

2.1.1 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. Three separate ranges were used - low, high and *Enhalus* biomass. The percentage contribution of each species to each quadrat's biomass also was recorded.

At the survey's completion the 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 estimates 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.

Results from previous surveys suggested the analysis of biomass for meadows where the large growing species *E. acoroides* was present but not dominant required a different method compared to meadows where *E. acoroides* was dominant (Roelofs et al. 2003). The dry weight biomass for *E.*

acoroides is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Therefore, isolated *E. acoroides* plants occurring within the *H. uninervis* dominated meadows (Meadows 1, 3, 5 and 8) were excluded from biomass comparisons in order to track the dynamics of these morphologically distinct species.

2.1.2 Geographic Information System

All survey data was entered into a Geographic Information System (GIS) using ArcGIS 10.8®. Satellite imagery of the Thursday Island 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 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1, 2), meadow landscape category (Figure 6).
- 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 6. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

Table 1. Nomenclature for seagrass community types.

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 2. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community type in the Port of Thursday Island.

Density	Mean-above ground biomass (g DW m^{-2})					
	***H. uninervis* (narrow)**	***H. ovalis* *H. decipiens***	***H. uninervis* (wide) *C. serrulata/rotundata* *S. isoetifolium***	***T. hemprichii* *H. spinulosa***	***Z. muelleri***	***E. acoroides* *T. ciliatum***
Light	< 1	< 1	< 5	< 15	< 20	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60	40 - 100
Dense	> 4	> 5	> 25	> 35	> 60	> 100

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 3). 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 1). Community density was based on mean biomass of the dominant species within the meadow (Table 2).

Table 3. Mapping precision and methods for seagrass meadows in the Port of Thursday Island 2020/21.

Mapping precision	Mapping method
1-10 m	Meadow boundaries mapped in detail by GPS from helicopter; Some meadow boundaries mapped by walking; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent aerial photography aided in mapping.
10-50 m	Meadow boundaries determined from helicopter and camera/grab surveys; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and aerial photography; Relatively high density of mapping and survey sites.

2.3 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 Thursday Island 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 7 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculations.

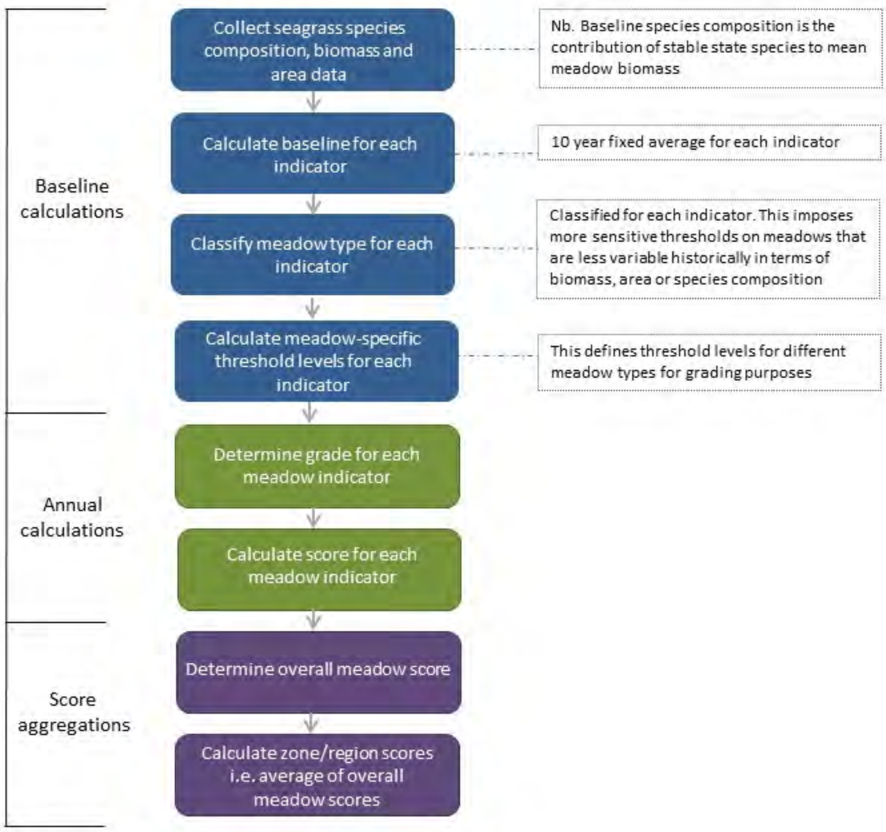


Figure 7. Flow chart to develop Thursday Island grades and scores.

3 RESULTS

3.1 Seagrasses in Thursday Island

A total of 277 sites were surveyed in the 2022 annual monitoring survey, with an additional 445 sites in the whole of port area (Figure 8). Eleven seagrass species were recorded with 24 seagrass community types identified throughout the port (Figure 9; Table 4). The total area of seagrass habitat mapped within the nine annual monitoring meadows was 153 ± 8 ha (Figure 1).

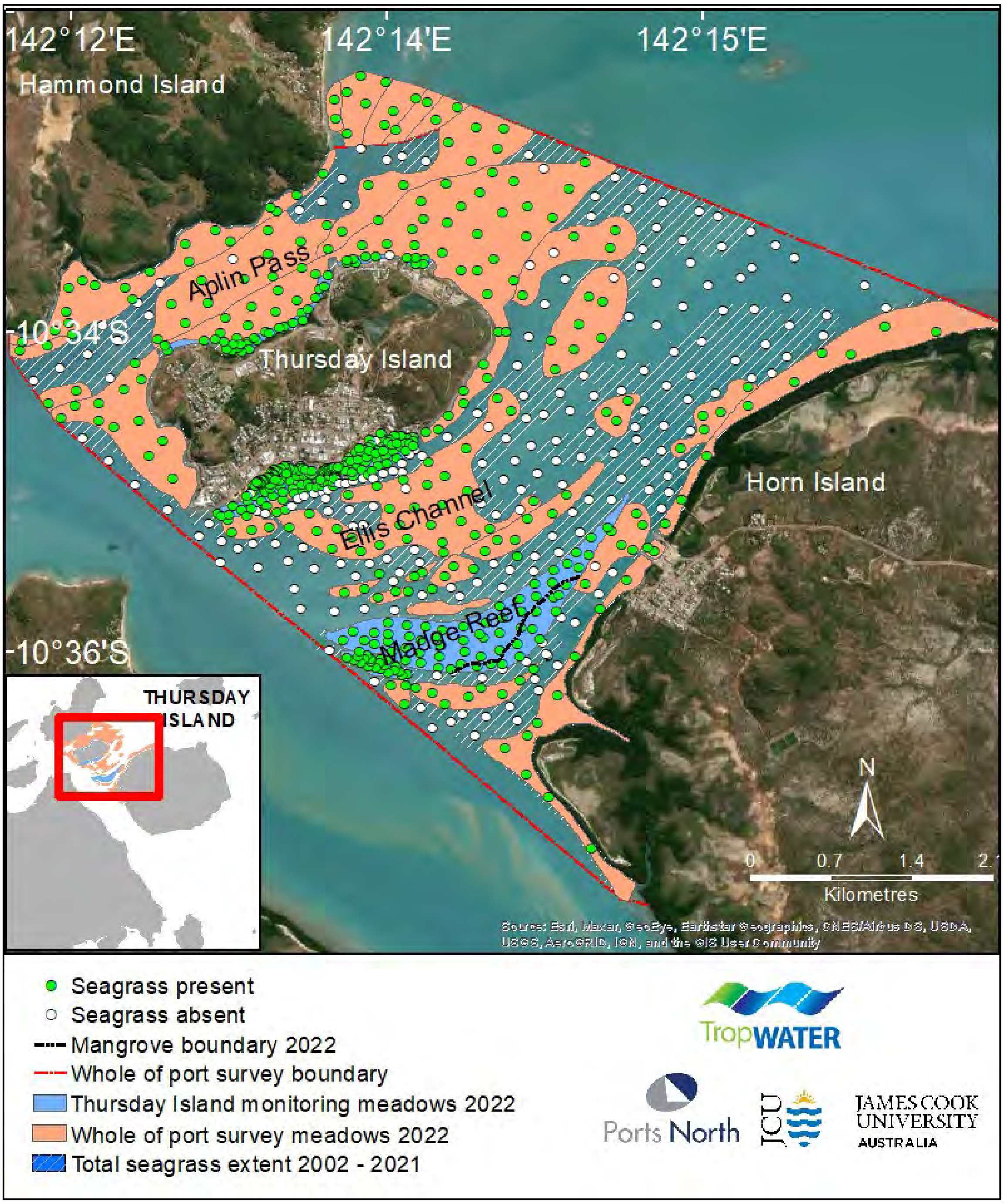


Figure 8. Port of Thursday Island seagrass meadows and seagrass presence/absence at sites surveyed for the whole of port survey meadows in 2022.

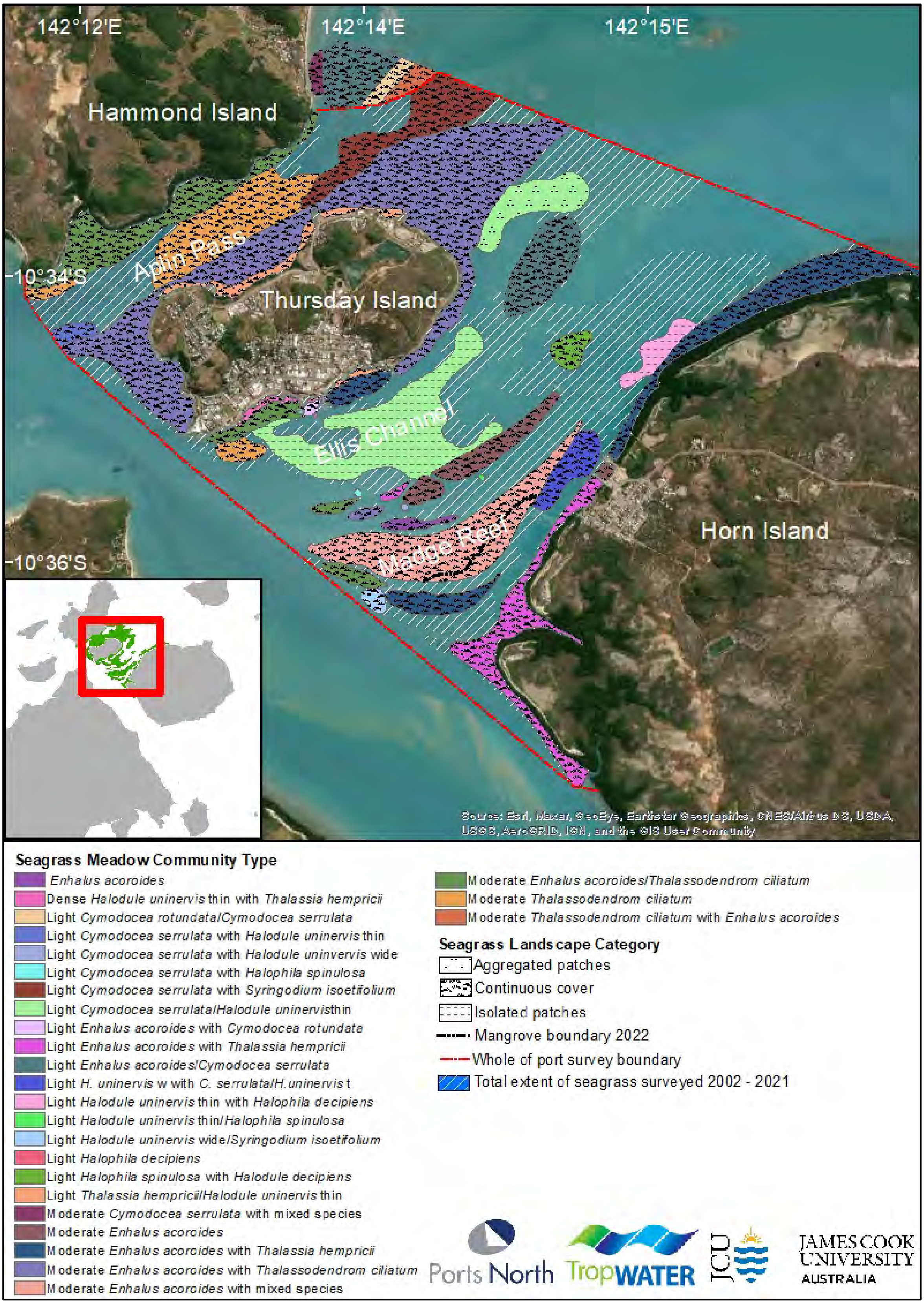


Figure 9. Port of Thursday Island seagrass distribution and community type for seagrass meadows for whole of port survey in 2022.

Table 4. Seagrass species present at the Port of Thursday Island in 2022.

FAMILY	SPECIES			
CYMODOCEACEA E Taylor		*Cymodocea serrulata* (R.Br.) Aschers and Magnus		*Halodule uninervis* (thin and wide leaf morphology) (Forssk.) Boiss.
		*Cymodocea rotundata* Asch. & Schweinf.		*Syringodium isoetifolium* (Ashcers.) Dandy
ZOSTERACEAE Drummortier		*Zostera muelleri* subsp. *capricorni* (Aschers.)		*Thalassodendron ciliatum* (Forssk.) Hartog
HYDROCHARITACEAE Jussieu		*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.		*Halophila ovalis* (R. Br.) Hook. F.
		*Enhalus acoroides* (L.F.) Royle		*Halophila decipiens* Ostenf.
				*Halophila spinulosa* (R. Br.) Asch.

3.2 Seagrass condition for annual monitoring meadows

The overall condition of seagrasses in the Port of Thursday Island annual monitoring meadows was good in March 2022 (Table 5). All monitoring meadows were in good or very good condition, with only a slight decrease in condition from very good to good in two meadows compared to the 2021 survey. All seagrass metrics for monitoring meadows were good or very good, and all meadows had scores of very good for biomass in 2022. Overall the seagrass in the port was in good condition.

The combined area of all annual monitoring meadows has been at or above the long-term average since 2016, and in 2022 reached the largest area since monitoring began (153 ± 8 ha) (Figure 2). Meadow area is the most stable of the three indicators (biomass, area and species composition) throughout the monitoring meadows.

Table 5. Grades and scores for seagrass indicators (biomass, area and species composition) for the Port of Thursday Island 2022. 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
1	1	0.71	0.98	0.71
2	0.88	0.93	0.88	0.88
3	1	0.83	0.97	0.83
4	0.89	0.92	0.69	0.79
5	0.86	0.78	0.93	0.78
6	1	0.69	0.91	0.69
8	0.93	0.95	0.96	0.93
26	0.88	0.98	0.80	0.84
27	0.97	0.84	0.83	0.84
Overall Score for the Port of Thursday Island				**0.81**

3.2.1 Inshore *Halodule uninervis* dominated meadows (Meadows 1, 3, 5, 8)

The intertidal *Halodule uninervis* meadows around Thursday Island have remained stable in terms of overall condition. There was an improvement in biomass condition at two of these meadows and a decrease in area condition at meadow 1 (Figures 12, 14, 16 and 18). *Halodule uninervis* or a more stable species dominated meadows 1, 3 and 8, making up over 91% of species composition, while meadow 5 had over 85% *H. uninervis,* resulting in a very good species score for all of these meadows (Table 5). An increase in larger growing more stable species in some meadows caused a shift away from the usually dominant *H. uninervis* which has also been documented in recent surveys.

The monitoring meadow at the south-east end of Thursday Island (meadow 1) remained in a good condition with increases in biomass and a small decrease in area since 2021. In 2022 the biomass of 16.2 ± 2.9 g DW m^{-2} was the highest recorded since monitoring began in this meadow, resulting in an improvement in score from good to very good (Figure 12, Appendix 4a). There was a small decrease in meadow area from 3.07 ± 0.37 ha in 2021 to 2.67 ± 0.45 ha in 2022, this was just below baseline levels and resulted in a decrease in area score for this meadow from very good to good (Table 5, Figure 12). This meadow was once again dominated by *H. uninervis* with a large proportion of *T. hemprichii* also present, the less stable species *H. ovalis* made up 4.4% of species composition (Figure 12; Appendix 3).

The trend in increases in both biomass and area in meadow 3, between the Main and Engineer's wharves, continued in 2022. Meadow biomass here was also the highest recorded since surveys began (11.4 ± 1.3 g DW m^{-2}), resulting in a very good biomass condition score here for the first time since 2017 (Figure 14, Appendix 4a). Meadow area also continued to increase from 0.29 ± 0.04 ha in 2021 to 0.40 ± 0.04 ha in 2022 and area was above baseline levels for the first time since 2018 (Figure 14, Appendix 4b). Species composition remains in very good condition with an increase in dominance of the more stable species *T. hemprichii* to 14.1%, while the less stable species *H. ovalis* only made up 3.9% of meadow biomass (Figure 14, Appendix 3).

The *H. uninervis* meadow at the western end of Thursday Island (meadow 5) remains in good condition in 2022. Both area and biomass decreased by a small amount but remained in good and very good condition respectively (Figure 16, Appendix 4a, 4b). There was a small reduction in the percentage of the dominant or more stable species in this meadow, in 2021 these species made up almost 95% of seagrass biomass, whereas in 2022 this fell to 85% but species composition remained very good (Figure 16, Appendix 3).

The only annual monitoring meadow on the northern side of Thursday Island (meadow 8) remained in very good condition, with all seagrass metrics scoring very good (Table 5, Figure 18). Meadow biomass decreased slightly from 16.2 ± 3.4 g DW m^{-2} in 2021 to 15.1 ± 1.8 g DW m^{-2} in 2022, but remained in very good condition (Figure 18, Appendix 4a). There was an increase in meadow area of just under 0.5 ha in 2022, again remaining stable in very good condition (Figure 18, Appendix 4b). Species composition remained in a very good condition, with a small increase in the percentage of the less stable species *H. ovalis* (Figure 18, Appendix 3).

3.2.2 *Enhalus acoroides* dominated meadows (Meadows 2, 4, 6, 26, 27)

The *E. acoroides* dominated monitoring meadows had a continuous cover light or moderate *E. acoroides* community with mixed species present (Figures 13, 15, 17, 19 and 20). The subtidal meadows on the southern side of Thursday Island (meadows 2, 4 and 6) maintained their high biomass values from 2021 and have remained stable in area with only meadow 6 declining from very good to good condition (Table 5). The intertidal *E. acoroides* meadows at Madge Reefs to the south (meadows 26 and 27) have also maintained their high biomass and both increased in area (Figures 19 and 20). Both meadows maintained their overall meadow scores of good in 2021 (Table 5).

All of these meadows maintained a high percentage cover of *E. acoroides* with some *T. ciliatum* also present, these species were driving the high biomass values recorded. In all but one (meadow 4) the proportion of *E. acoroides* and *T.ciliatum* is above baseline levels and all are in good or very good condition (Figures 13, 15, 17, 19 and 20; Appendix 3).

***E. acoroides* meadows around Thursday Island**

The intertidal/subtidal meadow at the south-eastern end of Thursday Island (meadow 2) remains in an overall very good condition for the second year in a row (Figure 13). Meadow biomass decreased from 80.3 ± 3.0 g DW m^{-2} in 2021 to 59.2 ± 6.5 g DW m^{-2} in 2022, but remained in very good condition (Figure 13, Appendix 4a). Biomass appeared to be patchier than in previous years and decreased around the edge of the meadow compared to previous surveys (Figure 10, 13). Both species composition and area were similar to 2021 and remained in very good condition. There was an increase in meadow area of over 0.5 ha compared to 2021 and a small increase in the percentage of the dominant species *E. acoroides* (Figure 13, Appendix 3, 4b).

Overall condition in the smallest *E. acoroides* meadow between the wharves (meadow 4) decreased from very good to good (Table 5). This decrease was driven by a change in species composition, with the dominant species *E. acoroides* making up 69.6% of the meadow, compared to 79.8% in 2021 (Figure 15; Appendix 3). Both area and biomass remained very good in this meadow (Figure 15, Appendix 4a, 4b). Similar to meadow 2, biomass at meadow 4 was patchier in 2022 and was lower on the meadow edge (Figure 10, 15).

Overall meadow condition of meadow 6 decreased from very good to good in 2022 (Table 5). This change was driven by a decrease in meadow area from 14.71 ± 1.12 ha in 2021 to 12.30 ± 1.14 ha in 2022 resulting in a good condition score (Figure 17). The loss in seagrass area was largely around the outer subtidal edge of the meadow, where seagrass was mapped, but due to the species composition being dominated by *C. serrulata* and *H. uninervis*, was not part of the monitoring meadow (Figure 9). Biomass was the highest recorded in this meadow, with some very high biomass hotspots dominated by *T. ciliatum* (Figure 10, 17, Appendix 4a). Species composition also remained in very good condition with over 87% of biomass made up of *E. acoroides* and *T. ciliatum* (Figure 17; Appendix 3).

Madge Reef meadows

The intertidal *E. acoroides* meadows at Madge Reef to the south both remained in good condition in 2022 (Table 5). There was a small increase in area in both meadows, of just under 5ha in meadow 26 and just over 0.5ha in meadow 27, this increase resulted in an improvement in area score in meadow 26 from good to very good, and meadow 27 maintained a score of good (Figure 19, 20). Biomass scores also remained stable and very good for both meadows, although there was a small decline at both meadows, the biomass in 2022 was still one of the highest recorded (Figure 19, 20, Appendix 4a). The hotspots of high biomass were also maintained, and appeared to be spreading throughout these meadows and increasing in biomass in 2022 (Figure 11).

Species composition at these meadows was dominated by *E. acoroides* and *T. ciliatum*, these species made up over 90% of the seagrass community in meadow 27 and *E. acoroides* made up over 80% of the community at meadow 26 (Figures 19 and 20; Appendix 3). In meadow 26 the increase in less stable seagrass species caused a decrease in score from very good to good (Figure 19). The dominance of *E. acoroides* or more stable species in both meadows remains well above the long-term average (Figures 19 and 20; Appendix 3).

An area of expanding mangroves has been monitored in this meadow over the course of the program. In 2022 the biomass of seagrass in this mangrove recruitment area was once again lower than the rest of the meadow, possibly due to mangrove establishment (Figure 11).

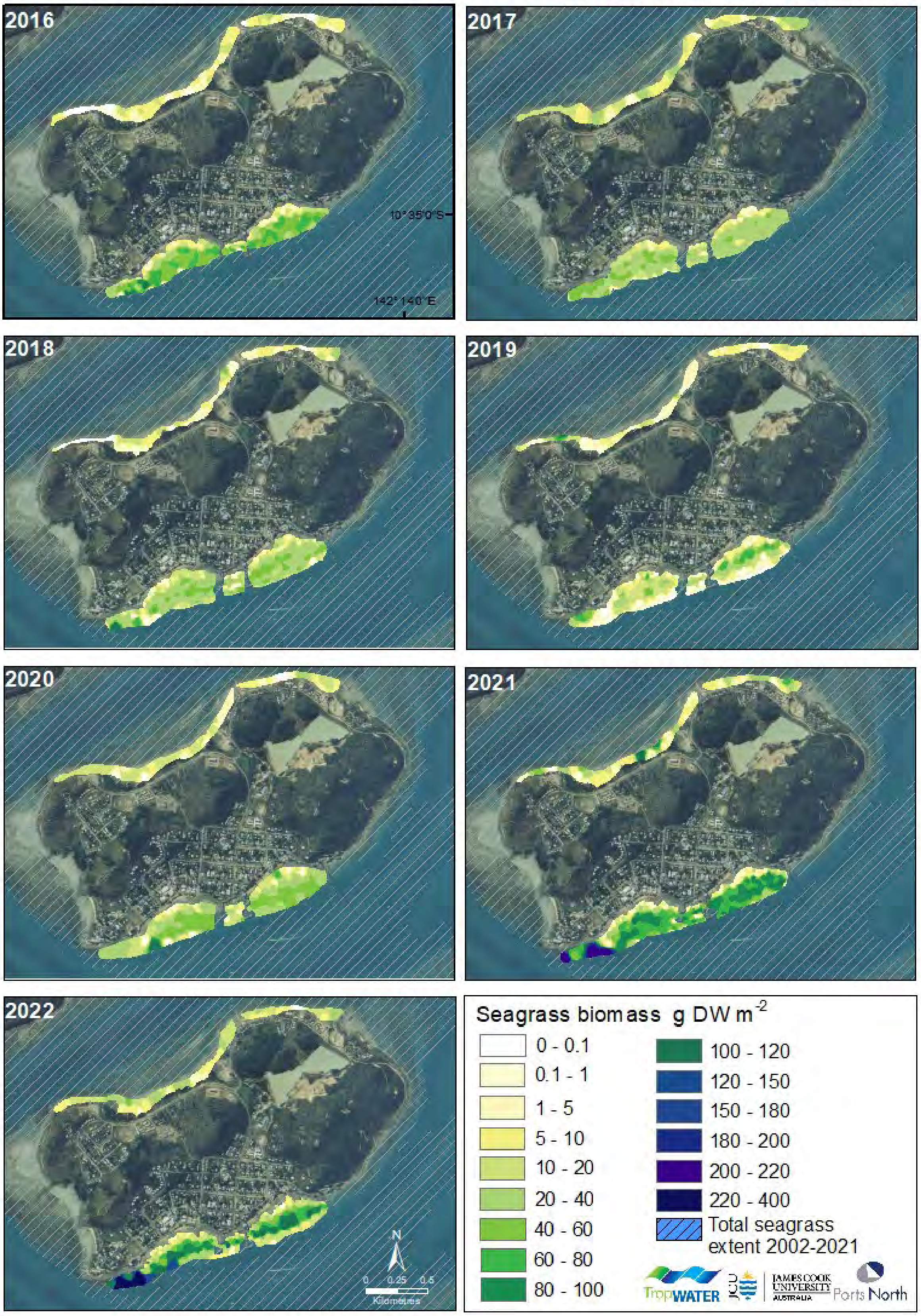


Figure 10. Changes in biomass and area (Meadows 1-6 and 8) in the Port of Thursday Island (2016-2022).

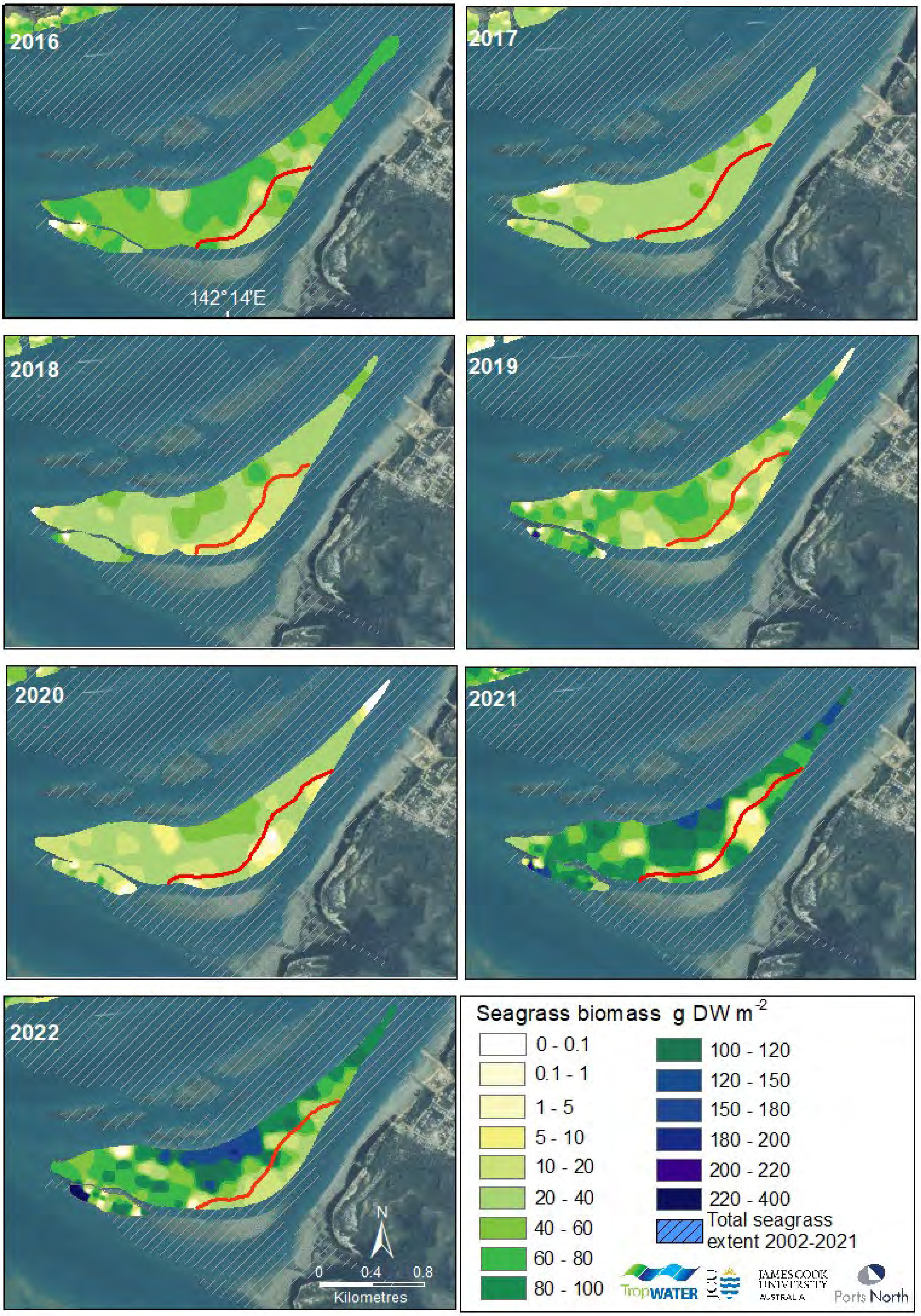


Figure 11. Changes in biomass and area (Meadows 26 and 27) in the Port of Thursday Island (2016-2022). The red line indicates the mangrove recruitment area boundary.

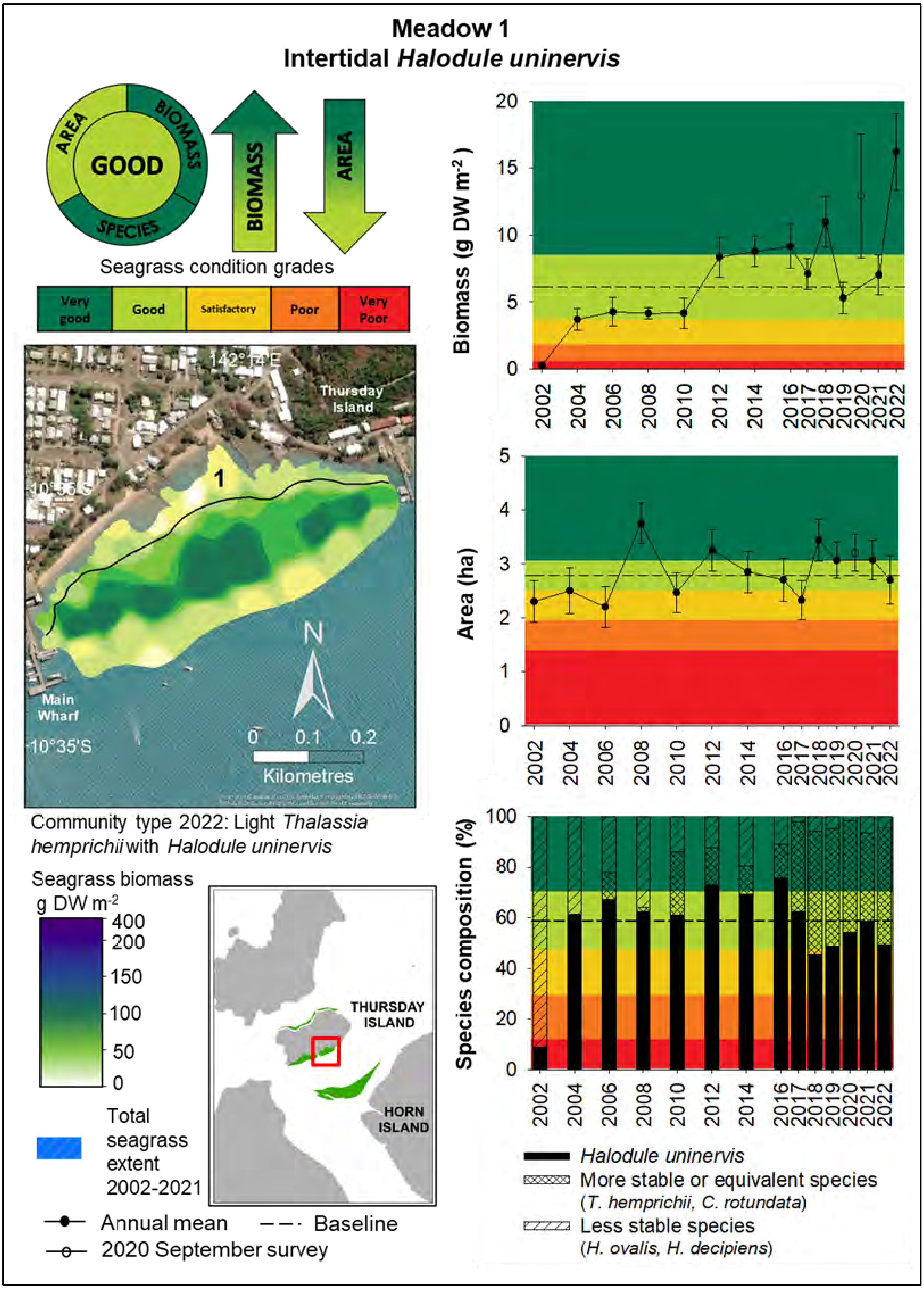


Figure 12. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 1 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

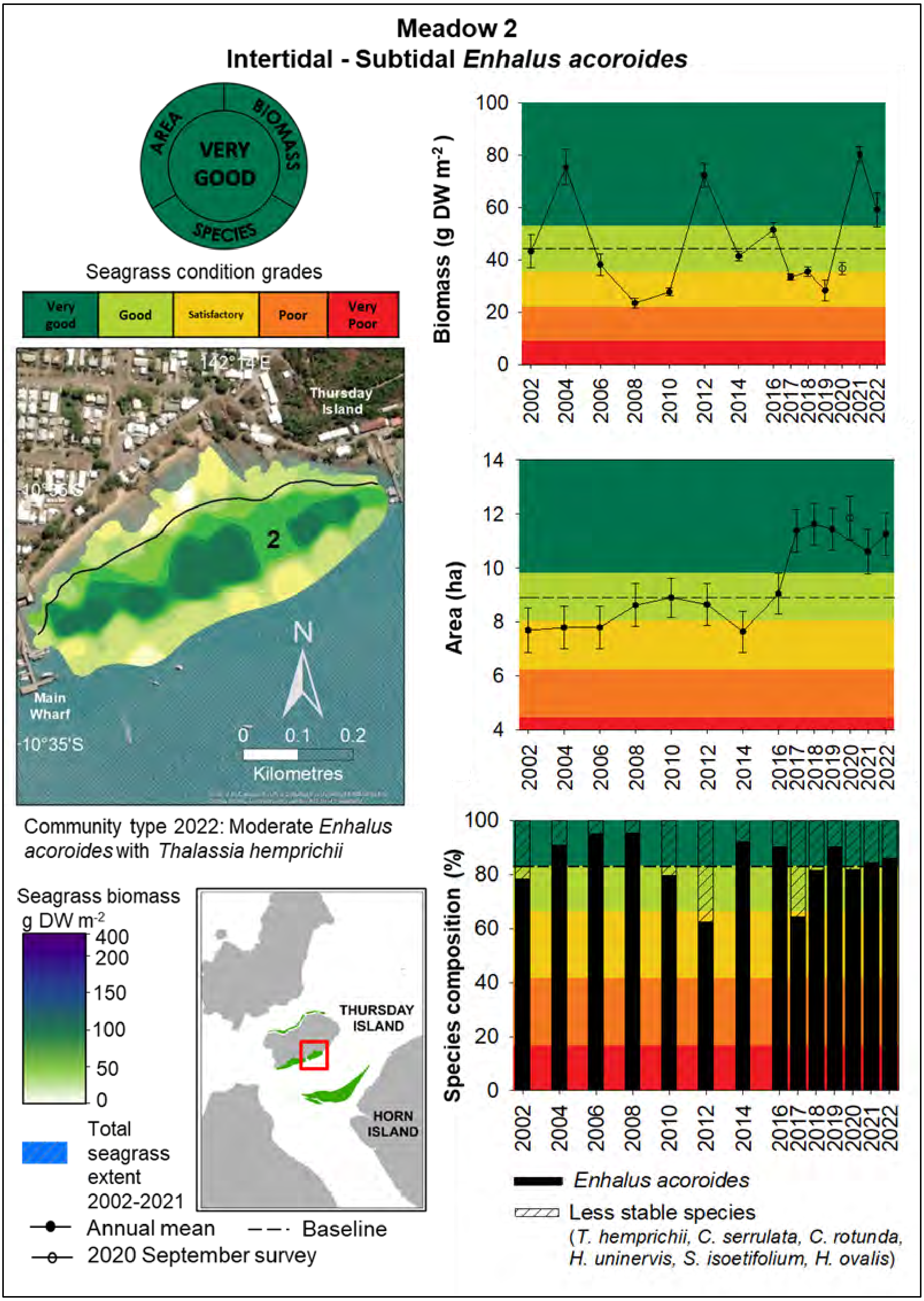


Figure 13. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 2 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

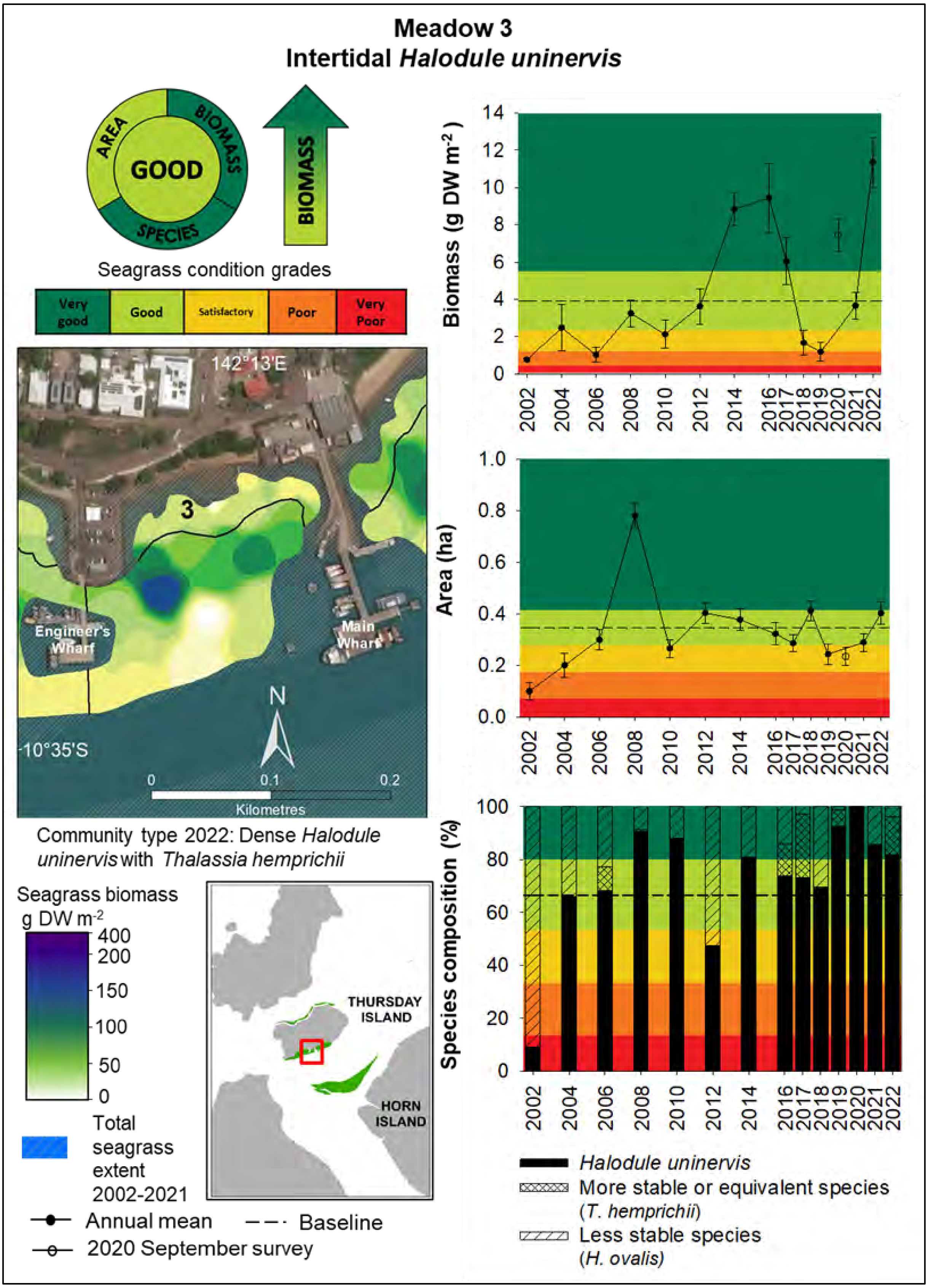


Figure 14. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 3 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

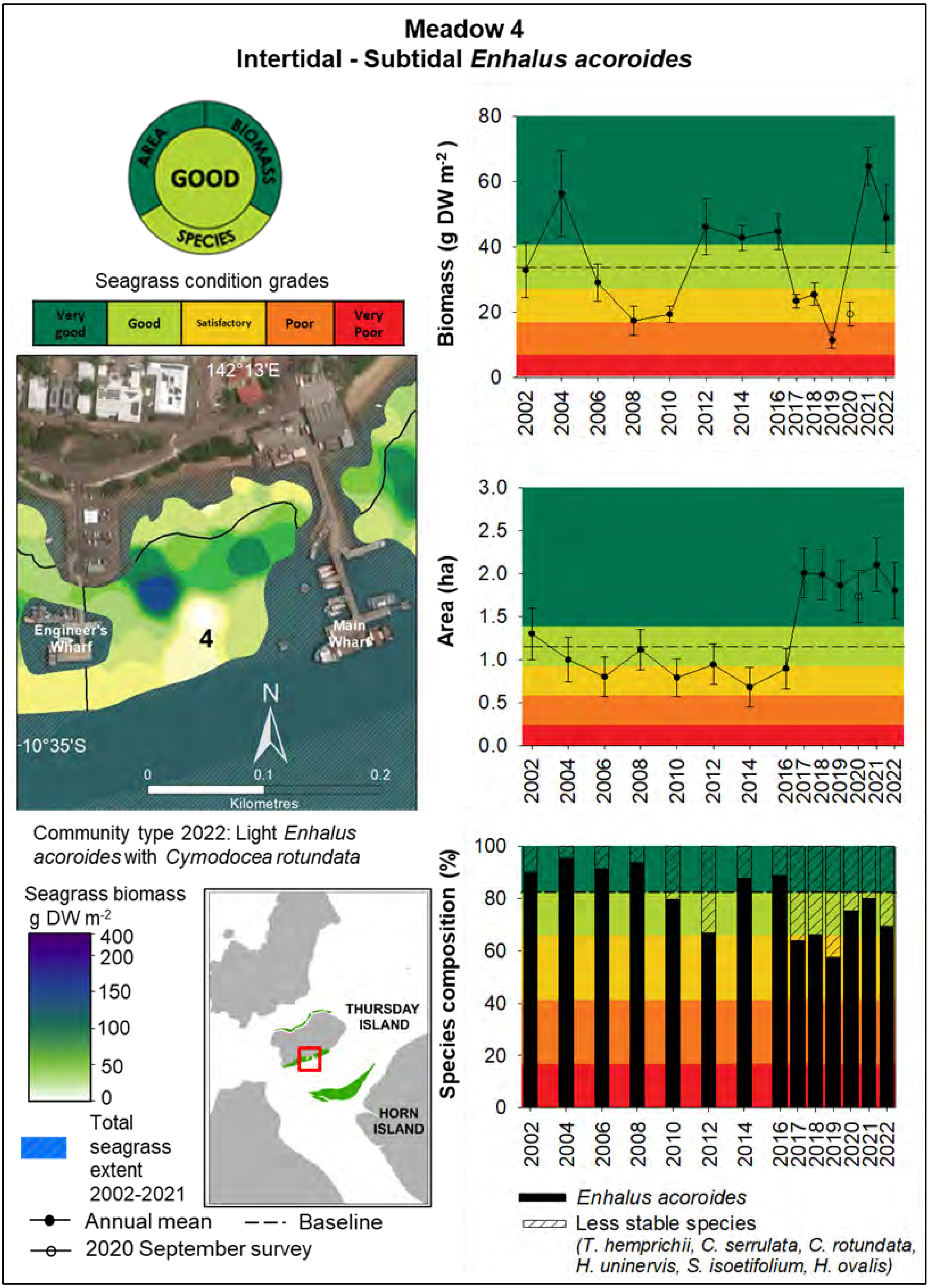


Figure 15. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 4 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

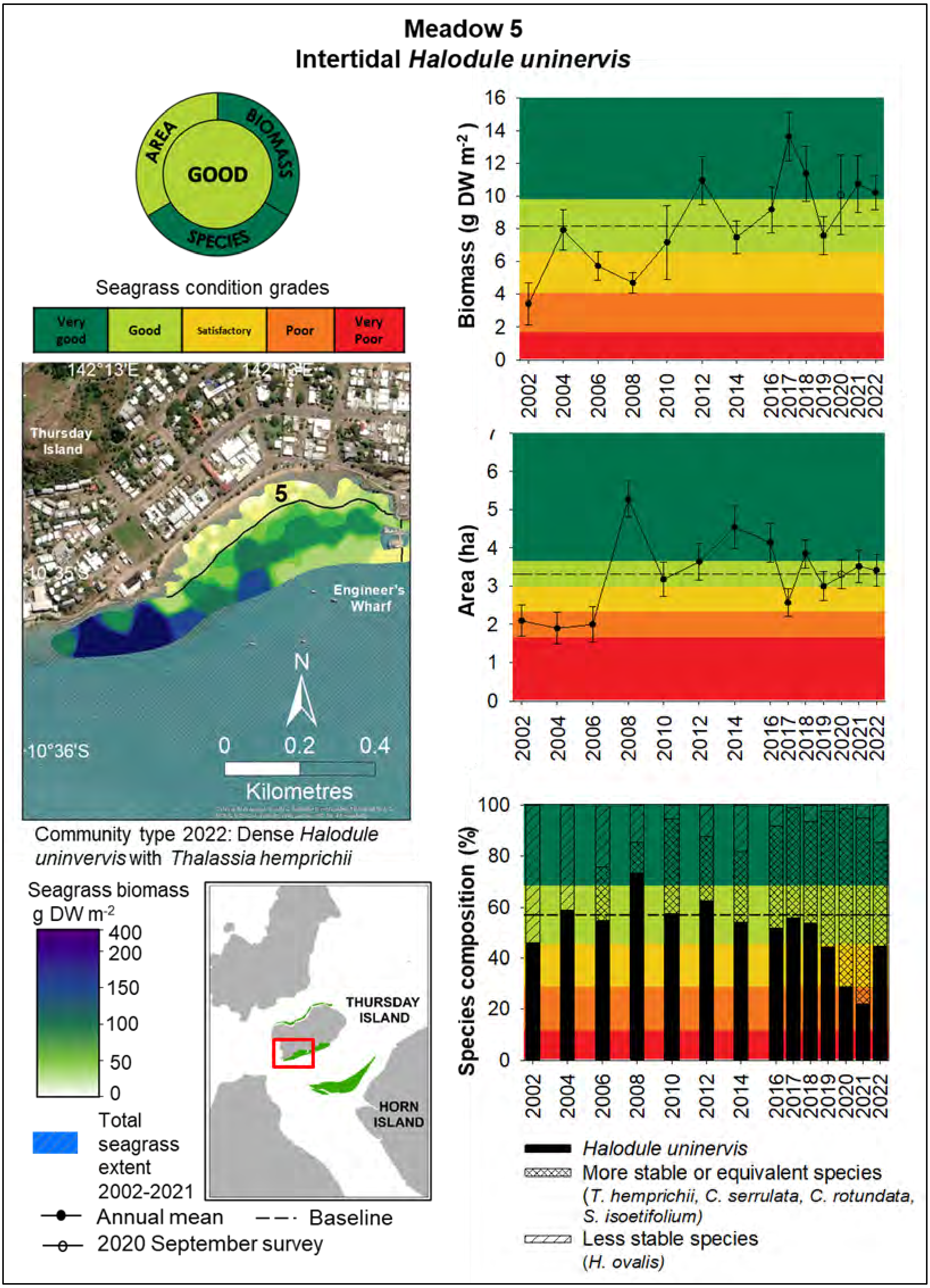


Figure 16. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 5 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

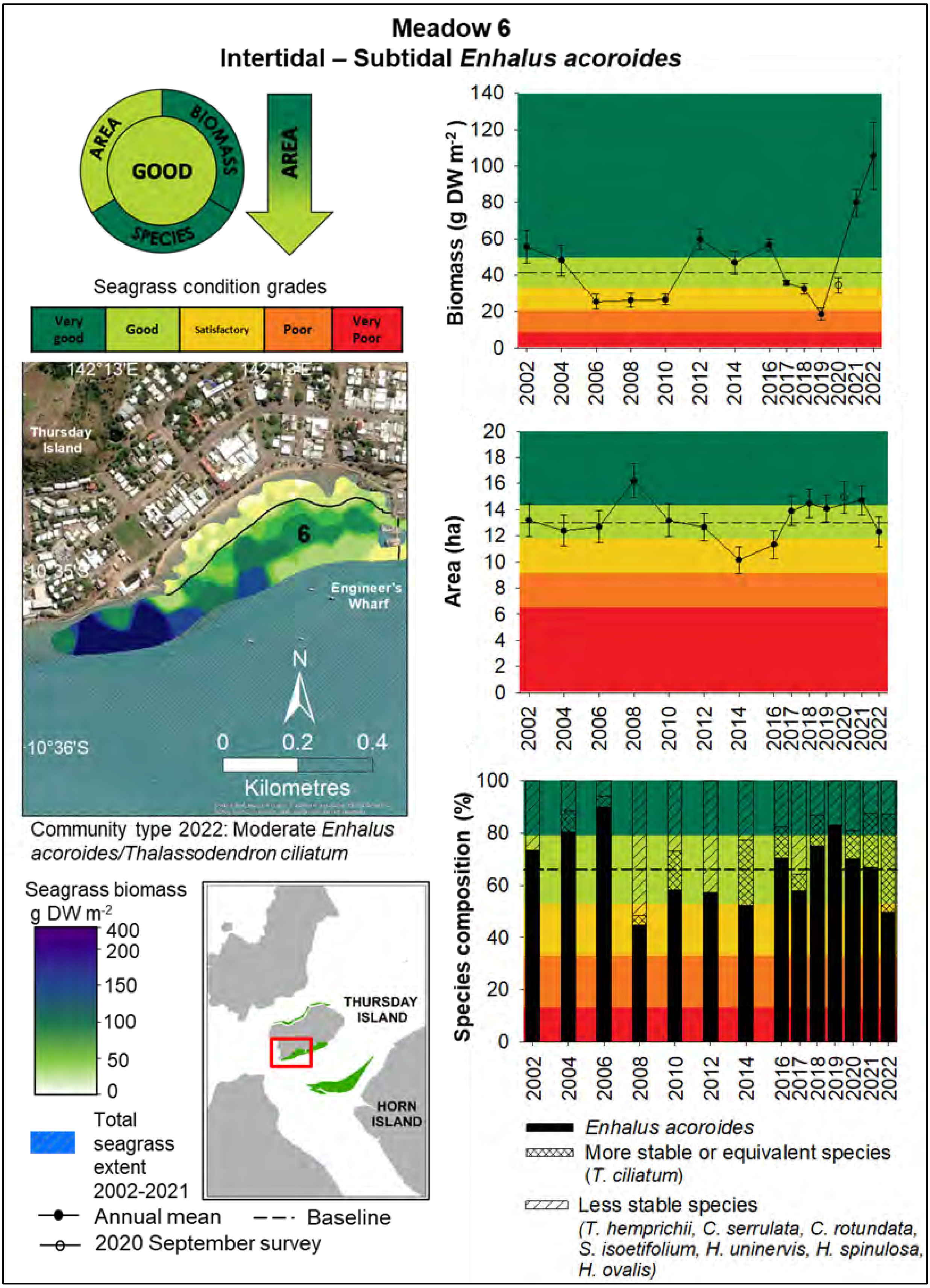


Figure 17. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 6 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

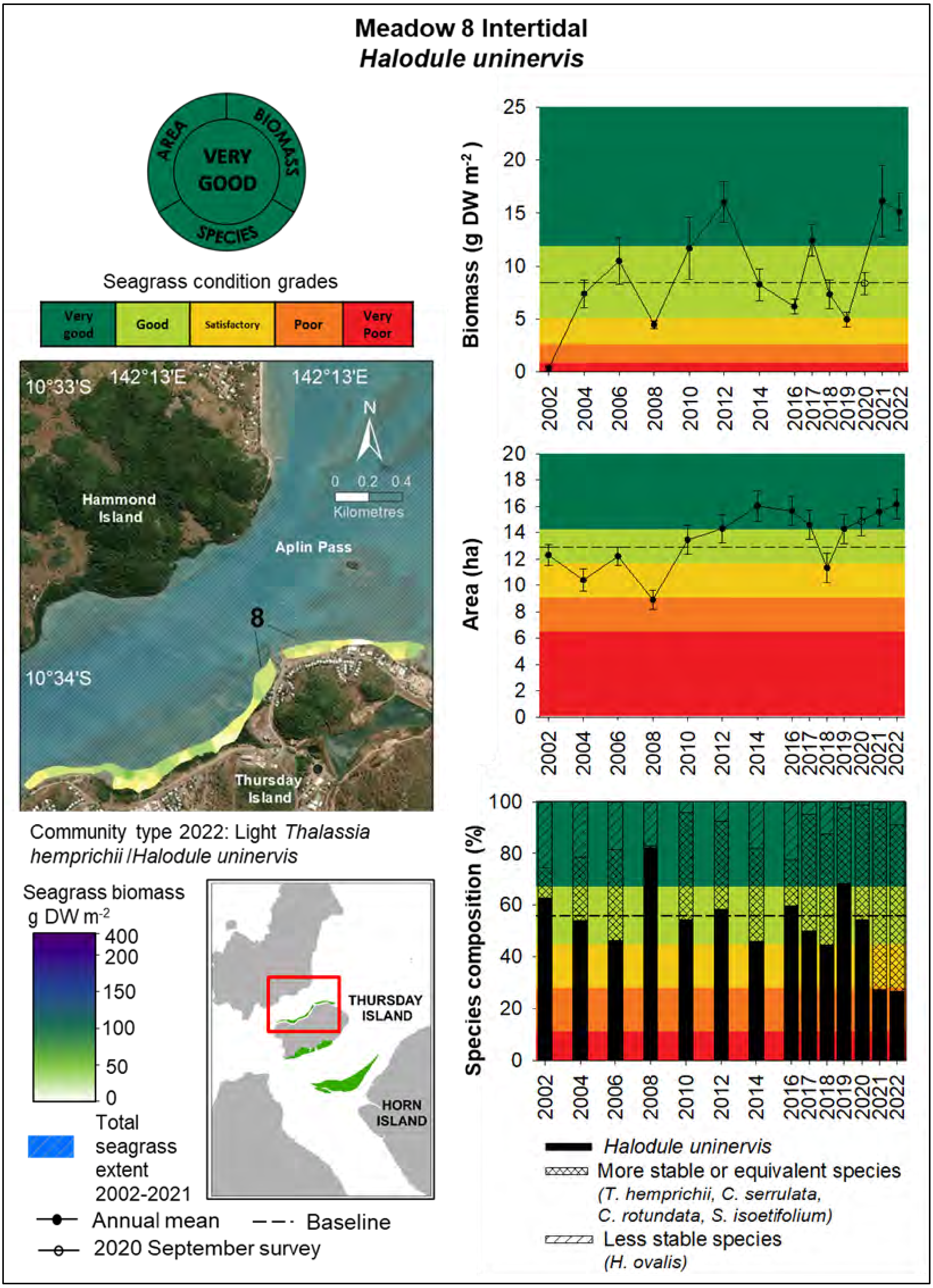


Figure 18. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 8 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

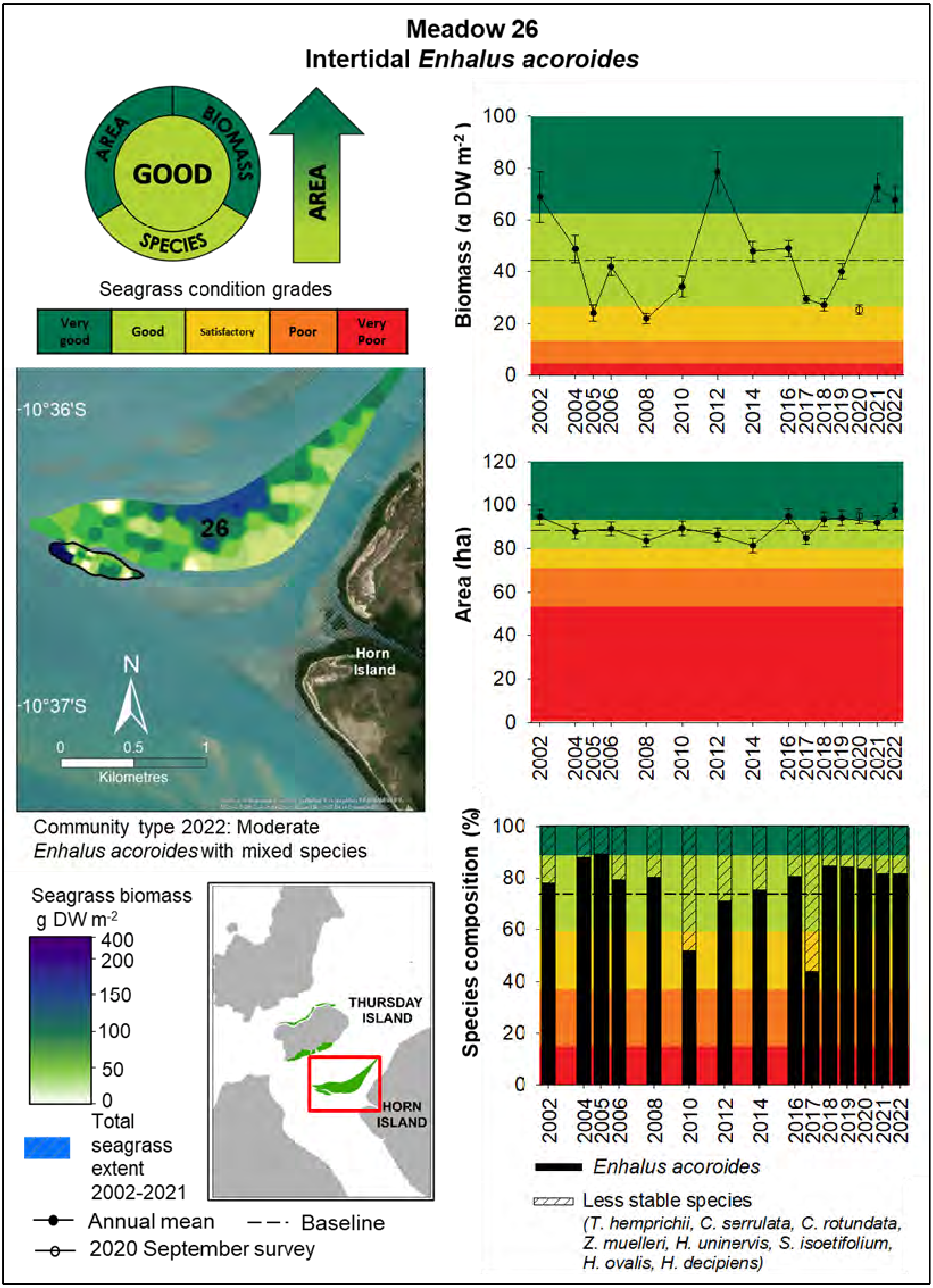


Figure 19. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 26 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

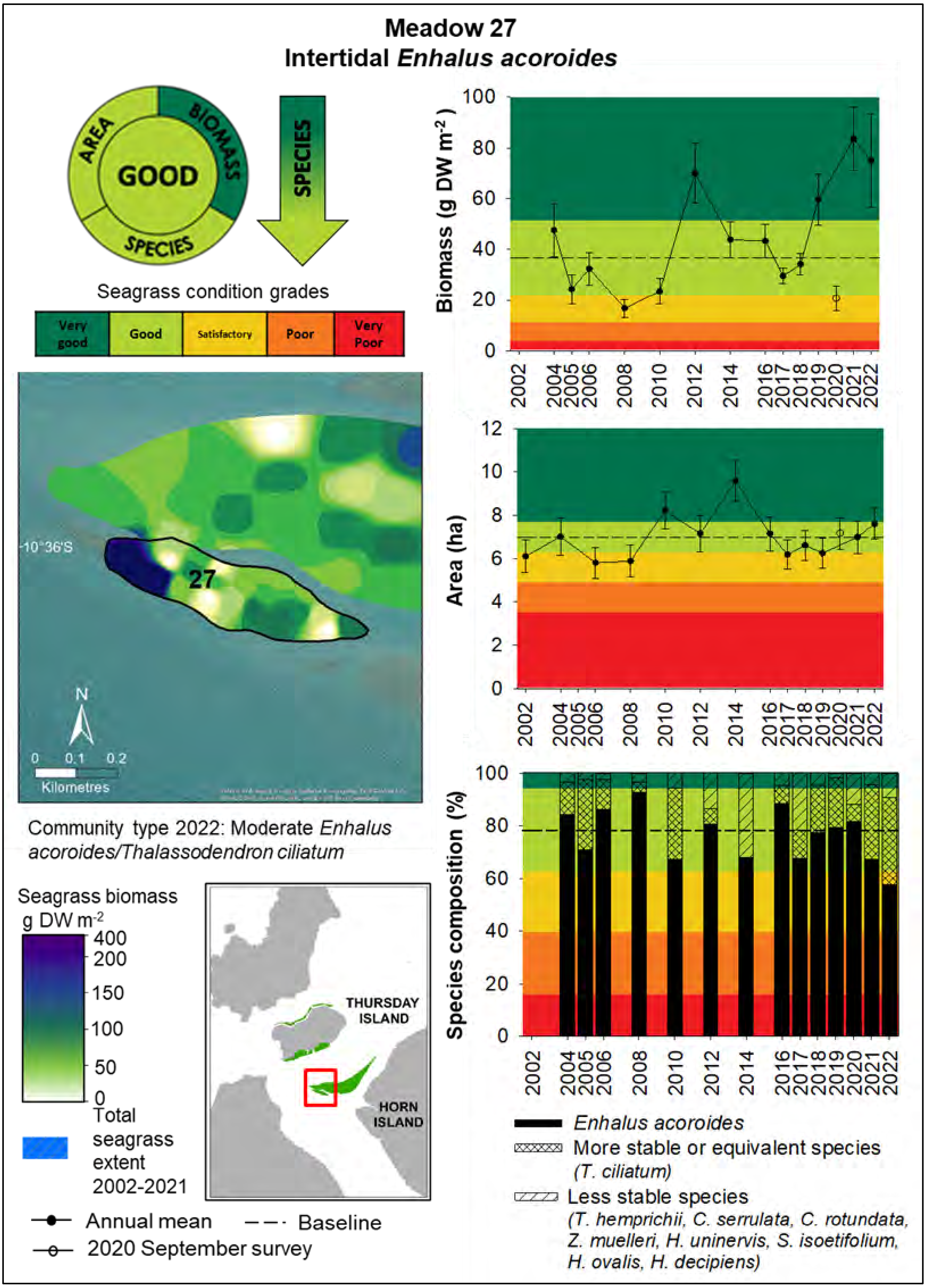


Figure 20. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 27 at Thursday Island from 2002 to 2022 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.3 Seagrasses in the whole of port area

The updated whole of port survey conducted concurrent to 2022 annual monitoring mapped 33 seagrass meadows outside of the annual monitoring meadows, covering an additional 957 ± 157 ha (Figures 8, 9 and 21). An additional five meadows were mapped outside of the survey limit towards Hammond Island, these covered a total area of 53.8 ha, as these were not included in previous whole of port surveys these meadows are not included in Figure 21. Meadow biomass peaked at 110 ± 74 g DW m^{-2} in the small *T. ciliatum* with *E. acoroides* meadow just outside of the survey boundary off Hammond Island; the lowest meadow biomass was just 0.13 ± 0.02 g DW m^{-2} for the small isolated *H. spinulosa* with *H. decipiens* meadow off in the northern part of Ellis Channel (Figures 8 and 9). The light *H. uninervis* meadows east of Ellis Channel had similar very low meadow biomass. The majority of meadows had continuous cover, with six meadows having isolated patches and one with aggregated patches.

This updated mapping of all seagrasses in the port area found that the spatial footprint of seagrasses in the Thursday Island region had declined since last surveyed in 2019. While area in the monitoring meadows has been increasing over time (Figure 1, 21), the whole of port meadow area of 958 ha was lower than both the 2002 and 2019 surveys (Figure 21). Meadows were more fragmented and were dominated by meadows of light to moderate cover similar to 2019, this continues the shift away from the dense cover recorded in 2002 (Figure 9). There were large decreases in meadow area documented in 2022 concentrated in deeper water meadows, the biggest was over 127 ha in one of the subtidal *H. uninervis* with *H. decipiens* meadows. However, the meadows with *E. acoroides* and *T. ciliatum* remained stable or increased, with some increases of up to 5 ha in meadow area in both intertidal and subtidal meadows dominated by *E. acoroides* and *T. ciliatum*.

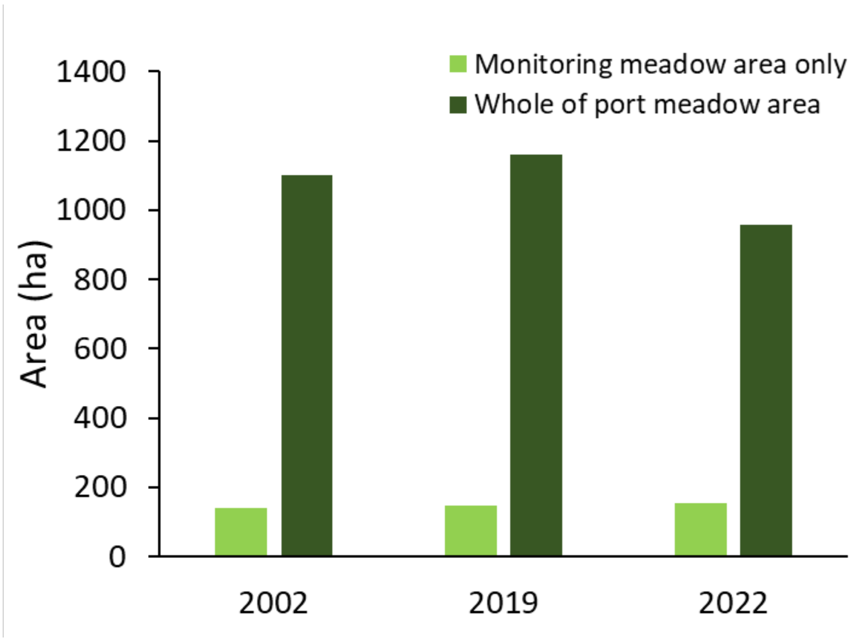


Figure 21. Comparison of seagrass area (hectares) in the monitoring meadows only and the whole of port meadow area excluding monitoring meadows in the Thursday Island region, in 2002, 2019 and 2022.

Just under half of the meadows in 2022 had a meadow biomass under 10 g DW m^{-2}, compared to 64% in 2019 and just 14% in 2002. There were some small declines in meadow biomass compared to 2019, but over 70% of meadows increased in biomass, and many of these increases were substantial; six meadows increased in biomass by over 50 g DW m^{-2}, and the largest increase was over 88 g DW m^{-2}. These large increases in biomass are due to a shift towards *E. acoroides* and a higher percentage of *T. ciliatum*; the two *T. ciliatum* meadows present shifted from light to moderate cover, while two light *E. acoroides* meadows shifted to moderate cover and five shifted to being a *E. acoroides* and *T. ciliatum* meadow. One dense *H. uninervis* meadow between the wharves on Horn Island switched to a moderate *E. acoroides* meadow.

3.4 Thursday Island climate patterns

3.4.1 Rainfall

Total annual rainfall in the Thursday Island area leading up to the 2022 survey was above the long-term average (Figure 21). The survey month (March 2022) was higher than the previous three years and above the long-term monthly average (Figure 22). The months preceding the survey had below average rainfall (Figure 23). All climate information in the following graphs is sourced from the Bureau of Meteorology, Station 027058, available at: www.bom.gov.au and Maritime Safety Queensland.

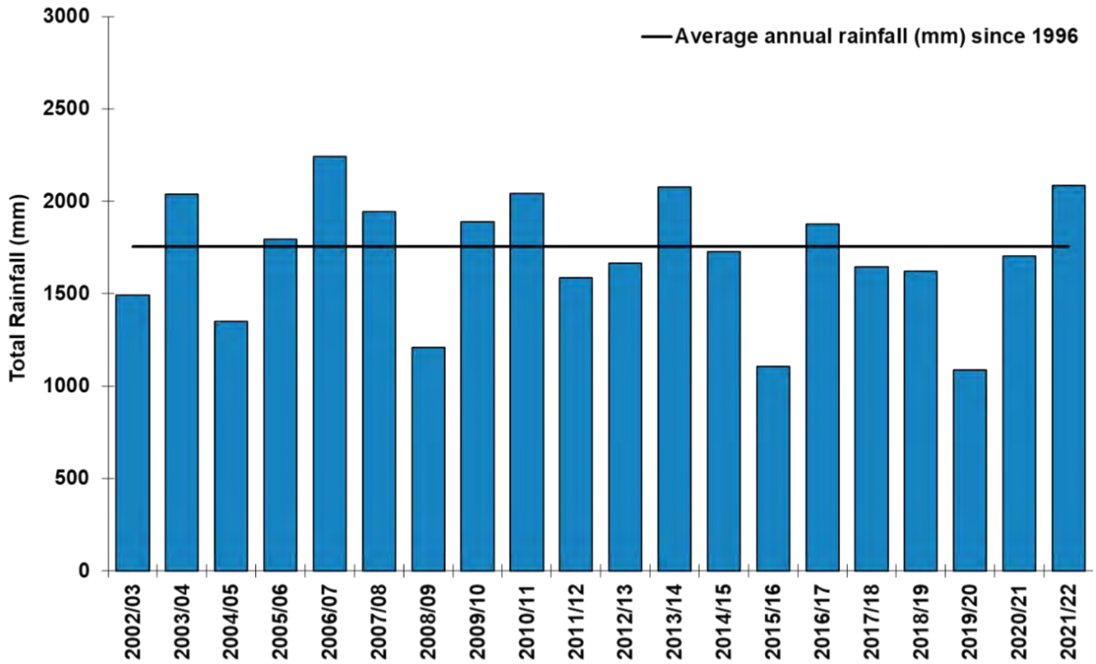


Figure 21. Total annual rainfall (mm) recorded at Horn Island, 2002/2003 – 2021/2022. Twelve-month year (2021/2022) is 12 months prior to survey.

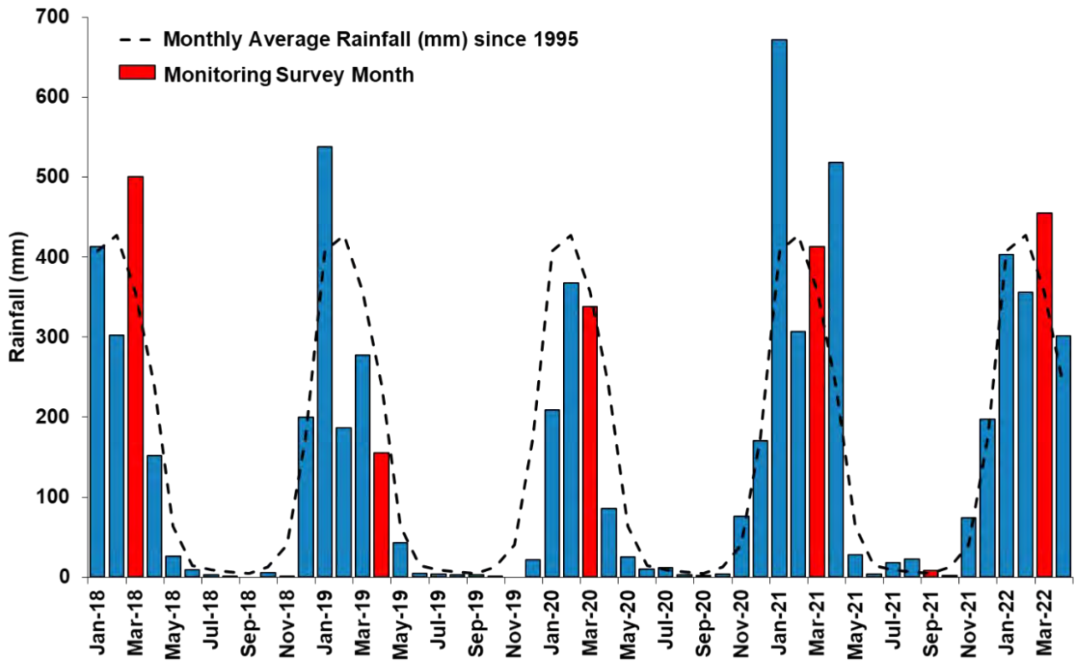


Figure 22. Total monthly rainfall (mm) recorded at Horn Island, January 2018 – April 2022. Annual monitoring survey months are coloured red.

3.4.2 Air Temperature

The annual average maximum daily air temperature has remained above the long-term average of 30.45°C since 2015/16 (Figure 24). The monthly average maximum daily air temperature during the survey month (March) was near the long-term average, following a month of above average temperatures (Figure 25).

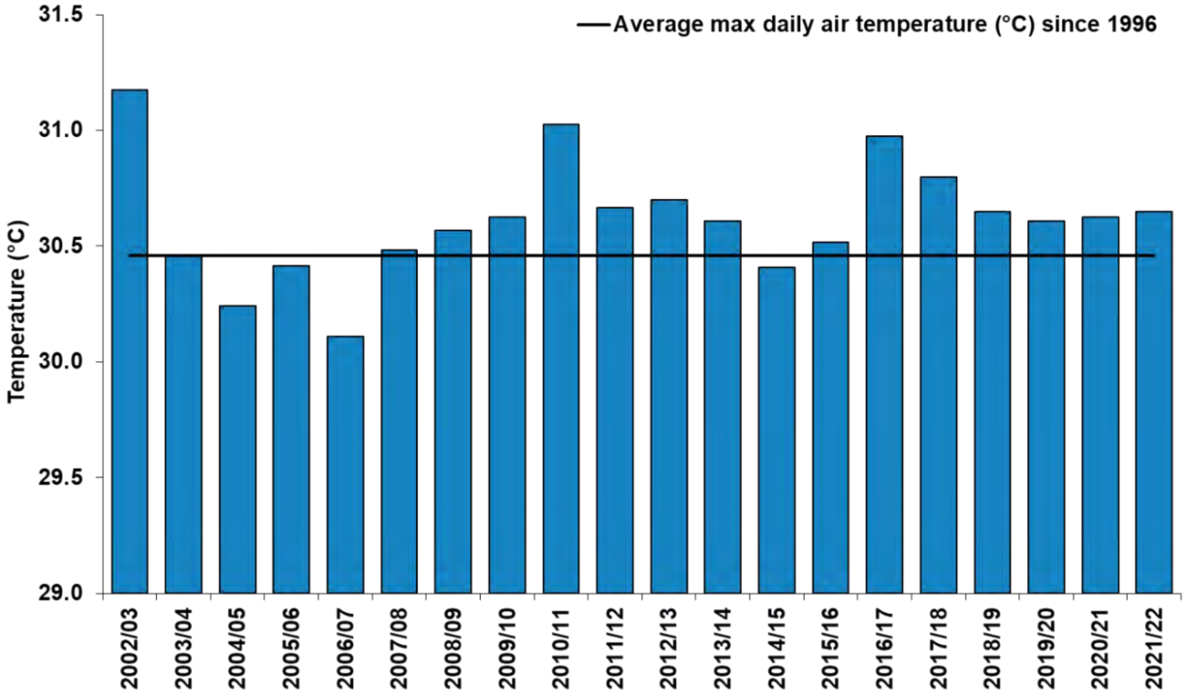


Figure 23. Maximum daily air temperature (annual average, °C) recorded at Horn Island, 2002/2003 – 2021/2022. Twelve month year (2021/2022) is 12 months prior to survey.

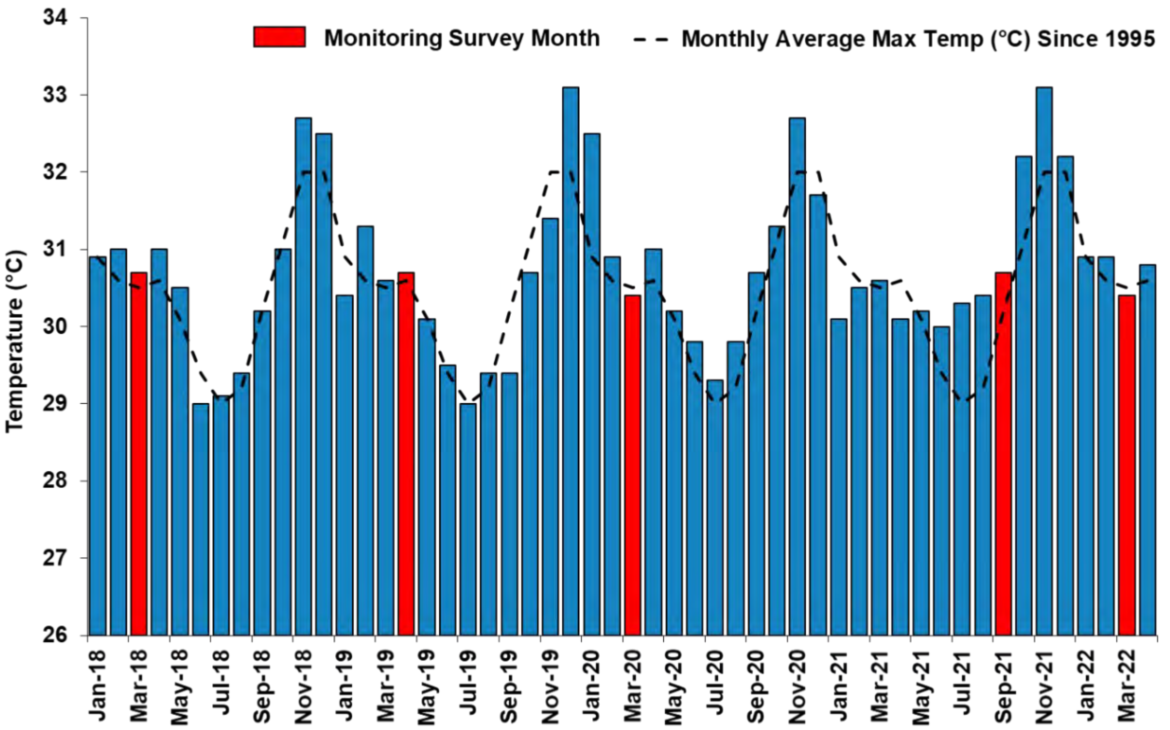


Figure 24. Maximum daily air temperature (monthly average, °C) recorded at Horn Island, January 2017 – April 2022. Annual monitoring survey months coloured red.

3.4.4 Tidal Exposure of Seagrass Meadows

Annual daytime tidal exposure of intertidal meadows was above the long-term average in 2021/22 for the fourth year in a row (Figure 25). Tidal exposure was close to or below average in the months preceding the survey (Figure 26).

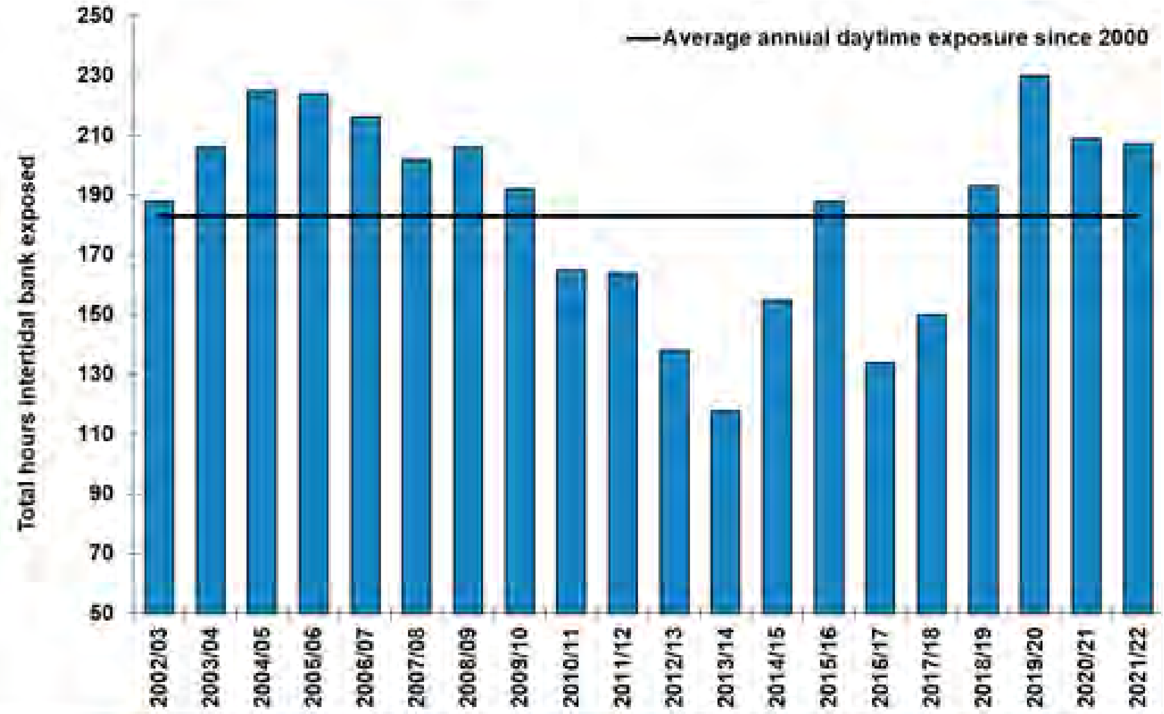


Figure 25. Annual daytime tidal exposure (total hours)* of seagrass meadows at the Port of Thursday Island, 2002/2003 – 2021/2022. Twelve-month year (2021/2022) is 12 months prior to survey. * Assumes intertidal banks expose at a tide height of 0.8m above Lowest Astronomical Tide.

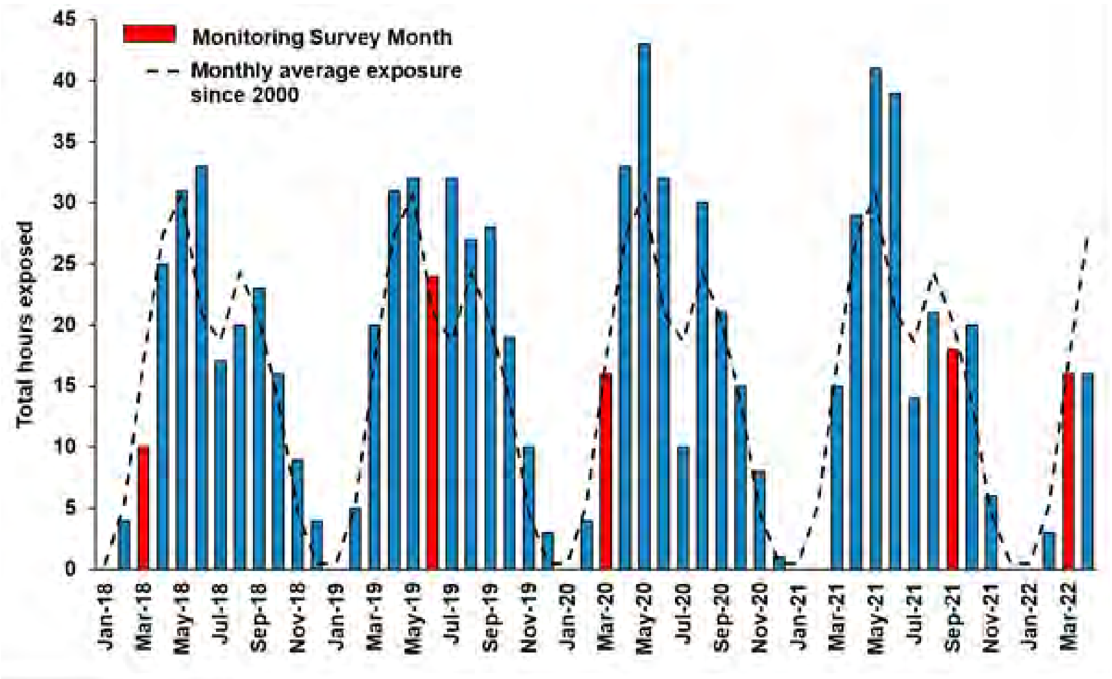


Figure 26. Monthly daytime tidal exposure (total hours) * at the Port of Thursday Island, January 2012 – April 2022. * Assumes intertidal banks expose at a tide height of 0.8m above Lowest Astronomical Tide.

3.4.3 Daily Global Solar Exposure

Daily global solar exposure (GSE) is a measure of the total amount of solar energy (Megajoules per square metre, MJ m^{-2}) falling on a horizontal surface in one day and can serve as a proxy for the light levels reaching seagrasses. Values are generally highest in clear sun conditions during spring/summer and lowest during autumn/winter. Solar exposure in the Thursday Island region has been above or close to the long-term average for since 2015 and this continued in 2021/22 (Figure 28). In 2022 in the months leading up to the survey, solar exposure was close to the long term average (Figure 29).

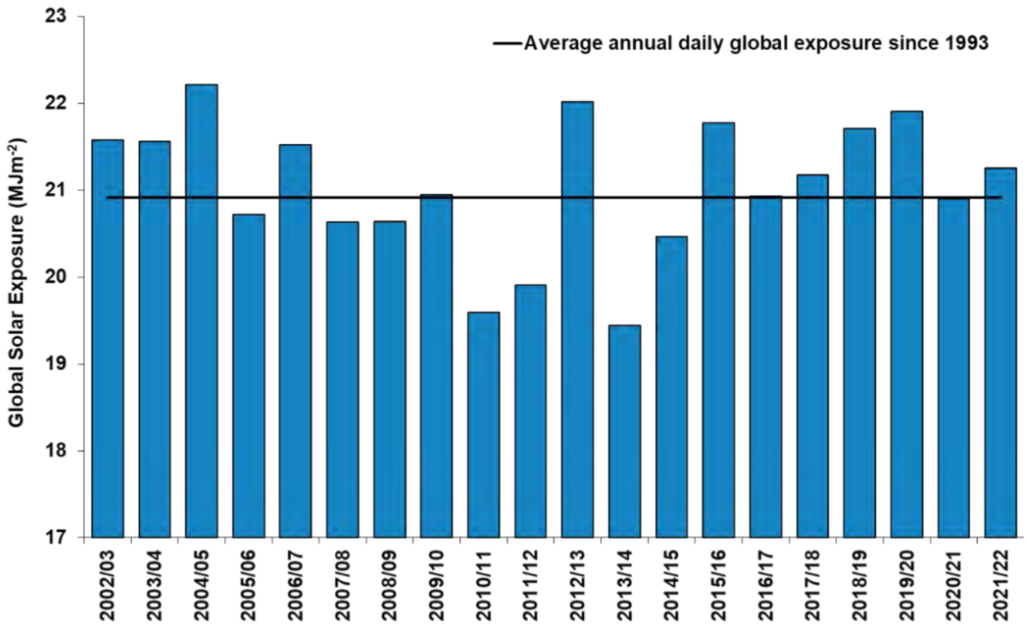
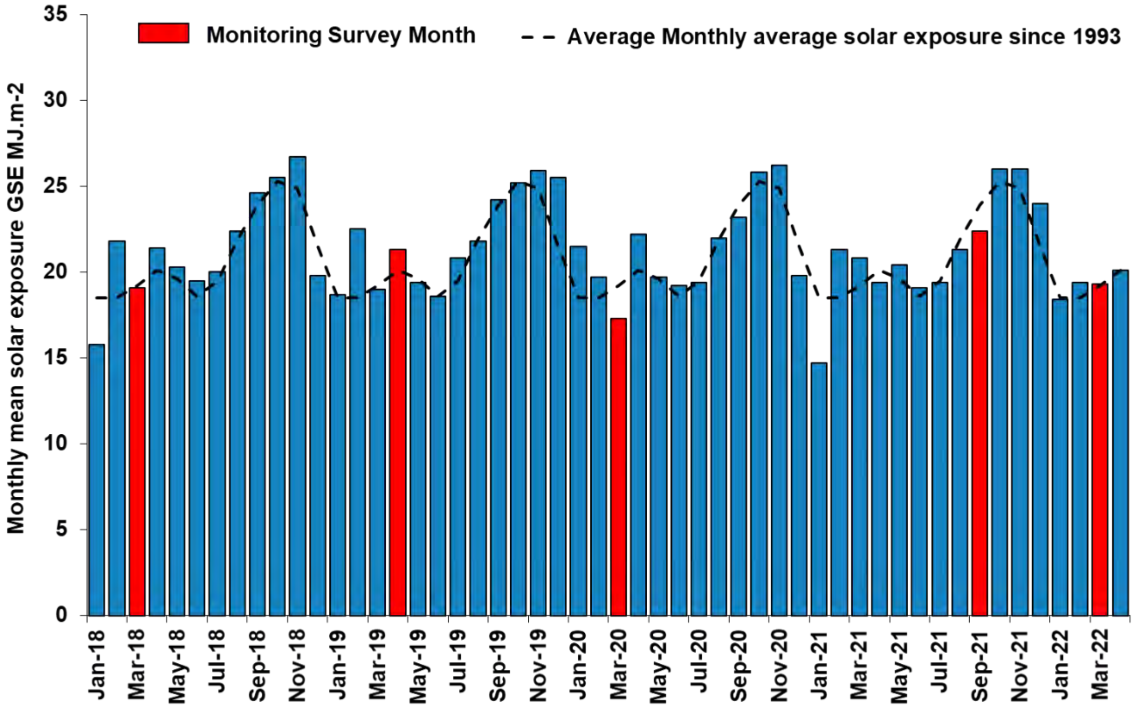


Figure 27. Daily global solar exposure (annual mean, MJ m^{-2}) recorded at Horn Island,



2002/2003 – 2021/2022. Twelve-month year (2021/2022) is 12 months prior to survey.

Figure 28. Daily global solar exposure (monthly mean, MJ m^{-2}) recorded at Horn Island, January 2017 – April 2022.

4 DISCUSSION

Seagrasses in the Port of Thursday Island maintained an overall good condition in 2022, for the second year in a row, with all monitoring meadows in good or very good condition. Monitoring meadows had the highest total area recorded since monitoring began and biomass remained high in all meadows, with large increases observed in some. Overall species composition remained stable, with a decrease in dominance of *E. acaroides* in two of the meadows. The shift documented in 2021 towards more stable seagrass species continued in many of the meadows in 2022 after another year of favourable climate conditions. These more stable species represent a shift towards meadows with slower growing higher biomass species that have below-ground energy reserves which mean they are more resilient to disturbances (Kilminster et al. 2015, Unsworth et al. 2015).

In 2019, seagrass biomass declines caused overall meadow condition in Thursday Island to be downgraded to satisfactory after years of good and very good scores (Wells et al. 2019). In 2021, seagrass biomass increased in all meadows and this trend of sustained recovery continued in 2022. The two *E. acoroides* meadows of particular concern in 2019, meadows 4 and 6, remained in good condition in 2022 after their recovery in 2021.

Figure 29. *Enhalus acoroides* flower and pollen (white balls) floating on the surface.

Environmental factors were favourable for seagrass growth in 2022. All climate variables remained around average, and while rainfall was above average during the survey month, there were no weather events that were likely to impact the seagrass. Annual tidal exposure was above average for the fourth year in a row, however the period found to be most influential on *E. acoroides* growth (one month prior to observation) was below the long-term average (Unsworth et al. 2012). Annual air temperature was once again above average, due to peaks in summer months, however tidal exposure was lowest in these months, meaning the seagrass blades were less susceptible to exposure related stresses such as desiccation and leaf burning at low tide.

The seagrasses around Thursday Island were reproducing sexually, in particular we observed *E. acoroides* flowers and pollen floating on the surface of the water in multiple meadows (Figure 29). Although asexual reproduction is the most important mechanism for recolonization after disturbance in many tropical seagrass meadows, the presence of a seed bank and production of seeds is also important in terms of recovery from large scale impacts (Rasheed 2004, Rasheed et al 2014).

The whole of port survey in 2022 showed that some of the deeper water meadows in the broader port had the lowest area recorded and had become more fragmented. However, there were also substantial biomass increases in some of these meadows which were driven by shifts in community towards the more stable species *E. acaroides* and *T. ciliatum*. The declines in deeper water seagrasses are consistent with other parts of Torres Strait, the 2020 and 2021 Torres Strait seagrass report cards identified regional declines in seagrass condition across the Western and Central clusters (Carter et al. 2020, 2021). These declines were caused by reductions in seagrass abundance (biomass/percentage cover) and were most dramatic and widespread in the Orman Reefs-Mabuyag Island region (Carter et al. 2020, 2021). The declines observed in this area were particularly evident in changes in larger and more stable seagrass species (Carter et al. 2020, 2021), so it is encouraging to see these species doing particularly well around Thursday Island. The species which are declining in the port area are the faster growing colonising species such as *Halophila spinulosa* with a rapid ability to recover from disturbances (Kilminster et al. 2015), meaning these meadows should be able to quickly return to their previous distribution under favourable conditions.

During the survey multiple dugongs and green turtles were observed feeding in seagrass meadows within the port area. These seagrass meadows are an important food source for a range of herbivore groups (Scott et al. 2018), and experiments have shown there is high herbivory pressure at sites in the region where seagrass meadows have declined (Scott et al. in prep). As both dugongs and green turtles can move large distances to feed in Torres Strait (Cleguer et al., 2016, Gredzens et al., 2014) the healthy seagrass around Thursday Island may become even more important as a foraging ground, should the declines in the region continue.

The 2022 Thursday Island seagrass survey shows the monitoring meadows have remained in a good condition, with record high overall area and record high biomass in many meadows. Although some of the deep-water meadows in the whole of port area did decline, many others had large increases in biomass due to a switch to more stable species. All of these results point to a healthy and resilient seagrass community in the Port of Thursday Island and a key indicator of a healthy marine environment in the port in 2022 with most meadows likely to be resilient to pressures that may affect seagrass growth during 2022. The results of this program also form a critical component to the Torres Strait regional seagrass report that incorporates community and JCU monitoring in the broader Torres Strait region (Carter et al 2021). The Port of Thursday Island seagrasses representing a bright spot of seagrass condition in the Torres Strait region in 2022.

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6 APPENDICES

Appendix 1

Baseline Conditions

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated from 2002 – 2018. This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014). Where possible, a long-term average of 10 sampling years of data is considered a more accurate representation of baseline conditions as this incorporates a range of environmental conditions over a longer time period including El Niño and La Niña. 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	-	CV < 40%	CV ≥ 40%	-
Area	< 10%	CV ≥ 10, < 40%	CV ≥ 40, <80%	CV ≥ 80%
Species composition	-	CV < 40%	CV ≥ 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. 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 (Table A3; see Carter et al. 2016; Carter et al. 2015 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. The score range for each grade used in the Thursday Island 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 *E. acoroides* 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. ovalis* 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 in Thursday Island, 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).

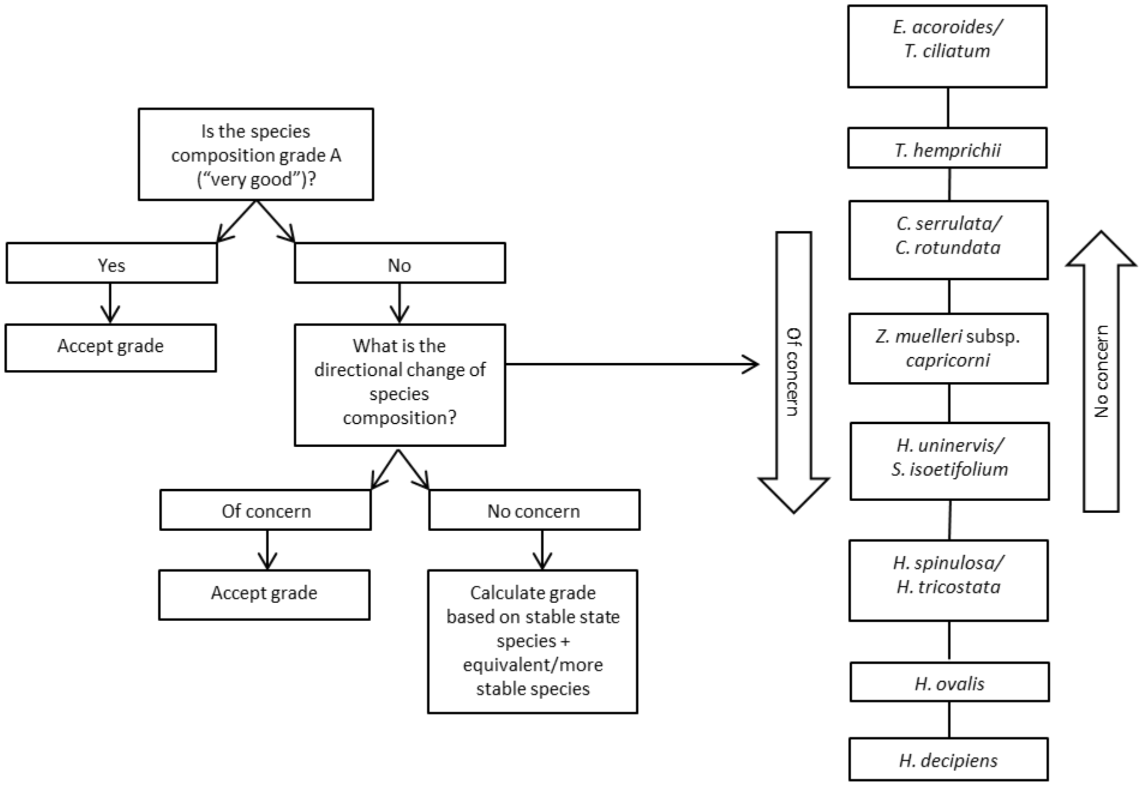


Figure A1. Decision tree and directional change assessment for grading and scoring seagrass species composition.

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.

Thursday Island grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, 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. Port grades are therefore more sensitive to changes in stable than variable meadows.

Appendix 2

An example of calculating a meadow score for biomass in satisfactory condition in 2019.

1. Determine the grade for the 2019 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in biomass (B_{diff}) between the 2019 biomass value (B_{2019}) and the area value of the lower threshold boundary for the satisfactory grade ($B_{satisfactory}$):

$$B_{diff} = B_{2019} - B_{satisfactory}$$

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:

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

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_{2019} takes up:

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

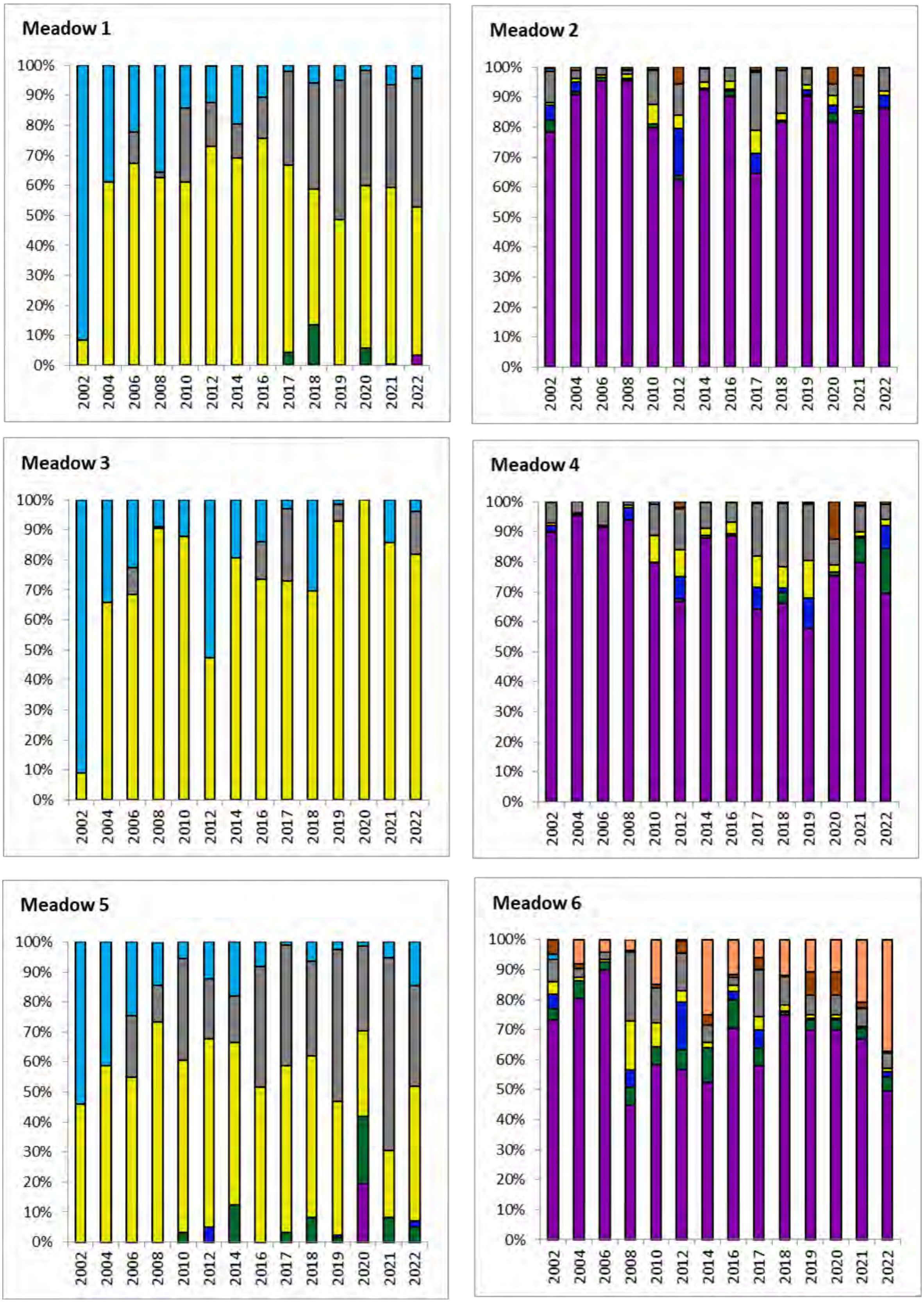
5. Determine the biomass score for 2019 ($Score_{2019}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

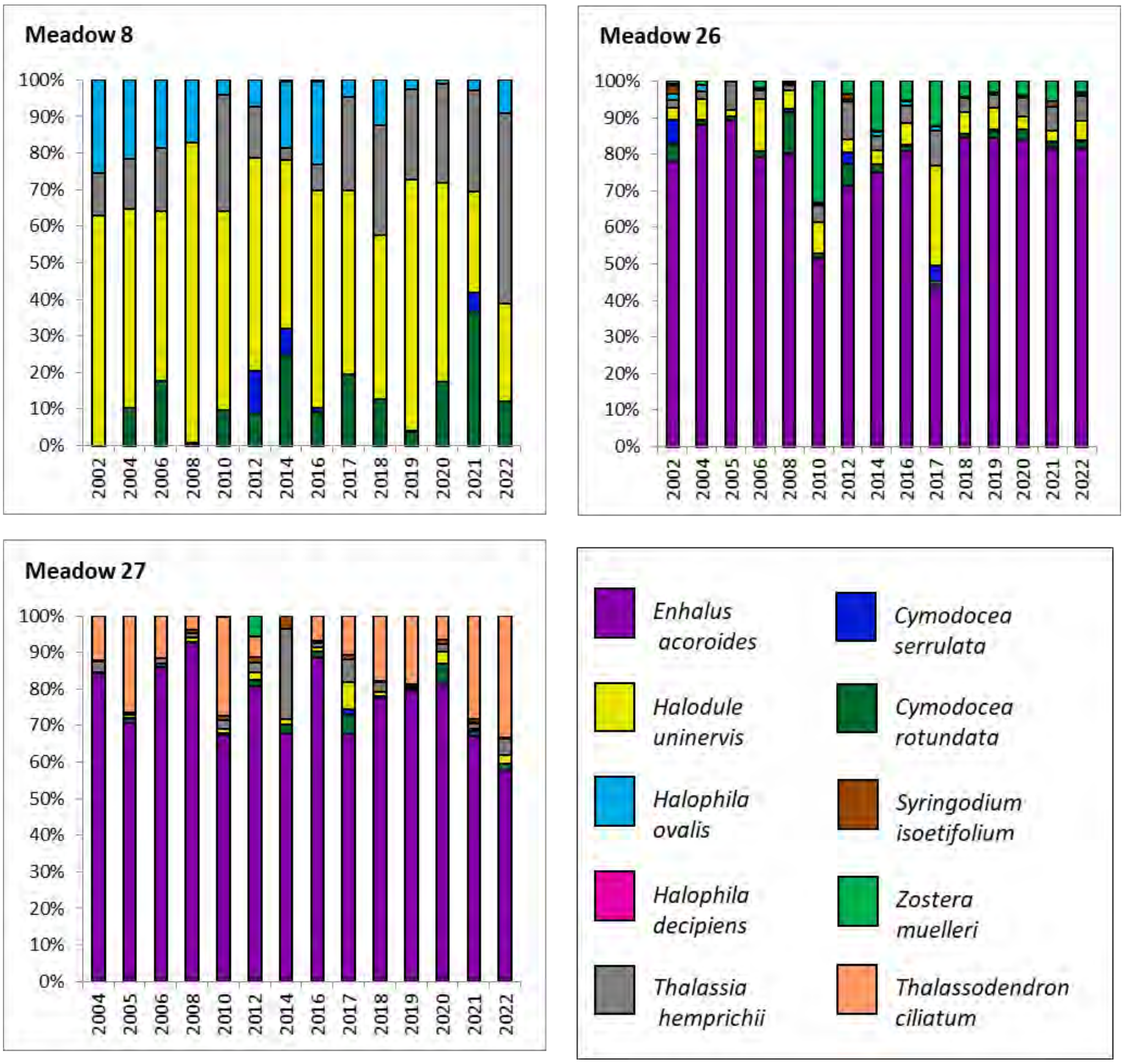
$$Score_{2019} = LB_{satisfactory} + (B_{prop} \times SR_{satisfactory})$$

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

Appendix 3

Species composition of monitoring meadows in the Port of Thursday Island; 2002–2022.




Meadow 8
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2002
2004
2006
2008
2010
2012
2014
2016
2017
2018
2019
2020
2021
2022
Meadow 26
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2002
2004
2005
2006
2008
2010
2012
2014
2016
2017
2018
2019
2020
2021
2022
Meadow 27
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2004
2005
2006
2008
2010
2012
2014
2016
2017
2018
2019
2020
2021
2022
Enhalus acoroides
Cymodocea serrulata
Halodule uninervis
Cymodocea rotundata
Halophila ovalis
Syringodium isoetifolium
Halophila decipiens
Zostera muelleri
Thalassia hemprichii
Thalassodendron ciliatum

Appendix 4a

Mean above-ground seagrass biomass (g DW m^{-2}) ± standard error and number of biomass sampling sites (in brackets) for each monitoring meadow within the Port of Thursday Island, 2002–2022.

Monitoring Meadow	Mean Biomass ± SE (g DW m^{-2}) (no. of sites)														
	March 2002	**March 2004**	**March 2005**	**March 2006**	**March 2008**	**February 2010**	**February 2012**	**February 2014**	**March 2016**	**March 2017**	**April 2018**	**March 2019**	**September 2020**	**March 2021**	**March 2022**
1 Intertidal *Halodule* dominated	0.27 ± 0.13 (10)	3.69 ± 0.80 (28)		4.26 ± 1.05 (23)	4.15 ± 0.43 (22)	4.17 ± 1.11 (27)	8.35 ± 1.53 (17)	8.77 ± 1.13 (25)	9.15 ± 1.64 (25)	7.08 ± 1.15 (26)	10.98 ± 0.81 (25)	5.3 ± 1.16 (19)	12.91 ± 4.61 (14)	7.01 ± 1.48 (23)	16.18 ± 2.86 (21)
2 Subtidal *Enhalus* dominated	43.26 ± 6.25 (12)	75.38 ± 6.85 (14)		38.16 ± 4.04 (20)	23.40 ± 1.95 (19)	27.73 ± 1.56 (35)	72.41 ± 4.63 (25)	41.46 ± 1.90 (34)	51.53 ± 2.85 (34)	33.40 ± 1.22 (37)	35.45 ± 1.82 (43)	28.32 ± 4.13 (39)	36.62 ± 2.17 (29)	80.29 ± 2.69 (41)	59.18 ± 6.51 (35)
3 Intertidal *Halodule* dominated	0.75 ± 0.07 (3)	2.48 ± 1.23 (7)		1.02 ± 0.40 (8)	3.24 ± 0.69 (9)	2.13 ± 0.75 (12)	3.62 ± 0.95 (5)	8.83 ± 0.88 (5)	9.42 ± 1.89 (9)	6.04 ± 1.27 (8)	1.66 ± 0.68 (8)	1.18 ± 0.5 (11)	7.44 ± 0.84 (2)	3.65 ± 0.70 (9)	11.35 ± 1.33 (13)
4 Subtidal *Enhalus* dominated	32.80 ± 8.49 (14)	56.19 ± 13.10 (6)		28.92 ± 5.71 (5)	17.30 ± 4.56 (5)	19.27 ± 2.52 (17)	46.07 ± 8.46 (17)	42.70 ± 3.81 (14)	44.66 ± 5.54 (12)	23.44 ± 2.09 (18)	25.34 ± 3.41 (21)	11.4 ± 2.54 (19)	19.36 ± 3.77 (9)	64.57 ± 5.96 (21)	48.79 ± 10.39 (15)
5 Intertidal *Halodule* dominated	3.41 ± 1.31 (8)	7.91 ± 1.23 (26)		5.73 ± 0.88 (25)	4.71 ± 0.62 (26)	7.17 ± 2.25 (18)	10.94 ± 1.49 (21)	7.47 ± 0.98 (24)	9.18 ± 1.42 (20)	13.65 ± 1.52 (20)	11.37 ± 1.69 (35)	7.57 ± 1.14 (30)	10.07 ± 2.45 (13)	10.74 ± 1.72 (34)	10.20 ± 1.04 (40)
6 Subtidal *Enhalus* dominated	55.71 ± 8.91 (15)	48.22 ± 8.54 (18)		25.52 ± 4.14 (22)	26.34 ± 3.76 (24)	26.70 ± 2.77 (50)	59.74 ± 5.72 (27)	47.03 ± 6.29 (34)	56.74 ± 2.94 (43)	35.81 ± 1.35 (48)	32.64 ± 2.81 (49)	18.65 ± 3.36 (35)	34.49 ± 4.21 (28)	80.17 ± 7.33 (41)	105.44 ± 18.78 (32)
8 Intertidal *Halodule* dominated	0.36 ± 0.25 (5)	7.37 ± 1.31 (31)		10.48 ± 2.18 (31)	4.46 ± 0.39 (32)	11.67 ± 2.95 (23)	16.04 ± 1.92 (31)	8.23 ± 1.49 (48)	6.17 ± 0.67 (55)	12.43 ± 1.48 (33)	7.32 ± 1.32 (43)	4.96 ± 0.72 (36)	8.34 ± 1.07 (39)	16.15 ± 3.41 (45)	15.09 ± 1.78 (39)
26 Intertidal *Enhalus* dominated	68.81 ± 9.83 (18)	48.78 ± 5.37 (31)	24.08 ± 3.03 (25)	41.89 ± 3.54 (32)	22.01 ± 1.97 (33)	34.24 ± 3.86 (33)	78.47 ± 8.11 (26)	47.84 ± 3.96 (33)	49.01 ± 3.19 (40)	29.33 +/- 1.53 (38)	27.14 ± 2.30 (41)	40.1 ± 3.08 (61)	25.28 ± 1.84 (49)	72.56 ± 5.39 (50)	67.77 ± 5.25 (60)
27 Intertidal *Enhalus* dominated	N/A (1)	47.57 ± 10.55 (13)	24.36 ± 5.71 (8)	32.38 ± 6.44 (10)	16.72 ± 3.45 (10)	23.45 ± 5.02 (25)	70.20 ± 11.85 (20)	43.85 ± 7.08 (21)	43.28 ± 6.60 (16)	29.57 +/- 2.98 (15)	34.16 ± 4.18 (15)	59.72 ± 10.15 (20)	20.66 ± 4.74 (16)	83.57 ± 12.55 (21)	75.05 ± 18.32 (22)

Appendix 4b

Total meadow area + R (ha) for each monitoring meadow within the Port of Thursday Island, 2002 – 2022.

Monitoring Meadow	Total meadow area + R (ha)													
	March 2002	**March 2004**	**March 2006**	**March 2008**	**February 2010**	**February 2012**	**February 2014**	**March 2016**	**March 2017**	**April 2018**	**March 2019**	**September 2020**	**March 2021**	**March 2022**
1 Intertidal *Halodule* dominated	2.30 ± 0.80	2.50 ± 0.90	2.20 ± 0.80	3.75 ± 0.19	2.47 ± 0.74	3.25 ± 0.77	2.85 ± 0.77	2.71 ± 0.79	2.32 ± 0.73	3.44 ± 0.77	3.07 ± 0.34	3.20± 0.35	3.07± 0.37	2.70± 0.45
2 Subtidal *Enhalus* dominated	7.70 ± 2.30	7.80 ± 1.60	7.80 ± 1.60	8.63 ± 0.86	8.91 ± 1.47	8.65 ± 1.59	7.65 ± 1.53	9.05 ± 1.55	11.38 ± 1.61	11.63 ± 1.58	11.44± 0.78	11.85± 0.79	10.61± 0.82	11.26± 0.80
3 Intertidal *Halodule* dominated	0.10 ± 0.05	0.20 ± 0.10	0.30 ± 0.20	0.78 ± 0.04	0.26 ± 0.19	0.40 ± 0.20	0.38 ± 0.21	0.32 ± 0.22	0.29 ± 0.17	0.41 ± 0.20	0.24 ± 0.04	0.23 ± 0.03	0.29 ± 0.03	0.40 ± 0.04
4 Subtidal *Enhalus* dominated	1.30 ± 0.60	1.00 ± 0.50	0.80 ± 0.50	1.11 ± 0.11	0.79 ± 0.45	0.94 ± 0.49	0.68 ± 0.48	0.89 ± 0.49	2.01 ± 0.60	1.99 ± 0.60	1.86 ± 0.29	1.73 ± 0.30	2.11 ± 0.34	1.80 ± 0.32
5 Intertidal *Halodule* dominated	2.10 ± 0.80	1.90 ± 0.80	2.00 ± 0.90	5.26 ± 0.26	3.17 ± 0.90	3.64 ± 0.97	4.54 ± 1.09	4.14 ± 1.02	2.56 ± 0.72	3.85 ± 0.74	3.00 ± 0.38	3.31 ± 0.39	3.52 ± 0.43	3.42 ± 0.42
6 Subtidal *Enhalus* dominated	13.20 ± 2.60	12.40 ± 2.40	12.70 ± 2.50	16.22 ± 1.62	13.18 ± 2.51	12.68 ± 2.16	10.15 ± 2.08	11.33 ± 2.14	13.90 ± 2.26	14.47 ± 2.18	14.08 ± 1.05	14.71 ± 1.11	14.94 ± 1.21	12.30 ± 1.14
8 Intertidal *Halodule* dominated	12.30 ± 2.00	10.40 ± 2.20	12.20 ± 1.80	8.88 ± 0.44	13.44 ± 2.74	14.29 ± 2.74	16.02 ± 2.85	15.64 ± 2.82	14.57 ± 2.79	11.32 ± 2.78	14.27 ± 1.09	14.84 ± 1.08	15.58 ± 1.08	16.15 ± 1.12
26 Intertidal *Enhalus* dominated	94.50 ± 1.50	87.70 ± 3.50	89.00 ± 3.10	83.52 ± 4.18	89.24 ± 3.19	86.26 ± 3.11	81.30 ± 3.23	94.75 ± 3.42	84.77 ± 2.88	93.43 ± 3.31	93.95 ± 3.29	94.92 ± 3.38	91.84 ± 3.32	97.58 ± 3.32
27 Intertidal *Enhalus* dominated	6.10 ± 0.70	7.00 ± 0.90	5.80 ± 0.70	5.88 ± 0.29	8.22 ± 0.86	7.15 ± 0.85	9.58 ± 0.94	7.14 ± 0.79	6.18 ± 0.68	6.61 ± 0.68	6.24 ± 0.69	7.16 ± 0.72	6.98 ± 0.75	7.61 ± 0.72