Centre for Tropical Water and Aquatic Ecosystem Research

SEAGRASS HABITAT IN THE PORT OF THURSDAY ISLAND:

Annual Monitoring Report 2021

Scott, AL & Rasheed, MA

Report No. 21/32

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Annual Monitoring Report 2021

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

Report No. 21/32

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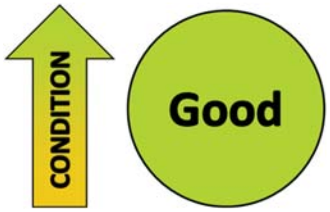
KEY FINDINGS

Seagrass Condition 2021



- Aerial and boat surveys of seagrass monitoring meadows were conducted between 8th – 9th March 2021. In 2020 the annual monitoring survey was delayed due to COVID restrictions, and results from the survey between 15th – 16th September are also presented.
- The overall condition of the annual monitoring meadows in the Port of Thursday Island was upgraded from satisfactory in 2019, to good in 2021, mainly due to increases in seagrass biomass.
- Previous declines recorded in the meadows around the Island in 2019 were reversed in the 2021 survey and some meadows had record high biomass in 2021.
- The subtidal meadows 4 and 6, which were of particular concern in 2019, recovered in 2021 to very good condition with large increases in biomass and an increase in area that saw these meadows join for the first time.
- The combined area of annual monitoring meadows was the highest recorded in the program in 2020 and second highest in 2021.
- Intertidal meadows showed a shift towards larger growing more stable seagrass species.
- Climate conditions were favourable for seagrass growth in 2020 and 2021.
- 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 2021.

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 March 2021 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 152 ± 8 ha of seagrass habitat mapped within the nine monitoring meadows in 2020 was the largest recorded since monitoring began in 2002 and the 2021 survey was the second largest area at 149 ± 8 ha (Figure 1).

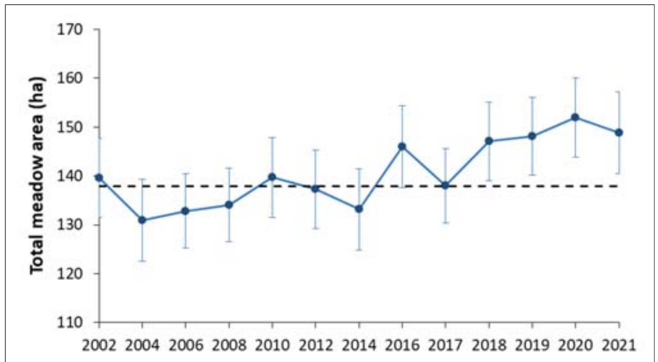


Figure 1. Total area of seagrass within the Thursday Island monitoring region from 2002 to 2021 (error bars = "R" reliability estimate). Dashed line indicates long-term average of meadow area.

There was a reversal of the declines seen in 2019, particularly for the meadows that were of greatest concern in that survey. Most improvements in meadow scores from 2019 were due to increases in biomass. Scores for the subtidal *E. acoroides* meadows on the south side of Thursday Island (meadows 4 and 6) increased to good or very good condition from the lowest recorded biomass in 2019, to the highest in 2021, and these meadows increased in area to join up. All meadow indicators were in good or very good condition in 2021 (Figure 2).

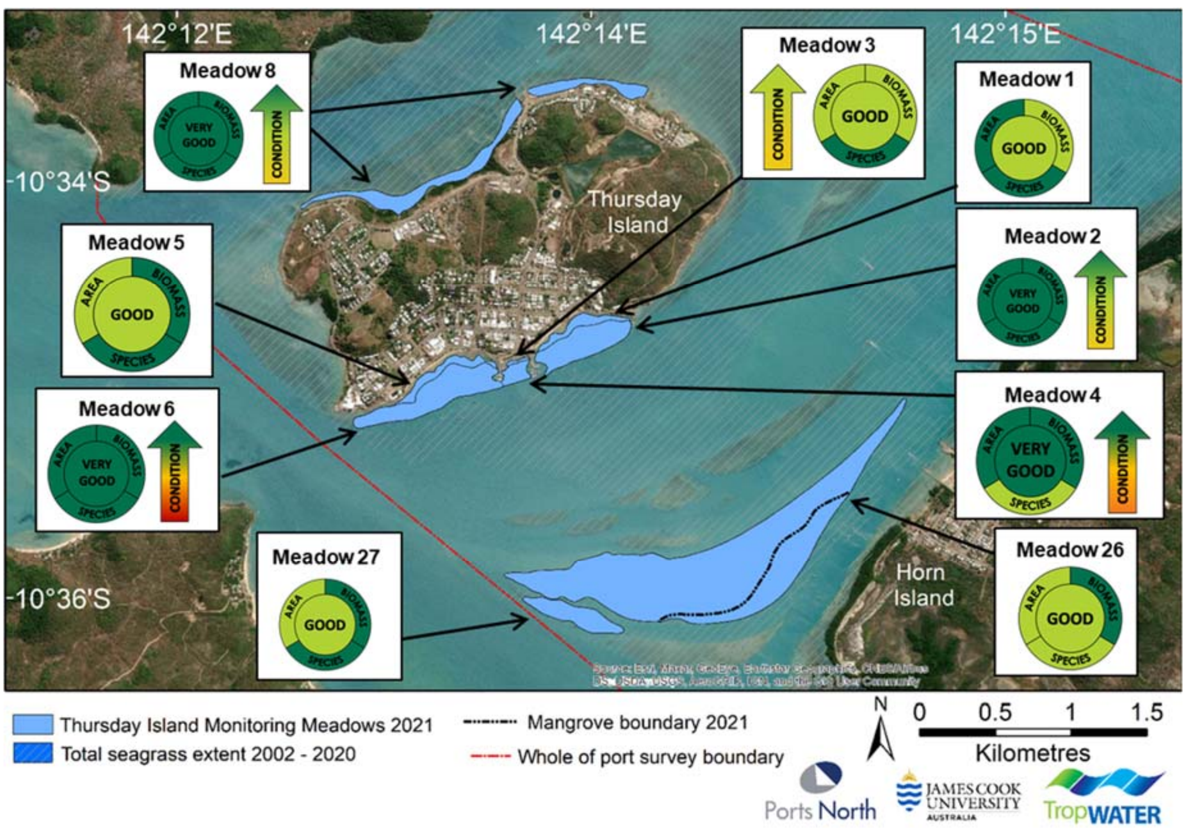


Figure 2. Seagrass condition for Port of Thursday Island annual monitoring meadows in 2021.

Climate conditions were favorable leading up to the March 2021 survey with no major storms or cyclones affecting the area. Air temperature and exposure were slightly above average, while rainfall and solar radiation were close to the long term average in 2021 (Figure 3).

Meadow condition improved in many of the meadows around Thursday Island from 2019 and all of the meadows around the Island were in good or very good condition for the first time since 2016. The meadows at Madge Reef remained stable and in good condition. There was a shift in species at some of the intertidal meadows around Thursday Island, away from the usual dominance of *Halodule uninervis* towards a more stable seagrass community with larger growing species increasing their contribution to overall meadow composition.

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 2021. This is in contrast other seagrass meadows in the Torres Strait particularly in the Central and Western Cluster areas where declines in seagrasses have been observed in 2020. At Weipa, the next closest seagrass long-term monitoring location to Thursday Island in the ports monitoring program (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/

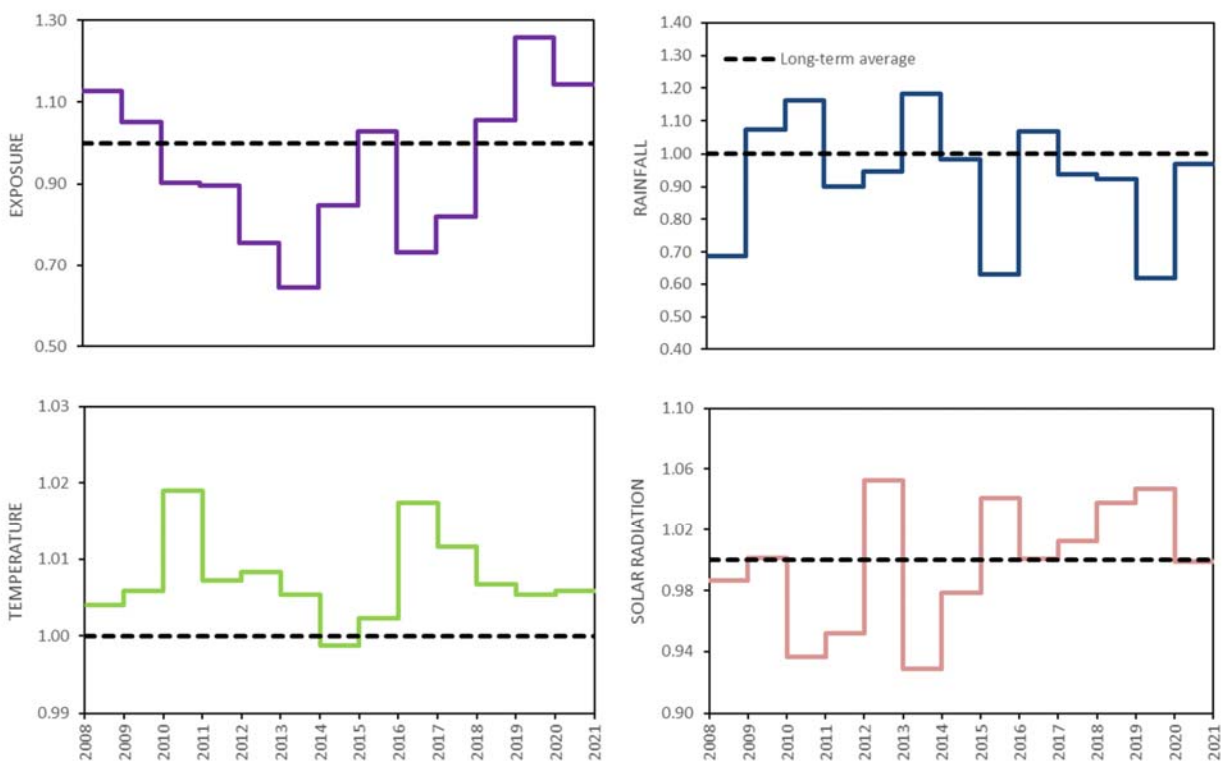


Figure 3. A diagrammatic summary of recent climate trends in Thursday Island: changes in climate variables as a proportion of the long-term average. See Section 3.4 for detailed climate data.

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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 both the March 2021 annual seagrass monitoring and the delayed 2020 survey that took place in September, including:

- Maps of seagrass distribution, abundance and species composition within the long-term annual monitoring meadows;
- 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;
- 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 TropWATER's Queensland-wide seagrass monitoring programs. The annual seagrass monitoring surveys of the nine long-term monitoring meadows (Figure 2) were conducted on 15 – 16th September 2020 and 8 – 9th March 2021.

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.

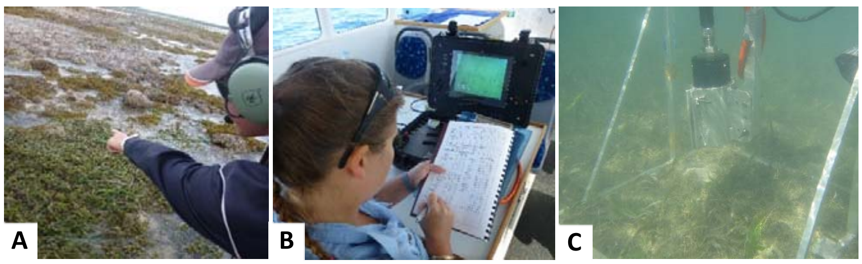

Figure 5. Seagrass monitoring methods. (A) helicopter aerial surveillance, (B, C) boat-based camera drops.

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.

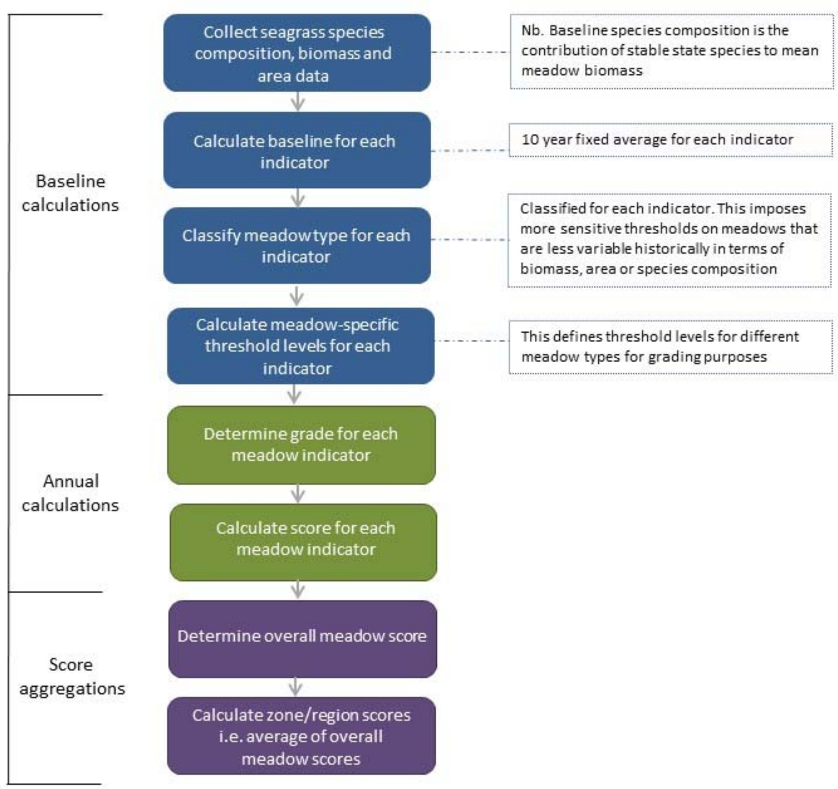

Figure 7. Flow chart to develop Thursday Island grades and scores.

3 RESULTS

3.1 Seagrasses in Thursday Island

A total of 307 sites were surveyed in the 2021 annual monitoring survey (Figure 8). Ten seagrass species were recorded with five seagrass community types identified (Figure 9; Table 4). The total area of seagrass habitat mapped within the nine annual monitoring meadows was 149 ± 8 ha (Figure 1).

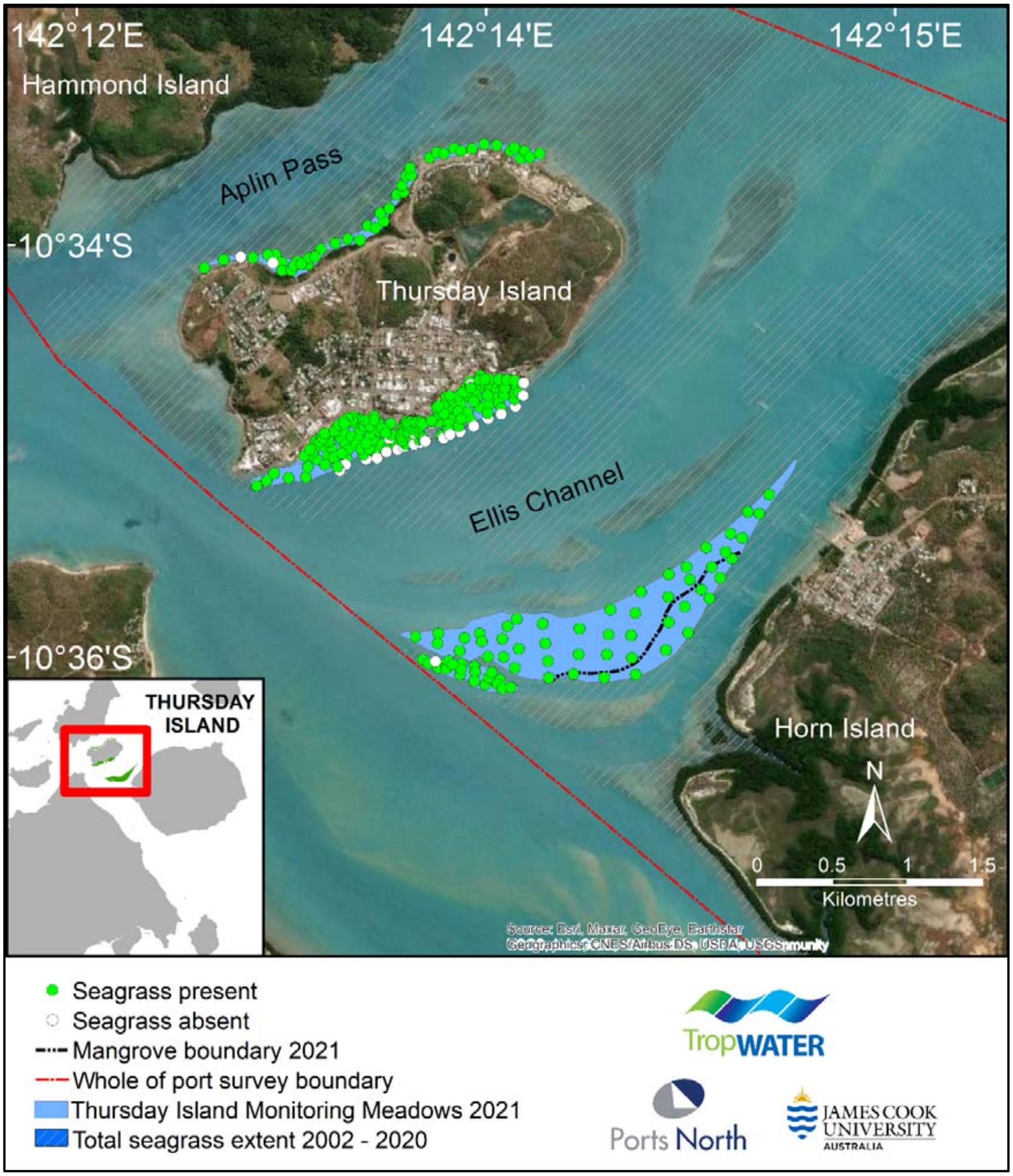

Figure 8. Port of Thursday Island seagrass meadows and seagrass presence/absence at sites surveyed for annual monitoring meadows in 2021.

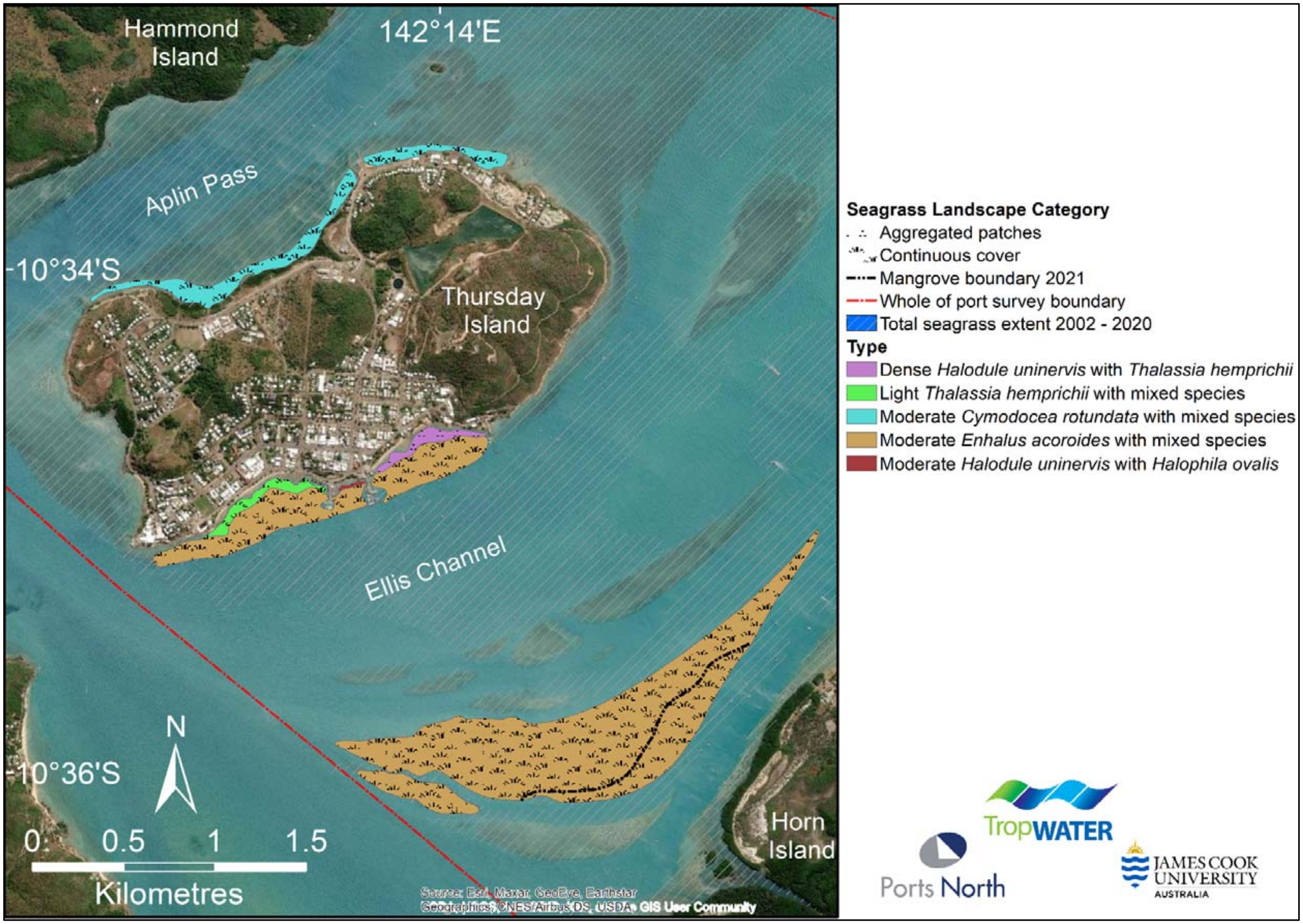

Figure 9. Port of Thursday Island seagrass distribution and community type for seagrass meadows for annual monitoring meadows in 2021.

Table 4. Seagrass species present at the Port of Thursday Island in 2021.

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
		*Thalassodendron ciliatum* (Forssk.) Hartog
ZOSTERACEAE Drummortier		*Zostera muelleri* subsp. *capricorni* (Aschers.)
HYDROCHARITACEAE Jussieu		*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.
		*Halophila ovalis* (R. Br.) Hook. F.
		*Enhalus acoroides* (L.F.) Royle

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 2021 (Table 5). All meadows were in good or very good condition with overall condition improvements in five of the nine meadows from 2019. These improvements in score were driven by increases in seagrass biomass at all five meadows, along with improvements in area for meadows 3 and 6 and species for meadow 4.

The combined area of all annual monitoring meadows has been at or above the long-term average since 2016, and in 2021 reached the second largest area since monitoring began (149 ± 8 ha), with the highest recorded area in 2020 (153 ± 8 ha) (Figure 2). Meadow area is the most stable of the three indicators (biomass, area and species composition) throughout the port monitoring meadows.

Due to COVID restrictions, we were unable to travel to Thursday Island in March 2020, so the annual monitoring survey was carried out in September 2020. As seagrass meadows around Thursday Island can vary considerably on a seasonal basis, the data from September cannot be compared directly to the usual March survey data. The 2020 data is shown in Figures 12 – 20, but all condition comparisons are based on the March 2019 survey.

Table 5. Grades and scores for seagrass indicators (biomass, area and species composition) for the Port of Thursday Island 2021. 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	0.79	0.85	0.97	0.79
2	0.99	0.90	0.86	0.88
3	0.73	0.67	0.89	0.67
4	0.98	0.97	0.82	0.90
5	0.88	0.81	0.98	0.81
6	1	0.88	0.91	0.88
8	0.96	0.92	0.99	0.92
26	0.91	0.83	0.80	0.82
27	1	0.75	0.89	0.75
Overall Score for the Port of Thursday Island				**0.82**

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 their spatial footprint with small increases in area at all of the meadows (Figures 12, 14, 16 and 19). All four *H. uninervis* monitoring meadows also increased in biomass since the 2019 survey. *Halodule uninervis* or a more stable species dominated meadows 1, 5 and 8, making up over 93% of species composition, while meadow 3 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*. In 2020 biomass was very high in the majority of these meadows, however this may reflect seasonal differences.

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 increase in area since 2019. Biomass is now above baseline levels in this meadow and area remains above baseline levels for the fourth year in a row (Figure 12; Appendix 4a). 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 6.5% of species composition (Figure 12; Appendix 3).

Increases in both biomass and area in meadow 3, between the Main and Engineer's wharves, resulted in an overall increase in condition from satisfactory to good. Meadow biomass more than doubled from 2019 levels and has recovered from satisfactory to good and is close to baseline levels (Figure 14; Appendix 4a). The increase in meadow area from 0.24 ± 0.04 ha in 2019 to 0.29 ± 0.04 ha in 2021 resulted in condition change from satisfactory to good, however meadow area is still below mean baseline levels (Figure 14; Appendix 4b). Species composition remains in very good condition despite the increase in the percentage of less stable species from 1.3% in 2019 to 14.3% in 2021, with the remainder made up of *H. uninervis* (Figure 14; Appendix 3).

The *H. uninervis* meadow at the western end of Thursday Island (meadow 5) remains in good condition. Increases in biomass from 7.6 ± 1.1 g DW m^{-2} in 2019 to 10.7 ± 1.7 g DW m^{-2} in 2021 have improved biomass condition from good to very good (Figure 16; Appendix 4a). Meadow area also increased above baseline levels to remain in good condition (Figure 16; Appendix 4b). Although the percentage of the dominant species *H. uninervis* was low (22.3%), the larger more stable species *C. rotundata* and *T. hemprichii* made up a high percentage (72.5%) giving the meadow a species score of very good.

The only annual monitoring meadow on the northern side of Thursday Island (meadow 8) was in very good condition (Figure 18). Meadow biomass increased substantially from 5.0 ± 0.7 g DW m^{-2} in 2019 to 16.2 ± 3.4 g DW m^{-2} in 2021 (Figure 18; Appendix 4a). This increase in biomass resulted in an improved biomass condition from satisfactory to very good and the same improvement in overall meadow condition (Figure 18). Meadow area increased and remained in very good condition (Figure 18; Appendix 4b). The meadow was comprised of over 69% more stable species than the usually dominant *H. uninervis* which made up 27.6% of the community, as the less stable species made up less than 3% of the meadow, the species composition indicator is in a very good condition (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 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) have record high biomass values and have remained stable in area resulting in all meadows being in very good condition (Table 5). The intertidal *E. acoroides* meadows at Madge Reef to the south have also increased substantially in biomass in 2021 and maintained their area and species composition scores (Figures 19 and 20). Both meadows maintained their overall meadow scores of good in 2021 (Table 5). In 2020 biomass was below baseline levels in these meadows, however this may be due to seasonal differences between March and September.

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. Declines in the dominance of *E. acoroides* in all five monitoring meadows were documented in 2017, which led to reductions in the above-ground biomass of these meadows below long-term averages (Figures 13, 15, 17, 19 and 20; Appendix 3). In all but one (meadow 4) the proportion of *E. acoroides* is above baseline levels and all are in good or very good condition.

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

The intertidal/subtidal meadow at the south-eastern end of Thursday Island (meadow 2) is in a very good condition for the first time since monitoring began (Figure 13). Meadow biomass was the highest recorded value of over 80 g DW m^{-2} with 84% of the dominant *E. acoroides* (Figure 13; Appendix 3, 4a). Meadow area declined in 2021 but remained well above baseline levels and in very good condition (Appendix 4b).

The smallest *E. acoroides* meadow between the wharves (meadow 4) also had the highest recorded biomass in 2021 and overall meadow condition increased from poor to very good (Figure 15; Appendix 4a), this meadow was dominated by 79.8% *E. acoroides* but species composition was just below baseline levels (Figure 15; Appendix 3). Area increased in 2021 to 2.0 ± 0.31 ha, close to the peak recorded in 2017 (Figure 15; Appendix 4b).

Overall meadow condition of meadow 6 improved significantly from poor to very good (Table 5). This improvement was driven by a large increase in meadow biomass and a small increase in meadow area (Figure 17). In 2021 the highest biomass since monitoring began was recorded (Figure 17; Appendix 4a) with over 85% *E. acoroides* and *T. ciliatum*, hotspots of very high biomass were present in the meadow and were dominated by *T. ciliatum* (Figure 17; Appendix 3). There was an increase in meadow area and seagrass was observed for the first time around and under the wharves.

Madge Reef meadows

The intertidal *E. acoroides* meadows at Madge Reef to the south have also maintained a similar meadow area, which is largely dictated by the shape of the reef top, meadow 26 had a small decrease in area from 2019 and meadow 27 increased to bring it back up to baseline levels (Figures 19 and 20; Appendix 4b). Both of these meadows had large increases in biomass to record the highest ever biomass at meadow 27 of 83.6 ± 12.6 g DW m^{-2} and second highest biomass at meadow 26 of 72.6 ± 5.4 g DW m^{-2} (Figures 19 and 20; Appendix 4a).

Species composition at these meadows was dominated by *E. acoroides* and *T. ciliatum*, these species made up over 95% 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). The dominance of *E. acoroides* in both meadows remains well above the long-term average (Figures 19 and 20; Appendix 3).

In contrast to the *E. acoroides* meadows around Thursday Island, biomass has been classed in good or very good condition for the monitoring meadows on Madge Reef since 2010 (Figures 19 and 20). These meadows maintained their overall meadow scores of good in 2021 (Table 5).

All three condition indicators (biomass, area and species composition) were maintained or increased in condition between 2019 and 2021 for both Madge Reef meadows (meadows 26 and 27; Table 5; Figures 19 and 20).

An area of expanding mangroves has been monitored in this meadow over the course of the program. In 2021 the biomass of seagrass in this mangrove recruitment area was lower than the rest of the meadow, possibly due to mangrove establishment (Figure 11).

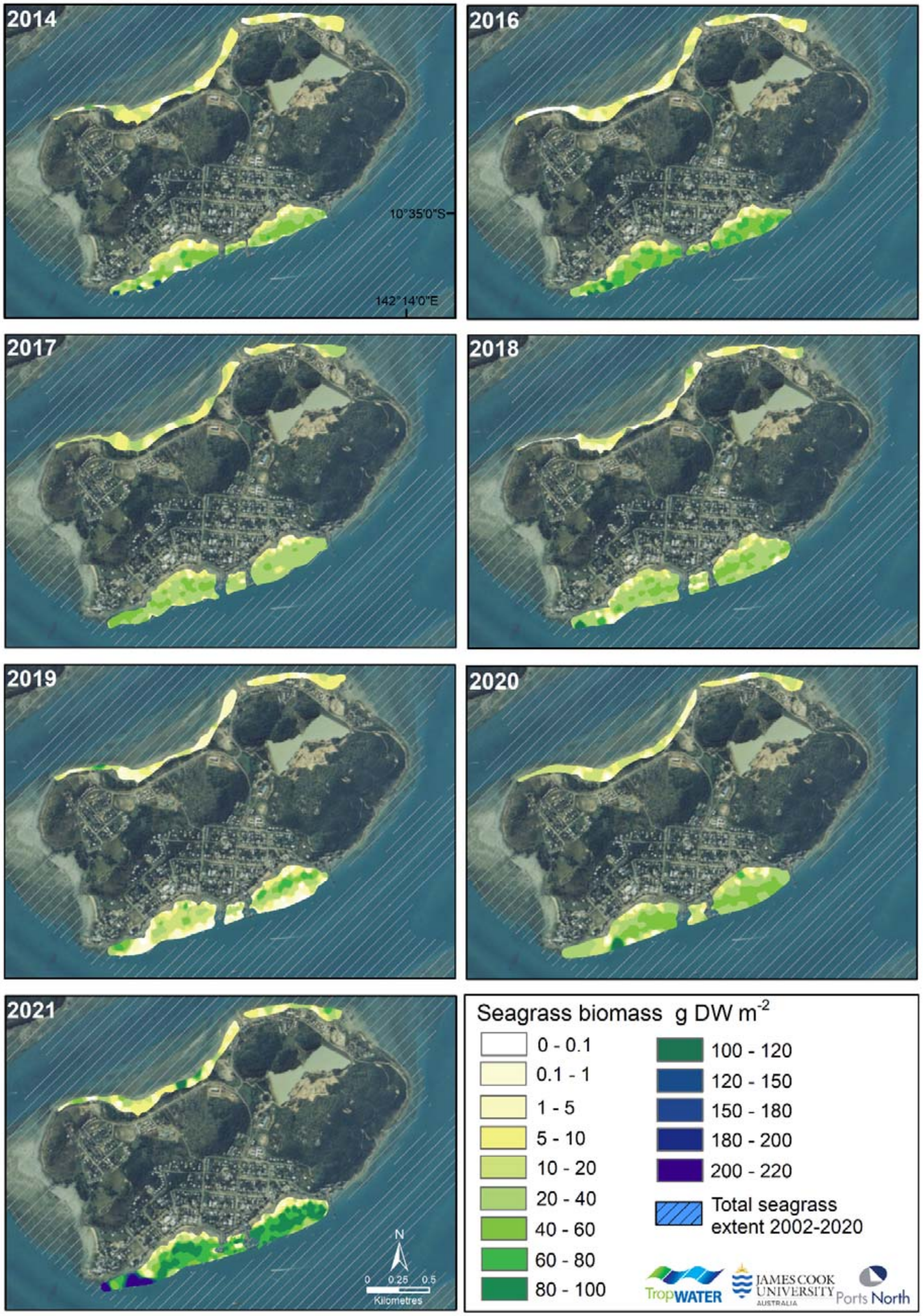

Figure 10. Changes in biomass and area (Meadows 1-6 and 8) in the Port of Thursday Island (2010-2021).

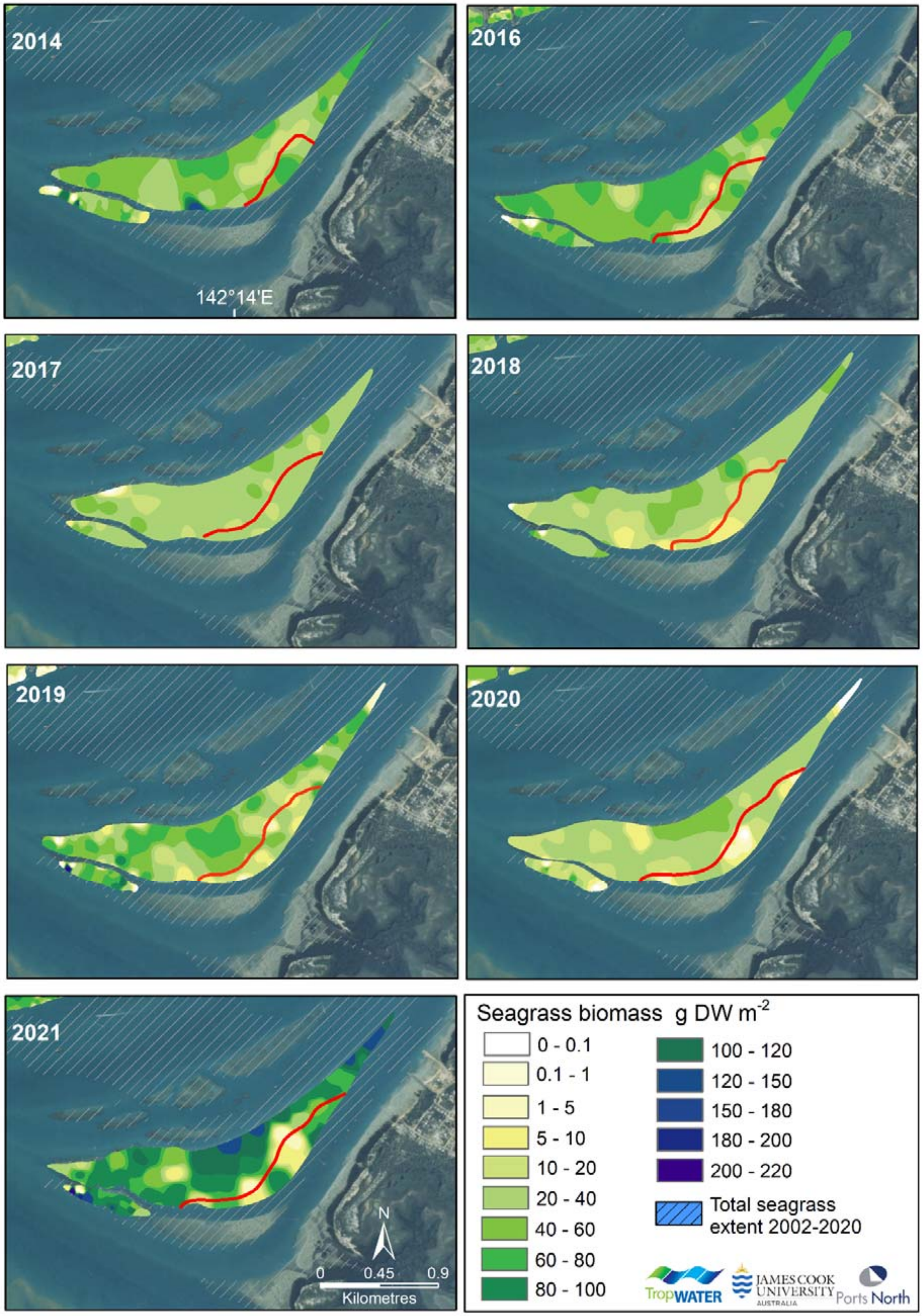

Figure 11. Changes in biomass and area (Meadows 26 and 27) in the Port of Thursday Island (2010-2021). The red line indicates the mangrove recruitment area boundary.

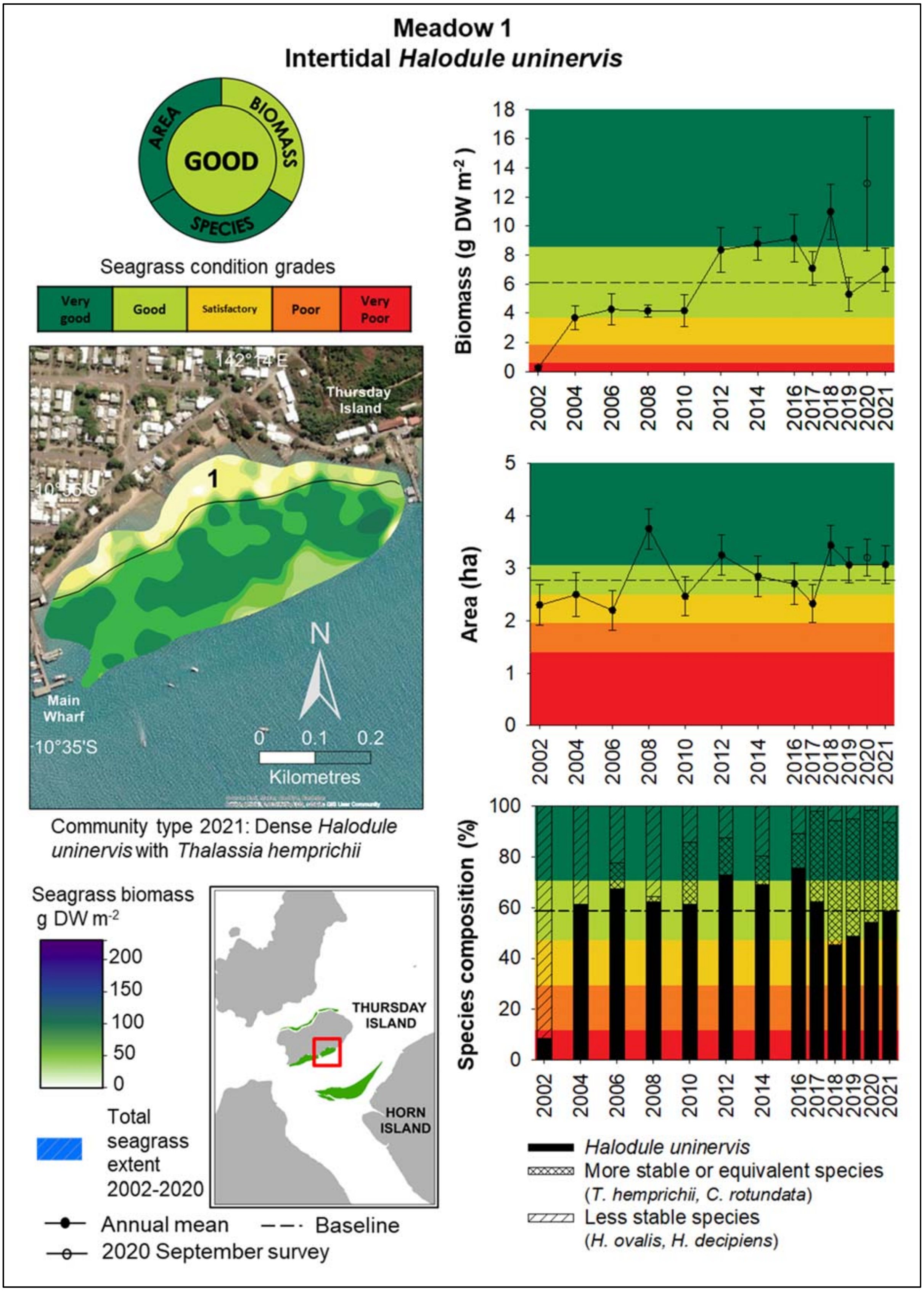

Figure 12. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 1 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

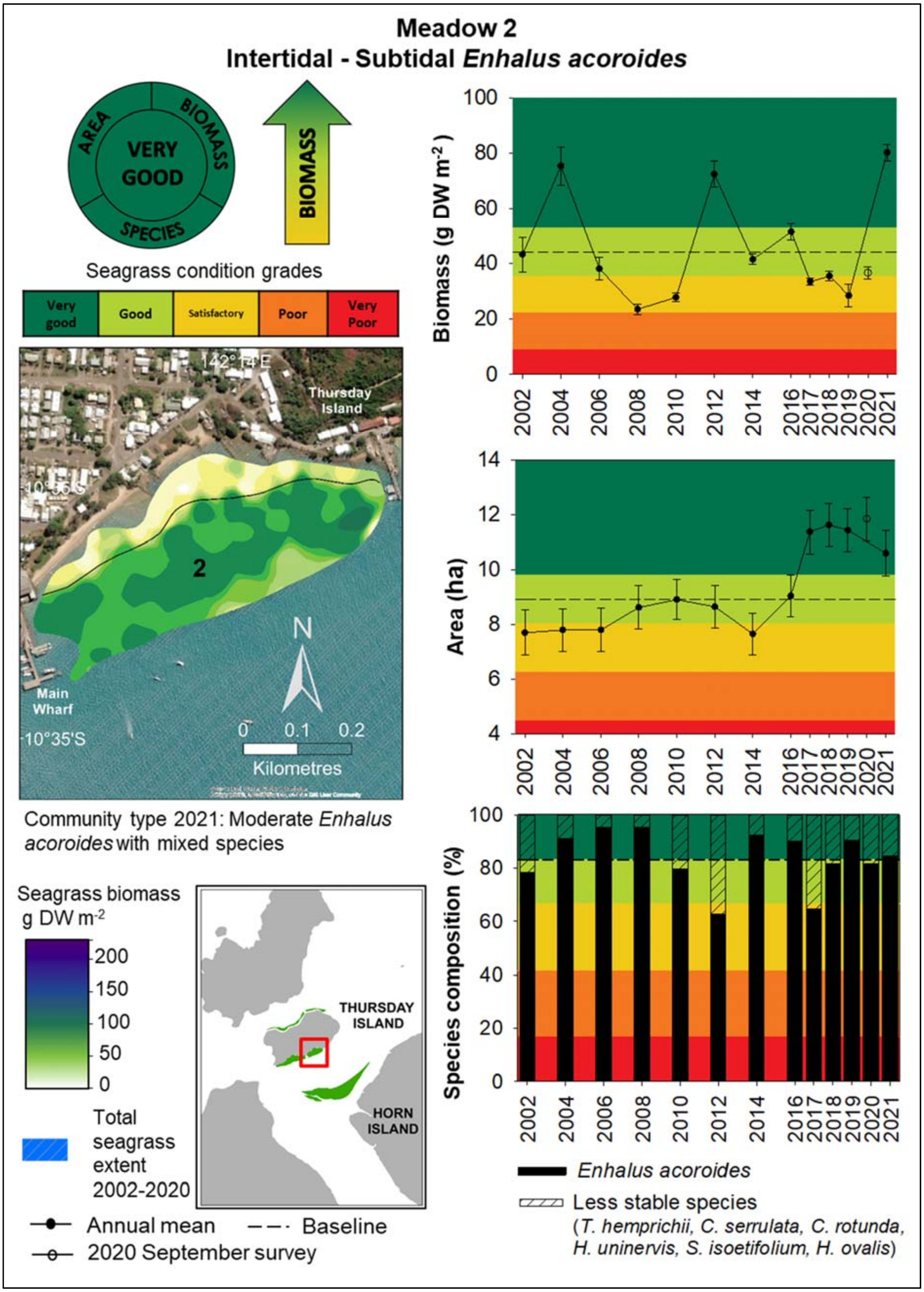

Figure 13. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 2 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

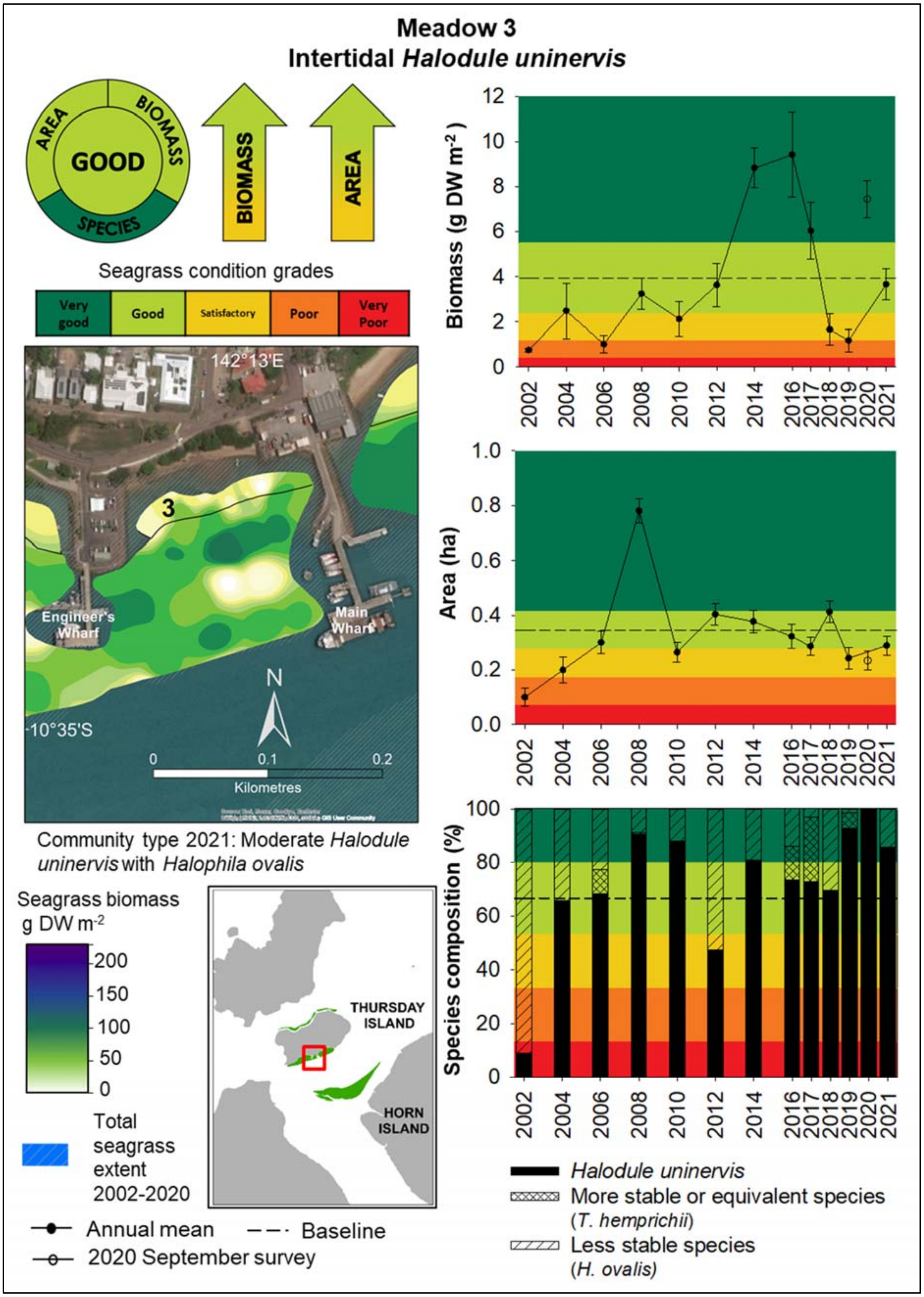

Figure 14. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 3 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

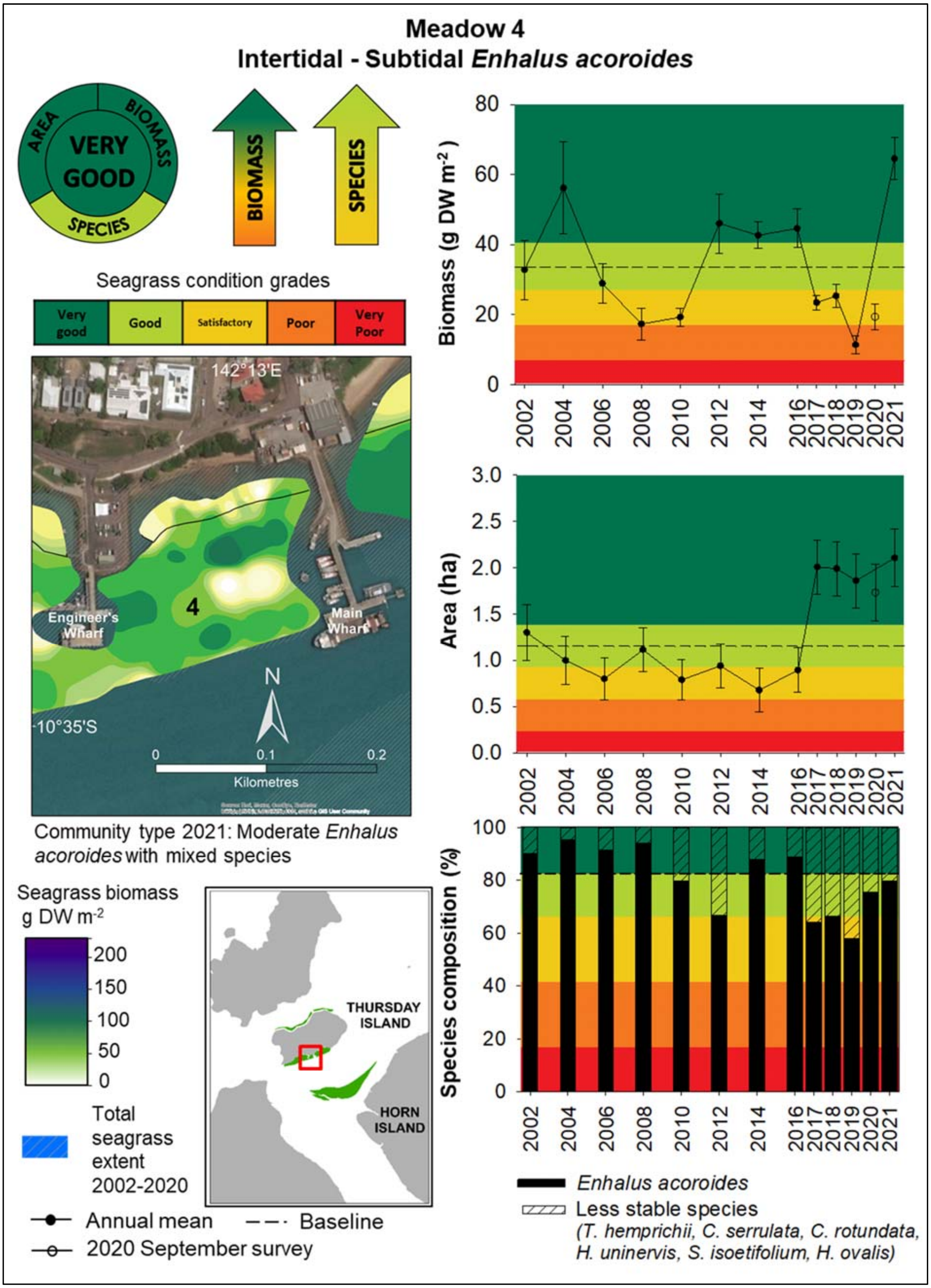

Figure 15. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 4 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

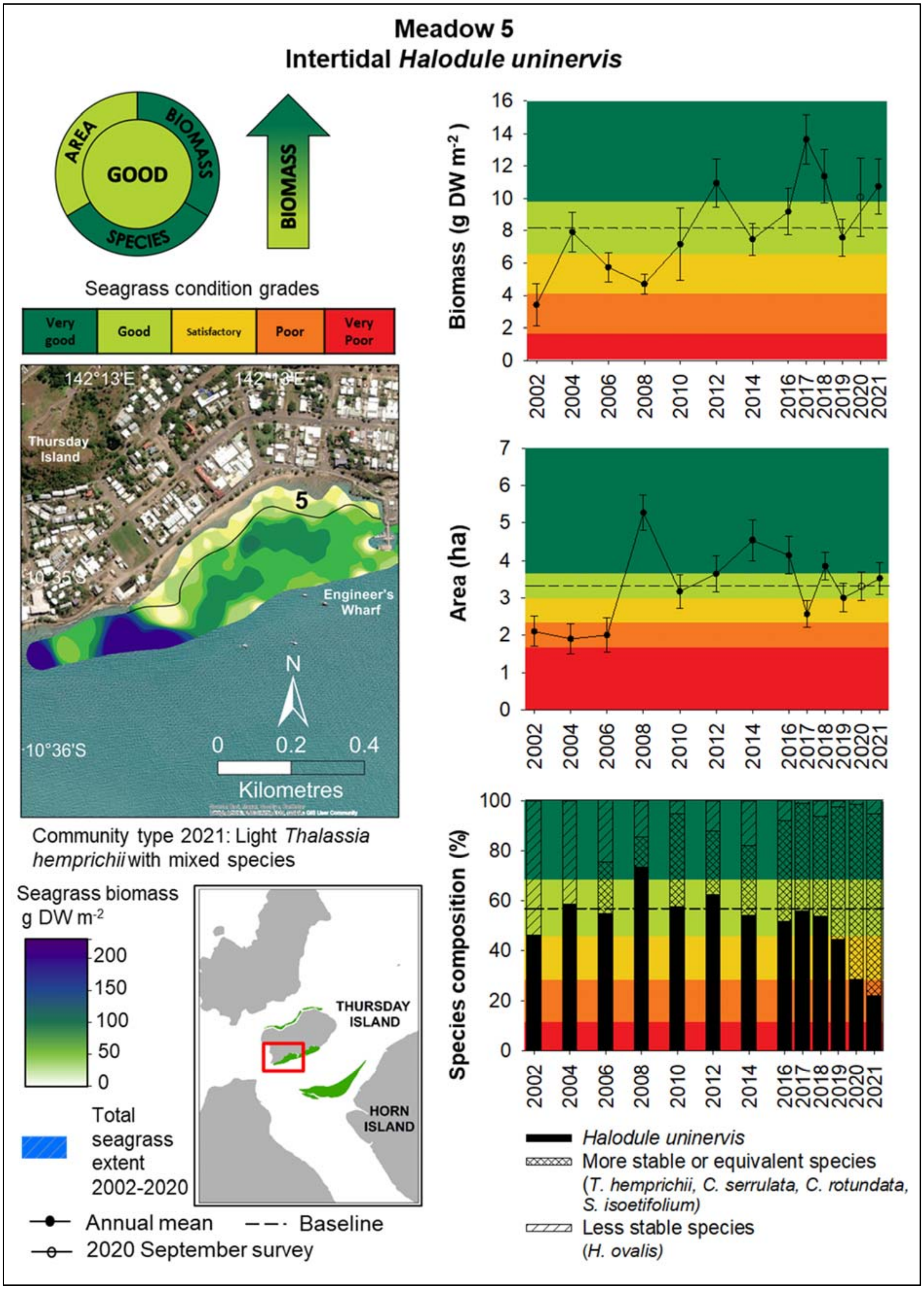

Figure 16. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 5 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

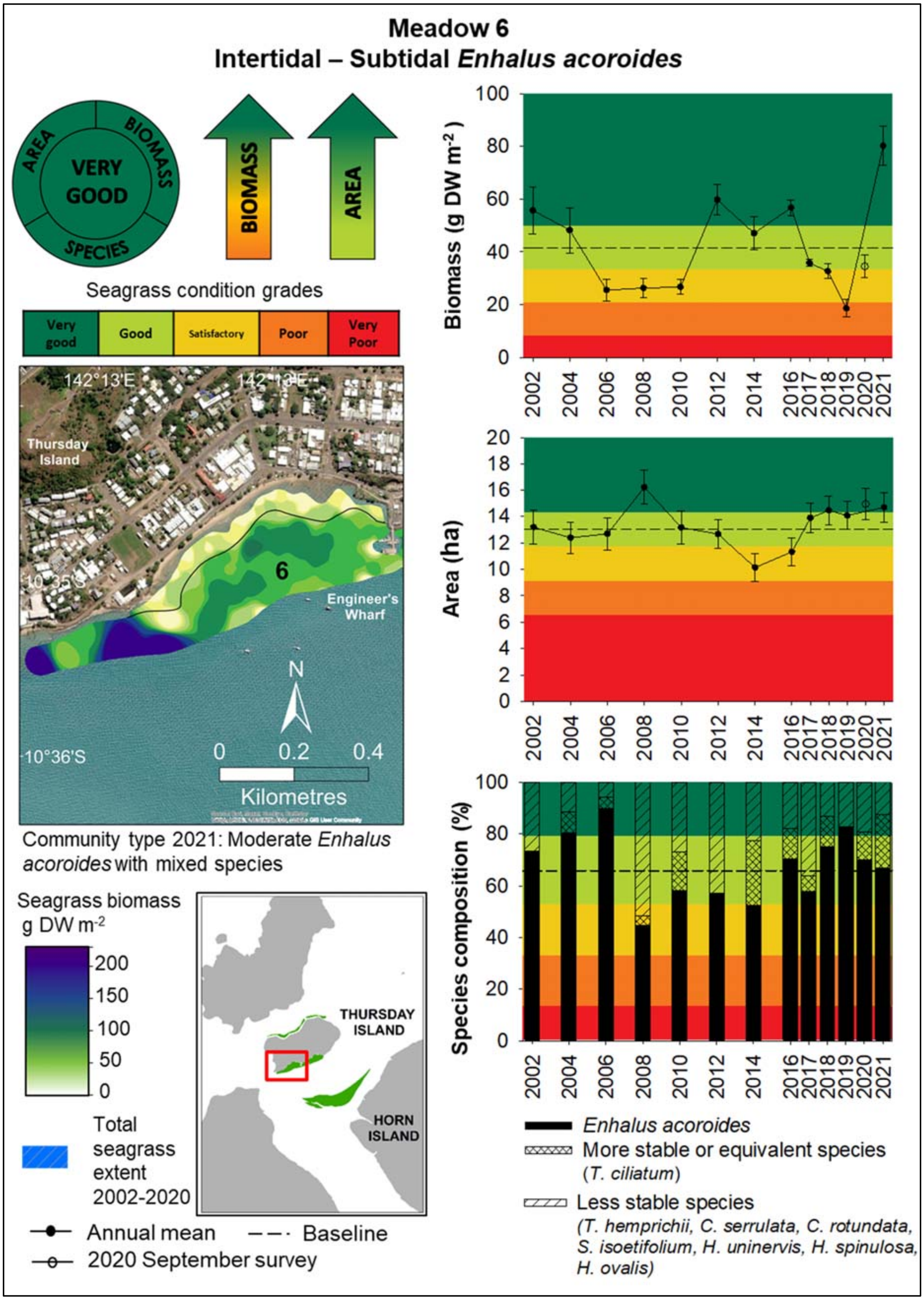

Figure 17. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 6 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

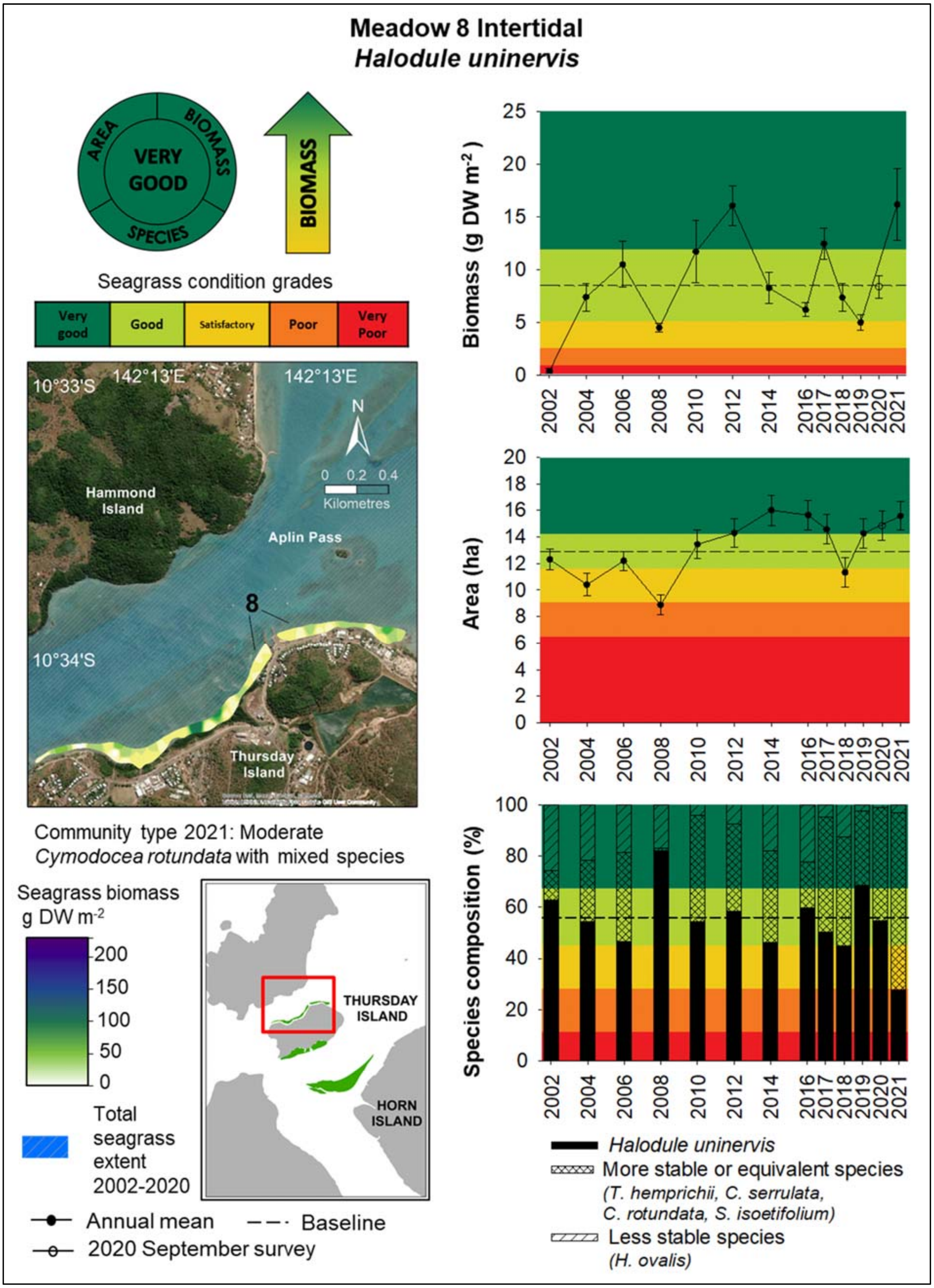

Figure 18. Changes in biomass, area and species composition for the *Halodule uninervis* dominated monitoring Meadow 8 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

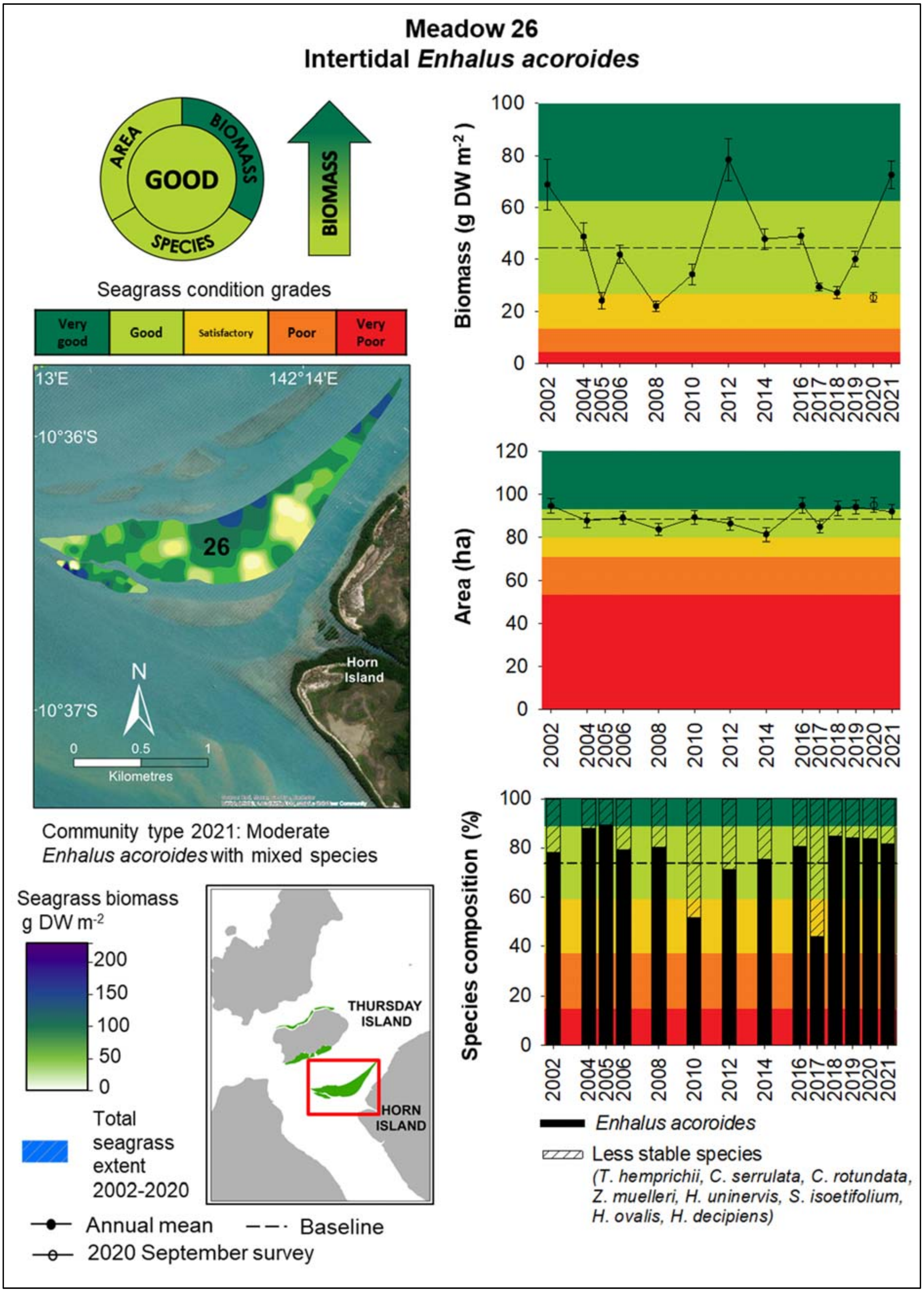

Figure 19. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 26 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

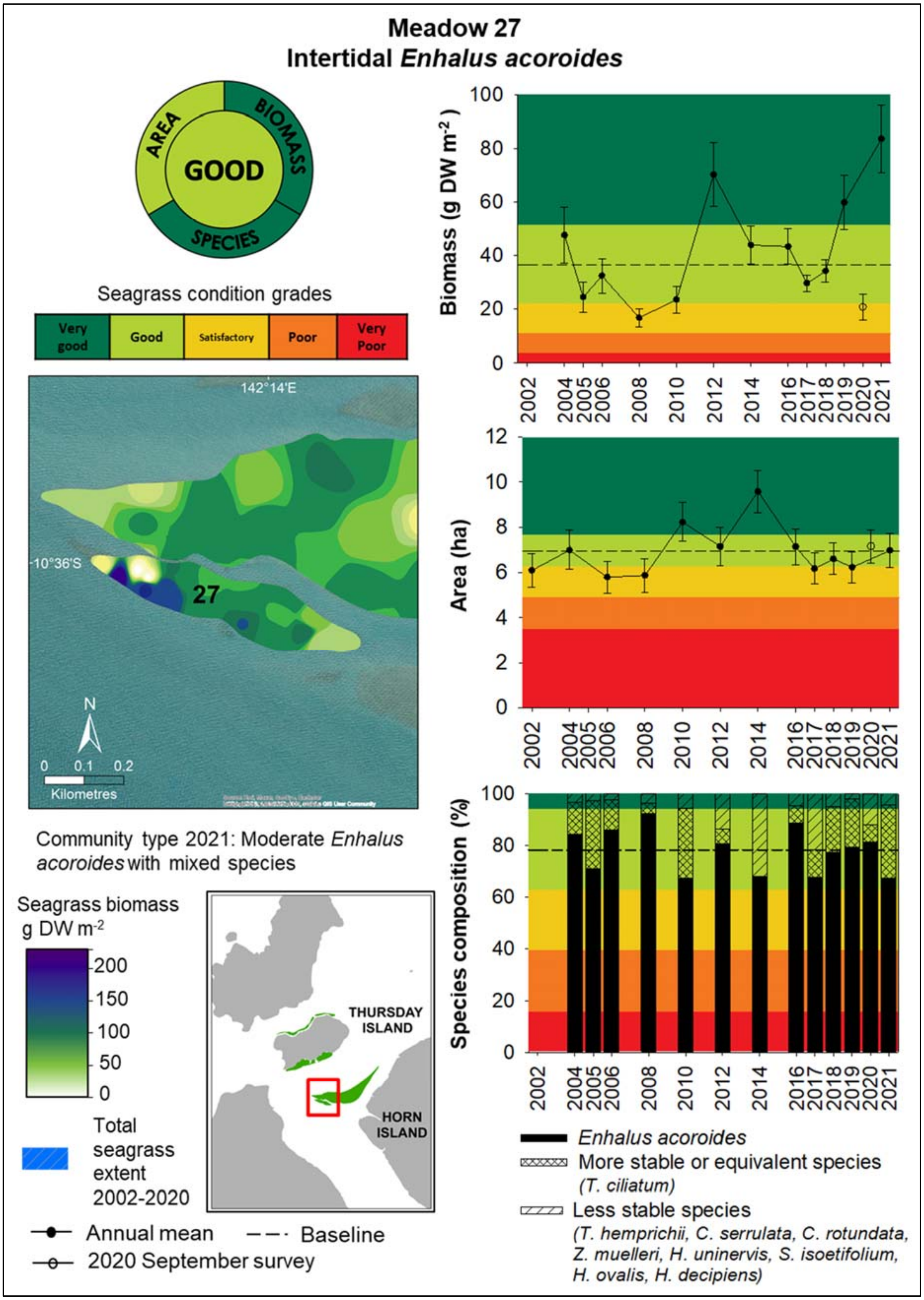

Figure 20. Changes in biomass, area and species composition for the *Enhalus acoroides* dominated monitoring Meadow 27 at Thursday Island from 2002 to 2021 (biomass error bars = SE; area error bars = "R" reliability estimate).

3.4 Thursday Island climate patterns

3.4.1 Rainfall

Total annual rainfall in the Thursday Island area leading up to the 2021 survey was just below the long-term average (Figure 22). The survey month (March 2021) was higher than the previous two years and near the long-term monthly average (Figure 23). The month preceding the survey had below average rainfall, however January 2021 had the highest monthly rainfall in the last 15 years (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.

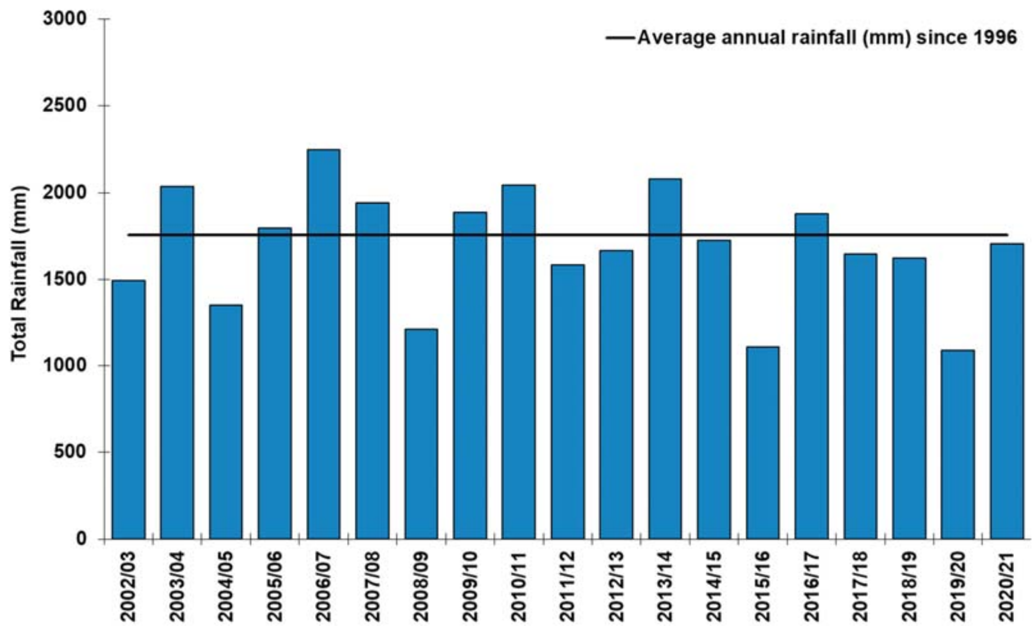

Figure 21. Total annual rainfall (mm) recorded at Horn Island, 2002/2003 – 2020/2021. Twelve-month year (2020/2021) is 12 months prior to survey.

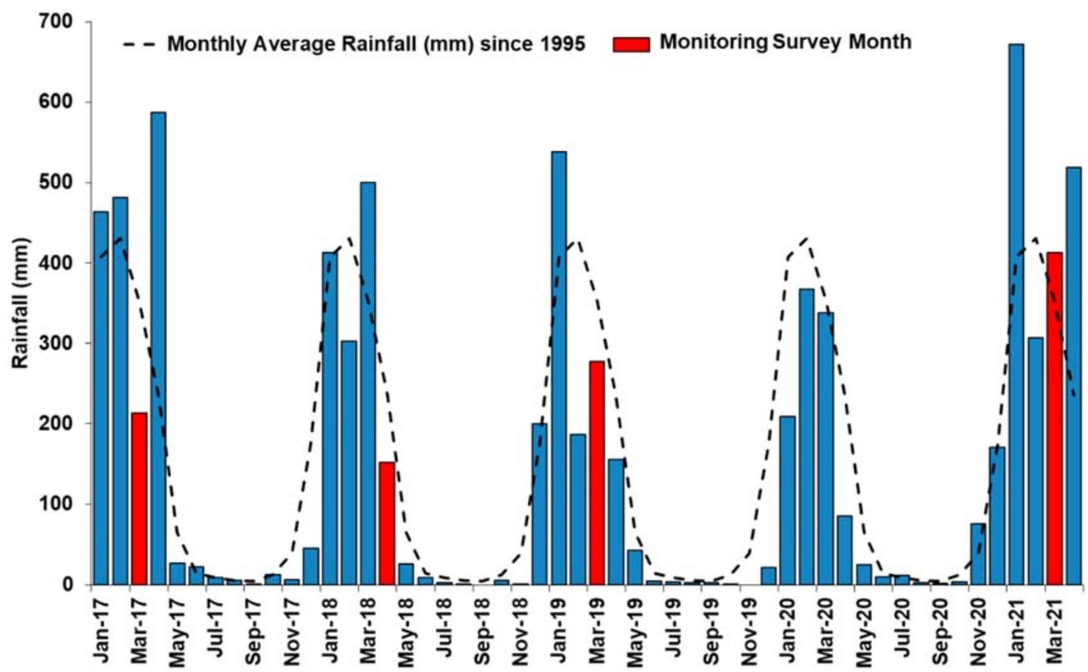

Figure 22. Total monthly rainfall (mm) recorded at Horn Island, January 2017 – April 2021. Annual monitoring survey months are coloured red.

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 two months of below average temperatures (Figure 25).

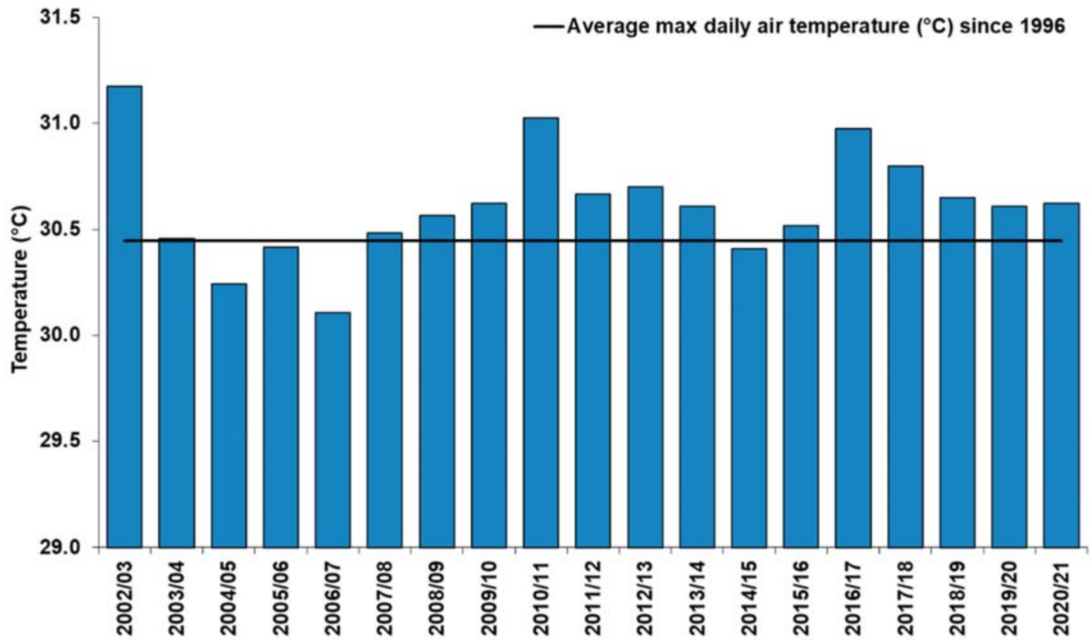

Figure 23. Maximum daily air temperature (annual average, °C) recorded at Horn Island, 2002/2003 – 2020/2021. Twelve month year (2020/2021) is 12 months prior to survey.

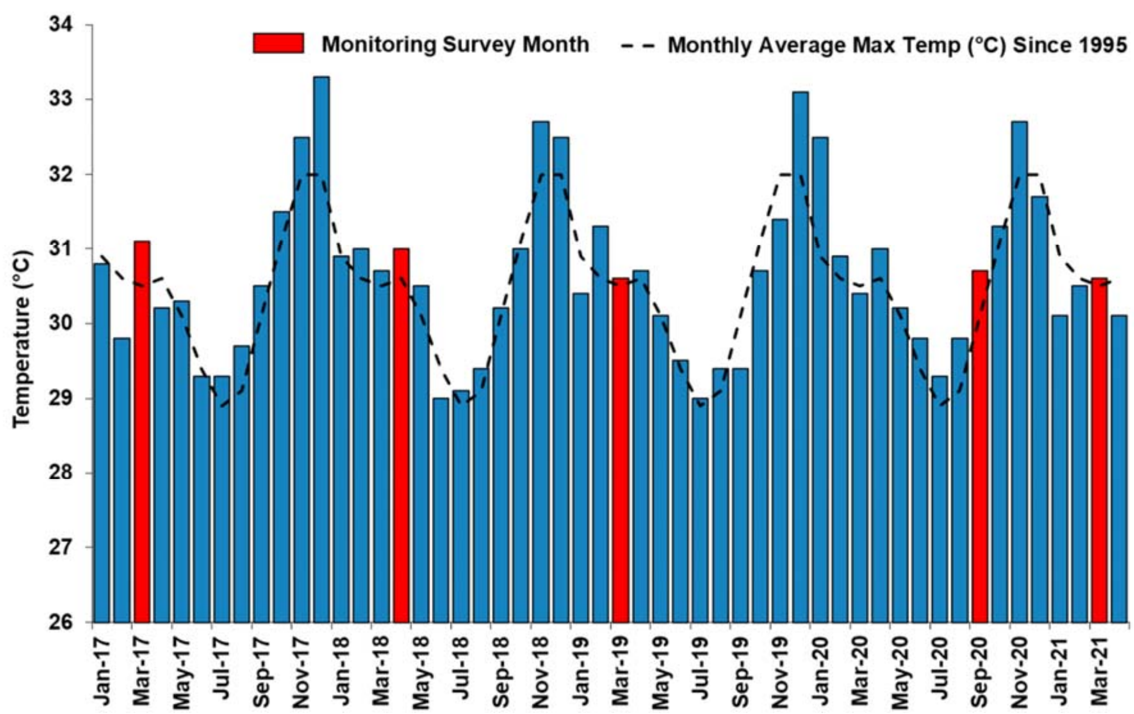

Figure 24. Maximum daily air temperature (monthly average, °C) recorded at Horn Island, January 2017 – April 2021. Annual monitoring survey months coloured red.

3.4.4 Tidal Exposure of Seagrass Meadows

Annual daytime tidal exposure of intertidal meadows was above the long-term average in 2020/21 for the third year in a row (Figure 25). The months immediately preceding the survey month had low tidal exposure (Figure 26).

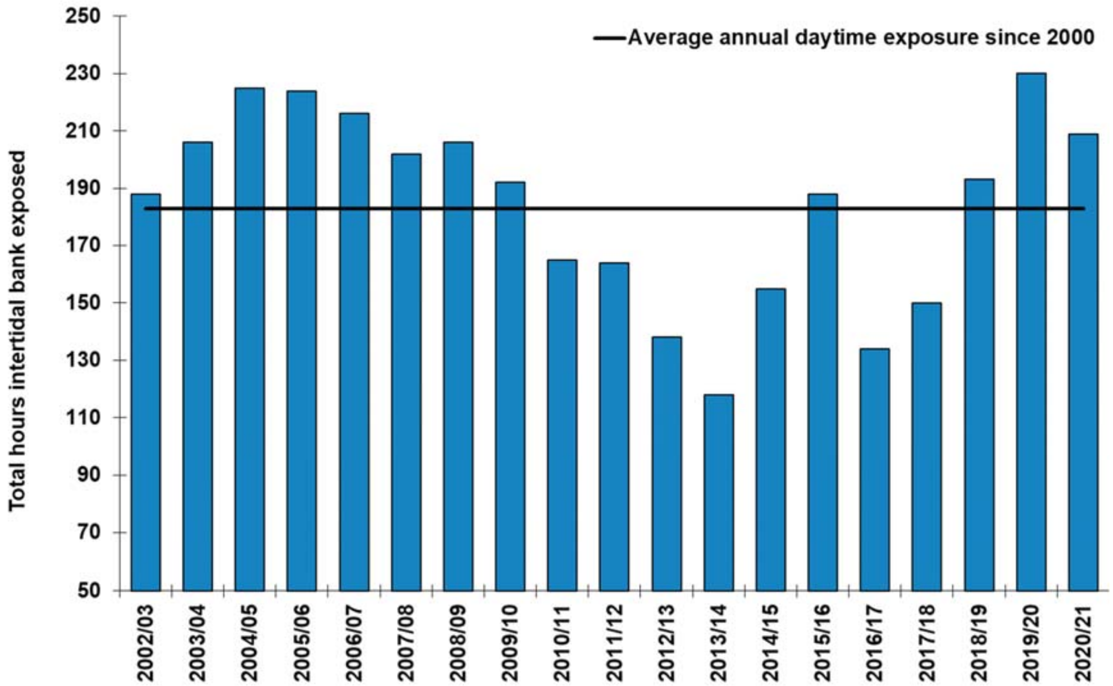

Figure 25. Annual daytime tidal exposure (total hours)* of seagrass meadows at the Port of Thursday Island, 2002/2003 – 2020/2021. Twelve-month year (2020/2021) is 12 months prior to survey. * Assumes intertidal banks expose at a tide height of 0.8m above Lowest Astronomical Tide.

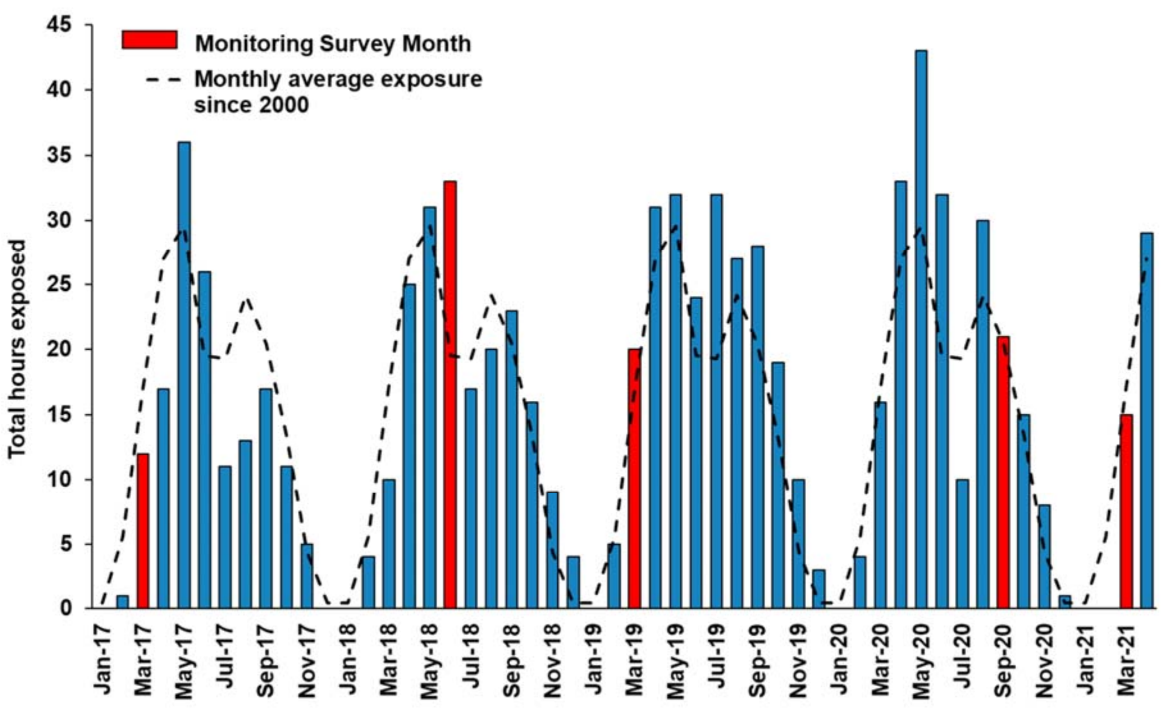

Figure 26. Monthly daytime tidal exposure (total hours) * at the Port of Thursday Island, January 2012 – May 2019. * Assumes intertidal banks expose at a tide height of 0.8m above Lowest Astronomical Tide.

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 the long-term average for the five years prior to the survey and was just below average in 2021 (Figure 28). In 2021 in the lead up to the survey both February and March had above average solar exposure (Figure 29).

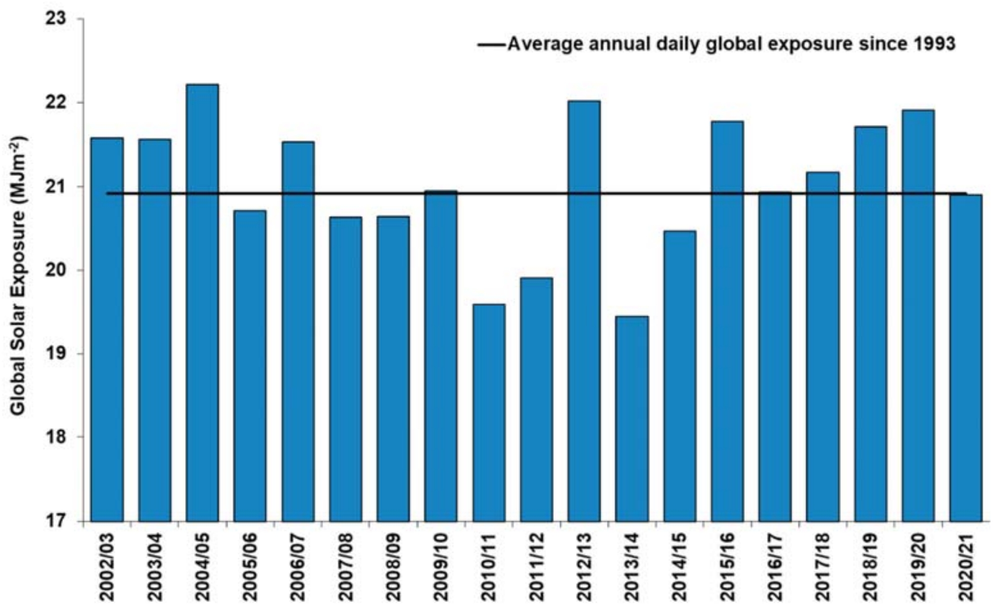

Figure 27. Daily global solar exposure (annual mean, MJ m^{-2}) recorded at Horn Island, 2002/2003 – 2020/2021. Twelve-month year (2020/2021) is 12 months prior to survey.

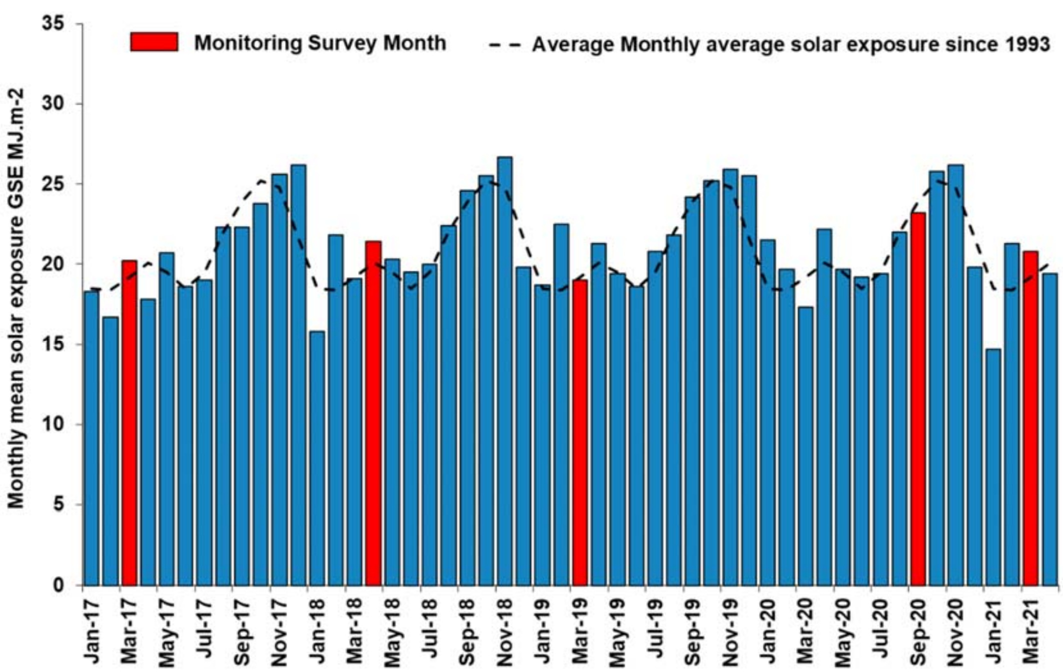

Figure 28. Daily global solar exposure (monthly mean, MJ m^{-2}) recorded at Horn Island, January 2017 – May 2021.

4 DISCUSSION

Seagrasses in the Port of Thursday Island were in an overall good condition in 2021, all individual meadows were in good or very good condition and five of the nine meadows surveyed improved in condition from 2019. In 2019, seagrass biomass declines caused overall meadow condition to be downgraded to satisfactory after years of good and very good scores. In 2021, seagrass biomass increased in all meadows and some meadows had the highest biomass since monitoring began, resulting in overall improvements in condition and a reversal of the 2019 declines. Annual monitoring meadows had the second highest total area recorded since monitoring began, with the highest area in the delayed 2020 survey. The two *E. acoroides* meadows of particular concern in 2019, meadows 4 and 6, had record high biomass in 2021 and expanded in area to join up for the first time.

Due to COVID restrictions, we were unable to carry out the 2020 annual monitoring survey in March in line with the previous surveys. The 2020 annual monitoring survey was carried out in September and while this data does give an overall indication of trajectories in terms of meadow metrics, these meadows vary considerably on a seasonal basis, so the 2020 results cannot be directly compared to the March annual survey data.

The intertidal meadows around Thursday Island remained in very good condition in terms of the species present. These meadows are usually dominated by *H. uninervis*, however there was a shift in community in some meadows in 2021; meadow 5 was dominated by *T. hemprichii* and meadow 8 was dominated by both *T. hemprichii* and *C. rotundata*. This represents a shift towards larger growing species and a more stable seagrass community with slower growing higher biomass species present and could indicate extended periods of favourable conditions for seagrass growth (Kilminster et al. 2015). These larger species have below-ground energy reserves that mean they are more resilient to disturbances (Kilminster et al. 2015, Unsworth et al. 2015).

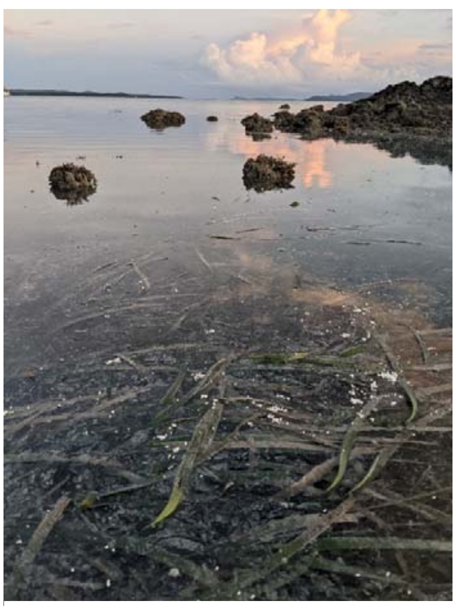

Figure 29. *Enhalus acoroides* pollen (white balls) floating on the surface

Environmental factors were favourable for seagrass growth since the 2019 survey. All climate variables remained around average, and while rainfall was very high in December 2020, there were no weather events that were likely to impact the seagrass. Annual tidal exposure was above average, 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* 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 reversal of declines and improvement in condition of seagrasses around Thursday Island is particularly positive in comparison to some of the other patterns of declining seagrass condition in the Torres Strait. The 2020 Torres Strait seagrass report card identified regional declines in seagrass condition across the Western and Central clusters (Carter et al. 2020). These declines were caused by reductions in seagrass abundance (biomass/percentage cover) and were particularly dramatic and widespread in the Orman Reefs-Mabuyag Island region (Carter et al. 2020). The cause for these declines is unknown, but it is encouraging to see vast improvements in the meadows around Thursday Island indicating that seagrasses in the Inner Cluster region of the Torres Strait were not affected.

The improvement in condition of seagrass meadows around Thursday Island is very encouraging, particularly for those meadows closest to human impact that were of concern (Wells et al. 2019). This recovery indicates that any stressor which may have been causing declines in 2019 is no longer impacting the seagrass meadows around Thursday Island. No signs of disturbance or stress were observed on the surveys. 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 2021 with meadows likely to be highly resilient to pressures that may affect seagrass growth during 2021. 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 2020). The Port of Thursday Island seagrasses representing a bright spot of seagrass condition in the Torres Strait region in 2021.

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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).

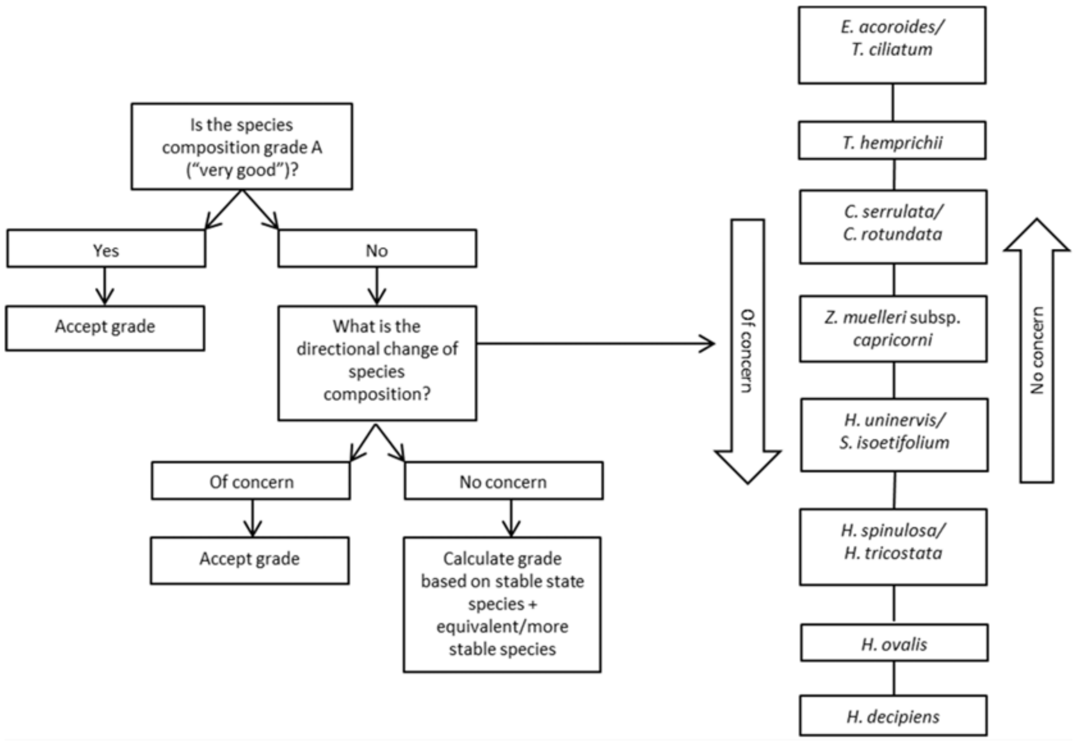


Figure A1. Decision tree and directional change assessment for grading and scoring seagrass species composition.

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 ($B_{satisfactory}$):

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

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_{2019} takes up:

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

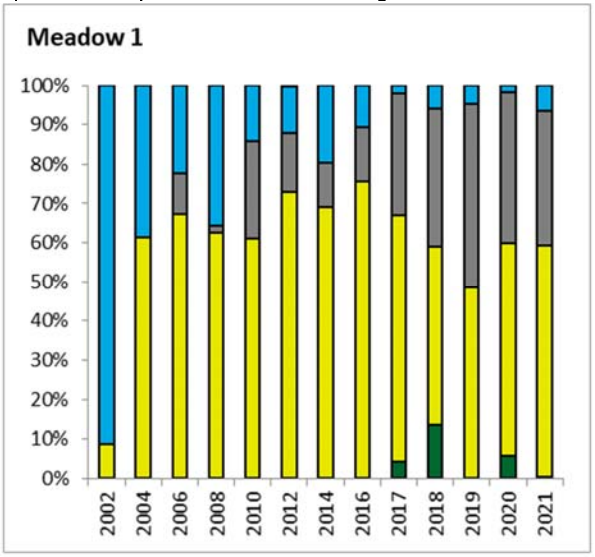
5. Determine the biomass score for 2019 ($Score_{2019}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

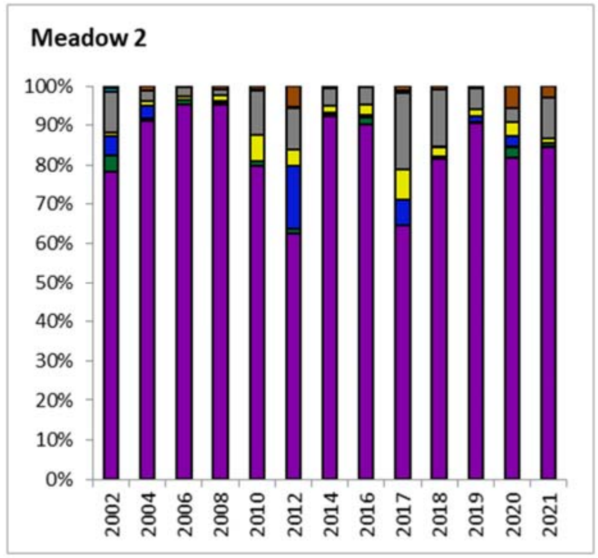
$$\mathrm{Score_{2019}} = \mathrm{LB_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

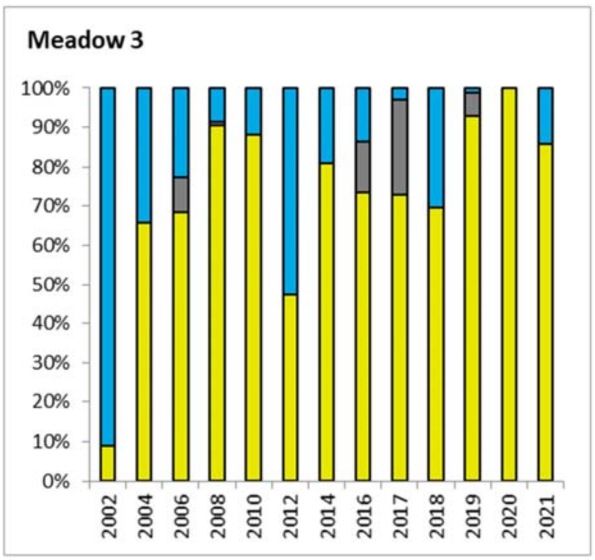
Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

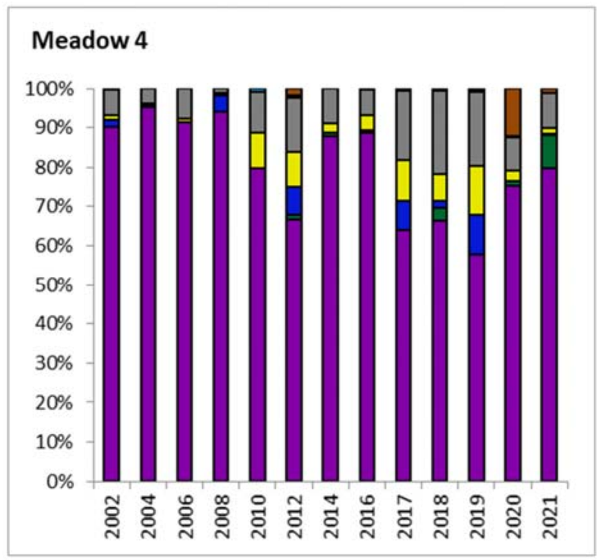
Appendix 3

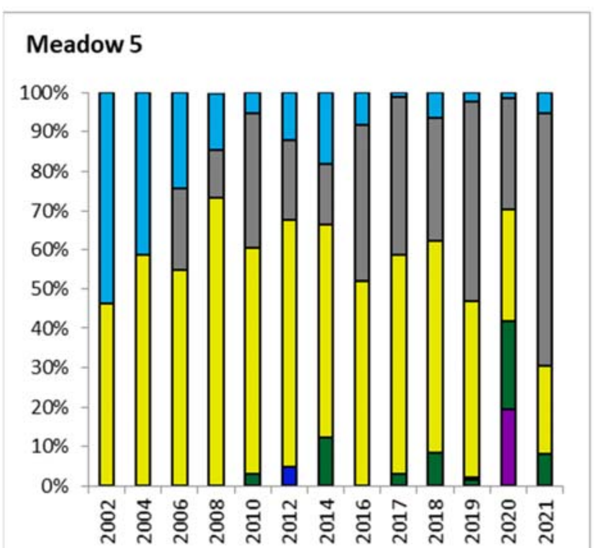
Species composition of monitoring meadows in the Port of Thursday Island; 2002–2019.

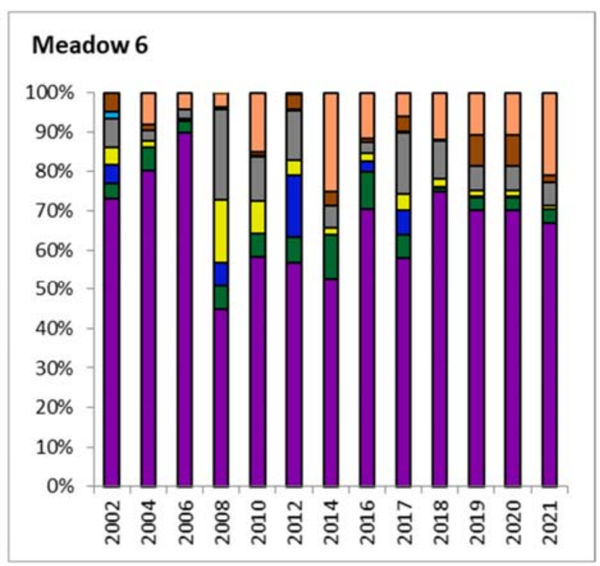


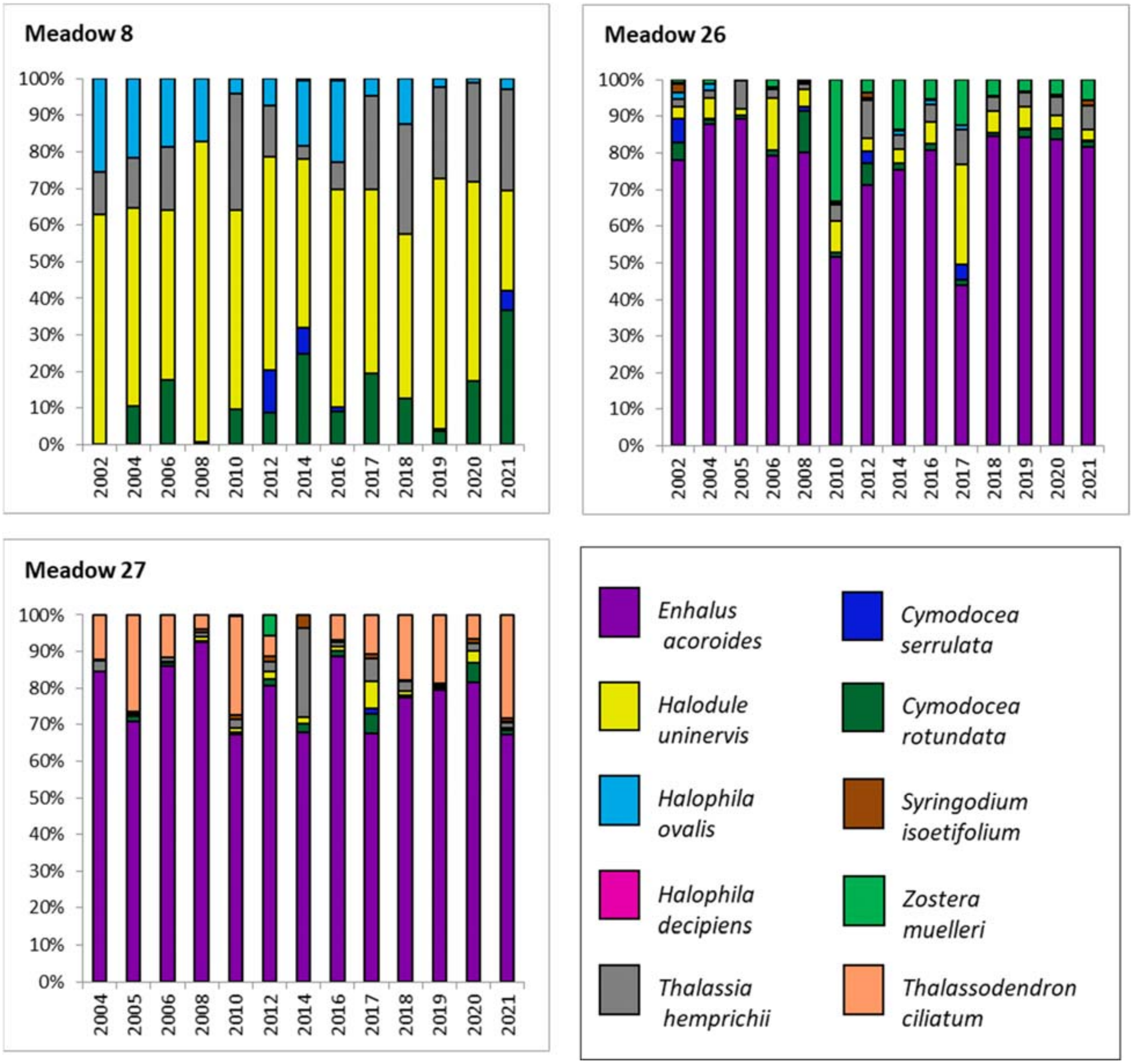











Meadow 8
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2002
2004
2006
2008
2010
2012
2014
2016
2017
2018
2019
2020
2021
Meadow 26
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
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2002
2004
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2018
2019
2020
2021
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
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}) $\pm$ standard error and number of biomass sampling sites (in brackets) for each monitoring meadow within the Port of Thursday Island, 2002–2019.

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**
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)
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)
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)
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)
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)
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)
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)
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)
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)

Appendix 4b

Total meadow area + R (ha) for each monitoring meadow within the Port of Thursday Island, 2002 – 2019.

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
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 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
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
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
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
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
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
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
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