 

TORRES STRAIT SEAGRASS

2021 REPORT CARD

Carter AB, David M, Whap T, Hoffmann LR, Scott A and Rasheed MA

Report No. 21/13

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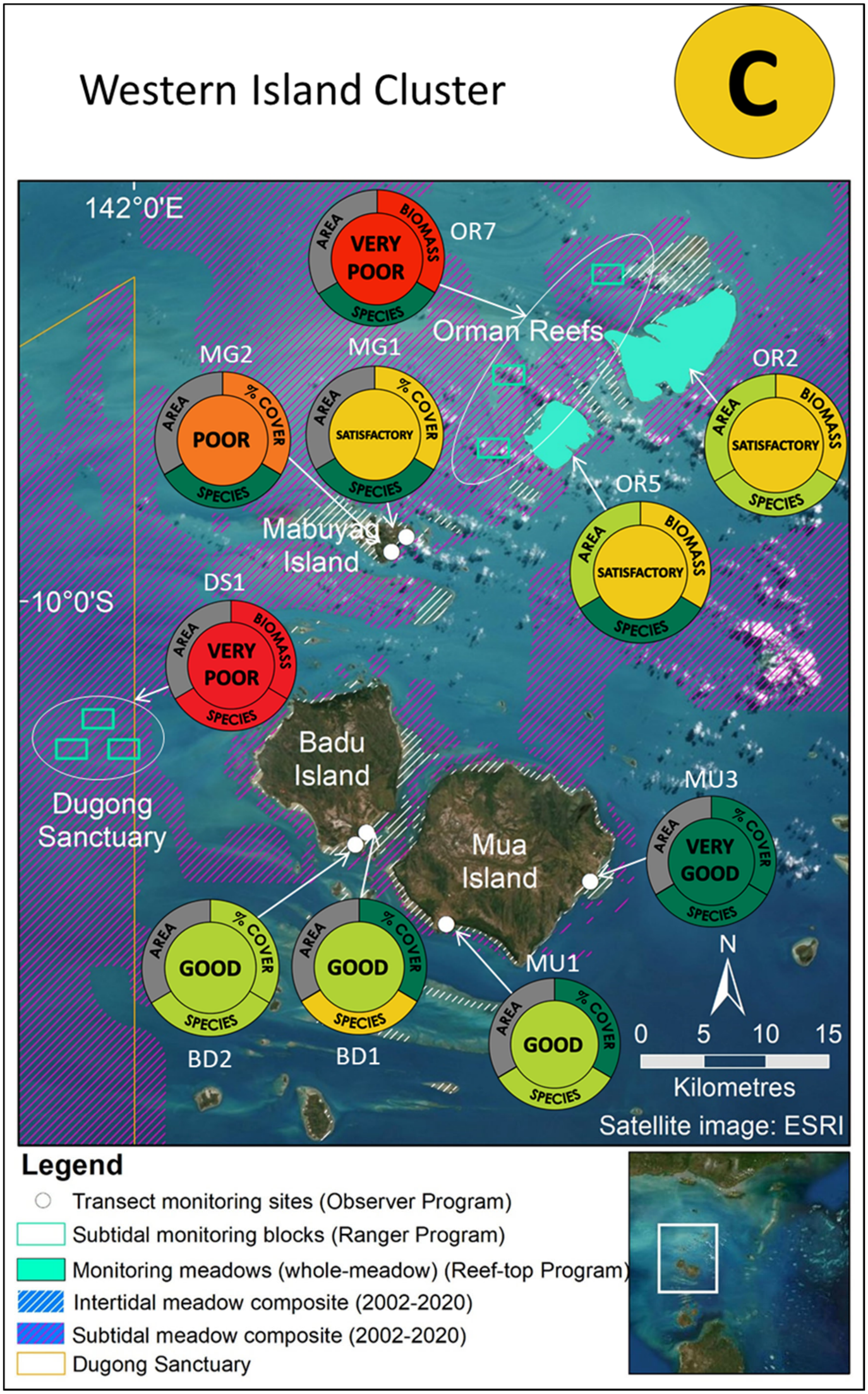
Please be advised this report may contain images of persons who have died. We offer our apologies for any distress caused if this occurs.

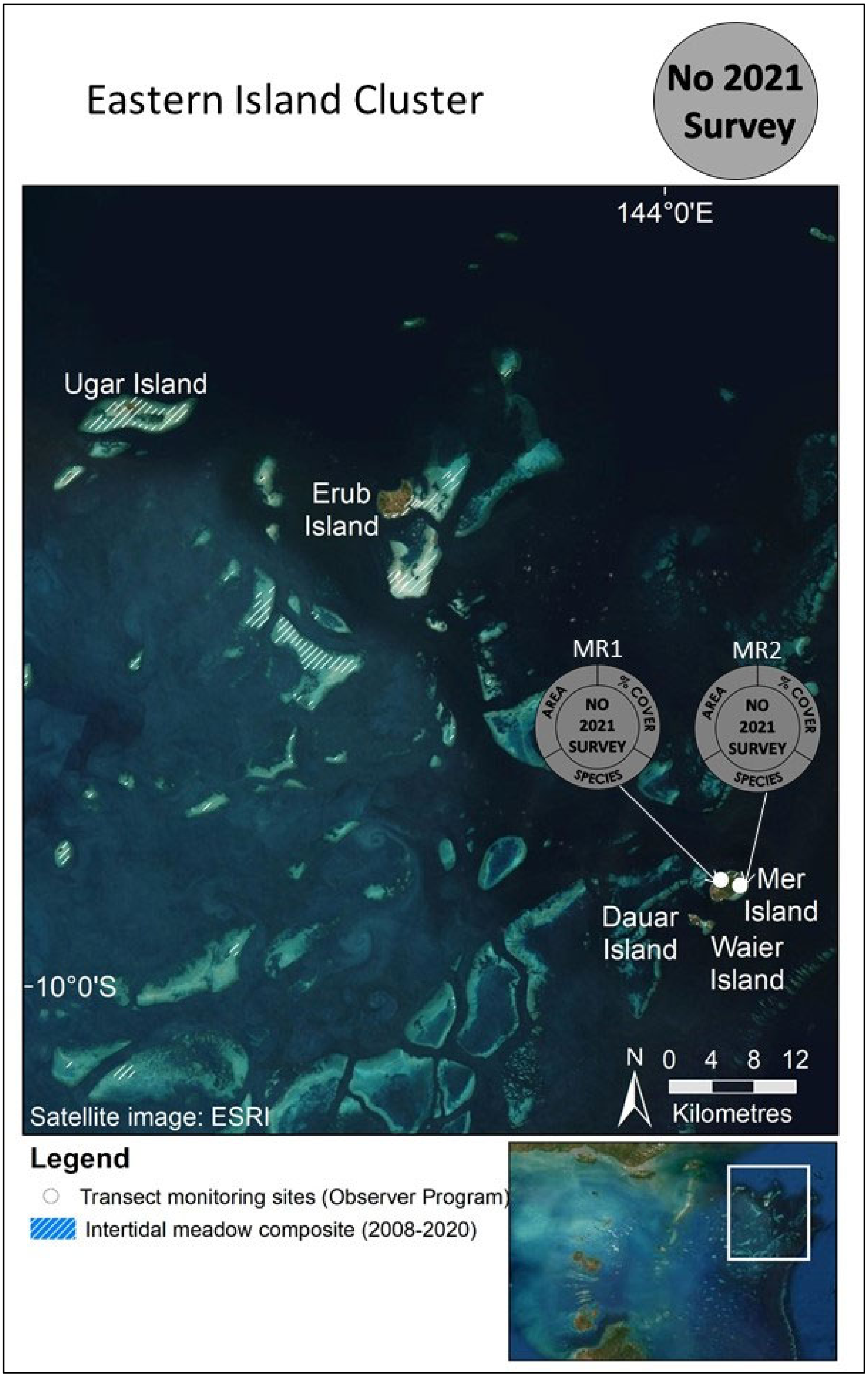
Acknowledgments:
The authors acknowledge the traditional owners and custodians on whose land and sea areas seagrass monitoring activities take place. This report card, and the monitoring programs on which it is based, would not be possible without the collaboration between TropWATER and the following Ranger groups - Mura Badhulgau, Mua Lagalgau, Mabuygiw, Porumalgal, Iamalgal, Warraberalgal, Masigalgal and Meriam Gesep A Gur Keparem Le. Thank you for your hard work and dedication to monitoring seagrass habitat in Torres Strait. This report was funded by Torres Strait Regional Authority's Land and Sea Management Unit through the Sea Team as a component of the consultancy CA-2021-00024. Ports North generously provided permission to reproduce Thursday Island and Madge Reefs (Inner Cluster) seagrass monitoring and annual report card results.

SUMMARY

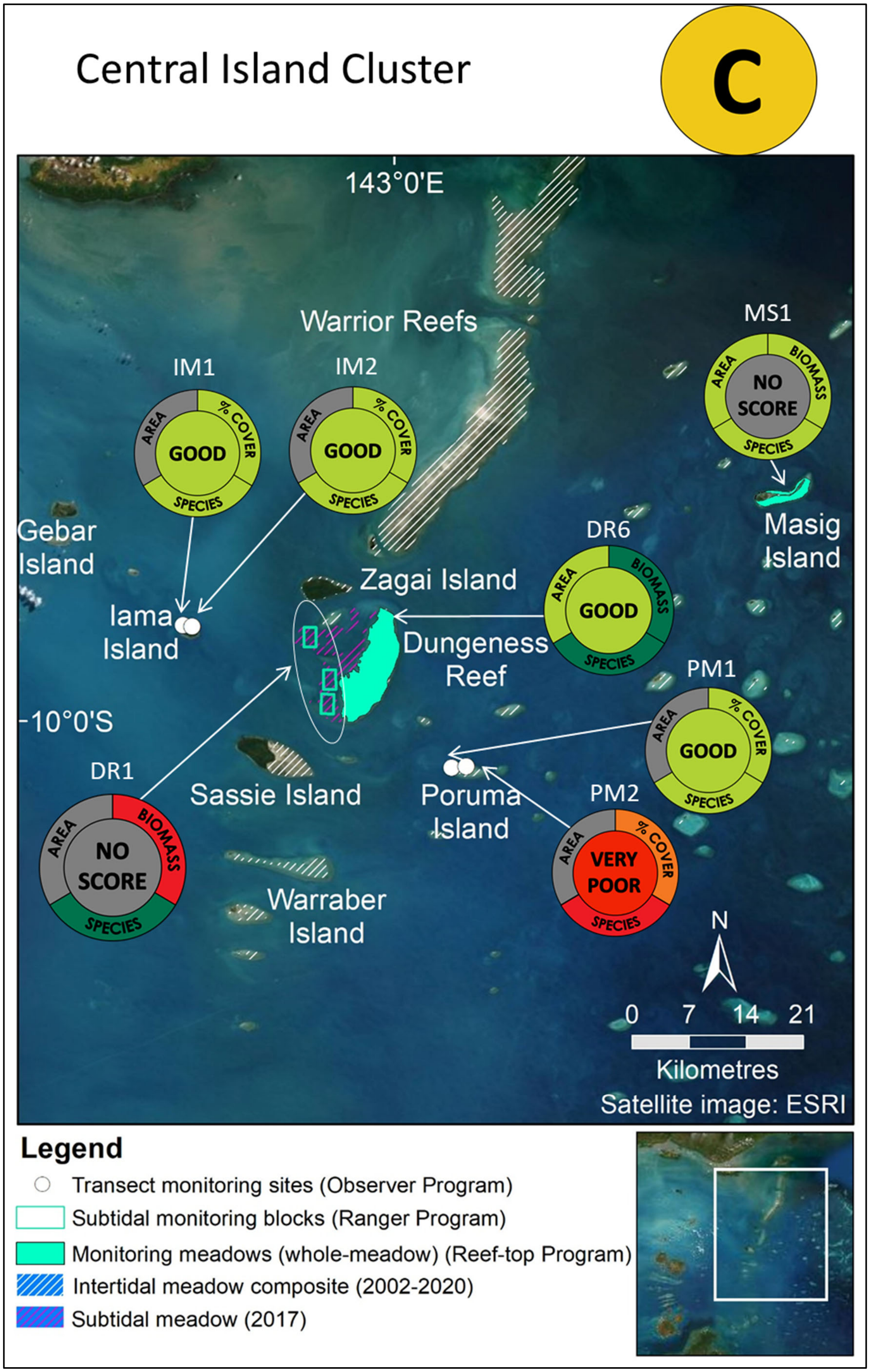
- Seagrass is a critical habitat in Torres Strait. Extensive seagrass meadows support populations of dugong, green turtle, and fishery species. Strong cultural and spiritual links exist between Torres Strait Island communities and these species and environments.
- The Torres Strait Seagrass Monitoring Program (TSSMP) incorporates an extensive network of seagrass monitoring programs that regularly assess the condition of this key habitat. The TSSMP incorporates the Torres Strait Seagrass Observers Program, Ranger Subtidal Monitoring Program, Queensland Ports Seagrass Monitoring Program, and Reef-top Monitoring Program. Data from these programs are integrated and used to produce this report on seagrass condition.
- Twenty-six sites/meadows were classified for the 2021 report card across the Western, Central and Inner Island Clusters. No monitoring occurred in the Eastern Cluster in 2021 (Map 2).
- Overall, seagrasses in the Inner Cluster were in a good condition and in a satisfactory condition in the Central and Western Clusters (Maps 1-4).
- Within these Clusters there were individual sites and types of meadows where seagrass condition is of substantial concern, including:
    a. Subtidal meadows across the Western and Central Clusters where large scale declines in biomass and loss of the key subtidal species *Halophila spinulosa* first noted in 2020 had continued in 2021 (Maps 1 and 3).
    b. Condition of intertidal meadows around Mabuyag Island and the Orman Reefs in the Western Cluster continued to be well-below average (Map 1).
    c. An individual monitoring site at Poruma Island where cover and species experienced a large decline due to localised sand movement.
- Investigations are ongoing into the potential causes of the declines in subtidal seagrass throughout the Western and Central Clusters and intertidal seagrasses in the Western Cluster, including the role of herbivory, potential for seagrass disease, and environmental conditions that may be contributing to sediment movement and light.
- Several important milestones were reached in the monitoring program in 2021:
    a. Meadow-scale monitoring commenced at Masig Island, filling a critical information gap in the Central Cluster (Map 3).
    b. Several sites reached 10-years of monitoring data, meaning that the baselines for these locations are now set.
    c. 5-years of monitoring data were achieved at Orman Reefs intertidal (Kai and Gariar Reefs) and Poruma Island (PM1 and PM2), allowing preliminary baseline conditions and overall grades and scores to be included in the report card for the first time.
- This report card highlights areas where information is lacking and suggests a pathway for better understanding seagrass dynamics, and improving representativeness and reliability of condition scores for seagrass in Torres Strait Island Clusters. We recommend: (1) establishing monitoring in the Top-Western Cluster, (2) expanding subtidal monitoring, (3) expanding meadow-scale monitoring in the Eastern Cluster, (4) establishing a comprehensive testing program for seagrass disease, and (5) adding local weather/wind and benthic light stations in areas of concern. These additions would vastly improve our annual assessment of seagrass condition and drivers of observed changes in the region.



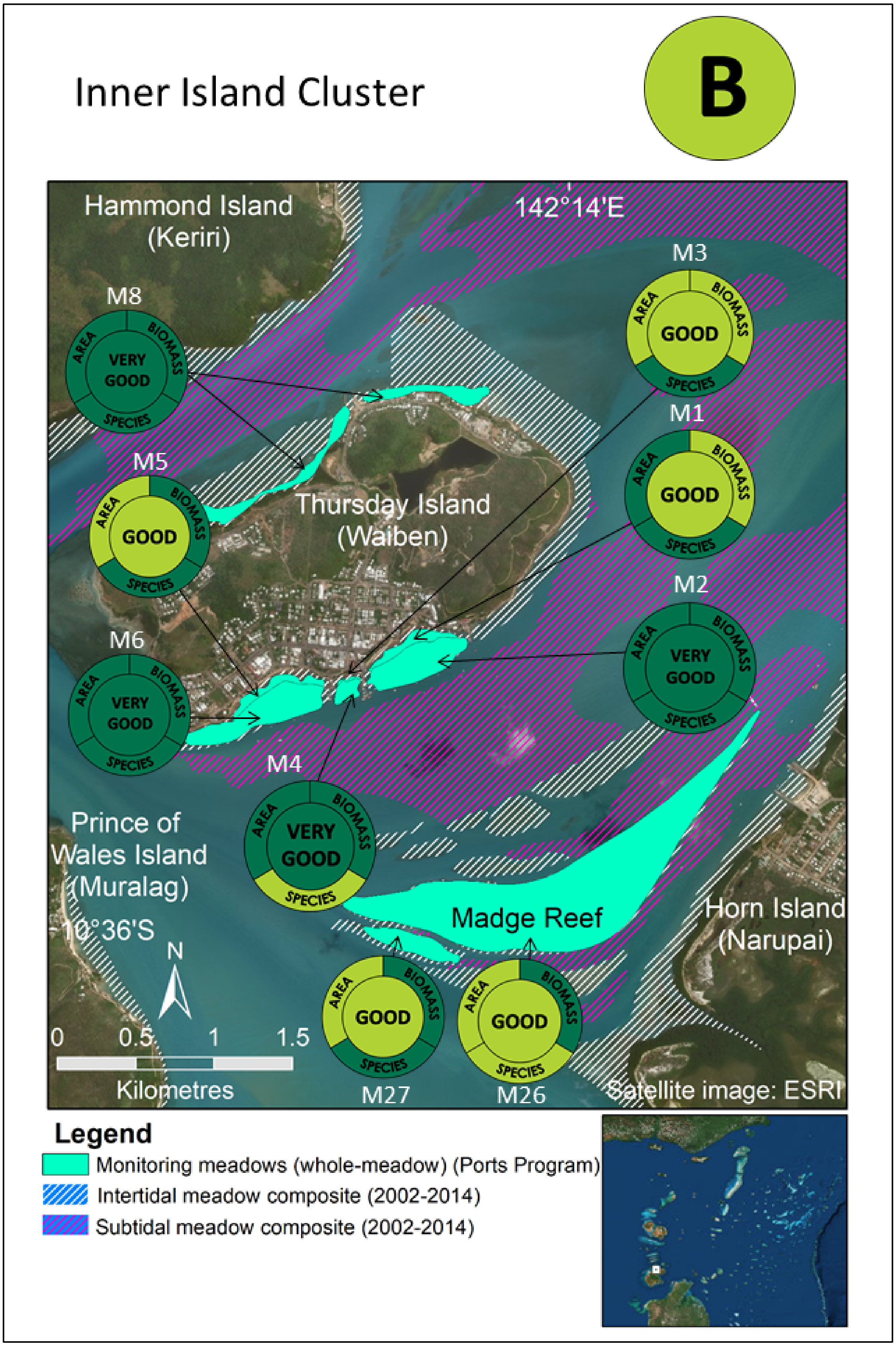
Map 1. Seagrass condition across the Western Cluster of Torres Strait



Map 2. Seagrass condition across the Eastern Cluster of Torres Strait



Map 3. Seagrass condition across the Central Cluster of Torres Strait



Map 4. Seagrass condition across the Inner Island Cluster of Torres Strait

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1 INTRODUCTION

1.1 Torres Strait Seagrass

Torres Strait seagrass meadows are abundant, widespread, and contain some of the greatest species diversity in the Indo-Pacific (Carter et al. 2014b; Coles et al. 2003; Poiner and Peterkin 1996). These seagrass habitats are of national significance due to their large size, their role in sustaining fisheries, and as a food source for the iconic and culturally important species dugong and turtle, which play a vital role in the ecology and cultural economy of the region (TSRA 2016).

Torres Strait Islanders depend heavily on their surrounding marine resources, and their consumption of marine species are among the highest in the world (Kleisner et al. 2015; Johannes and MacFarlane 1991). Most of these important species, including fish, prawns, beche de mer, and tropical rock lobster, are reliant on seagrass during some stage of their life-cycle (Marsh et al. 2015; Unsworth and Cullen 2010; Heck et al. 2008; Green 2006). The loss of seagrass would have detrimental flow on effects to Torres Strait Islanders' spiritual, cultural and economic well-being (TSRA 2016; Kleisner et al. 2015; Faury 2009).

Several substantial seagrass diebacks have been documented in Torres Strait. These include a widely reported dieback in the early 1970s (Johannes and MacFarlane 1991), and less widespread diebacks in north-western Torres Strait in the early 1990s (Poiner and Peterkin 1996) and in the Orman Reefs area in 1999-2000 (Marsh et al. 2004). The direct cause of these diebacks is still debated, but they are known to have significant impacts on local herbivore populations and were linked to dramatic increases in local dugong mortality and declines in dugong health (Marsh et al. 2004; Long and Skewes 1996). The 2020 seagrass report card demonstrated significant declines in seagrass condition in the Orman Reefs-Mabuyag Island region. These declines were concerning because of their widespread nature across seagrass habitats, including intertidal reef-top and subtidal reef-associated meadows and coastal intertidal meadows at two Mabuyag Island locations. Potential reasons for these declines included increased herbivory from green turtles and dugong, altered environmental conditions and disease. However, as with previous seagrass diebacks, no single reason was determined (Carter et al. 2020).

1.2 Torres Strait Seagrass Monitoring Program (TSSMP)

Seagrass habitats are ideal indicators for monitoring marine environmental health as they show measurable responses to changes in environmental condition (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993). A robust assessment of seagrass condition first requires baseline information on seagrass abundance, species composition, and meadow area, plus ongoing monitoring to understand natural variation and detect seagrass change.

The Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University (JCU) have been collecting baseline Torres Strait seagrass data and monitoring seagrass condition in the Port of Thursday Island since 2002. Seagrass monitoring was prioritised by the Torres Strait Scientific Advisory Committee, and expanded by the Torres Strait Regional Authority (TSRA) Land and Sea Management Unit (LSMU) when the Torres Strait Ranger Program began in 2009. The Torres Strait Seagrass Monitoring Program (TSSMP) incorporates three types of seagrass monitoring data: small-scale intertidal transects, medium-scale subtidal blocks, and large meadow-scale monitoring that incorporates spatial change in seagrass assessments. Several long-term monitoring programs undertaken by TropWATER with the TSRA LSMU or Ports North assess seagrass condition and change in the region (Table 1). These programs are:

(1) **Torres Strait Seagrass Observers Program (small-scale transect-based monitoring)** – This program evolved from the *Torres Strait CRC Project 4.1: Education Opportunities for Indigenous Involvement in*

Marine Ecosystem (Mellors et al. 2008). The program's aim is to provide Torres Strait Rangers with the skills to monitor independently intertidal seagrass at permanently marked transect sites representative of their home patch intertidal meadows. Rangers selected sites based on traditional use of the meadow or disturbance concerns (e.g. proximity to a storm water drain). Six islands (Mabuyag, Badu, Mua, Poruma, Iama, and Mer) are monitored as part of the program, with two sites on each island.

(2) **Ranger Subtidal Monitoring Program (medium-scale block-based monitoring)** – This program began in 2011 as a collaboration between TropWATER and Badu and Mabuyag Island Rangers to monitor seagrass in the Dugong Sanctuary. Rangers were trained by TropWATER staff to collect data in subtidal monitoring blocks, and now conduct monitoring independently and send data to TropWATER for analysis. The program was extended to Dungeness Reef in 2017 and Orman Reefs in 2018.

(3) **Reef-top Monitoring Program (large-scale meadow-based monitoring)** – The reef-top program began in 2017 at Dungeness Reef, 2018 at Orman Reefs, and this year at Masig Island. Aerial surveys are conducted by TropWATER staff annually and provide an assessment of intertidal reef-top seagrass condition at known turtle and dugong foraging areas.

(4) **Queensland Ports Seagrass Monitoring Program (large-scale meadow-based monitoring)** – The ports program is a long-term seagrass monitoring and assessment program that occurs in the majority of Queensland's commercial ports. The program is delivered by TropWATER in partnership with various Queensland port authorities. The Thursday Island component is funded by Ports North. The program provides an ongoing assessment of seagrass communities most at risk from cumulative threats in Queensland (Grech et al. 2011). A condition report card is produced annually for each port, and this information is included in several regional reports cards including the Wet Tropics Healthy Waterways Partnership, Dry Tropics Partnership for Healthy Waters, Mackay-Whitsundays-Isaac Healthy Rivers to Reef Partnership, and the Gladstone Healthy Harbour Partnership.

The individual programs that make up TSSMP differ in monitoring frequency and the seagrass condition indicators assessed. The program collectively monitors seagrass condition at 12 intertidal transect sites, 13 intertidal and subtidal whole-meadows, and three subtidal meadow blocks (Figure 1, Table 1). Monitoring incorporates eleven seagrass species from three families (Figure 2), and occurs within four of the five traditional island clusters (http://www.tsra.gov.au/the-torres-strait/community-profiles) - Western, Central, Eastern and Inner. No monitoring currently occurs in the Top-Western Cluster which includes Boigu, Dauan, Saibai islands.

Table 1. The Torres Strait Seagrass Monitoring Program (TSSMP) incorporates several long-term monitoring programs.

	Torres Strait Seagrass Monitoring Program			
	Torres Strait Seagrass Observers Program	**Reef-top Intertidal Program**	**Ranger Subtidal Monitoring Program**	**Thursday Island Ports Program**
Island cluster	Western, Central, Eastern	Western, Central	Western, Central	Inner
No. sites/meadows	12 sites	4 meadows	3 meadows	9 meadows
Condition indicators	Percent cover, species composition	Biomass, area, species composition	Biomass, species composition	Biomass, area, species composition
Habitat	Intertidal island	Intertidal reef-top	Subtidal	Intertidal island and reef-top, subtidal
Spatial scale	3 permanent transects per site	Whole-meadow	3 monitoring blocks per meadow	Whole-meadow
Temporal scale	Quarterly - biannual	Annual	Biannual	Annual
Funding provider	TSRA	TSRA	TSRA	Ports North

1.3 Report Card Objectives

The objectives of the 2021 Torres Strait report card were to provide:

(1) An assessment of Torres Strait seagrass condition in 2021 including grades and scores.

(2) A report describing data collection and methods used to determine grades and scores.

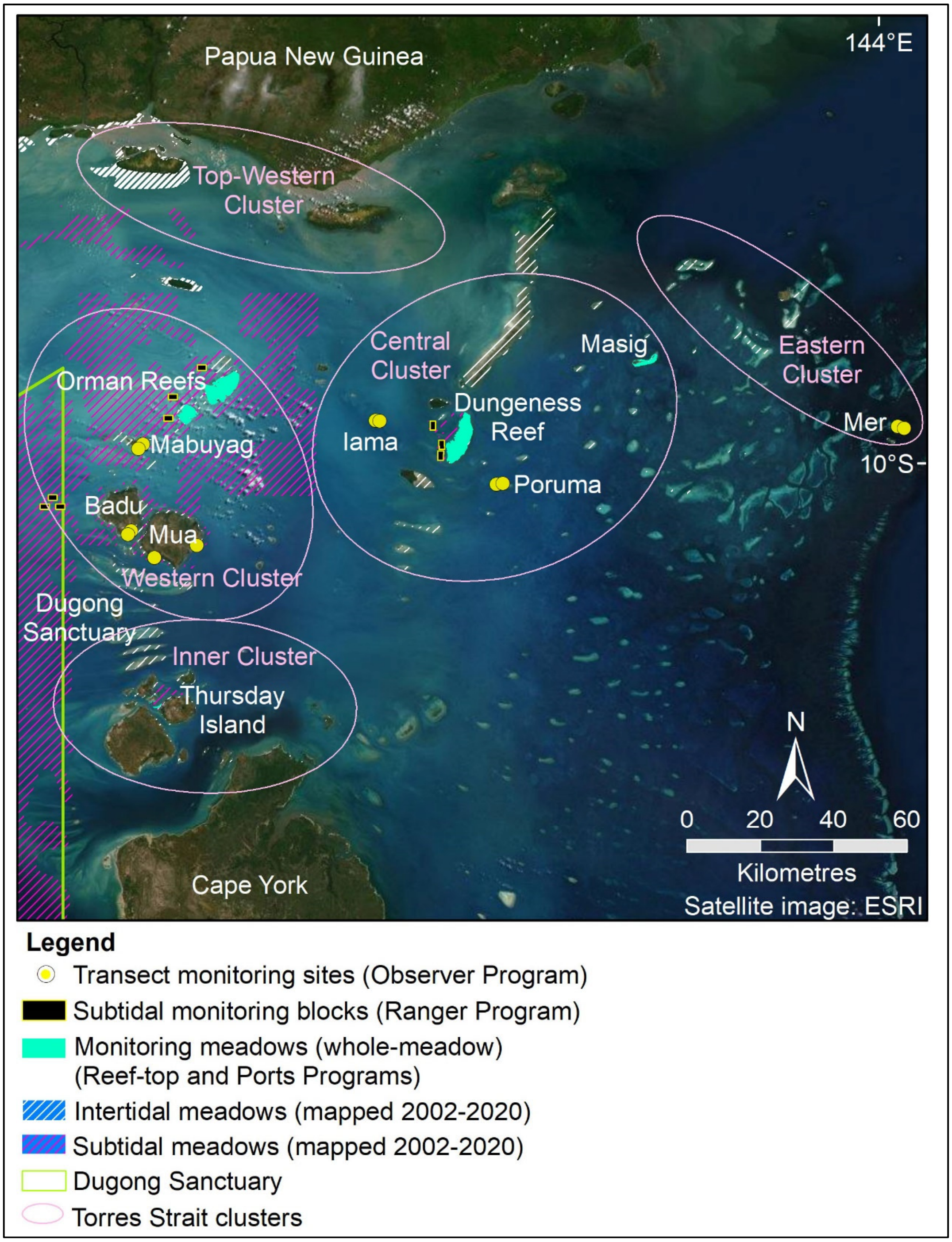

Figure 1. The Torres Strait Seagrass Monitoring Program incorporates four long-term monitoring programs spanning four island clusters.

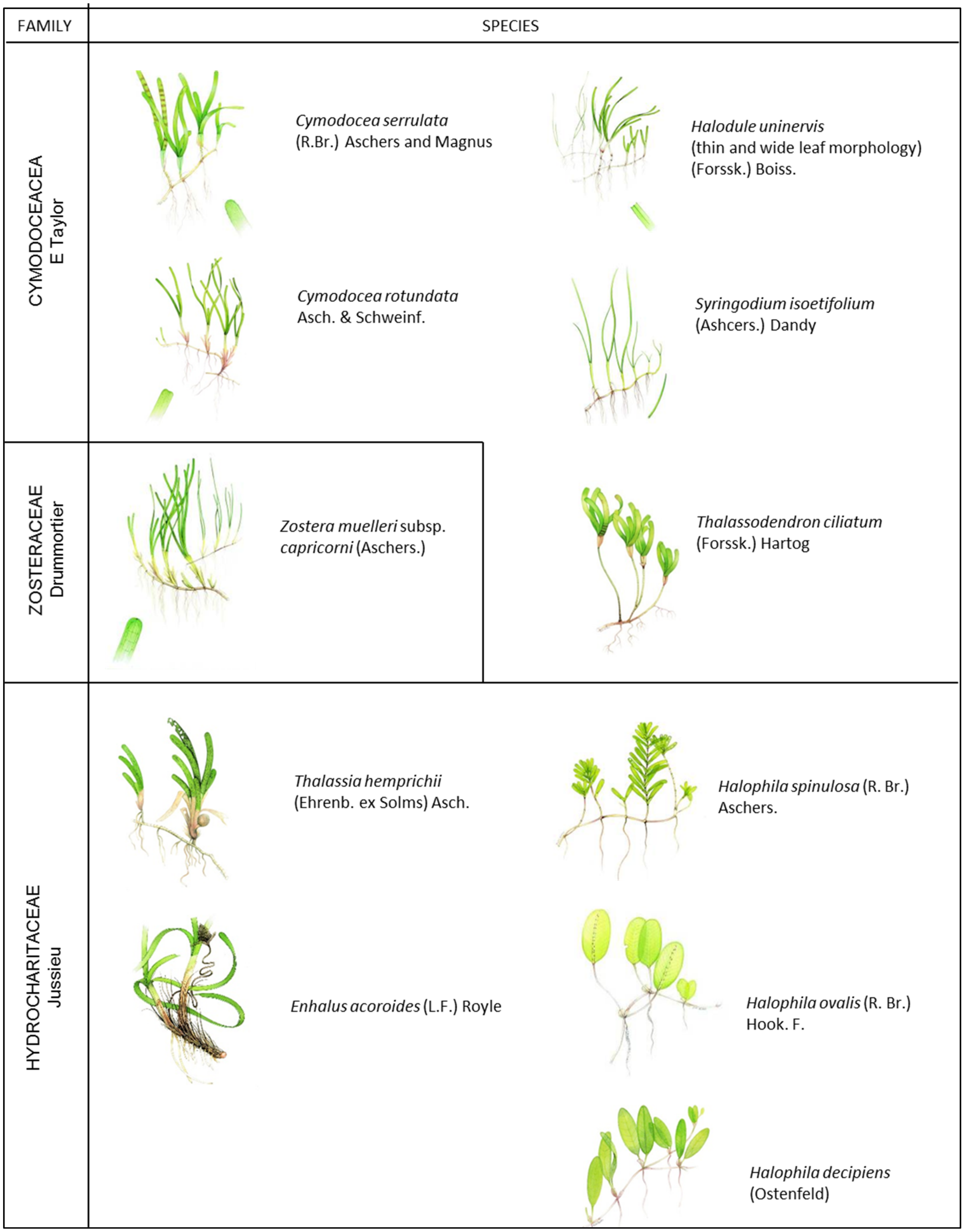

Figure 2. Seagrass species recorded across Torres Strait Seagrass Monitoring Program monitoring sites/ meadows.

2 METHODS

2.1 Sampling Approach and Data Collection Methods for Seagrass Indicators

The TSSMP survey times and frequencies vary, ranging from quarterly to biannual (observer and subtidal programs) to annual (reef-top and ports programs). This report card only uses data collected from September – April for intertidal surveys, and September – March for subtidal block surveys. The exclusion of data from late autumn and winter was based on expert discussion and examination of historical monitoring data, where a season of low seagrass abundance occurred from May to August during Sager, the south-east wind period. High seagrass abundance occurs from September to April during Naiger (north-east wind period) and Kuki (north-west monsoon) (McNamara et al. 2010; also see https://www.qcaa.qld.edu.au/about/k-12-policies/aboriginal-torres-strait-islander-perspectives/resources/seasons-stars). Excluding data collected when seagrass senesces controls for seasonal variation at each site, and means results for programs that survey only during the peak seagrass growing season are comparable with programs that survey throughout the year. This is a common practice for other Queensland report cards (Carter et al. 2016).

Survey methods vary among the TSSMP programs. These are:

(1) Torres Strait Seagrass Observers Program (small-scale transect-based monitoring) – Each site is a 50m x 50m relatively homogeneous area (low variability, even topography) in each seagrass meadow. Within each site, three replicate 50 m long transects are laid parallel to each other, 25 m apart and perpendicular to the beach. Along each transect, the rangers record seagrass percent cover and species composition within a 0.25 m^2 quadrat, with quadrats placed at 5 m intervals along a transect (Figure 3a, b). For each quadrat percent cover is estimated with the assistance of standardized percent cover photographs, and the percent contribution of individual species to total cover (species composition). 27% of quadrats are photographed for verification by TropWATER scientists during the QAQC process.

(2) Ranger Subtidal Monitoring Program (medium-scale block-based monitoring) – Survey methods follow the established techniques for the TropWATER subtidal block seagrass monitoring program, where three transects are surveyed in each of three blocks per meadow (Carter et al. 2017). Quadrats are assessed using underwater video. At each site, a GoPro is lowered from the ranger vessel to the sea floor (Figure 3d) and 10 replicate "camera drops" are conducted approximately 5 m apart while the boat moves at drift speed. The camera frame serves as a 0.25 m^2 quadrat, and the footage is viewed on an iPad at the surface and recorded. A sample of seagrass is collected in the field using a van Veen grab (grab area 0.0625 m^2) to identify species present at each transect (Figure 3e, f). Video footage is sent back to TropWATER scientists where biomass and species composition estimates are made.

(3) Reef-top Monitoring Program Queensland Ports Seagrass Monitoring Program (large-scale meadow-based monitoring) – Survey methods follow the established techniques for the TropWATER Queensland-wide ports seagrass monitoring program (see Unsworth et al. 2012; Rasheed and Unsworth 2011; Taylor and Rasheed 2011). Intertidal meadows are sampled at low tide using a helicopter (Figure 3c). GPS is used to record the position of meadow boundaries. Seagrass presence/absence, biomass, species composition is determined from three replicate 0.25 m^2 quadrats placed randomly within a 10 m^2 circular area while the helicopter maintains a low hover. Sites are randomly scattered within each meadow.

(4) Queensland Ports Seagrass Monitoring Program (large-scale meadow-based monitoring) – Survey methods for intertidal meadows are the same as for the reef-top program. Shallow subtidal meadows are sampled by boat using underwater video camera and van Veen grab. The camera frame serves as a 0.25 m^2 quadrat with three replicate quadrats per site, and the video footage is analysed in real time using CCTV on the boat. Sites are located along transects perpendicular to the shoreline at ~50 - 100 m intervals, or where major changes in bottom topography occur, and extend to the offshore edge of each seagrass meadow.

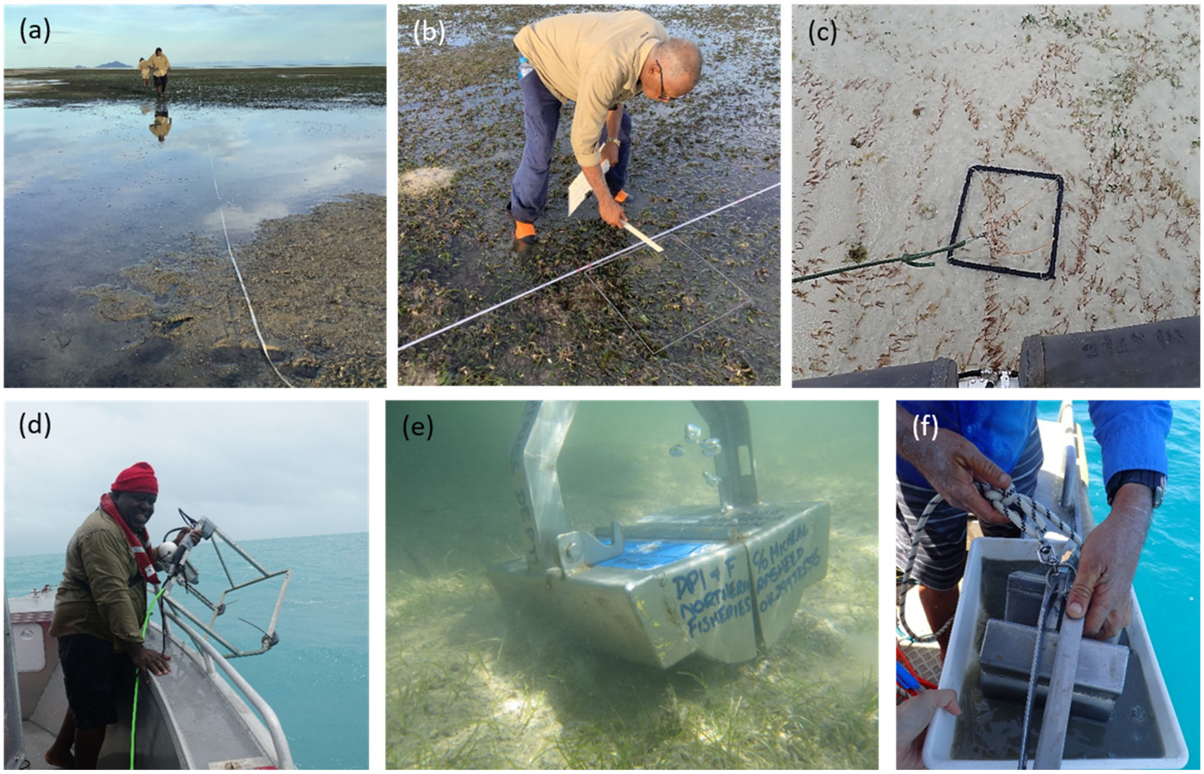

Figure 3. Seagrass survey methods include (a, b) walking along permanent transects, (c) quadrat lowered from a hovering helicopter, (d) underwater video drops and (e, f) van Veen grab. Photos courtesy Mua Lagalgau Rangers and TropWATER.

2.1.1 Biomass and Species Composition

Seagrass above-ground biomass was determined for the ranger, ports, and reef-top programs using a "visual estimates of biomass" technique (Mellors 1991; Kirkman 1978). For each quadrat a TropWATER trained observer assigns a biomass rank made in reference to a series of 12 quadrat photographs of similar seagrass habitats for which the ranks were previously measured (reference quadrats). The percent contribution of each seagrass species to above-ground biomass within each quadrat is also recorded. Three separate ranges are used - low biomass, high biomass, and *Enhalus acoroides* biomass. At the completion of ranking, the observer ranks a series of five calibration quadrat photographs that had previously been harvested and biomass measured in the laboratory for each range. A separate regression equation of biomass ranks versus actual biomass is calculated for each observer and each range, and applied to the biomass ranks given in the field. Field biomass ranks are converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}).

Species composition is calculated as the percent contribution of individual species to either above-ground biomass (ranger subtidal, ports, and reef-top programs) or total percent cover (observer program).

2.1.2 Meadow Area

Meadow area is assessed only in the large-scale meadow-based monitoring programs (ports and reef-top programs). Seagrass presence/absence site data, mapping sites, field notes, and satellite imagery are used to construct meadow boundaries in ArcGIS®. Seagrass meadows are assigned a meadow identification number; this allows individual meadows to be compared among years. Monitoring meadows are referred to by identification numbers throughout this report. Meadow area is determined in hectares using the calculate geometry function in ArcGIS. Meadows are assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 2). The mapping precision estimates are used to create a buffer representing the error around each meadow, the area of which is expressed as a meadow reliability estimate (R) in hectares.

Table 2. Mapping precision and methodology for seagrass meadows in Torres Strait.

Mapping precision	Mapping methodology
5 m	Meadow boundary mapped in detail by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide.
10 m	Meadow boundary determined from helicopter and/or boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from survey sites and aerial photography, Moderately high density of mapping and survey sites.
20 m	Meadow boundaries determined from helicopter and/or boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from boat survey sites, Lower density of survey sites for some sections of boundary.
50 m	Meadow boundaries determined from helicopter and/or boat surveys, Meadow boundaries determined from seagrass presence/absence data, Low density of survey sites for some sections of boundary.

2.2 Seagrass Condition

Seagrass condition is determined using a condition index to assess changes in abundance (biomass/percent cover), species composition, and meadow area (reef-top and ports programs only) relative to each site/meadow's baseline. Seagrass condition for each indicator in each site/meadow is scored from 0 – 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 4 summarises the methods used to calculate seagrass condition. Detailed description of how the report card method was developed can be found in Bryant et al. (2014), Carter et al. (2015), and Carter et al. (2016). Appendix 1 provides detailed methods used to determine baseline calculations, classify meadows, define thresholds, provide grades and scores, and aggregate those scores.

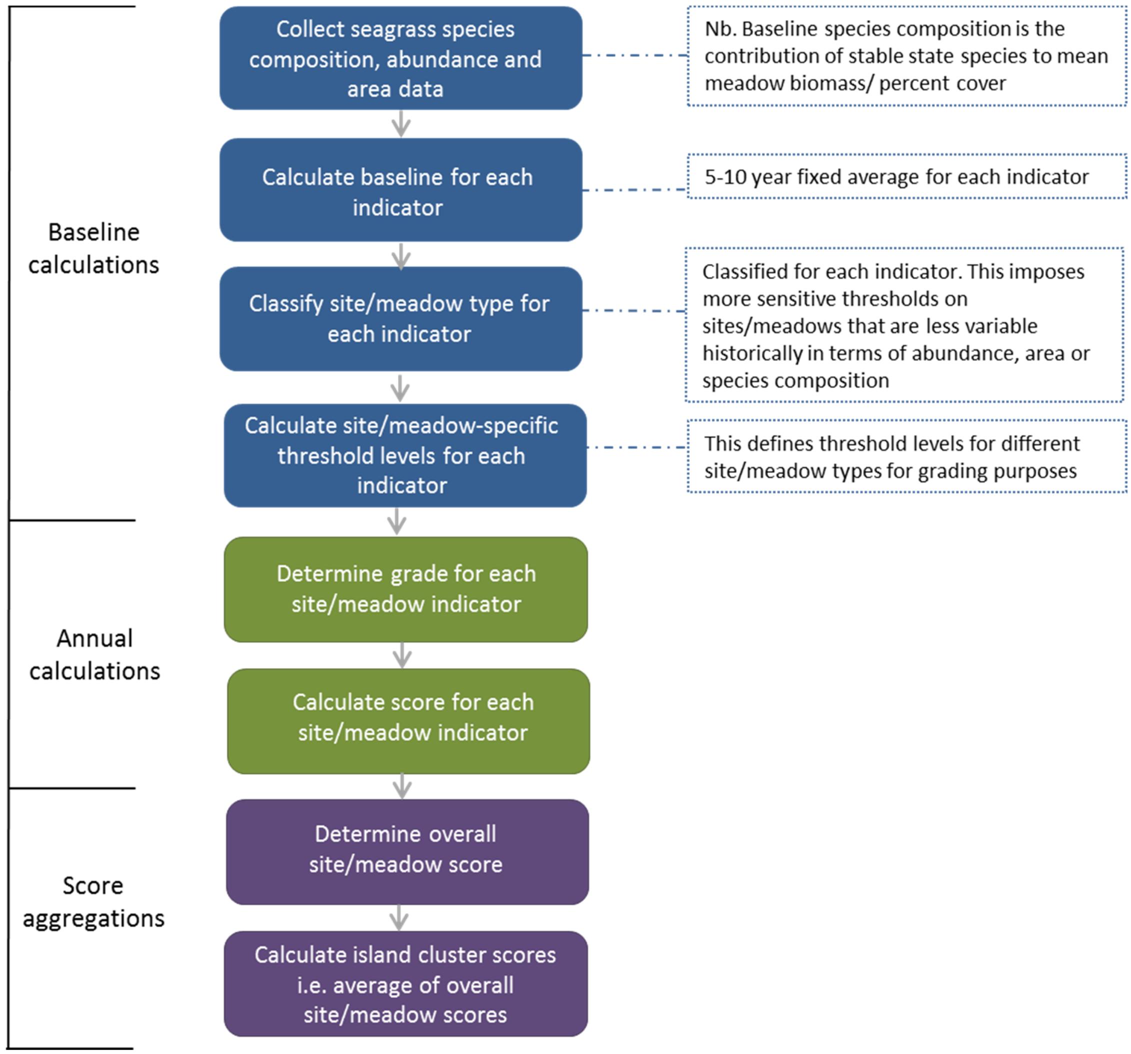

Figure 4. Flow chart of steps used to determine Torres Strait grades and scores.

3 RESULTS

3.1 Meadow Classifications

Twenty-six sites/meadows were classified for this report card. Of those, ~75% were characterised as having stable species composition. Site MR1 at Mer Island, and meadows M2 and M4 at Thursday Island are the only locations to be classed as single species due to the dominance of *T. hemprichii* and *E. acoroides*, respectively. All other sites/meadows are classed as mixed species (Table 3). Biomass/ percent cover was stable in 43% of sites/meadows. Meadow-scale monitoring occurred at 13 locations, nine of which are at Thursday Island/Madge Reef in the Inner Cluster; meadow area was classed as stable or highly stable in 11 of these meadows (Table 3).

3.1.1 Overall Site/Meadow Condition and Data Availability

Overall grades and scores were produced for 24 of the sites/meadows. Of the sites/meadows with overall condition scores, over half of the sites (17) were in overall good condition or very good condition, three were in satisfactory condition, one was in poor condition, and three were in very poor condition (Table 4). Overall site/meadow scores were driven by either percent cover/biomass or species composition (Table 4). The poor condition at Mabuyag Island site MG2 and very poor condition at Orman Reefs subtidal (OR7) were due to biomass declines. Very poor condition at Poruma Island site PM2 and the Dugong Sanctuary subtidal (DS1) were due to biomass declines and the loss of the dominant and more stable species. Where meadow scale monitoring occurs, meadow area was in good or very good condition (Table 4).

Several important milestones were reached in the monitoring program in 2021:

- Several sites reached 10-years of monitoring data, meaning that the baselines for these locations are now set. This occurred at Iama Island (IM1 and IM2), Badu Island (BD1), and Mua Island (MU3).
- Kai and Gariar Reefs (Orman Reefs intertidal meadows) and Poruma Island (PM1 and PM2) reached 5-years of monitoring data, meaning we have some confidence around preliminary baseline conditions and overall grades and scores are included in the overall cluster scores for this report card.
- Meadow-scale monitoring commenced at Masig Island (MS1) in the Central Cluster.
- Meadow-scale monitoring resumed in the Inner Cluster following postponed field trips in early 2020 due to COVID-19 travel restrictions.

Overall grades and scores for Dungeness Reef subtidal and Masig Island intertidal will be incorporated into the report card when 5 years of baseline data has been collected. No grades or scores were produced for Mer Island in 2021 as no monitoring occurred.

3.1.2 Overall Cluster Condition

The Western and Central Clusters were in satisfactory condition, and the Inner Cluster was in good condition. Overall condition in the Eastern Cluster is unknown in 2021 as Mer Island transect monitoring did not occur (Table 4).

Table 3. Classifications representing the historical stability or variability of seagrass site/meadow for biomass/ percent cover, area, and species composition within Torres Strait Island Clusters. Classifications were based on the coefficient of variation of the baseline for each indicator. int = intertidal; sub = subtidal.

ISLAND CLUSTER	LOCATION	SITE/ MEADOW ID	ABUNDANCE (BIOMASS or PERCENT COVER)	AREA	SPECIES COMPOSITION
Western	Mabuyag Island (int)	MG1[#]	Stable	^	Variable – mixed species
		MG2[#]	Variable	^	Stable – mixed species
	Badu Island (int)	BD1	Stable	^	Stable – mixed species
		BD2[#]	Stable	^	Stable – mixed species
	Mua Island (int)	MU1	Variable	^	Stable – mixed species
		MU3	Stable	^	Variable – mixed species
	Orman Reefs (int)	OR2[#]	Variable	Highly stable	Stable – mixed species
		OR5[#]	Variable	Highly stable	Variable – mixed species
	Orman Reefs (sub)	OR7[#]	Variable	^	Variable – mixed species
	Dugong Sanctuary (sub)	DS1[#]	Variable	^	Variable – mixed species
Central	Iama Island (int)	IM1	Stable	^	Stable – mixed species
		IM2	Stable	^	Stable – mixed species
	Poruma Island (int)	PM1[#]	Stable	^	Stable – mixed species
		PM2[#]	Variable	^	Variable – mixed species
	Dungeness Reef (int)	DR6[#]	Variable	Stable	Stable – mixed species
	Dungeness Reef (sub)	DR1[#]	Variable	^	Variable – mixed species
	Masig Island (int)	MS1[#]	Variable	Highly stable	Stable – mixed species
Eastern	Mer Island (int)	MR1	Stable	^	Stable – single species
		MR2	Variable	^	Stable – mixed species
Inner	Thursday Island (int)	M1	Variable	Stable	Stable – mixed species
		M3	Variable	Variable	Stable – mixed species
		M5	Stable	Stable	Stable – mixed species
		M8	Variable	Stable	Stable – mixed species
	Thursday Island (int-sub)	M2	Stable	Stable	Stable – single species
		M4	Stable	Variable	Stable – single species
		M6	Stable	Stable	Stable – mixed species
	Madge Reef (int)	M26	Variable	Highly stable	Stable – mixed species
		M27	Variable	Stable	Stable – mixed species

[#] <10 years of data available to classify meadows. Classifications for these sites/meadows should be interpreted with caution until 10-year baselines are available.
^ Area data not collected in current monitoring program.

Table 4. Grades and scores for seagrass condition indicators (abundance (biomass or percent cover), area, species composition) for sites/meadows and Torres Strait Island Clusters in 2021. Scores are on 0 – 1 scale; cells are coloured according to grade. See Appendix 1, Table A1.2 for grading scale.

Very good	Good	Satisfactory	Poor	Very Poor

ISLAND CLUSTER	LOCATION	SITE/ MEADOW ID	ABUNDANCE (BIOMASS or PERCENT COVER)	AREA	SPECIES COMP.	OVERALL SITE/ MEADOW SCORE	OVERALL CLUSTER SCORE
Western	Mabuyag Island (int)	MG1#	0.52	^	0.86	0.52	0.53
		MG2#	0.33	^	0.89	0.33	
	Badu Island (int)	BD1#	0.87	^	0.64	0.76	
		BD2#	0.66	^	0.68	0.66	
	Mua Island (int)	MU1	0.86	^	0.78	0.82	
		MU3#	0.90	^	0.88	0.89	
	Orman Reefs (int)	OR2#	0.57	0.78	0.77	0.57	
		OR5#	0.55	0.72	0.96	0.55	
	Orman Reefs (sub)	OR7#	0.21	^	0.91	0.21	
	Dugong Sanctuary (sub)	DS1#	0.02	^	0.00	0.01	
Central	Iama Island (int)	IM1	0.75	^	0.80	0.75	0.64
		IM2	0.69	^	0.84	0.69	
	Poruma Island (int)	PM1#	0.78	^	0.72	0.75	
		PM2#	0.36	^	0.07	0.22	
	Dungeness Reef (int)	DR6#	0.96	0.77	0.96	0.77	
	Dungeness Reef (sub)	DR1*	0.05	^	0.93	*	
	Masig Island (int)	MS1*	0.84	0.76	0.82	*	
Eastern	Mer Island (int)	MR1	NS	^	NS	NS	NS
		MR2	NS	^	NS	NS	
Inner	Thursday Island (int)	M1	0.79	0.85	0.97	0.79	0.82
		M3	0.73	0.67	0.89	0.67	
		M5	0.88	0.81	0.98	0.81	
		M8	0.96	0.92	0.99	0.92	
	Thursday Island (int-sub)	M2	0.99	0.90	0.86	0.88	
		M4	0.98	0.97	0.82	0.90	
		M6	1.00	0.88	0.91	0.88	
	Madge Reef (int)	M26	0.91	0.83	0.80	0.82	
		M27	1.00	0.75	0.89	0.75	

Baseline conditions based on 5-10 years of data. Grades/scores for these sites/meadows should be interpreted with caution until 10-year baseline has been established.

* Baseline conditions based on <5 years of data. No overall grades or scores provided until 5 years of monitoring data is available.

^ Area data not collected in current monitoring program.

NS, no survey in 2021 growing season.

3.2 Seagrass Condition for Each Monitoring Site/Meadow

3.2.1 Western Island Cluster

Seagrass condition in the Western Island Cluster remained satisfactory in 2021. Very poor seagrass condition in the Dugong Sanctuary and Orman Reefs subtidal meadows and at Mabuyag Island site MG2 was balanced by good and very good seagrass condition at Badu and Mua Islands (Figure 5). Seagrass monitoring in this cluster includes six intertidal transect sites across Mabuyag, Badu and Mua Islands, whole-meadow monitoring of two intertidal reef-top meadows at Orman Reefs, and block monitoring of the Dugong Sanctuary and Orman Reefs subtidal meadows (Figure 5). The Orman Reefs system was selected for monitoring because of its known value as a foraging ground for turtle and dugong.

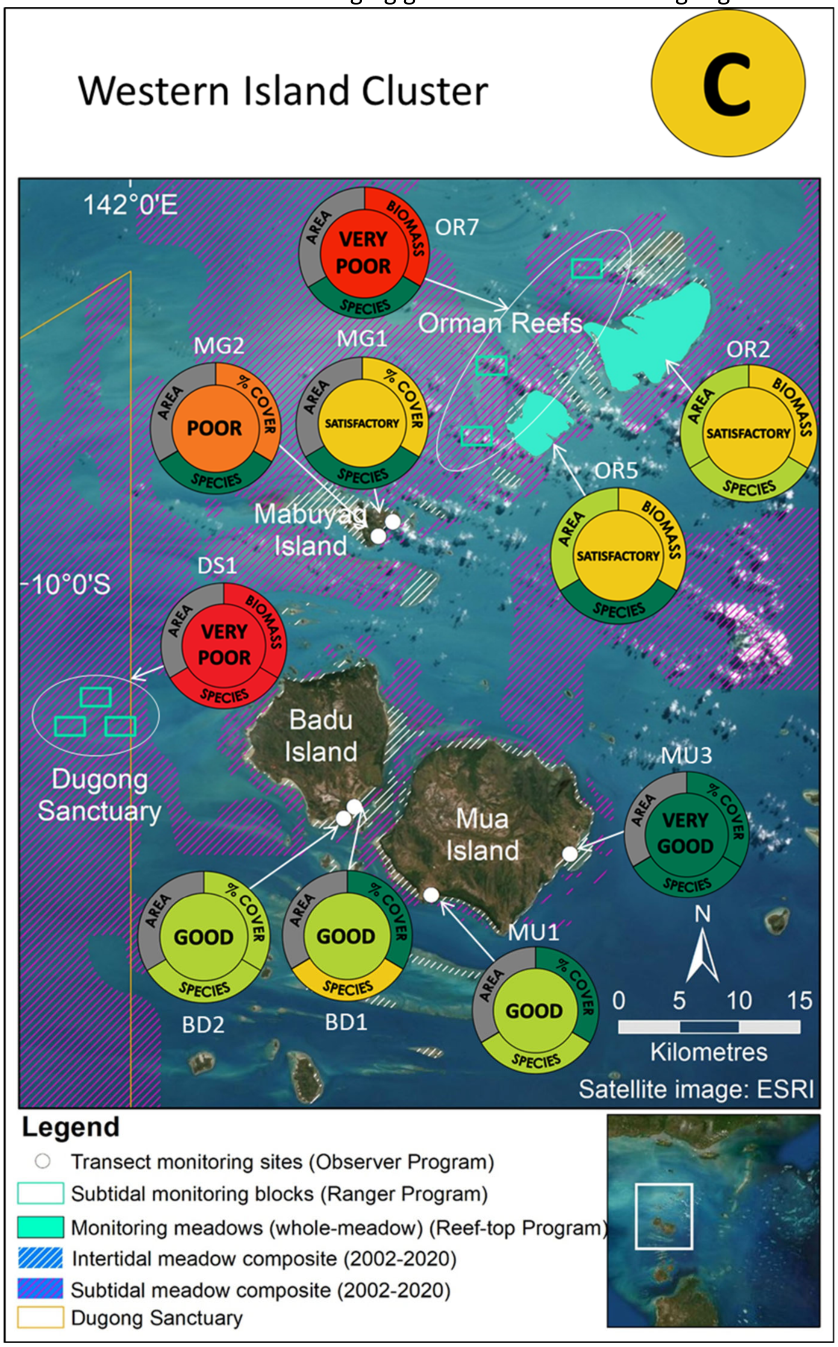

Figure 5. Seagrass condition across the Western Island Cluster of Torres Strait.

Mabuyag Island Site (MG1)

Monitoring at Panai, Mabuyag Island (site MG1) by Mabuygiw Rangers commenced in 2009 (Figure 6). Percent cover was relatively stable between 2009 and 2018, followed by a rapid decline from very good condition in 2018 to poor in 2020. Percent cover increased slightly in 2021 that resulted in a grade increase from poor to satisfactory condition; however, seagrass condition remains a concern (Table 4). The site continues to have high species diversity, with seven species recorded. Species composition has been variable over the years. The more stable species *T. hemprichii* replaced much of the *C. serrulata* in 2018 and 2020; in 2021 *C. serrulata* had returned to being the dominant species (Figure 6).

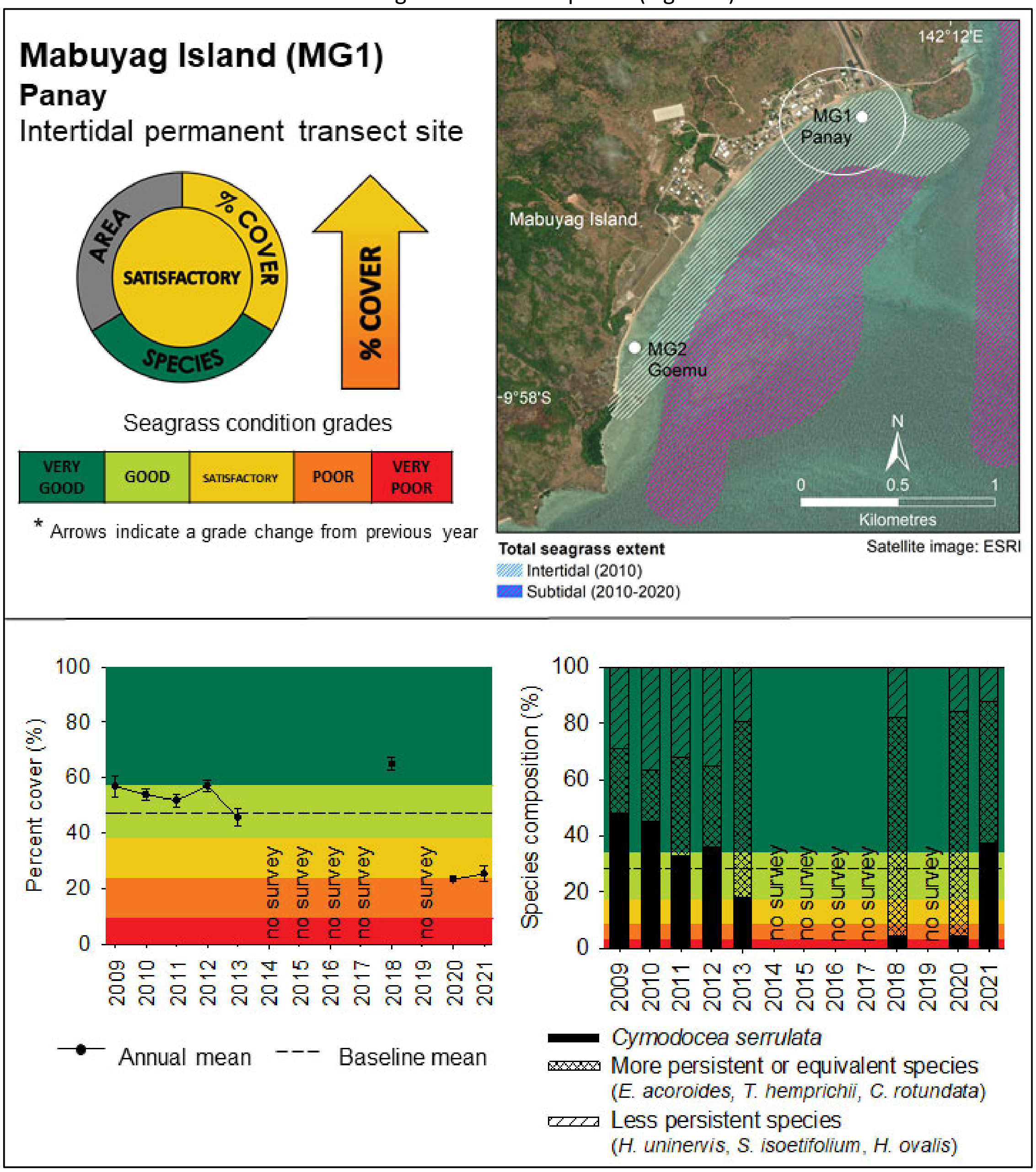

Figure 6. Seagrass mean percent cover and species composition at Mabuyag Island permanent transect site MG1, western Torres Strait, 2009 - 2021 (percent cover error bars = SE). Total seagrass extent from mapping surveys in 2009 – 2010 have been updated following a large-scale mapping project in December 2020. Note: Baseline conditions based on 8 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Mabuyag Island Site (MG2)

The monitoring site MG2 (Goemu) at Mabuyag Island was established in 2010 and is monitored by the Mabuygiw Rangers (Figure 7). As with MG1 (Panay), the site has high species diversity, with seven species recorded historically. However, *E. acoroides* and *C. serrulata* were only recorded in 2012, and *S. isoetifolium* was not present in 2020 or 2021. In 2021 the dominant baseline species switched from *H. uninervis* to *C. rotundata* due to increased contribution of that species to pecetn cover. The site is characterised by variable percent cover (Table 3). Seagrass percent cover declined dramatically between 2018 and 2020 (no monitoring occurred in 2019), and again in 2021. This resulted in the overall condition of this site being graded as poor for the second consecutive year (Figure 7). Mabuygiw Rangers a change in sediment with increased sand, shells and forams.

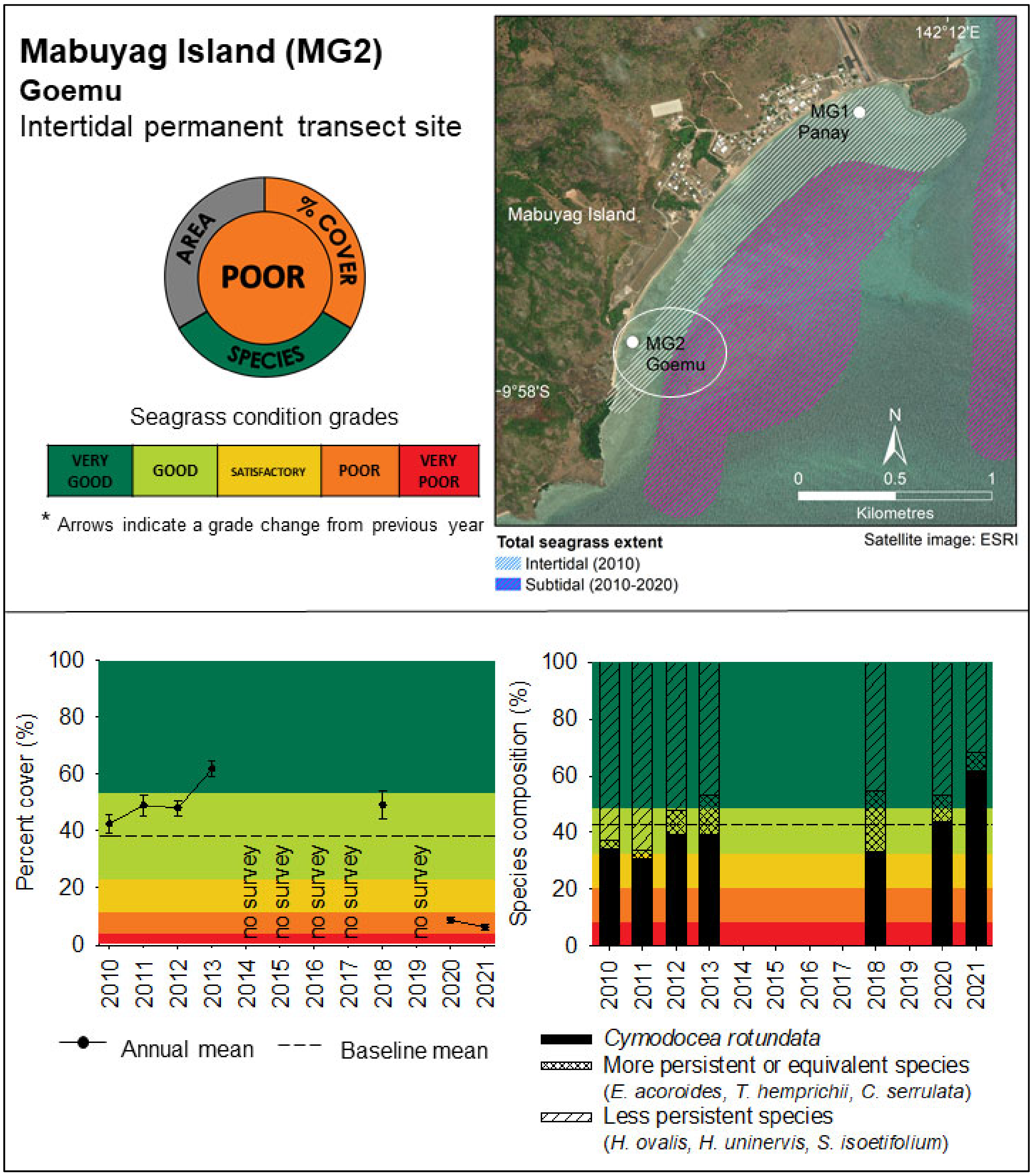

Figure 7. Seagrass mean percent cover and species composition at Mabuyag Island permanent transect site MG2, western Torres Strait, 2010 - 2021 (percent cover error bars = SE). Total seagrass extent from mapping surveys in 2009 – 2010 have been updated following a large-scale mapping project in December 2020. Note: Baseline conditions based on 7 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Badu Island Site (BD1)

The transect monitoring site BD1 (Dogai Wak) at Badu Island was established in 2010 and is monitored by the Mura Badhulgau Rangers (Figure 8). Intertidal monitoring at BD1 has now reached 10 years so the site now has a complete baseline dataset. The site is characterised by stable, mixed species and stable abundance (Table 3). Species composition condition declined due to a reduction in the dominant species *H. uninervis* relative to *H. ovalis*. The continued increase in seagrass abundance since 2019 increased the overall condition grade at Dogai Wak from satisfactory in 2020 to very good in 2021 (Figure 8).

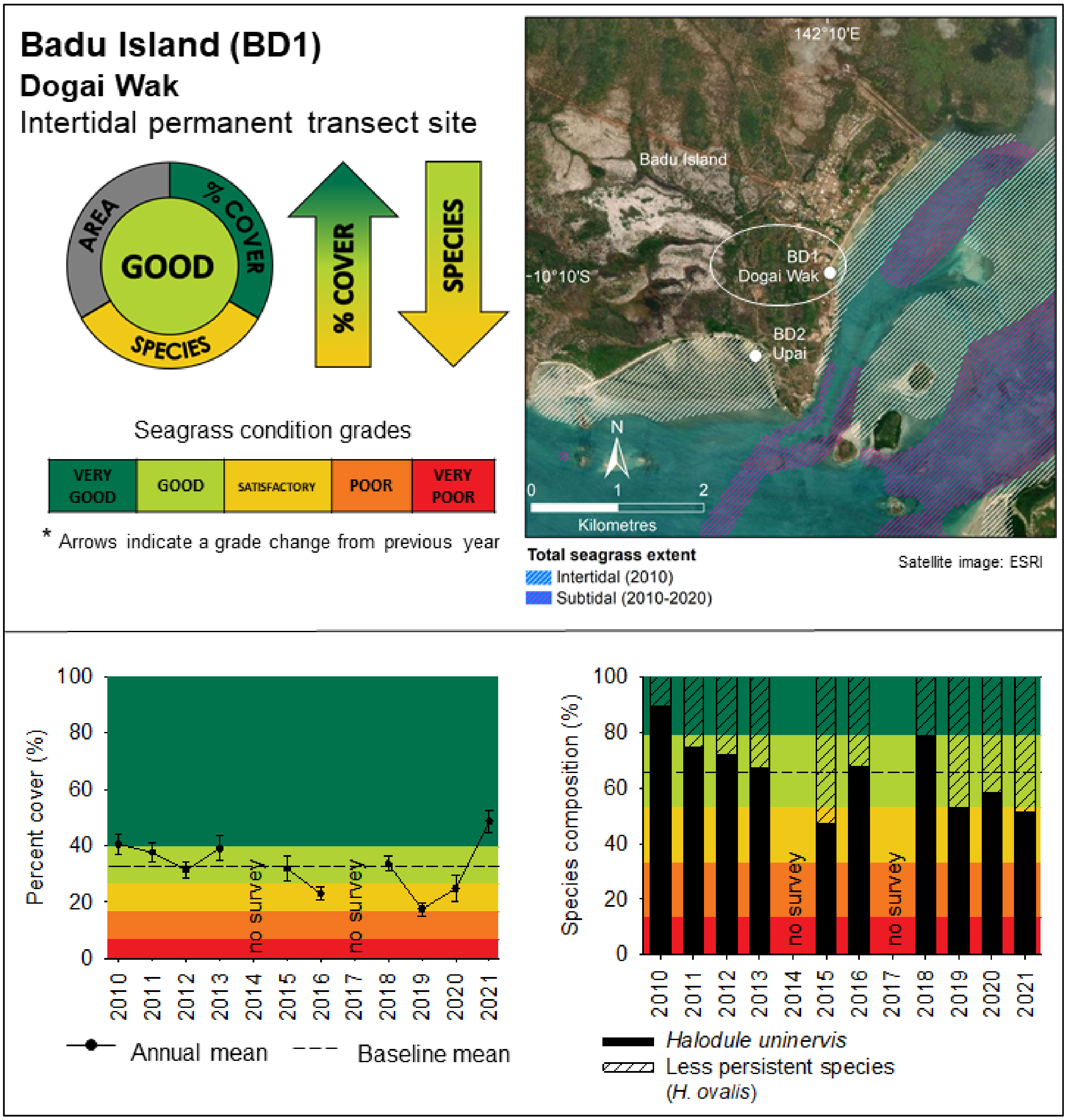

Figure 8. Seagrass mean percent cover and species composition at Badu Island permanent transect site BD1, western Torres Strait, 2010 - 2021 (percent cover error bars = SE Total seagrass extent from mapping surveys in 2010 have been updated following a large-scale mapping project in December 2020.

Badu Island Site (BD2)

The transect monitoring site BD2 (Upai) at Badu Island now has nine years of monitoring data and is monitored by the Mura Badhulgau Rangers (Figure 9). This site is characterised by stable percent cover and stable, mixed species composition (Table 3). Seven species have been recorded at this site, with five species regularly observed. In 2021, there was no change in species composition condition. Seagrass abundance reduced from ~60% cover (very good condition) to ~40% (Figure 9). Overall site condition remained good (Figure 9).

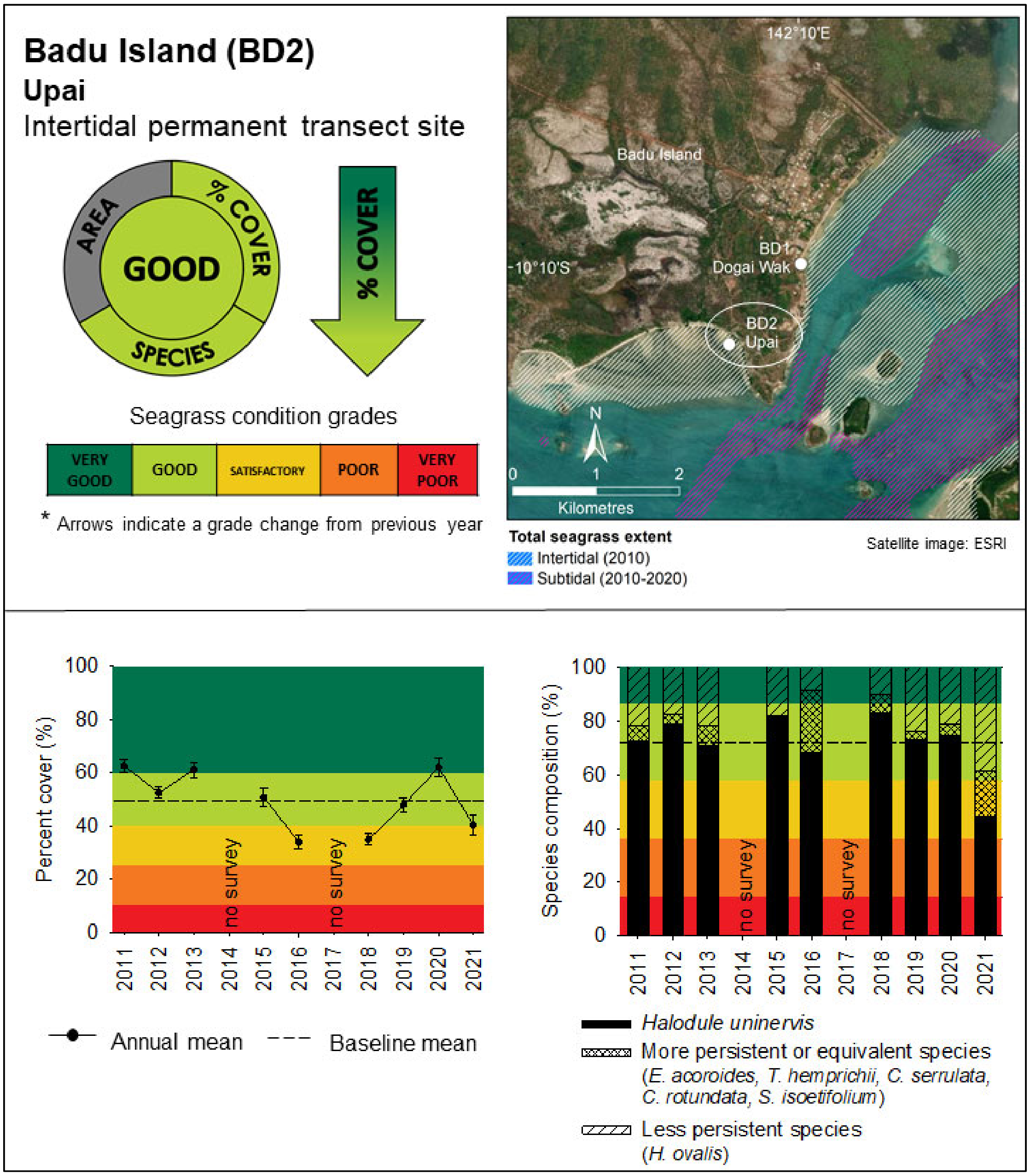

Figure 9. Seagrass mean percent cover and species composition at Badu Island permanent transect site BD2, western Torres Strait, 2011 - 2021 (percent cover error bars = SE Total seagrass extent from mapping surveys in 2010 have been updated following a large-scale mapping project in December 2020. Note: Baseline conditions based on 9 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Mua Island Site (MU1)

Monitoring at Kubin Beach Hotel, Mua Island (MU1), was established in 2011 and is conducted by the Mua Lagalgau Rangers. The site is characterised by variable percent cover and stable, mixed species composition (Table 3). Overall condition of the site was good in 2021 (Figure 10). Seagrass percent cover increased from good condition in 2020 to very good condition in 2021. The contribution of the dominant species *T. hemprichii* also increased relative to less persistent species *H. uninervis* and *H. ovalis*, resulting in species condition improving from poor condition in 2020 to good condition in 2021 (Figure 10).

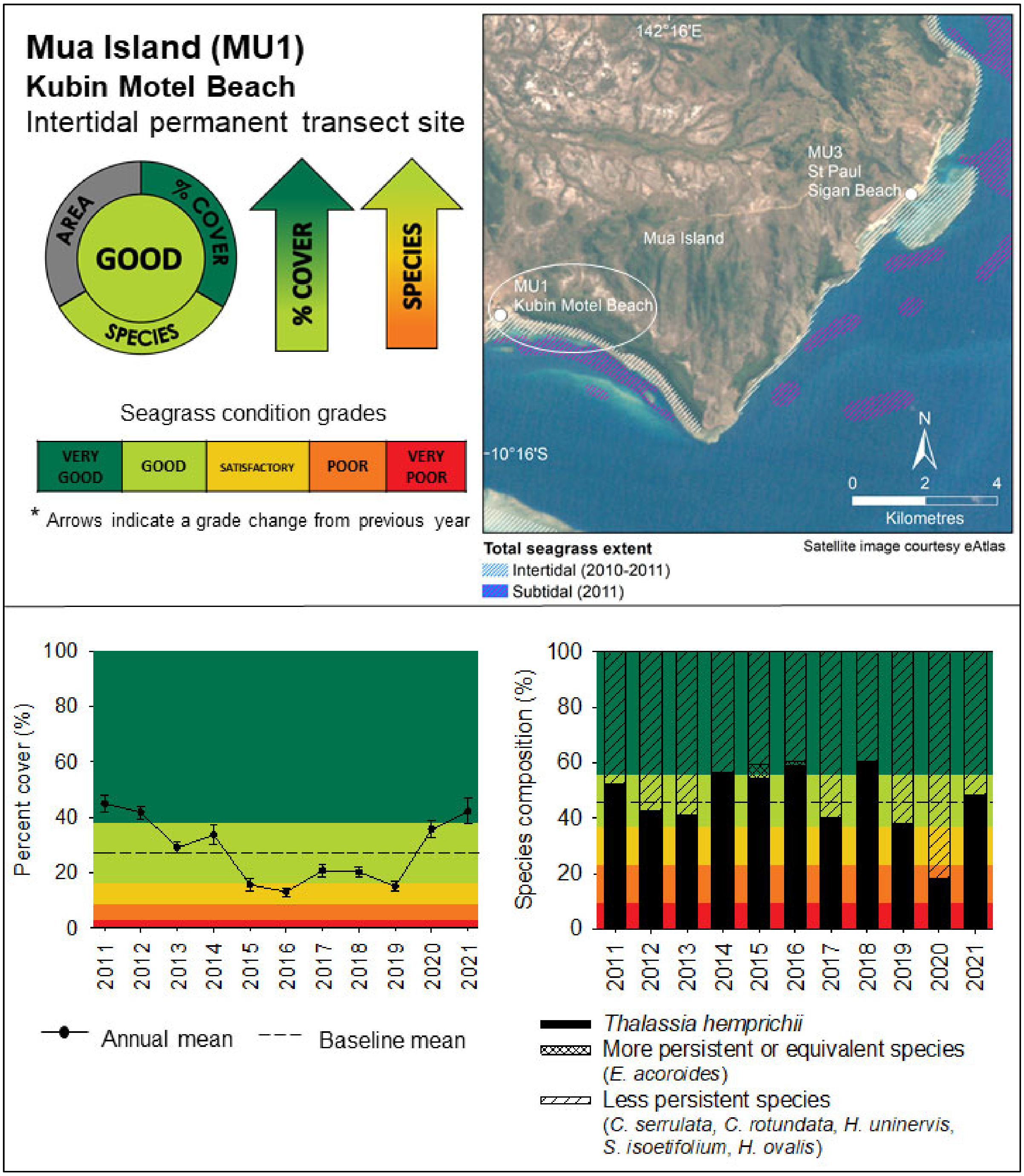

Figure 10. Seagrass mean percent cover and species composition at Mua Island permanent transect site MU1, western Torres Strait, 2011 - 2021 (percent cover error bars = SE). Total seagrass extent from mapping surveys in 2010 - 2011.

Mua Island Site (MU3)

Monitoring at St Pauls Sigan Beach, Mua Island (MU3), was established in late 2011 (2012 reporting year). The Mua Lagalgau Rangers monitor this site, which has now achieved 10 years of baseline data. Site MU3 is characterised by stable percent cover and variable, mixed species composition (Table 3). Overall site condition was very good (Figure 11). As with site MU1, percent cover increased from good condition in 2020 to very good condition in 2021. Species composition was also very good. The tracking species has switched back and forth between *C. rotundata* and *T. hemprichii* over the last few years. In 2021, the baseline species composition was set with *T. hemprichii* as the dominant species (Figure 11).

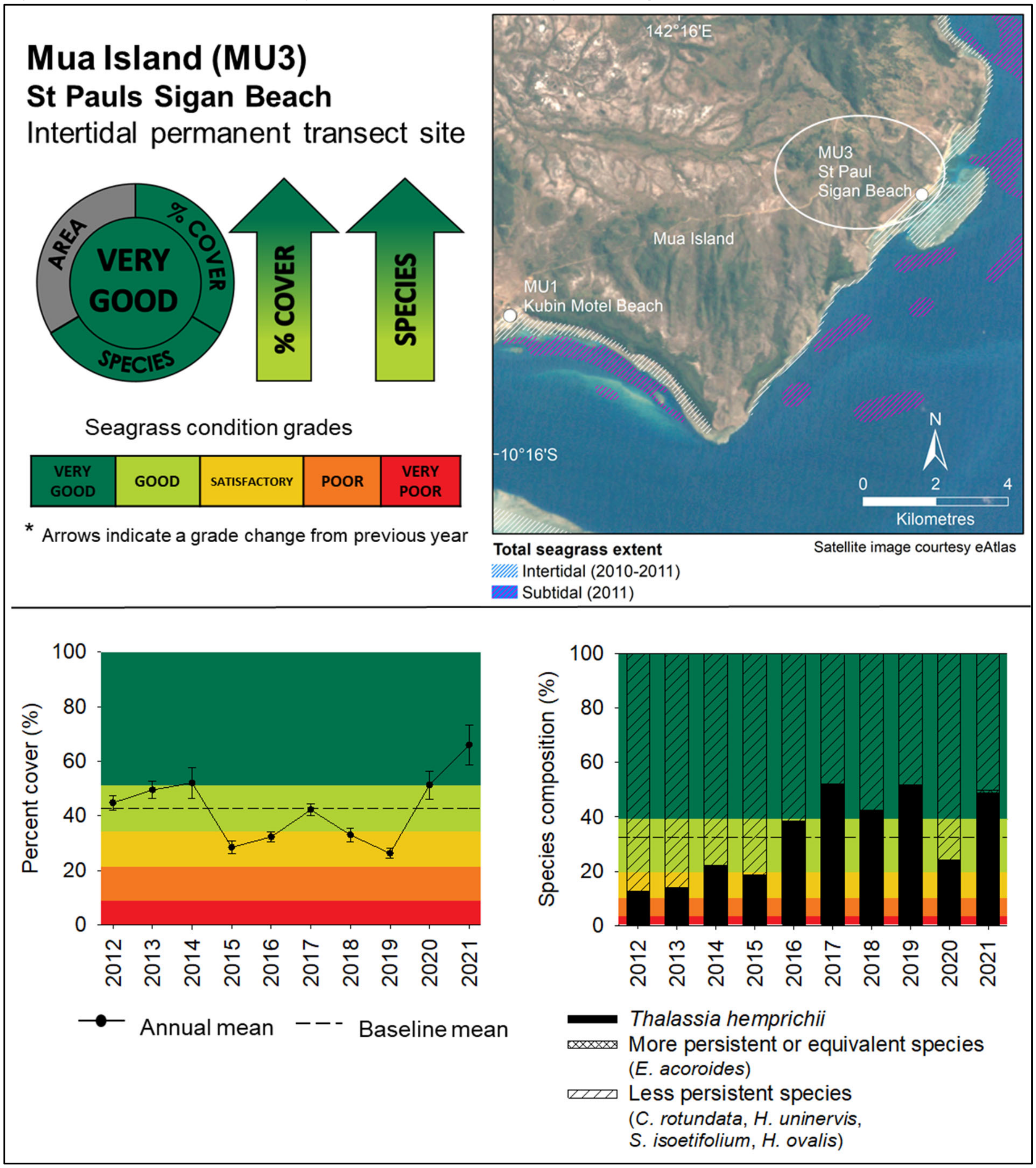

Figure 11. Seagrass mean percent cover and species composition at Mua Island permanent transect site MU3, western Torres Strait, 2012 - 2021 (percent cover error bars = SE). Total seagrass extent from mapping surveys in 2010-2011.

Kai Reef - Orman Reefs Intertidal Meadow (OR2)

Kai Reef (OR2) is the largest reef in the Orman Reefs system. Monitoring was established in 2017 (2018 reporting year) because of the reef's value as a turtle foraging ground, and is conducted by TropWATER researchers. This is the first year that overall meadow scores and grades are incorporated into the report card because the minimum 5-years of monitoring has occurred (Table 4). Preliminary assessments indicate variable biomass, highly stable area, and stable species composition (Figure 12; Table 3). Kai Reef's meadow biomass peaked in 2019 and has declined dramatically in the two years since then, resulting in a condition decline from very good in 2019 to satisfactory in 2021. Biomass hotspots were once again located along the eastern side of the reef but were less dense than previous years. Despite biomass declines, area and species composition condition remain good, with the highly stable meadow continuing to cover the majority of Kai Reef's intertidal reef-top and *T. hemprichii* remains the dominant species in the meadow. The high biomass species *E. acoroides* declined from 14% in 2018 to <1% in 2021 (Figure 12).

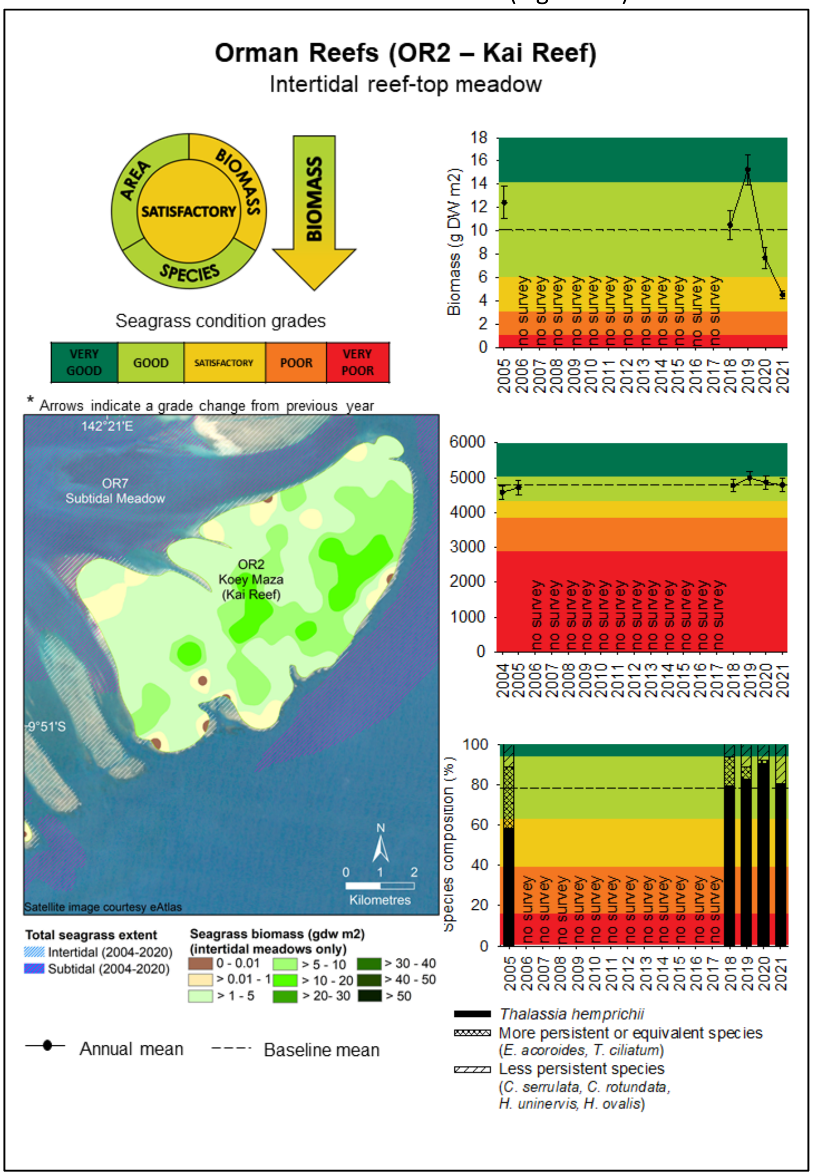

Figure 12. Seagrass mean biomass, area, and species composition at Orman Reefs (Kai Reef) intertidal meadow OR2, western Torres Strait, 2004/05 - 2021 (biomass error bars = SE; area error bars = reliability estimate). Note: Baseline conditions based on 5-6 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Gariar Reef - Orman Reefs Intertidal Meadow (OR5)

Gariar Reef (OR5) is in the southern section of the Orman Reefs system. Monitoring was established in 2017 (2018 reporting year) because of the reef's value as a turtle foraging ground, and is conducted by TropWATER researchers. This is the first year that overall meadow scores and grades are incorporated into the report card, because the minimum 5-years of monitoring has occurred (Table 4). Preliminary assessments indicate variable biomass, highly stable area, and variable species composition (Figure 13; Table 3). Biomass declined dramatically from 27 g DW m^{-2} (very good condition) to 3 g DW m^{-2} (poor condition) in 2020. Biomass increased slightly in 2021 to 5 g DW $m^{-2,}$ which resulted in a grade increase from poor to satisfactory condition (Table 4). Species composition remains very good because of the presence of the dominant species *T. hemprichii*; however, the very large declines in high biomass since 2019 and more persistent/stable species *T. ciliatum* and *E. acoroides* means that seagrass biomass and species composition remain a concern. The meadow covers the majority of Gariar Reef's intertidal reef-top and area is highly stable; in 2021 area remained in good condition for the fourth year in a row (Figure 13).

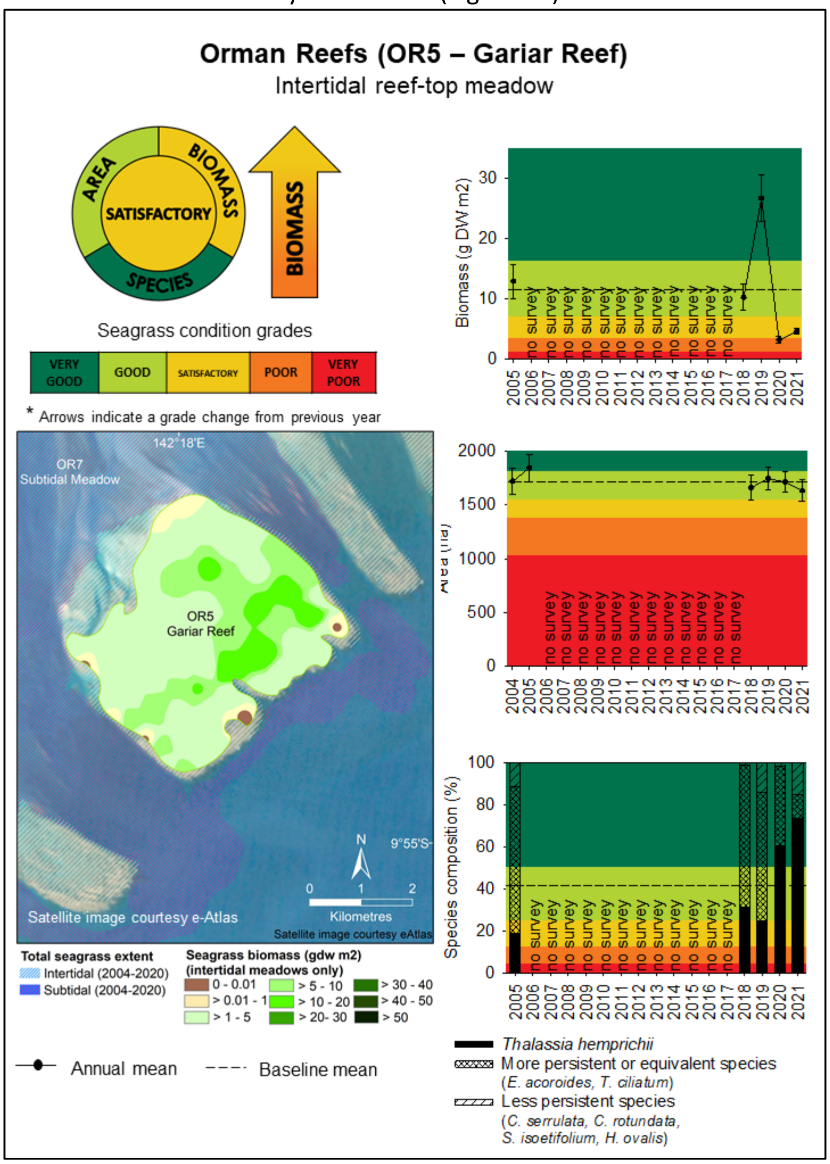

Figure 13. Seagrass mean biomass, area, and species composition at Orman Reefs (Gariar Reef) intertidal meadow OR5, western Torres Strait, 2004/05 - 2021 (biomass error bars = SE; area error bars = reliability estimate). Note: Baseline conditions based on 5-6 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Orman Reefs Subtidal Blocks (OR7)

Subtidal seagrass meadows surround Orman Reefs. Subtidal monitoring blocks are positioned along the western side of the reef system and are collectively referred to as OR7 (Figure 14). Subtidal blocks are monitored by the Mabuygiw and Mura Badhulgau Rangers. Overall meadow condition in 2021 was very poor for the second year following large reductions in seagrass biomass, from ~13 g DW m^{-2} in 2019 to <0.5 g DW m^{-2} in 2020 and 2021. The reduced biomass in 2020-2021 was largely due to the disappearance of the dominant subtidal species *H. spinulosa* (Figure 14). Species composition condition has been classed as very good despite the disappearance of *H. spinulosa* because more stable species (*C. serrulata*, *C. rotundata*, *H. uninervis*, *T. hemprichii*) continue to persist within the meadow (Figure 14).

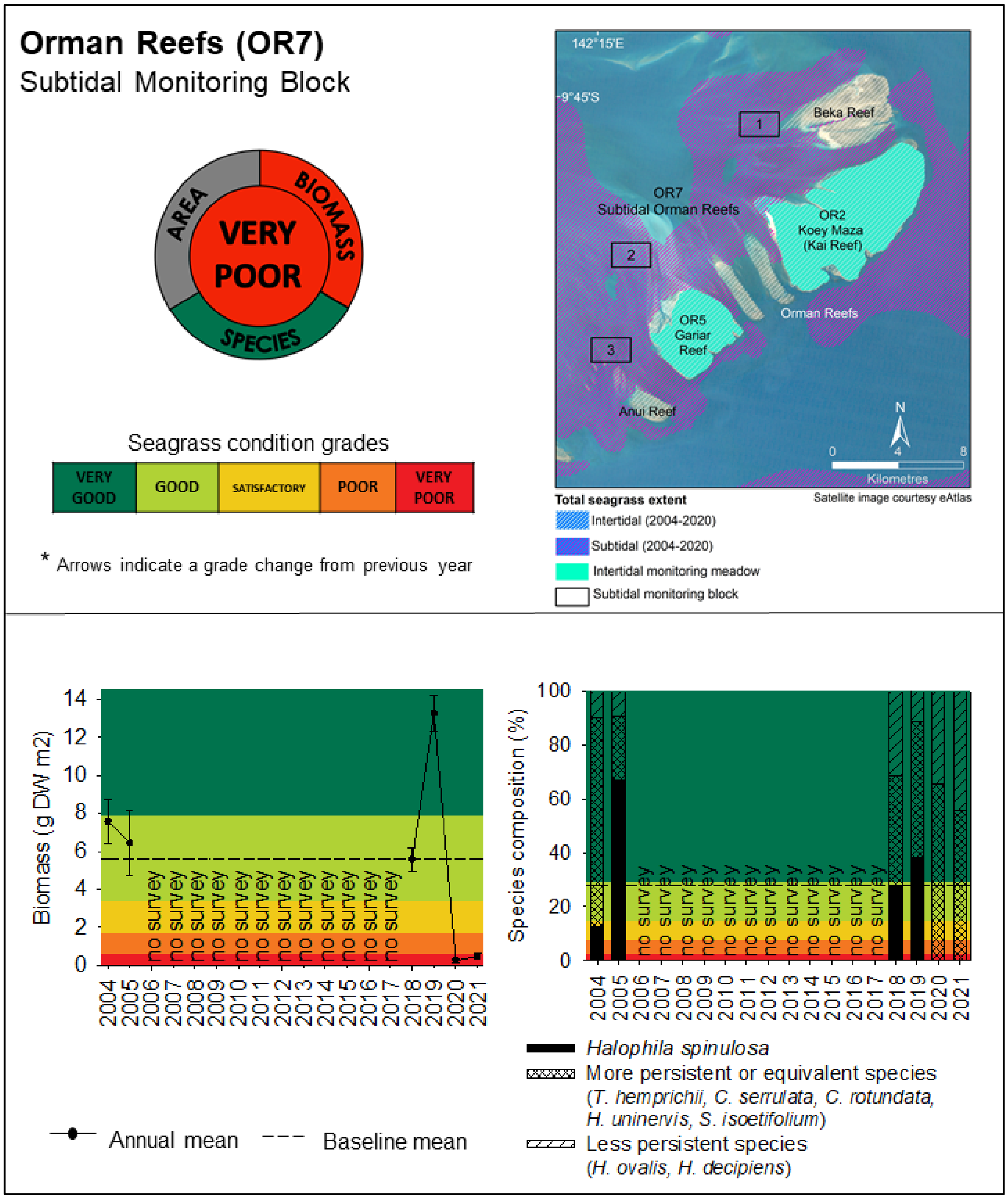

Figure 14. Seagrass mean biomass and species composition at Orman Reefs subtidal monitoring blocks, Western Cluster, 2004 - 2021 (biomass error bars = SE). Total seagrass extent from mapping surveys in 2004 – 2011 have been updated following a large-scale mapping project in December 2020. Note: Baseline conditions based on 6 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Dugong Sanctuary Subtidal Blocks (DS1)

The Dugong Sanctuary contains a large subtidal meadow that spans most of the sanctuary. Subtidal monitoring blocks are positioned in the north-eastern part of the meadow and are collectively referred to as DS1 (Figure 15). Subtidal blocks are monitored by the Mabuygiw and Mura Badhulgau Rangers. Overall meadow condition in 2021 was very poor. Biomass declined from 3 g DW m^{-2} in 2019 (good condition) to <0.1 g DW m^{-2} in 2021 (very poor condition). The reduced biomass in 2021 was due to the disappearance of the dominant subtidal species *H. spinulosa* and all other species classed as more stable and persistent. Species composition was graded very poor grade in 2021 due to the presence of only less persistent colonising species *H. ovalis* and *H. decipiens* (Figure 15).

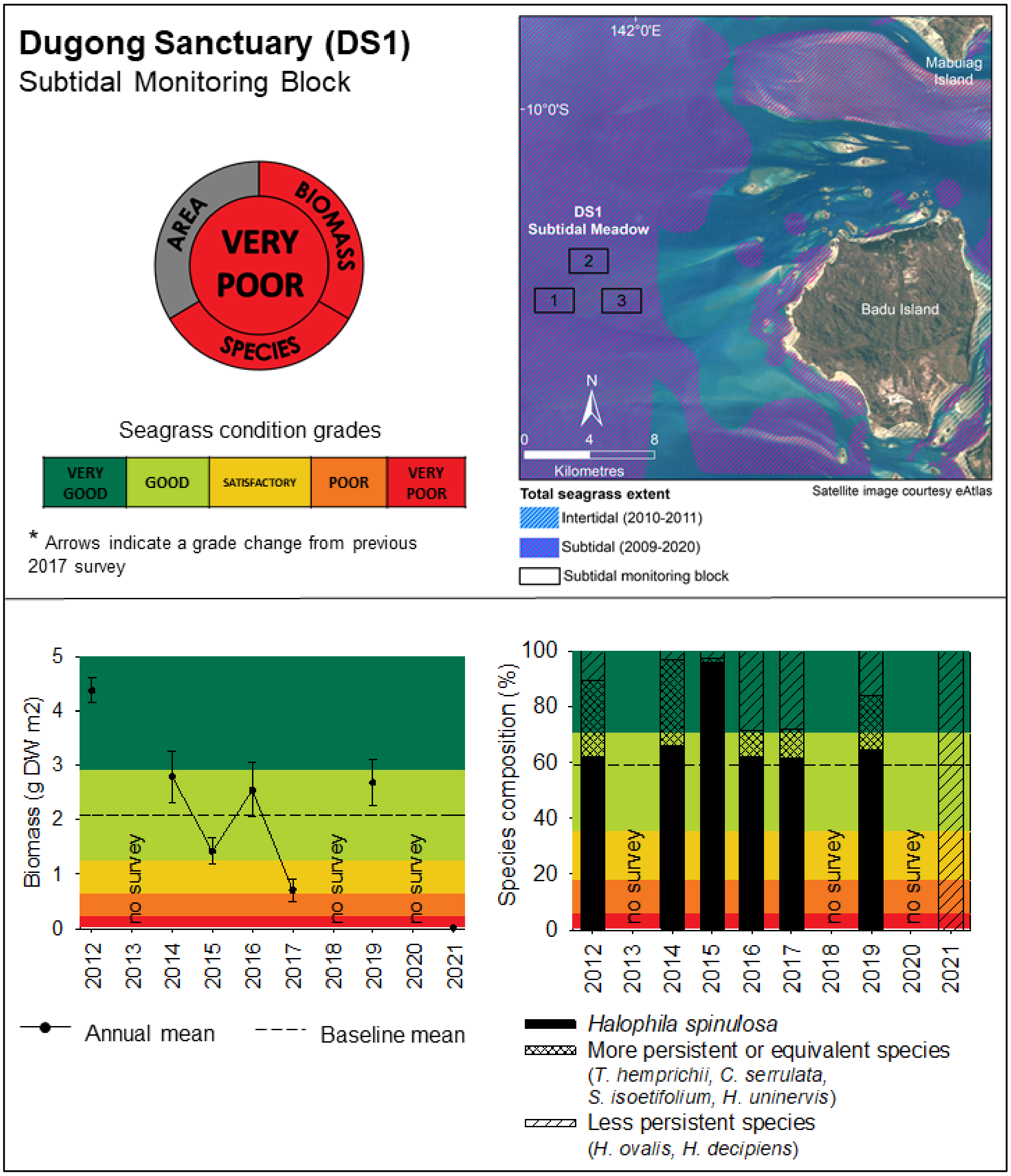

Figure 15. Seagrass mean biomass and species composition at Dugong Sanctuary subtidal monitoring blocks, western Torres Strait, 2012 - 2021 (biomass error bars = SE). Total seagrass extent from mapping surveys in 2010-2011 have been updated following a large-scale mapping project in December 2020. Note: Baseline conditions based on 7 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

3.2.2 Central Island Cluster

Seagrass condition in the Central Island Cluster declined from good to satisfactory in 2021, due to the decreases in seagrass abundance (percent cover) and species composition at Poruma Island site PM2 (Figure 16). Seagrass monitoring in this cluster includes four intertidal transect sites at Iama and Poruma Islands, whole-meadow monitoring of Dungeness Reef and Masig Island intertidal reef-tops, and block monitoring of the Dungeness Reef subtidal meadow (Figure 16). This is the first year monitoring has commenced at Masig Island.

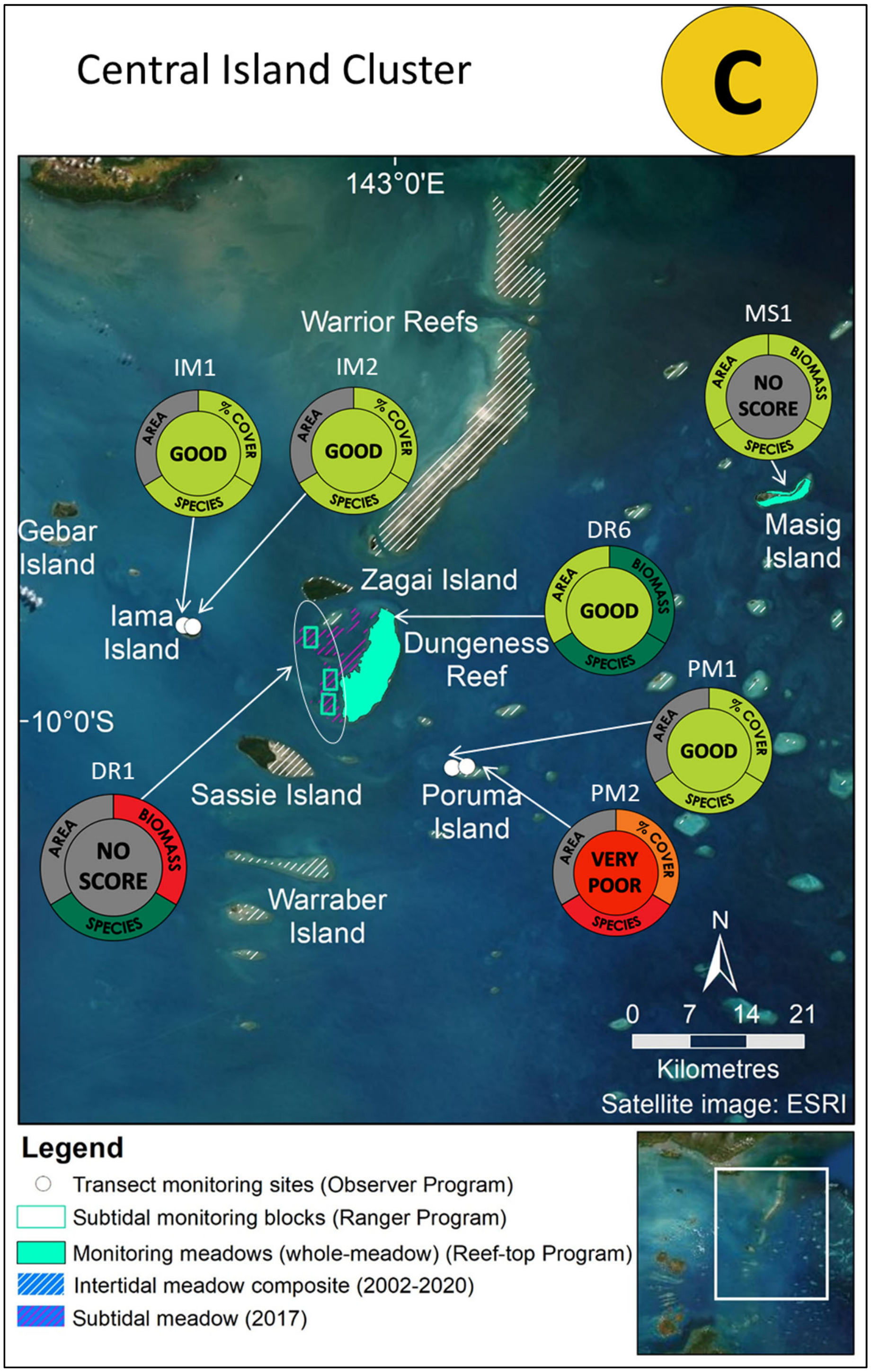

Figure 16. Seagrass condition across the Central Island Cluster of Torres Strait.

Iama Island Site (IM1)

The monitoring site IM1 at Mabuyag Point, north-west Iama Island, was established in August 2010 (2011 reporting year) (Figure 17). The site is monitored by the Iamalgal Rangers. Intertidal monitoring on Iama Island has now reached 10 years for both monitoring locations, and as such, now has a complete baseline dataset. Seagrass abundance and species composition are both stable at this site (Table 3). This is a mixed species meadow with six species of seagrass recorded within the site. Species composition, percent cover, and therefore overall seagrass condition, all remained good in 2021 (Figure 17).

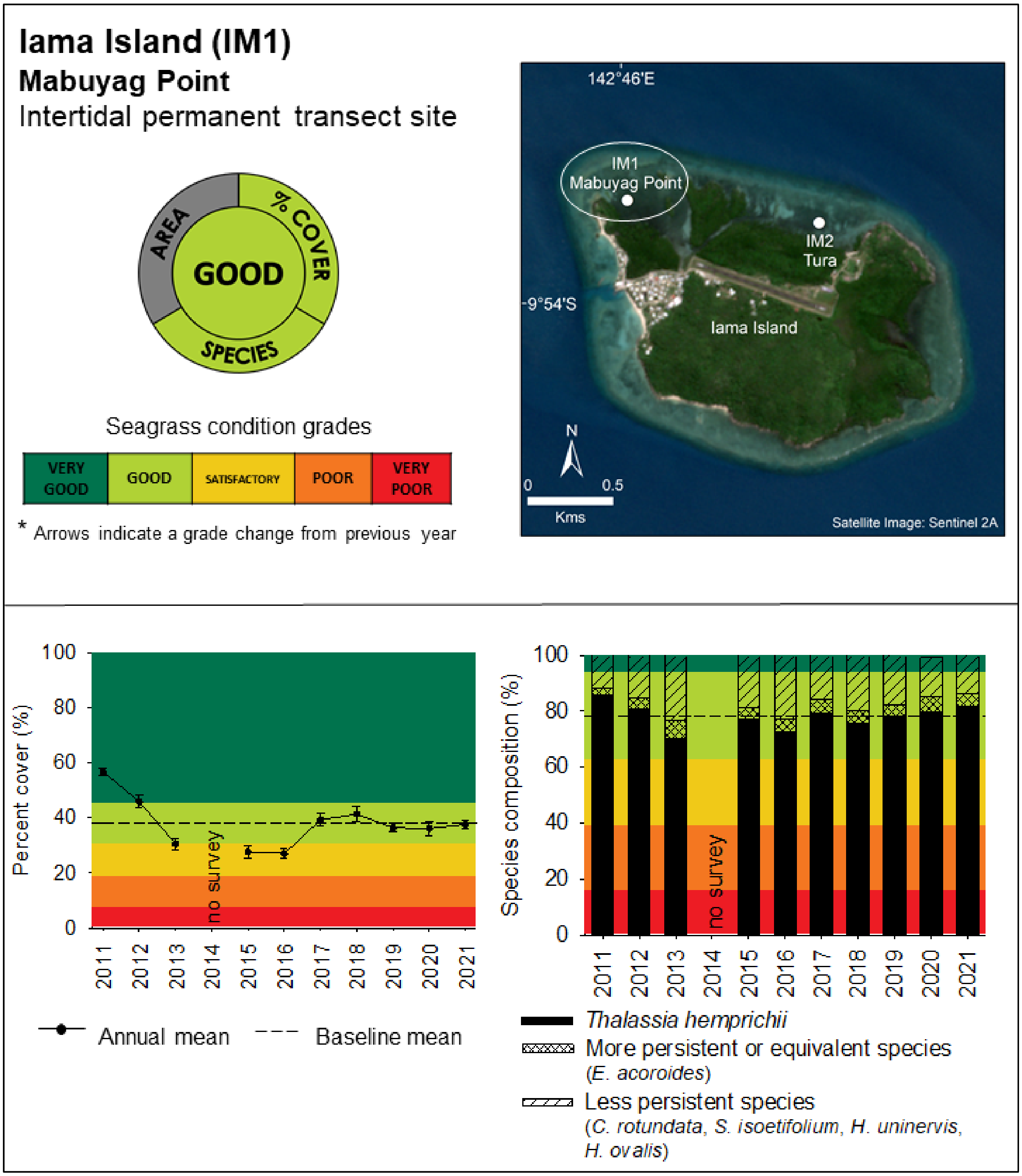

Figure 17. Seagrass mean percent cover and species composition at Iama Island permanent transect site IM1, central Torres Strait, 2011 - 2021 (percent cover error bars = SE).

Iama Island Site (IM2)

The monitoring site IM2 at Tura, Iama Island has been monitored by the Iamalgal Rangers since November 2010 (2011 reporting year) (Figure 18). Seagrass abundance and species composition at this site are both stable (Table 3). Percent cover and species composition, and therefore overall seagrass condition, remained in good condition in 2021 (Figure 18).

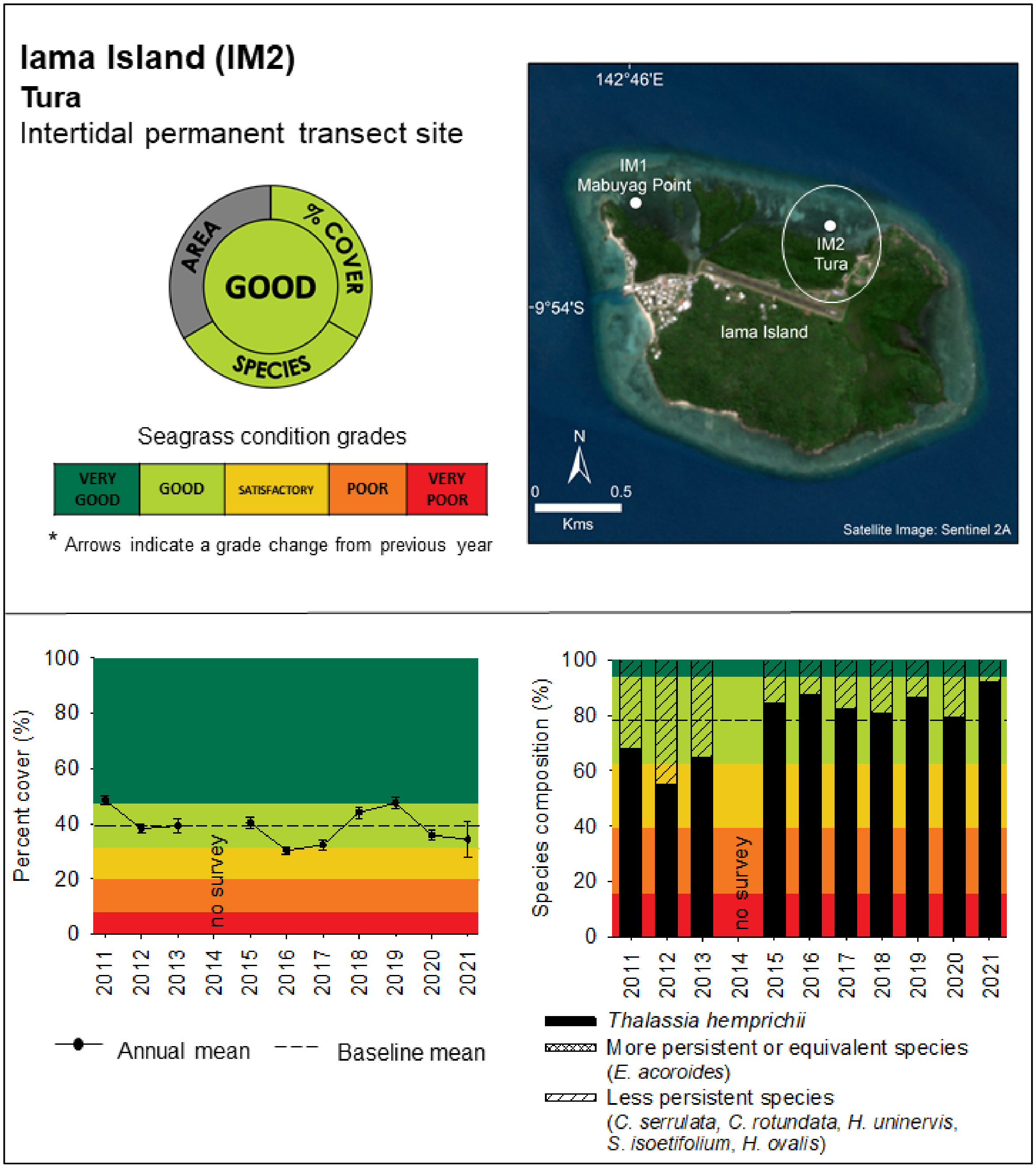

Figure 18. Seagrass mean percent cover and species composition at Iama Island permanent transect site IM2, central Torres Strait, 2011 - 2021 (percent cover error bars = SE).

Poruma Island Site (PM1)

Monitoring of PM1 at the south-west point of Poruma Island was established in August 2016 (2017 reporting year) by the Porumalgal Rangers. This is the first year that the overall site score and grade is incorporated into the report card, because the minimum 5-years of monitoring has occurred (Table 4). Preliminary assessments indicate stable percent cover and stable, mixed species composition (Table 3). Seagrass condition at PM1 in 2021 was good. Percent cover increased from 22% in 2020 to 31% in 2021, which resulted in a grade change from satisfactory to good. Species composition declined from very good condition in 2020 to good condition in 2021 due to a reduction in the dominant species *C. rotundata* and more persistent species *T. hemprichii*. The contribution of the less stable species *H. uninervis* increased from 2% in 2020 to 33% in 2021 (Figure 19).

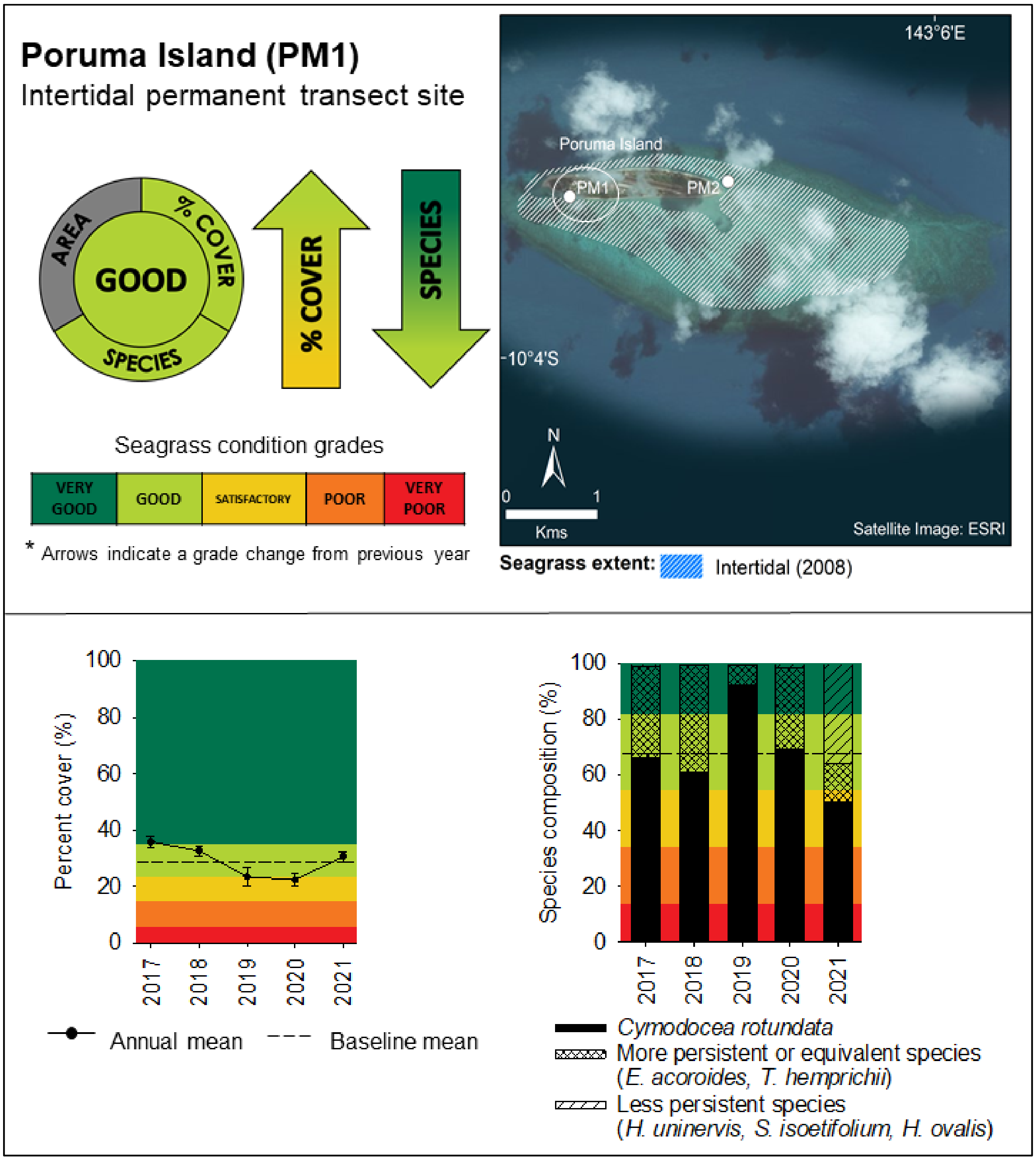

Figure 19. Seagrass mean percent cover and species composition at Poruma Island permanent transect site PM1, central Torres Strait, 2017 - 2021 (percent cover error bars = SE). Note: Baseline conditions based on 5 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Poruma Island Site (PM2)

Monitoring of PM2 at north-east Poruma Island started in August 2016 (2017 reporting year). The site is monitored by the Porumalgal Rangers. This is the first year that the overall site score and grade is incorporated into the report card because the minimum 5-years of monitoring has occurred (Table 4). Preliminary assessments indicate variable percent cover and variable, mixed species composition dominated by *C. rotundata* (Table 3). Seagrass condition at PM2 in 2021 was very poor due to large sand movement which covered the site. Percent cover declined from 15% in 2020 (good condition) to 3% in 2021 (poor condition) (Figure 20). Species composition was very poor following the complete loss of *C. rotundata* and *T. hemprichii* and replacement by the less persistent species *H. uninervis* (Figure 20).

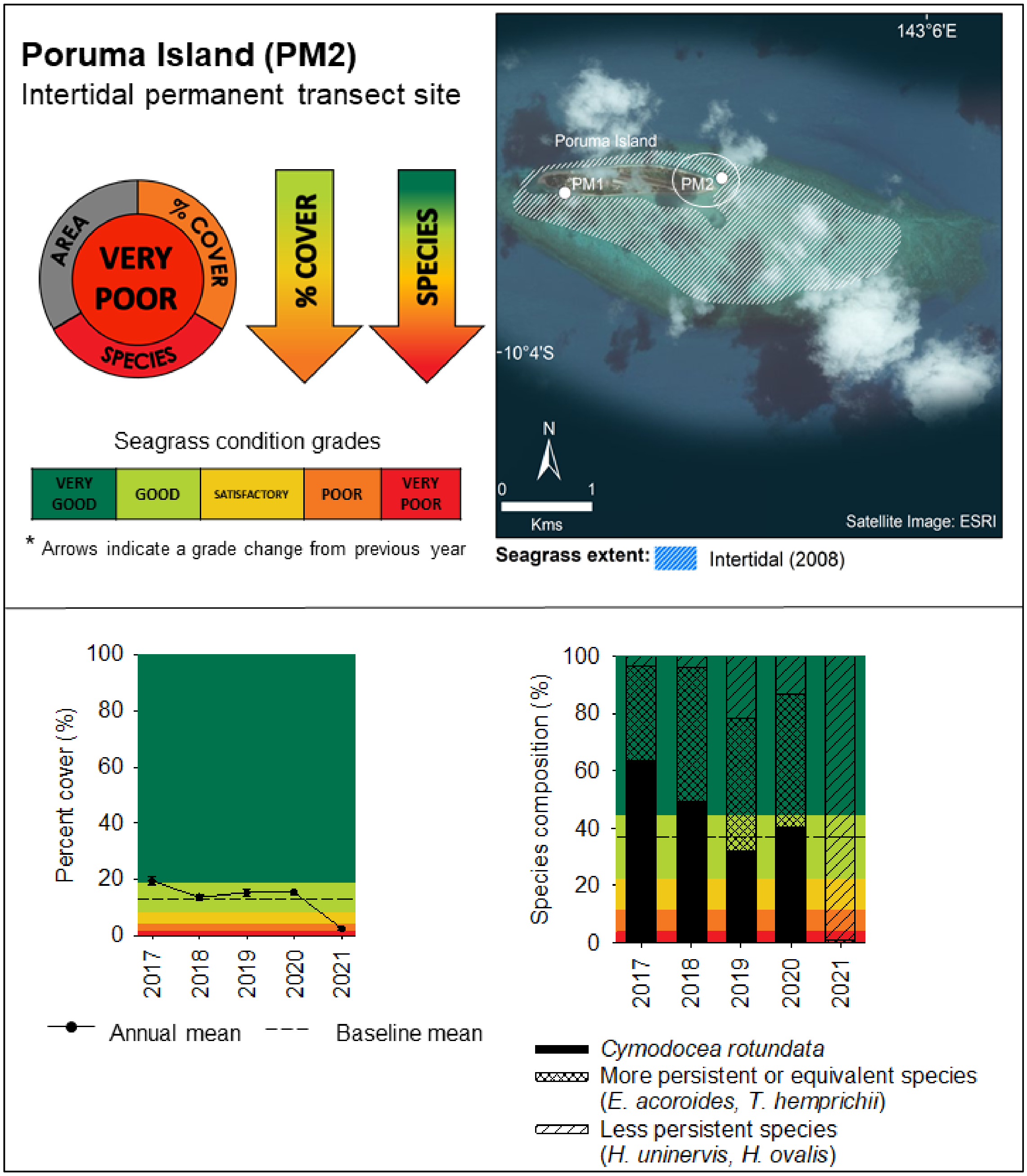

Figure 20. Seagrass mean percent cover and species composition at Poruma Island permanent transect site PM2, central Torres Strait, 2017 - 2021 (percent cover error bars = SE). Note: Baseline conditions based on 5 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Dungeness Reef Intertidal Meadow (DR6)

The Dungeness Reef meadow DR6 covers the majority of the reef-top intertidal area (Figure 21). Monitoring was established in late 2016 (2017 reporting year) because of the reef's value as a turtle foraging ground, and is conducted by TropWATER researchers. Preliminary assessments indicate the meadow has variable biomass, stable area and stable, mixed species. Overall meadow condition in 2021 was good, with area above the long-term average for the fourth year. Species composition also was very good. Five species are found in the meadow, but the dominant species *T. hemprichii* and the more stable and persistent species *E. acoroides* continued to contribute over 90% of meadow biomass (Figure 21). Biomass increased by 75% between 2020 and 2021 and was in very good condition; high biomass areas were mostly along the north-east edge of the reef and associated with the species *E. acoroides* and *T. ciliatum*.

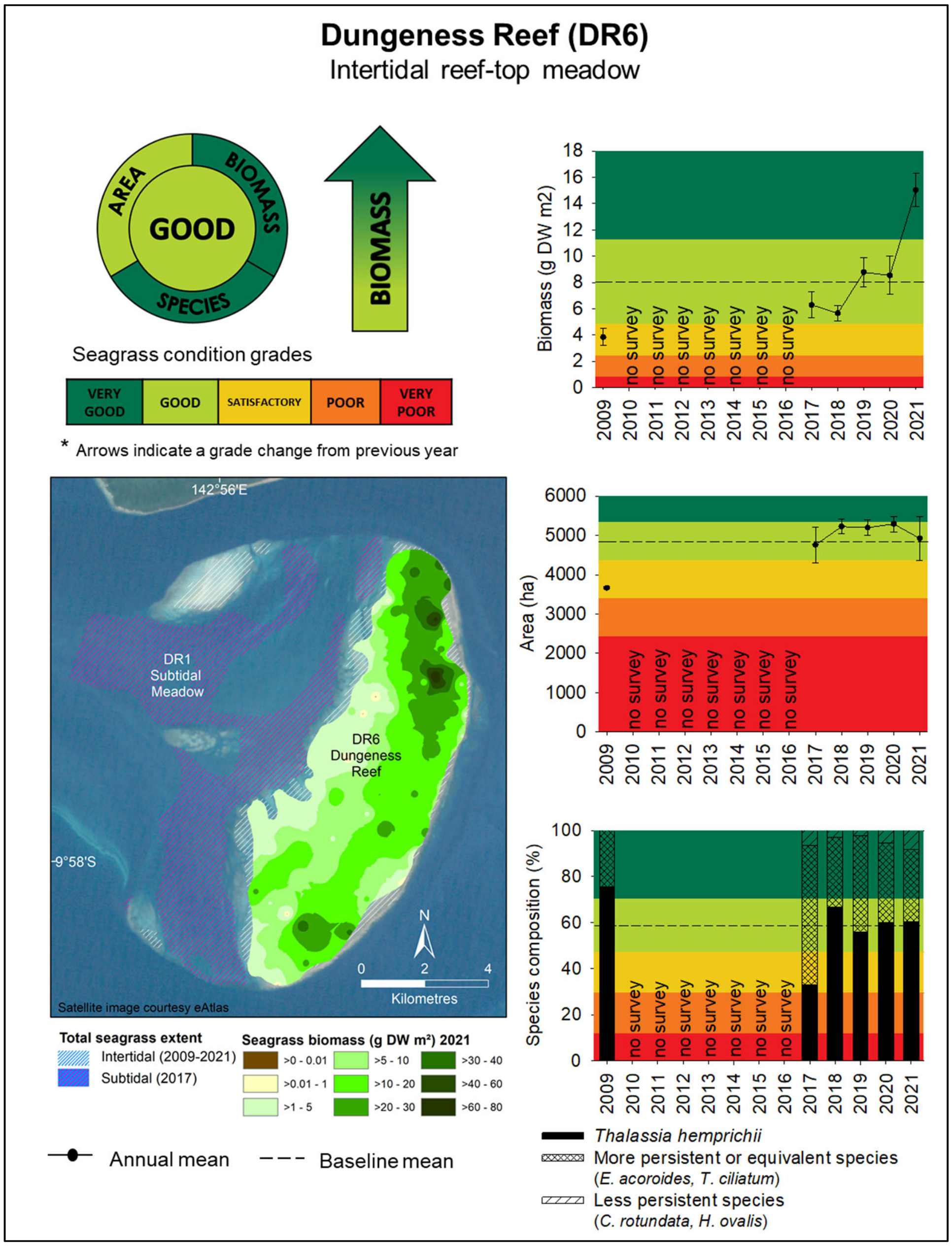

Figure 21. Seagrass mean biomass and species composition at Dungeness Reef intertidal meadow 6, central Torres Strait, 2009 - 2021 (biomass error bars = SE; area error bars = reliability estimate). Note: Baseline conditions based on 6 years of data; resulting grades should be interpreted with caution until the full 10-year baseline is available.

Dungeness Reef Subtidal Blocks (DR1)

An extensive subtidal seagrass meadow extends west of Dungeness Reef. Subtidal monitoring blocks within the meadow are collectively referred to as DR1 (Figure 22). These are monitored by Porumalgal, Iamalgal and Warraberalgal Rangers. No overall meadow score is provided for this meadow due to limited sampling events. As with other subtidal monitoring blocks at the Dugong Sanctuary and Orman Reefs, biomass in 2021 was very poor, declining from 12 g DW m^{-2} when the meadow was last monitored in 2018 (very good condition), to <0.2 g DW m^{-2} in 2021. Biomass declines were due to significant reductions in the dominant species *H. spinulosa* that is typical of subtidal communities, from 76% in 2020 to 18% in 2021. Species composition condition remained very good because remnants the more persistent species *C. serrulata* contributed more to species composition than in previous years (Figure 22).

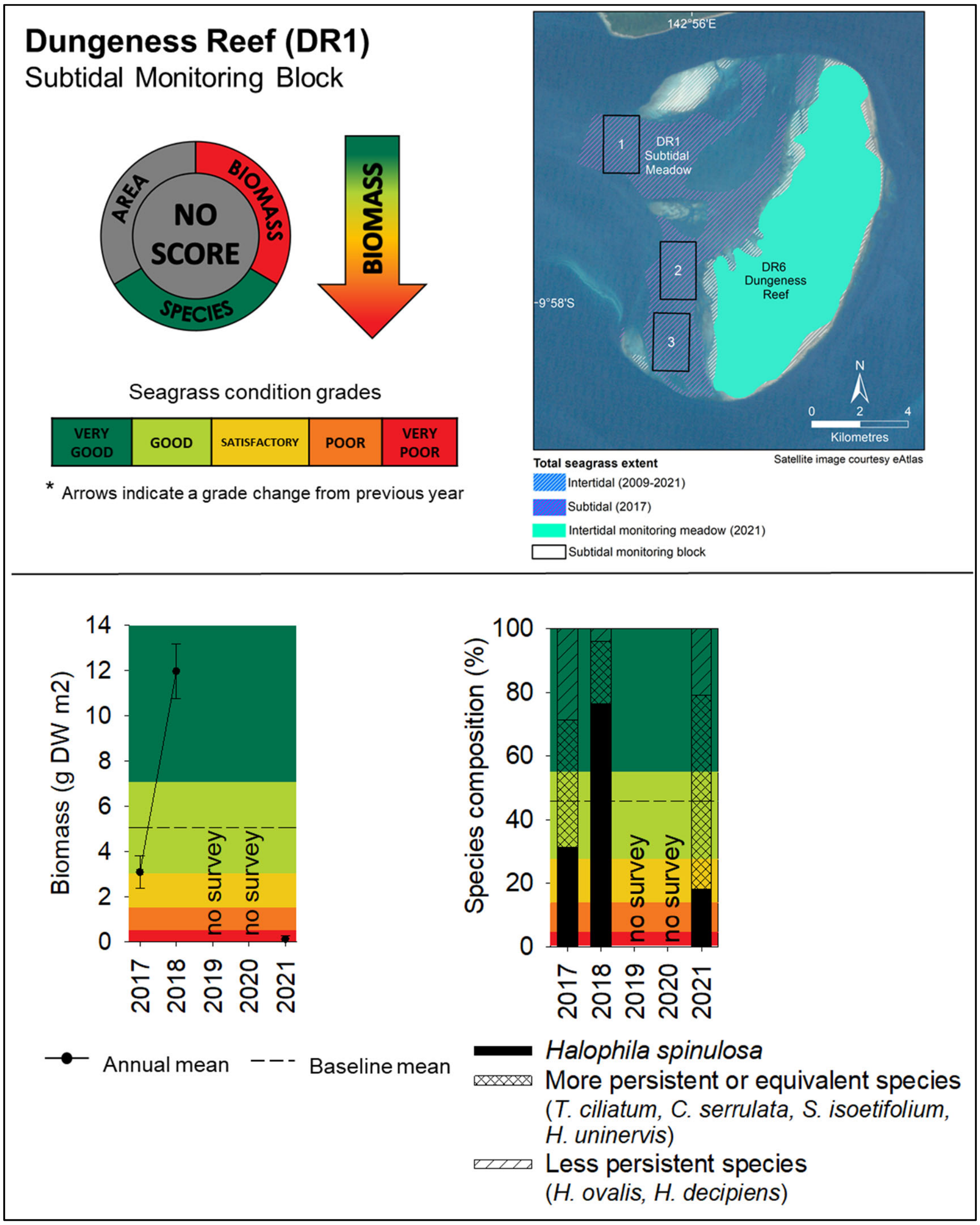

Figure 22. Seagrass mean biomass and species composition at Dungeness Reef subtidal monitoring blocks, central Torres Strait, 2017 - 2021 (biomass error bars = SE). Note: Baseline conditions based on 3 years of data; no overall grades or scores available until 5 years of data is available.

Masig Island Intertidal Meadow (MS1)

The extensive intertidal reef-top seagrass meadow that surrounds Masig Island was incorporated into the monitoring program and report card in 2021. Biomass, species composition and area were all in good condition in 2021. No overall meadow score is provided for Masig Island due to limited sampling events (Table 4). Preliminary assessments indicate a highly stable meadow area of ~790 ha and variable mean meadow biomass of ~7 g DW m^{-2}. Biomass is similar to Dungeness Reef's intertidal reef-top meadow (DR6). The mixed species community is dominated by *T. hemprichii*, which is typical of intertidal reef-top communities, including those at Dungeness Reef (DR6), Kai Reef (OR2) and Gariar Reef (OR5) (Figure 23).

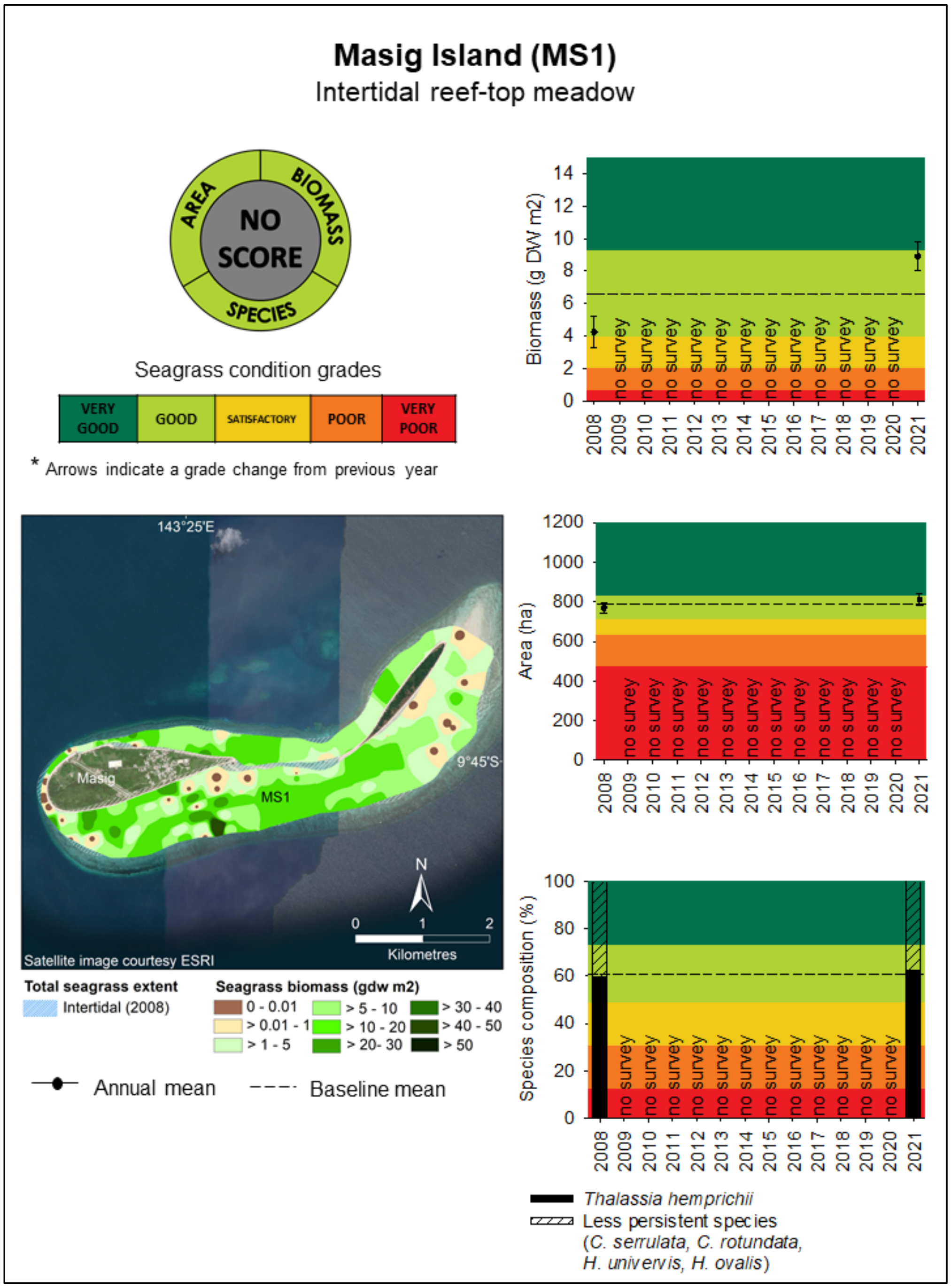

Figure 23. Seagrass mean biomass and species composition at Masig Island intertidal meadow, central Torres Strait, 2008 - 2021 (biomass error bars = SE). Note: Baseline conditions based on 2 years of data; no overall grades or scores available until 5 years of data is available.

3.2.3 Eastern Island Cluster

Seagrass condition in the Eastern Island Cluster is unknown in 2021 because monitoring did not occur at Mer Island's two intertidal transect sites (Figure 24). An extensive baseline survey was conducted in September 2020, which mapped intertidal seagrass meadows in the Eastern Cluster, including Mer Island for the first time (Carter et al. 2021d).

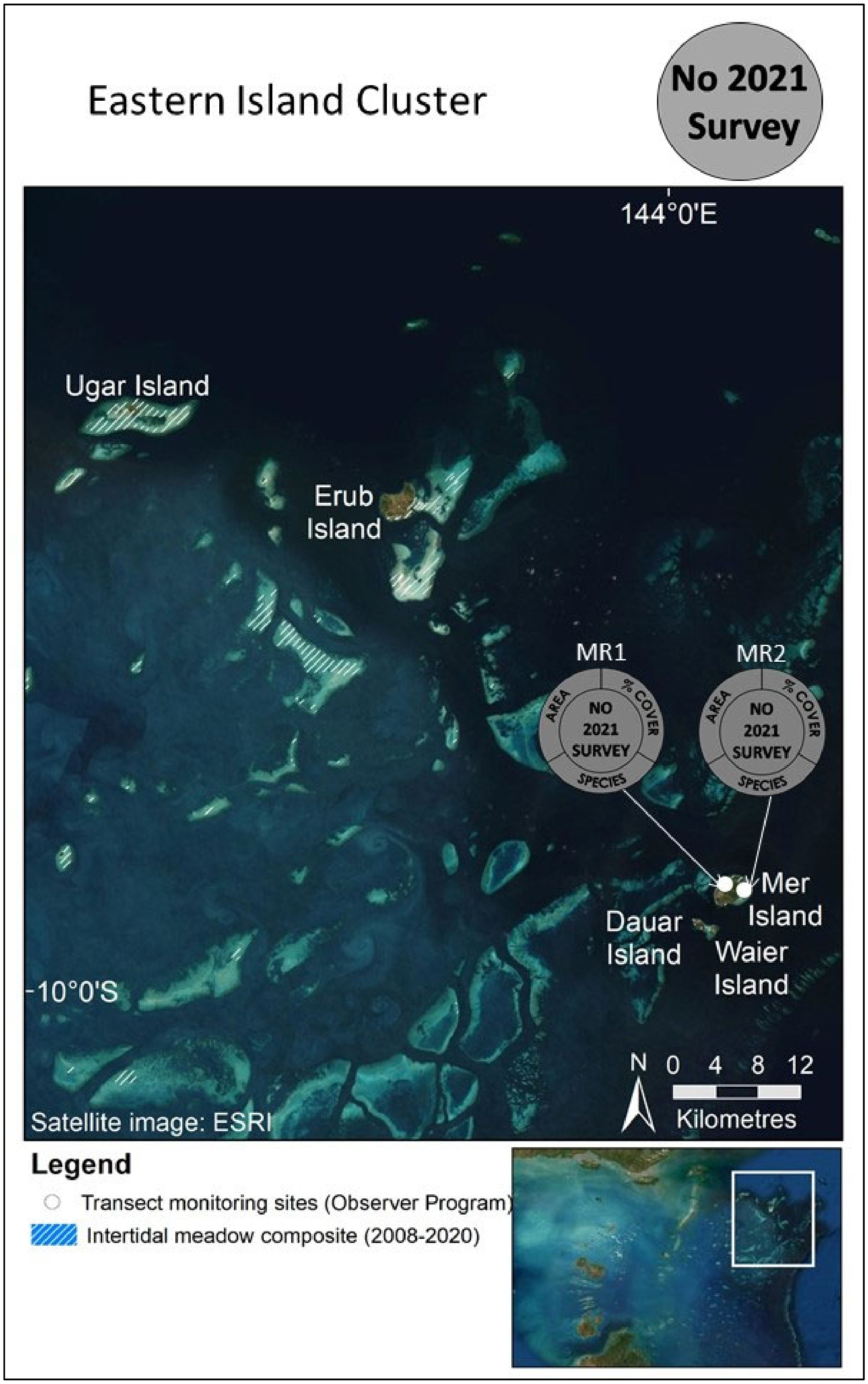

Figure 24. Seagrass condition across the Eastern Island Cluster of Torres Strait.

Mer Island Site (MR1)

The monitoring site MR1 (Maad) on the northern side of Mer Island is monitored by the Meriam Gesep A Gur Keparem Le Rangers (Figure 25). The site is characterised by stable percent cover and stable species composition dominated by a single species (> 80% *T. hemprichii*) which is unique to this program (Table 3). Seagrass condition at this site is unknown in 2021 because no monitoring occurred (Figure 25).

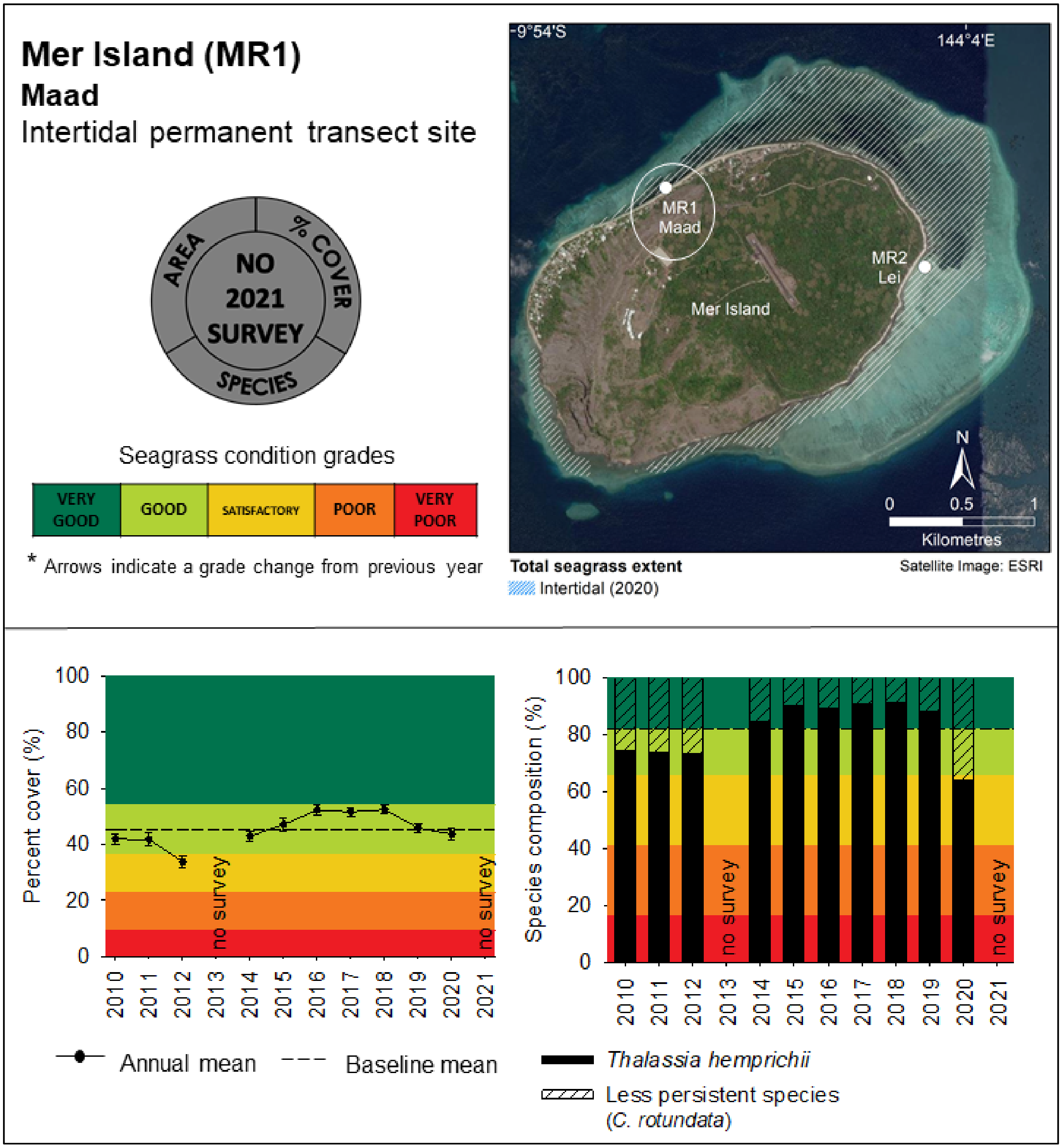

Figure 25. Seagrass mean percent cover and species composition at Mer Island permanent transect site MR1, eastern Torres Strait, 2010 - 2021 (percent cover error bars = SE).

Mer Island Site (MR2)

The monitoring site MR2 (Lei) on the eastern side of Mer Island has been monitored by the Meriam Gesep A Gur Keparem Le Rangers since 2010 (Figure 26). The site is characterised by variable percent cover and stable, mixed species composition (Table 3). This site is more diverse than MR1 with four species recorded. Seagrass condition at this site is unknown in 2021 because no monitoring occurred (Figure 26).

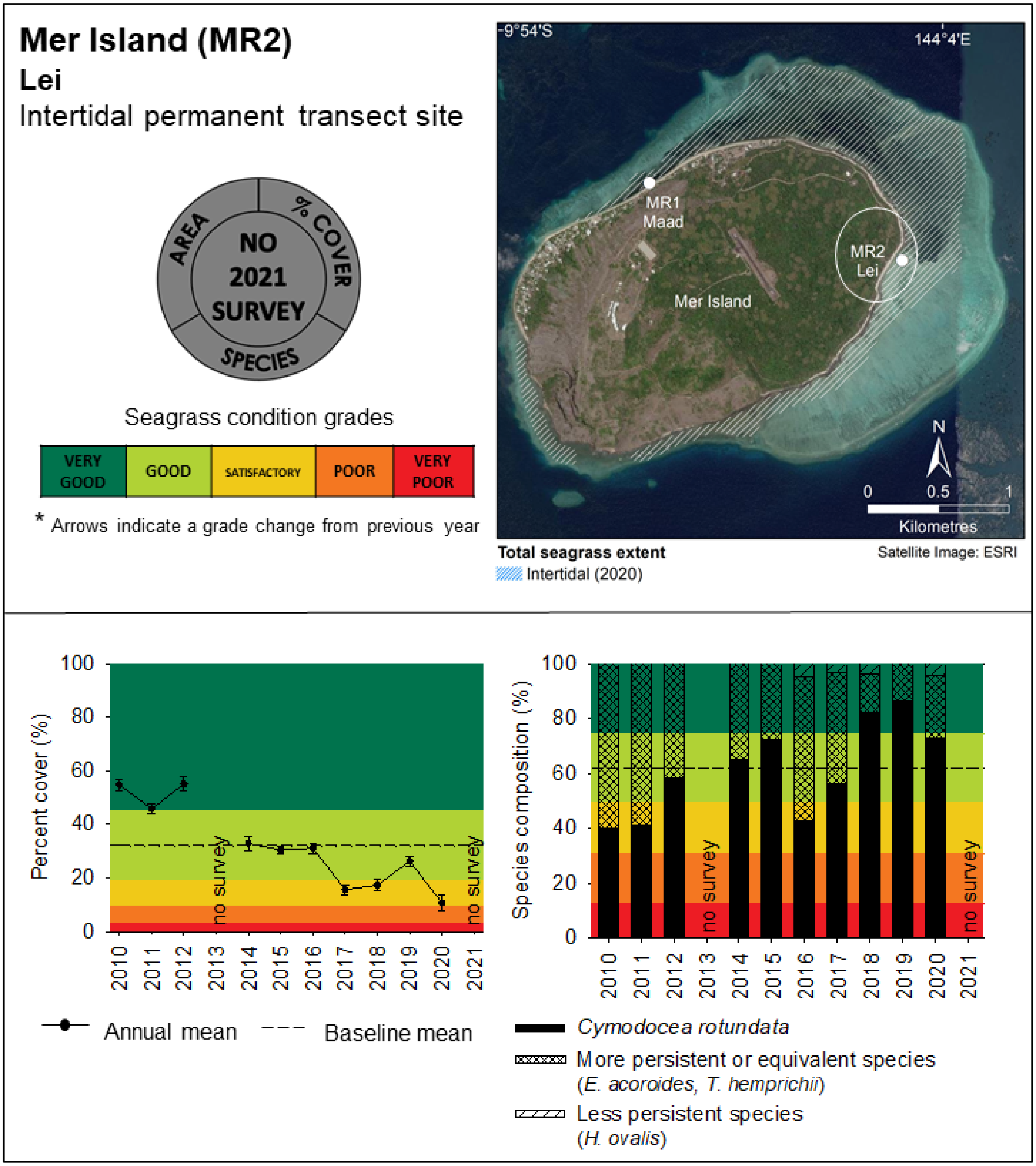

Figure 26. Seagrass mean percent cover and species composition at Mer Island permanent transect site IM2, eastern Torres Strait, 2010 - 2021 (percent cover error bars = SE).

3.2.4 Inner Island Cluster

Seagrass condition in the Inner Island Cluster was good in 2021 - an improvement from satisfactory condition in 2019 when scores were last calculated (Figure 27). The improved condition was due primarily to increased biomass, particularly of the species *E. acoroides*, in many of the meadows monitored. Seagrass in this cluster is monitored across six intertidal and three intertidal-subtidal meadows by TropWATER as part of the ports program (Figure 27). Results from an "out-of-season" survey in September 2020 (Inner Cluster annual surveys always occur in March-April) are presented on figures but are not included in score and grade calculations for this cluster.

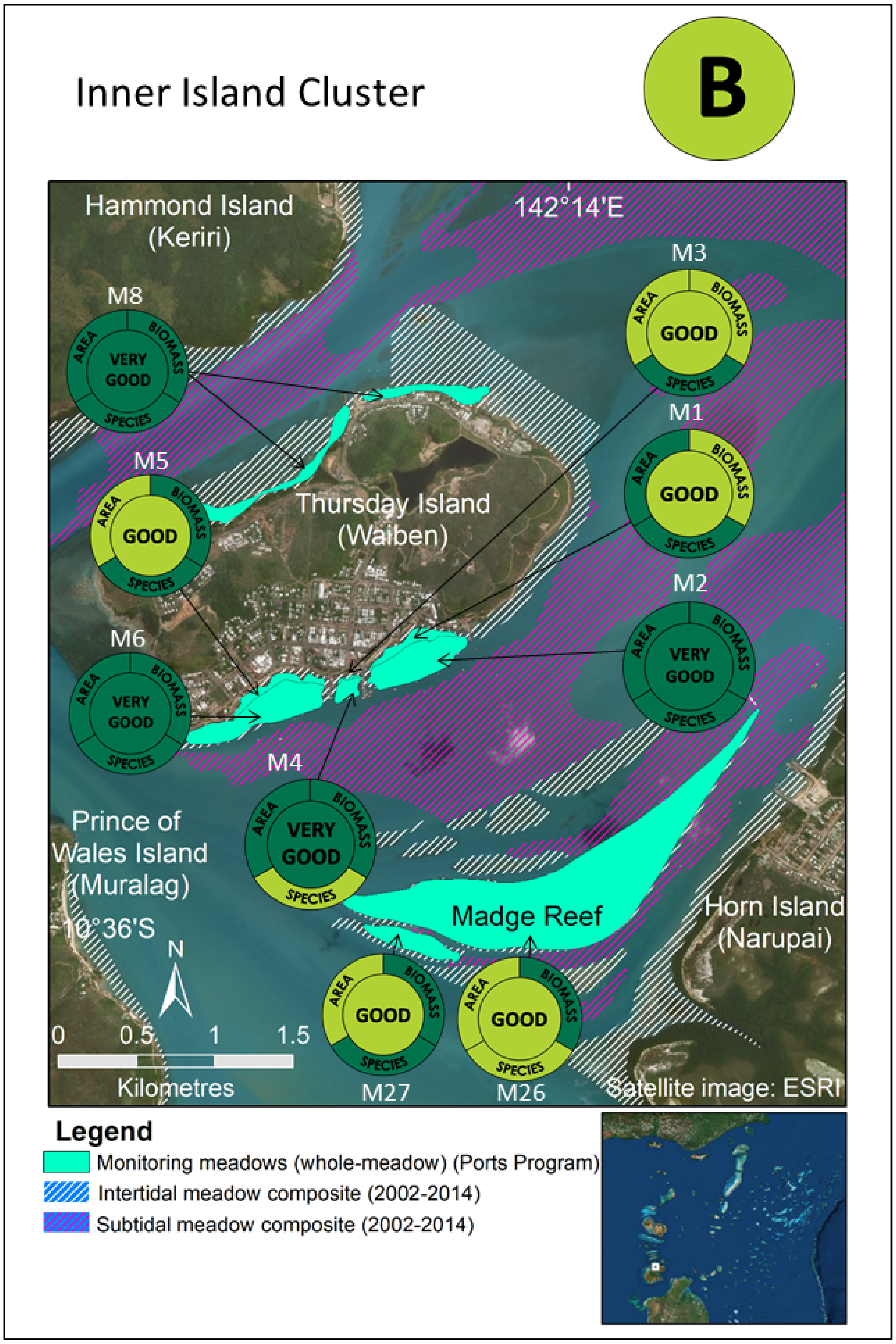

Figure 27. Seagrass condition across the Inner Island Cluster of Torres Strait.

Thursday Island (Waiben) Intertidal Meadow (M1)

The Thursday Island meadow M1 is a small intertidal meadow characterised by stable area and species composition, but variable biomass (Table 3). The overall meadow condition was good in 2021, with very little change in biomass, area or species composition since 2019 (Figure 28). Meadow area and species composition condition remained very good. Over 90% of meadow biomass came from the dominant species *H. uninervis* and the more stable and persistent species *T. hemprichii* (Figure 28). Baseline meadow biomass of ~6 g DW m^{-2} is typical of other *H. uninervis* dominated meadows at Thursday Island.

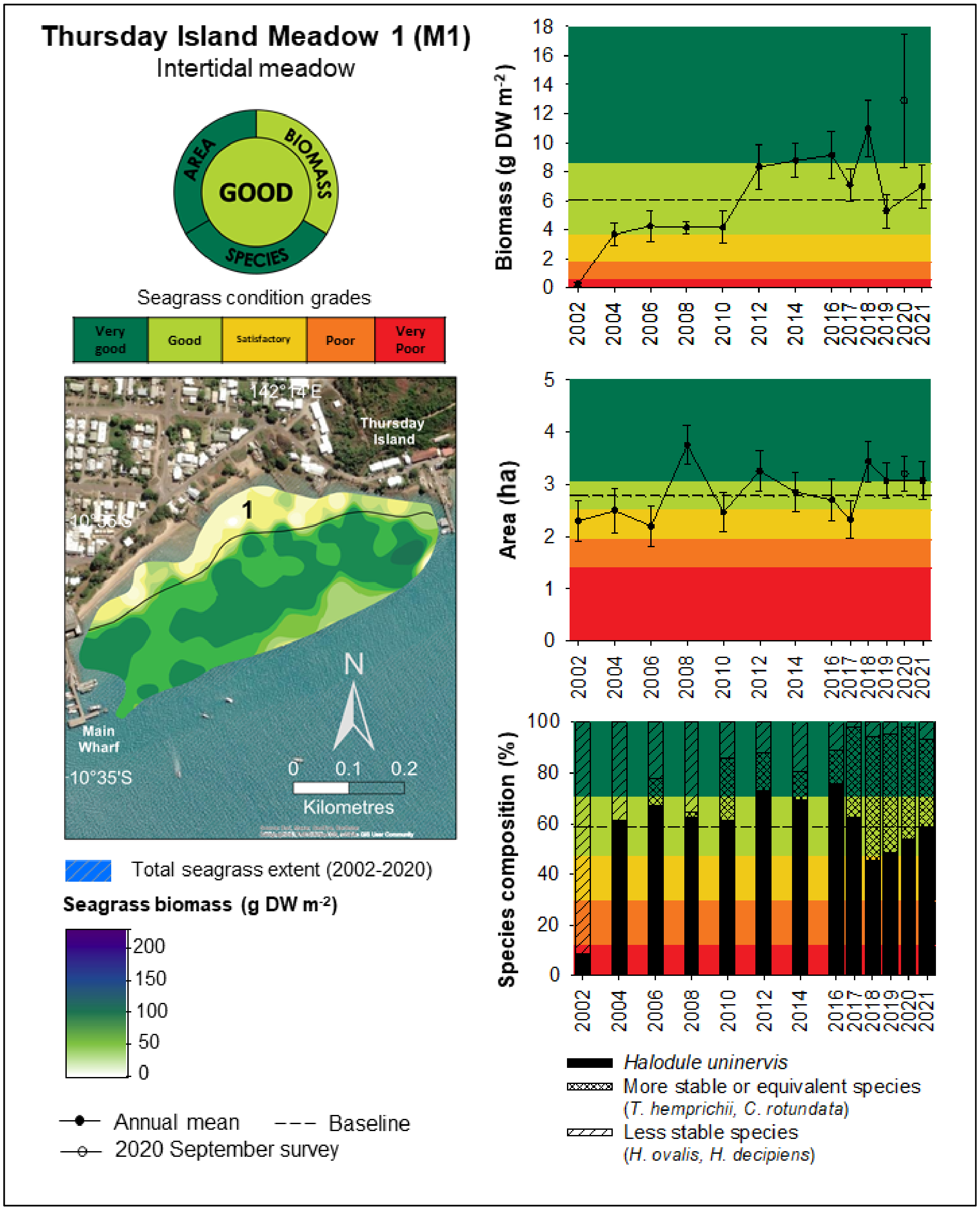

Figure 28. Seagrass mean biomass, area and species composition at Thursday Island intertidal meadow 1, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal-Subtidal Meadow (M2)

The Thursday Island meadow M2 is adjacent to M1, with the boundary between meadows defined by the transition from a *H. uninervis* dominated to *E. acoroides* dominated meadow (Figure 29). Meadow M2 is characterised by stable area, biomass and species composition (Table 3). The meadow extends from the intertidal zone into shallow subtidal waters. Overall meadow condition increased from satisfactory in 2019 to very good in 2021 due to a large mean biomass increase from 28 g DW m^{-2} to 80 g DW m^{-2}. Area condition remained very good for the fifth consecutive year. Species composition also remained very good due to the dominance of *E. acoroides* relative to less persistent species, particularly *T. hemprichii* and *H. uninervis* (Figure 29).

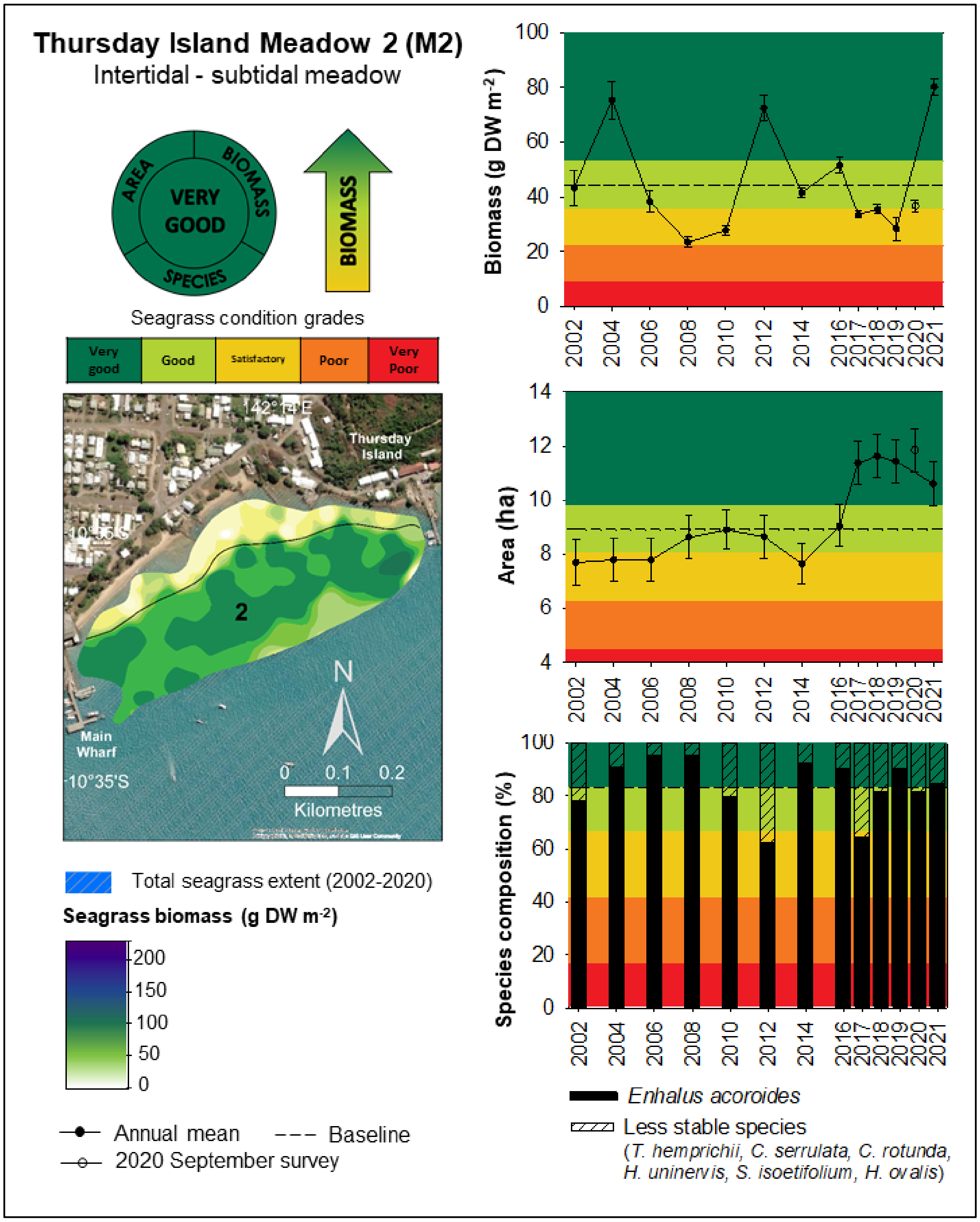

Figure 29. Seagrass mean biomass, area and species composition at Thursday Island intertidal-subtidal meadow 2, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal Meadow (M3)

The Thursday Island meadow M3 is a small intertidal meadow between the Engineer's Wharf and Main Wharf (Figure 30). The meadow is characterised by stable species composition, but variable biomass and area (Table 3). Overall meadow condition improved from satisfactory in 2019 to good in 2021 due to increases in meadow area and biomass. Species composition condition remained very good due to the dominant species *H. uninervis* comprising 85% of seagrass biomass relative to less stable species (Figure 30).

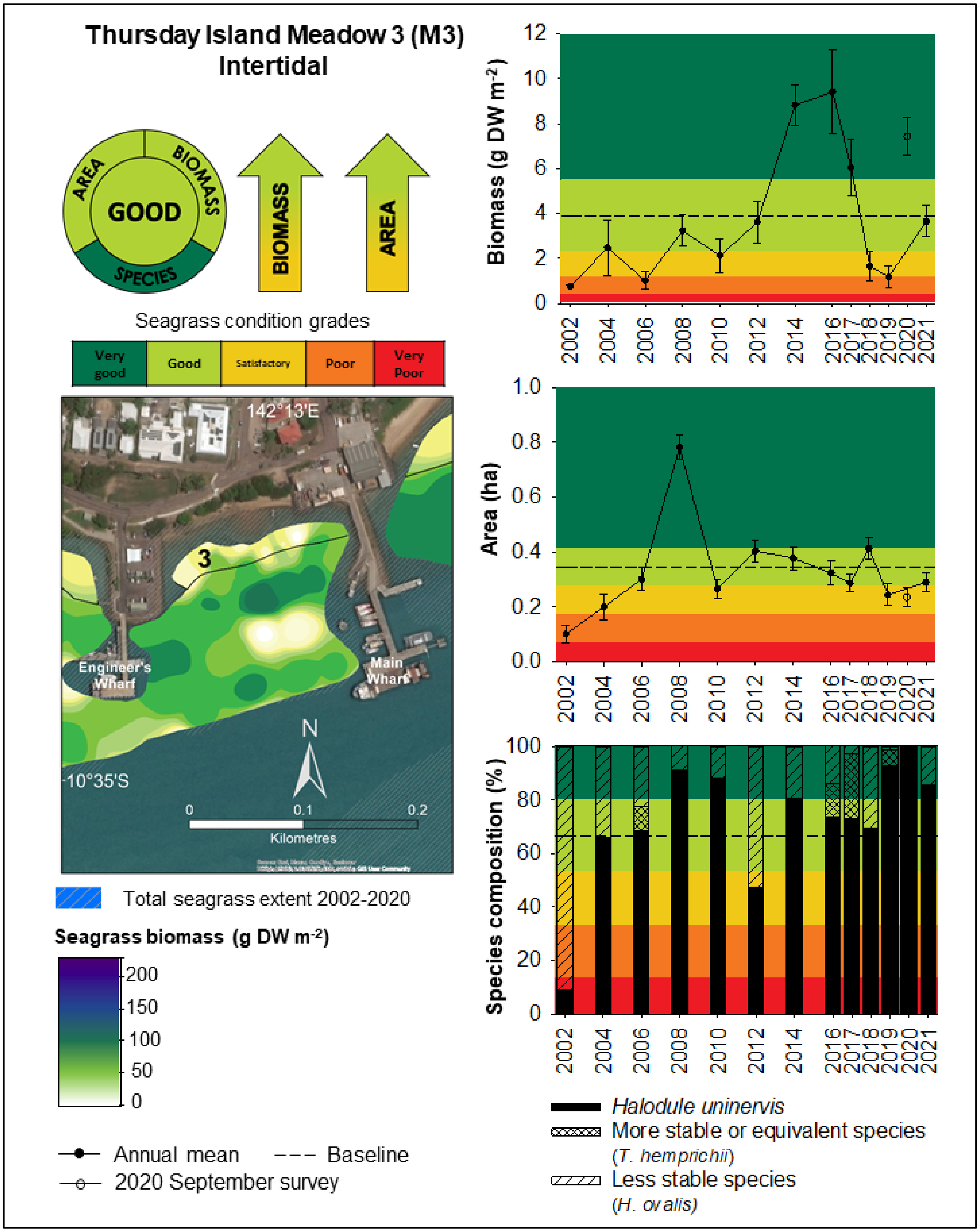

Figure 30. Seagrass mean biomass, area and species composition at Thursday Island intertidal meadow 3, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal/Subtidal Meadow (M4)

The Thursday Island meadow M4 is adjacent to M3, with the meadow boundary defined by the transition from a *H. uninervis* dominated to *E. acoroides* dominated meadow (Figure 31). Meadow M4 extends from the intertidal zone into shallow subtidal waters and is characterised by stable biomass and species composition, and variable area (Table 3). Meadow condition improved from poor in 2019 to very good in 2021. Biomass increased dramatically from 11 g DW m^{-2} in 2019 to 65 g DW m^{-2} in 2021 (very good condition). Species composition condition improved from satisfactory to good condition due to a larger contribution of the dominant species *E. acoroides* in 2021. Area was in very good condition and remains largely unchanged since 2017 (Figure 31).

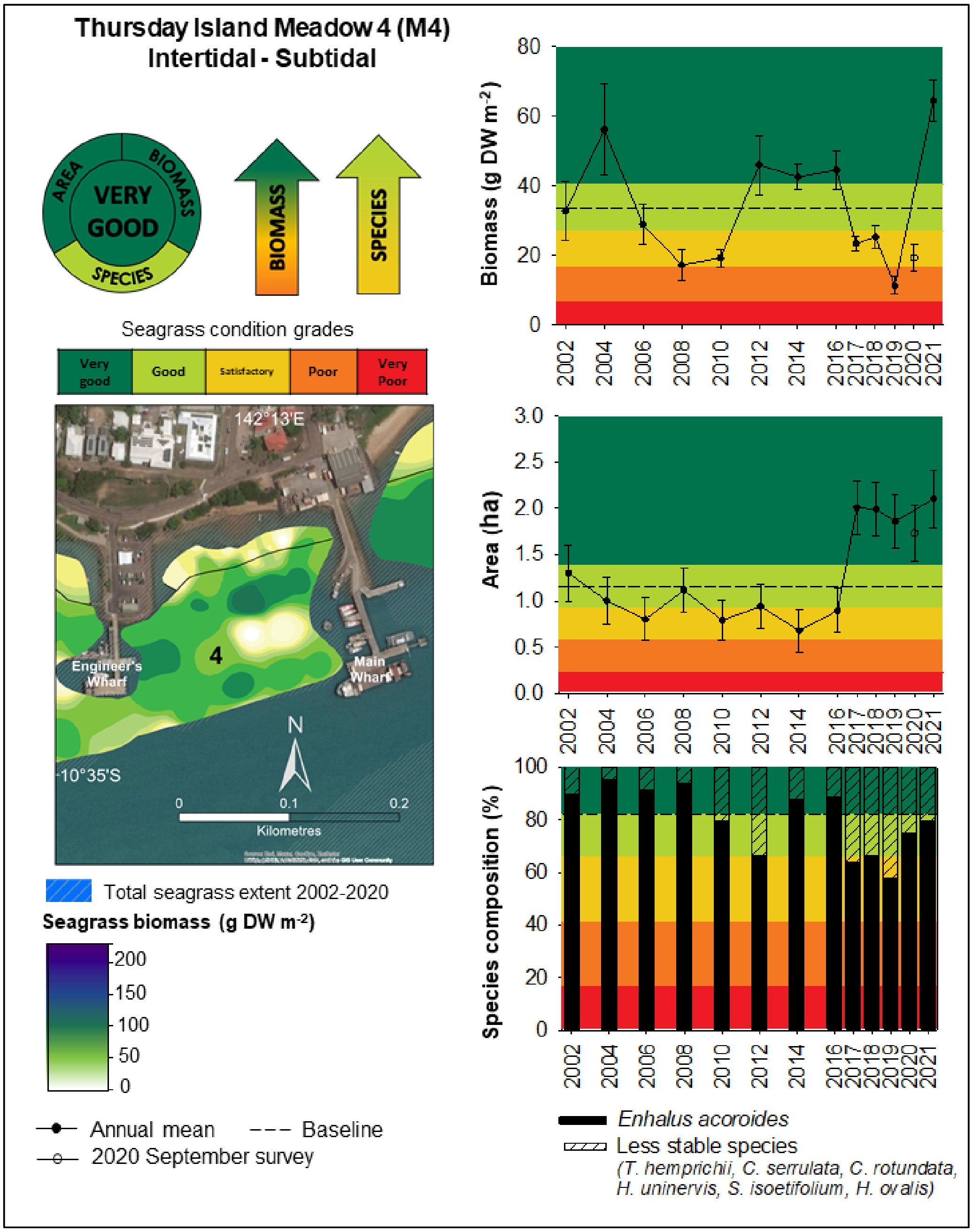

Figure 31. Seagrass mean biomass, area and species composition at Thursday Island intertidal-subtidal meadow 4, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal Meadow (M5)

The Thursday Island meadow M5 is a small intertidal meadow characterised by stable biomass, area and species composition (Table 3). In 2021, overall meadow condition was good (Figure 32). Meadow biomass and area both increased above baseline values of 3.3 ha and 8 g DW m^{-2} since 2019, with biomass now in very good condition and area in good condition. The meadow was comprised almost entirely of the dominant species *H. uninervis* and more stable and persistent species (Figure 32).

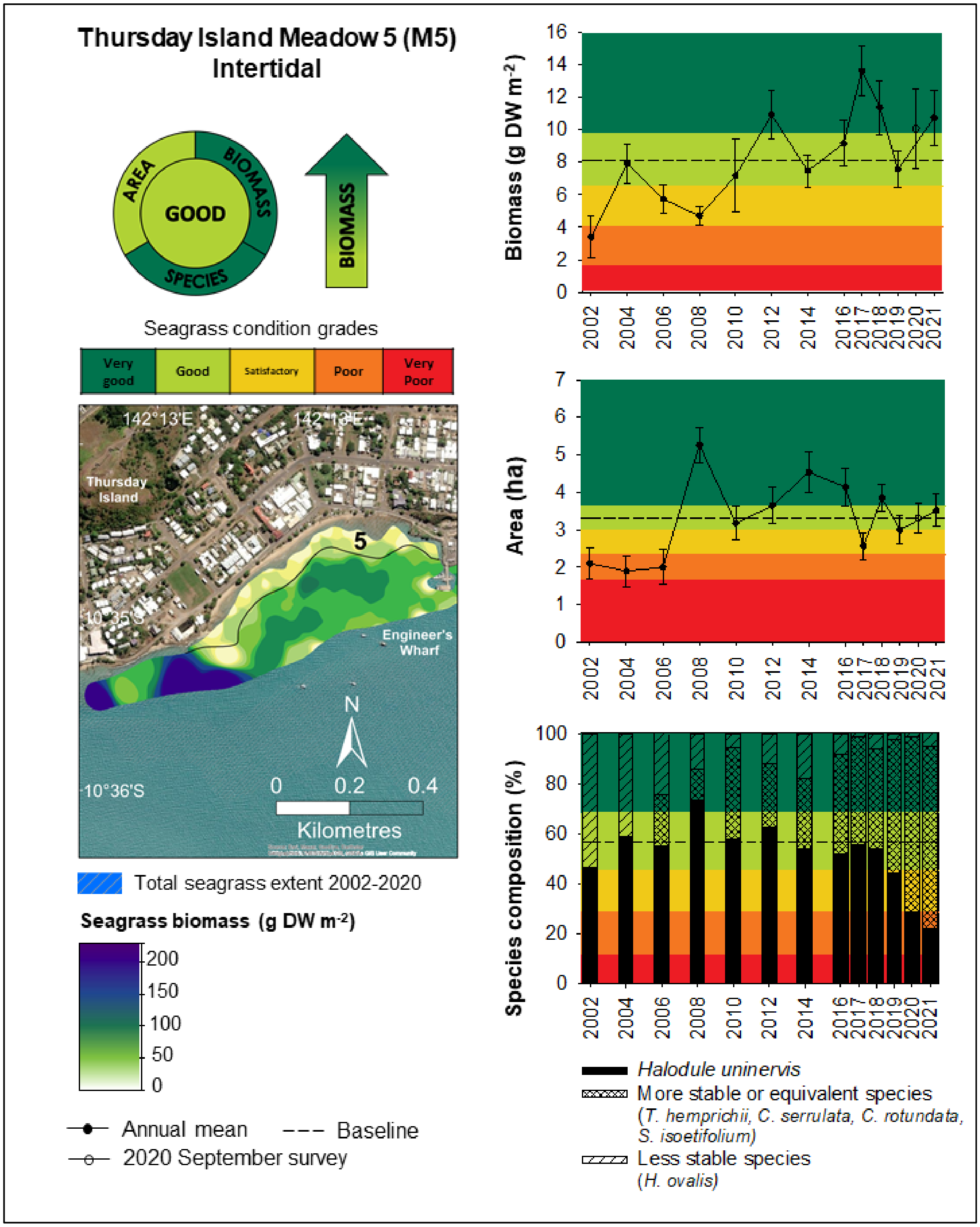

Figure 32. Seagrass mean biomass, area and species composition at Thursday Island intertidal meadow 5, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal/Subtidal Meadow (M6)

The Thursday Island meadow M6 is adjacent to M5, with the meadow boundary defined by the transition from a *H. uninervis* dominated to *E. acoroides* dominated meadow (Figure 33). The meadow extends from the intertidal zone into shallow subtidal waters. Meadow M6 is characterised by stable area, biomass, and species composition (Table 3). Biomass increased from 19 g DW m^{-2} in 2019 (poor condition) to 80 g DW m^{-2} in 2021 (very good condition). This improvement followed successive biomass declines between 2016 and 2019. Area condition also improved from good in 2019 to very good in 2021, due to a slight increase above the "good grade" threshold. Species composition condition remained very good due to the ongoing dominance of *E. acoroides* relative to less persistent species (Figure 33).

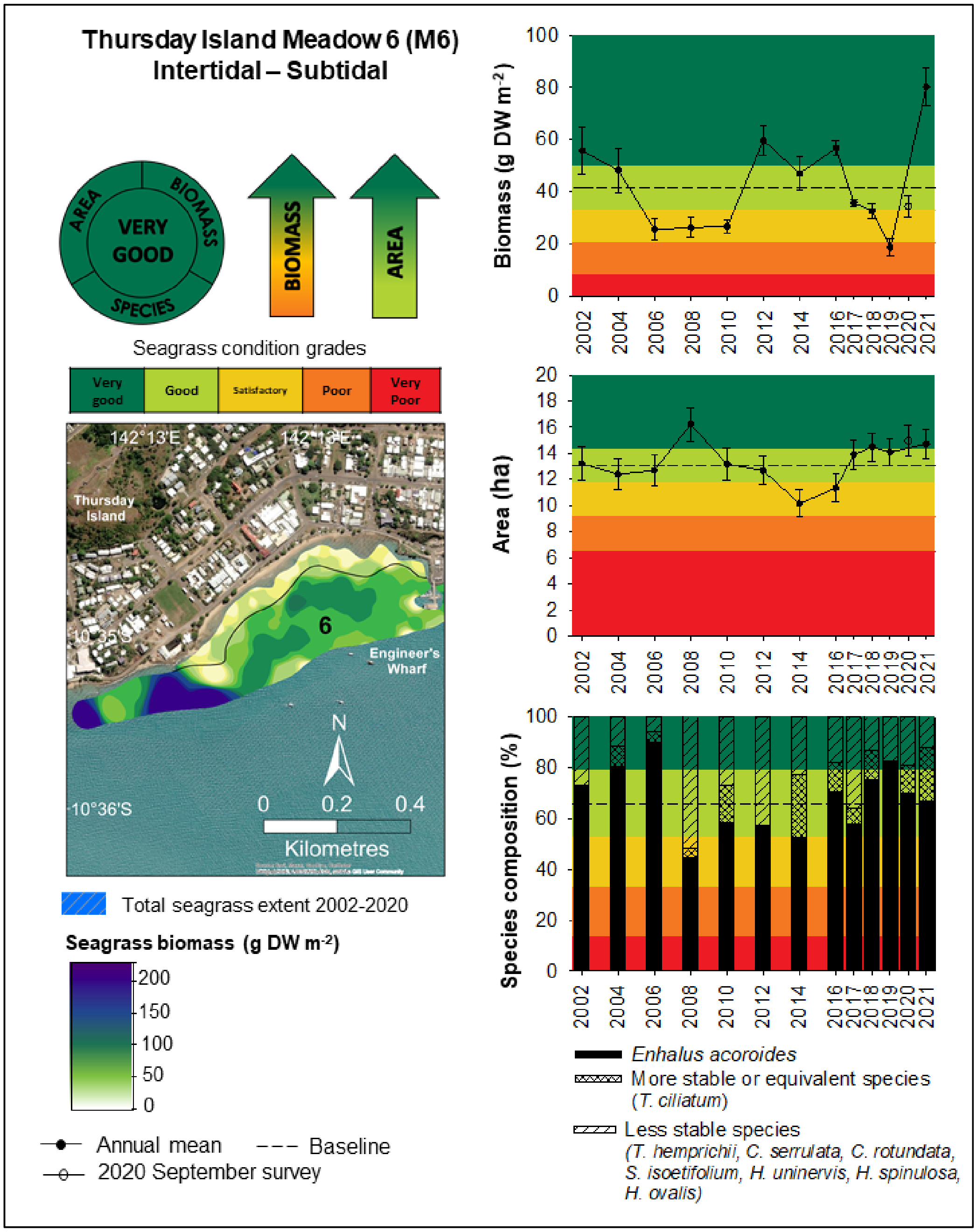

Figure 33. Seagrass mean biomass, area and species composition at Thursday Island intertidal-subtidal meadow 6, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Thursday Island (Waiben) Intertidal Meadow (M8)

Meadow 8 is a long thin intertidal meadow that extends along the northern shore of Thursday Island (Figure 34). It is characterised by stable area and species composition, but variable biomass (Table 3). Meadow condition in 2021 is very good, driven by an increase in meadow biomass since 2019. Area continued to increase following a decline in 2018. Species composition condition remained very good due to the presence of the dominant species *H. uninervis* and increased contribution of more stable and persistent species *T. hemprichii* and *C. rotundata* to meadow biomass (Figure 34).

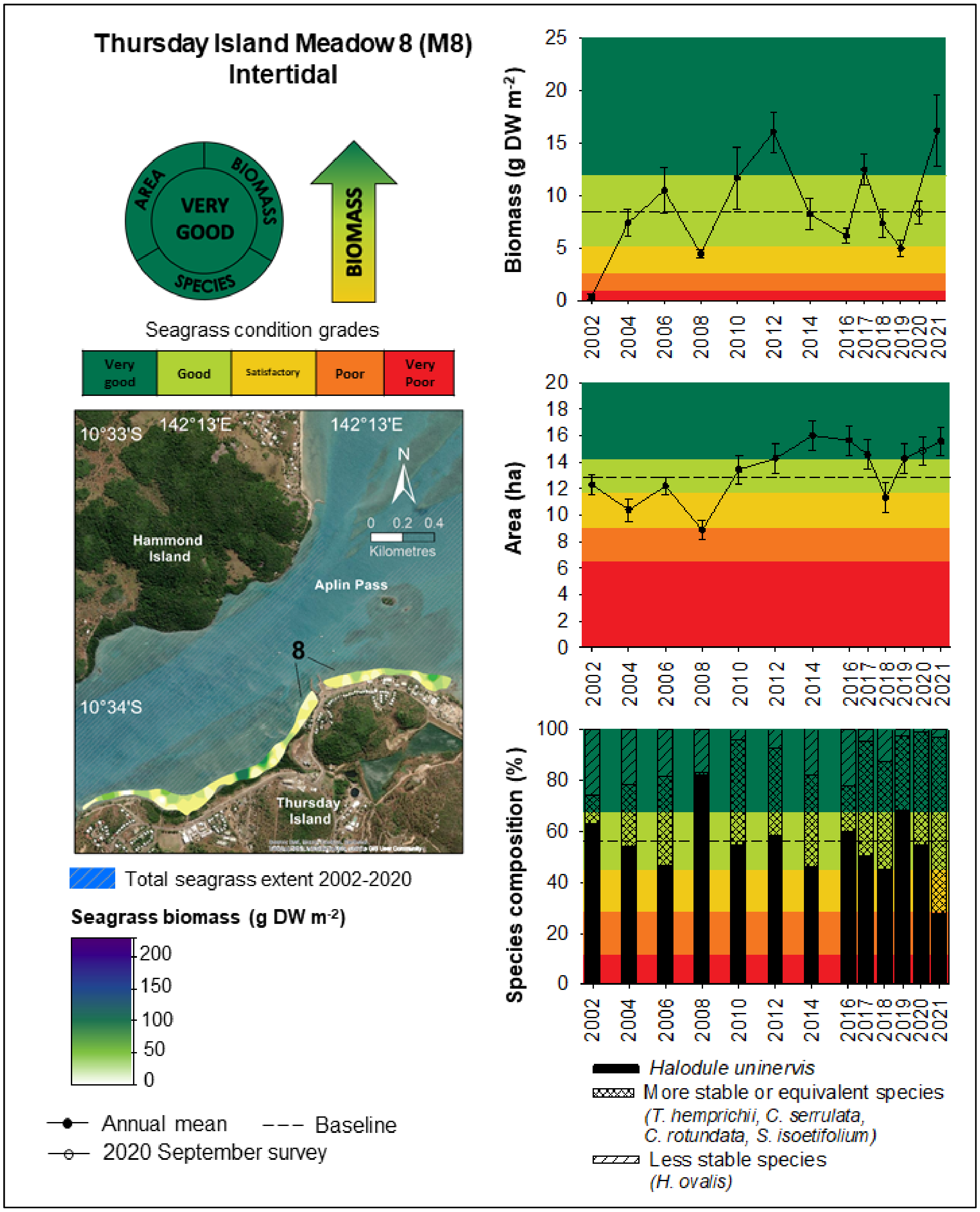

Figure 34. Seagrass mean biomass, area and species composition at Thursday Island intertidal meadow 8, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Madge Reef Intertidal Meadow (M26)

Meadow M26 at Madge Reefs covers the majority of the intertidal reef-top (Figure 35). Meadow area is highly stable, species composition is stable, and biomass is variable (Table 3). The meadow remained in good condition in 2021, with no grade changes in species composition or area. Biomass condition increased from good in 2019 (40 g DW m^{-2}) to very good in 2021 (73 g DW m^{-2}) (Figure 35).

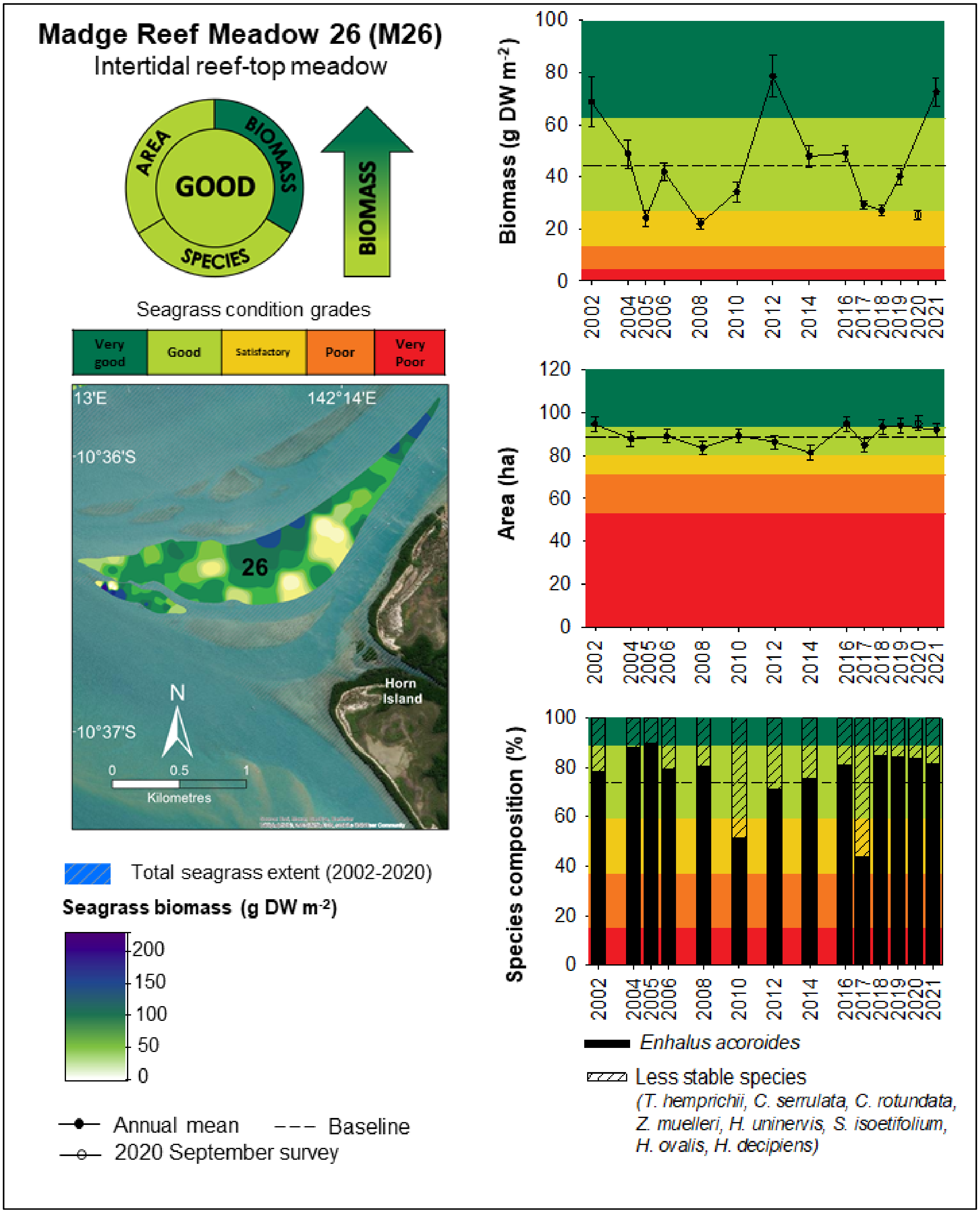

Figure 35. Seagrass mean biomass, area and species composition at Madge Reefs intertidal meadow 26, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

Madge Reef Intertidal Meadow (M27)

Meadow M27 is a small intertidal reef-top meadow that forms part of Madge Reefs (Figure 36). Meadow area and species composition are stable, while biomass is variable (Table 3). Meadow area has been relatively unchanged since 2017 and was in good condition in 2021. Species composition remains very good, with the dominant species *E. acoroides* and equivalent species *T. ciliatum* accounting for almost all of the meadow's biomass. Biomass condition increased and remained in very good condition (Figure 36).

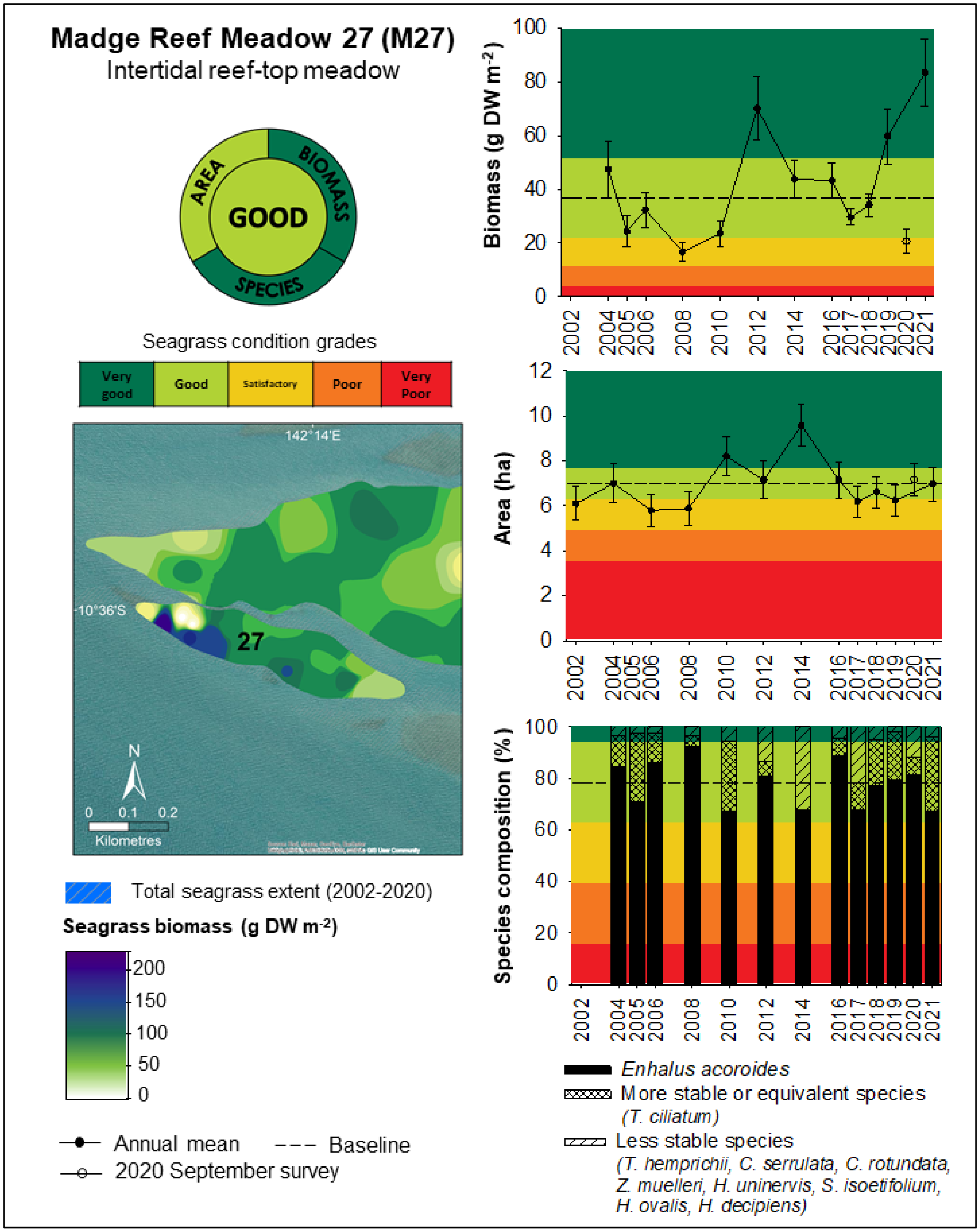

Figure 36. Seagrass mean biomass, area and species composition at Madge Reefs intertidal meadow 27, Torres Strait Inner Island Cluster, 2002 - 2021 (biomass error bars = SE; area error bars = reliability estimate).

4 DISCUSSION

4.1 Seagrass Condition in Torres Strait

The Torres Strait seagrass annual report card enables comparisons of seagrass habitat among sites, meadows, and island clusters by incorporating the most recent data on key characteristics of seagrass health - abundance (biomass/percent cover), area, and species composition - into a series of grades and scores. In 2021, the strength of this integrated approach is again clear. Areas of concerning seagrass decline were identified across three monitoring programs – the Ranger-led Torres Strait Seagrass Observers Program, Ranger-led Subtidal Monitoring Program, and the meadow-scale intertidal Reef-top Monitoring Program (Figure 37).

The decline of seagrass in the Western Cluster first reported in 2020, and the emergence of localised declines in the Central Cluster in 2021, is concerning. Large-scale biomass declines and near-complete loss of the dominant subtidal species, *H. spinulosa*, have occurred at all subtidal monitoring locations in the Western Cluster (Orman Reefs, Dugong Sanctuary) and Central Cluster (Dungeness Reef) (Figure 37b). An extensive subtidal seagrass survey conducted in December 2020, triggered by concerns raised in the 2020 seagrass report card, found these declines occurred throughout subtidal waters in the Western Cluster and were not limited to long-term monitoring blocks (Carter et al. 2021c).

The loss of high diversity, high biomass subtidal seagrass habitat in the Western and Central Clusters is alarming because this region is where Torres Strait's most extensive subtidal seagrass habitat occurs. Seagrass species are mostly found in shallow waters due to high light requirements of most species (Carter et al. 2021b), and light availability is an important positive driver of seagrass growth and distribution in Torres Strait (Carter et al. 2014a; Taylor et al. 2013). Seagrass growing conditions in the Western and Central Clusters are generally ideal, with subtidal meadows extending throughout shallow waters (<20 m) west of the Warrior Reefs and into the Dugong Sanctuary (Carter et al. 2021c; Carter et al. 2014b). Beyond this, suitable growing conditions diminish. Subtidal seagrass does not grow beyond the western edge of the Dugong Sanctuary where waters are deeper than 30 m (Carter et al. 2014b). Subtidal seagrass also is sparse in the Top-Western Cluster where low light conditions from turbid water along the Papua New Guinea coastline limit the light available for seagrass growth even in very shallow water (Figure 31; Carter and Rasheed 2016). In the Eastern Cluster, no subtidal seagrass has been reported in the inter-reef waters (Haywood et al. 2008), where depths often exceed 40 m.

The condition of intertidal seagrass in 2021 in the Western and Central Clusters was generally much better than subtidal seagrasses although some sites remained well below average and results were mixed. Reef-top seagrass biomass remained well below-average at Kai and Gariar Reefs (Orman Reefs) in the Western Cluster for the second consecutive year (Figures 12, 13, 38), but was at a record high on Dungeness Reef in the Central Cluster (Figure 21). At intertidal island sites, seagrass percent cover remained diminished at both Mabuyag Island monitoring sites for the second year (Figures 6 and 7), and for the first time at Poruma Island's north-east site (Figure 20). However, seagrass condition at many island sites remains good or very good, including at Iama Island and Poruma Island's south-west site in the Central Cluster, and at Badu and Mua Islands in the Western Cluster.

It is unfortunate that no monitoring occurred at Mer Island's transect sites this year to allow a comparison of seagrass condition over time for the Eastern Cluster. However, Mer Island was surveyed in September 2020 as part of a baseline intertidal survey of entire meadows in the Eastern Cluster (Carter et al. 2021d). An extensive, high biomass meadow was mapped that covered the majority of the intertidal reef-top that fringes Mer Island, indicating a large and healthy meadow remained at this location. Large and diverse seagrass meadows also were mapped around the continental islands of Erub, Dauar and Waier Islands. The absence of subtidal seagrass in the Eastern Cluster (Haywood et al. 2008) means these intertidal seagrass meadows have high ecological importance because they account for the majority of seagrass habitat in this region

(Carter et al. 2021d). The expansion of intertidal annual monitoring to a network of locations in the Eastern Cluster would ensure a more comprehensive assessment of seagrass condition and reduce the likelihood of Cluster-scale knowledge gaps in annual reporting.

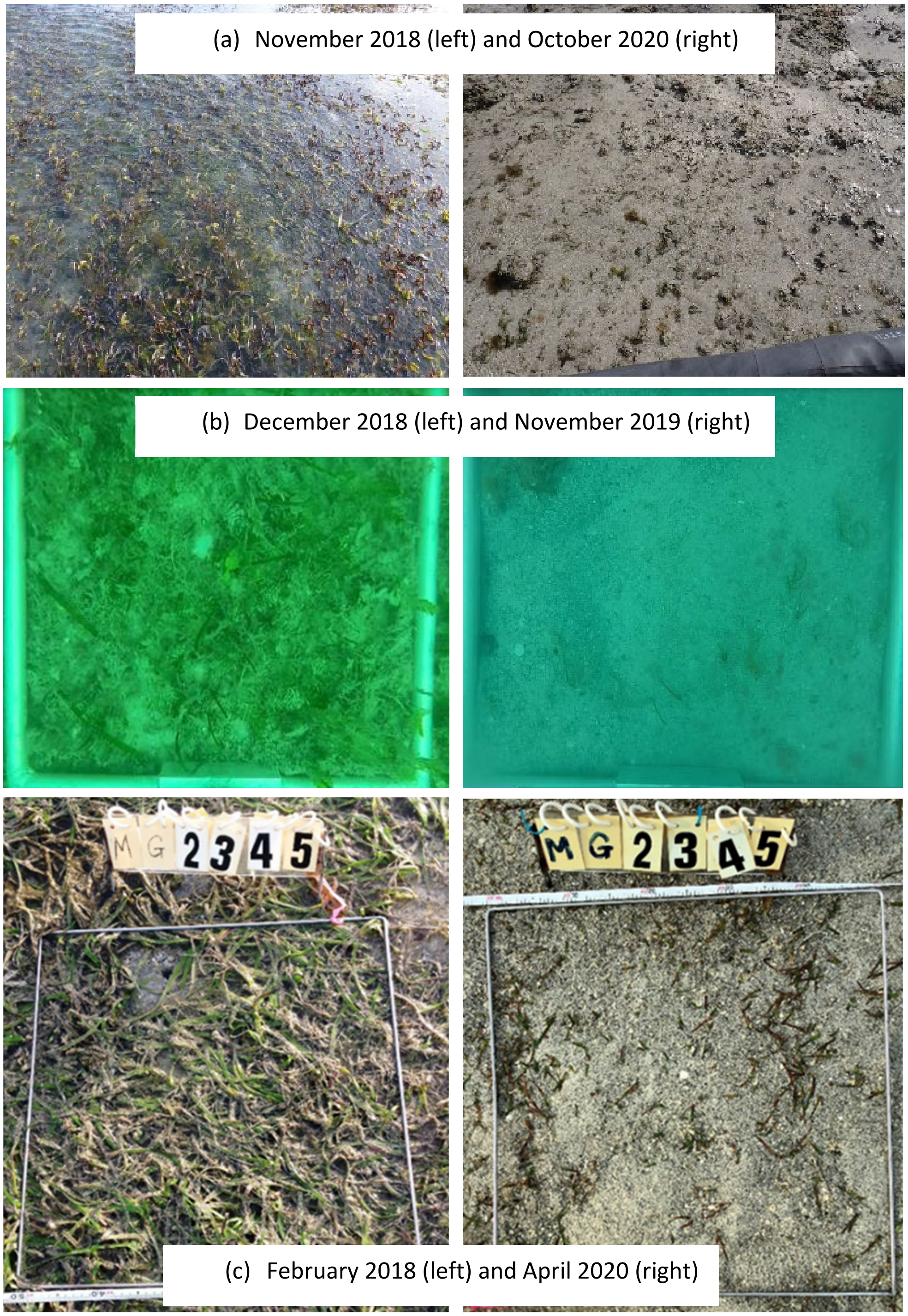

Figure 37. Seagrass abundance (biomass/ percent cover) declines were detected by all the three monitoring programs in the Western and Central Clusters: (a) meadow-scale intertidal Reef-top Monitoring Program at Gariar Reef, (b) Ranger-led Subtidal Monitoring Program at Orman Reefs, and (c) Ranger-led Torres Strait Seagrass Observers Program at Mabuyag Island.

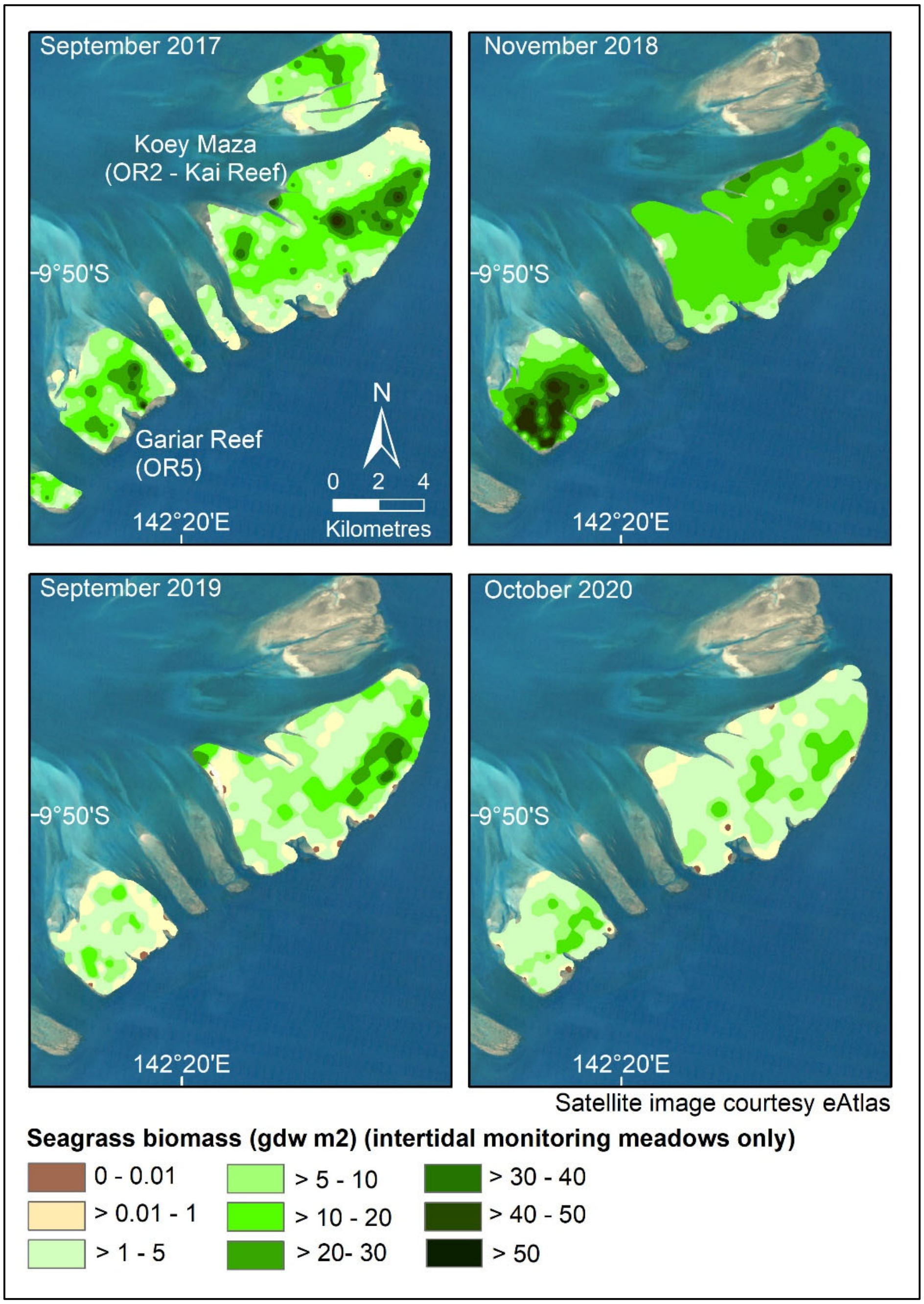

Figure 38. Change in seagrass biomass across intertidal reef-top meadows at Kai and Gariar Reefs (Orman Reefs), 2017-2020 (2018-2021 reporting years).

Seagrass condition in the Inner Cluster was not included in the 2020 report card because the March 2020 field trip was postponed due to COVID-19. Inner Cluster seagrass in 2021 has recovered from the condition declines that occurred between 2018 (good condition) and 2019 (satisfactory condition). This decline was largely due to biomass reductions, particularly in the meadows closest to Thursday Island where human impact is greatest. The reason for the biomass declines were unclear, but the largest losses occurred at the deeper subtidal margins of the *E. acoroides* meadows along the southern shore of Thursday Island, suggesting a localised lack of light. However, this was not directly measured as part of the monitoring program, and environmental conditions in the 12 months prior to the survey (rainfall, global solar exposure, daytime tidal exposure) were favourable for seagrass growth (Wells et al. 2019). The return of these Inner Cluster meadows to good condition in 2021 indicates the Thursday Island declines were due to a short-term and localised impact from which the meadows have since recovered.

There is no evidence that the seagrass declines recorded in some parts of Torres Strait are part of a broader trend in the Cape York region. Weipa is the closest location where the Queensland Ports Seagrass Monitoring Program occurs, and in 2019 and 2020 overall condition for the five seagrass monitoring meadows was good or very good. This was despite an extreme wet season and the Weipa region being impacted by Tropical Cyclone (TC) Penny and TC Trevor in early 2019 (Rasheed et al. 2020; Smith et al. 2020b). Inshore seagrass along Cape York's east coast monitored by the Marine Monitoring Program (MMP) experienced an overall decline in abundance (percent cover) condition from moderate in 2018–19 to poor in 2019–20. However, this occurred at intertidal and subtidal sites at Bathurst Bay and the Flinders Group which are 500 km south of Torres Strait, and where reductions were attributed to flooding of the nearby Normanby River (McKenzie et al. 2021). Closer to Torres Strait in northern Cape York, the MMP found seagrass abundance was either unchanged or slightly increased, despite above-average river discharges and TC Penny and Trevor. It should be noted that seagrass monitoring at Weipa and along Cape York's east coast focuses on intertidal meadows and some shallow subtidal meadows. No deep-water seagrass is found at Weipa. Large-scale loss of deep-water seagrass similar to the declines in Torres Strait would therefore not be detected by these monitoring programs.

4.2 Potential Causes of Western and Central Cluster Seagrass Declines

Threats to Torres Strait seagrass vary in spatial scale. Small-scale localised impacts include trampling, boat traffic, propeller scars and infrastructure work; medium-scale impacts include shipping and port activities/accidents and megaherbivore (turtle and dugong) overgrazing; and large-scale impacts include run-off during the wet season, migrating sand waves, disease and climate change (Scott et al. 2021a; Waterhouse et al. 2013; Green et al. 2010; Halpern et al. 2008; Green 2006).

Documented large-scale episodic seagrass loss in Torres Strait goes back half a century. Intertidal and subtidal seagrass dieback was reported by Torres Strait Islanders across the region in the early 1970s (Johannes and MacFarlane 1991). Less widespread diebacks occurred in north-western Torres Strait in the early 1990s (Poiner and Peterkin 1996), and in the Orman Reefs in 1999-2000 (Marsh et al. 2004). The region around Orman Reefs is particularly dynamic; for example, subtidal seagrass grows in the troughs of large and moving underwater sand dunes (Daniell et al. 2008). However, seagrass in this region grows across a range of habitats – reef, coast, intertidal, deep-water – with each community likely to respond to impacts depending on the niche it occupies. In 2020 and 2021, declines occurred in all of these habitats to varying degrees.

In the 2020 seagrass report card we identified three potential causes for significant declines in seagrass abundance in the Orman Reefs-Mabuyag Island region that year: altered environmental conditions, increased megaherbivore density and feeding intensity, and seagrass disease. Ongoing seagrass monitoring and large-scale surveys have confirmed that the seagrass loss in subtidal areas reported last year is more widespread than initially thought, most acute in subtidal *H. spinulosa* dominated meadows, and is likely due to a range of factors that do not include disease.

4.2.1 Seagrass Disease

Disease has been attributed to large-scale seagrass diebacks in temperate waters (Trevathan-Tackett et al. 2018; Sullivan et al. 2013). Three known groups of pathogens can cause seagrass disease, all of which are understudied: labyrinthulids, oomycetes and Phytomyxea (Sullivan et al. 2013). In particular, pathogenic forms of *Labyrinthula* spp. have been attributed as the cause of seagrass "wasting disease" reported since the 1930s (Martin et al. 2016; Fischer-Piette et al. 1932), including the loss of 90% of *Zostera marina* seagrass in the northern Atlantic in the 1930s (Muehlstein et al. 1991; 1988).

Labyrinthula typically acts as a decomposer of plant material in the marine environment (Tsui et al. 2009), but can also penetrate the cell wall of the living host, causing chloroplast and cell necrosis which disrupt oxygen and nutrient transport, and appear as black lesions on the seagrass blade (Martin et al 2016, Sullivan et al 2018). Pathogenic forms of *Labyrinthula* spread via blade-to-blade contact, floating detritus, and waterborne transport (Martin et al. 2016; Muehlstein 1992). Host-pathogen-environment interactions are complex and the biotic or abiotic triggers for *Labyrinthula* to become pathogenic are unconfirmed, but believed to be due to host-stress situations (Martin et al. 2016). It is likely that where pathogenic *Labyrinthula* is detected, other environmental stressors such as varying water temperature, salinity, sediment sulfide levels, and eutrophication are also contributing factors to seagrass stress that make it susceptible to pathogenic forms of *Labyrinthula* (Sullivan et al. 2018; Martin et al. 2016; Bishop 2013).

The potential role of disease was not investigated in previous Torres Strait seagrass diebacks, but *Labyrinthula*-caused lesions have been recorded on seagrass leaves in temperate Australia (Trevathan-Tackett et al. 2018). In 2020, the TSRA, Rangers and TropWATER collaborated with the Department of Agriculture, Water and Environment (DAWE) lab in Cairns to collect seagrass samples from areas of decline at Mabuyag Island and the Orman Reefs to test whether pathogenic forms of *Labyrinthula* were present. *Labyrinthula*–like lesions were apparent at a very low incidence and severity in the seagrass samples (Figure 39). *Labyrinthula* was successfully isolated from both a symptomatic and an asymptomatic sample. Similarly, molecular detection tests identified *Labyrinthula* in approximately equal numbers of dried seagrass leaf blade tissues collected from both locations of seagrass decline and unaffected areas. This suggests that this genus is present in the seagrass, as is normal elsewhere, but there is no evidence from this round of sampling for the existence of a pathogenic relationship. Such a relationship would be expected to show up as a high incidence and severity of characteristic black seagrass blade lesions (Richard Davis, DAWE, pers. comm.). DAWE's phylogenetic assessment found the Torres Strait *Labyrinthula* was most closely related to *Labyrinthula* found in southern Australia, indicating the diversity of *Labyrinthula* may well be a natural component of Torres Strait waters rather than introduced through shipping (Richard Davis, DAWE, pers. comm.).

It should be emphasised that these preliminary disease assessments were based on a limited number of samples, and samples did not include *Halophila spinulosa*, the subtidal species that has declined most. We recommend developing a comprehensive testing program for disease that includes broader testing for *Labyrinthula* for seagrass samples collected across the network of seagrass monitoring locations to develop a baseline, and opportunistic sampling and testing of samples when lesions on leaf blades are evident during monitoring.

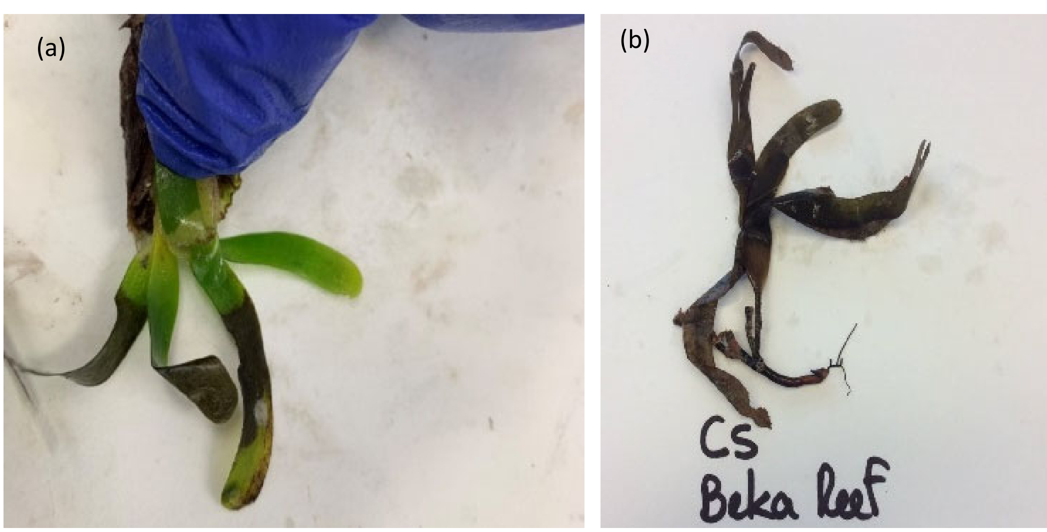

Figure 39. *Labyrinthula*-like lesions on seagrass samples collected at (a) Mabuyag Island and (b) Beka Reef (Orman Reefs) in 2020.

4.2.2 Environmental Conditions

Australian seagrass distribution, abundance and species composition reflects the environmental conditions meadows grow in, including exposure to run-off, physical disturbance, light, tidal fluctuations, and water temperature. Environmental conditions during extreme weather - strong winds, turbulent water flow, storm surge, increased rainfall, and increased sediment movement - can cause significant seagrass declines due to reductions in the light required for seagrass growth, and sediment movement that can either bury or dislodge plants, meadows, and seed banks (Waycott et al. 2007). This occurred recently along Queensland's east coast, where flooding, storms and tropical cyclones in 2009-2011 caused significant seagrass loss in shallow coastal habitats and in deeper water meadows (Coles et al. 2015; Rasheed et al. 2014). Saint-Cast proposed that a likely cause of previous seagrass diebacks in Torres Strait were due to reduced light from sediment resuspension, courtesy of two major depocentres (i.e. areas of maximum deposition) on either side of Torres Strait, with resuspension exacerbated during periods of prolonged monsoon winds and/or extreme weather (Saint-Cast 2008).

Extremes in water temperature can also cause significant seagrass loss. The single largest global loss in dense seagrass extent occurred in Shark Bay, Western Australia, following a marine heatwave in the summer of 2010-2011, following more than two months of elevated water temperatures 2-4°C above the long-term average (Strydom et al. 2020; Arias-Ortiz et al. 2018). For intertidal meadows, prolonged daytime tidal exposure, particularly when this coincides with high winds, sun and heat, can cause seagrass burning which also leads to abundance declines (Unsworth et al. 2012). Water temperature is unlikely to have contributed to seagrass declines in the Orman Reefs-Mabuyag Island region. Water temperature data for Thursday Island and Mabuyag Island from 2019-2020 provides no evidence of dramatic or prolonged spikes in water temperature that indicate a marine heatwave when seagrass declines first occurred (Figure 29c), and the species of seagrass that occur in the Torres Strait have a relatively high temperature tolerance compared to the temperate/ sub-tropical species that were lost in Shark Bay.

There is anecdotal evidence that recent environmental conditions may have contributed to seagrass loss in the Western and Central Clusters. Senior Mabuygiw Ranger Terrence Whap observed large areas of the intertidal seagrass that grows around Mabuyag Island eroded and washed away in 2019-2020. The impact was particularly bad for the smaller and shallow-rooted species *H. ovalis* and *H. uninervis*, with patches of the large and deep-rooted species *E. acoroides* the only remaining species in areas that were previously diverse meadows (Figure 40c). Changes in sediment also were observed along Mabuyag Island's coast, with fine muddy sediment replaced by sand at transect monitoring sites (Figure 37c). TropWATER researchers also observed in October 2020 an influx of carbonate sand in an intertidal area at Mabuyag Island that the previous year was a seagrass meadow with extensive dugong feeding trails growing in soft muddy sediment (Figure 40a, b). Ranger Whap attributed this influx of sandy sediment into Mabuyag Island's coastal meadows to personal observations of the island experiencing much windier conditions than usual. Porumalgal Ranger Freddie David observed the decline at site PM2 was caused by the build-up of sand on the eastern side of Poruma Island, and that when he removed the top layer of sand the seagrass was underneath. Ranger David attributed this to seasonal changes, and predicted that the seagrass would return with the Sager (south-east) winds. Ranger David also noted the decline at PM2 was very localised and there remained extensive seagrass habitat next to the monitoring site.

Environmental data (where available) shows winds were within normal long-term range between July 2019 and January 2021 (Figure 41a). Winds at Thursday Island were more northerly than usual in January and February 2021 (Figure 41b); however, these measurements are not available for Mabuyag or Poruma Islands. Tidal data from Thursday Island shows daytime exposure was above the long-term average most months between in June and August 2020 (Figure 41c). Above-average daytime tidal exposure, potentially coupled with an increase in sediment movement from tidal forcing, is a potential contributor to biomass declines in the Orman Reefs-Mabuyag Island region. However, environmental observations data come from Thursday Island, so comparisons to other islands may not be appropriate. Interpretation of wind patterns that may drive erosion and sediment deposition and thereby influence seagrass condition is limited by the lack of local weather data in the Torres Strait.

Figure 40. (a) Intertidal seagrass meadow at Mabuyag Island with dugong feeding trails in September 2019 and (b) the same location at Mabuyag Island covered in carbonate sand in October 2020. (c) Erosion left the roots of the seagrass *E. acoroides* exposed and washed away smaller seagrass species at Mabuyag Island in 2019. (d) Healthy seagrass meadow at Poruma Island site PM1. (e) Seagrass site PM2 on the north-eastern side of Poruma Island was covered in sand during monitoring in April 2021. Photos courtesy: L. Shepherd, T. Whap, and Porumalgal Rangers.

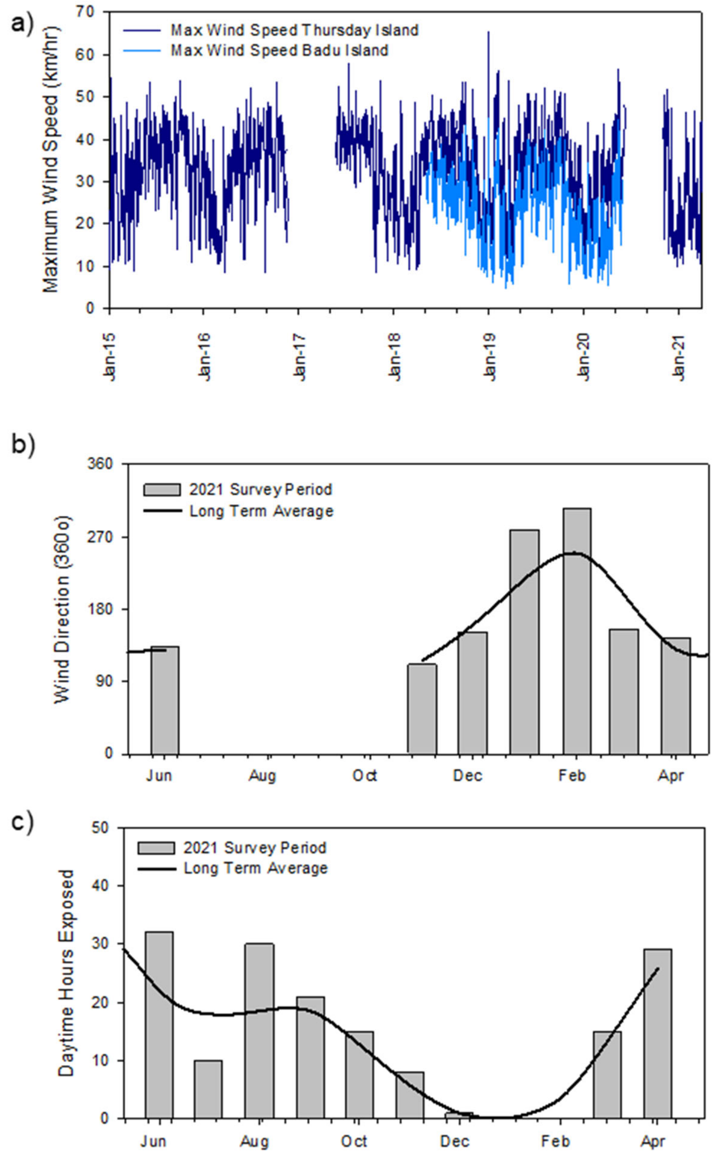

Figure 41. Environmental variables that commonly affect seagrass biomass: (a) Maximum wind speed (km/hr), (b) Wind direction (360º) and, (c) Daytime hours exposed. All data from Thursday Island weather observation station unless otherwise indicated. In (b) and (c) the 2021 survey period is June 2020 to April 2021, and the long-term average is calculated using data from January 2015 to June 2020.

4.2.3 Increased Herbivory by Turtles and Dugong

Grazing by large herbivores such as green turtles and dugong has the potential to lead to large-scale changes in seagrass meadows. Individually, these animals consume large quantities of seagrass per day - up to 5 kgs for green turtles and 40 kgs for dugong (Preen 1992) - and Torres Strait has globally significant populations of both. The importance of seagrass for dugong and turtle health and survival is well established. For example, seagrass loss in Torres Strait has been linked to reduced condition and reproduction, and increased mortality for dugong (Marsh and Kwan 2008; Marsh et al. 2004; Long and Skewes 1996; Johannes and MacFarlane 1991; Nietschmann 1984), and reduced condition and reproduction of green turtles in Torres Strait and along Queensland's east coast (Fuentes et al. 2016; Marsh and Kwan 2008; Limpus and Nicholls 2000; Preen and Marsh 1995).

Less understood is how plant-herbivore interactions shape the characteristics and condition of the diversity of tropical seagrass meadows (Scott et al. 2018; York et al. 2017). Large numbers of herbivores can lead to overgrazing and significant declines in seagrass biomass (Fourqurean et al. 2010; Lal et al. 2010; Masini et al. 2001), and recent work on the Great Barrier Reef demonstrated significant increases in seagrass biomass when turtles and dugong were prevented from grazing small plots (Figure 42a) (Scott et al. 2021a; b). In Torres Strait, Johannes and MacFarlane (1991) cite one source that attributed the large-scale dieback in the 1970s to overgrazing by unusually large numbers of turtles and dugong. The effect of turtle and dugong grazing on seagrass will be investigated at Mabuyag Island and Orman Reefs by Traditional Owners, Mabuygiw Rangers and TropWATER researchers commencing in August 2021.

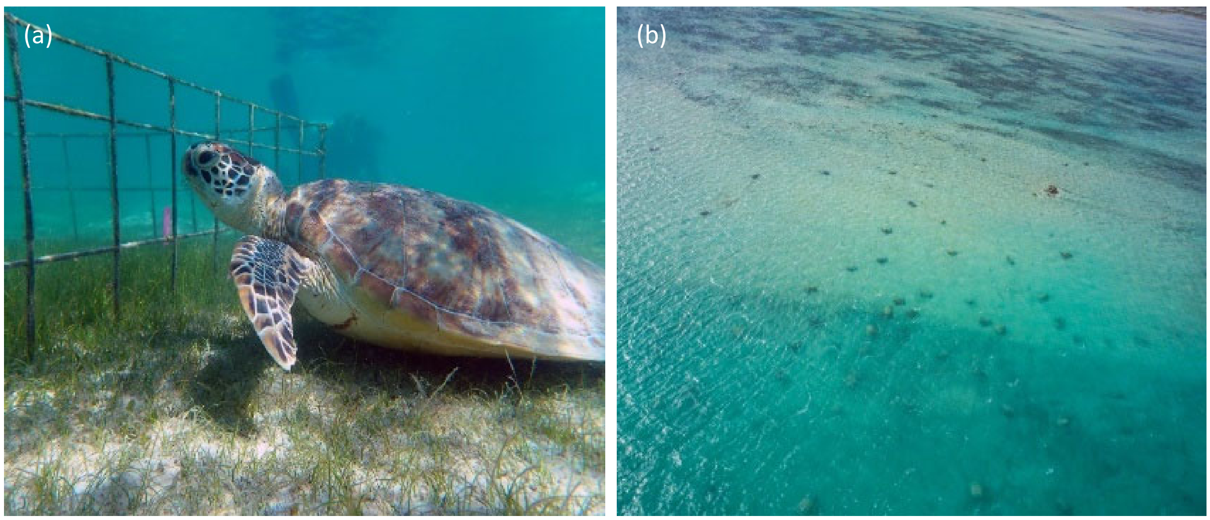

Figure 42. (a) Megaherbivores such as turtle and dugong can have significant effects on seagrass biomass that are only apparent once seagrass is protected from grazing. (b) Large numbers of green turtles were sited during seagrass surveys at Orman Reefs in September 2019 and October 2020. Photos courtesy: A. Scott and L. Shepherd.

The observations of TropWATER researchers, local Rangers and community indicate high levels of herbivory by green turtle and dugong is a likely contributor to declines in seagrass abundance in the intertidal Orman Reefs-Mabuyag Island region over the past two years. Mabuygiw Ranger Terrence Whap received numerous anecdotes from community members and other Rangers of high dugong and turtle densities in the area in recent years, and that dugong were coming in close to the Mabuyag Island foreshore more frequently than usual. Mura Badhulgau Ranger Troy Laza observed the same behaviour of dugong at Badu Island in the past year. Similarly, TropWATER researchers during the September 2019 survey observed dugong feeding trails up to the shoreline at Mabuyag Island, although this section of the Mabuyag Island meadow was covered with sand by October 2020 (Figure 41a, b). TropWATER researchers also observed much greater numbers of green turtles at Orman Reefs during the September 2019 (Figure 42b) and October 2020 surveys, and greater dugong numbers in October 2020, than had been observed during 2018 and 2017 surveys.

The Western Cluster is known for high dugong and green turtle densities relative to the rest of Torres Strait (Cleguer et al. 2016; Hagihara et al. 2016). However, without regular green turtle and dugong monitoring it is unclear whether the apparent increase in turtle and dugong density is due to: (1) regional-scale migration of foraging turtle and dugong to Torres Strait from places such as the Gulf of Carpentaria or the Great Barrier Reef; (2) Cluster-scale movement within Torres Strait where animals have migrated to the Western Cluster from other Clusters; or (3) habitat-scale movement where the widespread loss of subtidal seagrass biomass has forced animals to increasingly rely on reef-top and island meadows for food in the Western Cluster, thereby increasing their interactions with, and visibility to, island communities and researchers.

4.2.4 Timeline for Recovery

Seagrass recovery time following loss can vary. Experimental work at Mabuyag Island demonstrated recovery can take anything from several months (assuming asexual reproduction is possible), to several years for intertidal meadows of large growing species if total meadow loss occurred and recovery depends only on sexual reproduction (Taylor et al. 2013). Following widespread loss in Torres Strait in the early-1970s, Johannes and Macfarlane reported intertidal and deep-water seagrass took a decade to recover (Johannes and MacFarlane 1991). Decadal-scales of decline and recovery have also occurred along Queensland's east coast (Carter et al. 2021a). This cycle has been most pronounced in the last decade, where seagrasses have continued to improve following large-scale loss in 2009-2011 during a La Nina associated period of above average rainfall, river flow and tropical cyclones (McKenna et al. 2015).

Recovery in the past decade has occurred on the east coast of Queensland, including at Abbot Point (Van De Wetering et al. 2020b), Cairns (Reason et al. 2020), Mackay and Hay Point (York and Rasheed 2020), Townsville (McKenna et al. 2020), and Gladstone (Smith et al. 2020a), although the time to recovery has varied among locations and seagrass community types within each location. In general, *Halophila* dominated meadows were much quicker to recover than other meadow types, particularly when a seed bank exists (Rasheed et al. 2014). These species are fast growing and produce large amounts of seed and can rapidly take advantage of favourable conditions to recover (York et al. 2015; Rasheed et al. 2014). *Halophila* meadows generally produce substantial long-lived seed banks in the sediment that allow for seagrass recovery, with seeds remaining viable for at least two years (Hovey et al. 2015; Rasheed et al. 2014; McMillan 1991; McMillan and Soong 1989). The potential for rapid recovery of the Torres Strait subtidal meadows is therefore good, particularly as some *H. spinulosa* remained in the affected regions that could drive this recovery. However, remnant plants were generally observed to be in poor condition and the status of seed banks is unknown.

High connectivity, the presence of a viable seedbank, and a return to environmental conditions that support seagrass recruitment and recovery are key (Grech et al. 2018; Rasheed et al. 2014). Low connectivity and the absence of a viable seed bank of foundation species are the main reasons why seagrass meadows have not recovered in other locations, such as Mourilyan Harbour (Van De Wetering et al. 2020a). There is good potential for seagrass recovery in the Western and Central Clusters in the coming year assuming the reasons for the initial decline have passed. The combination of high connectivity in Torres Strait (Johnson et al. 2018), the maintenance of seagrass area coverage despite significant abundance declines, the persistence of species that have experienced the worst declines (e.g. subtidal *H. spinulosa*) at a reduced number of sites, and the relatively short time elapsed since declines began, means recovery is likely via a range of mechanisms. These include dispersal of seagrass fragments and seeds, recovery of biomass in remaining plants, and germination of seeds within existing seed banks. Ongoing monitoring will provide a valuable opportunity to observe when and how different seagrass communities recover from these declines in the coming years.

4.3 Report Card Strengths, Limitations and General Recommendations

4.3.1 Report Card Strengths

The extensive seagrass monitoring and research effort in Torres Strait continues to enhance our understanding of this important habitat. The 2021 report card highlights the value of the range of ongoing monitoring programs and the long-term data sets these generate. Integrating the results of these monitoring efforts into a single report card provides a powerful means of evaluating current seagrass condition against baseline conditions, comparing seagrass condition among habitats and clusters, identifying areas of concern, and providing an indication of seagrass resilience.

Continuation of annual data collection for the long-term monitoring program is vital for accurate assessments of seagrass condition and identifying change. The time scale for effective long-term monitoring of ecosystems depends on the time scale of the ecological process being studied, which for many systems is measured in decades (Lindenmayer and Likens 2009). This period allows studies to separate changes in population patterns from seasonal differences (within-year variability) and annual variability or "noise".

Analysis of long-term datasets on seagrass change throughout Queensland, including sites with over 25 years of data, demonstrates that a 10 year period of monitoring is required to set reliable baselines for seagrass condition (Bryant et al. 2014). That 10-year milestone has now been achieved for the majority of long-term monitoring locations in Torres Strait, including at Iama Island (IM1 and IM2), Badu Island (BD1) and Mua Island (MU3) in 2021. This report card also provides interim scores for monitoring locations with 5-9 years of baseline data. In 2021, 5-years of monitoring data was achieved at the intertidal reef-top meadows at Kai and Gariar Reefs and Poruma Island (PM1 and PM2) meaning overall site and meadow scores were included for the first time. Only Dungeness Reef subtidal (3 years) and the recently added Masig Island intertidal meadow (2 years) have less than 5 years data. As the program matures, and more locations achieve 10 years of information, the representativeness and robustness of the program will continue to improve.

4.3.2 Report Card Limitations

Significant gaps in our knowledge of seagrass condition in Torres Strait remain. These include the Top-Western Cluster where no monitoring occurs, and the Eastern Cluster where monitoring is limited to two transect sites at Mer Island and no meadow-scale monitoring occurs. Subtidal seagrass declines have also highlighted the limited number of deep-water monitoring locations across all clusters.

The spatial scale at which monitoring occurs is an important consideration when extrapolating monitoring results to determine trends. The seagrass scores for many of the Island Clusters are largely reliant on small-scale permanent transect monitoring. This scale of monitoring does not provide essential information on change in seagrass meadow extent, which is both a key indicator of change for a range of pressures on seagrass meadows, and an essential component of seagrass condition required for management of associated assets such as dugong, turtle and fisheries. Where small-scale variability occurs within a meadow, larger meadow-scale monitoring is likely to produce a more reliable measure of overall condition and change. The 2021 decline at Poruma Island's site PM2 is a good example of this, where the north-east permanent transect site is in very poor condition after a large amount of sand covered the site, while a large meadow persists next to the site (Freddie David, pers.com). Meadow-scale monitoring at Masig Island is a welcome addition to the Central Cluster monitoring network to address this issue, and is also recommended for the Eastern and Top-Western Clusters.

4.4 Recommendations

The current monitoring effort in Torres Strait is substantial; however, to improve the program's ability to meet management requirements we recommend the following should resources and funding opportunities allow:

(1) Establish seagrass monitoring in the Top-Western Cluster. Seagrass data collected during a large-scale baseline survey in late 2015 provides a good basis for selecting intertidal and subtidal meadows suitable for monitoring.
(2) Establish meadow-scale seagrass monitoring in clusters where this does not occur so that changes in meadow area, a fundamental indictor of seagrass meadow condition, can be included in future condition assessments. Potential meadows include Boigu Island in the Top-Western Cluster and Erub, Mer, Dauar and Waier Islands in the Eastern Cluster. These could include investigating the potential for Ranger or Community-led drone surveys of intertidal seagrass meadows.
(3) Establish additional subtidal block monitoring in clusters where this currently does not occur so that this important and extensive habitat is better represented in future condition assessments and further loss or recovery are detected. Recommended locations include south of Boigu Island in the

Top-Western Cluster, west of the Warrior Reefs in the Central Cluster, and the southern section of the Dugong Sanctuary.

(4) Conduct baseline surveys in areas where data is lacking or is more than 10 years old, and potentially important seagrass habitat is most likely. For intertidal seagrass this includes the Warrior Reefs (Central Cluster), Ugar Island (Eastern Cluster), and Saibai Island (Top-Western Cluster). For subtidal seagrass this includes the region between the Warrior Reefs and Gebar Island (Central Cluster), and the southern Dugong Sanctuary (Kaurareg sea country).

The seagrass condition declines described in this report card highlight the importance of regular monitoring to detect change, but the limitations of monitoring only one component of the environment, e.g. seagrass, and not a range of ecosystem indicators makes it difficult to identify the causes of seagrass change. To overcome this we recommend:

(1) *Comprehensive disease/pathogen assessment of Torres Strait seagrass.* Preliminary testing at the Cairns DAWE lab found no evidence of pathogenic *Labyrinthula.* However, this was based on a small number of samples from Mabuyag Island and Orman Reefs only. We recommend development of a comprehensive testing program for disease that includes testing for seagrass samples across the network of monitoring locations to develop a baseline, and opportunistic testing of samples when lesions on leaf blades are evident during monitoring. Testing of *H. spinulosa* is a priority.

(2) *Regular turtle and dugong monitoring*. Turtle and dugong aerial surveys occur sporadically in Torres Strait (Cleguer et al. 2016; Hagihara et al. 2016; Fuentes et al. 2015), but not at the frequency that variations in animal density can be linked to seagrass dynamics. Unmanned aerial vehicles (UAVs) or drones are increasingly being used as a cost-effective and efficient method to monitor large marine animals, including dolphins, manatees, turtles and whales (Dunstan et al. 2020; Ramos et al. 2018; Rees et al. 2018; Hodgson et al. 2017). We recommend a pilot study to explore the use of drones as a more cost-effective method for island/meadow scale turtle and dugong monitoring at a range of locations in Torres Strait.

(3) *Establishing light monitoring.* As a critical driver of seagrass change, some in-situ benthic light (PAR) logging at key locations would provide valuable insight into the role of light in seagrass changes observed in the Torres Strait.

(4) *Local wind and weather stations in the Western Cluster*. Interpretation of wind patterns that may drive erosion and sediment deposition and thereby influence seagrass condition is currently limited by the lack of local weather data.

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APPENDICES

Appendix 1.

Baseline Calculations

Baseline conditions for site/meadow biomass/percent cover, area and species composition were established from annual means calculated during the first 10 years of monitoring. This baseline was set based on results of the 2014 pilot report card (Bryant et al. 2014). Where <10 years of data were available the baseline was calculated over the longest available time period. Condition assessments with 5-10 years of data should be considered preliminary as the baseline will be updated annually. Sites/meadows with <5 years of data are included in this report but no overall grades/scores are presented due to the lack of data.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean site/meadow biomass/percent cover of the baseline years. Meadows were classified as single species (one species comprising ≥80% of baseline species composition) or mixed species dominated (no species comprise ≥80% of baseline species composition). Where a meadow baseline contained an approximately equal split in two species (i.e. two 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 (Figure A1).

Meadow Classification

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

Table A1.1 Coefficient of variation (CV; %) thresholds used to classify stability or variability of site/meadow abundance (biomass/percent cover), area and species composition baselines.

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

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 sites/meadows and Torres Strait Island Clusters (Table A2).

Score calculations for each site/meadow's condition required calculating the biomass/percent cover, area and species composition for that year (described in Section 2.1), allocating a grade for each indicator by comparing 2019 biomass/percent cover, area, and species values against site/meadow-specific thresholds for each grade, then scaling biomass/percent cover, 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 A2). Within each site/meadow, the upper limit for the very good grade (score = 1) for percent cover and species composition were set as 100%. 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. For sites/meadows with <10 years of baseline data this upper limit will be recalculated each year until the 10-year baseline period is complete.

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

Table A1.2 Score range and grading colours used in the Torres Strait 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/stable species were driving this grade/score (Figure A1). If this was the case, the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species was reserved for those meadows where the directional change from the stable state species is of concern (Figure 5). This would occur when the stable state species is replaced by species considered earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *T. hemprichii* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. ovalis* to *H. decipiens*, the most marginal species found in Torres Strait, 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).

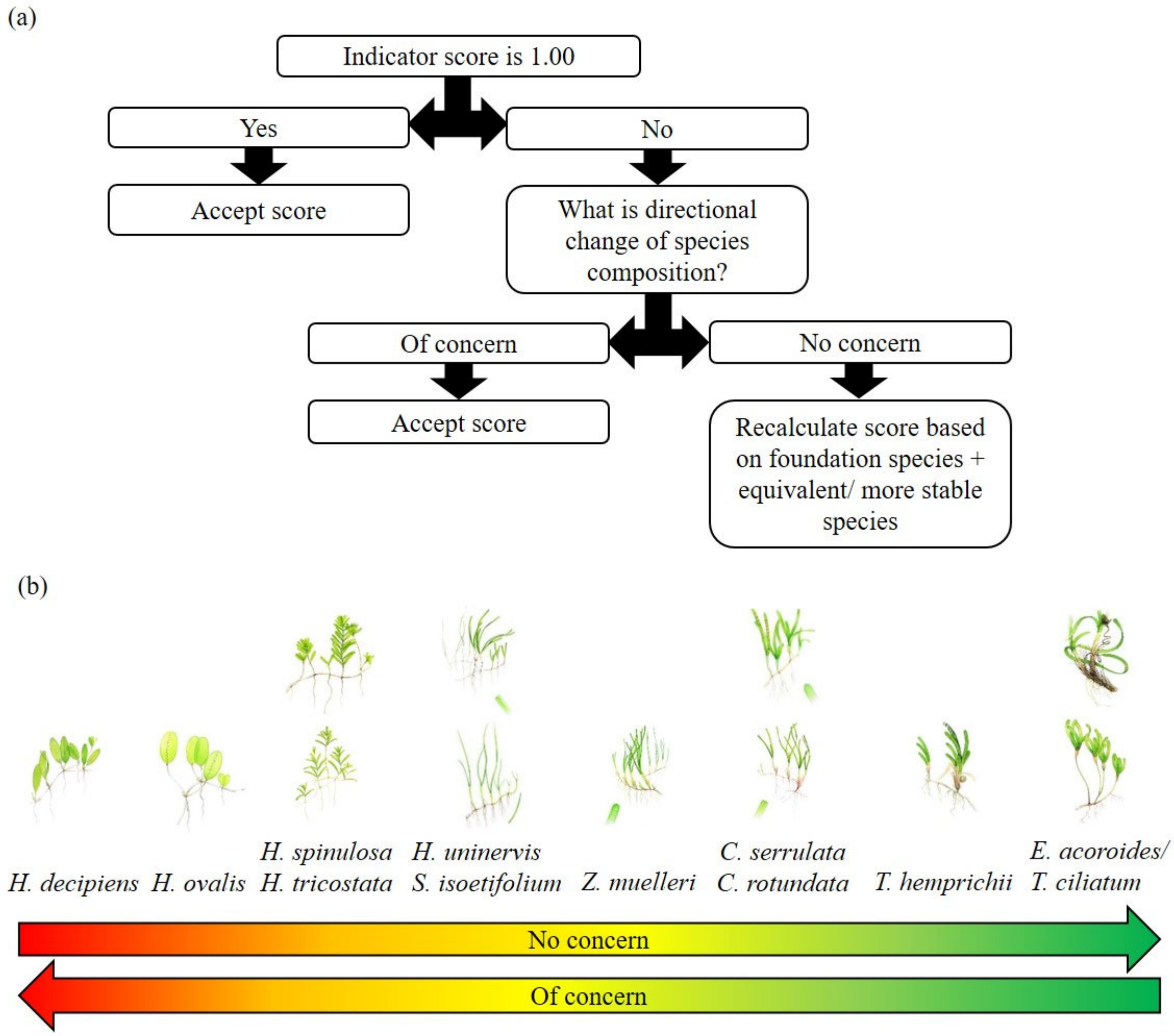


Figure A1.1 (a) Decision tree and (b) directional change assessment for grading and scoring species composition.

Threshold Definition

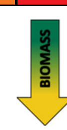
Each seagrass condition indicator was assigned one of five grades: very good (A), good (B), satisfactory (C), poor (D), very poor (E). Threshold levels for each grade were set relative to the baseline and based on site/meadow class. This approach accounted for historical variability within the monitoring sites/meadows and expert knowledge of the different site/meadow types and assemblages in the region (Table A3).

Score Aggregation

The overall site/meadow grade and score is defined as the lowest indicator score where this is driven by biomass/percent cover or area. Where species composition is the lowest score, it contributes 50% of the overall site/meadow score, and the next lowest indicator (area or biomass/percent cover) contributes the remaining 50%. The lowest of the biomass/percent cover or area scores, rather than the mean of the three indicator scores, was applied in recognition that a poor grade for either of these indicators described a seagrass meadow in poor condition. The 50% weighting of species composition acknowledges that this is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition.

Torres Strait Island Cluster grades/scores were calculated by averaging the overall site/meadow scores for each monitoring site/meadow within a given cluster, and assigning the corresponding grade to that score. Where multiple sites/meadows were present within a cluster, no weighting system was applied at this stage of the analysis. The classification process applies smaller and more sensitive thresholds for stable sites/meadows, and less sensitive thresholds for variable sites/meadows. The classification process serves therefore as a proxy weighting system where any condition decline in the stable sites/meadows is more likely to trigger a grade reduction compared with more variable sites/meadows. Cluster grades therefore are more sensitive to changes in stable than variable sites/meadows.

Table A1.3 Threshold levels for grading seagrass indicators for various site/meadow classes relative to the baseline. Upwards/downwards arrows are included in figures where a change in condition grade has occurred in any of the three indicators (biomass/percent cover, area, species composition) from the previous year.

Seagrass condition indicators/ Site/meadow class		Seagrass grade				
		A Very good	**B Good**	**C Satisfactory**	**D Poor**	**E Very Poor**
Biomass/ Percent cover	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		

Appendix 2. An example of calculating a meadow score for area in satisfactory condition in 2021.

1. Determine the grade for the 2021 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2021 area value (A_{2021}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{\text{diff}} = A_{2021} - A_{\text{satisfactory}}$$

Where $A_{satisfactory}$ 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 area values (A_{range}) in that grade:

$$A_{\text{range}} = A_{\text{good}} - A_{\text{satisfactory}}$$

Where $A_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.
Note: For species composition and percent cover, 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 (A_{prop}) that A_{2021} takes up:

$$A_{\text{prop}} = \frac{A_{\text{diff}}}{A_{\text{range}}}$$

5. Determine the area score for 2021 ($Score_{2021}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$\text{Score}_{2021} = \text{LB}_{\text{satisfactory}} + \left(A_{\text{prop}} \times \text{SR}_{\text{satisfactory}}\right)$$

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