Mackay-Whitsunday-Isaac Seagrass Monitoring 2019:

Marine Inshore South Zone

van de Wetering C, Carter AB, Wilkinson J, Rasheed MA

Report No. 20/18

June 2020

Mackay-Whitsunday-Isaac Seagrass Monitoring 2019:

Marine Inshore South Zone

Report No. 20/18

June 2020

Chris van de Wetering, Alex Carter, Juliette Wilkinson and Michael Rasheed

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
PO Box 6811
Cairns Qld 4870
Phone : (07) 4781 4262
Email: seagrass@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

Information should be cited as:
Van de Wetering C, Carter AB, Wilkinson J, and Rasheed MA (2020) 'Mackay-Whitsunday-Isaac Seagrass Monitoring 2019: Marine Inshore South Zone', Centre for Tropical Water & Aquatic Ecosystem Research Publication 20/18. James Cook University, Cairns, 25 pp.

For further information contact:
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
seagrass@jcu.edu.au
PO Box 6811
Cairns QLD 4870

This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:

This project was funded by the Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership. We thank Ricci Churchill from Dalrymple Bay Coal Terminal (pictured) for assistance with field work.

KEY FINDINGS

- Clairview seagrass meadow condition continues to improve following Tropical Cyclone Debbie in early 2017.
- After 3 years of surveys in the southern zone, we present preliminary condition grades for area, biomass and species composition. All indicators were in good or very good condition in the three monitoring meadows.
- All three meadows had the greatest biomass since monitoring began in 2017. Meadow area was also the largest on record for the two coastal meadows.
- Dugong feeding trails were recorded in both coastal meadows but were absent in the smaller Flock Pidgeon Island meadow.
- Ongoing annual monitoring will provide a more robust baseline against which to assess seagrass condition into the future.

TABLE OF CONTENTS

Key Findings ..... **i**

1 INTRODUCTION **1**

2 METHODS **4**

2.1 Survey Approach 4
2.2 Field Surveys 4
2.3 Biomass and Species Composition 4
2.4 Seagrass Meadow Mapping and Geographic Information System (GIS) 5
2.5 Seagrass Meadow Condition Index 6

3 RESULTS **8**

4 DISCUSSION **15**

5 REFERENCES **17**

6 APPENDICES **21**

Appendix 1. Seagrass Condition Calculations 21
A1.1 Baseline Calculations **21**
A1.2 Meadow Classification **21**
A1.3 Threshold Definition **21**
A1.4 Grade and Score Calculations **22**
A1.5 Score Aggregation **24**
Appendix 2. Biomass score calculation example 25

1 INTRODUCTION

Seagrass habitats are immensely productive and provide a range of ecosystem services with substantial economic value (Costanza *et al.* 2014; Scott *et al.* 2018). These services include coastal protection, support of fisheries production, nutrient cycling, particle trapping, removal of bacterial pathogens, and acting as a carbon sink (Fourqurean *et al.* 2012; Hemminga and Duarte 2000; Lamb *et al.* 2017). Seagrasses provide food for herbivores like dugongs (*Dugong dugon*) and green turtles (*Chelonia mydas*) (Heck *et al.* 2008; Unsworth and Cullen 2010).

Natural and anthropogenic factors contribute to global declines in seagrass (Waycott *et al.* 2009). Natural disturbances include tropical cyclones, floods, disease, and overgrazing by herbivores (Fourqurean *et al.* 2010; McKenna *et al.* 2015; Robblee *et al.* 1991). Anthropogenic activities that threaten seagrass habitat in the tropical Indo-Pacific region include industrial and urban run-off, port and coastal development, and dredging (Grech *et al.* 2012; York *et al.* 2015).

The sensitivity of seagrass to disturbance events and environmental change make it an excellent indicator of marine environmental health (Abal and Dennison 1996; Dennison *et al.* 1993; Orth *et al.* 2006). Seagrass condition assessments require adequate baseline information on seagrass presence/absence, biomass, species composition, and meadow area, plus ongoing monitoring to understand and detect change. Long-term monitoring and condition reporting on Queensland's seagrass is largely undertaken by the Queensland Ports Seagrass Monitoring Program (QPSMP) that occurs in the majority of commercial ports (www.jcu.edu.au/portseagrassqld), and the Marine Monitoring Program (MMP) that focusses on the inshore Great Barrier Reef (GBR) (http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program) and reports seagrass condition as part of the Reef Water Quality Protection Plan (https://www.reefplan.qld.gov.au/measuring-success/report-cards/).

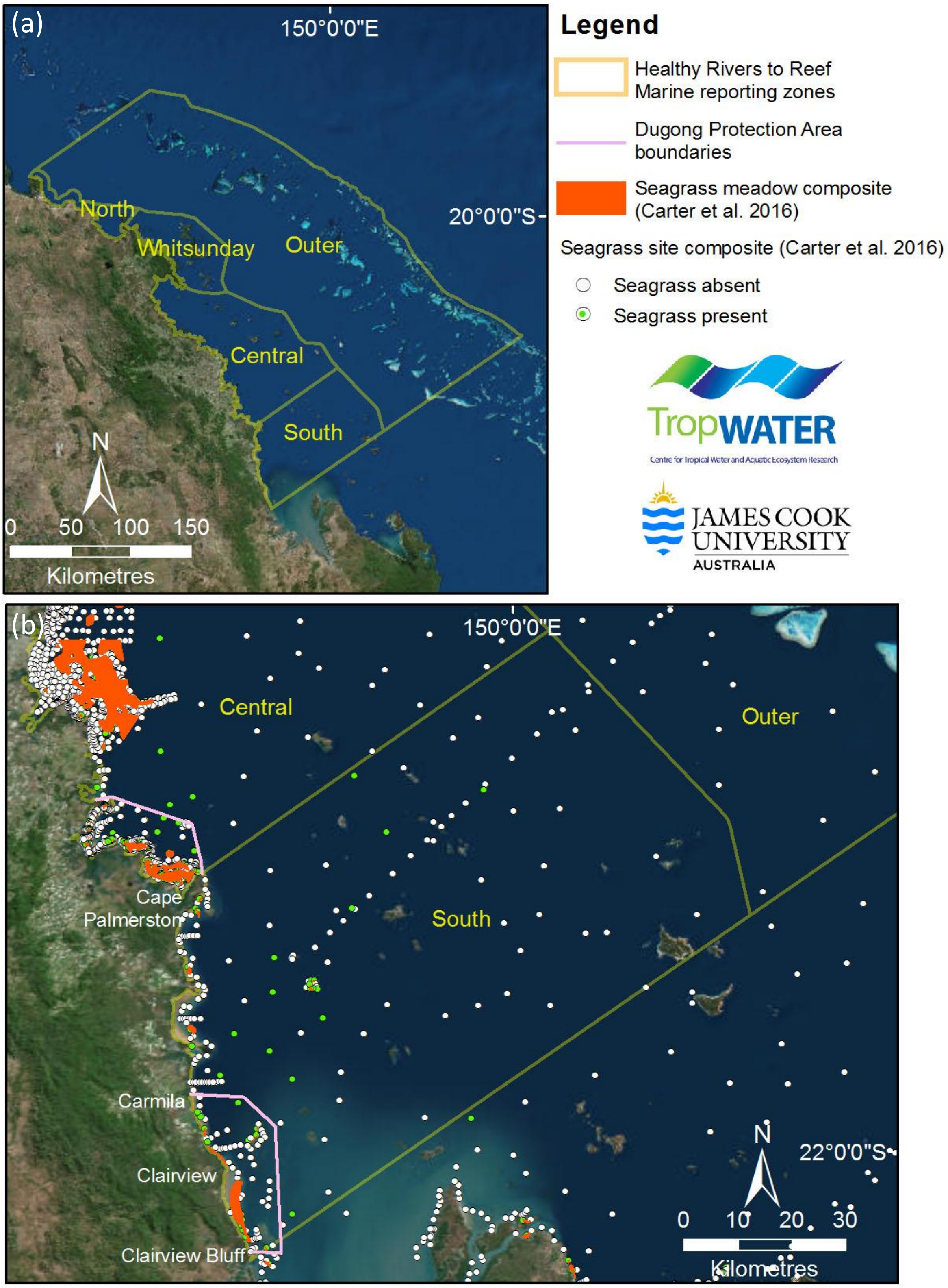
The QPSMP and MMP contribute their seagrass condition assessments to a variety of regional report cards. These include the Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership (HR2RP; http://healthyriverstoreef.org.au/), the Wet Tropics Healthy Waterways Partnership (WTHWP; http://wettropicswaterways.org.au/report-card/), the Dry Tropics Partnership for Healthy Waters (DTPHW; https://drytropicshealthywaters.org/report-cards-1), and the Gladstone Healthy Harbour Partnership (GHHP; http://ghhp.org.au/report-cards/2018). Regional report cards at the Natural Resource Management (NRM) scale are divided into zones defined largely by habitat and latitude (Figure 1a). Attempts to report zone-scale seagrass condition revealed a number of gaps with no long-term monitoring data available to inform report card scores. For the HR2RP report card, the southern inshore marine zone was identified as a major data and knowledge gap for seagrass condition (http://healthyriverstoreef.org.au/report-card-results/).

TropWATER were contracted in 2017 by HR2RP to address the knowledge gaps in environmental condition, including seagrass, for the southern inshore marine zone. The longer-term (5 years) objective is to provide report card scores for seagrass in this zone that will be incorporated into the regional report card. TropWATER have conducted seagrass surveys previously in this zone: (1) in 1987, as part of large-scale seagrass assessments along the Queensland coast (Coles *et al.* 1987); (2) in 1997, during GBR-wide deep water surveys (Coles *et al.* 2009); (3) in 1999, during assessments for Dugong Protection Areas (Coles *et al.* 2002); and (4) in 2003-2004, during GBR-wide seabed biodiversity surveys led by CSIRO (Pitcher *et al.* 2007). These surveys revealed substantial intertidal seagrass meadows along the coast, but sparse and patchy subtidal seagrass. The largest intertidal meadows were located in the Clairview Dugong Protection Area (DPA) between Carmila and Clairview Bluff (Figure 1b). These meadows were mapped in 1987 (Coles *et al.* 1987), and revisited in 1999 (Roder *et al.* 2002), and were the focus for TropWATER's seagrass baseline survey in 2017.

The 2017 survey was an important first step in addressing seagrass knowledge gaps in the southern inshore zone of the HR2RP report card (Carter and Rasheed 2018). The 2017 and 1999 surveys revealed similar seagrass distribution, biomass, and species composition to the original 1987 survey, indicating these seagrass areas are likely to be relatively permanent features and ideal for monitoring. Three meadows were selected for long-term monitoring: two large intertidal meadows between Clairview and Clairview Bluff (Meadows 6 and 7), and the intertidal meadow at Flock Pigeon Island (Meadow 2).

This report presents findings from the 2019 seagrass monitoring survey of the HR2RP southern inshore marine zone. Our objectives were to:

- Map seagrass distribution, density and community composition in monitoring meadows;
- Compare results with previous seagrass monitoring results of these meadows;
- Incorporate results into a Geographic Information System (GIS) database for the zone.



Map produced by TropWATER, James Cook University. Satellite Image Layer Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User

Figure 1. (a) Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership reporting zones for inshore marine (North, Whitsunday, Central, South) and offshore marine (outer); and (b) historical seagrass survey data collected 1987 – 2004 in the southern inshore marine zone.

2 METHODS

2.1 Survey Approach

The survey was conducted in September 2019 to coincide with the peak seagrass growing season, when meadows are likely to contain maximum biomass and area. Survey methods and the seagrass metrics recorded followed the established methods for Queensland seagrass monitoring which also occur at Townsville (McKenna *et al.* 2020), Gladstone (Smith *et al.* 2020), Cairns (Reason *et al.* 2020), Mourilyan (Van De Wetering *et al.* 2020a), Mackay-Hay Point (York and Rasheed 2020), Abbot Point (Van De Wetering *et al.* 2020b), Thursday Island (Wells *et al.* 2019), Weipa (Rasheed *et al.* 2020), and Karumba (Shepherd *et al.* 2020). Using standardised methods ensures seagrass data is comparable with that used to report seagrass condition for other marine inshore zones in the HR2RP report card, and in the WTHWP, DTPHW, GHHP, and QPSMP report cards. Standardisation also allows for comparisons with historical data sets collected previously in the same area.

2.2 Field Surveys

Intertidal meadows were sampled at low tide using a helicopter. Monitoring meadows are all intertidal because: (1) the large tidal range (up to 8.5m) means that intertidal seagrasses are exposed during spring low tides so helicopter surveys are likely to capture the majority of seagrasses in the region; and (2) subtidal meadows form a relatively minor component of seagrass area and are restricted to very shallow subtidal water, with the same species composition as the much larger adjacent/adjoining intertidal meadows (Carter and Rasheed 2018).

At each site the helicopter came to a low hover (within a metre of the ground). Within a $10m^2$ circular area seagrass biomass was ranked, and the percent contribution of each species to that biomass was estimated, from three 0.25 m^2 randomly placed quadrats. Within the larger $10m^2$ circular area the percent cover of seagrass, algae, and other benthic macro-invertebrates (BMI) were recorded. GPS was used to record the position of each site, and also intertidal meadow boundaries when visible.

2.3 Biomass and Species Composition

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (Kirkman 1978; Mellors 1991). For each 0.25 m^2 quadrat an observer assigned a biomass rank, made in reference to a series of 12 quadrat photographs of similar seagrass habitats for which the above-ground biomass had previously been measured. At the completion of ranking, the observer also ranked a series of at least five photographs of calibration quadrats that represented the range of seagrass observed during the survey. These calibration quadrats had previously been harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from the calibration quadrats were generated for each observer and applied to the biomass ranks given in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}; total and for each species).

2.4 Seagrass Meadow Mapping and Geographic Information System (GIS)

All survey data were entered into a Geographic Information System (GIS) developed for the HR2RP southern inshore zone using ArcGIS 10.7. Three GIS layers were created to describe seagrass features in the region: a seagrass site layer, seagrass meadow layer, and seagrass biomass interpolation layer.

Site layer
The site layer contains data collected at each site, including:

- Temporal details – survey date.
- Spatial details – latitude and longitude.
- Habitat information – sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); percent cover of seagrass, algae, and open substrate; presence/absence of DFTs.
- Sampling method and any relevant comments.

Interpolation layer
The interpolation layer describes spatial variation in seagrass biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

Meadow layer
The meadow (polygon) layer provides summary information for all sites within each of the three monitoring meadows, including:

- Temporal details – survey date.
- Habitat information – depth category (intertidal/subtidal), mean meadow biomass ± standard error (SE), meadow area (hectares) ± reliability estimate (R), number of sites within each meadow, seagrass species present, meadow density and community type, meadow landscape category (Figure 2).
- Meadow identification number – A unique number assigned to each monitoring meadow to allow comparisons over time.
- Sampling method and any relevant comments.

Meadow boundaries were constructed using seagrass presence/absence site data, field notes, GPS marked meadow boundaries, colour satellite imagery of the survey region (Source: Sentinel 2, courtesy Copernicus Open Access Hub www.scihub.copernicus.eu/; and Landsat 2017, courtesy ESRI), and aerial photographs taken during helicopter surveys.

Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were also assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow. The mapping precision for coastal seagrass meadows ranged from ±20 m for intertidal seagrass meadows with boundaries mapped by helicopter, to ±50 m for boundaries mapped by distance between sites with and without seagrass. The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Meadows were described using a standard nomenclature system. Seagrass community type is defined using the dominant species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Meadow density is based on mean biomass and the dominant species within the meadow (Table 2).

Isolated seagrass patches
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

Continuous seagrass cover
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

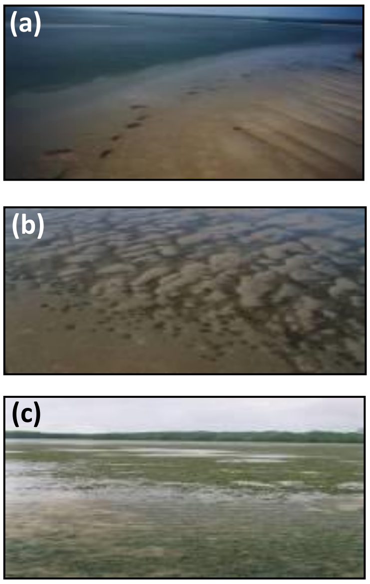


Figure 2. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

Table 1. Seagrass meadow community types.

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2. Seagrass meadow density categories.

	Mean above-ground biomass (g DW m^{-2})	
Density	*H. uninervis* (thin) / *Z. muelleri* subsp. *capricorni* (thin)	*H. ovalis* / *H. decipiens*
Light	< 1	< 1
Moderate	1 - 4	1 - 5
Dense	> 4	> 5

2.5 Seagrass Meadow Condition Index

A condition index is being developed for seagrass monitoring meadows in the HR2RP southern inshore marine zone based on changes in mean above-ground biomass, total meadow area, and species composition relative to a baseline. This is the first year that monitoring meadows in the southern inshore zone have been given preliminary grades. Seagrass condition for each indicator in each meadow is scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). A seagrass condition score for the southern inshore zone is expected for the HR2RP 2021 report card. This is when 5 years of baseline data will be available for each monitoring meadow, allowing overall meadow condition index to be calculated as the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it will contribute 50% of the overall meadow score, and the next lowest indicator (area or biomass) will contribute the remaining 50%. The flow chart in Figure 3 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score and grade calculations.

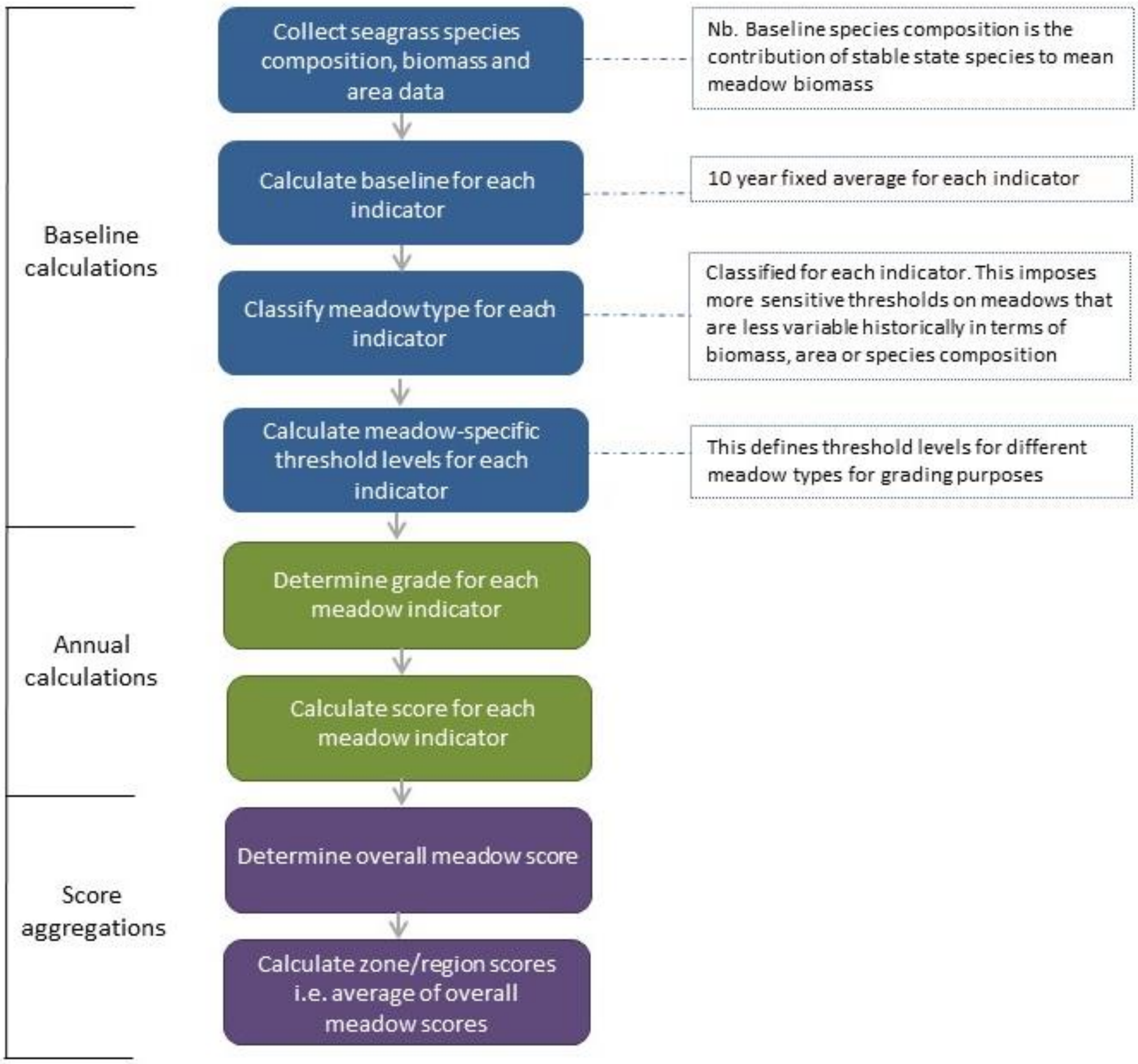


Figure 3. Process used to determine seagrass monitoring meadow condition grades and scores each year in the HR2RP southern inshore marine zone. Score aggregations will be applied and incorporated into the HR2RP regional waterway health report card when 5 years of monitoring data is available.

3 RESULTS

Four seagrass species were recorded during the 2019 survey: *Zostera muelleri* subsp. *capricorni* (abbreviated to *Z. capricorni* throughout this report), *Halodule uninervis*, *Halophila decipiens* and *Halophila ovalis* (Figure 4). Only the thin leaf morphologies of *Z. capricorni* and *H. uninervis* were observed.

Extensive seagrass habitat was recorded, with seagrass present at 79% of the 94 intertidal survey sites (Figure 5). The coastal meadows 6 and 7 were characterised by aggregated patches of seagrass, while Meadow 2 at Flock Pigeon Island had continuous seagrass cover (Figure 6).

Biomass in Meadow 2 was 2.6 $\pm$ 0.7 g DW m^{-2} in 2019, the largest recorded in three years of monitoring and a substantial increase from 2018 (0.9 ± 0.3 g DW m^{-2}). Biomass was therefore considered in very good condition as a preliminary assessment until such time as a longer baseline period is obtained by the monitoring program. Area condition in 2019 was considered good (101 ± 11 ha; Figures 7 and 10). Meadow 2 is dominated by *Z. capricorni*, although the contribution of this more stable species relative to *H. uninervis* has declined between 2017 and 2019 resulting in a preliminary species composition condition grade of good (Figure 7).

Meadow 6 is the largest monitoring meadow in the southern inshore zone. In 2019 record biomass (2.6 ± 0.2 g DW m^{-2}) and area (1421 ± 45 ha) resulted in these indicators being considered in very good condition (Figure 8). Meadow 6 is dominated by *H. uninervis*, however the increasing presence of the more stable species *Z. capricorni* between the 2017 and 2019 surveys is a positive sign for the stability of the meadow. The increasing contribution of *Z. capricorni* to meadow biomass and high proportion of *H. uninervis* resulted in a preliminary grade of very good for species composition (Figure 9).

Meadow 7 was redefined in 2019 to incorporate an area of seagrass that was previously labelled as Meadow 10 in 2018 (Carter and Rasheed 2019) and that had no seagrass in 2017 (Carter and Rasheed 2018). Meadow 7 had the greatest biomass (2.9 ± 0.5 g DW m^{-2}) and area (219 $\pm$ 27 ha) recorded since 2017 and were given preliminary grades of good and very good, respectively (Figure 9). The mean species composition of Meadow 7 is 50% *Z. capricorni*, with less stable species *H. uninervis* and *H. decipiens* making up the remainder of seagrass biomass. Species composition condition was considered very good in 2019 due to above-average contribution of *Z. capricorni* (Figure 9).

Biomass varied greatly among sites throughout all meadows, ranging from 0 to 6.8 g DW m^{-2} (Figures 7-9). Biomass was greatest in the southern section of Meadow 6, which coincided with the highest number of dugong feeding trails (Figure 10). No dugong feeding was recorded in Meadow 2.

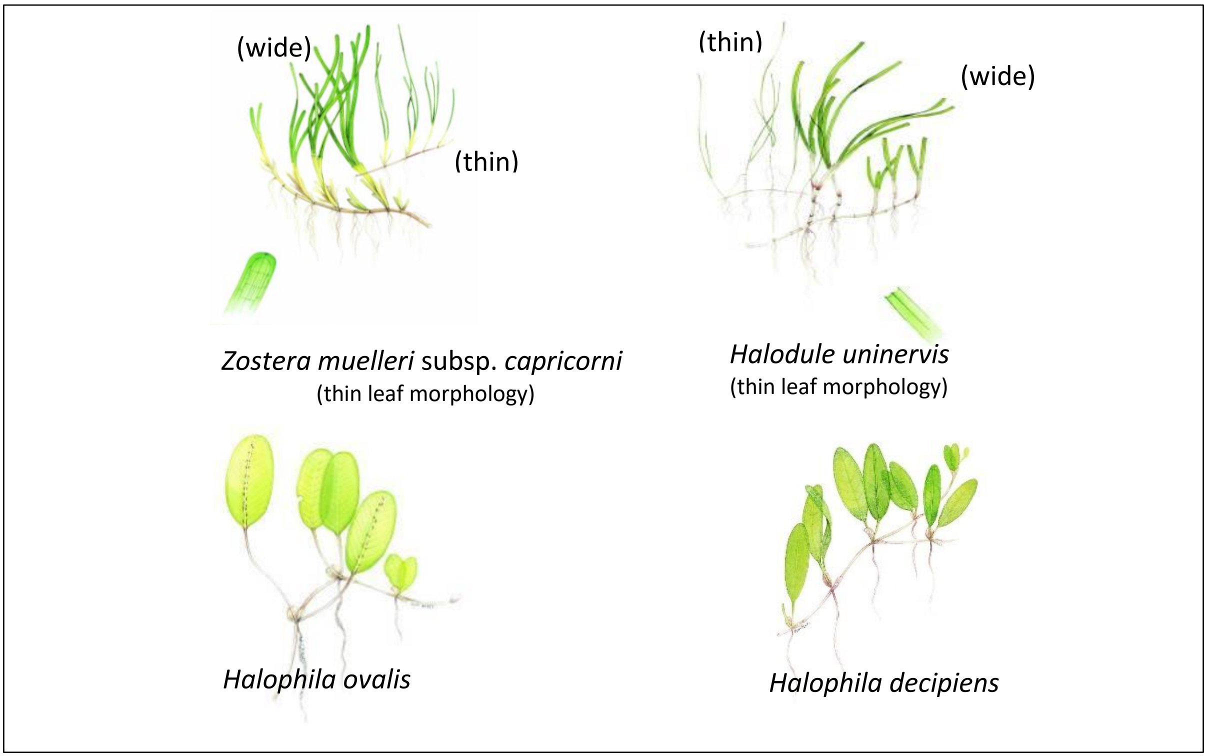


Figure 4. Seagrass species present in the HR2RP southern inshore marine zone during the September 2019 survey.

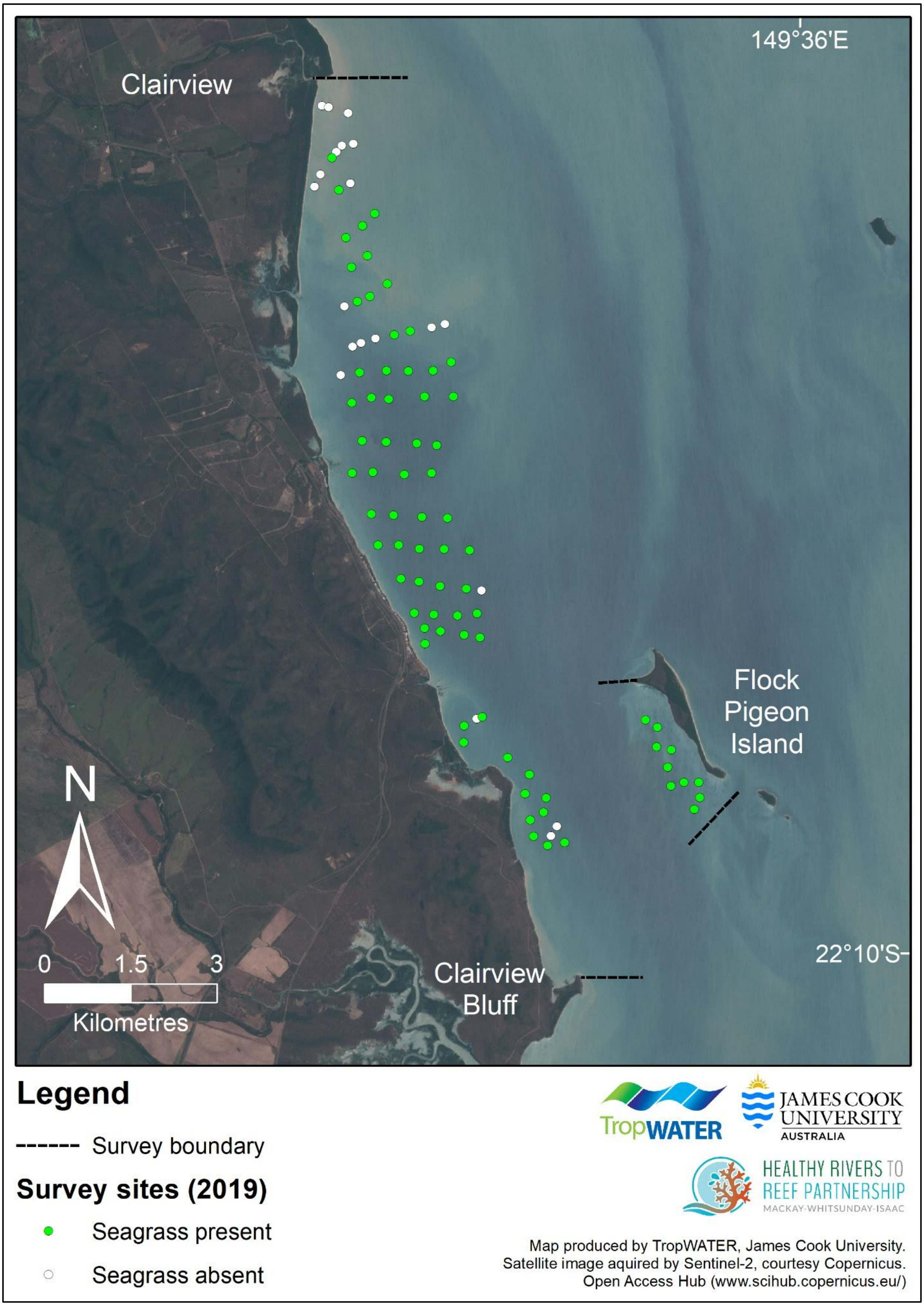


Figure 5. Location of intertidal survey sites in the southern inshore marine zone with seagrass presence/absence in 2019.

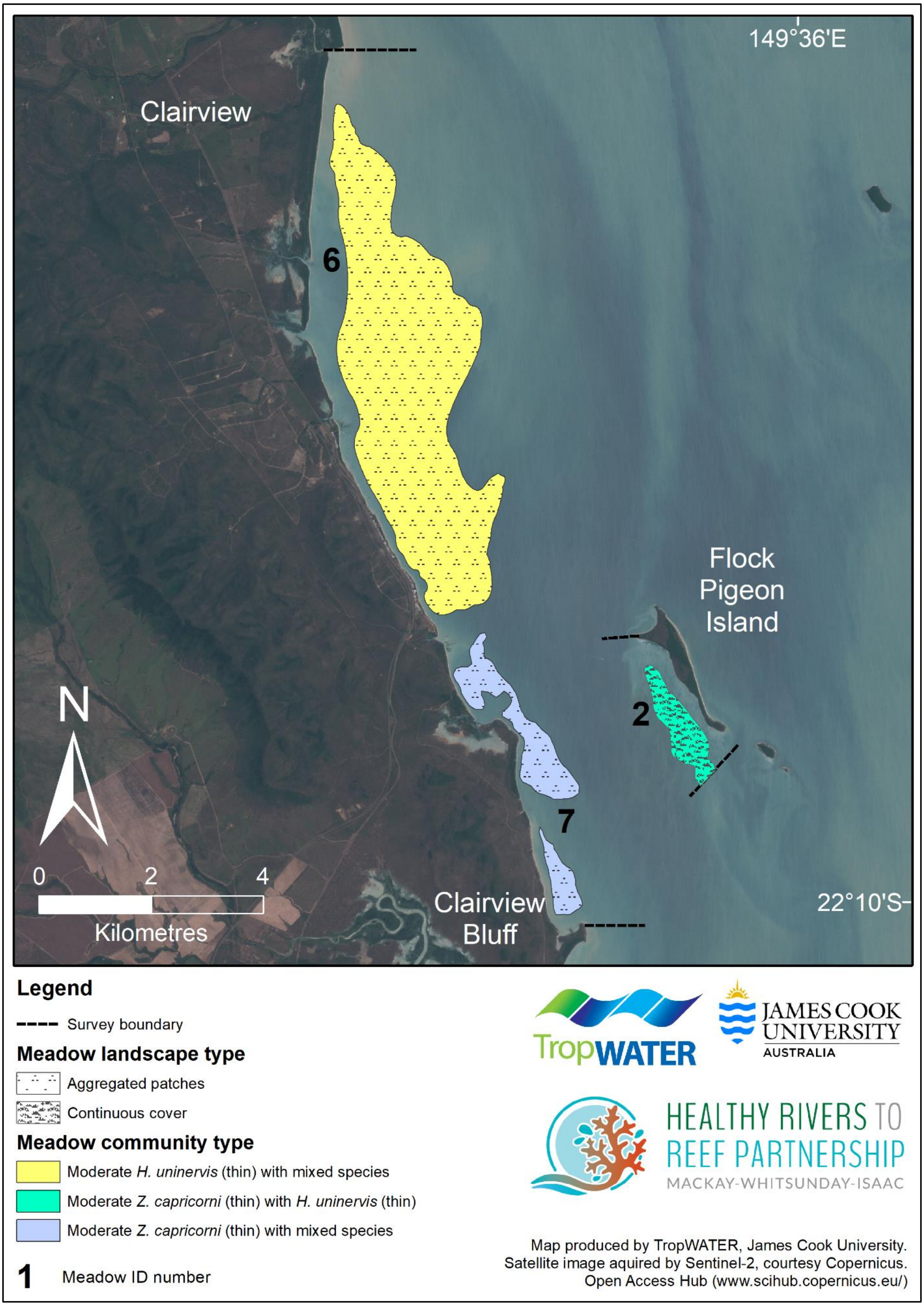


Figure 6. Seagrass monitoring meadow landscape categories and community types in 2019.

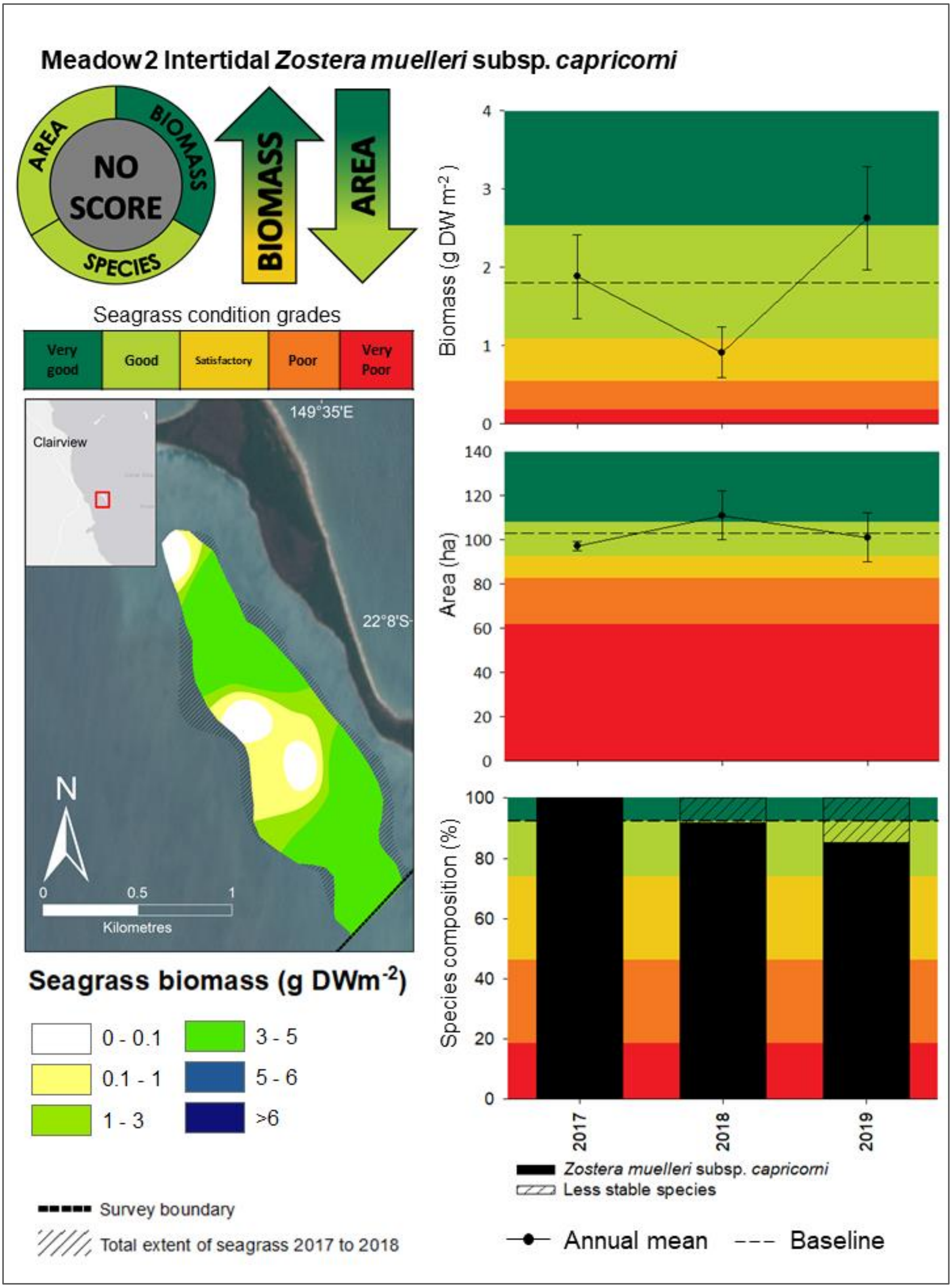


Figure 7. Changes in biomass, area and species composition for Meadow 2, 2017 - 2019 (biomass error bars = SE; area error bars = "R" reliability estimate).

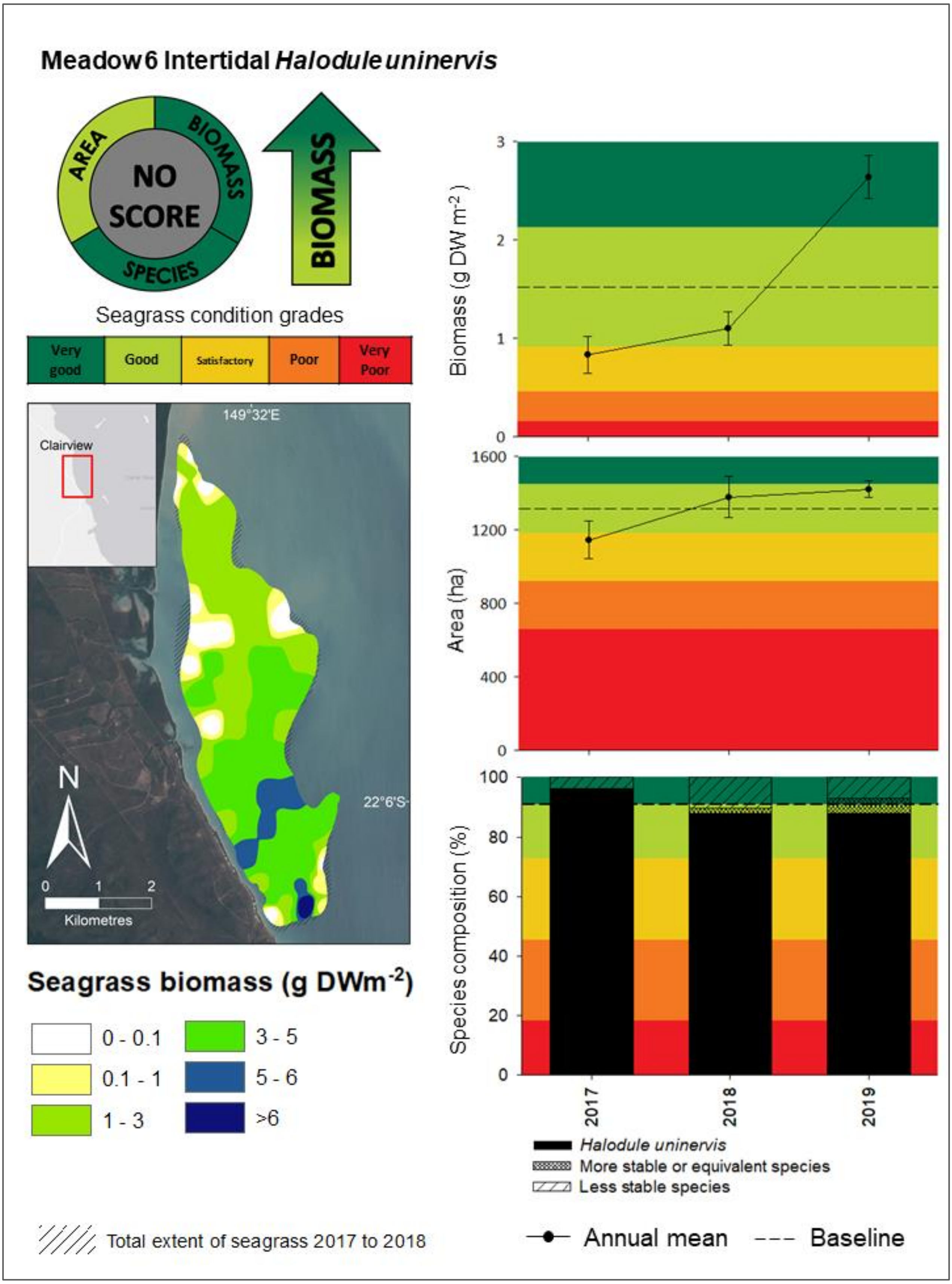


Figure 8. Changes in biomass, area and species composition for Meadow 6, 2017 - 2019 (biomass error bars = SE; area error bars = "R" reliability estimate).

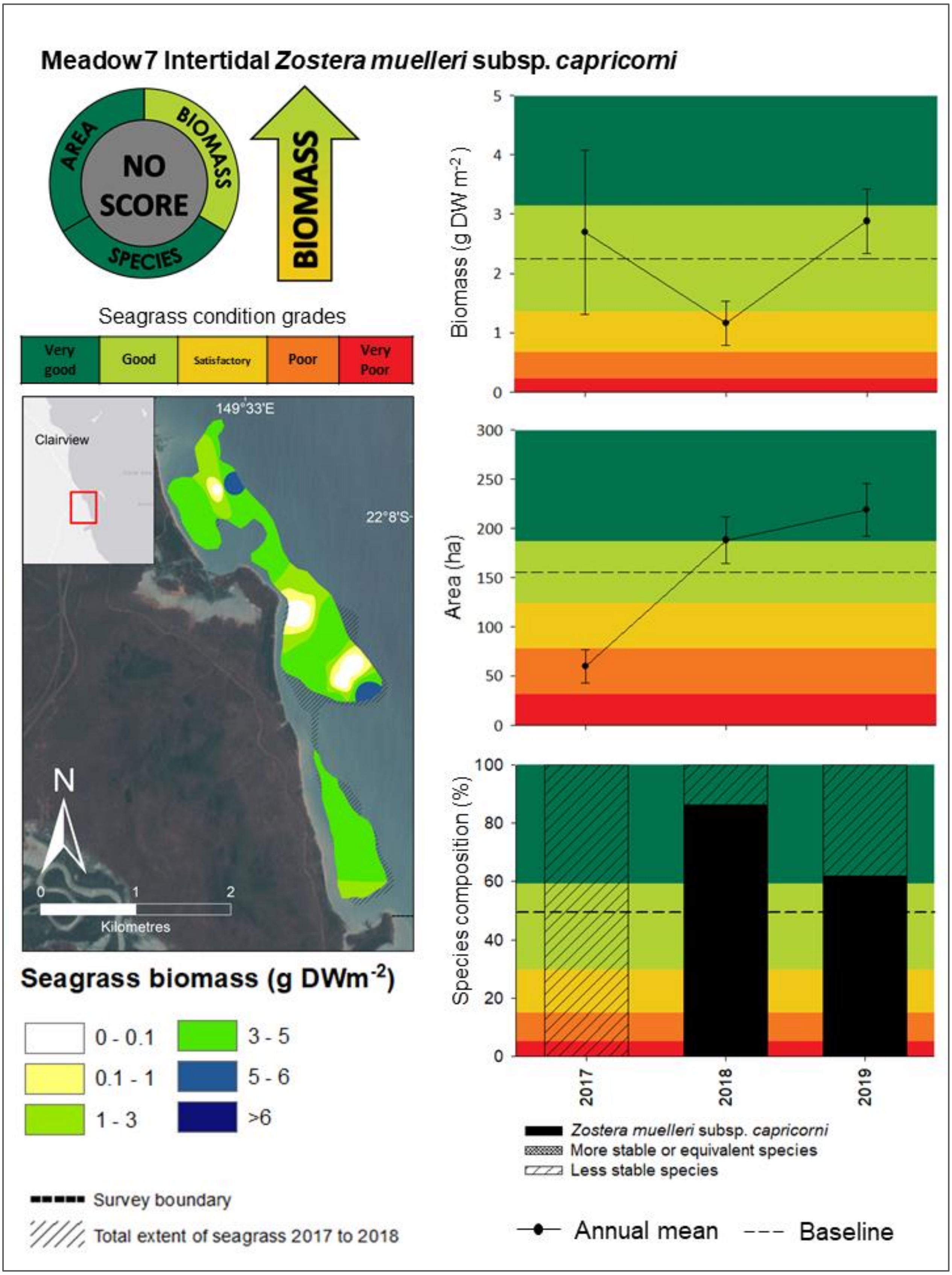


Figure 9. Changes in biomass, area and species composition for Meadow 7, 2017 - 2019 (biomass error bars = SE; area error bars = "R" reliability estimate).

4 DISCUSSION

This is the third year of seagrass monitoring in the southern inshore marine zone of the HR2RP report card. In 2019 seagrass results were positive, with two of the three meadows covering the largest area, and in all three meadows the greatest biomass since monitoring began. Meadows were also dominated by the larger and more stable species found in the survey region, *Z. capricorni* and *H. uninervis,* further indicating seagrasses were in good condition. Dugong feeding trails were recorded in the higher biomass areas of both coastal seagrass meadows in 2019.

In this report we provide interim scores for the three seagrass indicators (area, biomass and species composition) using the standard methodology applied for score development throughout the HR2RP sites (Carter *et al.* 2015). The grades are preliminary as they are only based on 3 monitoring events, but all indicators were rated as good to very good condition. These grades should be treated with caution at this stage and are subject to change as the program matures and more baseline data is collected that will encompass the expected natural variability in seagrass conditions.

The relatively low biomass of these monitoring meadows is typical for coastal seagrasses in the Mackay-Whitsunday-Isaac region (Davey and Rasheed 2018; York and Rasheed 2018). This is due to the relatively harsh environmental conditions for inshore seagrasses here compared to some other areas of the GBR, including large currents, extended periods of tidal exposure, and naturally turbid water conditions that largely restrict seagrass meadows to intertidal banks where they receive adequate light for growth.

Despite their seemingly low above-ground biomass, these meadows play an important role in the region's marine ecology. Seagrasses are a critical food source for dugong and green turtle (Heck *et al.* 2008; Unsworth and Cullen 2010) and the large intertidal seagrass meadows in the Clairview region appear to be highly utilised by both species. Dugong feeding trails in 2019 were concentrated around areas of high seagrass biomass within the meadows (Figure 10) and continued the pattern of high use recorded in the two previous surveys in the monitoring program. The value of the Clairview region to dugongs is recognised by the declaration of a Dugong Protection Area, and dugong are also an iconic image for the Clairview community highlighted in road signage and tourist information. Dugong and turtle are vulnerable to large-scale seagrass loss, with previous increases in mortality from starvation recorded in response to seagrass loss along Queensland's east coast in 2011 (DERM 2011). The monitoring program in the Mackay-Whitsunday–Isaac southern inshore zone provides key information on the state of seagrass that can assist in the management of the region's green turtle and dugong populations.

It is likely that seagrasses in the southern inshore zone have been recovering from below average conditions from the beginning of the current monitoring program in 2017. Monitoring in the zone commenced immediately after the region was hit with a series of cyclones from 2011 onwards, with the last significant event being tropical cyclone Debbie early in 2017. These weather events contributed towards severe wet seasons accompanied by heavy rainfall, flooding and strong winds in the area. This culmination of severe environmental conditions were the likely cause of seagrass condition declines recorded in neighbouring inshore zones within the Mackay-Whitsunday–Isaac region where long-term monitoring has been in place, such as Abbot Point and Hay Point in 2017 (Davey and Rasheed 2018; York and Rasheed 2018). As the southern inshore zone monitoring program only began in 2017, it is difficult to confidently define what a "healthy" seagrass condition is at this early stage. However, the improvements in seagrass condition (particularly biomass and area) since 2017 in line with favourable weather conditions generally reflect the recovery recorded at other nearby monitoring locations (Van De Wetering *et al.* 2020b; York and Rasheed 2020). Full recovery from large-scale disturbances can take anywhere from 2-4 years (Preen *et al.* 1995) or upwards of 5 years (Birch and Birch 1984) dependant on the severity of the initial event and any subsequent disturbances that may occur.

The first three years of monitoring have shown that seagrass biomass within meadows presents a shifting spatial mosaic of biomass “hot-spots” through time (Figure 10). Substantial variation has been observed from year to year in the locations within meadows that have the highest and lowest biomass rather than seagrass coverage being uniform across the entire meadow. With such dynamic and spatially variable meadows a monitoring strategy that examines the entire meadow gives a much more accurate assessment of regional seagrass condition than could be achieved using smaller-scale fixed assessment approaches. Spatial variation caused by aggregated distribution patterns can significantly influence the precision and interpretation of time series analyses, and the scale of sampling relative to the distributional pattern of the organisms to be sampled is critically important (Greig-Smith 1983). In addition, meadow scale sampling provides a critical insight into the overall amount of seagrass available in the region by mapping changes to the spatial extent of around two thirds of the known seagrass distribution of the southern inshore zone (Carter and Rasheed 2018).

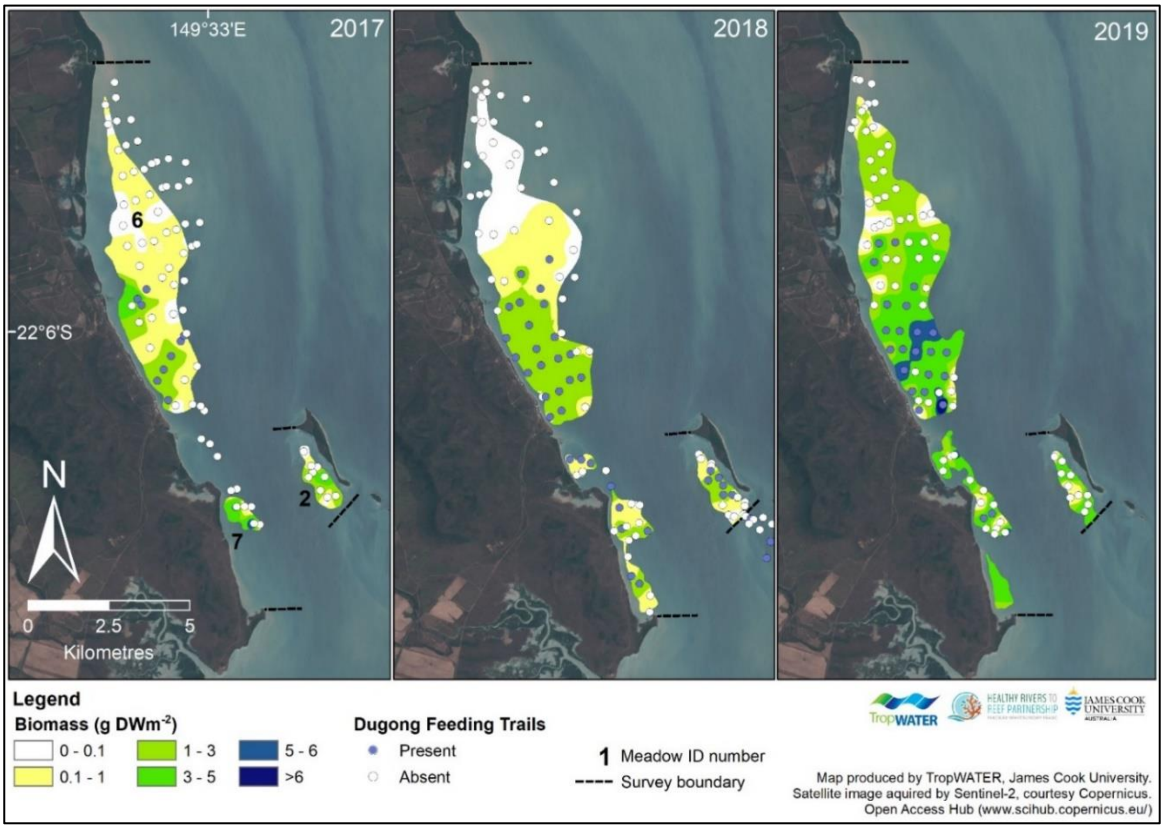


Figure 10. Variation in intertidal seagrass biomass within monitoring meadows, and presence of dugong feeding trails, 2017-2019.

The Mackay-Whitsunday-Isaac HR2RP provides a valuable opportunity to understand seagrass communities within the southern inshore zone. These surveys fill an important information gap for the regional report card. After 3 years of surveys, a preliminary assessment of seagrass condition in the zone has been presented. However, these scores should be interpreted with a high degree of caution as they are based on only limited understanding of the natural variability and range of conditions for seagrasses in the area. Previous analysis has shown that seagrasses in north Queensland require a 10 year history in order to best describe their base condition. This is because 10 years generally encompasses the range of environmental conditions that could influence seagrass condition such as El Niño Southern Oscillation cycles (Bryant *et al.* 2014). The approach of the QPSMP monitoring programs is therefore to wait 5 years to produce a reportable score, and the baseline is updated until 10 years of data is collected. Ongoing monitoring will build our understanding of seagrass communities and the robustness of our condition assessments into the future. For this reason, we recommend that scores are not incorporated into the HR2RP report card until 5 years of data has been collected.

5 REFERENCES

Abal, E., and Dennison, W. (1996). Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. *Marine and Freshwater Research* **47**, 763-771.

Birch, W., and Birch, M. (1984). Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia: A decade of observations. *Aquatic Botany* **19**, 343-367.

Bryant, C., Jarvis, J.C., York, P., and Rasheed, M. (2014). Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 14/53, James Cook University, Cairns.

Carter, A., and Rasheed, M. (2018). Mackay-Whitsunday 2017 Baseline Seagrass Survey: Marine Inshore South Zone. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 18/08, James Cook University, Cairns.

Carter, A.B., Jarvis, J.C., Bryant, C.V., and Rasheed, M.A. (2015). Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 15/29, James Cook University, Cairns.

Carter, A.B., and Rasheed, M.A. (2019). Mackay-Whitsunday Seagrass Monitoring 2018: Marine Inshore South Zone. Centre for Tropical Water & Aquatic Ecosystem Research Publication 19/05. James Cook University, Cairns.

Coles, R., McKenzie, L., De'ath, G., Roelofs, A., and Long, W.L. (2009). Spatial distribution of deepwater seagrass in the inter-reef lagoon of the Great Barrier Reef World Heritage Area. *Marine Ecology Progress Series* **392**, 57-68.

Coles, R.G., Lee Long, W.J., McKenzie, L.J., and Roder, C.A. (2002). Seagrass and Marine Resources in the Dugong Protection Areas of Upstart Bay, Newry Region, Sand Bay, Llewellyn Bay, Ince Bay and the Clairview Region: April/May 1999 and October 1999. Great Barrier Reef Marine Park Authority, Townsville.

Coles, R.G., Mellors, J., Biddy, J.M., Derbyshire, K.J., Squire, B.A., Squire, L.C., and Lee Long, W.J. (1987). Distribution of seagrasses and associated juvenile commercial prawns and fish between Bowen and Water Park Point. A report to the Great Barrier Reef Marine Park Authority. Queensland Department of Primary Industries, Brisbane.

Collier, C.J., Chartrand, K., Honchin, C., Fletcher, A., and Rasheed, M. (2016). Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme, Cairns.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., and Turner, R.K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change* **26**, 152-158.

Davey, P., and Rasheed, M. (2018). Port of Abbot Point Long-Term Seagrass Monitoring Program - 2017. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns.

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W., and Batiuk, R.A. (1993). Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. *BioScience* **43**, 86-94.

DERM (2011). Marine strandings update December 2011. Department of Environment and Resource Management (DERM), Queensland, Australia.

Fourqurean, J.W., Duarte, C.M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M.A., Apostolaki, E.T., Kendrick, G.A., Krause-Jensen, D., and McGlathery, K.J. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* **5**, 505-509.

Fourqurean, J.W., Manuel, S., Coates, K.A., Kenworthy, W.J., and Smith, S.R. (2010). Effects of excluding sea turtle herbivores from a seagrass bed: Overgrazing may have led to loss of seagrass meadows in Bermuda. *Marine Ecology Progress Series* **419**, 223-232.

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., Taylor, H., and Coles, R. (2012). A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. *Environmental Research Letters* **7**, 024006.

Greig-Smith, P. (1983) Quantitative plant ecology. 3rd edn Blackwell Scientific Publications. In '.' (Oxford)

Heck, K.L., Carruthers, T.J.B., Duarte, C.M., Hughes, A.R., Kendrick, G., Orth, R.J., and Williams, S.W. (2008). Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems* **11**, 1198-1210.

Hemminga, M.A., and Duarte, C.M. (2000). 'Seagrass Ecology.' (Cambridge University Press: Cambridge, United Kingdom.)

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G.A., Scanes, P., McKenzie, L., O'Brien, K.R., Lyons, M., Ferguson, A., Maxwell, P., Glasby, T., and Udy, J. (2015). Unravelling complexity in seagrass systems for management: Australia as a microcosm. *Science of The Total Environment* **534**, 97-109.

Kirkman, H. (1978). Decline of seagrass in northern areas of Moreton Bay, Queensland. *Aquatic Botany* **5**, 63-76.

Lamb, J.B., van de Water, J.A.J.M., Bourne, D.G., Altier, C., Hein, M.Y., Fiorenza, E.A., Abu, N., Jompa, J., and Harvell, C.D. (2017). Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. *Science* **355**, 731-733.

McKenna, S., Chartrand, K., Van De Wetering, C., Wells, J., Carter, A., and Rasheed, M. (2020). Port of Townsville Seagrass Monitoring Program: 2019. James Cook University, Cairns.

McKenna, S., Jarvis, J., Sankey, T., Reason, C., Coles, R., and Rasheed, M. (2015). Declines of seagrasses in a tropical harbour, North Queensland, Australia, are not the result of a single event. *Journal of Biosciences* **40**, 389-398.

Mellors, J.E. (1991). An evaluation of a rapid visual technique for estimating seagrass biomass. *Aquatic Botany* **42**, 67-73.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., and Williams, S.L. (2006). A global crisis for seagrass ecosystems. *Bioscience* **56**, 987-996.

Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., Bartlett, C., Browne, M., Campbell, N., Cannard, T., Cappo, M., Carini, G., Chalmers, S., Cheers, S., Chetwynd, D., Colefax, A., Coles, R., Cook, S., Davie, P., De'ath, G., Devereux, D., Done, B., Donovan, T., Ehrke, B., Ellis, N., Ericson, G., Fellegara, I., Forcey, K., Furey, M., Gledhill, D., Good, N., Gordon, S., Haywood, M., Hendriks, P., Jacobsen, I., Johnson, J., Jones, M., Kinninmoth, S., Kistle, S., Last, P., Leite, A., Marks, S., McLeod, I., Oczkowicz, S., Robinson, M., Rose, C., Seabright, D., Sheils, J., Sherlock, M., Skelton, P., Smith, D., Smith, G., Speare, P., Stowar, M., Strickland, C., Van der Geest, C., Venables, W., Walsh, C., Wassenberg, T., Welna, A., and Yearsley, G. (2007). Seabed Biodiversity on the Continental Shelf of the Great Barrier Reef World Heritage Area. AIMS/CSIRO/QM/QDPI CRC Reef Research Task Final Report.

Preen, A.R., Lee Long, W.J., and Coles, R.G. (1995). Flood and cyclone related loss, and partial recovery, of more than 1000 km^2 of seagrass in Hervey Bay, Queensland, Australia. *Aquatic Botany* **52**, 3-17.

Rasheed, M., Hoffmann, L., Reason, C., and McKenna, S. (2020). Port of Weipa long-term seagrass monitoring program, 2000 - 2019. James Cook University, Cairns.

Reason, C., McKenna, S., and Rasheed, M. (2020). Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2019. James Cook University, Cairns.

Robblee, M.B., Barber, T.R., Carlson, P.R., Jr., Durako, M.J., Fourqurean, J.W., Muehlstein, L.K., Porter, D., Yarbro, L.A., Zieman, R.T., and Zieman, J.C. (1991). Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). *Marine Ecology Progress Series* **71**, 297-299.

Roder, C.A., Coles, R.G., McKenzie, L.J., and Lee Long, W.J. (2002). Seagrass Resources of the Clairview Region Dugong Protection Area - Reconaissance 1999. In 'Seagrass and Marine Resources in the Dugong Protection

Areas of Upstart Bay, Newry Region, Sand Bay, Ince Bay, Llewellyn Bay and Clairview Region, April/May 1999 and October 1999. Final report to Great Barrier Reef Marine Park Authority, research publication no.72. (Eds R. G. Coles, W. J. Lee Long, L. J. McKenzie and C. A. Roder.) pp. 85-115: Cairns)

Scott, A.L., York, P.H., Duncan, C., Macreadie, P.I., Connolly, R.M., Ellis, M.T., Jarvis, J.C., Jinks, K.I., Marsh, H., and Rasheed, M.A. (2018). The Role of Herbivory in Structuring Tropical Seagrass Ecosystem Service Delivery. *Frontiers in Plant Science* **9**.

Shepherd, L., Wilkinson, J., Carter, A., and Rasheed, M. (2020). Port of Karumba Long-term Annual Seagrass Monitoring 2019. James Cook University, Cairns.

Smith, T., Chartrand, K., Wells, J., Carter, A., and Rasheed, M. (2020). Seagrasses in Port Curtis and Rodds Bay 2019 Annual long-term monitoring and whole pot survey. James Cook University, Cairns.

Unsworth, R.K.F., and Cullen, L.C. (2010). Recognising the necessity for Indo-Pacific seagrass conservation. *Conservation Letters* **3**, 63-73.

Van De Wetering, C., Carter, A., and Rasheed, M. (2020a). Seagrass habitat of Mourilyan Harbour: Annual Monitoring Report – 2019. James Cook University, Cairns.

Van De Wetering, C., Reason, C., Rasheed, M., Wilkinson, J., and York, P. (2020b). Port of Abbot Point Long-Term Seagrass Monitoring Program - 2019. James Cook University, Cairns.

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., and Williams, S.L. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* **106**, 12377-12381.

Wells, J., Rasheed, M., and Coles, R. (2019). Seagrass Habitat in the Port of Thursday Island: Annual Monitoring Report 2019. James Cook University, Cairns.

York, P., Carter, A., Chartrand, K., Sankey, T., Wells, L., and Rasheed, M. (2015). Dynamics of a deep-water seagrass population on the Great Barrier Reef: Annual occurrence and response to a major dredging program. *Scientific Reports* **5**, 13167.

York, P., and Rasheed, M. (2020). Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2019. James Cook University, Cairns.

York, P.H., and Rasheed, M.A. (2018). Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2017. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 18/13. James Cook University, Cairns.

6 APPENDICES

Appendix 1. Seagrass Condition Calculations

A1.1 Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition will be established from annual means calculated over the first 10 years of monitoring, following the methods of Carter *et al.* (2015) and Bryant *et al.* (2014).

Baseline conditions for species composition are based on the annual percent contribution of each species to mean meadow biomass of the baseline years. Meadows are classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). Where a meadow baseline contains an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline is set according to the percent composition of the more persistent/stable species of the two (see A1.4 Grade and Score Calculations and Figure A1.1).

A1.2 Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow is used to determine historical variability. Meadow biomass and species composition are classified as either stable or variable (Table A1.1). Meadow area is classified as either highly stable, stable, variable, or highly variable (Table A1.1). The CV is calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

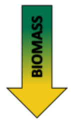
Table A1.1 Coefficient of variation (CV; %) thresholds used to classify stability or variability of meadow biomass, area and species composition.

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

A1.3 Threshold Definition

Seagrass condition for each indicator is assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), and very poor (E)). Threshold levels for each grade are set relative to the baseline and based on meadow class. This approach accounts for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A1.2).

Table A1.2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

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

A1.4 Grade and Score Calculations

A score system (0–1) and score range is applied to each grade to allow numerical comparisons of seagrass condition (see Carter *et al.* 2015 for a detailed description, and Table A1.3). Score calculations for each meadow's condition require calculating the biomass, area and species composition for that year (see A1.1 Baseline Calculations, above), allocating a grade for each indicator by comparing the current year's values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade. Scaling was required because the score range in each grade was not equal (Table A1.3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition is set as 100% (as a species could never account for >100% of species composition). For biomass and area, the upper limit is set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.

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

Table A1.3. Score range and grading colours used in the seagrass 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 is determined to be anything less than in "perfect" condition (i.e. a score <1), a decision tree is used to determine whether equivalent and/or more persistent species are driving this grade/score (Figure A1.1). If this is the case then the species composition score and grade for that year is recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1.1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *H. uninervis* 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 is 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* 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 A1.1).

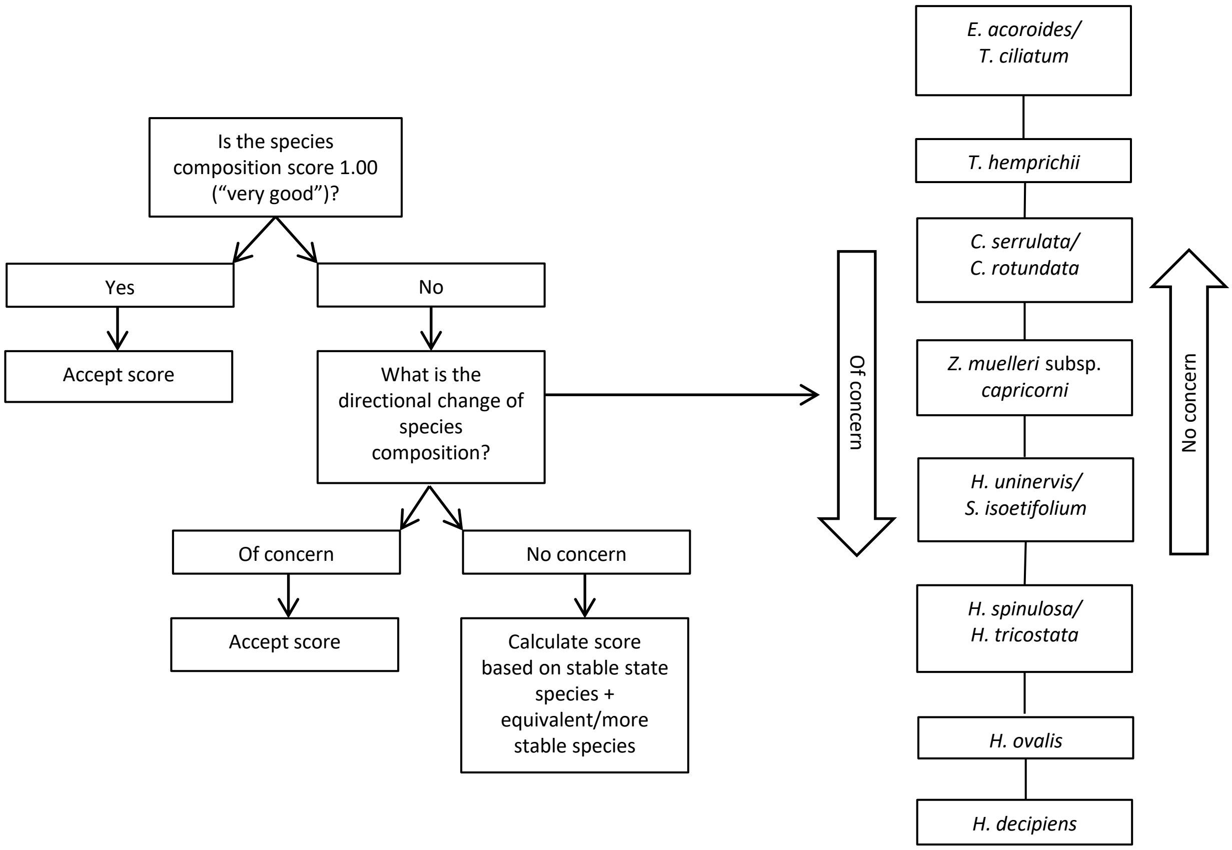


Figure A1.1. (a) Decision tree and (b) directional change assessment for grading and scoring seagrass species composition.

A1.5 Score Aggregation

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

Appendix 2. Biomass score calculation example

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

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

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

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

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

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

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

4. Calculate the proportion of the good grade (B_{prop}) that B_{2019} takes up:

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

5. Determine the biomass score for 2019 ($Score_{2019}$) by scaling B_{prop} against the score range (SR) for the good grade (SR_{good}), i.e. 0.20 units (see Table A1.3):

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

Where LB_{good} is the defined lower bound (LB) score threshold for the good grade, i.e. 0.65 units.