SEAGRASS HABITAT OF MOURILYAN HARBOUR: Annual Monitoring Report – 2020

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SEAGRASS HABITAT OF MOURILYAN HARBOUR:
Annual Monitoring Report – 2020

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

Report No. 21/10

April 2021

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KEY FINDINGS

Seagrass Condition 2020

Very Poor

1. Seagrass was in a very poor condition in Mourilyan Harbour in 2020, declining from poor in 2019.
2. Seagrass was present in three of the five monitoring meadows, all dominated by small colonising *Halophila* species. The condition of meadows vary between very poor, poor and satisfactory.
3. Throughout the year environmental conditions in Mourilyan appeared favourable for seagrass growth, however, September saw double the average rainfall for that month which may have reduced the condition for *Halophila* species prior to the survey.
4. The continued absence of the foundation species *Zostera muelleri* is the principal factor leading to the poor to very poor condition of Mourilyan Harbour seagrasses. An extended period of *La Nińa* weather conditions that included floods and cyclones from 2009-2011 saw this species disappear.
5. The loss of *Zostera muelleri* has impacts on ecosystem functions and services within the estuary with likely consequences being a reduced capacity for juvenile fish habitat, carbon storage and sediment stabilisation and accretion.
6. Restoration appears the best option to re-establish *Zostera muelleri* in Mourilyan Harbour.

IN BRIEF

Seagrasses in Mourilyan Harbour have been monitored annually since 2000, following initial assessments conducted between 1993 and 1996. Five seagrass meadows are monitored annually. These meadows represent the range of different seagrass community types found in Mourilyan Harbour, and are assessed for changes in biomass, area and species composition. These indicators are used to develop a seagrass condition index (see section 2.5.1 of this report for further details).

Overall seagrass condition was very poor in 2020, declining from poor the previous year. Seagrass was only present at three of the five monitoring meadows which are dominated by colonising *Halophila spp*. and are highly variable in abundance and distribution. In 2020 the meadow condition of both the Seaforth Edge (4) and Channel (5) stayed consistent with 2019 as poor and satisfactory respectively, despite a slight decline in biomass in these subtidal meadows. The intertidal Seaforth Bank (3) meadow condition declined to poor due to a large decline in area and a species shift from *H. ovalis* to *H. decipiens*. The overall meadow condition of seagrasses in Mourilyan Harbour is heavily influenced by the absence of *Zostera muelleri* from Bradshaw (1) and Lily (2) meadows. This species was absent again in 2020 and has not been present in these meadows since 2009 and 2008 respectively.

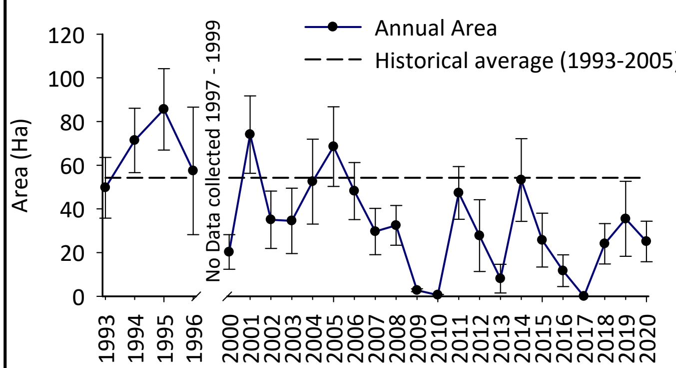

Figure 1: Mourilyan Harbour seagrass monitoring meadow total area (Ha) from 1993 to 2020.

Environmental and climate variables seemed favourable to seagrass growth with below average river flows and low levels of daytime tidal exposure. This is supported observationally by the presence of a healthy narrow meadow of *Halodule uninervis* along the sand bank on the northern side of the channel and isolated patches of *Enhalus acoroides* persisting on Seaforth Bank. While the average annual rainfall at Mourilyan was below the long term average in 2020, the rainfall in September, the month before the survey, was double the monthly long term average. This may have led to a decline in water quality and light availability in the period leading up to the survey and resulted in a decline in meadow area and biomass. *Halophila* species have been shown to have much lower resistance to light deprivation than other seagrass species with decline and mortality occurring in days to weeks rather than months for other larger seagrass species.

The continued absence of the foundation species *Z. muelleri* from the Bradshaw and Lily Island meadows since 2009-2010 indicates that a recruitment bottleneck is likely to be inhibiting the re-establishment of this species in Mourilyan Harbor. This absence also reduces the effectiveness of important ecosystem functions within the estuary such as nursery habitat for juvenile fish and prawns, storage of carbon in sediments and sediment stabilisation and particle trapping that improve water quality. This highlights the need for restoration of *Z. muelleri* at the site to be prioritised. In 2020, TropWATER, in partnership with OzFish Unlimited undertook a small and successful pilot study using vegetative fragments of *Z. muelleri,* which will assist to inform further restoration trials or ultimately a large-scale restoration project to return the seagrass to its previous healthy condition and re-establish the vital ecological functions that it can provide.

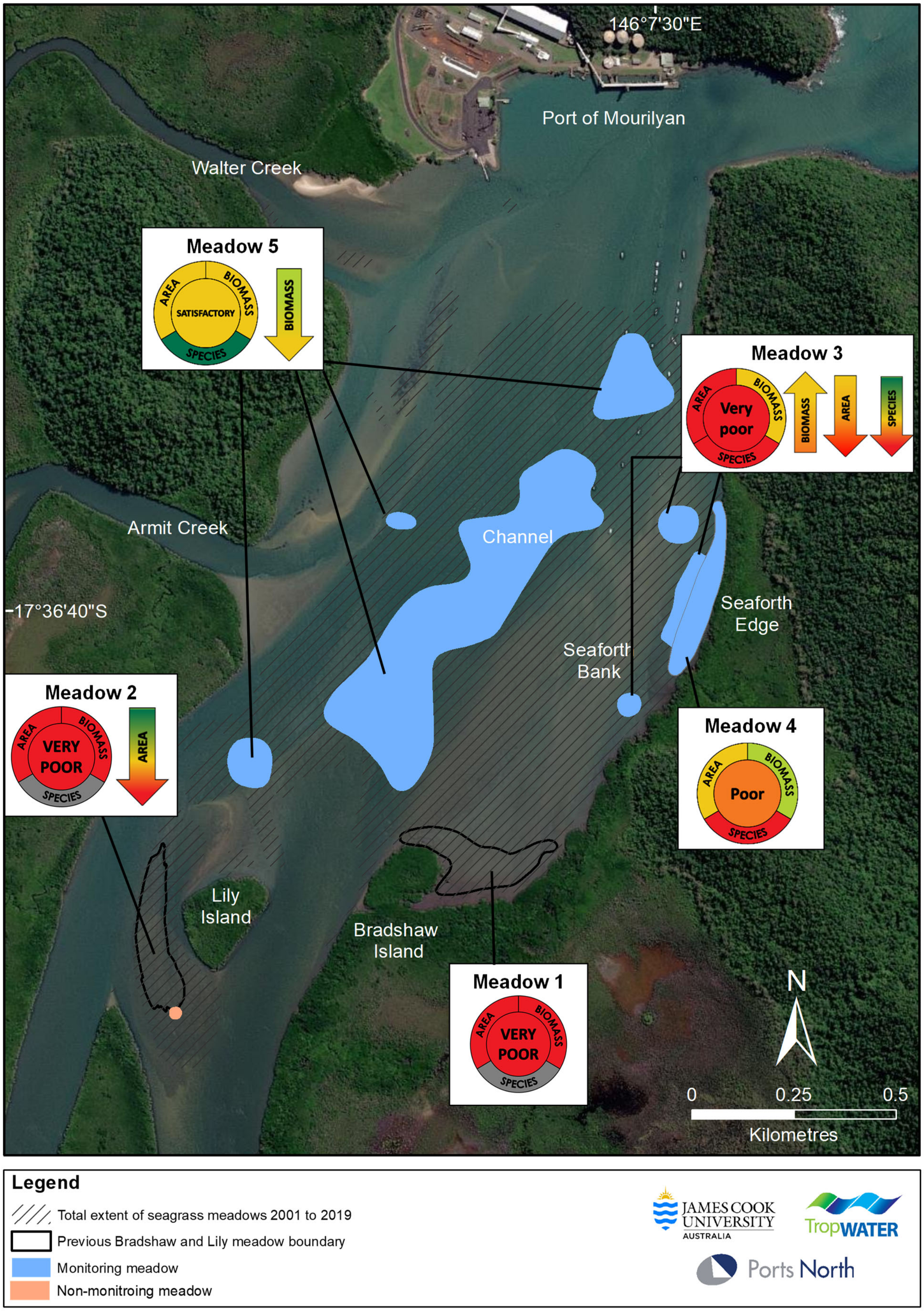

Figure 2. Seagrass condition for Mourilyan Harbour seagrass meadows in 2020.

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1 INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services worth substantial economic value (Costanza et al. 2014). These services include the provision of nursery habitat for economically-important fish and crustaceans (Coles et al. 1993; Heck et al. 2003; Hayes et al. 2020), and food for grazing megaherbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018; Scott et al. 2020). Seagrasses also play a major role in the cycling of nutrients (McMahon and Walker 1998), sequestration of carbon (Fourqurean et al. 2012; Lavery et al. 2013; York et al. 2018), stabilisation of sediments (James et al. 2019), and the improvement of water quality (McGlathery et al. 2007).

Globally, seagrasses have been declining due to natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution and eutrophication (Short and Wyllie-Echeverria 1996). In the Great Barrier Reef (GBR) coastal region, the hot spots with highest threat exposure for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot-spots arise as seagrasses occur in the same sheltered coastal locations where ports and urban centres are established (Coles et al. 2015). In Queensland this has been recognised and a strategic monitoring program of these high risk areas has been established to aid in their management (Coles et al. 2015).

1.1 Queensland ports seagrass monitoring program

The majority of Queensland's commercial ports have a long-term seagrass monitoring program. The program was developed by the Seagrass Ecology Group at James Cook University's (JCU) Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. A common program, methods and rationale provides a network of seagrass monitoring locations comparable across the State (Figure 3).

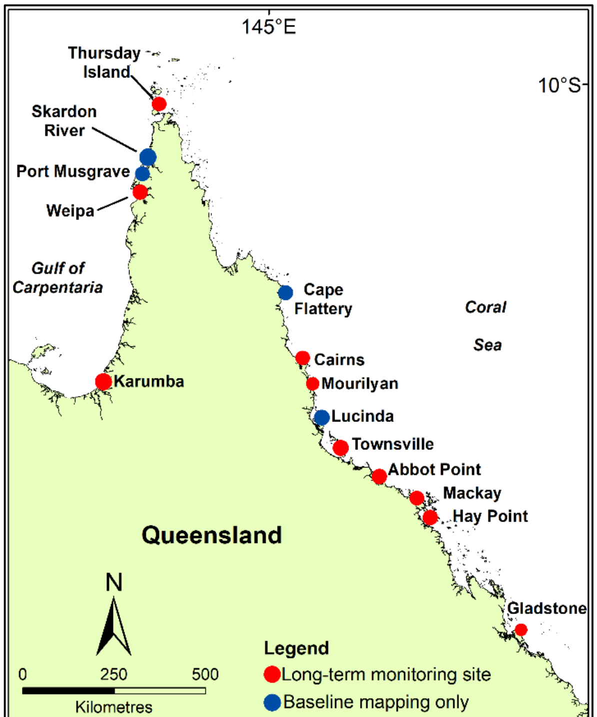


Figure 3. Location of Queensland ports seagrass monitoring locations.

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

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

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

1.2 Mourilyan Harbour monitoring program

Initial seagrass surveys were conducted between 1993 and 1996, then an annual monitoring program was established in 2000. Five meadows were selected for annual monitoring that represented the range of seagrass species and habitat types (intertidal and subtidal) identified within the port limits. This monitoring program has provided critical information on variation in seagrass communities and the links between seagrass change and climate.

Seagrass monitoring is conducted between October and December each year, and provides an assessment of seagrass condition and resilience that informs port management. Expanded seagrass surveys occur periodically to assess the state of seagrass across the whole harbour; these were most recently conducted in 2015 and 2018.

This report presents findings from the 2020 monitoring survey, including:

- Maps of seagrass distribution, abundance, and species composition within the annual monitoring meadows;
- Assessments and comparison of seagrass condition in the monitoring meadows within the context of historical seagrass conditions, and discussion of the observed changes in a regional and state-wide context;
- Overview of environmental conditions that are likely to impact seagrass condition;
- Discussion of the implications of monitoring results in relation to the overall health of the marine environment in the harbour, and advice for management.

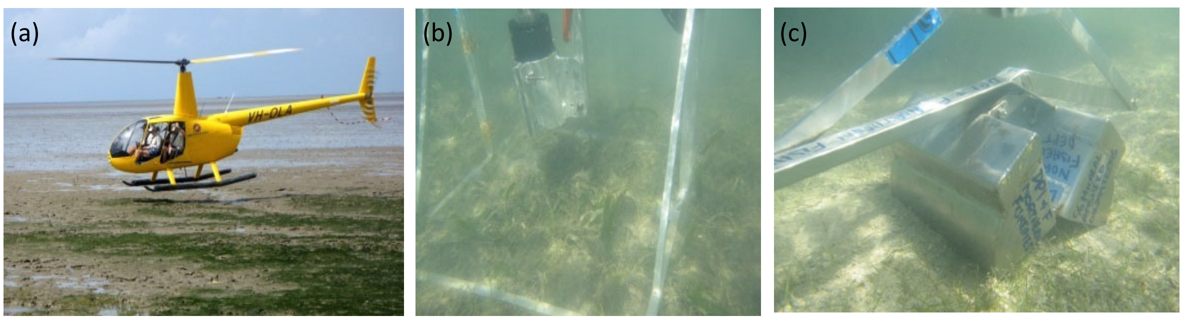
2 METHODS

2.1 Field surveys

The survey involved mapping and assessing the 5 annual monitoring meadows in Mourilyan Harbour during the seasonal peak of seagrass growth. Aerial surveys were conducted on 15th October and boat based surveys on 13th November 2020. Survey methods followed the established techniques for TropWATER's Queensland-wide seagrass monitoring programs.

Intertidal meadows were surveyed at low tide using a helicopter. GPS was used to map the position of meadow boundaries and survey sites. Sites were scattered haphazardly within each meadow and surveyed while the helicopter hovered less than one metre above the substrate (Figure 4a). Subtidal seagrass was sampled by boat using camera drops and van Veen grab (Figure 4b, c). Subtidal sites were positioned at ~50 - 100 m intervals running perpendicular from the shoreline, or where major changes in bottom topography occurred, and extended offshore beyond the edge of each meadow. Random sites also were surveyed within each meadow. The details recorded at each site are listed in Section 2.3.1.

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



2.2 Seagrass biomass estimates

Seagrass above-ground biomass was determined using a "visual estimates of biomass" technique (Mellors 1991; Kirkman 1978). At each site a 0.25 m^2 quadrat was placed randomly with three replicates. An observer assigned a biomass rank to each quadrat while referencing a series of quadrat photographs of similar seagrass habitats where the above-ground biomass had previously been measured. Two separate ranges were used - low biomass and high biomass. The percentage contribution of each species to each quadrat's biomass also was recorded.

At the survey's completion, the observer ranked a series of calibration quadrat photographs representative of the range of seagrass biomass and species composition observed during the survey. These calibration quadrats had previously been harvested and the above-ground biomass weighed in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks recorded in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^{-2}) for each of the three replicate quadrats per site. Site biomass, and the biomass of each species at the site, is the mean of the three replicates.

2.3 Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.8®. Three GIS layers were created to describe seagrass in the survey area: a site layer, biomass interpolation layer and meadow layer.

2.3.1 Site layer

The site (point) layer contains data collected at each site, including:

- Site number
- Temporal details – Survey date and time.
- Spatial details – Latitude, longitude, depth below mean sea level (metres) for subtidal sites.
- Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail presence/absence.
- Sampling method and any relevant comments.

2.3.2 Interpolation layer

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

2.3.3 Meadow layer

The meadow (polygon) layer provides summary information for all sites within each meadow, including:

- Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass ± standard error (SE), meadow area (hectares) ± reliability estimate (R) (Table 1), number of sites within the meadow, seagrass species present, meadow community type and density (Tables 2, 3), and meadow landscape category (Figure 5).
- Sampling method and any relevant comments.

Meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 1). Mapping precision ranged from 1 m for intertidal seagrass meadows with boundaries mapped by helicopter to ±30 m for subtidal meadows with boundaries mapped by distance between sites with and without seagrass. The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 2). Community density was based on mean biomass of the dominant species within the meadow (Table 3).

Table 1. Mapping precision and method for Mourilyan Harbour seagrass meadows.

Mapping precision	Mapping method
± 1 - 5 m	Meadow boundaries determined from helicopter; High density of mapping and survey sites;
± 10 - 30 m	Some intertidal meadow boundaries determined from helicopter; Most meadow boundaries determined from camera/grab surveys; Patchy cover of seagrass throughout meadow; Moderate density of survey sites; Recent aerial photography aided in mapping.

Table 2. Nomenclature for seagrass community types in Mourilyan Harbour.

Community type	Species composition
Species A	Species A is >90-100% of composition
Species A with Species B (2 species present) Species A with mixed species (>2 species)	Species A is >60-90% of composition
Species A/Species B	Species A is 40-60% of composition

Table 3. Density categories and mean above-ground biomass ranges for each species used in determining seagrass meadow density in Mourilyan Harbour.

Density	Mean above-ground biomass (g DW m^{-2})			
	Halodule uninervis (narrow)	*Halophila ovalis/ Halophila decipiens*	*Halodule uninervis* (wide)	*Enhalus acoroides*
Light	< 1	< 1	< 5	< 40
Moderate	1 - 4	1 - 5	5 - 25	40 – 100
Dense	> 4	> 5	> 25	> 100

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

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

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

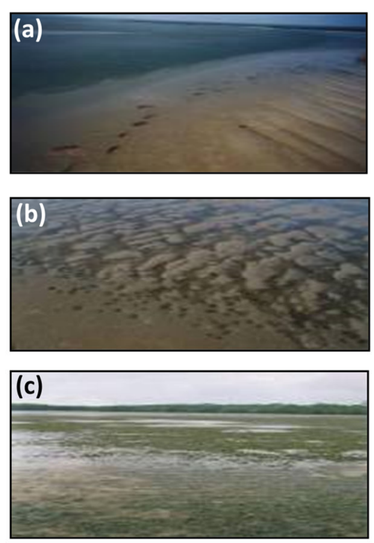


Figure 5. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

2.4 Seagrass condition index

A condition index was developed for Mourilyan Harbour's seagrass monitoring meadows based on changes in mean above-ground biomass, meadow area, and species composition relative to a baseline. Seagrass condition for each indicator in each meadow was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The flow chart in Figure 6 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.

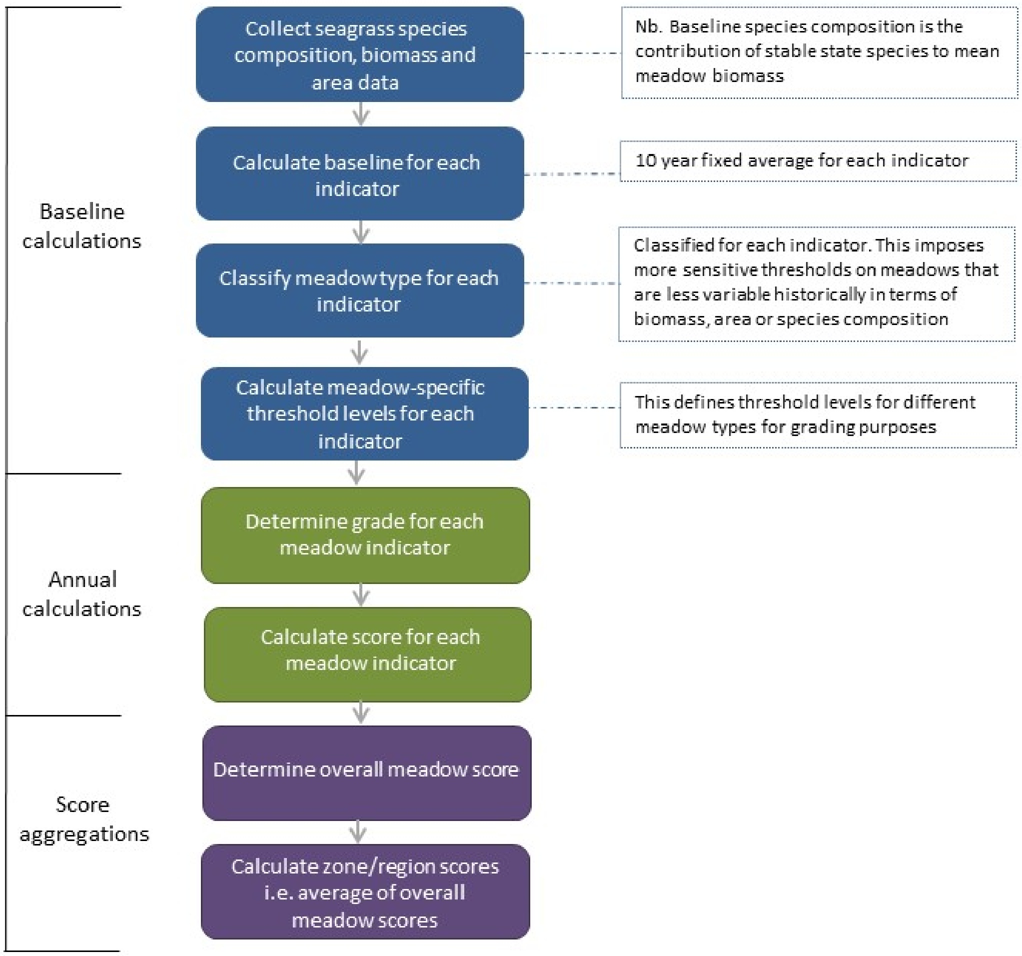


Figure 6. Flow chart to develop Mourilyan Harbour grades and scores.

2.5 Environmental data

Temperature, river flow and tidal exposure are environmental conditions that impact seagrass biomass and distribution (Rasheed & Unsworth 2011). Increased rainfall and flooding events can cause sudden changes in water quality, in particular increased turbidity that reduces the light available for photosynthesis (Campbell & McKenzie 2004; Waycott et al. 2007; Cardoso et al. 2008; Rasheed et al. 2014; Mckenna et al. 2015). Increased direct sunlight during tidal exposure can severely reduce above ground biomass through burning seagrasses (Stapel & Manuntun 1997). When all seasonal data is combined poor correlations were found between seagrass productivity and seasonal water temperatures (Lee et al. 2007), however numerous researchers consider temperature to play a vital role in seasonal growth and signalling stages within their life cycle (Lee et al. 2007; Lee & Dunton 1996). Therefore we find it important to track these environmental factors, and in order to provide insight on what is influencing seagrass conditions we need to analyse such environmental data.

Tidal data was provided by Maritime Safety Queensland (MSQ) (© The State of Queensland (Department of Transport and Main Roads) 2020, Tidal Data) for Mourilyan (MSQ station #063012A; www.msq.qld.gov.au). This data allows us to calculate daytime tidal exposure of intertidal meadows. Assuming intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

Total daily rainfall (mm), temperature and solar exposure was obtained for the nearest weather station from the Australian Bureau of Meteorology (Innisfail station #32197 and 032025; http://www.bom.gov.au/climate/data/). Daily global solar exposure is a measure of the total amount of solar energy falling on a horizontal surface. The values are usually highest in clear, sunny conditions during the spring/summer prior to the wet season and lowest during winter. River-flow data is unavailable for the Moresby River which flows directly into Mourilyan Harbour, so flow for the nearby South Johnstone River (recorded at Upstream Central Mill, 2000 – 2020), which flows to the north of Mourilyan Harbour, is presented instead. South Johnstone River flow data (gigalitres; GL) was obtained from the Department of Natural Resources and Mines (station #112101B; https://water-monitoring.information.qld.gov.au/).

3 RESULTS

3.1 Seagrasses in Mourilyan Harbour

A total of 214 sites were surveyed in 2020 with seagrass present at 22% of sites (Figure 7). The total area of the annual monitoring meadows was 25 ± 9.3 ha, approximately 29 ha below the long-term average (Figure 1). Four species were observed including two seagrass species from the *Halophila* family in the monitoring meadows, and *Enhalus acoroides* and *Halodule uninervis* was observed outside of the monitoring meadows (Figures 8 and 9).

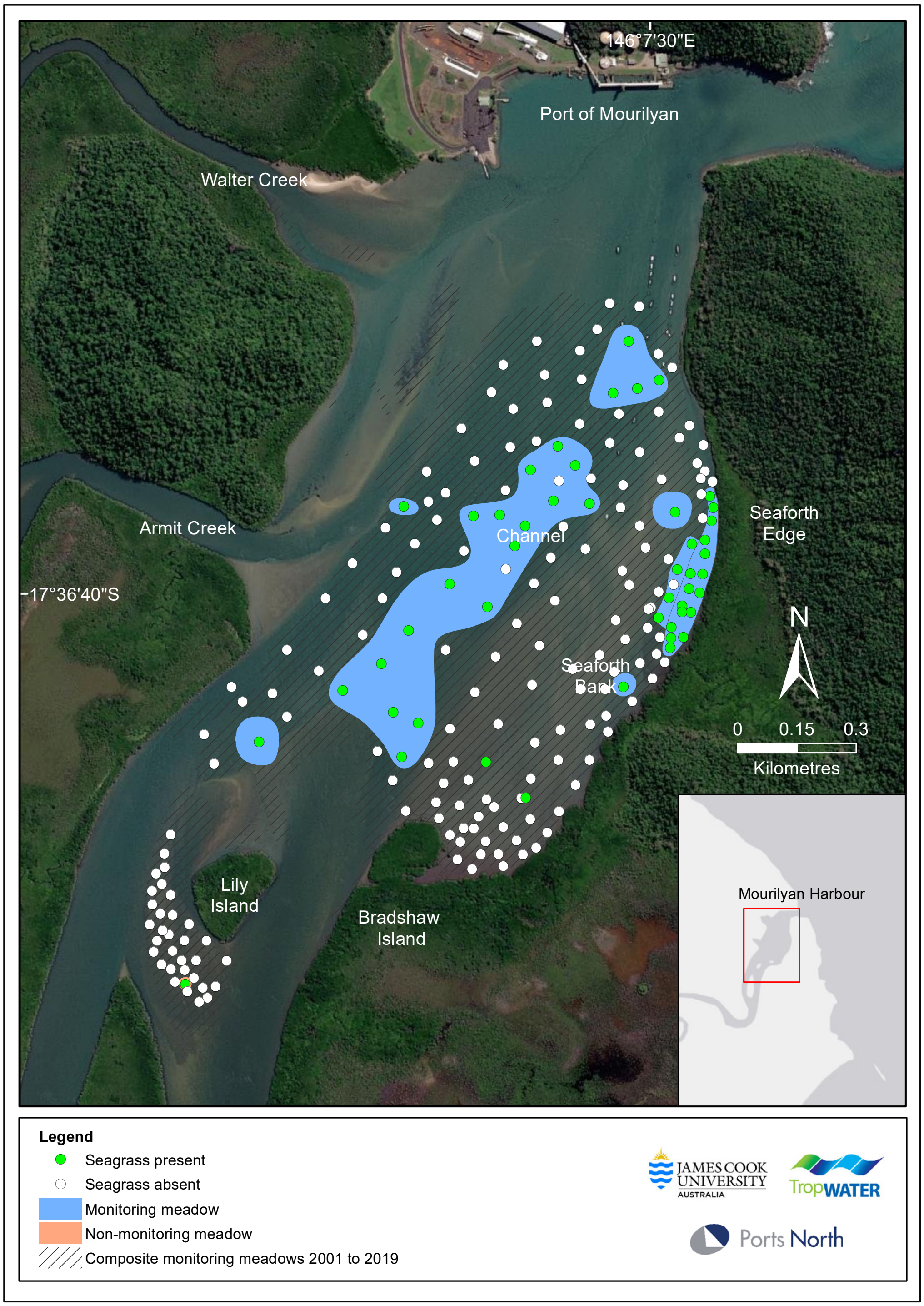


Figure 7. Seagrass presence/absence at survey sites, 2020.

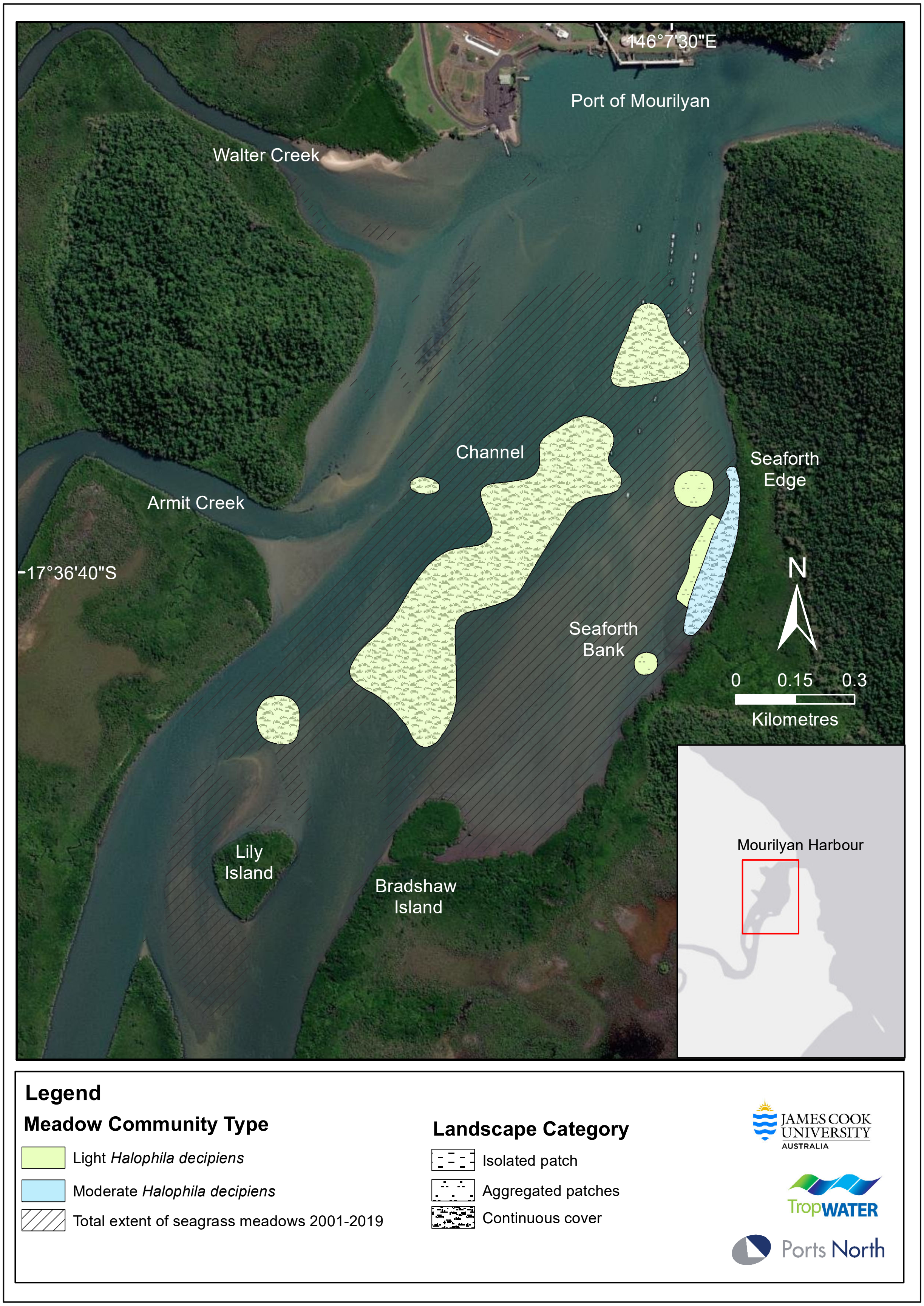


Figure 8. Mourilyan Harbour seagrass distribution and community type for all mapped meadows, 2020.

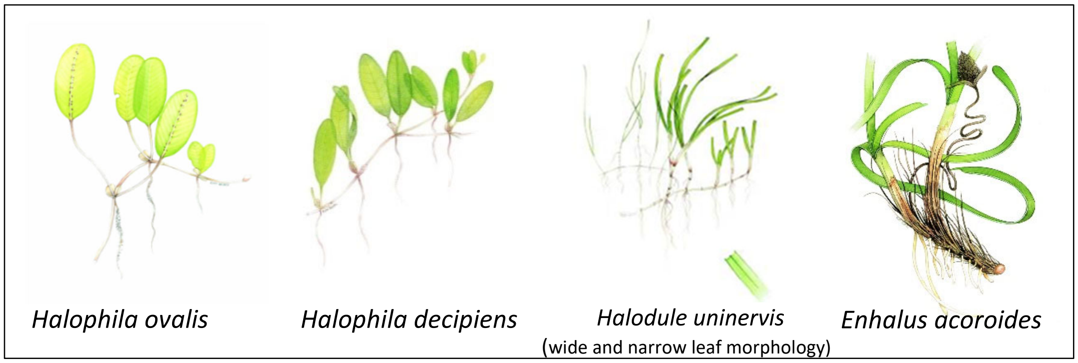


Figure 9. Seagrass species present in Mourilyan Harbour, 2020.

3.2 Seagrass condition for annual monitoring meadows

Overall seagrass condition was very poor in Mourilyan Harbour at the time of the 2020 annual monitoring survey, a decline from poor in 2019. Seagrass was present in three of the five monitoring meadows in Mourilyan Harbour in 2020. The condition of two of those meadows (Seaforth Edge and the Channel) remained stable compared to the previous year, while the Seaforth Bank meadow declined in condition from poor in 2019 to very poor in 2020 (Table 4).

Table 4. Grades and scores for condition indicators (biomass, area and species composition) for Mourilyan Harbour monitoring meadows, 2020 (see Section 2.4, Appendix 1 and Table A3 for a full description of how scores and grades are calculated).

Meadow	Biomass Score	Area Score	Species Composition Score	Overall Meadow Score
1 - Bradshaw	0.00	0.00	0.00	0.00
2 - Lily	0.00	0.00	0.00	0.00
3 - Seaforth Bank	0.56	0.14	0.00	0.14
4 - Seaforth Edge	0.70	0.64	0.00	0.32
5 - Channel	0.53	0.58	1.00	0.53
Mourilyan Harbour Overall Score				0.19

The Bradshaw Island meadow (1) and Lily Island meadow (2) were absent in 2020. Both intertidal meadows were once dominated by *Z. muelleri*, however this foundation species has been absent since 2010 (Figures 10 and 11; Appendix 3). The Bradshaw Island meadow remains absent for the eleventh successive year (Figures 10 and 15). While seagrass within the Lily Island monitoring meadow was absent, there was a very small isolated patch of colonising species *H. ovalis* just outside of the monitoring meadow footprint (Table 4; Figure 11).

The Seaforth Bank Meadow (3) declined from poor to very poor in 2020 driven by an 81% reduction in area from 9.70 ± 1.57 ha in 2019 to 1.8 ± 0.5 ha in 2020 and shift in species composition (Figure 12). This intertidal meadow is usually dominated by *H. ovalis*, however, in 2020 it was made up of small patches of *H. decipiens*. Biomass did improve to a satisfactory condition with 0.40 ± 0.18g DW m^{-2} in 2020, the highest it's been since 2004 (Figure 12).

The Seaforth Edge meadow (4) remained in a poor condition due to the dominance of the less stable species *H. decipiens* as opposed to *H. ovalis,* which usually dominates the meadow (Table 4; Figure 13; Appendix 3). The condition of biomass and area stabilised since 2019 and remained within the condition category of good and satisfactory respectively. Biomass declined to 1.16 ± 0.42g DW m^{-2} in 2020, but was still catagorised as in good condition against its baseline condition (Table 4; Figure 13; Appendix 3). Area slightly increased by 9% in 2020 to 2.17 ± 0.96 ha, the largest area recorded since 2005 (Table 4; Figure 13; Appendix 3). The main driver for the poor overall meadow condition was the shift in species composition to less stable colonising species (Table 4; Figure 13; Appendix 3).

The Channel meadow (5) had an overall condition of satisfactory in 2020 (Table 4; Figure 14). This meadow scored the highest condition of all 5 monitoring meadows in Mourilyan Harbour with very good species condition and satisfactory area and biomass. Biomass declined by 46% to 0.39 ± 0.15g DW m^{-2} in 2020 and is the lowest since seagrass was absent in the meadow in 2000, 2009, and 2017 (Figure 14). Meadow area also declined slightly from 2019 but remained satisfactory at 21 ± 7.8 ha (Figures 14 and 15). *Halophila decipiens* continues to dominate this subtidal meadow in 2020.

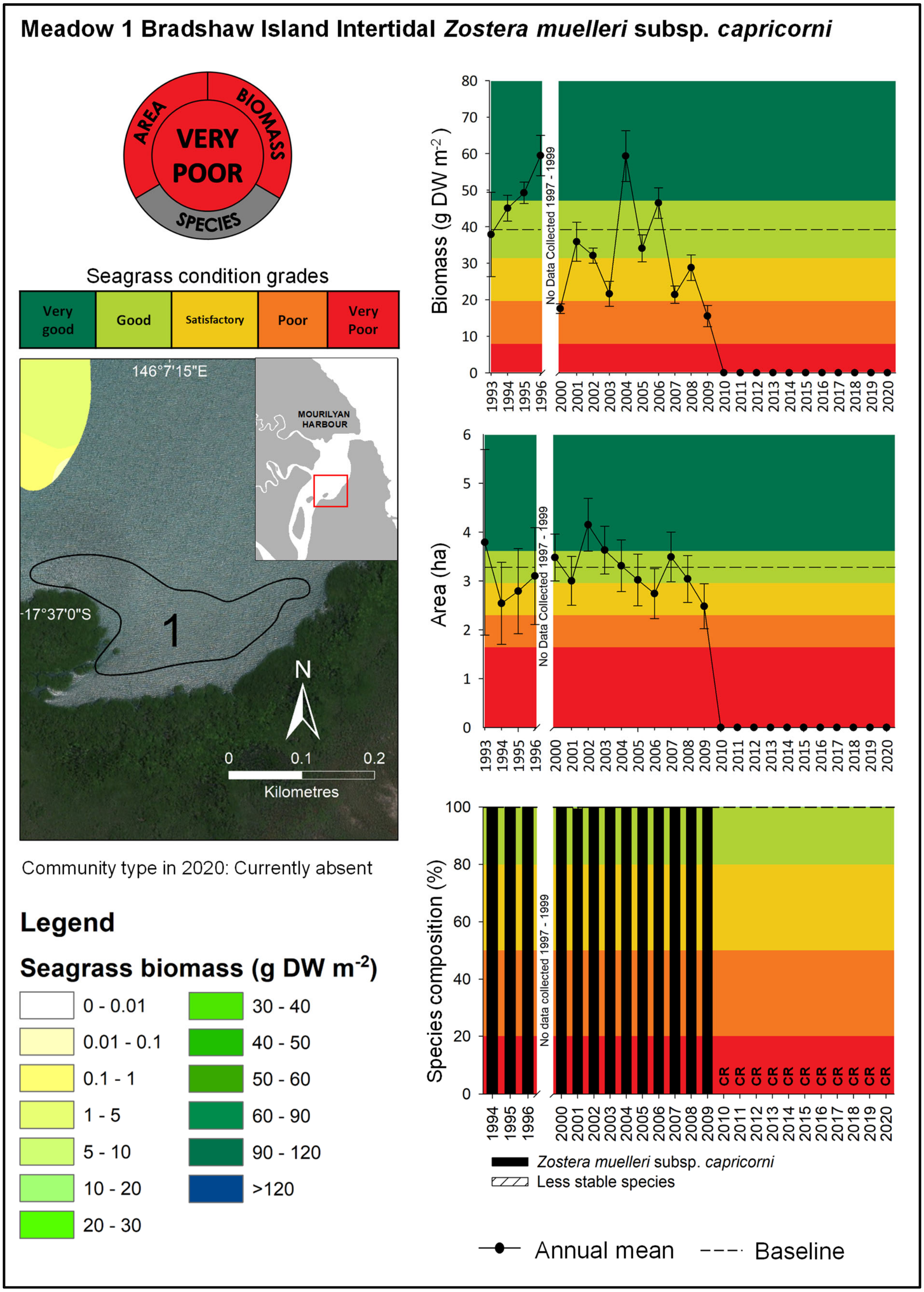


Figure 10. Changes in biomass, area and species composition for the Bradshaw Island meadow from 1993 – 2020 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

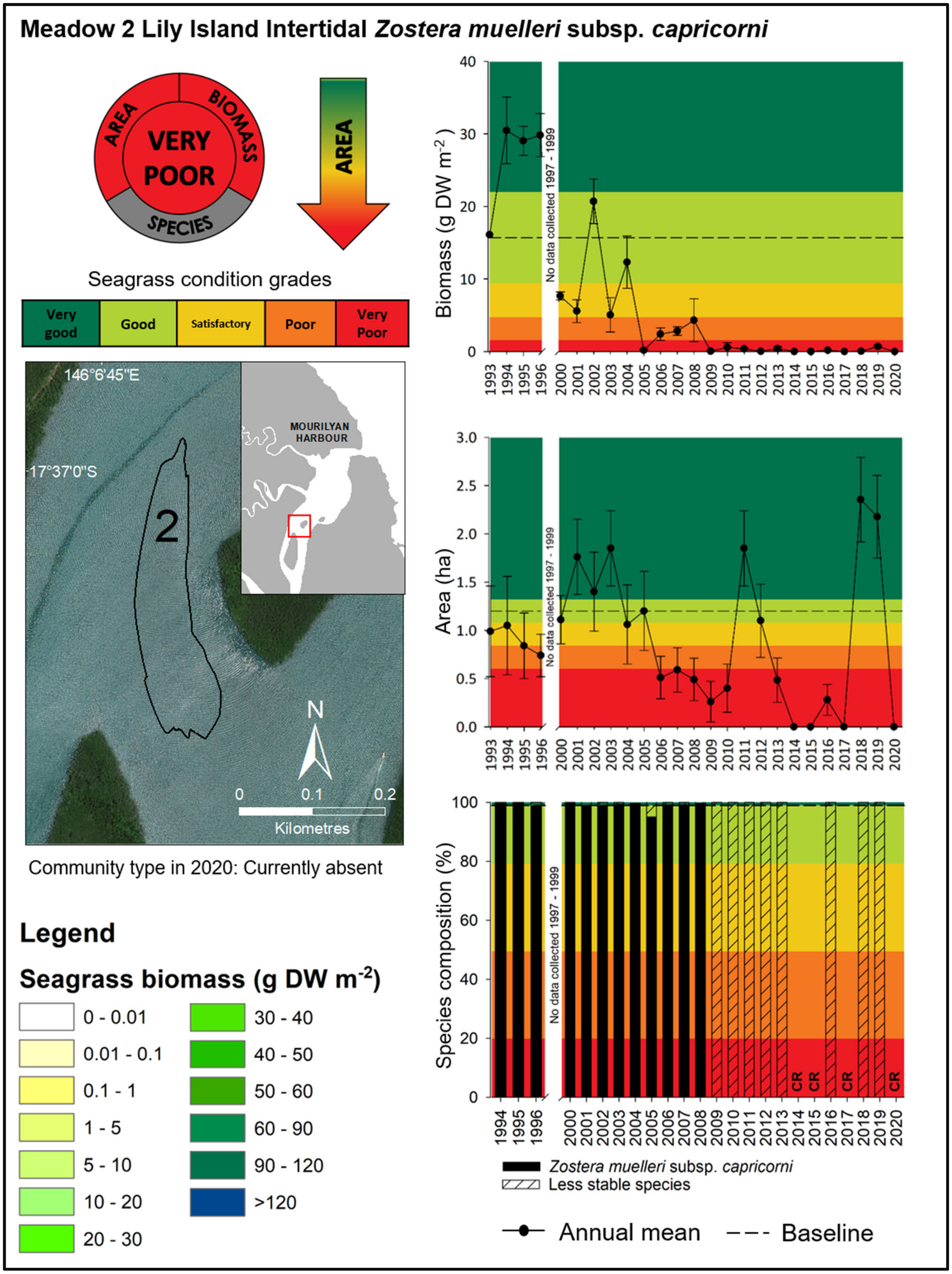


Figure 11. Changes in biomass, area and species composition for the Lily Island meadows from 1993 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

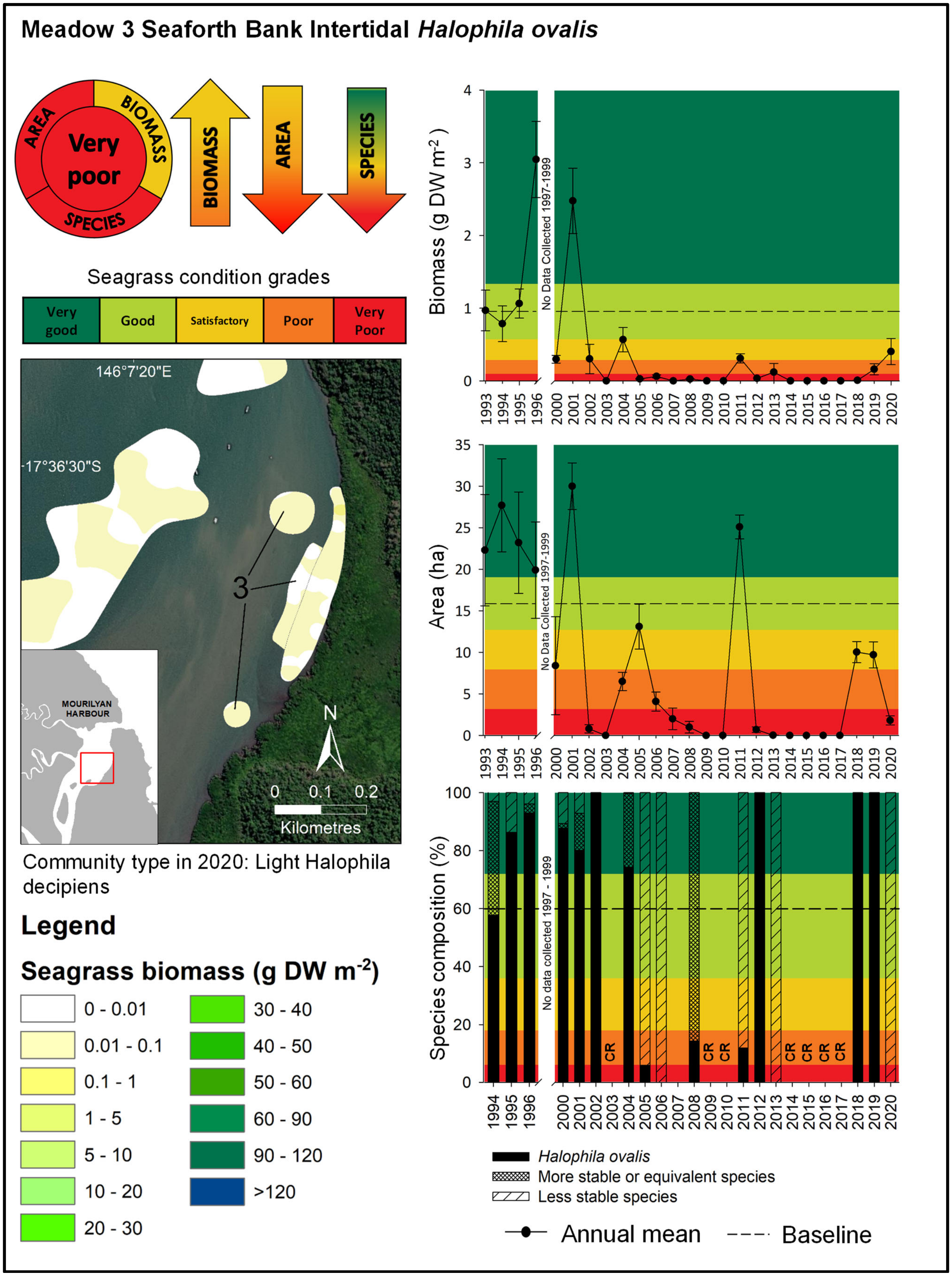


Figure 12. Changes in biomass, area and species composition for Seaforth Bank meadow from 1993 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

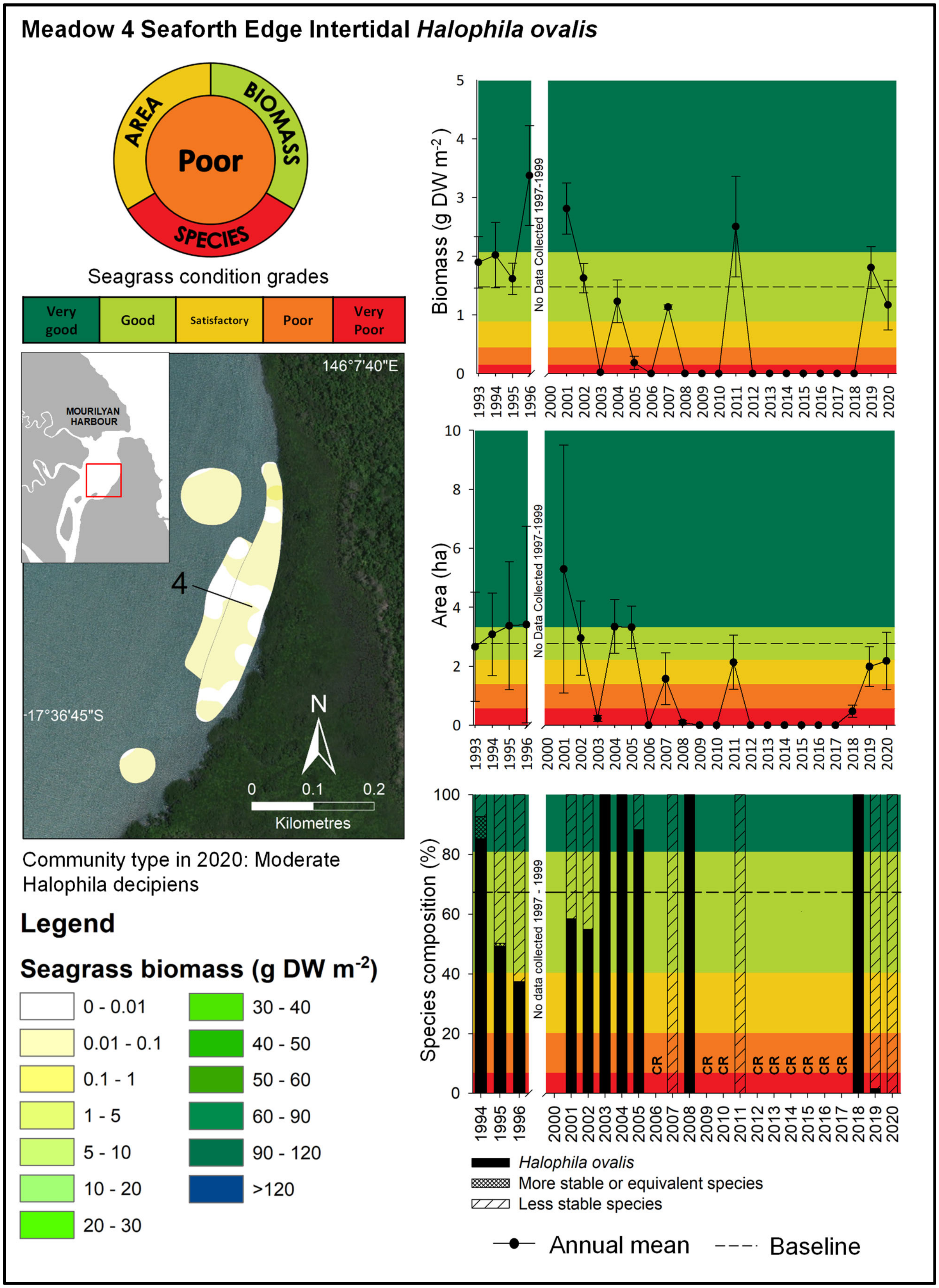


Figure 13. Changes in biomass, area and species composition for the Seaforth Edge meadow from 1993 – 2020 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

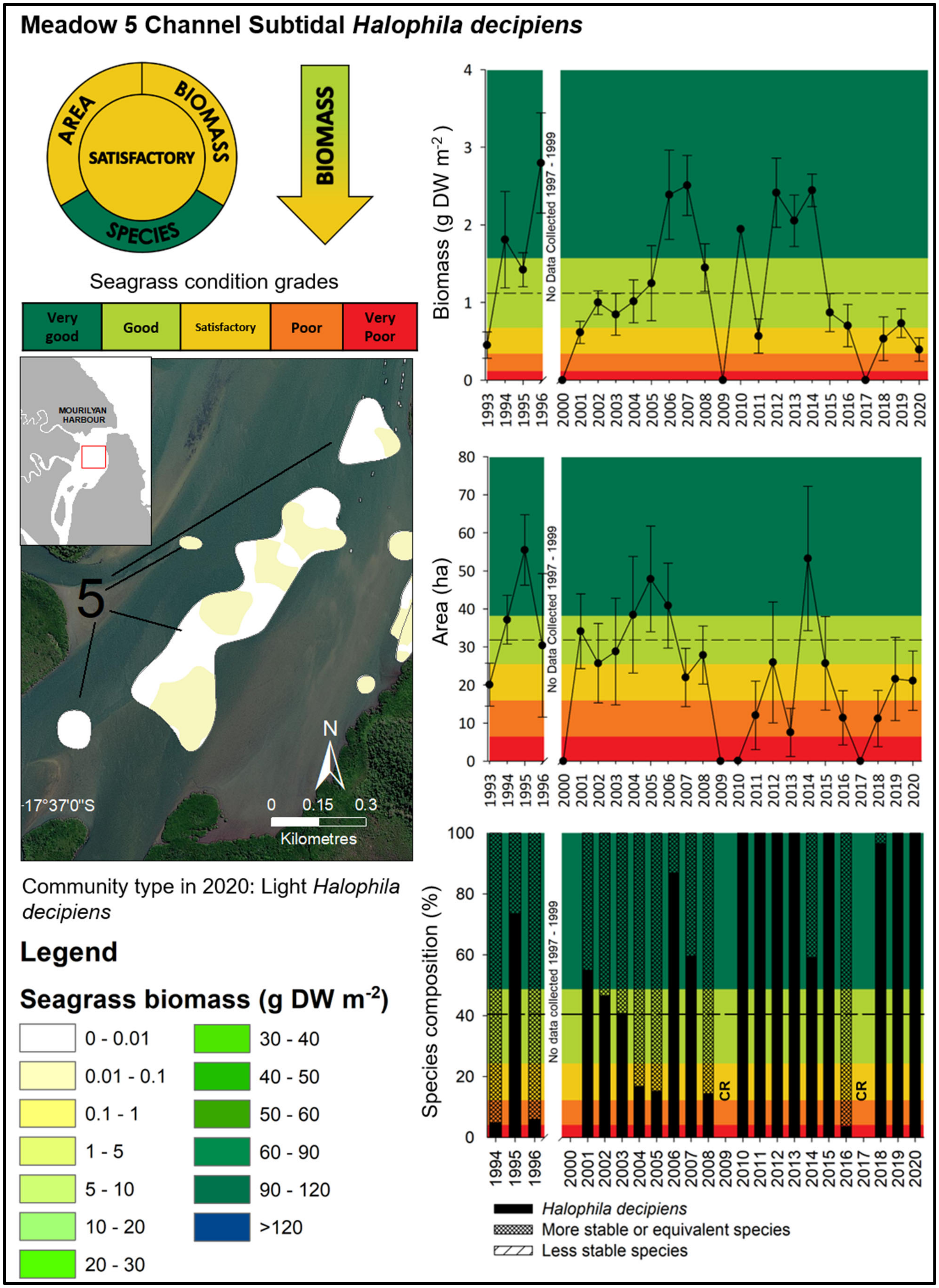


Figure 14. Changes in biomass, area and species composition for the Channel meadow from 1993 – 2020 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

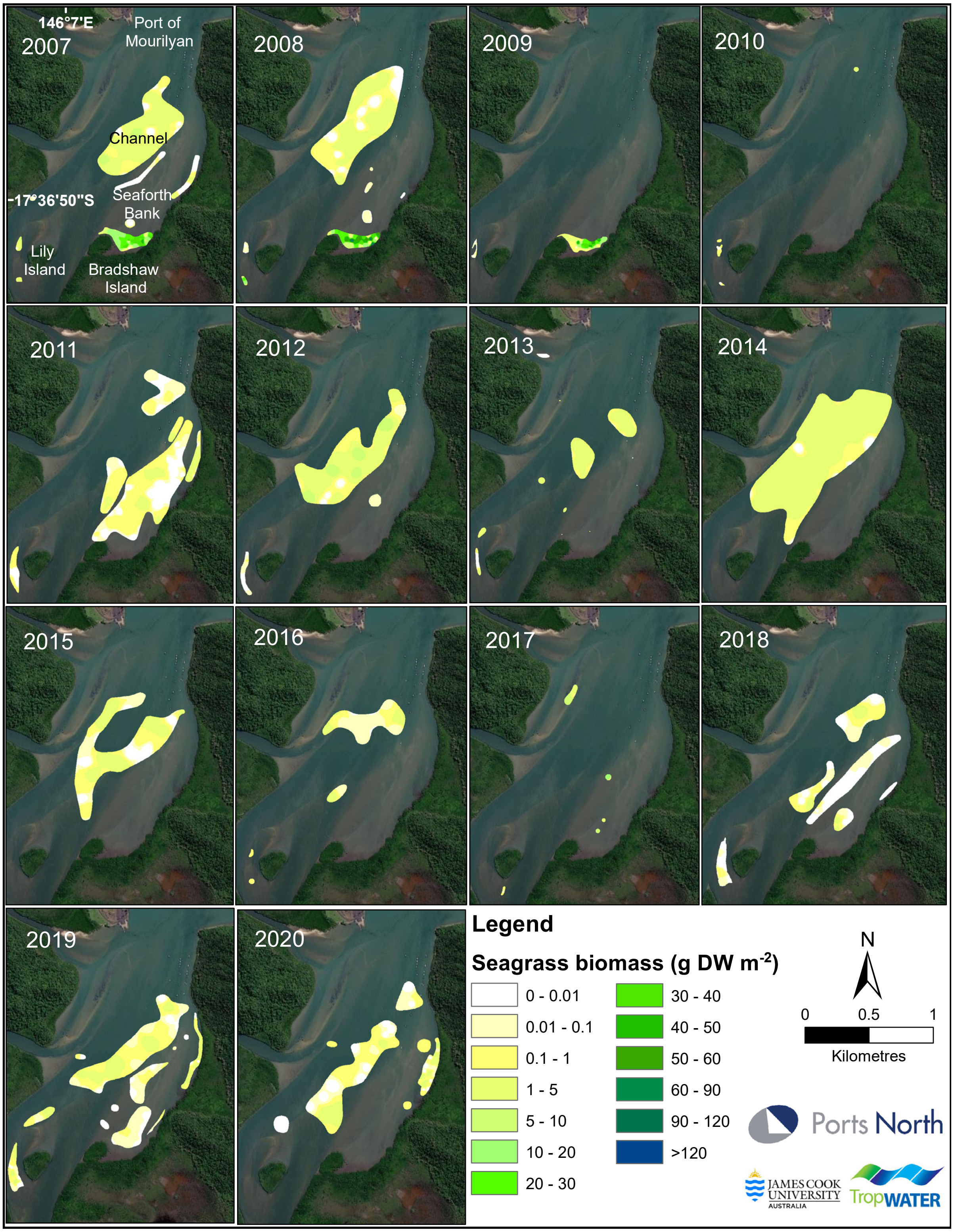


Figure 15. Change in seagrass distribution over time (2007-2020) in Mourilyan Harbour.

3.4 Mourilyan Environmental Data

3.4.1 Rainfall

Total annual rainfall in Mourilyan Harbour during the twelve months preceding the 2020 survey (2551 mm) was well below the long term average (3547 mm) (Figure 16). Rainfall spiked above the monthly average in May and September in 2020 then remained near or below the monthly average for the rest of the year (Figure 17).

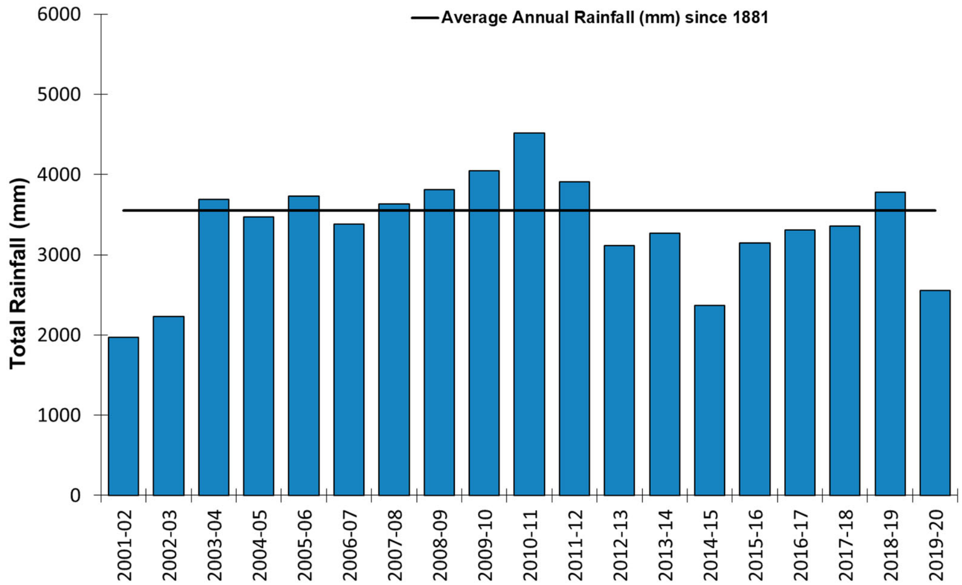


Figure 16. Total annual rainfall (mm) recorded in the twelve months prior to survey, at Innisfail, 2001 – 2020. Source: Bureau of Meteorology, Station 032025, 32197 available at: **www.bom.gov.au**.

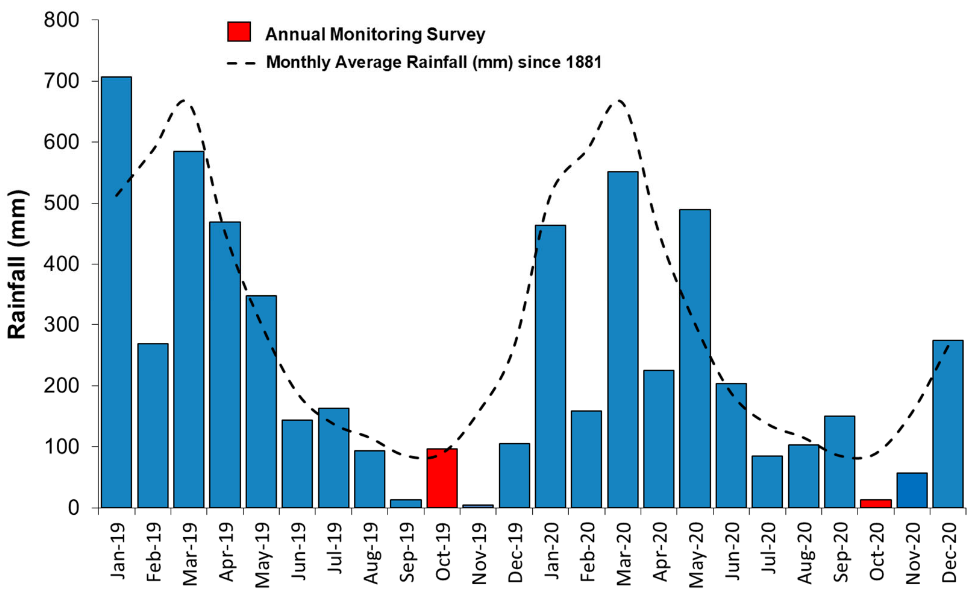


Figure 17. Total monthly rainfall (mm) recorded at Innisfail, January 2019 – December 2020. Source: Bureau of Meteorology, Station 032025, 32197 available at: **www.bom.gov.au**.

3.4.2 River Flow

South Johnstone River total annual flow was 551 GL in 2020, well below the long-term mean of 818 GL and the lowest since 2016 (Figure 18). Total monthly river flow was above average from May to August in the lead up to the survey month (Figure 19).

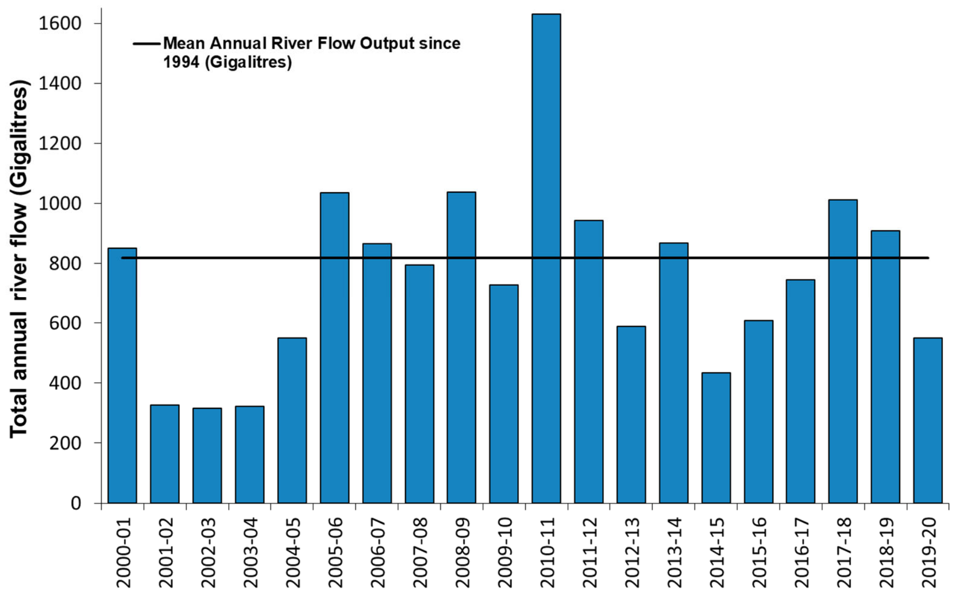


Figure 18. Annual river flow (gigalitres, GL) for the South Johnstone River. Source: Queensland Department of Environment and Resource Management, Station 112101B, available at: **http://watermonitoring.derm.qld.gov.au/host.htm**

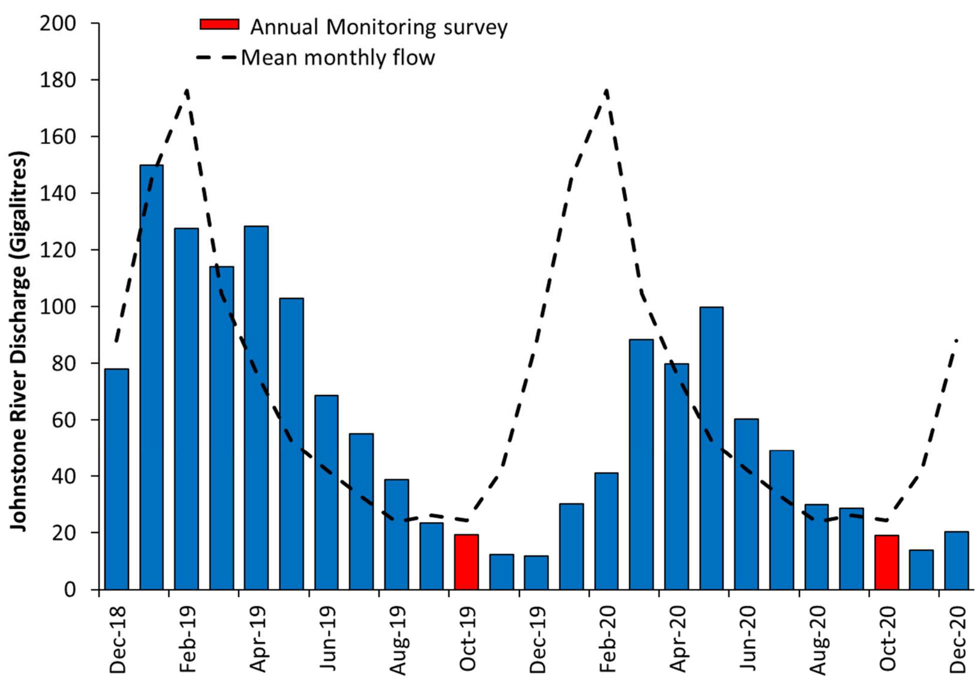


Figure 19. Monthly river flow (gigalitres) for the South Johnstone River, December 2018 – December 2020. Source: Queensland Department of Environment and Resource Management, Station 112101B, available at: **http://watermonitoring.derm.qld.gov.au/host.htm**

3.4.3 Air Temperature and Daily Global Solar Exposure

Mean annual maximum daily air temperature of 28.9°C recorded at Innisfail in 2020 was above the long-term average of 27.9°C and the hottest temperature recorded since 2000 (Figure 20). Daily global solar exposure in the twelve months leading up to the survey was above average at 20.11 MJ m^{-2} (Figure 21).

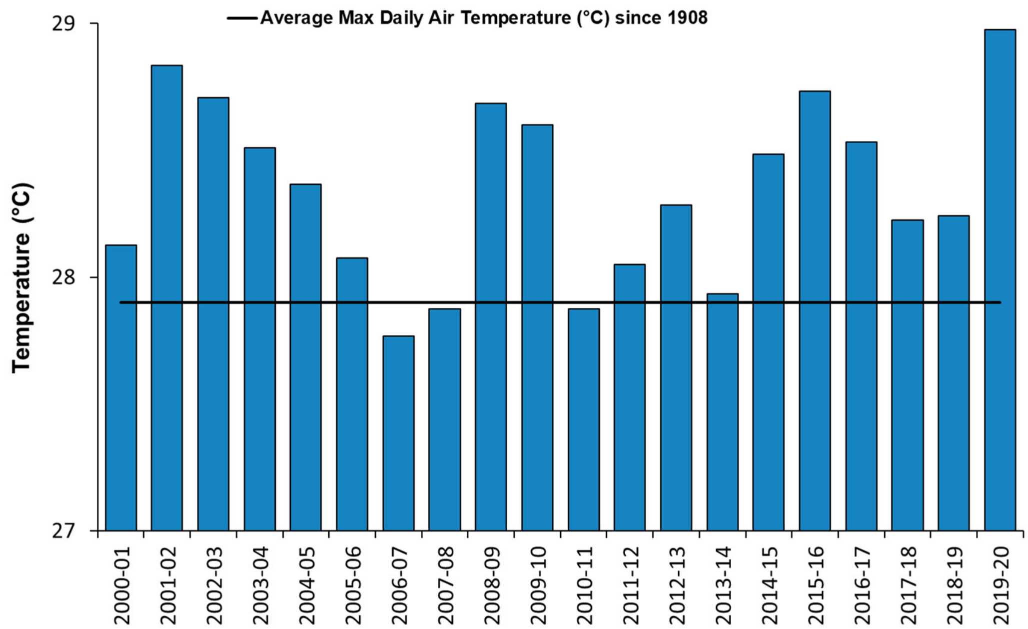


Figure 20. Mean annual maximum daily air temperature (°C) recorded at Innisfail in the twelve months prior to survey, 2000 – 2020. Source: Bureau of Meteorology, Station 032025, 32197, available at: **www.bom.gov.au**.

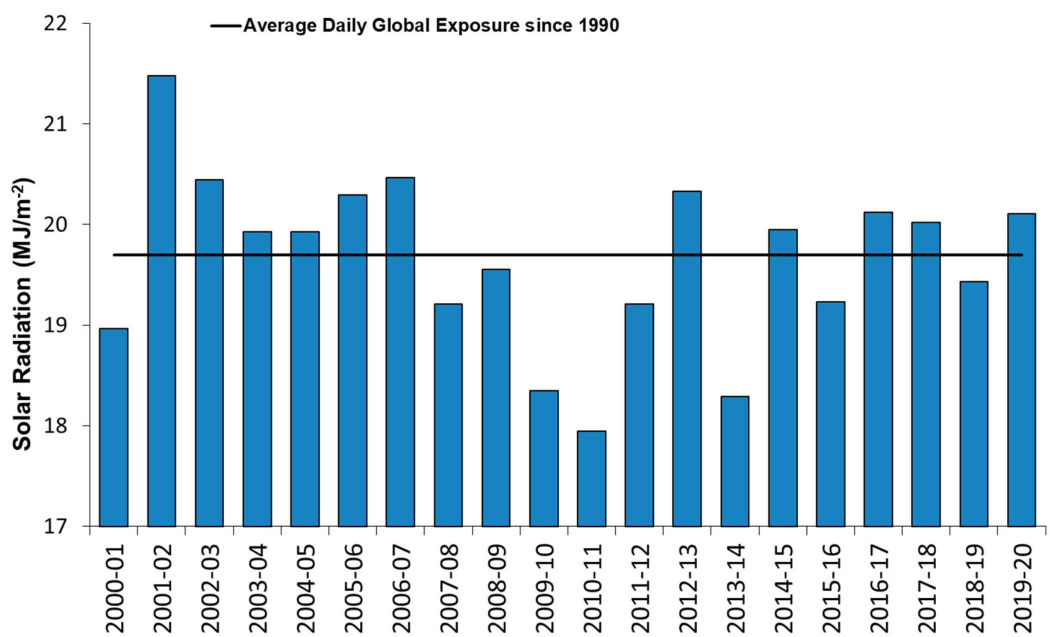


Figure 21. Mean annual daily global solar exposure (MJ m^{-2}) recorded at Innisfail in the twelve months prior to survey, 2000 – 2020. Source: Bureau of Meteorology, Station 032025, available at: **www.bom.gov.au**.

3.4.4 Tidal Exposure of Seagrass Meadows

Total annual daytime exposure of Mourilyan Harbour's intertidal seagrass meadows in 2020 (136 hours) was well below the long-term annual average (179 hours) (Figure 22). August was the only month to experience exposure close to the average in 2020 (Figure 23).

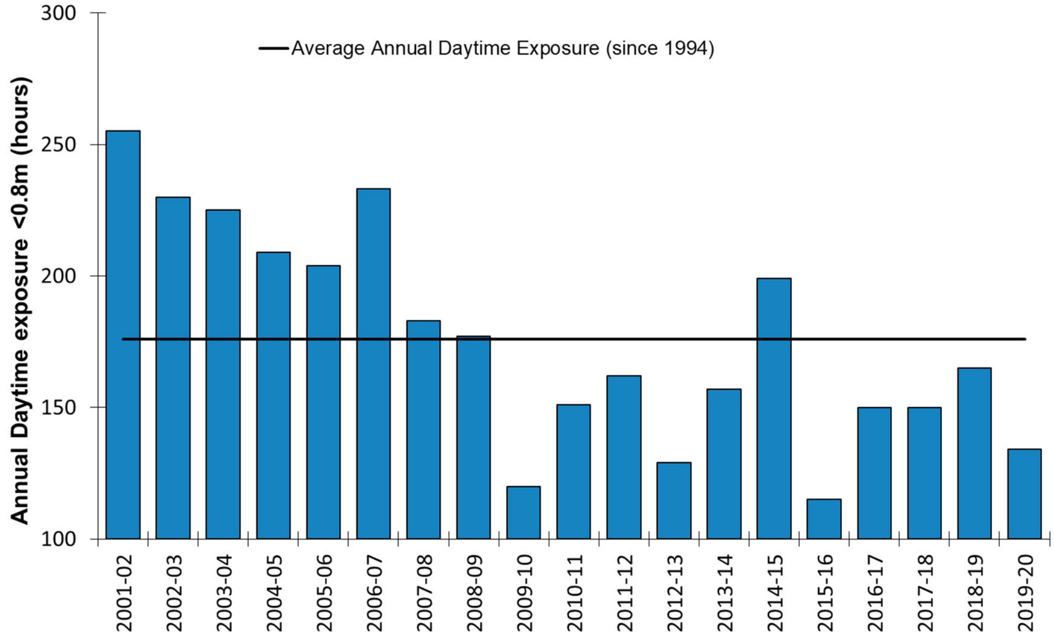


Figure 22. Annual daytime tidal exposure (total hours) of seagrass meadows in Mourilyan Harbour in the twelve months prior to survey; 2001 - 2020. Source: Maritime Safety Queensland, 2020.

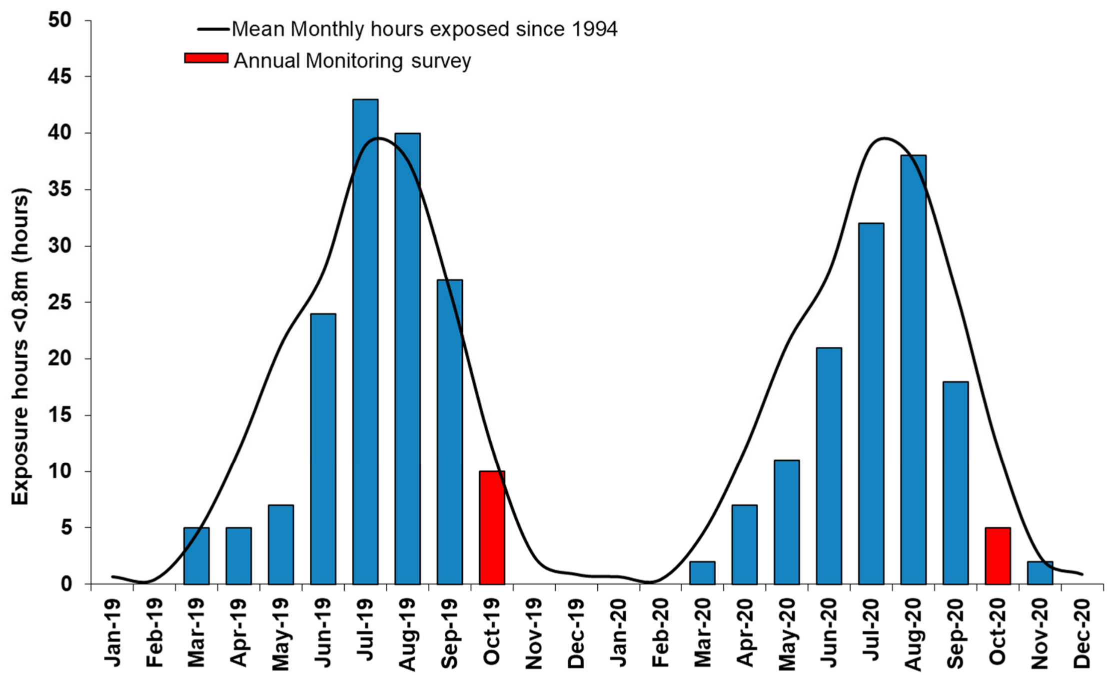


Figure 23. Total monthly daytime tidal exposure (total hours) in Mourilyan Harbour; January 2019 – December 2020. Source: Maritime Safety Queensland, 2020.

4 DISCUSSION

Mourilyan Harbour's seagrass meadows were in a very poor condition in the 2020 survey. This is a decline from a poor rating in 2019 and a return to the very poor rating that occurred over the previous six years. Overall meadow condition is heavily influenced by the absence of the foundation species *Zostera muelleri* from Bradshaw (1) and Lily (2) meadows. This species was absent again in 2020 and has not been present in Mourilyan Harbour since 2009. This has resulted in a poor-very poor status of seagrass in Mourilyan Harbour since the condition index system began in 2014. The Seaforth Bank (3), Seaforth Edge (4) and Channel (5) meadows are dominated by colonising *Halophila spp*. which are highly variable in abundance and distribution (Kilminster et al. 2015). In 2020 the overall meadow condition of both the Seaforth Edge (4) and Channel (5) stayed consistent with 2019 as poor and satisfactory. The Seaforth Bank (3) meadow condition declined to poor due to a large decline in area and a species shift from *H. ovalis* to *H. decipiens*.

In the three Mourilyan Harbour monitoring meadows with seagrass present, species consisted of colonisers from the genus *Halophila* (*H. ovalis* and *H. decipiens*) that are adapted to surviving in low light conditions (Josselyn et al. 1986, McKenna et al. 2015, Chartrand et al. 2017). *Halophila* species have been shown to have much lower resistance to light deprivation than other seagrass species with mortality occurring in days to weeks rather than months for other larger seagrass species (Collier et al. 2016). While the average annual rainfall at Mourilyan was below the long term average in 2020, the rainfall in September, the month before the survey, was double the monthly long term average. This may have led to a decline in water quality and light availability in the period leading up to the survey and resulted in the declines in meadow area and biomass for *Halophila*. Due to high light requirements for photosynthesis, light availability is one of the more important environmental factors controlling seagrass distribution (Longstaff & Dennison 1999; Dennison et al. 1993; Ralph et al. 2007; Chartrand et al. 2016). Other environmental variables seemed favourable to seagrass growth with below average river flow and low levels of daytime tidal exposure. This is supported observationally during the survey with the presence of a narrow meadow of the larger growing *H. uninervis* along the sand bank on the northern side of the channel (Figure 24) and two small patches of *E. acoroides* that persist on Seaforth Bank. The narrow *H. uninervis* meadow is outside of the annual monitoring meadow footprint and was not surveyed in 2020.

Figure 24. Narrow meadow of *Halodule uninervis* adjacent to the Channel (5) monitoring meadow.

The continued absence of the foundation species *Z. muelleri* from the Bradshaw and Lily Island meadows since 2010 indicates that a recruitment bottleneck is likely to be inhibiting the re-establishment of this species in Mourilyan Harbor. Prior to the extreme weather conditions that led to the loss of *Z. muelleri*, this species was present and relatively stable in all surveys dating back to 1994. Conditions in the region following the loss have generally been favourable for seagrass growth and populations of *Z. muelleri* that had been severely impacted at the same time to the north in Cairns and south in Townsville have since recovered (Reason et al. 2021; McKenna et al. 2021). Potential recovery from a seed bank was prevented due to floods and cyclones in 2010-11 and since 2014 no *Z. muelleri* seeds have been detected in sediment cores from within the Bradshaw Island meadow footprint (Reason & Rasheed 2017). The distance from potential sources of viable propagules (Trinity Inlet and Hinchinbrook Passage) and the small and restricted entrance to Mourilyan Harbour makes the probability of recruitment via natural (biotic and abiotic) dispersal unlikely (Tol et al. 2017; Grech et al. 2016). This highlights the need for restoration of *Z. muelleri* at the site to be prioritised.

The loss of the foundation species in Mourilyan Harbour also reduces important ecosystem functions within the estuary. Seagrasses are an ecologically important structural component within coastal ecosystems (Coles et al. 2015). While colonising species such as *Halophila spp*. provide important ecosystem services such as nursery habitat for fish (Hayes et al. 2020), storage of carbon (York et al. 2018) and sediment stabilisation (Fonseca 1989), these morphologically small species are perceived to be less effective at these functions than larger sized seagrasses like *Z. muelleri* (Nordlund et al. 2016). *Zostera muelleri* in north Queensland has been identified as an important habitat for juvenile fish and prawns from studies in Trinity Inlet, Cairns (Coles et al. 1993; Watson et al. 1993) with species of commercial and recreational importance also found in the seagrass meadows in Mourilyan Harbour prior to its disappearance (McKenzie et al. 1996). In depositional environments like the Bradshaw Island meadow, *Z. muelleri* beds can also store high amounts of Blue Carbon in their muddy sediments (Ricart et al. 2020). The rhizomes and roots of seagrasses can also bind the substrate and reduce erosion and resuspension of sediments, while the leaf canopy slows water movement and traps suspended particles contributing to both improved water quality and elevation of the seabed (Bos et al. 2007; Potouroglou et al. 2017).

Monitoring trends for seagrass condition in the broader Queensland monitoring network varied among locations. Cairns Harbour seagrass meadows dominated by more persistent species such as *Z. muelleri* and *H. uninervis* improved to be in good condition for the first time since the 2010-11 collapse, however, seagrass upstream in the Trinity Inlet estuary that consist of small highly ephemeral species declined to be in a poor condition (Reason et al. 2021). Seagrass meadows in Townsville to the south improved to a good condition, recovering well after declines from major flooding in February 2019 (McKenna et al. 2021). Further south, offshore seagrasses at Hay Point also dominated by *Halophila* species declined from a good to a poor condition while coastal meadows dominated by *H. uninervis* were in a satisfactory condition (York et al. 2021). In Gladstone, seagrasses remained in a good condition for a second consecutive year after several years of poor condition (Smith et al. 2021).

The Mourilyan Harbour seagrasses have been in poor condition since the severe *La Nińa* events from 2009-11 that included multiple floods and Tropical Cyclone Yasi and resulted in the loss of the foundation species *Z. muelleri* from the estuary in 2010. The lack of recovery in the decade since, despite a return of this species to pre-disturbance levels in nearby locations highlights the need for habitat restoration efforts at this location. In 2020, TropWATER, in partnership with volunteers from OzFish Unlimited undertook a small pilot study using vegetative fragments of *Z. muelleri* tied to planting frames that were placed in the meadow area from a small vessel. In March 2021, seven months after planting and following several heavy rainfall events during the wet season, seagrasses were establishing and growing around many of the frames. This pilot study will assist to inform further restoration trials or ultimately a large-scale restoration project to return the seagrass to its previous healthy condition and to re-establish the vital ecological functions that it provides.

5 REFERENCES

Bos AR, Bouma TJ, de Kort GLJ & van Katwijk MM (2007). Ecosystem engineering by annual intertidal seagrass beds: Sediment accretion and modification. *Estuarine, Coastal and Shelf Science,* **74:** 344-348

Campbell SJ, & McKenzie LJ. (2004). Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. *Estuarine, Coastal and Shelf Science*, **60**: 477-490

Cardoso PG, Raffaelli D, & Pardal MA. (2008). The impact of extreme weather events on the seagrass *Zostera noltii* and related *Hydrobia ulvae* population. *Marine Pollution Bulletin*, **56**: 483–492

Chartrand KM, Bryant CV, Carter AB, Ralph PJ & Rasheed MA. (2016). Light thresholds to prevent dredging impacts on the Great Barrier Reef seagrass, Zostera muelleri ssp. capricorni. *Frontiers in Marine Science*, **3**,:106, 1-17

Chartrand KM, Bryant CV, Sozou S, Ralph P.J and Rasheed MA (2017). Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment, Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns.

Coles RG, Lee Long WJ, Watson RA, Derbyshire KJ (1993). Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, northern Queensland. *Australia. Australian Journal of Marine and Freshwater Research*, **44**: 193-210

Coles RG, Rasheed MA, McKenzie LJ, Grech A, York PH, Sheaves MJ, McKenna S and Bryant CV (2015). The Great Barrier Reef World Heritage Area seagrasses: managing this iconic Australian ecosystem resource for the future. *Estuarine, Coastal and Shelf Science*, **153**: A1-A12

Collier, CJ, Chartrand, K, Honchin, C, Fletcher, A 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. Reef and rainforest Research Centre Limited, Cairns (41pp.).

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

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

Fonseca MS (1989). Sediment stabilization by (*Halophila decipiens*) in comparison to other seagrasses. *Estuarine, Coastal and Shelf Science,* **29:** 501-507

Fonseca MS. (1996). The role of seagrasses in nearshore sedimentary processes: A review. In: *Estuarine Shores: Evolution, Environments and Human Alterations* (eds K. F. Nordstrom, C. T. Roman), pp. 261–286. John Wiley and Sons, Chichester.

Fourqurean JW, Duarte CM, Kennedy H, Marba N, Holmer M, Mateo MA, Apostolaki ET, Kendrick GA, Krause-Jensen D, McGlathery KJ and Serrano O (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience,* **5**: 505-509

Grech A, Coles R and Marsh H (2011). A broad-scale assessment of the risk to coastal seagrasses from cumulative threats, *Marine Policy,* **35**: 560-567

Grech A, Wolter J, Coles R, McKenzie L, Rasheed M, Thomas C, Waycott M, and Hanert E (2016). Spatial patterns of seagrass dispersal and settlement, Diversity and Distributions*,* **22**: 1150-1162

Hayes MA, McClure EC, York PH, Jinks KI, Rasheed MA, Sheaves M & Connolly RM (2020) The Differential Importance of Deep and Shallow Seagrass to Nekton Assemblages of the Great Barrier Reef. *Diversity,* **12:** 292

Heck KL, Hays G, Orth RJ (2003). Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series,* **253**: 123-136

Heck KL, Carruthers TJB, Duarte CM, Hughes AR., Kendrick G, Orth, RJ, Williams SW (2008). Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems,* 11:1198-1210

James RK, Silva R, van Tussenbroek BI, Escudero-Castillo M, Mariño-Tapia I, Dijkstra HA, van Westen RM, Pietrzak JD, Candy AS, Katsman CA, van der Boog CG, Riva REM, Slobbe C, Klees R, Stapel J, van der Heide T, van Katwijk MM, Herman PMJ and Bouma TJ (2019). Maintaining tropical beaches with seagrass and algae: a promising alternative to engineering solutions. BioScienc, 69:136-142

Kilminster K, McMahon K, Waycott M, Kendrick GA, Scanes P, McKenzie L, O'Brien KR, 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.

Josselyn M, Fonseca M, Niesen T and Larson R (1986). Biomass, production and decomposition of a deep water seagrass, Halophila decipiens Ostenf, Aquatic Botany, 25:47–61

Lavery PS, Mateo M-Á, Serrano O and Rozaimi M (2013). Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PLoS ONE, 8: e73748.

Lee KS, & Dunton KH. (1996). Production and carbon reserve dynamics of the seagrass Thalassia testudinum in Corpus Christi Bay, Texas, USA. *Marine Ecology. Progress. Series*, **143:** 201–210

Lee KS, Park SR, & Kim YK (2007). Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: A review. *Journal of Experimental Marine Biology and Ecology*, **350**: 144–175

Longstaff BJ, & Dennison WC (1999). Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*. *Aquatic Botany,* **65**: 105–121

McKenna S, Jarvis J, Sankey T, Reason C, Coles R, & 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

McKenna SA, Chartrand KM, Jarvis JC, Carter AB, Davies JN and Rasheed MA (2015). Port of Abbot Point: initial light thresholds for modelling impacts to seagrass from the Abbot Point Growth Gateway project. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, pp. 18.

McKenna S, Wilkinson J, Chartrand K, and Van De Wetering C (2021), 'Port of Townsville Seagrass Monitoring Program: 2020,' James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

McKenzie LJ, Rasheed MA, Lee Long, WJ & Coles RG. (1996). Port of Mourilyan Seagrass Monitoring, Baseline Surveys -Summer (December) 1993 and Winter (July) 1994. *Ports Corporation EcoPorts.*

McGlathery KJ, Sundback K and Anderson IC (2007). Eutrophication in shallow coastal bays and lagoons: the role of plants in the coastal filter. *Marine Ecology-Progress Series,* **348**: 1-18

McMahon K and Walker DI (1998). Fate of seasonal, terrestrial nutrient inputs to a shallow seagrass dominated embayment. *Estuarine, Coastal and Shelf Science* **46**: 15-25

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

Nordlund, L, Koch, E, Barbier, E & Creed, J (2016) Seagrass ecosystem services and their variability across genera and geographical regions. *PLoS ONE*, **11**: e0169942

Potouroglou M, Bull JC, Krauss KW, Kennedy HA, Fusi M, Daffonchio D, Mangora MM, Githaiga MN, Diele K & Huxham M (2017). Measuring the role of seagrasses in regulating sediment surface elevation. *Scientific Reports,* **7:** 11917

Ralph PJ, Durako MJ, Enriquez S, Collier CJ, & Doblin MA. (2007). Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology Ecology,* **350:** 176-193

Rasheed MA, McKenna SA, Carter SA, & Coles RG (2014). Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, *Australia. Marine Pollution Bulletin,* **83**: 491-499.

Rasheed MA, & Unsworth RKF (2011). Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. *Marine Ecology Progress Series,* **422**: 93–103

Reason CL, & Rasheed MA (2017). Seagrass habitat of Mourilyan Harbour: Annual Monitoring Report – 2017. James Cook University, Cairns.

Reason CL, Smith TM & Rasheed MA (2021). Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2020. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication 21/09, Cairns.

Ricart AM, York PH, Bryant CV, Ierodiaconou D & Macreadie PI (2020) .High variability of blue carbon storage in seagrass meadows at the estuary scale *Scientific Reports,* **10:** 1-12

Scott AL, York PH, Duncan C, Macreadie PI, Connolly RM, Ellis MT, Jarvis JC, Jinks KI, Marsh H, Rasheed MA (2018). The role of herbivory in structuring tropical seagrass ecosystem service delivery. *Frontiers in Plant Science* **9**: 127

Scott AL, York PH and Rasheed MA (2020). Green turtle (*Chelonia mydas*) grazing plot formation creates structural changes in a multi-species Great Barrier Reef seagrass meadow. *Marine Environmental Research* **162**: 105183

Short FT and Wyllie-Echeverria S (1996). Natural and human-induced disturbance of seagrasses. *Environmental Conservation* **23:** 17–27

Smith TM, Reason C, McKenna S and Rasheed MA (2021). Seagrasses in Port Curtis and Rodds Bay 2020 Annual long-term monitoring. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/16, James Cook University, Cairns, 54 pp.

Stapel J, Manuntun R, & A HM (1997). Biomass loss and nutrient redistribution in an Indonesian *Thalassia hemprichii* seagrass bed following seasonal low tide exposure during daylight. *Marine Ecology Progress Series*, **148**: 251–262

Tol SJ, Jarvis JC, York PH, Grech A, Congdon BC, & Coles, RG (2017). Long distance biotic dispersal of tropical seagrass seeds by marine mega-herbivores. *Scientific Reports,* **7:** 1–8

Watson RA, Coles RG, Lee Long WJ (1993). Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. *Australian Journal of Marine and Freshwater Research* **44**: 211-220

Waycott M, Collier C, McMahon K, Ralph PJ, McKenzie LJ, Udy JW, & Grech A (2007). Vulnerability of seagrasses in the Great Barrier Reef to climate change - Chapter 8. *Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Part II: Species and species groups* (J.E. Johnson, and P.A. Marshall, eds): Great Barrier Reef Marine Park Authority pp. 193-236.

Waycott M, Duarte CM, Carruthers TJB, Orth R Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck Jr KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT and Williams SL (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

York PH, Macreadie PI & Rasheed MA (2018) Blue carbon stocks of Great Barrier Reef deep-water seagrasses. *Biology Letters,* **14**: 20180529

York PH and Rasheed MA (2021), 'Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2020', JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication 21/20, Cairns. 42pp.

APPENDICES

Appendix 1. Seagrass Condition Index

Baseline Calculations

Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (1993/94 – 2005/06). The 1993/94 – 2005/06 period incorporates a range of conditions present in Mourilyan Harbour, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events (McKenna et al. 2008).

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). In 2016 an additional rule was applied: where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Grade and Score Calculations section and Figure A1).

Meadow Classification

A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass, area and species composition was classified as either stable or variable (Table A1). One further classification for meadow area was added in the 2016 reporting year: highly stable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

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

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

Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).

Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

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

Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows within a port, and among all the ports monitored by TropWATER (Table A3, see Carter et al. 2015 for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year (see Baseline Calculations section), allocating a grade for each indicator by comparing 2019 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.

Table A3. Score range and grading colours used in the 2019 Mourilyan Harbour report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥0.25	<0.50
E	Very poor	0.00	<0.25

Where species composition was determined to be anything less than in “perfect” condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure A1). If this was the case, then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. muelleri* subsp. *capricorni* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *H. uninervis* and *Z. muelleri)*, 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*, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure A1).

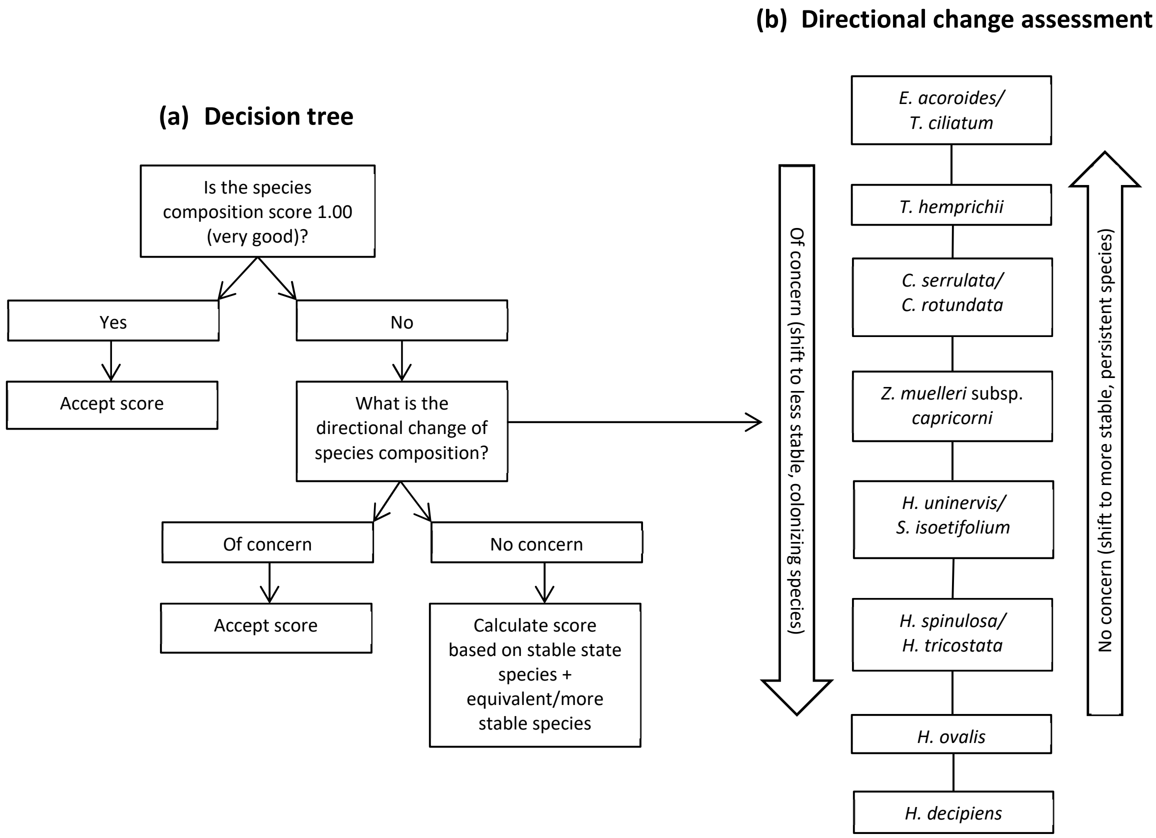


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Mourilyan Harbour.

Score Aggregation

A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years' annual report. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change acknowledges that species composition 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. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such a food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a “0” score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lower of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in Mourilyan Harbour as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Abbot Point, Mackay, Hay Point, Port Curtis, Torres Strait, Weipa and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across Gladstone (and the other locations), where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Overall Mourilyan Harbour grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Port grades are therefore more sensitive to changes in stable than variable meadows.

Appendix 2. Example of calculations meadow condition scores

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

1. Determine the grade for the 2018 (current) area value (i.e. satisfactory).

2. Calculate the difference in area (A_{diff}) between the 2018 area value (A_{2018}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

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

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:

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

Where $A_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.
Note: For species composition, the upper limit for the very good grade is set as 100%. For area and biomass, the upper limit for the very good grade is set as the maximum value of the mean plus the standard error (i.e. the top of the error bar) for a given year during the baseline period for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (A_{prop}) that A_{2018} takes up:

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

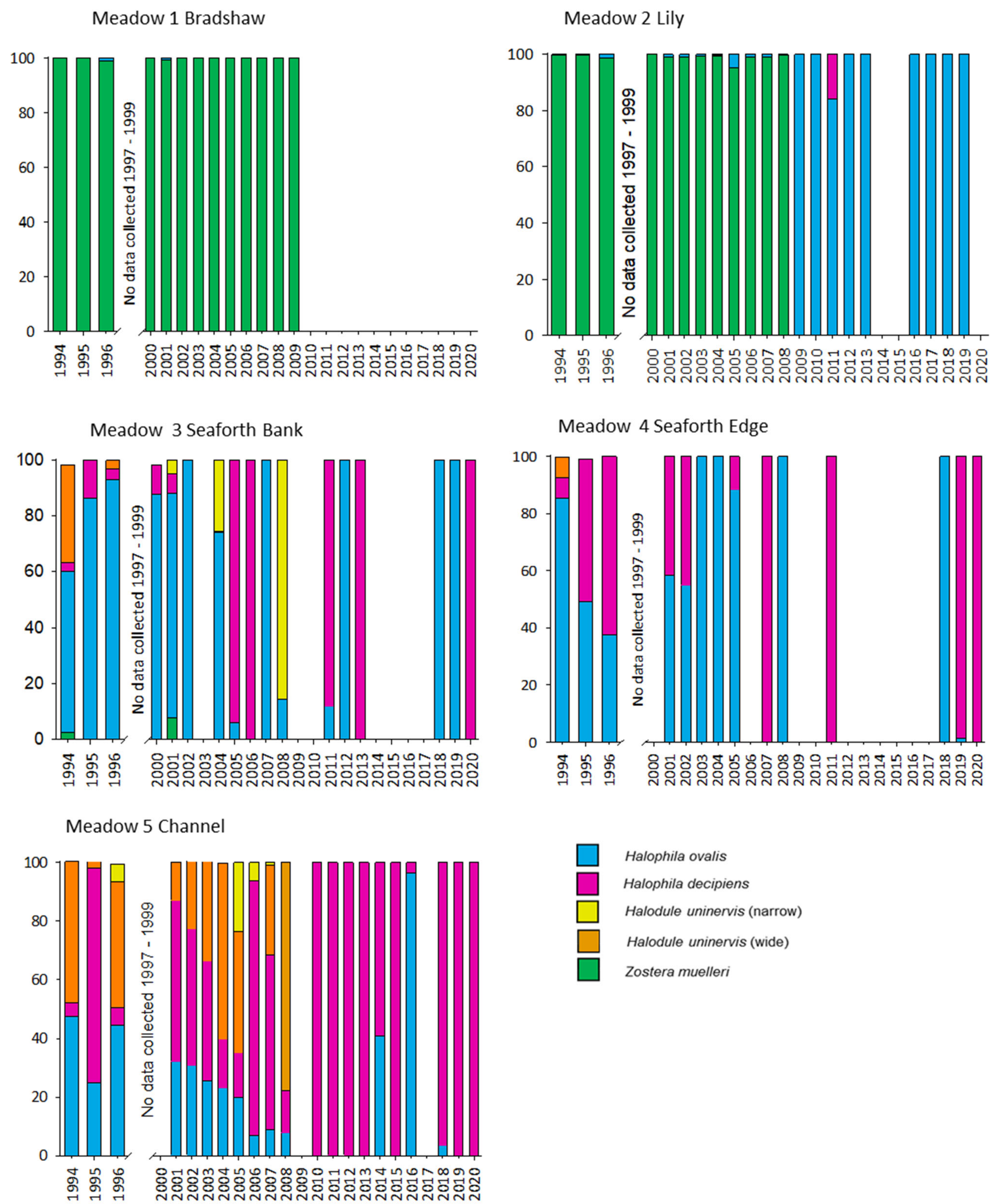
5. Determine the area score for 2018 ($Score_{2018}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

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

Appendix 3. Species composition of monitoring meadows

Species composition of monitoring meadows in the Port of Mourilyan, 1993 – 2020.



Appendix 4a. Area changes: 1993 – 2019

Seagrass monitoring meadow area (ha) in Mourilyan Harbour, 1993-2020 (±R = reliability estimate).

Meadow (ID no.)	Area (ha) (±R)																								
	Jan 1993	Dec 1994	Jan 1995	Dec 1996	Dec 2000	Dec 2001	Nov 2002	Dec 2003	Dec 2004	Nov 2005	Nov 2006	Oct Dec 2007	Oct Dec 2008	Oct Nov 2009	Oct Nov 2010	Sept Nov 2011	Oct 2012	Oct Nov 2013	Dec 2014	Sept Nov 2015	Oct Nov 2016	Oct Nov 2017	Oct Dec 2018	Oct Dec 2019	Oct 2020
Bradshaw (1)	3.7 ±1.9	2.5 ±0.8	2.7 ±0.8	3.1 ±0.9	3.4 ±0.4	3.0 ±0.5	4.1 ±0.5	3.6 ±0.4	3.3 ±0.5	3.0 ±0.5	2.7 ±0.5	3.4 ±0.5	3.0 ±0.4	2.4 ±0.4	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Lily (2)	0.9 ±0.4	1.0 ±0.5	0.8 ±0.3	0.7 ±0.2	1.1 ±0.2	1.7 ±0.3	1.4 ±0.4	1.8 ±0.3	1.0 ±0.4	1.2 ±0.4	0.5 ±0.2	0.5 ±0.2	0.4 ±0.2	0.2 ±0.2	0.4 ±0.2	1.74 ± 0.3	1.1 ±0.3	0.4 ±0.2	NP	NP	0.283 ±0.16	NP	2.35 ±0.44	2.18 ±0.43	NP
Seaforth Bank (3)	22.1 ±4.0	27.5 ±5.5	23.1 ±6.0	19.7 5.8	15.6 ±7.1	29.8 ±2.8	0.8 ±0.5	NP	6.3 ±2.2	13.1 ±2.6	4.0 ±1.1	1.9 ±1.3	0.9 ±0.7	NP	NP	25.1 ±1.4	0.6 ±0.1	0.02 ±0.01	NP	NP	NP	NP	10.02 ±1.27	9.70 ±1.57	1.80 ±0.54
Seaforth Edge (4)	2.6 ±1.8	3.0 ±1.4	3.3 ±2.1	3.4 ±3.3	NP	5.2 ±4.2	2.9 ±1.2	0.2 ±0.1	3.3 ±0.9	3.3 ±0.7	NP	1.5 ±0.8	0.1 ±0	NP	NP	2.1 ±0.9	NP	NP	NP	NP	NP	NP	0.47 ±0.20	1.98 ±0.66	2.18 ±0.97
Channel (5)	20.0 ±5.63	37.1 ±6.4	55.4 ±9.2	30.3 ±18.8	NP	34.1 ±9.8	25.7 ±10.4	28.8 ±14.1	38.4 ±15.3	47.8 ±13.9	40.8 ±11.1	21.9 ±7.6	27.8 ±7.6	NP	0.11 ±0	12.0 ±9.0	25.9 ±15.9	7.5 ±6.3	53.2 ±18.9	25.70 ±12.33	11.39 ±7.1	NP	11.18 ±7.37	21.59 ±10.93	21.11 ±7.79
Total (ha) combined	**49.6 ±13.8**	**71.3 ±14.7**	**85.6 ±18.6**	**57.4 ±29.1**	**20.2 ±7.8**	**74.0 ±17.7**	**35.0 ±13.1**	**34.5 ±14.9**	**52.4 ±19.4**	**68.5 ±18.2**	**48.1 ±13.0**	**29.6 ±10.5**	**32.4 ±9.1**	**2.7 ±0.6**	**0.51 ±0.3**	**47.3 ±12.0**	**27.7 ±16.4**	**8.0 ±6.5**	**53.2 ±18.9**	**25.70 ±12.33**	**11.67 ±7.26**	**NP**	**24.02 ±9.28**	**35.45 ±17.16**	**25.09 ±9.3**

NP - seagrass not present.

Note: no data collected in 1997, 1998 and 1999.

Appendix 4b. Above-Ground Biomass changes: 1993 – 2019

Mean above-ground biomass (g DW m^{-2}) of seagrass for monitoring meadows in Mourilyan Harbour, 1993-2020.

Meadow (ID no.)	Mean biomass ± SE (g DW m^{-2})																								
	Jan 1993	Dec 1994	Jan 1995	Dec 1996	Dec 2000	Dec 2001	Nov 2002	Dec 2003	Dec 2004	Nov 2005	Nov 2006	Oct Dec 2007	Oct Dec 2008	Oct Nov 2009	Oct Nov 2010	Sept Nov 2011	Oct 2012	Oct Nov 2013	Dec 2014	Sept Nov 2015	Oct Nov 2016	Oct Nov 2017	Oct Dec 2018	Oct Dec 2019	Oct 2020
Bradshaw (1)	37.8 ±11.5	45.1 ±3.5	49.2 ±2.9	59.4 ±5.4	17.5 ±1.3	35.8 ±5.3	32.1 ±2.0	21.5 ±3.4	59.3 ±6.9	34.1 ±3.6	46.5 ±4.1	21.4 ±2.3	28.7 ±3.5	15.5 ±2.9	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Lily (2)	16.1 ±0	30.4 ±4.5	29.4 ±2.0	29.8 ±2.9	7.6 ±0.5	5.5 ±1.5	20.6 ±3.0	5.0 ±2.3	12.3 ±3.6	0.1 ±0.1	2.4 ±0.8	2.8 ±0.6	4.3 ±2.9	0.03 ±0.01	0.57 ±0.19	0.37 ±0.13	0.03 ±0.01	0.4 ±0.2	NP	NP	0.17 ±0.004	NP	0.04 ± 0.04	0.69 ± 0.19	NP
Seaforth Bank (3)	0.9 ±0.2	0.7 ±0.2	1.1 ±0.2	3.0 ±0.5	0.2 ±0.05	2.4 ±0.4	0.3 ±0.2	NP	0.5 ±0.1	0.02 ±0.005	0.06 ±0.02	NR	0.02 ±0.006	NP	NP	0.3 ±0.06	0.03 ±0.0	0.1 ±0.1	NP	NP	NP	NP	0.007 ± 0.003	0.16 ± 0.08	0.40 ± 0.18
Seaforth Edge (4)	1.8 ±0.4	2.0 ±0.5	1.6 ±0.2	3.3 ±0.8	NP	2.1 ±0.4	1.6 ±0.2	0.02 ±0.02	1.2 ±0.3	0.1 ±0.1	NP	1.1 ±0.03	NR	NP	NP	2.5 ±0.8	NP	NP	NP	NP	NP	NP	NR	1.80 ± 0.36	1.17 ± 0.42
Channel (5)	0.4 ±0.1	1.8 ±0.6	1.4 ±0.2	2.7 ±0.6	NP	0.6 ±0.1	1.0 ±0.1	0.8 ±0.2	1.0 ±0.2	1.2 ±0.4	2.3 ±0.5	2.5 ±0.3	1.5 ±0.3	NP	1.94 ±0	0.56 ±0.21	2.41 ±0.45	2.1 ±0.3	2.4 ±0.2	0.87 ±0.24	0.70 ±0.27	NP	0.53 ± 0.28	0.73 ± 0.18	0.39 ± 0.15

NR (Not recorded) - seagrass present but too sparse to record biomass;
NP - seagrass not present.
Note: no data collected in 1997, 1998 and 1999.