Centre for Tropical Water and Aquatic Ecosystem Research

SEAGRASS HABITAT OF MOURILYAN HARBOUR: Annual Monitoring Report – 2021

Reason, C.L., York, P.H. and Rasheed, M.A.

Report No. 22/04

March 2022

SEAGRASS HABITAT OF MOURILYAN HARBOUR:
Annual Monitoring Report – 2021

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

Report No. 22/04

March 2022

Prepared by Carissa Reason, Paul York 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: https://www.tropwater.com/

Information should be cited as:
Reason, C.L., York, P.H., Rasheed, M.A. 2022, 'Seagrass habitat of Mourilyan Harbour: Annual Monitoring Report – 2021', Centre for Tropical Water & Aquatic Ecosystem Research, JCU Publication 22/04, Cairns, 39pp.

For further information contact:
Seagrass Ecology Group
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 Ports North. Thanks to TropWATER staff for valuable assistance in the field and laboratory.

KEY FINDINGS

Seagrass Condition 2021

Very Poor

1. Seagrass was in a very poor condition in Mourilyan Harbour in 2021.
2. All meadows were classified as in a very poor condition as the biomass and extent were well below the long-term average, even though seagrass was present in three of the five monitoring meadows.
3. Two of the monitoring meadows received a very good condition grade for species composition, a return to *Halophila ovalis* in Seaforth bank (3) and the Bradshaw meadow (1) which saw a return of foundation species *Zostera muelleri* through restoration trials for the first time since 2009.
4. The whole of port survey looked for overall seagrass distribution in the harbour area. Two additional meadows were mapped, a decline from the 11 previously found in 2018.
5. Above average rainfall and river flow in the months leading up to the survey may have reduced the environmental conditions favourable to seagrass growth and survival prior to the survey.
6. A return of the foundation species *Zostera muelleri* in Mourilyan Harbour is a promising sign that preliminary restoration efforts were successful and can be scaled up for a full restoration program for Bradshaw and Lily meadows.
7. Current seagrass condition was unlikely to be related to port operations with the major losses and declines associated with previous La Niña climate events and more recent wet weather and river flows.

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). This report also includes an extended survey encompassing all seagrasses within the harbour to capture the health and condition of the whole system.

In 2021 overall seagrass condition remained very poor. While seagrass was present at three of the five monitoring meadows, it was in a very small capacity and wasn't enough to improve overall condition grades. The most noteworthy improvement in 2021 was the return of *Zostera muelleri* in the Bradshaw (1) meadow for the first time since it disappeared in 2010. This foundation species has been absent for many years and due to a pilot restoration program, its return is a positive sign of improvement for Mourilyan Harbour. Seaforth Bank (3) declined in biomass and area but received a very good grade for the species shift back to *Halophila ovalis*. Seaforth Edge (4) also declined on all three condition grades, however there was a small patch of *Halophila* rhizome present but biomass was unable to be recorded. The two meadows that were absent in 2021; Lily (2) and Channel (5), have been dominated by colonising *Halophila spp*. in the past few years and are highly variable in abundance and distribution. While the overall meadow condition of seagrasses in Mourilyan Harbour is heavily influenced by the presence/absence of *Zostera muelleri* in Bradshaw (1) and Lily (2) meadows, the return of this species in 2021 is a positive sign of improvement going forward.

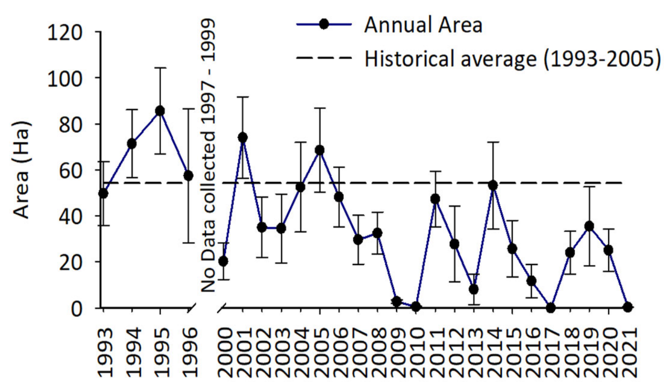


Figure 1: Mourilyan Harbour seagrass monitoring meadow total area (Ha) from 1993 to 2021.

The distribution of seagrass in the broader harbour declined from previous years with a narrow strip of intertidal *Halodule uninervis* that has persisted in the same location over the past few years. A small isolated patch of *Enhalus acoroides* has persisted in the same location on Seaforth Bank and was again present however with a smaller footprint.

Environmental conditions in Mourilyan Harbour for 2021 were not favourable for seagrass growth with above average river flow in the six months leading up to the survey. Rainfall was also above average in the three month lead up to the survey and there was a large rainfall event in April 2021 which may have led to a decline in water quality and light availability 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 patch of *Halodule uninervis* along the sand bank on the northern side of the channel and isolated patch of *Enhalus acoroides* on Seaforth Bank are evidence that conditions may be just favorable enough for these larger species to persist.

In 2020, JCU/TropWATER, in partnership with OzFish Unlimited undertook a small and successful pilot restoration study using vegetative fragments of *Z. muelleri.* This 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. The return of the foundation species *Z. muelleri* to the Bradshaw (1) meadow in 2021 from this pilot should lead to the start of a return 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 expanded to full meadow scale and JCU is exploring funding options to expand this work in the future.

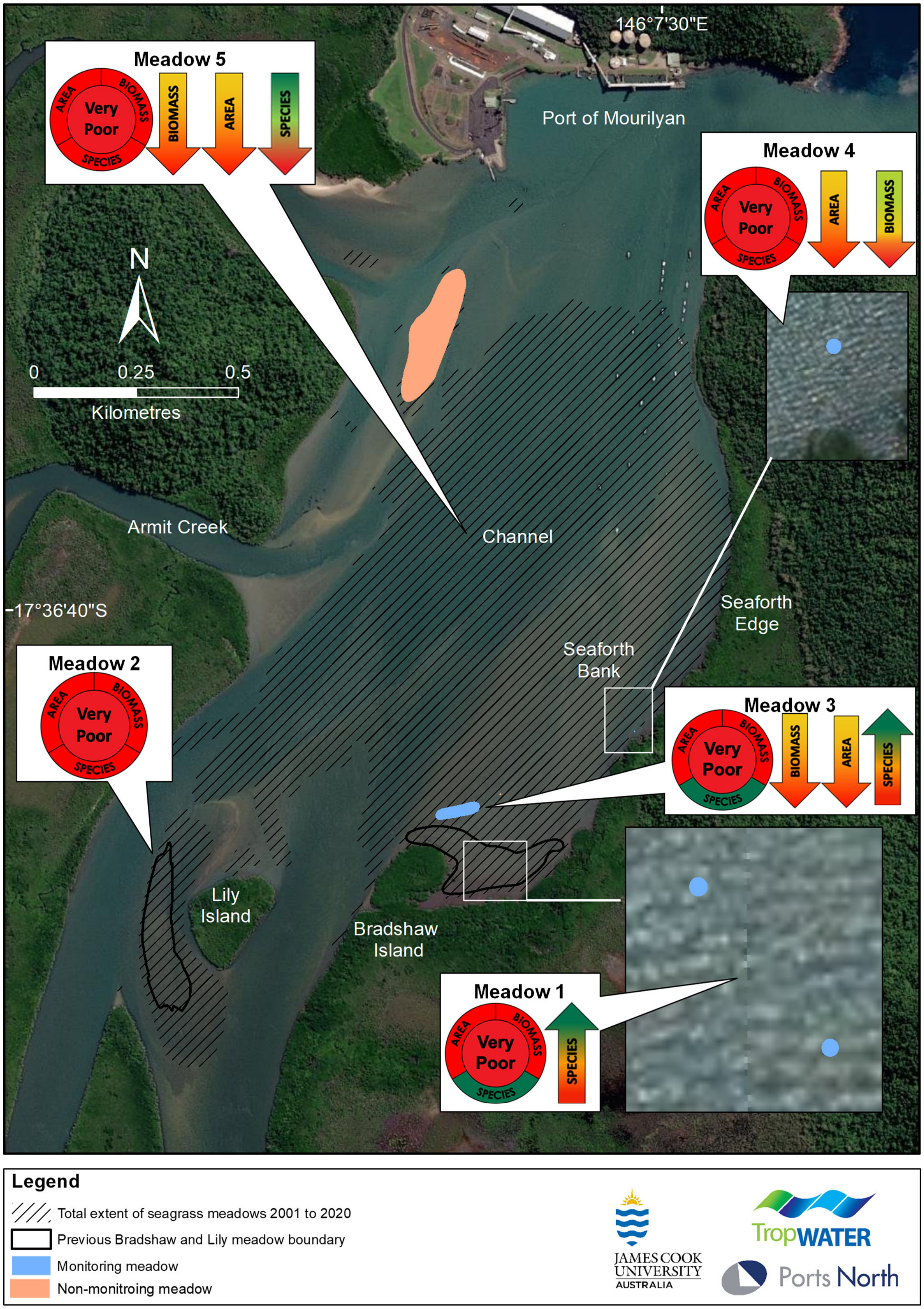


Figure 2. Seagrass condition for Mourilyan Harbour seagrass meadows in 2021.

TABLE OF CONTENTS

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).

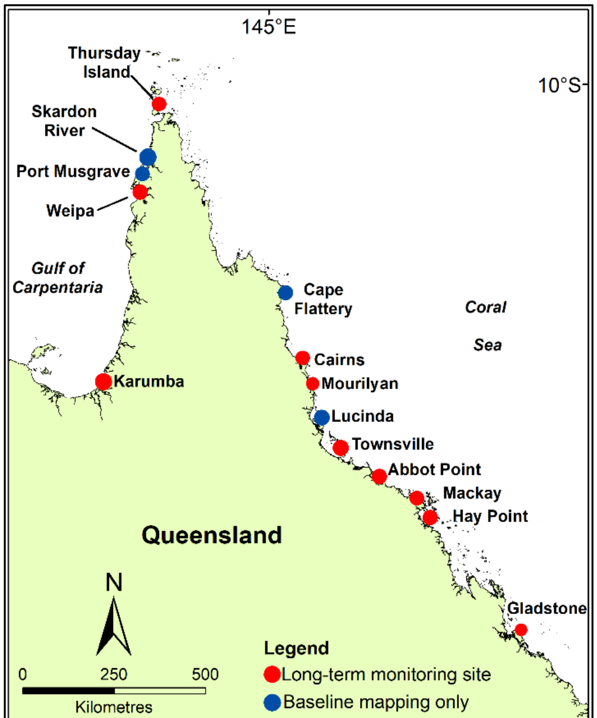


Figure 3. Location of Queensland ports seagrass monitoring locations.

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, 2018 and 2021.

Results of the program also contribute an important information feed on Estuarine seagrass condition for the Wet Tropics Healthy Waterways annual report card

This report presents findings from the 2021 monitoring survey, including:

- Maps of seagrass distribution, abundance, and species composition within the annual monitoring meadows and within the broader whole of harbour area;
- 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;
- Comparison with previous whole of harbour surveys of the extent and composition of seagrass meadows not included in annual monitoring meadows;
- 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.

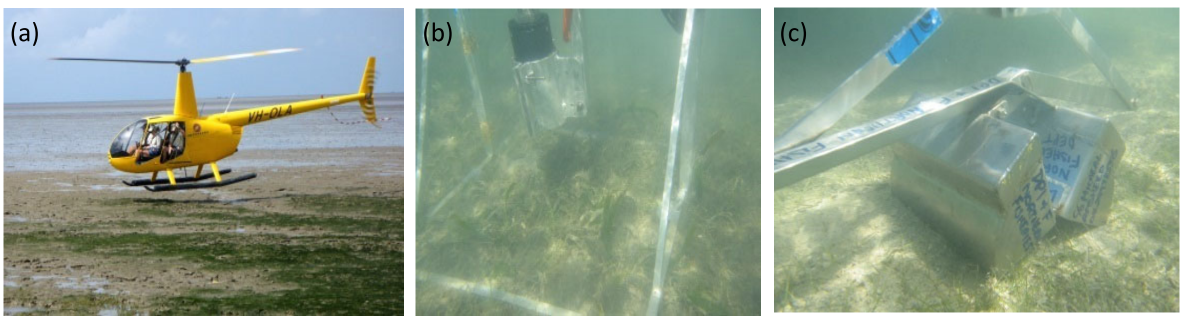
2 METHODS

2.1 Field surveys

The survey involved mapping and assessing the five annual monitoring meadows in Mourilyan Harbour during the seasonal peak of seagrass growth. Aerial surveys were conducted on 5th October and boat based surveys on 6th and 7th October 2021. 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. 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
0 m	Intertidal meadows completely exposed or visible at low tide; High resolution drone photogrammetry aided in mapping; Meadow boundaries determined by orthomosaic imagery;
± 1 - 5 m	Intertidal meadows completely exposed or visible at low tide; Aerial photography aided in mapping; 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.

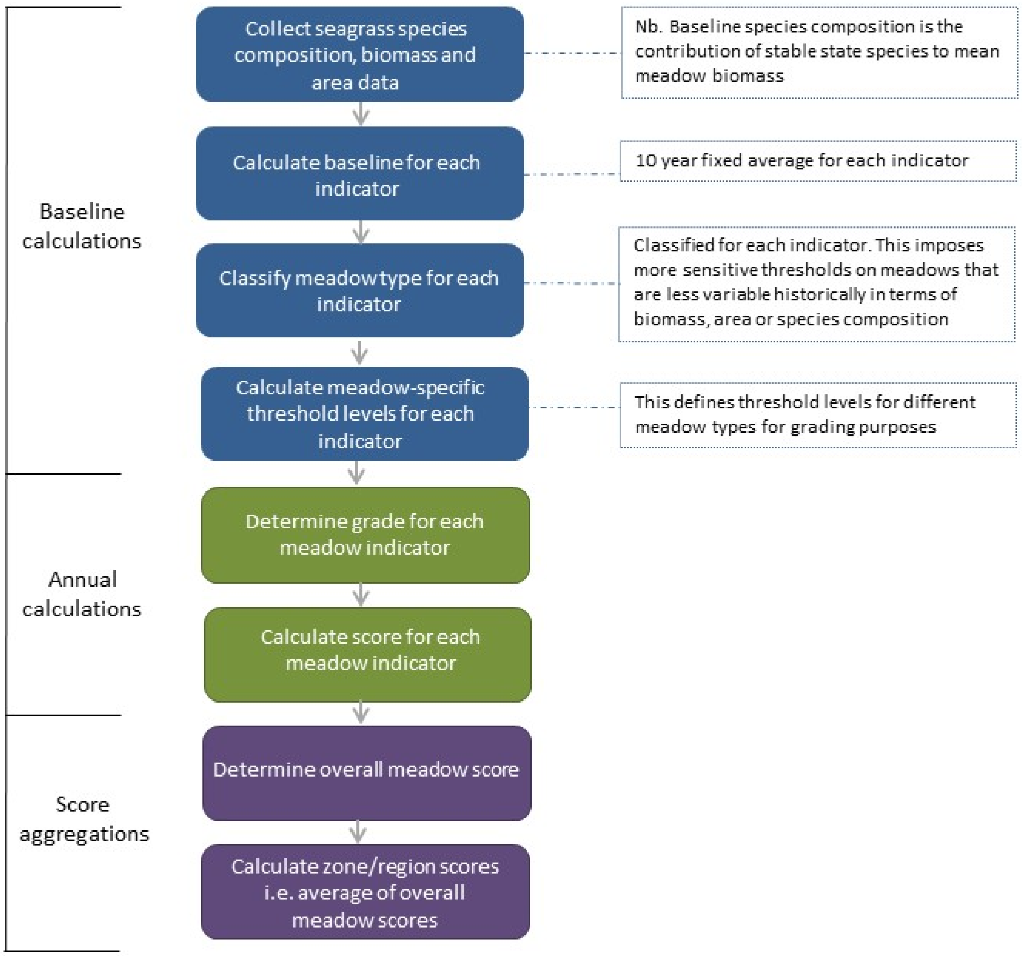


Figure 6. Flow chart to develop Mourilyan Harbour grades and scores.

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). As part of the monitoring program we examine available data on these environmental factors, to provide insight on their potential influencing on seagrass condition.

Tidal data was provided by Maritime Safety Queensland (MSQ) (© The State of Queensland (Department of Transport and Main Roads) 2021, 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;) (BOM 2022). 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 – 2021), 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

Seagrass was present at 3.2% of the 373 sites surveyed in 2021 (Figure 7). The total area of the annual monitoring meadows was 0.3 ± 0.08 ha, well below the long-term average of 54 ha (Figure 1). Seagrass species found in the monitoring meadows include *Halophila ovalis* and *Zostera muelleri*, while *Enhalus acoroides* and *Halodule uninervis* were observed outside of the monitoring meadows (Figures 8 and 9).

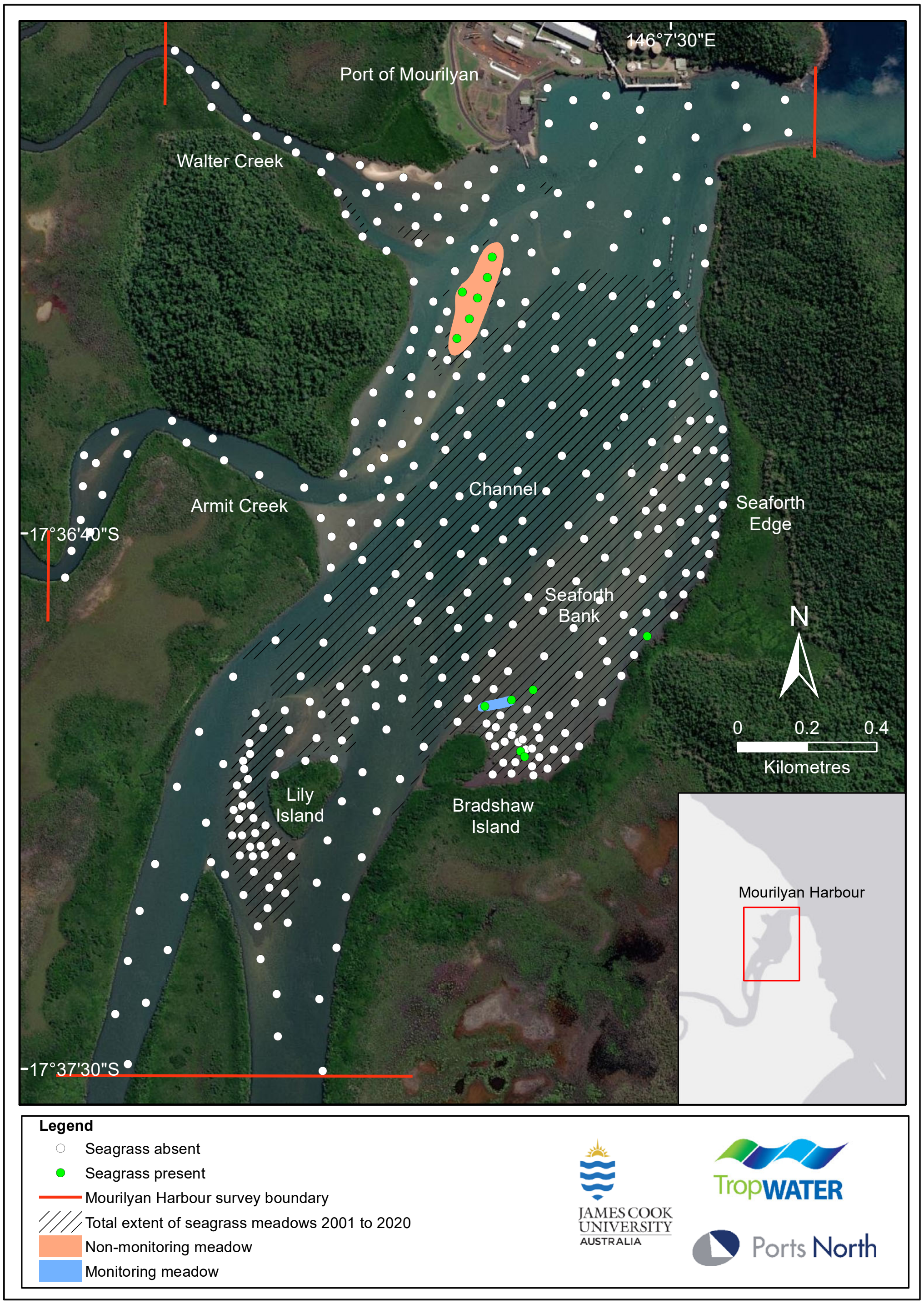


Figure 7. Seagrass presence/absence at survey sites, 2021.

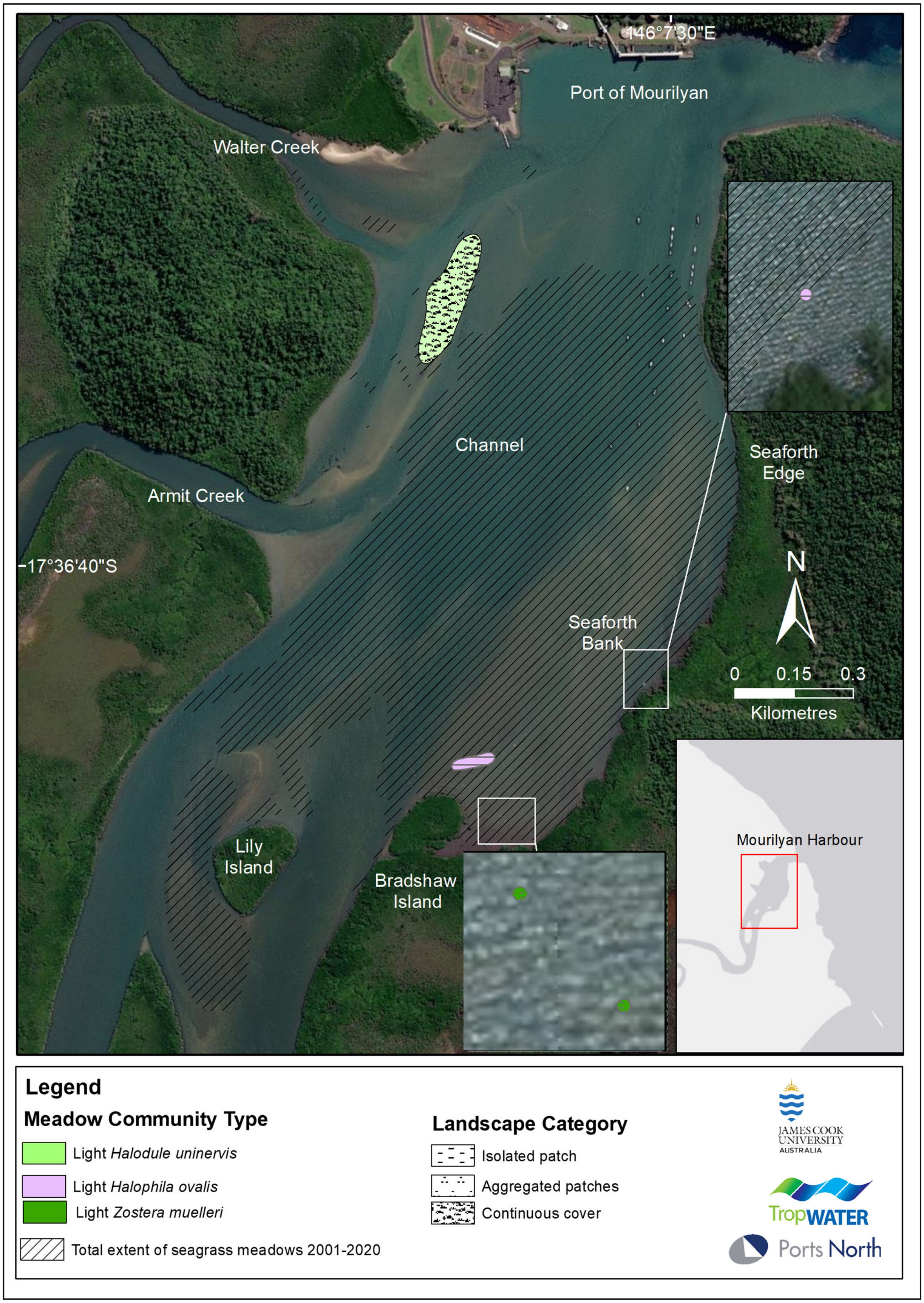


Figure 8. Mourilyan Harbour seagrass distribution and community type for all mapped meadows, 2021.

Figure 9. Seagrass species present in Mourilyan Harbour, 2021.

3.2 Seagrass condition for annual monitoring meadows

Overall seagrass was in a very poor condition in Mourilyan Harbour in 2021. Seagrass was present in three of the five monitoring meadows, however at a very small extent compared to baseline conditions. The condition of Lily (1) and Seaforth Bank (3) remained very poor while Seaforth Edge (4) and Channel (5) declined in condition to very poor. Improvement was seen in the Bradshaw (1) meadow for the first time since 2010 due to recent pilot restoration efforts (Table 4).

Table 4. Grades and scores for condition indicators (biomass, area and species composition) for Mourilyan Harbour monitoring meadows, 2020.

Meadow	Biomass Score	Area Score	Species Composition Score	Overall Meadow Score
1 - Bradshaw	0.09	0.000064	1.00	0.000064
2 - Lily	0.00	0.00	0.00	0.00
3 - Seaforth Bank	0.05	0.02	1.00	0.02
4 - Seaforth Edge	0.00	0.00	0.00	0.00
5 - Channel	0.00	0.00	0.00	0.00
Mourilyan Harbour Overall Score				0.004

The Bradshaw Island meadow (1) showed signs of improvement in 2021 with the presence of *Z. muelleri* detected for the first time since it disappeared in 2010 due to the spread from recent pilot restoration plots. While the biomass and footprint remain in a very poor condition the condition grade of species composition has improved to very good. This meadow was once dominated by *Z. muelleri* up until climate events in 2009 – 2010 resulted in complete meadow loss. In 2020 efforts were put into a pilot seagrass restoration project to trial seagrass restoration methods in Mourilyan Harbour. The presence of a small area of *Z. muelleri* (4.2 m^2 – Appendix 4a) is the result of the successful trial of small-scale seagrass restoration methods from this study.

The Lily Island meadow (2) remained absent in 2021 and in a very poor condition. This intertidal meadow was once dominated by *Z. muelleri*, however this foundation species has been absent since 2009 (Figures 10 and 11; Appendix 3). From year to year there have been small isolated patches of colonising *H. ovalis* within and just outside the meadow, however in 2021 there were no signs of this colonising species (Table 4; Figure 11).

The Seaforth Bank Meadow (3) remained in a very poor condition in 2021. Species composition returned to being dominated by *H. ovalis*, the condition grade indicator species, however it was present in a very small footprint which resulted in a very poor condition grade for area and biomass (Figure 12). There was an isolated patch of *Enhalus acoroides* present in the same location that has been observed in the past few years, however this species is not part of the long term monitoring condition assessment as it falls outside of the meadow stable state species classification.

The Seaforth Edge meadow (4) declined from a poor condition to a very poor condition in 2021. A very small patch of *H. ovalis* rhizomes was found in this meadow however no biomass was recorded due to lack of above ground structure. The presence of seagrass in this meadow is intermittent with multiple years without seagrass from 2012 to 2017. Since 2018 species composition has alternated between colonising species *H. ovalis* and *H. decipiens*(Table 4; Figure 13; Appendix 3).

The Channel meadow (5) was not present in 2021 resulting in an overall condition decline from satisfactory to very poor (Table 4; Figure 14). This meadow has been absent in the past in 2009 and 2017 and has managed to return by the following season due to the colonising nature of the *H. decipiens* species found here.

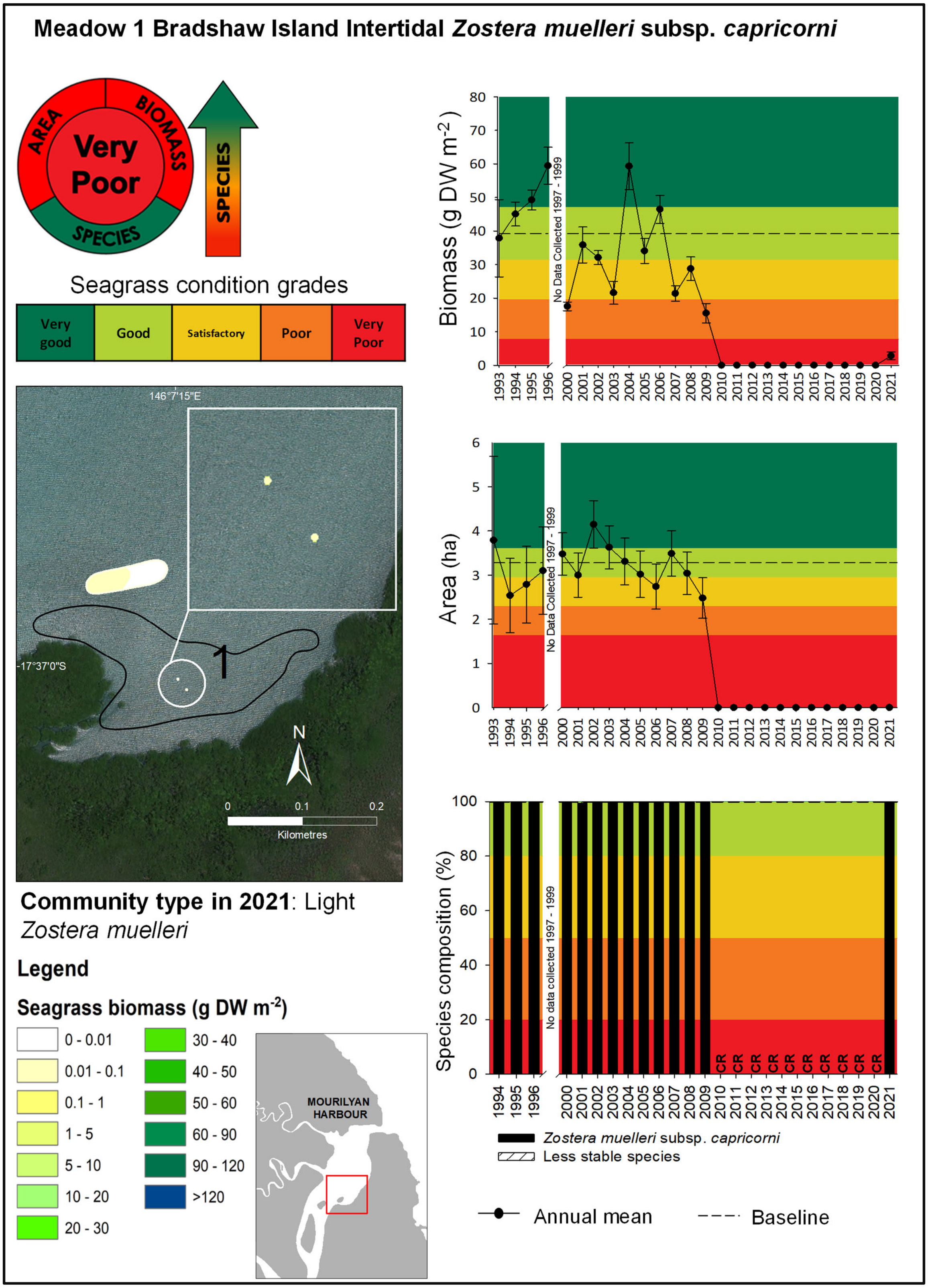


Figure 10. Changes in biomass, area and species composition for the Bradshaw Island meadow from 1993 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

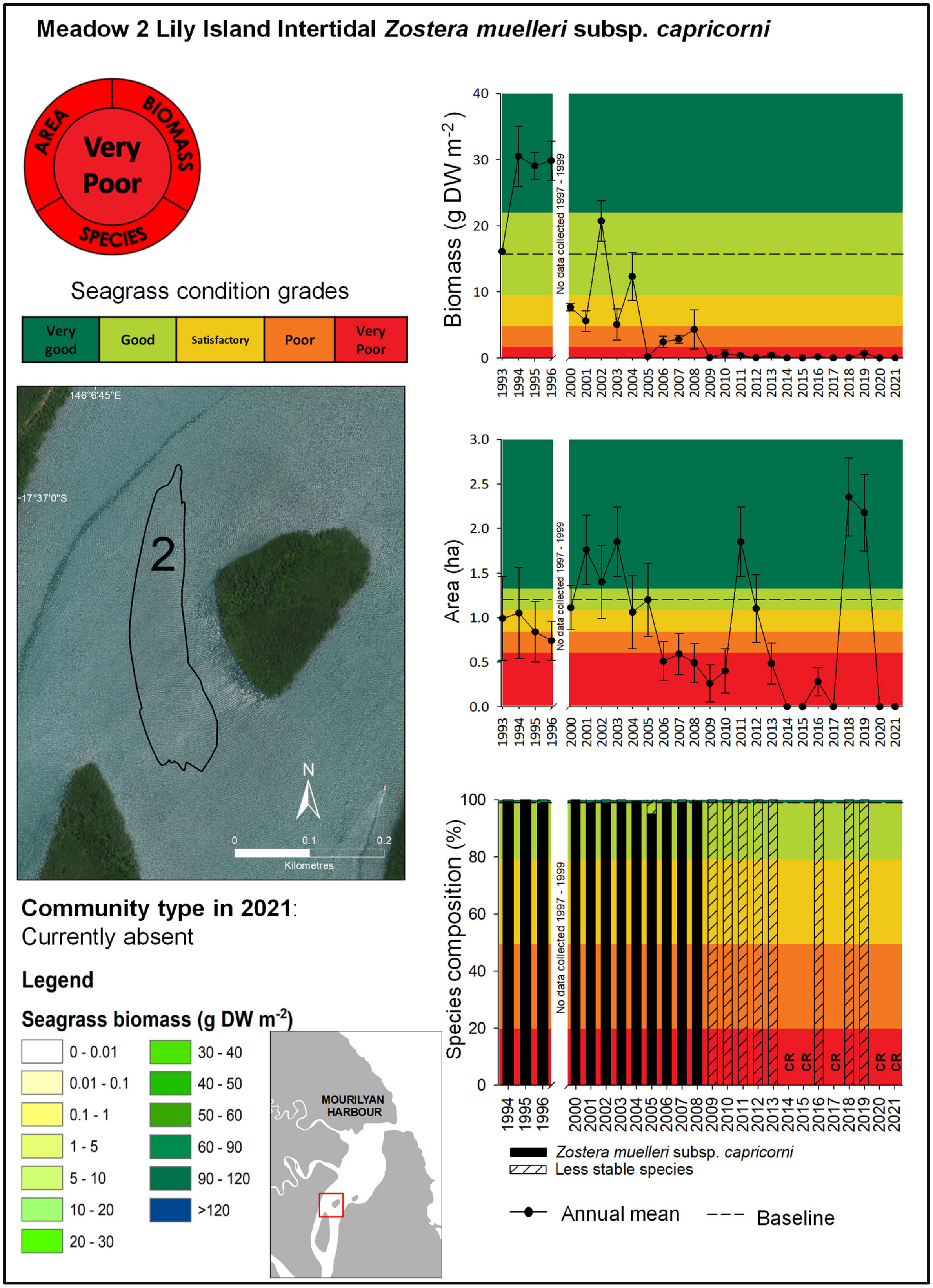


Figure 11. Changes in biomass, area and species composition for the Lily Island meadows from 1993 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

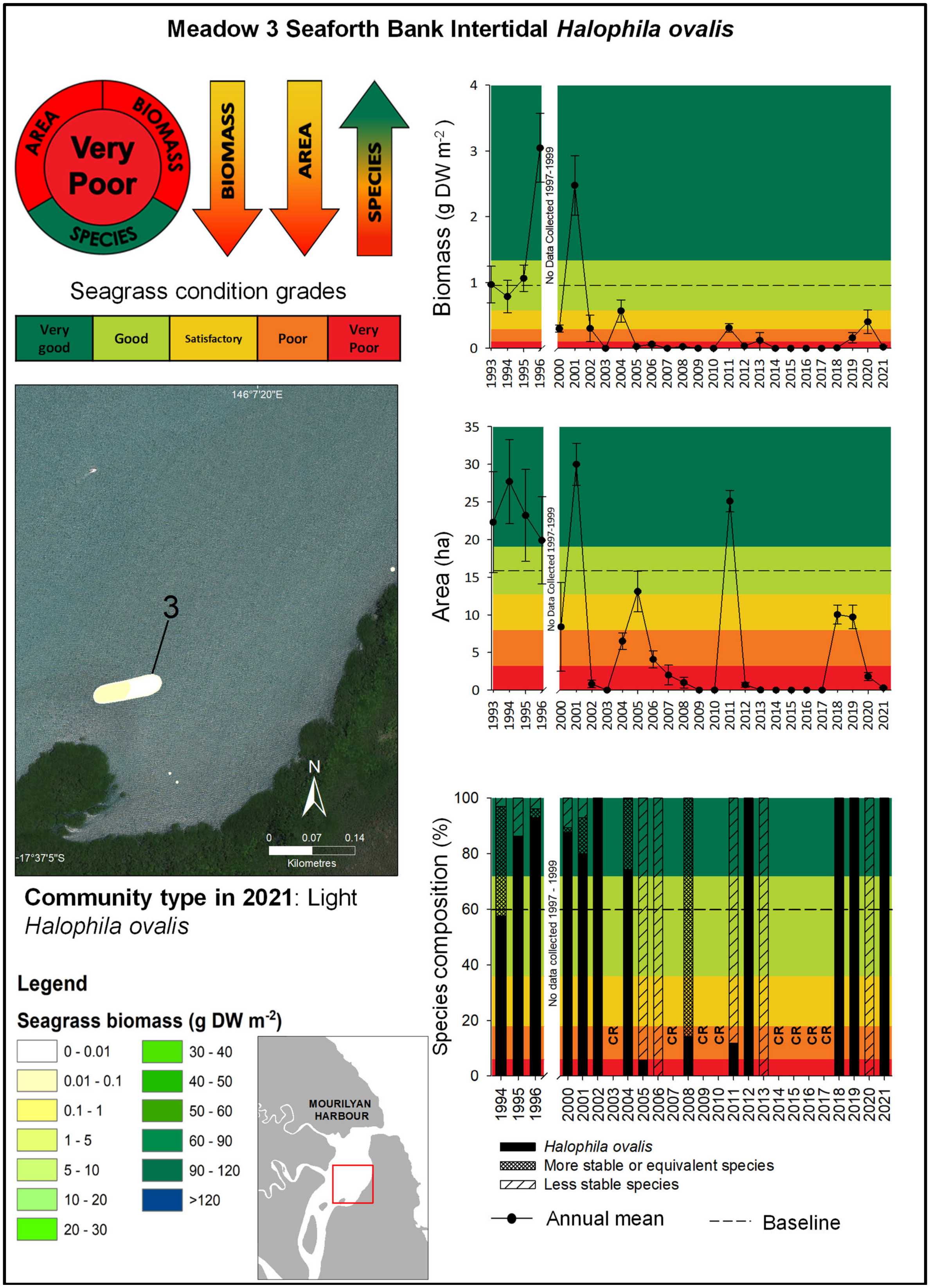


Figure 12. Changes in biomass, area and species composition for Seaforth Bank meadow from 1993 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

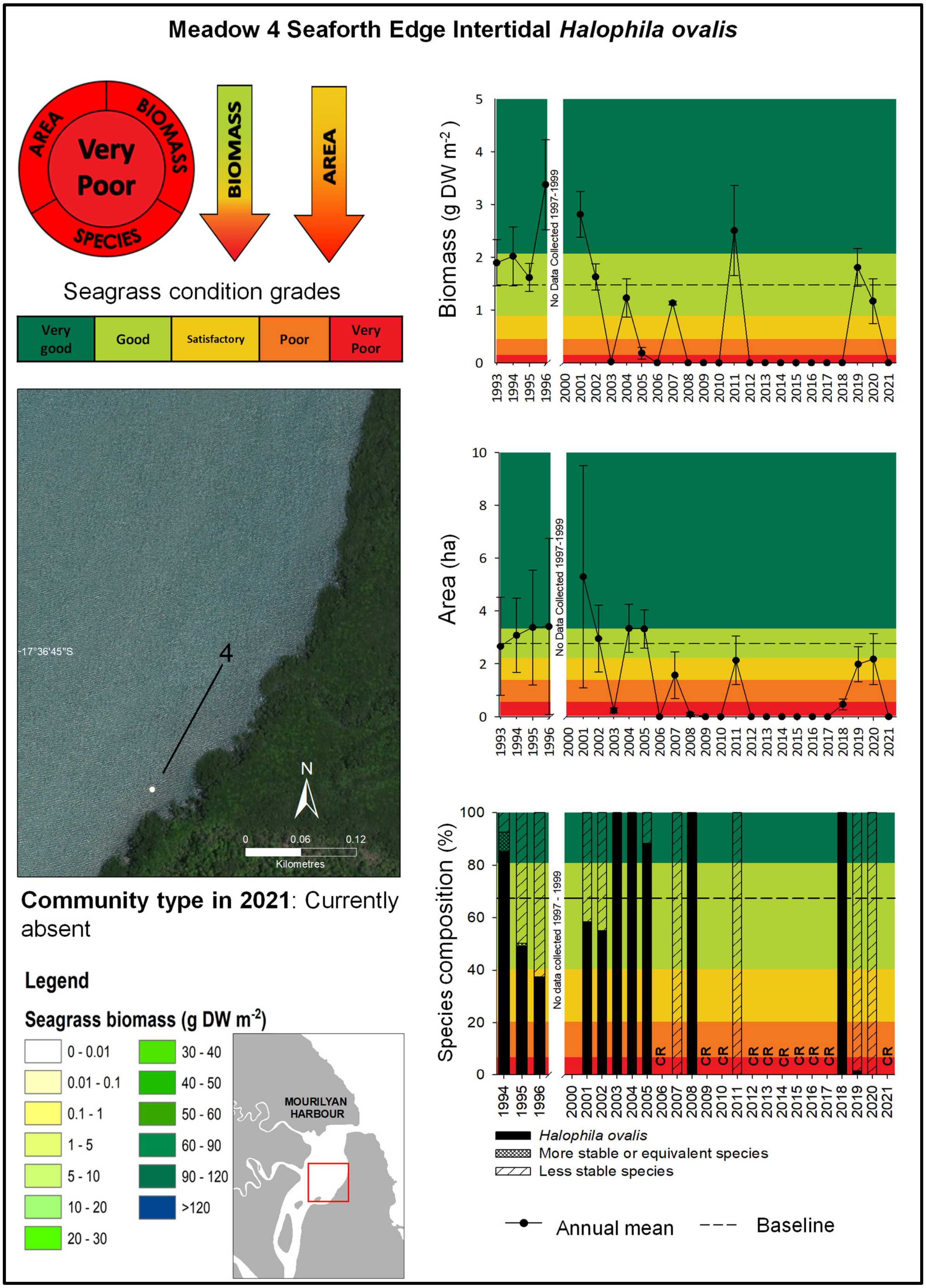


Figure 13. Changes in biomass, area and species composition for the Seaforth Edge meadow from 1993 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

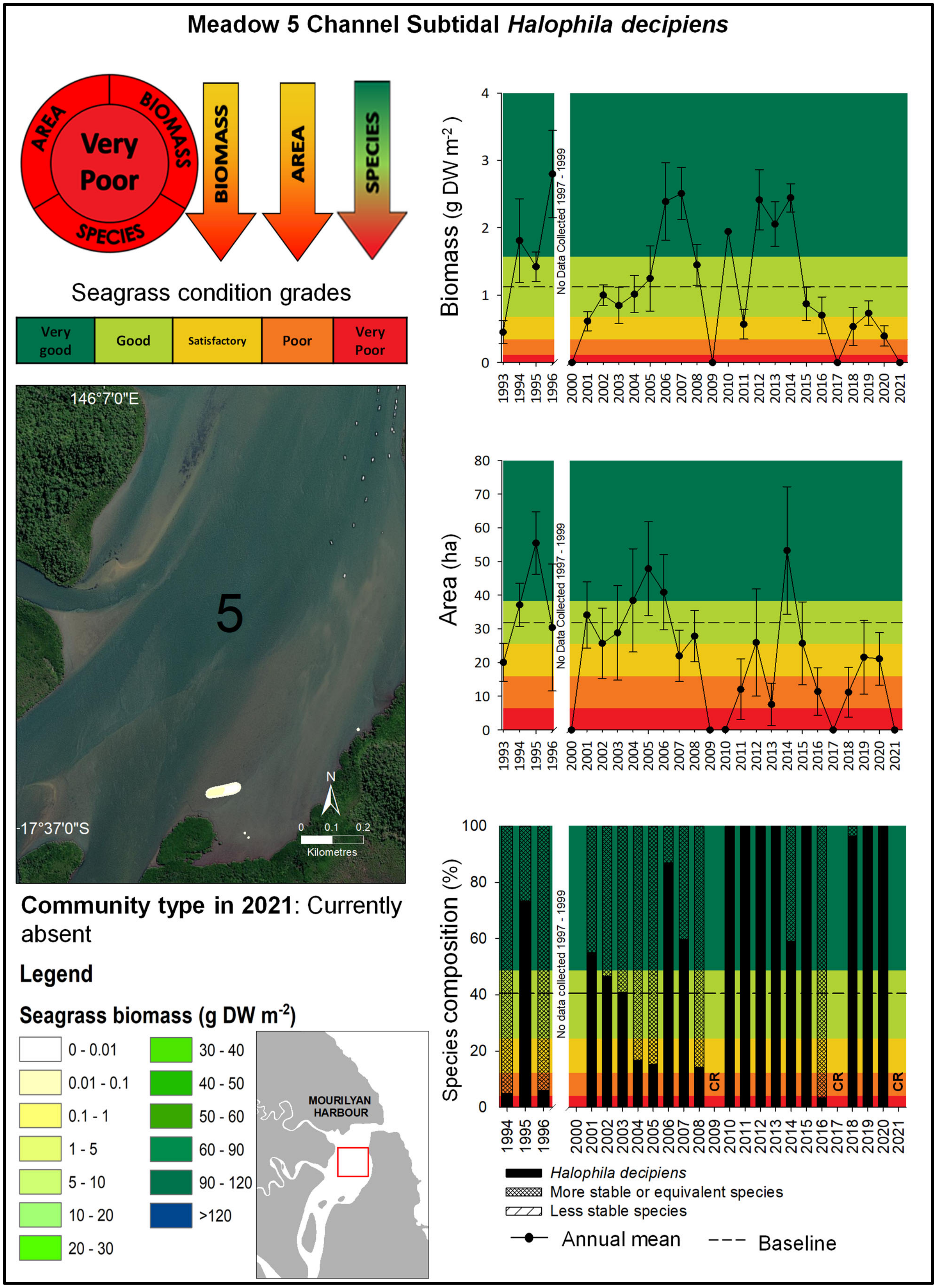


Figure 14. Changes in biomass, area and species composition for the Channel meadow from 1993 – 2021 (biomass error bars = SE; area error bars = "R" reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.

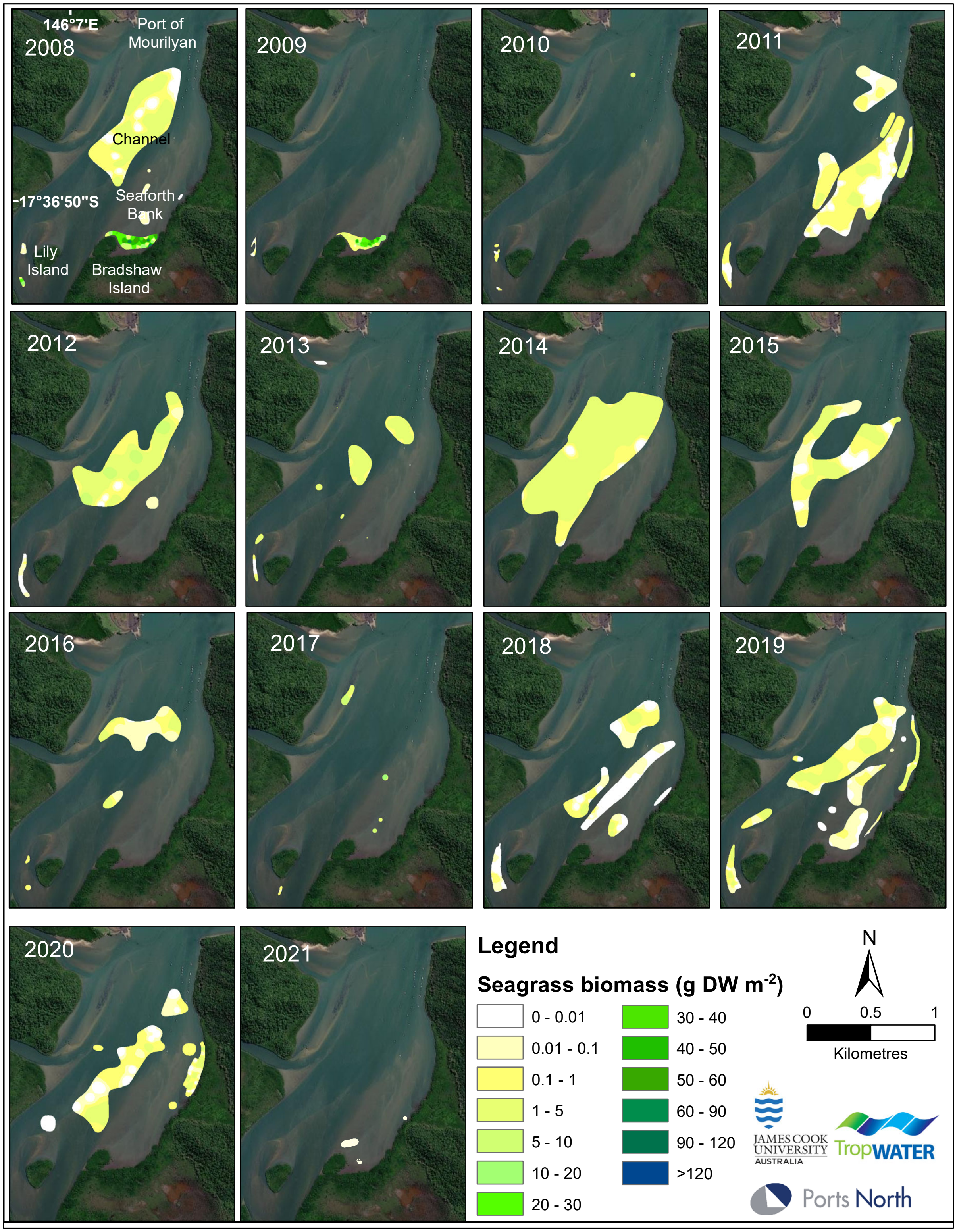


Figure 15. Change in seagrass distribution over time (2007-2021) in Mourilyan Harbour.

3.3 Seagrasses in the whole of harbour area

In addition to the five long-term monitoring meadows assessed annually (see Section 3.2), two other seagrass meadows were mapped within the whole of Mourilyan Harbour area (Figure 8). This included one small isolated patch of *E. acoroides* on Seaforth bank and a continuous intertidal meadow of *H. uninervis* on the sandbanks to the west of the main channel near the mouth of Walter Creek. The *E. acoroides* patch has been present in the same location for the past few years however it had reduced from multiple small patches to only one small patch observed in 2021. The *H. uninervis* meadow was also present during the previous whole of harbour survey, and it has decreased from a dense meadow of 5.8 ± 1.35 g DW m^{-2} in 2018 to a light meadow with biomass of 0.91 ± 0.21 g DW m^{-2} in 2021 (Figure 8).

The whole of port seagrass habitat re-mapping in Mourilyan Harbour in 2021 found a 91% decrease in seagrass compared with the previous whole harbour survey in 2018 (Figure 16). The decline coincides with the decline in monitoring meadow footprint and is a result of the absence of isolated patches of colonisers and larger more persistent species that have been previously observed. The *H. uninervis* meadow has remained persistent since it was observed in 2015 and is a positive sign for the resilience of the larger species within Mourilyan Harbour and may also aid recovery within the adjacent meadows in the future. Overall the decline in footprint is consistent with the trends that have occurred in the annual monitoring meadows since 2009.

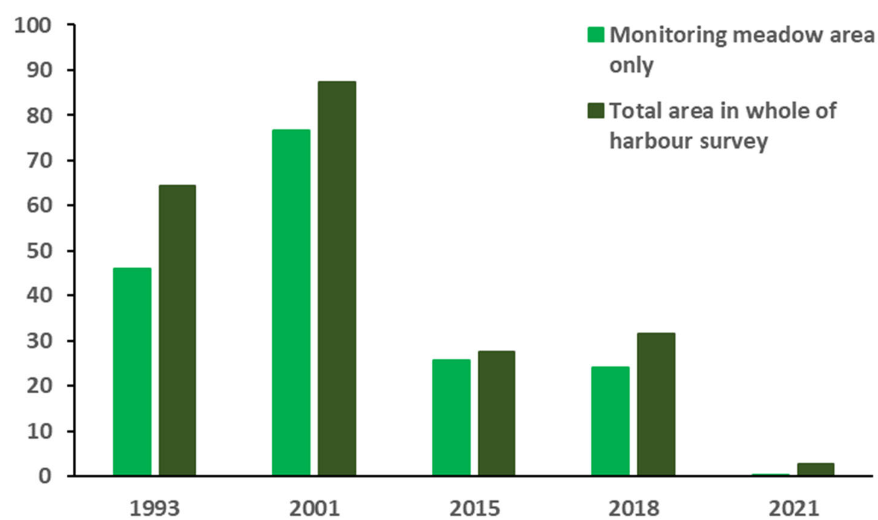


Figure 16. Comparison of total seagrass area (hectares) in the broader Mourilyan Harbour region in 1993, 2001, 2015 and 2018, 2021.

3.4 Mourilyan Environmental Data

3.4.1 Rainfall

In the twelve months preceding the 2021 survey total annual rainfall in Mourilyan Harbour (2393 mm) was well below the long term average (3547 mm) (Figure 17). However, rainfall spiked to well above the monthly average in April 2021 and was also above the monthly average for three months leading up to the survey in October (Figure 18).

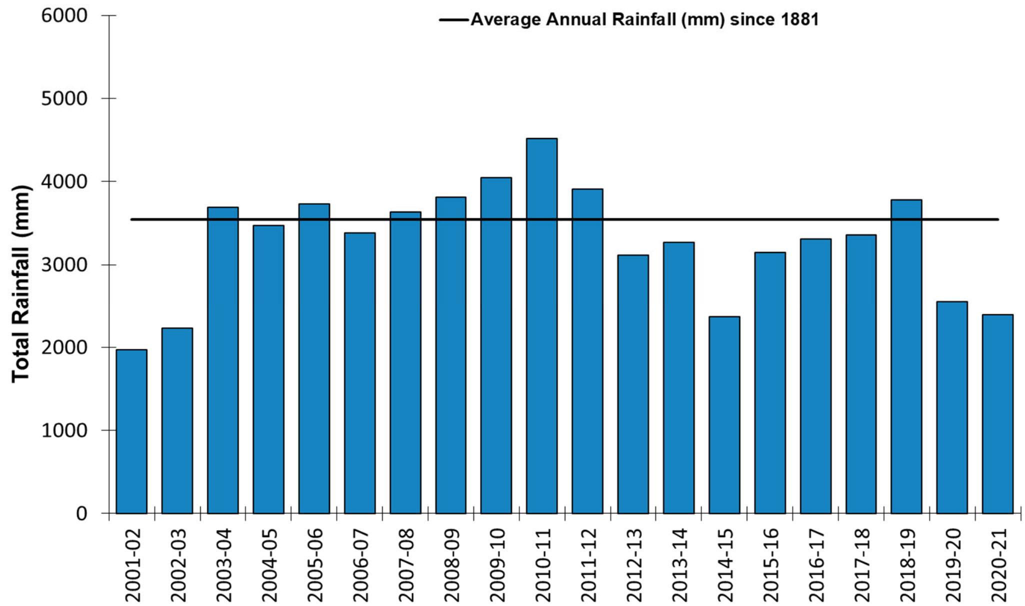


Figure 17. Total annual rainfall (mm) recorded in the twelve months prior to survey, at Innisfail, 2001 – 2021. Source: Bureau of Meteorology, Station 032025, 32197 available at: **www.bom.gov.au**.

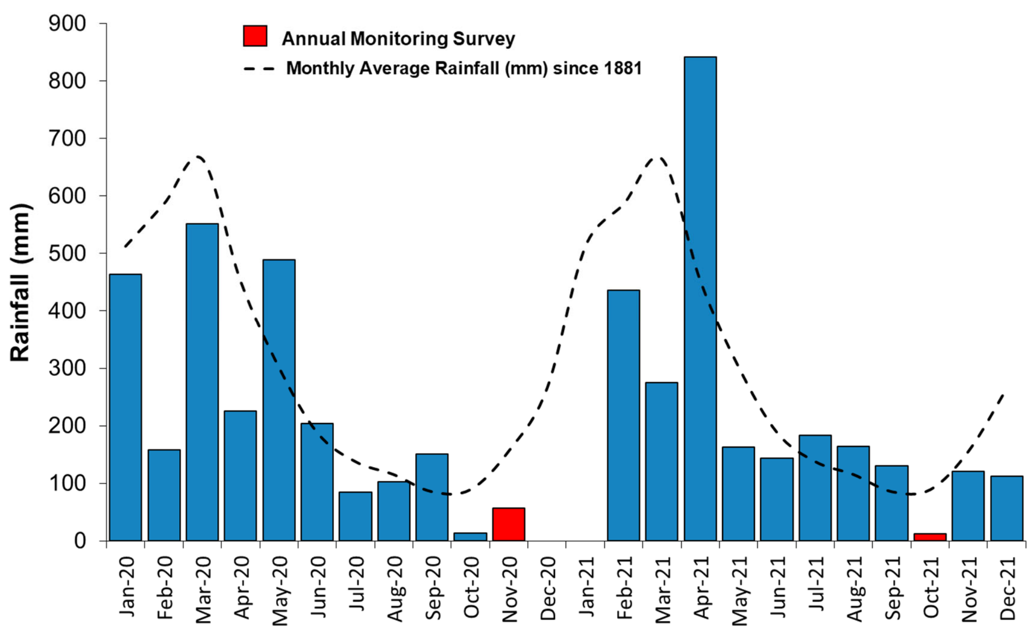


Figure 18. Total monthly rainfall (mm) recorded at Innisfail, January 2020 – December 2021. Source: Bureau of Meteorology, Station 032025, 32197 available at: **www.bom.gov.au**.

3.4.2 River Flow

South Johnstone River total annual flow was 957 GL in 2021, above the long-term mean of 808 GL and an increase on last year (Figure 19). Total monthly river flow was above average for seven of the nine months in the lead up to the survey in October (Figure 20).

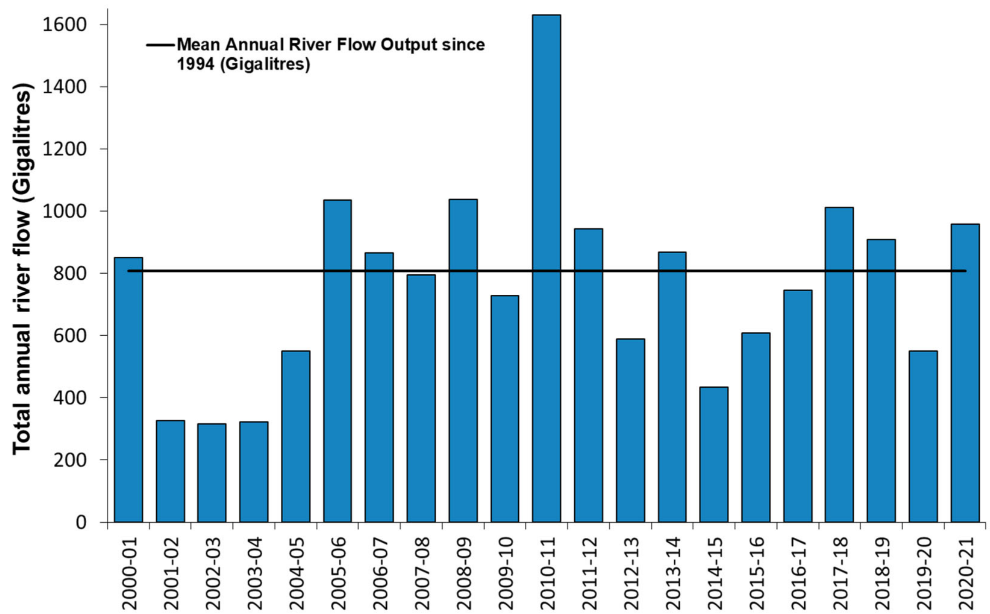


Figure 19. Annual river flow (gigalitres, GL) for the South Johnstone River. Source: Queensland Department of Environment and Resource Management, Station 112101B, available at: **http://watermonitoring.derm.qld.gov.au/host.htm**

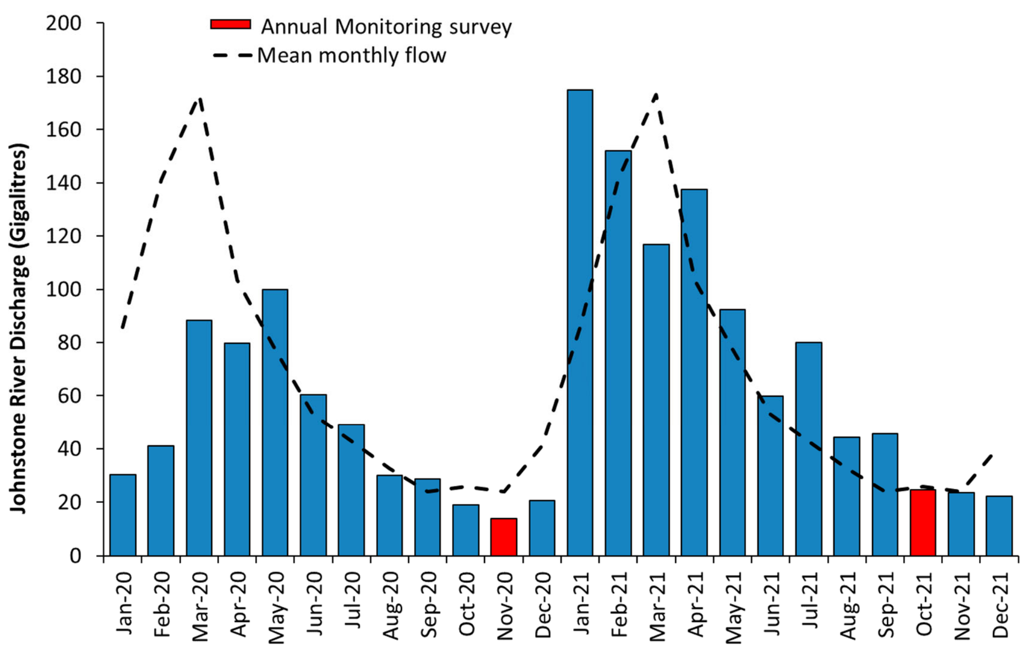


Figure 20. Monthly river flow (gigalitres) for the South Johnstone River, December 2018 – December 2021. Source: Queensland Department of Environment and Resource Management, Station 112101B, available at: **http://watermonitoring.derm.qld.gov.au/host.htm**

3.4.3 Air Temperature and Daily Global Solar Exposure

Mean annual maximum daily air temperature of 28.8°C recorded at Innisfail in 2021 was approximately one degree warmer than the long-term average of 27.9°C (Figure 21). Daily global solar exposure in the twelve months leading up to the survey was below average at 18.8 MJ m^{-2} (Figure 22).

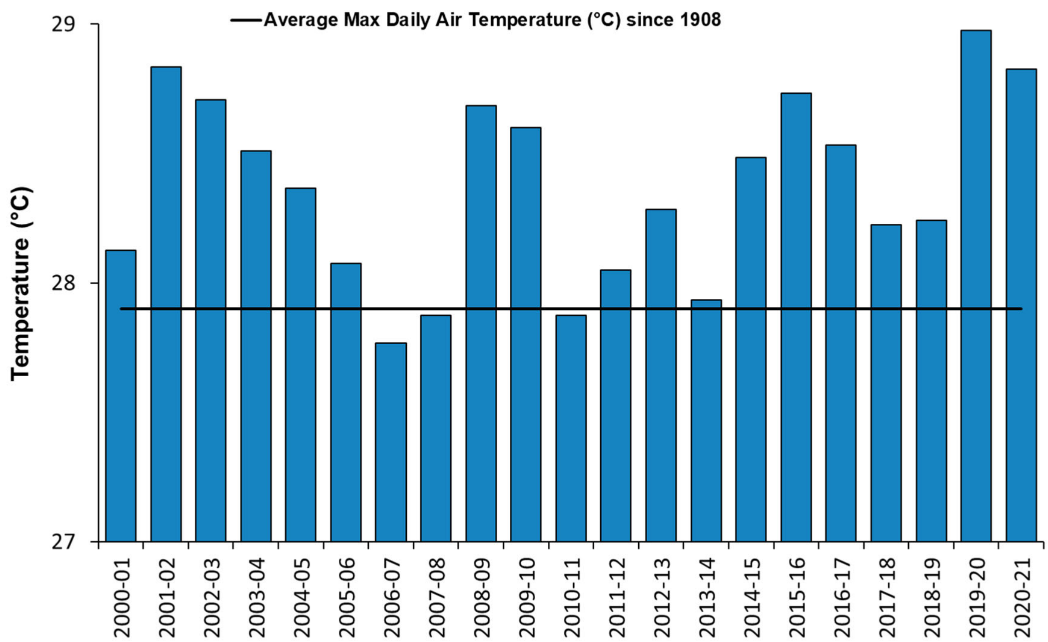


Figure 21. Mean annual maximum daily air temperature (°C) recorded at Innisfail in the twelve months prior to survey, 2000 – 2021. Source: Bureau of Meteorology, Station 032025, 32197, available at: **www.bom.gov.au**.

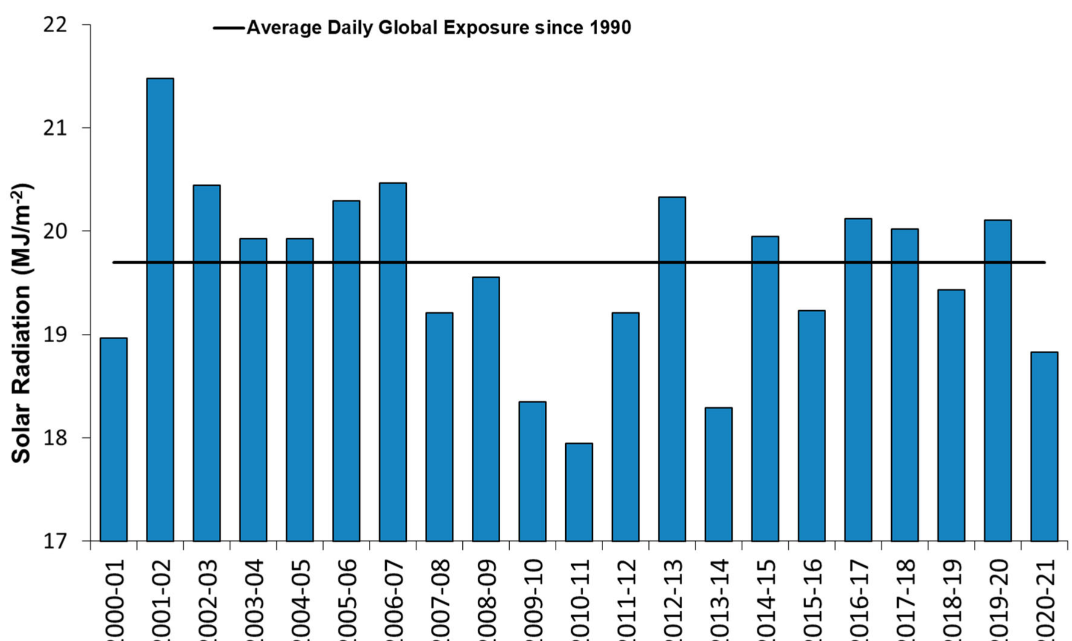


Figure 22. Mean annual daily global solar exposure (MJ m^{-2}) recorded at Innisfail in the twelve months prior to survey, 2000 – 2021. Source: Bureau of Meteorology, Station 032025, available at: **www.bom.gov.au**.

3.4.4 Tidal Exposure of Seagrass Meadows

Total annual daytime exposure of Mourilyan Harbour's intertidal seagrass meadows in 2021 (132 hours) was well below the long-term annual average (174 hours) (Figure 23). August was the only month to experience exposure close to the average in 2021 (Figure 24).

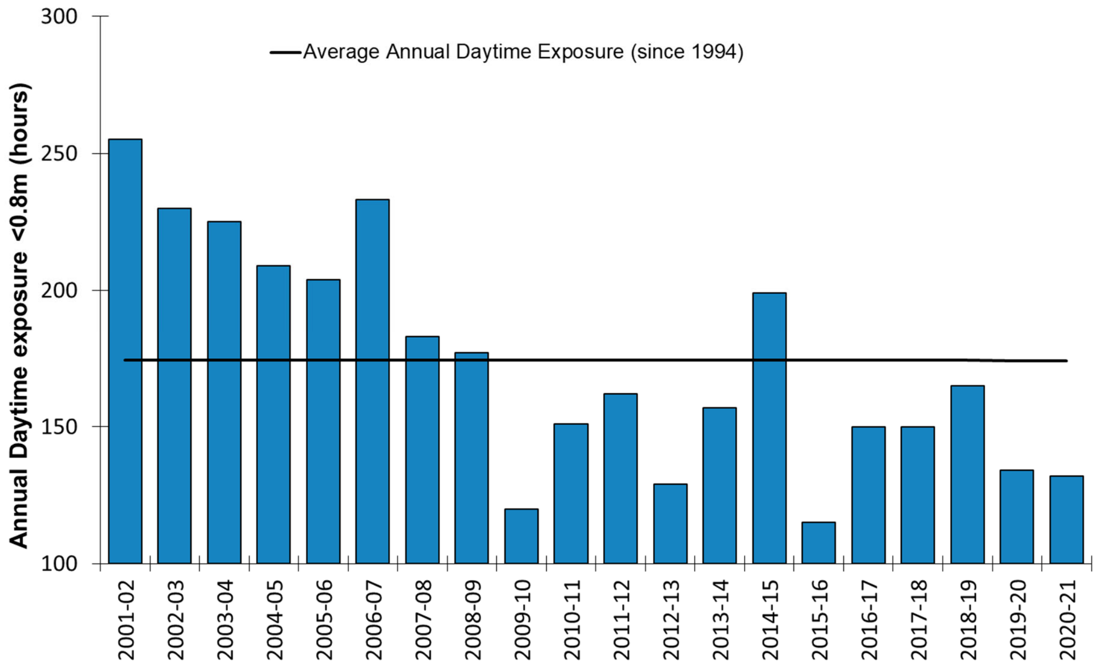


Figure 23. Annual daytime tidal exposure (total hours) of seagrass meadows in Mourilyan Harbour in the twelve months prior to survey; 2001 - 2021. Source: Maritime Safety Queensland, 2020.

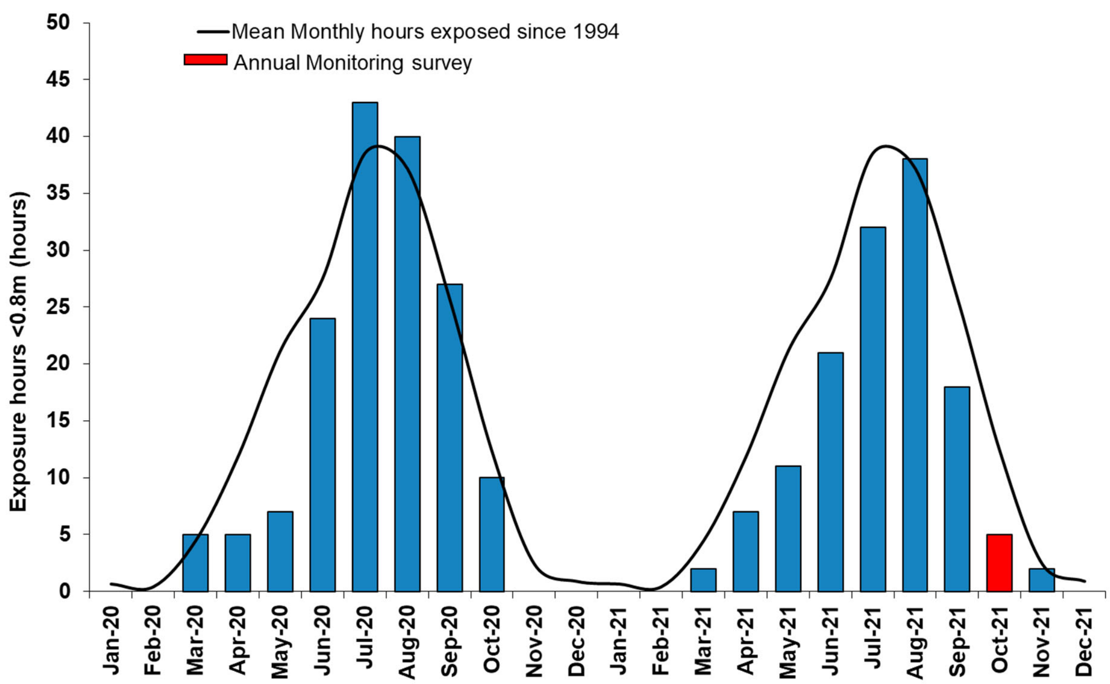


Figure 24. Total monthly daytime tidal exposure (total hours) in Mourilyan Harbour; January 2019 – December 2021. Source: Maritime Safety Queensland, 2020.

4 DISCUSSION

In 2021 the seagrass in Mourilyan Harbour's monitoring meadows were in a very poor condition. This is a continuation of very poor condition grades experienced in biomass and area over the past few years. Seagrass was found in 3 of the 5 monitoring meadows at a very low extent compared to baseline conditions. The whole of port survey found two other meadows outside of the monitoring meadow zones.

In the monitoring meadows there was a return of foundation species *Zostera muelleri* in small isolated patches in the Bradshaw (1) meadow, for the first time since it disappeared in 2010 as a result of recent pilot restoration efforts at the site. The pilot seagrass restoration program conducted by TropWATER JCU researchers in collaboration with OzFish and the Mandubarra Rangers trialled transplanting seagrass fragments collected from a donor meadow in Cairns Harbour. While the overall condition of this meadow remained very poor, the return of the foundation species is a promising sign for further recovery of this meadow with additional restoration efforts. The other intertidal *Z. muelleri* meadow Lily (1), was completely absent in 2021 with no colonising species in or around the perimeter as has been found in previous years. Overall meadow condition in Mourilyan Harbour is heavily influenced by the absence of this once abundant foundation species from both Bradshaw (1) and Lily (2) meadows. The persistence and growth of the isolated patches of *Z. muelleri* through another wet season and the potential survival of newer seagrass transplants from 2021 may further improve the condition of these meadows into the future.

The overall meadow condition of Seaforth Bank (3), Seaforth Edge (4) declined in condition compared to the previous year due to a large decline in area. The Channel (5) meadow was absent with none of the usual *Halophila* species found. The Seaforth Bank (3), Seaforth Edge (4) and Channel (5) meadows are usually dominated by colonising *Halophila spp*. which are highly variable in abundance and distribution (Kilminster et al. 2015) and rapidly decline in response to low light conditions.

The whole of harbour survey conducted in 2021 also found seagrass distribution to have declined compared to previous surveys. The two meadows that were found have been observed previously in 2015 and 2018 and include a narrow meadow of the larger growing *H. uninervis* along the sand bank on the northern side of the channel and small patch of persistent *E. acoroides* on Seaforth Bank. The isolated and aggregated patches of *Halophila* found in previous whole of port surveys were not observed in 2021 and their absence was likely due to unfavorable growing conditions associated with high rainfall and river flows during 2021.

The increased rainfall and river flow prior to the survey may have impacted the ability for seagrass growth and survival of colonising species in 2021. While the overall average annual rainfall at Mourilyan was below the long term average in 2021, the rainfall in the three months leading up to the survey was above average and following a very large rainfall event in April. Total annual river flow for the South Johnstone River was also above average for 2021 and the monthly river flow was above average for six months leading up to the survey. If the river flow patterns were the same in the Moresby River then this may have led to a decline in water quality and light availability in the period prior to the survey and resulted in the declines and losses of *Halophila* species. Due to their 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). *Halophila* species have been shown to have much lower resistance to light deprivation than other larger seagrass species with mortality occurring in days to weeks rather than months (Collier et al. 2016). Low incident light levels and the deeper net position of the intertidal meadows due to natural variations in tidal cycles between years may also have further exacerbated the reduction in light associated with rainfall and river flows.

There is no evidence that port activities or operations have led to the recent declines in seagrasses. No major changes to activities or development activity for the port have occurred during the periods of seagrass decline over recent years. Rather, observed changes have been linked with major climate and weather events resulting in the loss of foundation seagrass species and the periodic impact to colonising species within the harbour.

Seagrass condition in the broader Queensland monitoring network generally all showed signs of improvement. Cairns Harbour seagrass meadows continued their decade long recovery with increases in the dominance of larger growing foundation species such as *Zostera muelleri*, and overall good condition of the coastal meadows (Reason et al. 2022). However, seagrass upstream in the Trinity Inlet estuary that consist of the same small highly ephemeral *Halophila* species that occur throughout Mourilyan Harbour were in a poor condition (Reason et al. 2022). Townsville seagrass meadows to the south remained in a good condition due to stable climate conditions over the past two years (McKenna et al. 2022). Seagrass in the Gulf of Carpentaria in Weipa and Karumba were in a good and very good condition also due to favourable climate conditions (McKenna et al. 2021; Scott et al. 2022).

The Mourilyan Harbour seagrasses have been in poor to very poor condition since severe weather events from 2009-11 resulted in the loss of the foundation species *Z. muelleri* from the estuary in 2010. Seagrasses are an ecologically important structural component within coastal ecosystems (Coles et al. 2015). The loss of the foundation species in Mourilyan Harbour reduces important ecosystem functions within the estuary. In North Queensland *Zostera muelleri* 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). Regaining these meadows and their functions back to their state prior to 2009 would provide significant benefits.

In 2020 and 2021, JCU/TropWATER, in partnership with volunteers from OzFish Unlimited and Mandubarra Rangers undertook two small scale pilot studies in Bradshaw meadow using vegetative fragments of *Z. muelleri*. Transplants were tied to either steel frames, biodegradable mesh frames of two sizes or individually weighted shoots and placed within the meadow footprint. The trials from 2020 resulted in several persistent seagrass patches that have survived the wet season and were still expanding 14 months after planting. These patches were surveyed and included in this report. The 2021 pilot study saw good preliminary results in the months after planting and will be reassessed in 2022 following the wet season to determine success. The results of these two trials are so far very promising and provide a pathway to a large-scale restoration project that can return the seagrass to its previous healthy condition and to re-establish the vital ecological functions that it provides.

5 REFERENCES

BOM (2022). http://www.bom.gov.au/climate/data/

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

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

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

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.

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.A., Smith T.M., Reason, C.L. & Rasheed, M.A. 2021, 'Port of Weipa long-term seagrass monitoring program, 2000 - 2021'. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), JCU Cairns.

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, S.A., Van De Wetering, C., and Wilkinson, J. 2022, 'Port of Townsville Seagrass Monitoring Program: 2021,' 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

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, York PH & Rasheed MA (2022). Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2021. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication 22/03, 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

Scott, A.L., McKenna, S.A., & Rasheed, M.A. 2022. Port of Karumba Long-term Annual Seagrass Monitoring 2021, Centre for Tropical Water & Aquatic Ecosystem Research Publication Number 21/70, James Cook University, Cairns, 28 pp.

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

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

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

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 .

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		 BIOMASS	Decrease below threshold from previous year	 BIOMASS	

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).

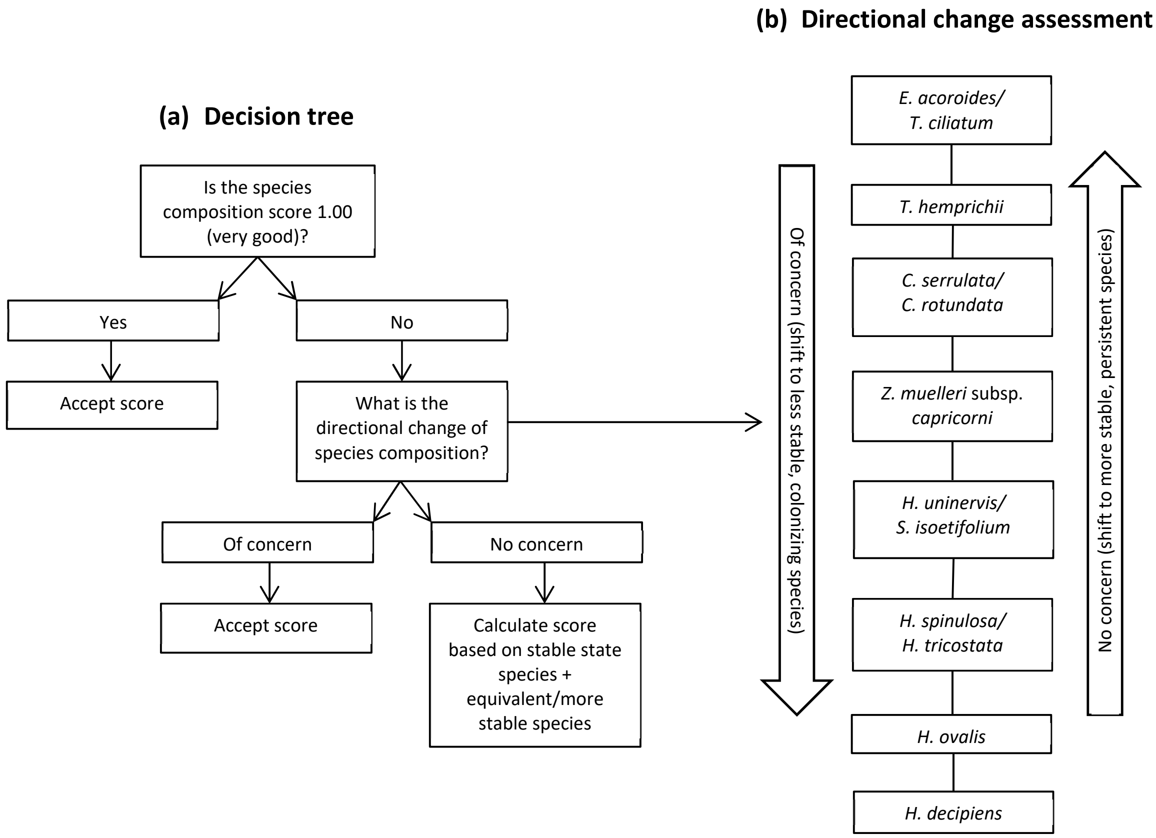


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Mourilyan Harbour.

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:

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

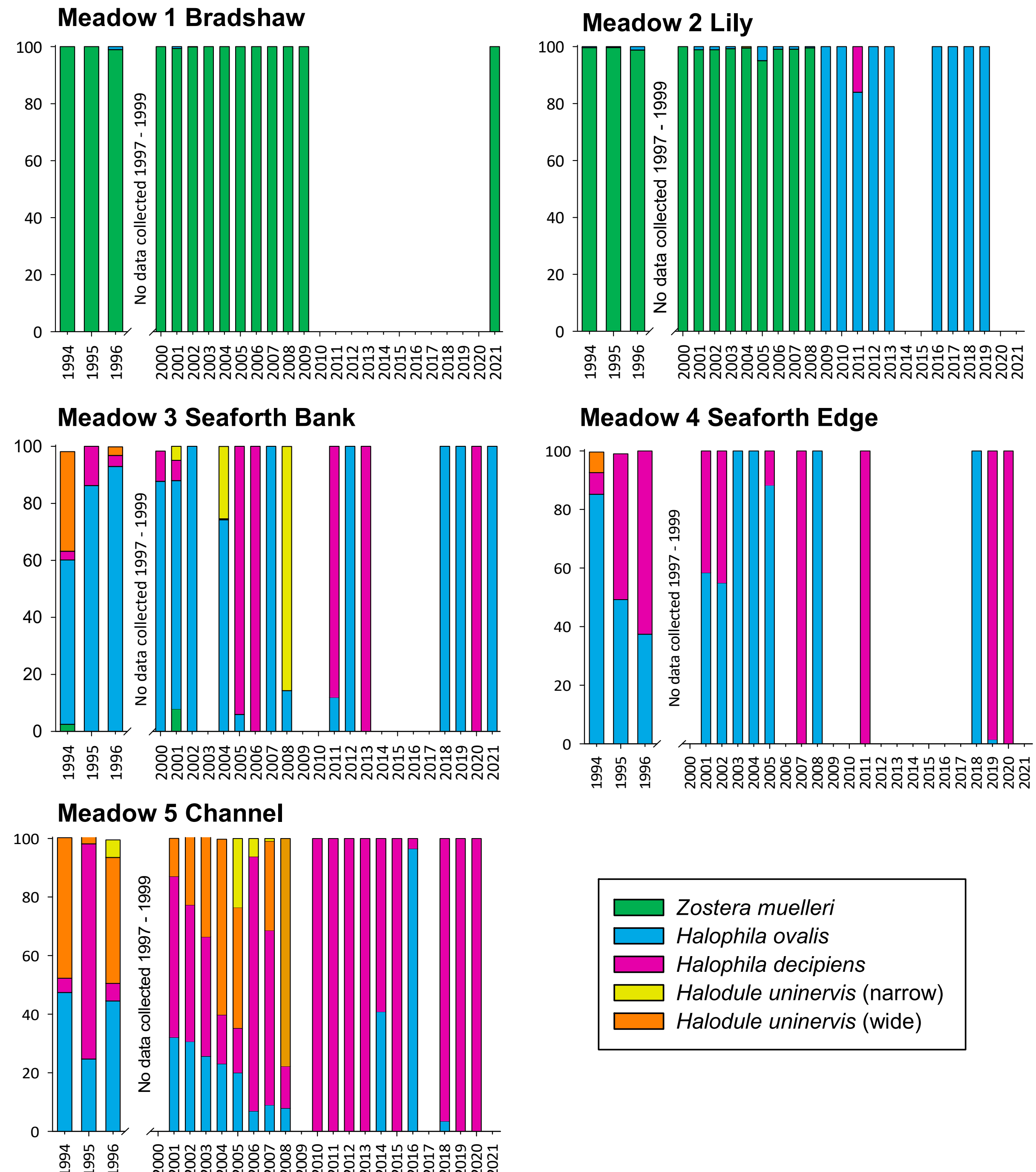
5. Determine the area score for 2018 ($Score_{2018}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

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

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 – 2021.



Appendix 4a. Area changes: 1993 – 2021

Seagrass monitoring meadow area (ha) in Mourilyan Harbour, 1993-2021 (±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	Oct 2021
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	0.00042 ±0.0
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	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	0.29 ±0.07
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	0.0014 ±0.0007
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	NP
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**	**0.30 ±0.079**

NP - seagrass not present.

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

Appendix 4b. Above-Ground Biomass changes: 1993 – 2021

Mean above-ground biomass (g DW m¯2) of seagrass for monitoring meadows in Mourilyan Harbour, 1993-2021.

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	Oct 2021
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	2.82 ±1.21
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	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	0.018 ± 0.018
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	NR
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	NP

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