 

PORT OF KARUMBA LONG-TERM ANNUAL SEAGRASS MONITORING 2020

Scott AL and Rasheed MA

Report No. 21/05

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A Report for Ports North

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KEY FINDINGS

Seagrass Condition 2020

SATISFACTORY

1. This report compiles findings of the annual Karumba long-term seagrass monitoring conducted in September 2020.
2. Seagrass at the Alligator Bank monitoring meadow improved in 2020 from the poorest condition in more than two decades recorded in 2019, associated with consecutive years of flooding from local rivers.
3. In 2020 there were increases in seagrass above-ground biomass as well as a small increase in meadow area.
4. While reduced from recent years, the meadow still had a seed bank present in 2020 and evidence of recent germination of some of the seeds.
5. The meadow is an important foraging ground for dugong with their feeding trails recorded at more than half of sites sampled in the 2020 survey.
6. The 2020 results are encouraging with improvement linked to favourable conditions for seagrass growth, including the absence of major flooding during 2020. However, much of the recovery was from less stable colonising species and total area of seagrass remained one of the smallest recorded in the program.
7. Continued recovery will depend on favourable environmental conditions during 2021 as seagrasses were still in a reduced state of resilience and therefore vulnerable to further pressures.

IN BRIEF

Seagrasses have been monitored annually in the Port of Karumba since 1994. Each year, the monitoring meadow between the Norman and Bynoe Rivers at Alligator Bank (Figure 1) is assessed for changes in biomass (density), distribution (area), species composition, and reproductive capacity (seed bank, fruits and flowers). Changes to area, biomass and species composition are assessed using a seagrass condition index (see 2.3 and Appendix 1 of this report for further details).

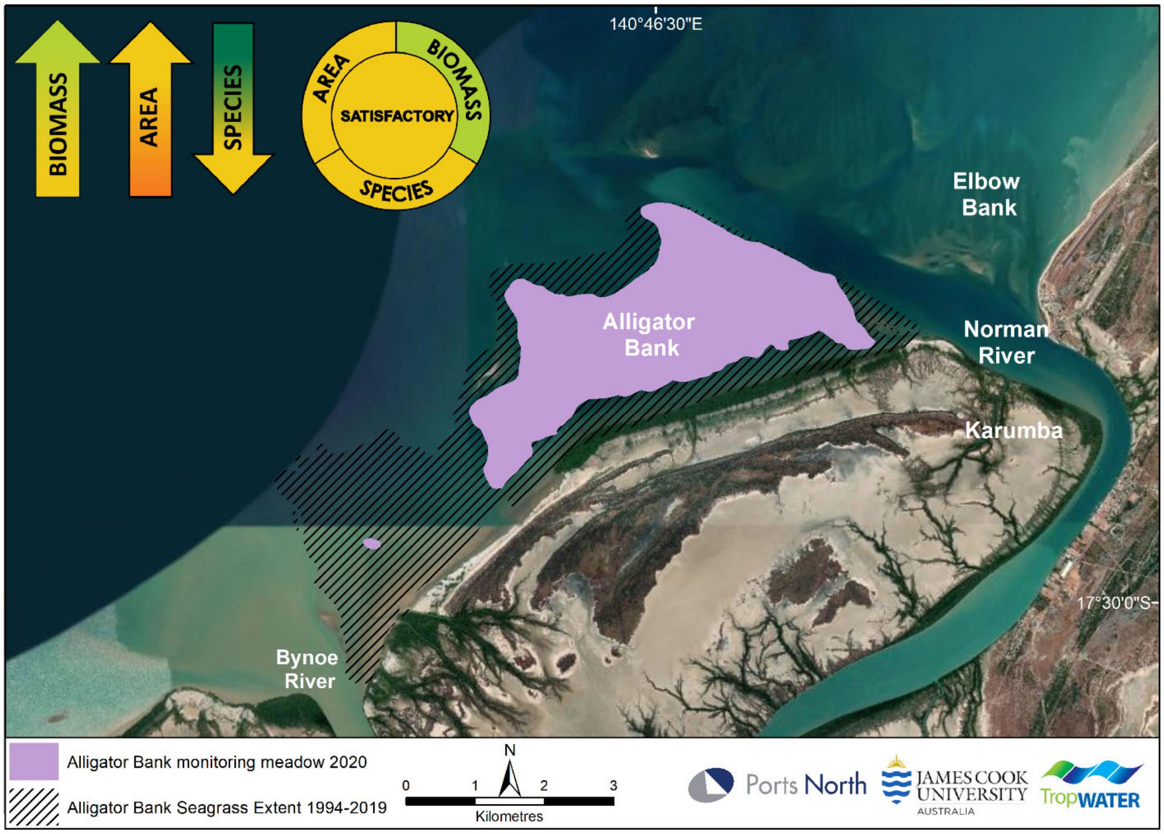

Figure 1. Seagrass condition at Alligator Bank, Karumba, 2020.

Seagrass meadow condition in Karumba improved to satisfactory in 2020, this improvement was driven by an increase in meadow area and biomass that resulted in an improved score from 2019. Species composition in the meadow shifted towards a higher proportion of the colonising species *Halophila ovalis* leading to a decrease in the species score to satisfactory for the first time in the 27-year history of monitoring at Karumba. Seed numbers in the meadow were lower than recent years, but there was an above average number of seed casings, indicating that seeds have recently germinated and the seed bank may be driving some of the observed recovery. Dugong feeding trails were found throughout the meadow at more than half of the sites sampled, showing this meadow is once again an important foraging ground after limited dugong feeding was recorded in 2019.

Weather conditions were broadly favourable for seagrass growth in 2020 with the absence of major flow events of the Norman River. Although a significant rainfall event in January 2020 may have caused short-term impacts that could have reduced the extent of recovery and growth in the Alligator Bank meadow during 2020.

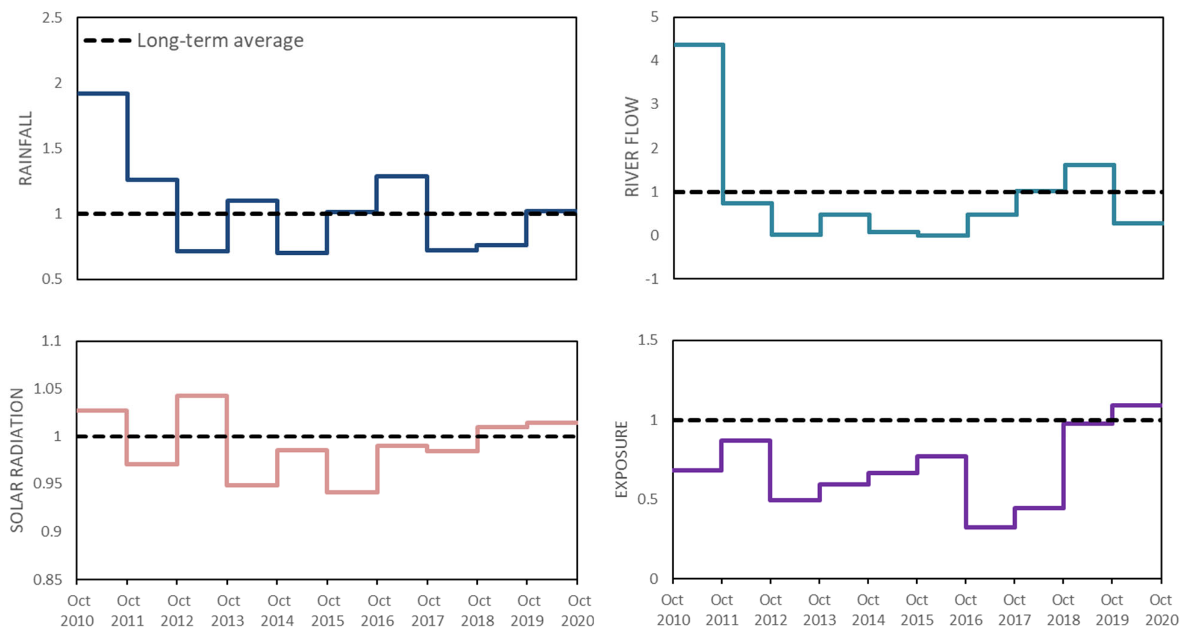

Figure 2. Change in climate variables as a proportion of the long-term average in Karumba. See Section 3.5 for detailed climate data.

These results are encouraging with the overall trajectory of seagrass improvement linked to more favourable conditions for seagrass growth during 2020. However, much of the recovery was from less stable colonising species and total area of seagrass remained one of the smallest recorded in the program. This means that seagrasses were likely to be less resilient to pressures that may occur in 2021 than they have been in the recent past. Subsequent to this survey Karumba has been subjected to substantial flooding associated with monsoon conditions and cyclones in the Gulf of Carpentaria. The impact of these on continued seagrass recovery will be apparent during monitoring in 2021

Karumba seagrass monitoring is part of a broader seagrass program that examines the condition of seagrasses in the majority of Queensland commercial ports and areas of high anthropogenic activity, and is a component of TropWATER's broader seagrass assessment and research program. Overall seagrass condition in 2020 was good at Weipa. Coastal seagrass condition along the east coast of Queensland monitored as part of this program, e.g. Abbot Point, Hay Point, Mackay, Townsville, Cairns and Gladstone have generally improved between 2013 - 2020 following declines between 2009 and 2011. Other locations such as Mourilyan Harbour have yet to recover from the 2009-2011 impacts and remain in a vulnerable condition. For full details of the Queensland ports seagrass monitoring program, see https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

TABLE OF CONTENTS

KEY FINDINGS ..... **i**

IN BRIEF ..... **ii**

1 INTRODUCTION **1**

1.1 Queensland Ports Seagrass Monitoring Program 1

1.2 Karumba Seagrass Monitoring Program 1

1.3 Sampling Approach 2

2 METHODS **2**

2.1 Sampling Methods 2

2.2 Habitat Mapping and Geographic Information System 3

2.3 Seagrass Meadow Condition Index 5

2.4 Environmental data 5

2.5 Seagrass Reproduction Analysis 5

3 RESULTS **7**

3.1 Seagrass Species 7

3.2 Seagrass Condition in the Alligator Bank Monitoring Meadow 7

3.3 Comparison with Previous Monitoring Surveys 10

3.4 Seagrass Reproductive Capacity 10

3.5 Dugong Feeding Activity 12

3.6 Karumba Environmental Conditions 14

4 DISCUSSION **19**

5 REFERENCES **21**

6 APPENDICES **24**

Appendix 1. Seagrass Score Calculation 24

Appendix 2. Biomass score calculation example 28

1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (Costanza et al. 2014; Hemminga & Duarte 2000; Costanza et al. 1997). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long-term health of marine environments (Orth et al. 2006; Abal & Dennison 1996; Dennison et al. 1993).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland's commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. While each location is funded separately, a common methodology and rationale is used, providing a network of seagrass monitoring locations throughout Queensland (Figure 3).

Figure 3. Location of Queensland port seagrass assessment sites.

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure that seagrasses and ports can co-exist. These results are useful for planning and implementing port development and maintenance programs to ensure minimal impact on seagrasses. The program also provides an ongoing assessment of many of the most threatened seagrass communities in Queensland.

The data collected as part of this program has resulted in significant advances in the science and knowledge of tropical seagrass ecology. This data has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses. The program also provides an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

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

1.2 Karumba Seagrass Monitoring Program

The Karumba port entrance and the Norman River channel are naturally shallow, and require periodic maintenance dredging to allow the passage of ships associated with mining and live cattle export. Dredging has the potential to cause a high level of environmental risk to marine habitats such as seagrass meadows (Erftemeijer and Lewis 2006) unless management strategies are adopted to minimise potential risks. Ports North is responsible for dredging in the port and for managing and monitoring Karumba's port environment. Seagrass meadows are the key marine habitat that occur within the Port of Karumba that can be affected by port activities.

Seagrasses form a key ecological habitat in the Karumba region and Ports North have funded a long-term seagrass monitoring program since 1994. The initial six year (1994-2000) seagrass monitoring program was commissioned as part of a wider range of environmental studies to assess and monitor the impacts of dredging and other port developments (Rasheed et al 2001). Following this, a long-term seagrass monitoring program for the Port of Karumba was developed.

Results from the monitoring program are used by Ports North to assess the health of the ports' marine environment and help identify possible effects of port operations and developments on seagrasses. The program also provides an assessment of the resilience of seagrass meadows to withstand a range of potential influences, e.g. land runoff and dredging impacts, and provides a simple assessment of condition to confirm that port activities are not impacting the seagrass. The program also satisfies environmental monitoring requirements as part of the port's long-term dredge management plan, and is used by management agencies to assess the status and condition of seagrass resources in the region.

This report presents results from the September 2020 annual monitoring survey. The objectives of the survey were:

1. Map seagrass distribution in the Alligator Bank monitoring meadow between the Norman and Bynoe River;
2. Determine seagrass species composition and biomass within the monitoring meadow;
3. Measure the reproductive capacity of the monitoring meadow;
4. Assess seagrass condition in the Alligator Bank monitoring meadow by comparing results with previous monitoring surveys, and compare results with other seagrass monitoring programs throughout Queensland.

1.3 Sampling Approach

The 2020 survey was designed to provide updated information on seagrass habitats within the Port of Karumba, including seagrass distribution, density and species composition. The sampling method used followed those established for the Karumba long-term seagrass monitoring program as well as other seagrass programs established in Queensland Ports including Weipa, Cairns, Mourilyan Harbour, Townsville, Gladstone, Mackay, Thursday Island and Abbot Point.

For more details see: https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

2 METHODS

2.1 Sampling Methods

The Karumba seagrass survey was conducted on 27th September 2020. The survey area covered the intertidal area of Alligator Bank. Detailed monitoring program methods are available in previous reports (Rasheed et al. 1996; Rasheed et al. 2001; McKenna and Rasheed 2011).

Seagrass meadow boundaries were mapped from a helicopter survey conducted during the spring low tide when intertidal banks were exposed. Waypoints were recorded around the edge of the meadow using a global positioning system (GPS) and digitised into a Geographic Information System (GIS).

Seagrass metrics were recorded at survey sites scattered haphazardly within the meadow. The number of sites was based on a power analysis that considered within-meadow variability (Unsworth et al. 2009). Site characteristics including seagrass species composition and above-ground biomass, epiphyte cover, algae and other benthic cover, and dugong feeding activity were recorded at each site.

Seagrass above-ground biomass was measured using a visual estimate of biomass technique (as described by Kirkman 1978 and Mellors 1991). This method has been used in surveys throughout Queensland (e.g. Rasheed et al. 2008; Rasheed and Unsworth 2011; Rasheed et al. 2014; McKenna et al. 2015; York et al. 2015). The method involves an observer ranking above-ground seagrass biomass within three randomly placed 0.25m^2 quadrats at each site. Observer measurements are calibrated against biomass values from quadrats harvested and dried to determine mean above-ground biomass in grams dry weight per square metre (g DW m^{-2}) at each site. The percent contribution of each seagrass species to total biomass within each quadrat also was recorded.

Sampling of the seagrass seed bank (seeds stored in the sediments) and other seagrass reproductive structures (fruit and flowers) was conducted at 19 sites within the monitoring meadow. A Van Veen sediment grab ($0.0625m^{-2}$) was used to collect samples at sites haphazardly scattered throughout the meadow. Seagrass and sediment/seed samples were sorted by passing the sample through a 1 mm sieve. Any seagrass reproductive structures in the 1 mm fraction were identified and counted. The 1 mm mesh size was small enough to retain seeds/pericarps of *H. uninervis* and fruits and flowers of *H. uninervis* and *H. ovalis*. Seeds of *H. ovalis* were not measured because their small size allows them to pass through the sieve mesh and requires a microscope to locate them.

2.2 Habitat Mapping and Geographic Information System

All survey data was entered into a GIS for presentation of seagrass spatial data. Satellite imagery of the Karumba region plus information recorded during the monitoring survey was used to map seagrass meadows. Three seagrass GIS layers were created in ArcMap® 10.8:

2.2.1 Site layer

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

- Site number
- Temporal details – Survey date and time.
- Spatial details – Latitude and longitude.
- 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.

2.2.2 Biomass interpolation

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 the mapped meadow.

2.2.3 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), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1, 2), meadow landscape category (Figure 4).
- Sampling method and any relevant comments.

Meadow boundaries were constructed using GPS marked meadow boundaries, seagrass presence/absence site data, field notes, and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcMap®. The meadow boundary was assigned a mapping precision estimate (in metres) based on mapping methodology used for that meadow. Mapping precision was estimated to be ±5 m due to the error associated with GPS fixes. 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.

Table 1. Seagrass meadow community type nomenclature in the Port of Karumba.

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

Table 2. Seagrass meadow density categories based on mean above-ground biomass ranges for each species in the Port of Karumba.

Density	Mean above-ground biomass (g DW m^{-2})	
	Halodule uninervis (narrow)	*Halophila ovalis*
Light	< 1	< 1
Moderate	1 - 4	1 - 5
Dense	> 4	> 5

Isolated seagrass patches

The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches

Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries

Continuous seagrass cover

The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of unvegetated sediment

Figure 4. Seagrass meadow landscape categories: (A) isolated seagrass patches, (B) aggregated seagrass patches, (C) continuous seagrass cover.

2.3 Seagrass Meadow Condition Index

A condition index was developed for seagrass monitoring meadows in Karumba based on changes in mean above-ground biomass, total 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 5 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.

2.4 Environmental data

Environmental data were collated for the 12 months preceding each survey:

- Tidal data was provided by Maritime Safety Queensland (MSQ) (© The State of Queensland (Department of Transport and Main Roads) 2019, Tidal Data) for Karumba (www.msq.qld.gov.au). Predicted data were used for five days in August and three days in September 2020 where the tidal guage was not working.
- Data for rainfall (mm), air temperature (°C), and global solar exposure (MegaJoules, MJ m^{-2}) were obtained for the nearest weather station from the Australian Bureau of Meteorology (BOM) (Normanton Airport, Station #029063; http://www.bom.gov.au/climate/data/).
- Norman River flow data (megalitres; ML) was obtained from the Queensland Government (Glenore Weir, Station #916001B; https://water-monitoring.information.qld.gov.au/).

2.5 Seagrass Reproduction Analysis

Halodule uninervis seeds and pericarps in the sediment were compared among years (2003-2020) using a negative binomial regression model in R (version 3.6.2) using the *MASS* package (Venables and Ripley 2002). Data exploration protocols prior to all analyses followed Zuur et al. (2010) and included checks for zero inflation and overdispersion. Statistical significance of year in each model was tested using a likelihood ratio test. Statistical analyses could not be performed on *H. uninervis* and *H. ovalis* fruit and flower counts due to the large number of zeros in the data; this data is presented graphically instead.

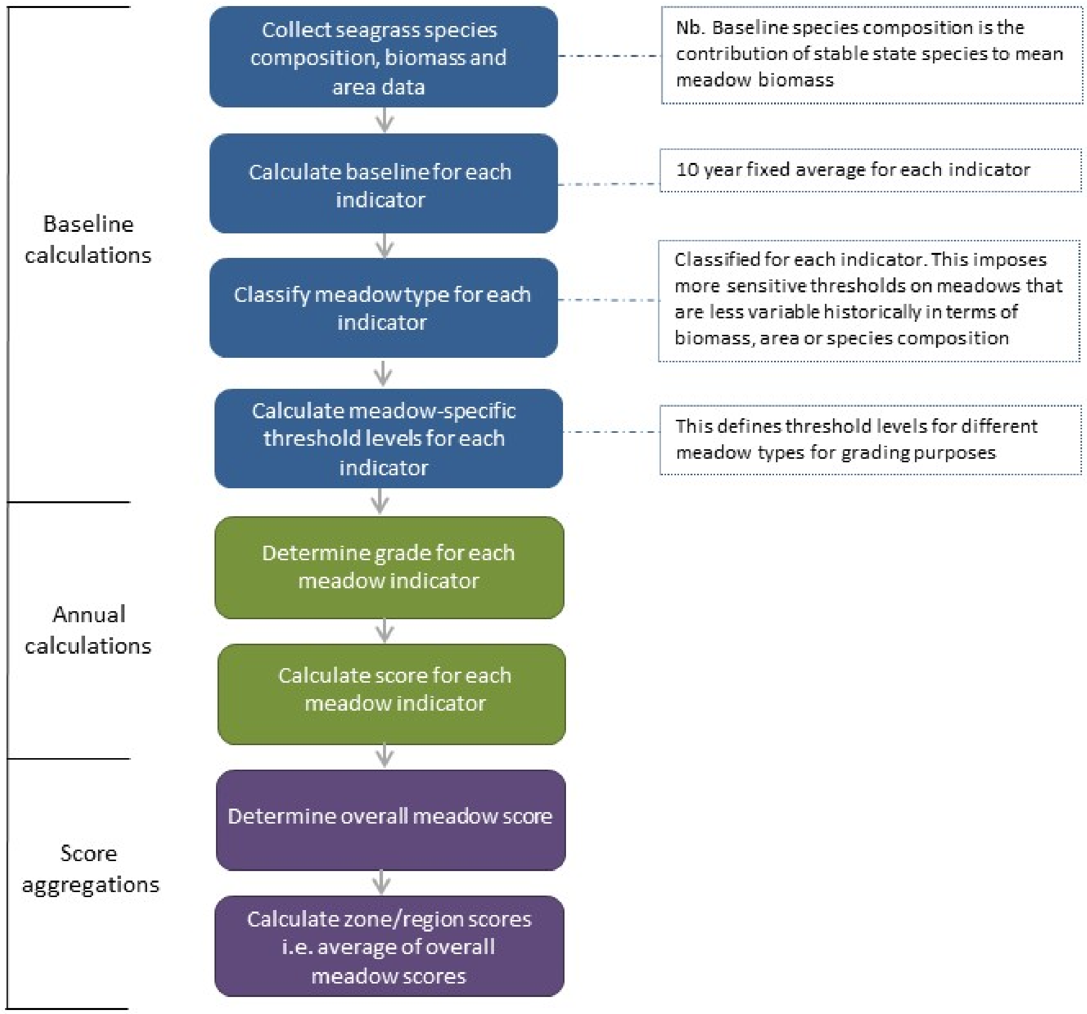

Figure 5. Process used to determine Karumba seagrass monitoring meadow condition grades and scores each year.

3 RESULTS

3.1 Seagrass Species

Seagrass was present at 99 of the 103 sites surveyed in 2020. Two seagrass species were present: *H. uninervis* (narrow leaf form) was the dominant species recorded and accounted for approximately 54% of above-ground seagrass biomass, while *H. ovalis* accounted for the remaining 46% (Figures 6 and 7).

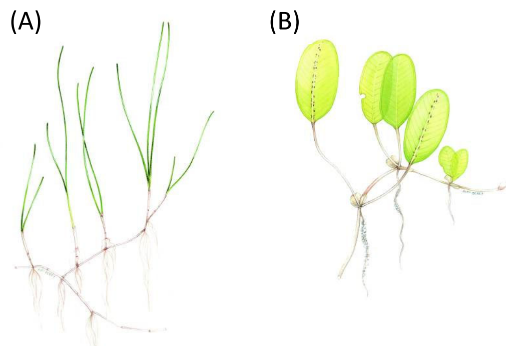

Figure 6. Seagrass species found in Karumba: (A) *Halodule uninervis*, Family Cymodoceaceae (narrow leaf form); (B) *Halophila ovalis*, Family Hydrocharitaceae.

3.2 Seagrass Condition in the Alligator Bank Monitoring Meadow

Seagrass was in an overall satisfactory condition in 2020 (Table 3, Figure 7). The Alligator Bank meadow had recovered from of the losses in biomass and area documented in the 2019 survey. Above-ground biomass increased from 1.7 ± 0.2 g DW m^{-2} in 2019 to 3.8 ± 0.3 g DW m^{-2} and remained in good condition (Table 3, Figure 7). Meadow area increased from 802 ± 9 ha in 2019 to 933 ± 9 ha in 2020 and improved from poor to satisfactory condition (Table 3, Figures 7 and 8). As the Alligator Bank meadow has begun to recover from the losses documented in 2019 due to flooding (see Shepherd et al. 2020), there has been a shift in the seagrass species present in the meadow with an increase in colonising species leading to the lowest score for species composition in the 27-year history of Karumba seagrass monitoring – although this was still rated as satisfactory condition (Table 3, Figure 7). Such shifts in species composition occur as colonising seagrass species such as *H. ovalis* will recover quickly and be the first to expand into new areas compared with the relatively slower growing and larger *H. uninervis* (Kilminster et al. 2015).

Table 3. Grades and scores for seagrass indicators (biomass, area and species composition) for Karumba.

Meadow	Biomass	Area	Species Composition	Overall Meadow Condition
Alligator Bank	0.73	0.58	0.57	0.58

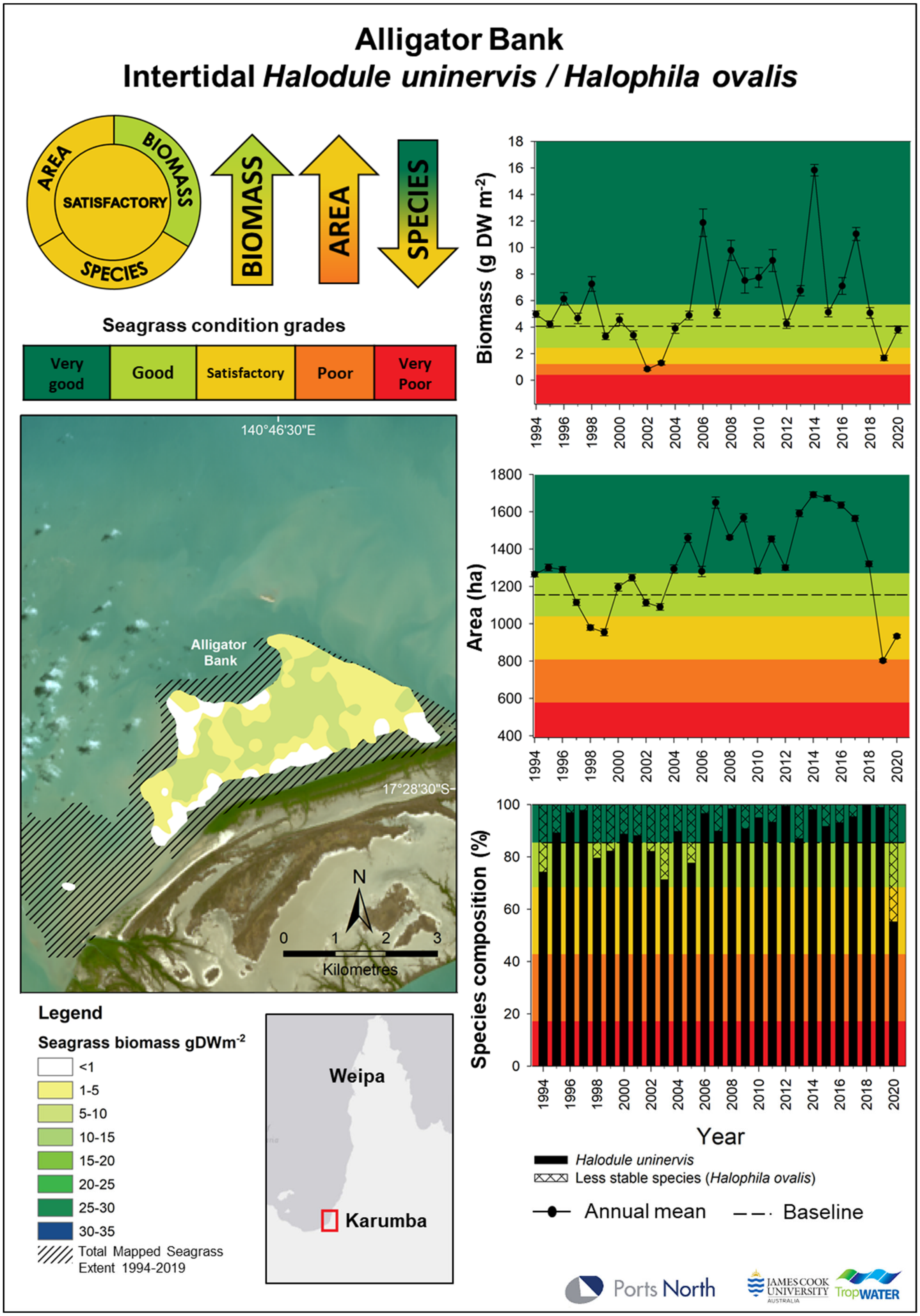

Figure 7. Changes in biomass, area and species composition for the Karumba seagrass monitoring meadow from 1994 to 2020 (biomass error bars = SE; area error bars = "R" reliability estimate).

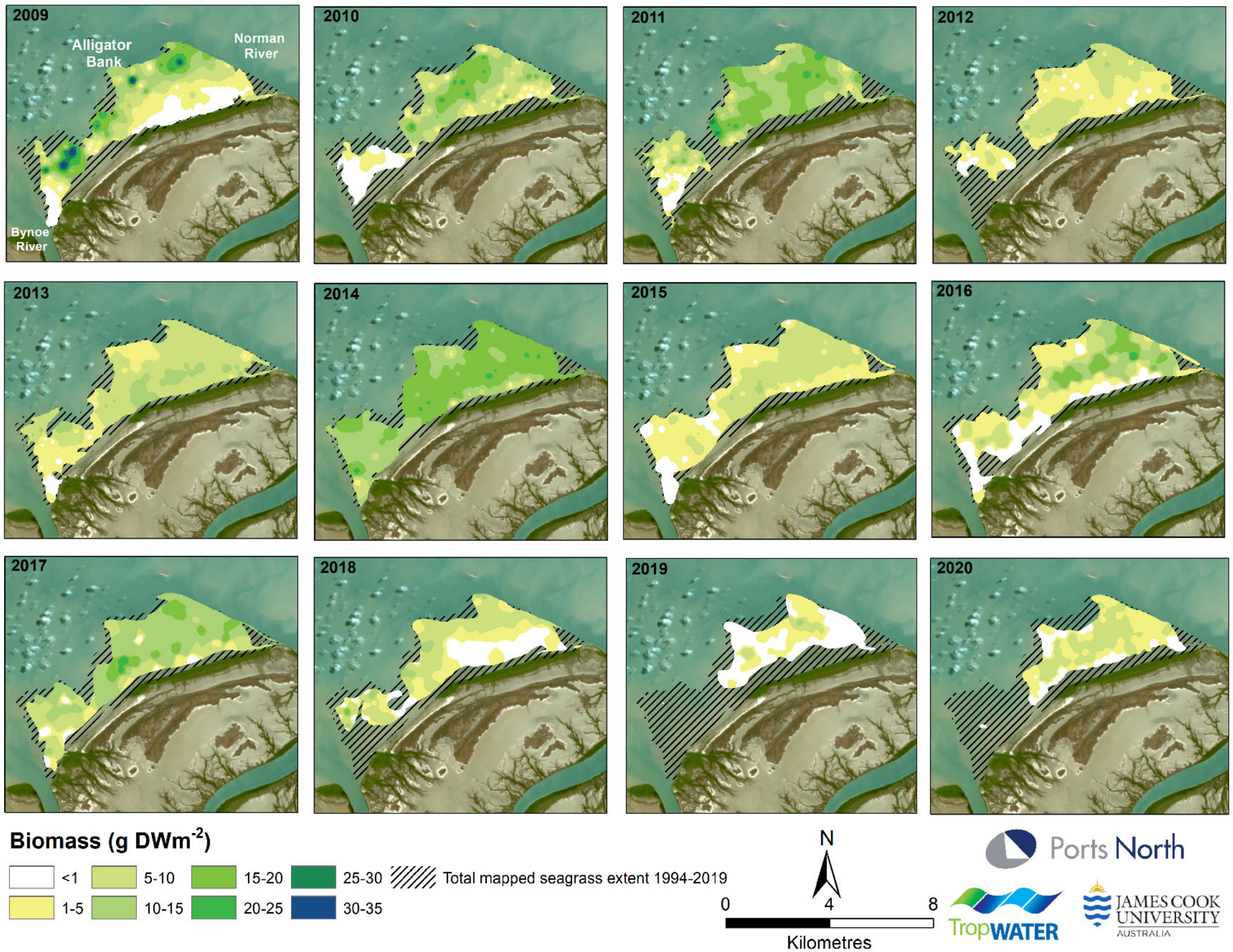

Figure 8. Biomass and area change in the Alligator Bank monitoring meadow, 2009 to 2020.

3.3 Comparison with Previous Monitoring Surveys

Overall seagrass condition improved from poor in 2019, to satisfactory in 2020 (Table 3, Figures 7 and 8). This change in score was driven by an increase in meadow area in 2020 and an improvement in area score from poor to satisfactory. Above-ground biomass increased in 2020 and improved from satisfactory to good. Species composition decreased from good to satisfactory condition in 2020, with the lowest score for this meadow recorded since monitoring began.

Average meadow above-ground biomass increased by over double from 2019 (Figure 7). This recovery in above-ground biomass from the low levels seen in the previous survey means that seagrass biomass is now once again at baseline levels in the Alligator Bank meadow, and was in good condition (Figure 7). This biomass is now distributed more evenly across the whole meadow, compared to the patchy distribution in the previous survey (Figures 7 and 8).

In this report there has been an update to the biomass results for the meadow for the period 2016 to 2019 which has resulted in subtle shifts in the biomass values compared with that presented in previous reports. However, this did not result in any substantial changes to the results in those years or the overall condition and rating of the meadow.

Seagrass meadow area also improved in 2020, with a 16% increase compared to 2019. Seagrass area condition improved from poor to satisfactory, however the meadow area is the second lowest recorded in the 27-year history of seagrass monitoring at Karumba. The meadow has expanded along the southern edge towards the mangroves, and a new small patch of seagrass was found at the south western end of the meadow (Figure 7).

Seagrass species composition shifted away from the historically stable community that has been present since monitoring began. There was a decrease in the dominant species *H. uninervis* from 99% in 2019, to 55% in 2020 and an increase in *H. ovalis* from 1% in 2019 to 45% in 2020. This change caused the species composition score to decrease from very good to satisfactory for the first time in the 27-year history of seagrass monitoring at Karumba (Figure 7).

3.4 Seagrass Reproductive Capacity

Halodule uninervis seeds and pericarps (outer casings of seeds) were found throughout the meadow in 2020 (Figure 9), with a mean density of 32 seeds m^{-2} and 79 pericarps m^{-2} across the meadow. As the 2019 survey used a different sampling method, these results cannot be directly compared, however other survey years used a Van Veen grab and can be directly compared to 2020. *Halodule uninervis* seed density varied significantly among years at the .05 level (Chi square=97, df=16, p=<0.001) when compared against the NULL model, post hoc analysis showed that in 2020 the number of seeds was significantly lower than in 2017 (p=<0.05), but did not differ from any other year (Figure 10A). *Halodule uninervis* pericarp density varied significantly among years at the .05 level (Chi square=106, df=16, p=<0.001) when compared against the NULL model, post hoc analysis showed that pericarp densities in 2020 were significantly higher than 2005 – 2007 (p=<0.05), but were not different to any other year (Figure 10A). There was one *H. uninervis* flower found in the meadow but no fruits, and no *H. ovalis* flowers but four fruits, these low numbers are similar to both 2017 and 2018 data (Figure 10 B and C).

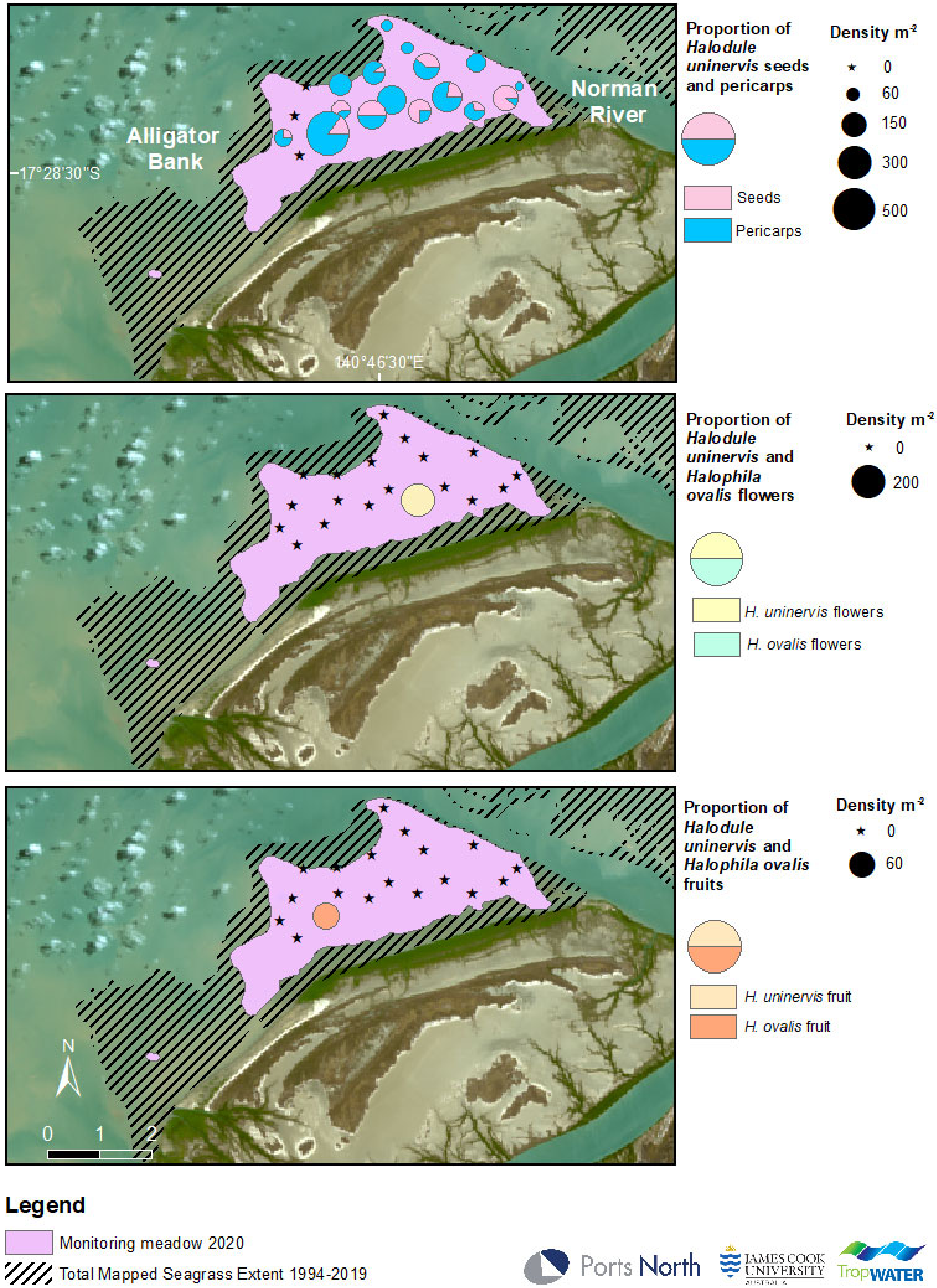

Figure 9. Density of *H. uninervis* seeds and pericarps, and *H. uninervis* and *H. ovalis* flowers and fruits in 2020.

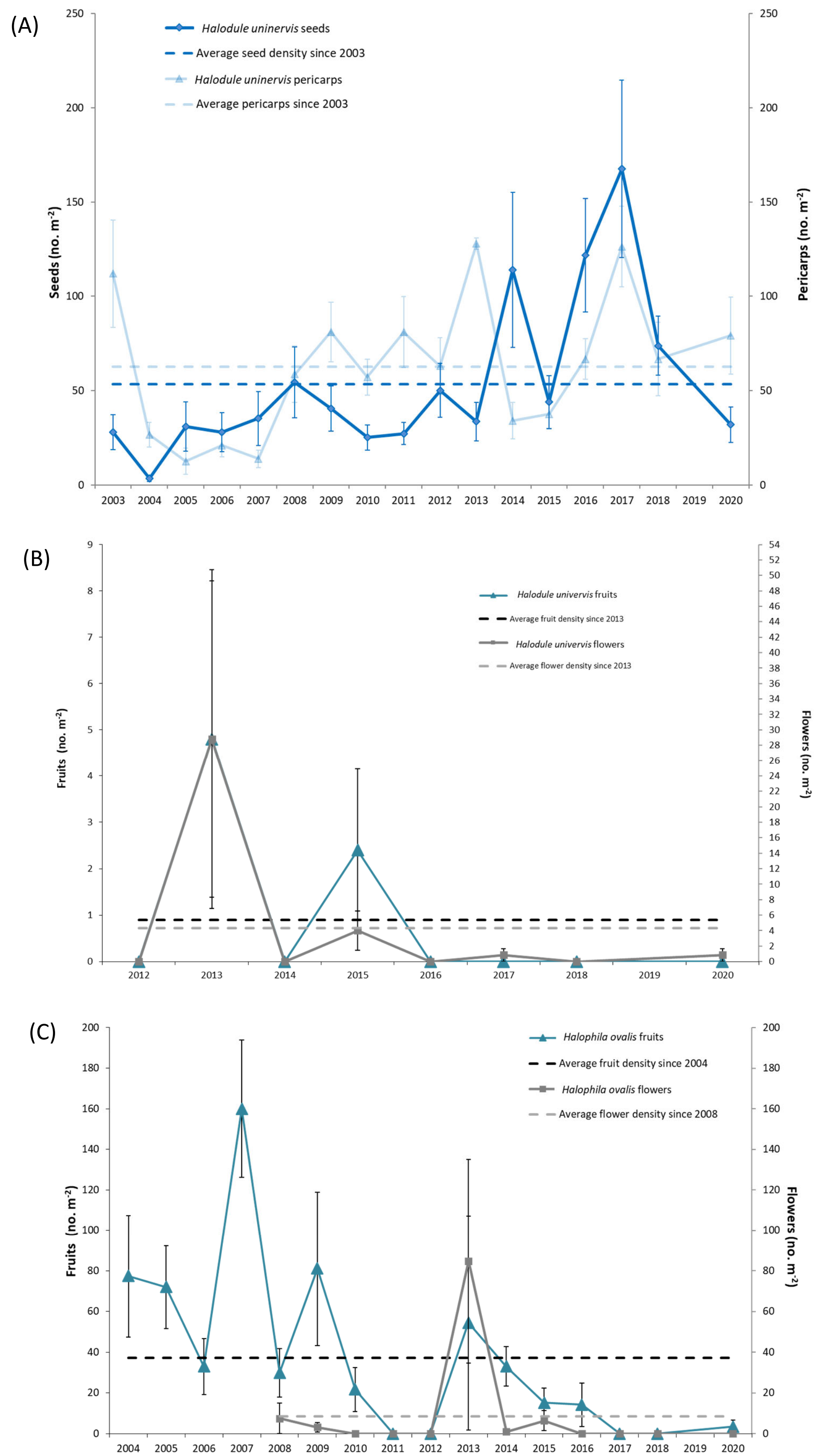

Figure 10. Mean density (± SE) of (A) *Halodule uninervis* seeds and pericarp pieces, (B) *H. uninervis* fruits and flowers, and (C) *Halophila ovalis* fruits sampled within the monitoring meadow. Data from 2019 have been excluded due to a different sampling method used.

3.5 Dugong Feeding Activity

Dugong feeding trails have been observed within seagrass meadows over the history of the Karumba monitoring program (Figure 11). Dugong feeding trails were observed at 52% of sites in 2020, an increase from 9% in 2019 and 29% in 2018. Feeding trails were found throughout the meadow and were particularly abundant in higher biomass areas (Figures 11 and 12).

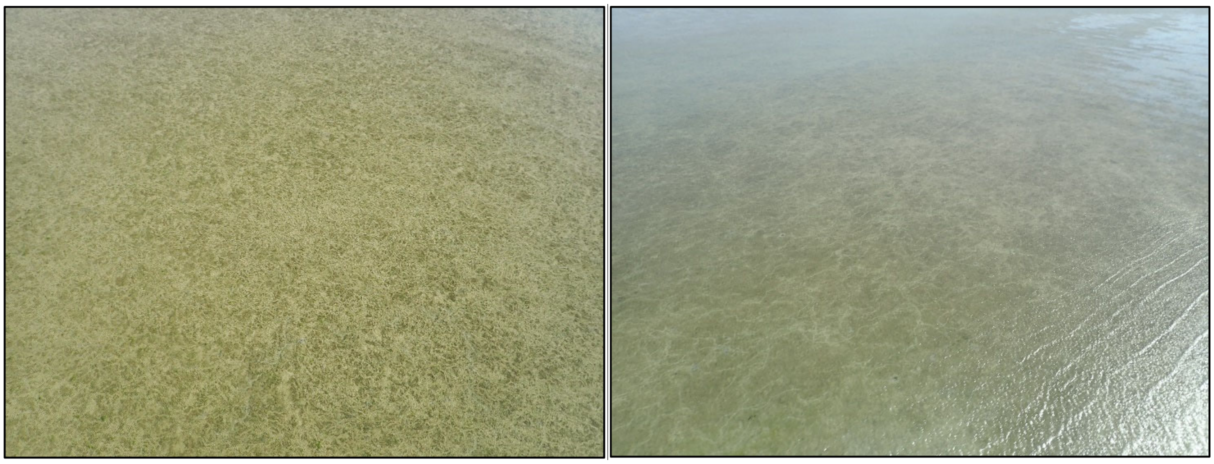

Figure 11. Dugong feeding trails in the Alligator Bank seagrass meadow in 2020.

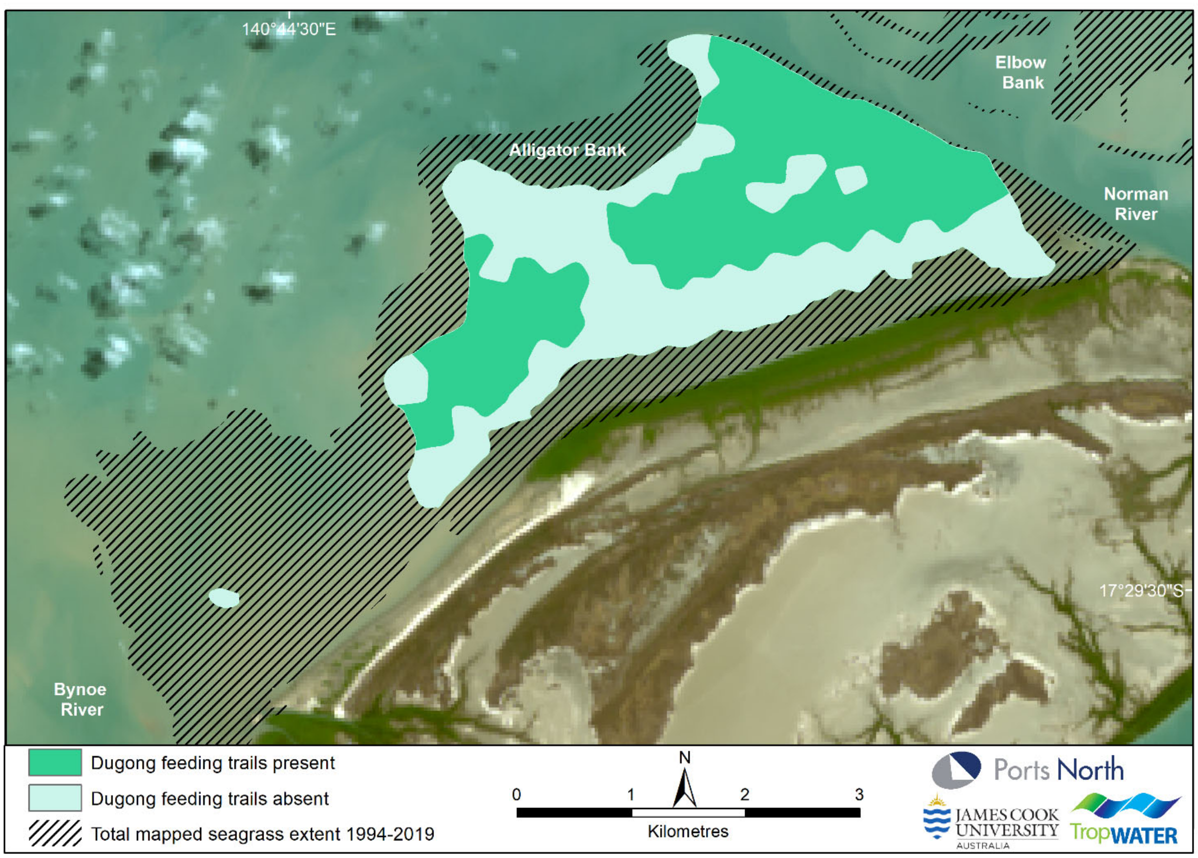

Figure 12. Location of dugong feeding trails within the Alligator Bank meadow in September 2020.

3.6 Karumba Environmental Conditions

3.6.1 Rainfall

Total annual rainfall for the Normanton area in the twelve months prior to the September 2020 survey was 807 mm. This was just above the average annual rainfall for the area (Figure 13), however, over half of this total (490 mm) occurred in January 2020 (Figure 14). January usually has the highest average rainfall, however the total rainfall in January 2020 was over double the monthly average. No rainfall occurred during the survey month, and only 0.4 mm fell in the three months leading up to the survey (Figure 14).

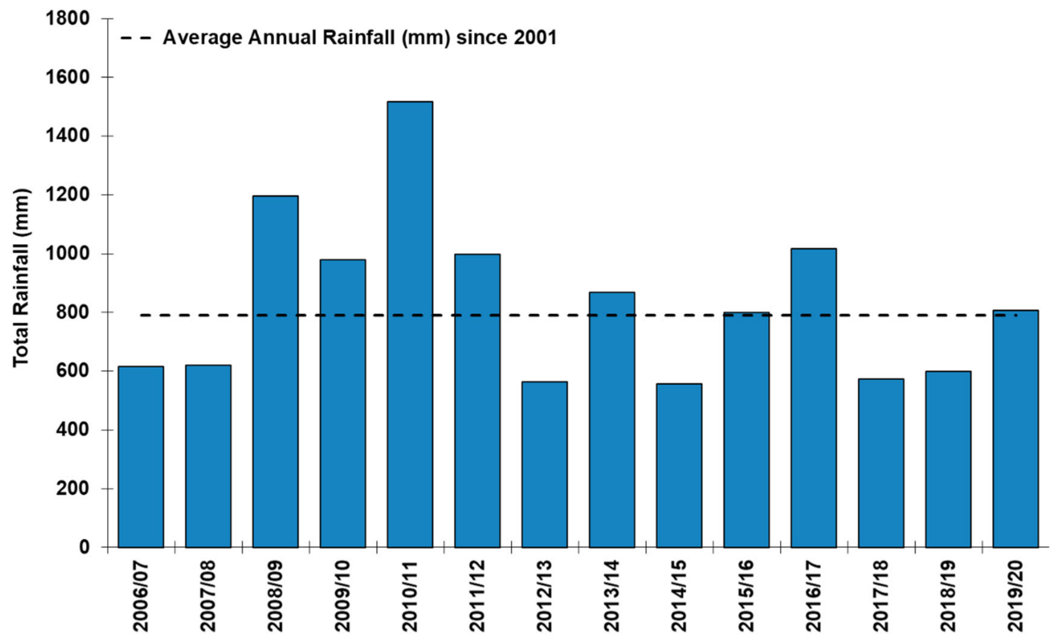

Figure 13. Total annual rainfall (mm) recorded at Normanton Airport, 2006/07 – 2019/20, in each 12 months prior to seagrass survey.

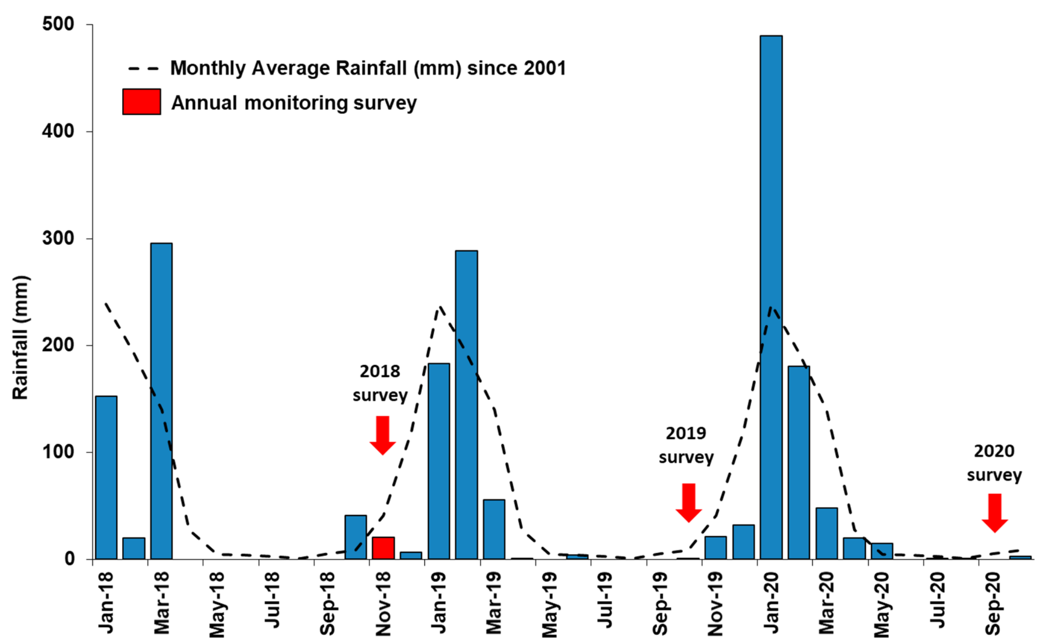

Figure 14. Total monthly rainfall (mm) recorded at Normanton Airport, January 2017 - October 2020.

3.6.2 River flow

Total annual river flow 12 months prior to the seagrass survey was 502 GL, the majority of this flow occurred in January and February 2020 (Figures 15 and 16). The total annual river flow was well below the average (Figure 15) and all of the monthly flow values were also well below average (Figure 16).

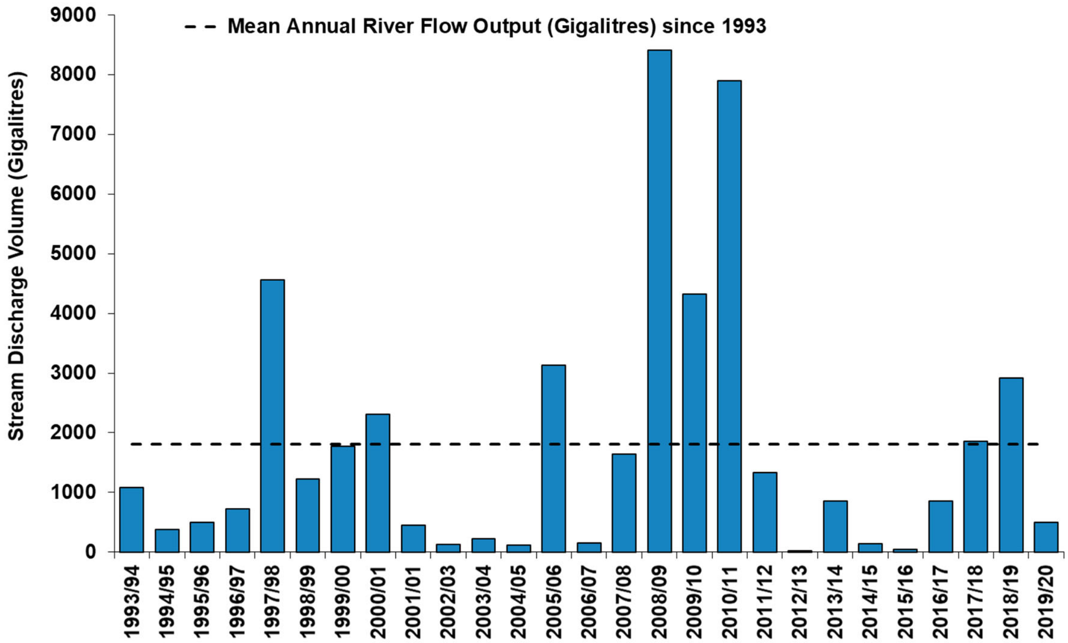

Figure 15. Total Norman River flow (measured as stream discharge volume in Gigalitres, GL) recorded at Glenore Weir, 1993/94 – 2019/20 Twelve month year (2019/20) is twelve months prior to survey.

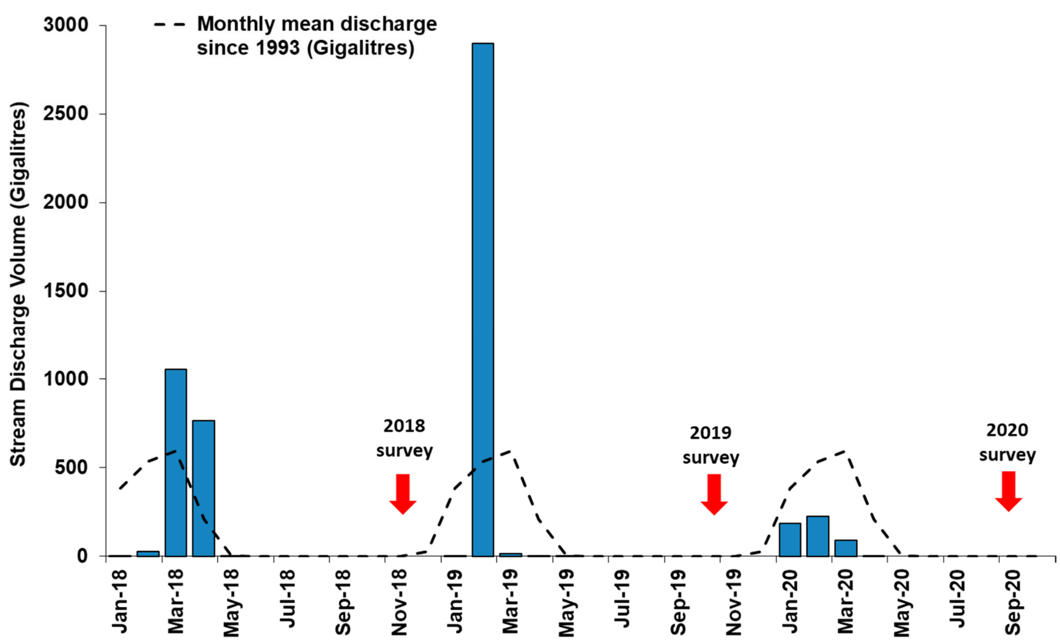

Figure 16. Total Norman River flow (measured as stream discharge volume in Gigalitres) recorded at Glenore Weir, January 2018 - October 2020.

3.6.3 Air Temperature

Air temperature was above-average in the region in 2019/20, with a mean annual daily maximum air temperature of 34.4°C (Figure 16). Monthly average maximum daily temperatures were slightly higher than the average for the year prior the survey, with spike of 38.8°C in December 2019 (Figure 18).

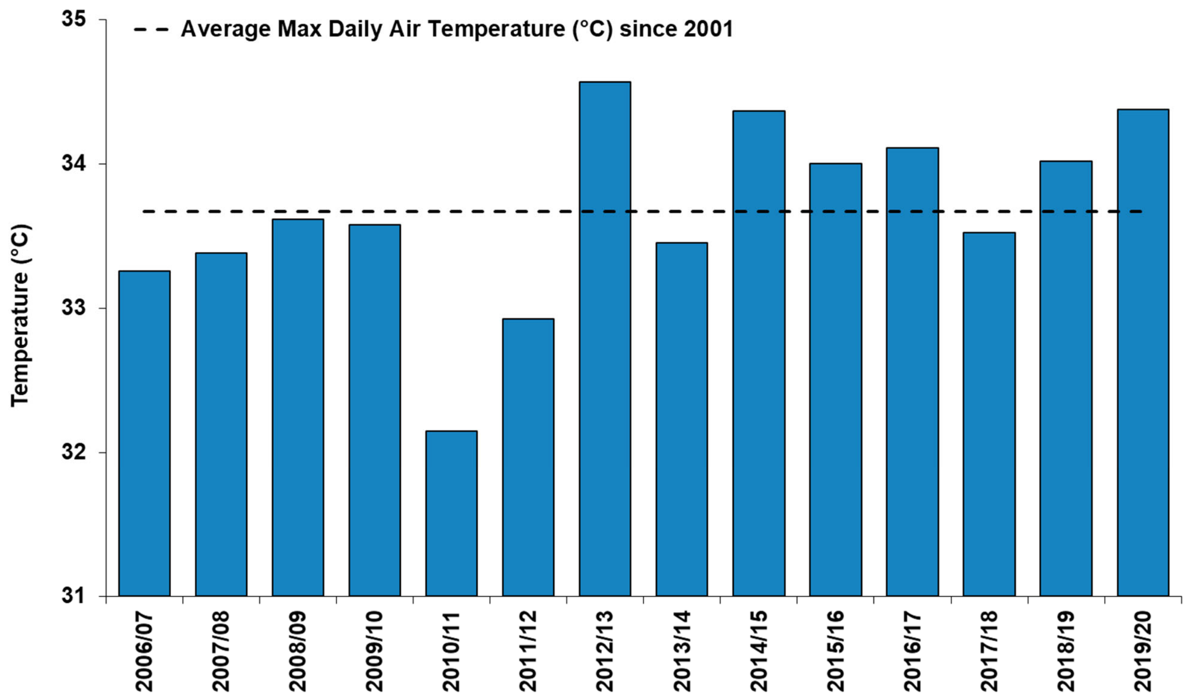

Figure 17. Mean maximum daily air temperature (°C) recorded at Normanton Airport, 2006/07 - 2019/20. Twelve month year (2019/20) is twelve months prior to survey.

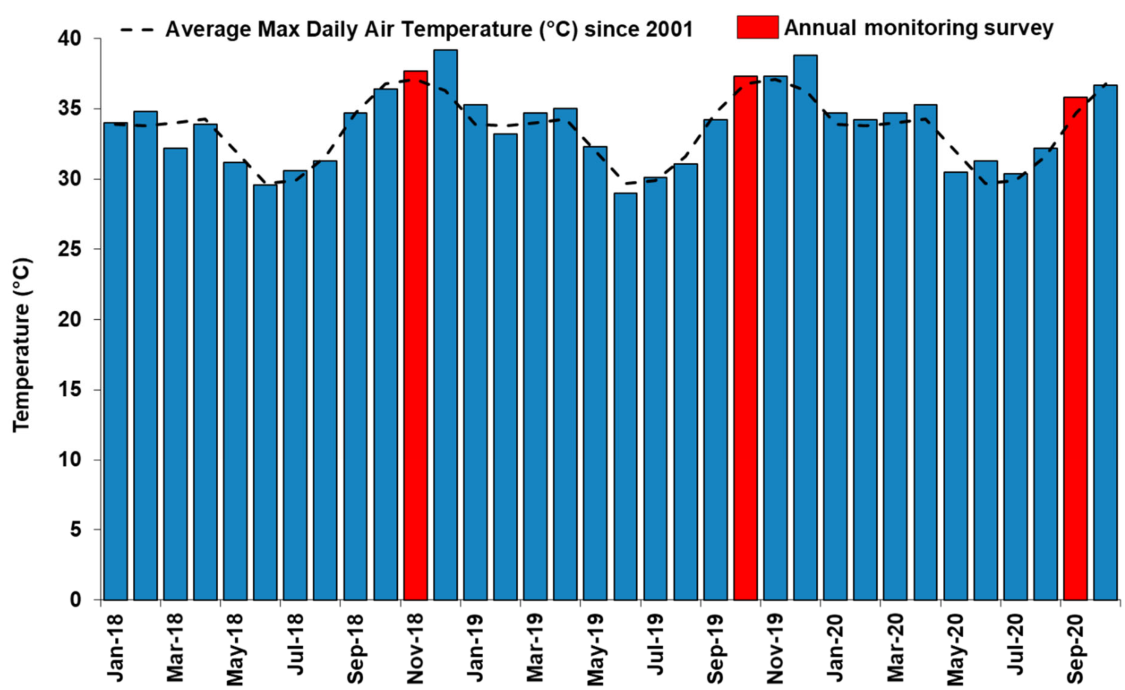

Figure 18. Monthly mean maximum daily air temperature (°C) recorded at Normanton Airport, January 2018 – October 2020.

3.6.4 Daily Global Solar Exposure

Daily global solar exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Global solar exposure in the Normanton area was above-average in 2019/20 at 22.5 MJ m^{-2} (MegaJoules m^{-2}) (Figure 19), driven by above-average solar exposure in November and December 2019 and slightly above-average solar exposure in February and March 2020 (Figure 20).

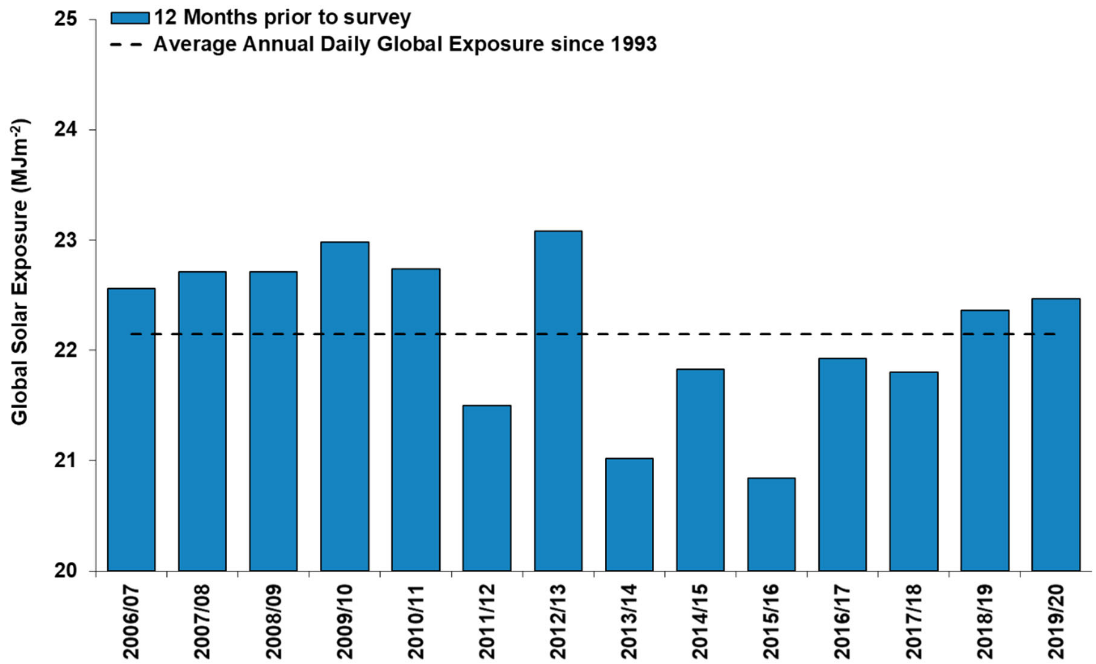

Figure 19. Mean daily global exposure (MegaJoules m^{-2}) recorded at Normanton Airport, 2006/07 – 2019/20. Twelve month year (2019/20) is twelve months prior to survey.

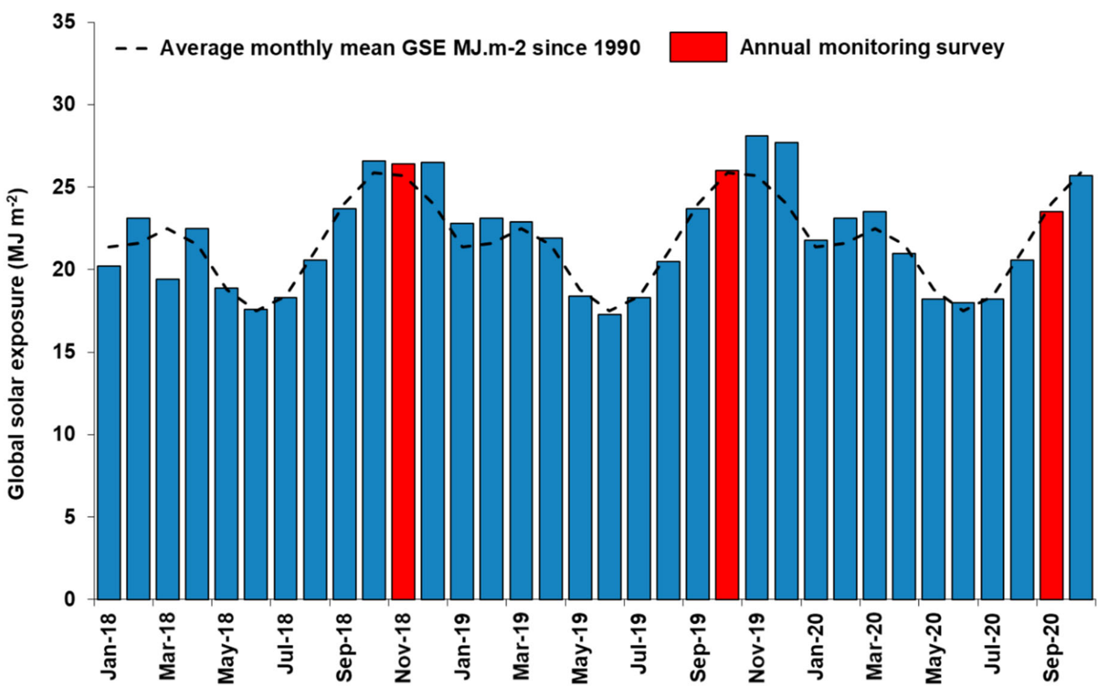

Figure 20. Mean daily global solar exposure (MegaJoules m^{-2}) recorded at Normanton Airport, January 2018-October 2020.

3.6.5 Tidal Exposure of Seagrass Meadows

Annual daytime exposure to air for intertidal seagrass was above-average in 2020 (Figure 21). Intertidal banks were exposed for a total of 201 hours in the 12 months prior to the survey (Figure 21). Daytime exposure to air was also above-average in the month prior to the survey (Figure 22).

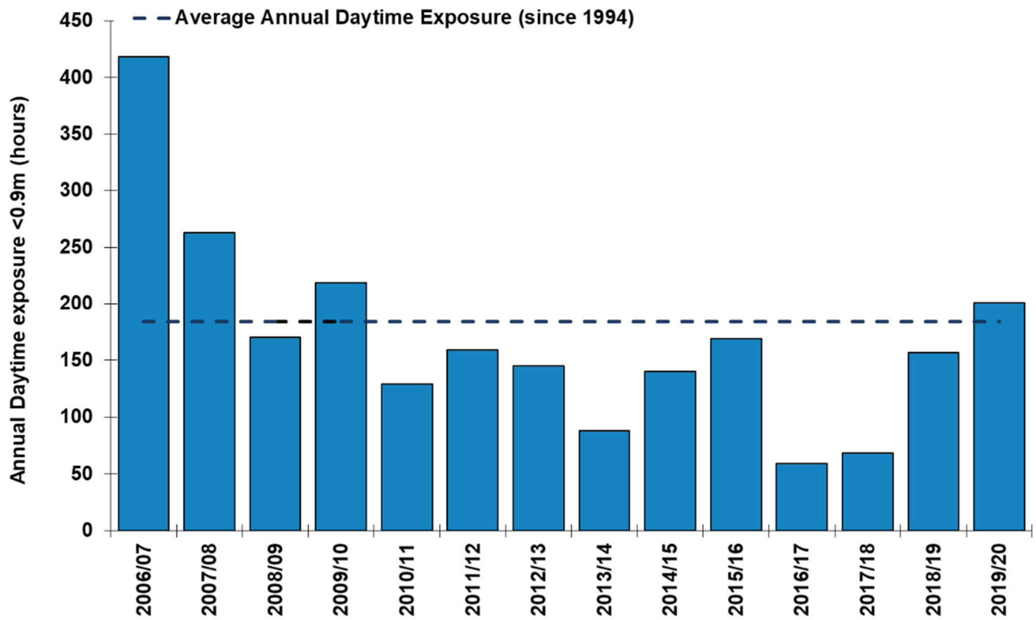

Figure 21. Total hours daytime exposure (annual) of intertidal seagrass in Karumba; 2006/07 – 2019/20. Twelve month year is twelve months prior to survey. *Assumes intertidal banks become exposed at a tide height <0.9m above Lowest Astronomical Tide.

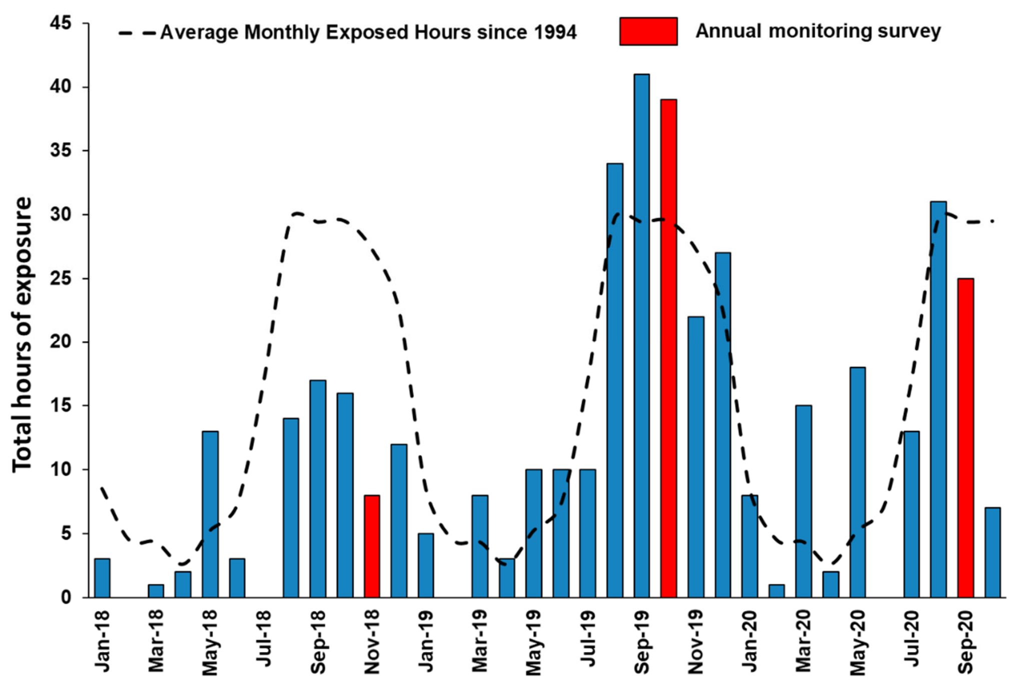

Figure 22. Total hours of daytime exposure (monthly), January 2018 to October 2020. *Assumes intertidal banks become exposed at a tide height <0.9m above Lowest Astronomical Tide. Predicted values used in August/September 2020.

4 DISCUSSION

In 2019 the condition of the Alligator Bank seagrass meadow was historically low, due to consecutive years of flooding of the Norman River. The 2020 survey showed some recovery, with environmental conditions returning to be favourable for seagrass growth. Much of this recovery was driven by less stable colonising species, resulting in a shift in species composition away from the usually dominant and more stable *Halodule uninervis*. Although seeds were found throughout the meadow, these were in lower numbers than recent years and may indicate that the seed bank is being used to aid recovery, but is yet to be replenished.

Consecutive flooding and rainfall events from 2009-2011 caused declines in seagrass area and biomass in 2012, but by 2013 both had improved and were in good condition, as was the meadow overall (McKenna and Rasheed 2013, Taylor et al. 2014). This rapid return to good condition was enabled by more favourable climatic conditions in 2012 and 2013, and was due to the fact that the meadow condition did not decrease below good during this period. As both meadow biomass and area declined to very low levels in 2019 and conditions have not been favourable for seagrass growth, improvements to the same meadow condition recorded in 2014-2017 may take some time.

Flooding of the Norman River in 2018/19 caused large-scale declines of seagrass biomass and area in Karumba, these flooding and flow events created a persistent turbid plume that reduced light levels and resulted in seagrass loss (Shepherd et al. 2020, Van De Wetering et al. 2019). In 2020, conditions were much more favourable for seagrass growth, with no sustained river flooding events. River flow, temperature and long-term tidal exposure cycles have been identified in past research as strongly influencing changes in seagrass biomass and distribution in Karumba meadows (Rasheed and Unsworth 2011) and in 2020 these were all at levels considered to be favourable for seagrass growth. There were no substantial changes to port operations or coastal developments in the area during 2020 that may have impacted seagrass condition. These favourable conditions allowed seagrass to begin to recover from the 2019 losses.

There was a short intense period of rainfall recorded in January 2020 and although the monthly rainfall total was over double the average, it did not result in major sustained flooding. Over two-thirds of this rain fell in a seven-day period at the end of the month and resulted in short-term localised flooding, but did not result in high river flows or the formation of a persistent turbid plume over the seagrass meadow as was recorded in 2019. While this didn't impact the meadow in the same manner as 2019, it is possible that short term reductions in light may have reduced the degree of recovery that otherwise may have occurred in 2020.

In 2020 the colonising species *H. ovalis* made up 45% of seagrass biomass in the meadow, the highest proportion in the 27-year history of sampling at Karumba. The life history strategy of *Halophila* species means they are well adapted for recovery once conditions become favourable, as they are fast growing and rapid colonisers (Hammerstrom et al. 2006) producing large numbers of long lived seeds and growing from fragments (McMillan 1991, Longstaff and Dennison 1999, Hammerstrom and Kenworthy 2003, Hammerstrom et al. 2006). In tropical Queensland and elsewhere *Halophila* species are often the first to return following disturbance events, where they persist at higher densities until the recovery of larger slower growing species occurs (Rasheed 2004). The pattern of high *Halophila* density recorded in Karumba in 2020 was therefore typical of tropical seagrass recovery in Queensland meadows and if conditions continue to be favourable for seagrasses we would expect to see a return of the usual species mix.

Seed densities in Karumba were low in 2020 compared with recent years. This is likely due to the substantially reduced seagrass in the meadow for the previous few years, leading to a reduced supply of seeds to replenish the sediment seed bank. A similar pattern in seed numbers was observed in Cairns Harbour following seagrass declines caused by climatic conditions, and the seagrass meadows there were able to recover over time and a viable seed bank returned (Reason et al. 2020). Germination of seeds in the seedbank driving some of the 2020 recovery could also have contributed to the low numbers of seeds recorded. Evidence of this germination can be seen by high numbers of seed casings found in 2020. Seed germination also appears to have contributed to the recruitment of *H. ovalis* during the survey, with multiple patches of *H. ovalis* observed that appeared to have recently germinated and grown from seed (Figure 23).

Figure 23. *Halophila ovalis* patches growing from seed and vegetative expansion.

Seagrasses provide a wide range of important ecosystem services and the recovery of meadow area and biomass in Karumba will likely increase the delivery of a range of services (Nordlund et al. 2016, Scott et al. 2018). For example, Karumba seagrasses are an important nursery ground for prawns and fish (Rasheed et al. 1996) and feeding ground for megaherbivores such as dugong. The seagrass at Karumba is the only substantial area of seagrass for dugong feeding between Mornington Island and the Archer River in the southern Gulf of Carpentaria (Rasheed et al. 1996).

Dugong feeding activity in the Karumba seagrass increased in 2020 compared to very low numbers of feeding trails observed in 2019. Megaherbivore feeding activity can maintain the meadow in a lower biomass state, but could also have positive impacts for the meadow such as increasing seagrass productivity and spreading seeds (Scott et al. 2018, Tol et al 2017). Dugong feeding may have also contributed to the species shift in the meadow, as dugong feeding creates a disturbance that favours faster growing species such as *H. ovalis* (Preen 1995). The high levels of feeding observed could also reduce above-ground biomass and limit meadow recovery.

The seagrass meadow in Karumba can continue to recover through sexual reproduction and asexual growth as long as conditions are favourable. Although numbers of seeds are low, a seed bank is present, and with higher biomass now in the meadow, this could begin to be replenished. Although we did not measure viability of seeds present, these seeds can remain dormant in the seed bank for a number of years (Campbell and McKenzie 2004). Both seagrass species in Karumba are capable of rapid asexual growth and expansion (Rasheed, 2004), therefore when above-ground biomass is high, there may be less reliance on the seed bank to drive recovery. Experience from other areas of the state where seagrasses are monitored shows that as long as there are reasonable areas of the adult population remaining, recovery can be quite rapid. In Townsville for example, where areas of seagrasses still remained within meadows following large scale losses in 2011, seagrasses were able to come back within one to three years through asexual colonisation (Davies et al 2013). In Karumba, the last time seagrass area had declined in a major way was in 1998 and they were able to bounce back to a good condition within two years.

The state of seagrass in Karumba at the end of 2020 means that the meadow has recovered some of its resilience from the low points over the previous two years, but still remained somewhat vulnerable to further natural or anthropogenic pressures in 2021. Continued recovery of the meadow will rely on the absence of further major climate events to allow time for seagrasses to fully rebuild their resilience. At the time of the production of this report, one Tropical Cyclone had impacted Karumba in January 2021. Tropical Cyclone Imogen crossed the coast just north of Karumba on 4th January 2021, with 263 mm of rain falling in one day causing flooding and high river flow rates for much of January. This may have further impacted upon the meadow since the time of the October 2020 survey. Karumba seagrasses have been resilient to past maintenance and capital dredging and we would recommended that upcoming campaigns do not result in any substantial changes to previous practice, that might add further stress to seagrasses during 2021.

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6 APPENDICES

Appendix 1. Seagrass Score Calculation

A1.1 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 (1994-2003) following the methods of Carter et al. (2015) and Bryant et al. (2014). The 1994-2003 period incorporates a range of conditions present in the Port of Karumba, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events (Sozou et al. 2016).

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

A1.2 Meadow Classification

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

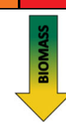
Table A1.1 Coefficient of variation (CV; %) thresholds used to classify historical stability or variability of meadow biomass, area and species composition.

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

A1.3 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 A1.2).

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

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

A1.4 Grade and Score Calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition (see Carter et al. 2015 for a detailed description, and Table A1.3).

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

Scaling was required because the score range in each grade was not equal (Table A1.3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area, the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.

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

Table A1.3. Score range and grading colours used in the Karumba seagrass report card.

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

Where species composition 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 A1.1). 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 A1.1). This would occur when the stable state species is replaced by species considered to be earlier colonisers.

Such a shift indicates a decline in meadow stability (e.g. a shift from *H. uninervis* to *H. ovalis*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species).

The directional change assessment 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 A1.1).

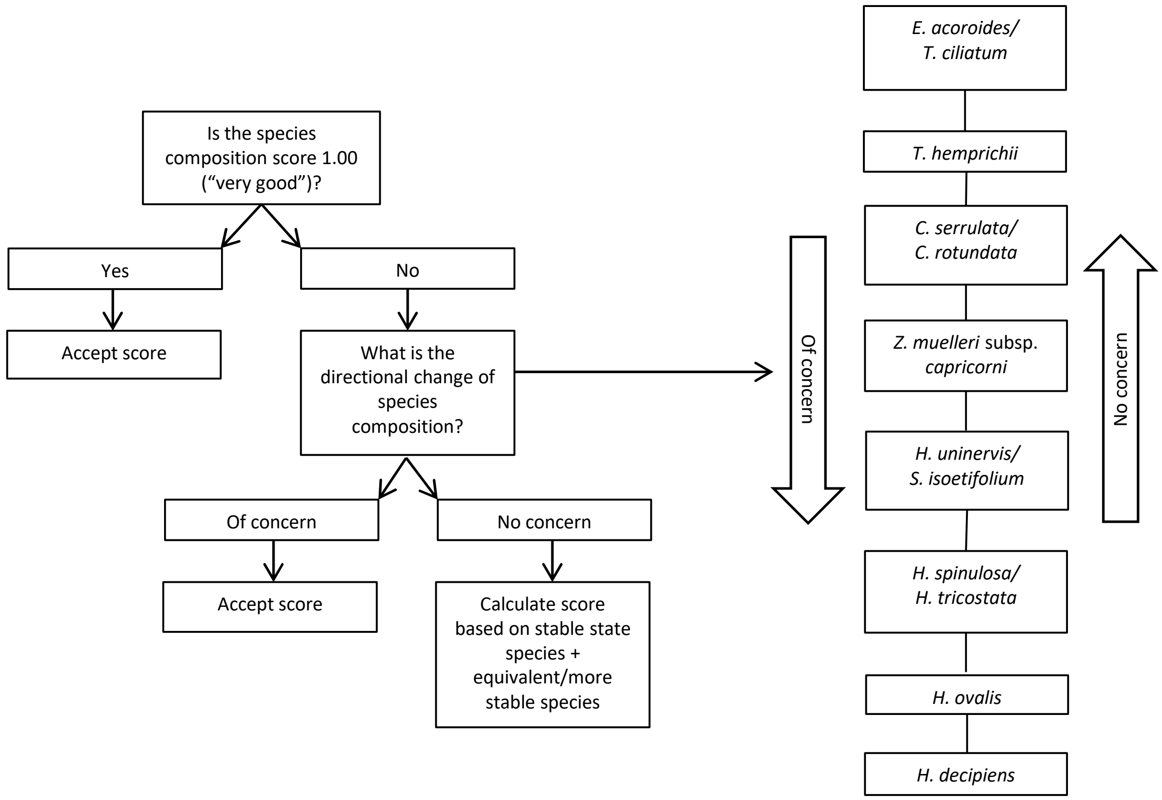


Figure A1.1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition for Karumba seagrass.

A1.5 Score Aggregation

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

Appendix 2. Biomass score calculation example

1. Determine the grade for the 2015 (current) biomass value (i.e. good).

2. Calculate the difference in biomass (B_{diff}) between the 2015 biomass value (B_{2015}) and the biomass value of the lower threshold boundary for the "good" grade (B_{good}):

$$\mathrm{B_{diff}} = \mathrm{B_{2015}} - \mathrm{B_{good}}$$

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

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

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

Where B_{good} is the upper threshold boundary for the good grade.

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

4. Calculate the proportion of the good grade (B_{prop}) that B_{2015} takes up:

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

5. Determine the biomass score for 2015 ($Score_{2015}$) by scaling B_{prop} against the score range (SR) for the good grade (SR_{good}), i.e. 0.20 units (see Table 6):

$$\mathrm{Score_{2015}} = \mathrm{LB_{good}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{good}}\right)$$

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