Centre for Tropical Water and Aquatic Ecosystem Research

PORT OF KARUMBA LONG-TERM ANNUAL SEAGRASS MONITORING: NOVEMBER 2018

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Report No. 19/12

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

Report No. 19/12

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KEY FINDINGS

Seagrass Condition 2018

1. This report compiles the findings of aerial and boat surveys conducted on 28th-29th November 2018.

2. Seagrasses in the Port of Karumba were in a satisfactory condition in 2018, a reduction following several years of good to very good condition.

3. The reduction was due to a decline in seagrass biomass likely as a result of flooding and significant flow events of the Norman River in March and April 2018 associated with cyclone Nora.

4. Although at reduced density, seagrass remained across the historical footprint of its distribution and a healthy seed-bank (seeds stored in the sediment) was recorded.

5. In 2018 seagrasses in the broader port limits were surveyed as part of expanded surveys conducted every 3 years in the monitoring program. Results of this survey confirmed seagrass area on Elbow Bank remained similar to previously recorded extents, although biomass was lower, similar to other meadows in the port.

6. Extensive areas of dugong feeding trails were recorded throughout the seagrass meadows in Karumba.

7. The maintenance of seagrass across the historical footprint of its distribution and the presence of the seedbank means the Karumba seagrass meadows were likely to be able to increase in biomass and recover should growing conditions be favourable during 2019. However their resilience to future impacts was likely to be reduced compared to recent years, and subsequent to this survey extensive flooding in the southern Gulf of Carpentaria has been recorded.

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 (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 then used to develop a seagrass condition index (see 2.3 and Appendix 1 of this report for further details).

In 2018 seagrasses in the broader port limits were also surveyed as part of expanded surveys conducted every 3 years in the monitoring program. This included intertidal areas on Elbow Bank on the opposite side of the Norman River to the annual monitoring meadow (Alligator Bank).

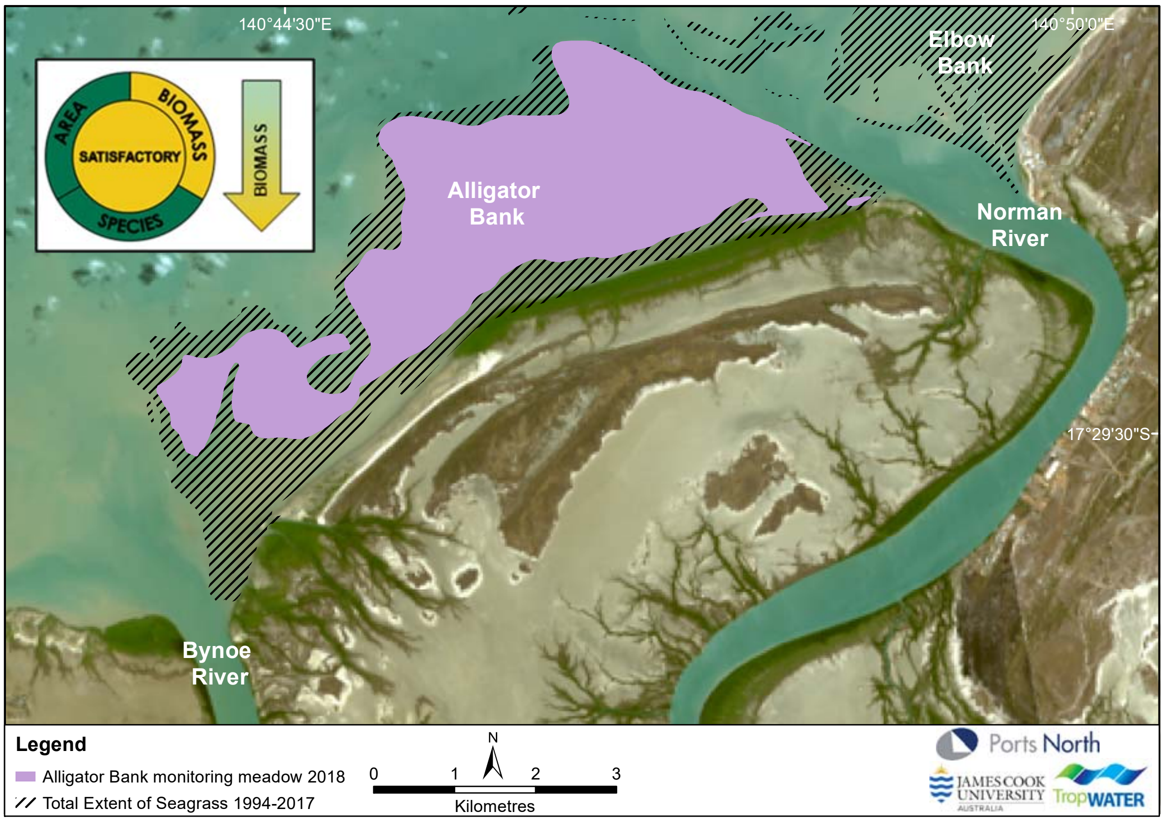


Figure 1. Seagrass condition index for the Karumba seagrass monitoring meadow November 2018.

In 2018 seagrasses in the Port of Karumba had reduced substantially in biomass from the high levels recorded over the past decade but species composition and area of seagrasses remained in very good condition. The density of *Halodule uninervis* seeds in the seed bank was above the long-term average and dugong feeding trails were recorded throughout the monitoring meadows.

In the broader port limit area seagrass was mapped on Elbow Bank and covered a similar footprint as in previous years when whole of port surveys have been conducted. The Elbow Bank seagrass was dominated by *Halodule uninervis,* and similar to the Alligator Bank monitoring meadows, had a reduced biomass when compared to previous years.

In March and April 2018 substantial flows and flooding of the Norman River were recorded for the first time since 2011. The flooding and flow events of the Norman River associated with Tropical Cyclone Nora were the most likely cause of the observed seagrass biomass declines. Other environmental conditions such as tidal exposure and temperature remained favourable for seagrass growth.

In 2018, resilience of Karumba's seagrass meadows to stress and impacts is likely to be reduced compared with recent years due to its reduction in biomass. However, as seagrass remained throughout its historical footprint and a healthy seed bank was maintained, the Karumba seagrass meadows maintained a capacity to rapidly recover in biomass should conditions be favourable for seagrass growth during 2019.

The results of the 2018 survey show seagrasses in Karumba remained in a satisfactory condition with changes linked to climate/weather conditions rather than localised anthropogenic activities. The largest concern would be how seagrasses have fared following the early 2019 floods of the southern Gulf of Carpentaria that occurred in the months following this survey, particularly as seagrasses were already in a reduced state at the end of 2018.

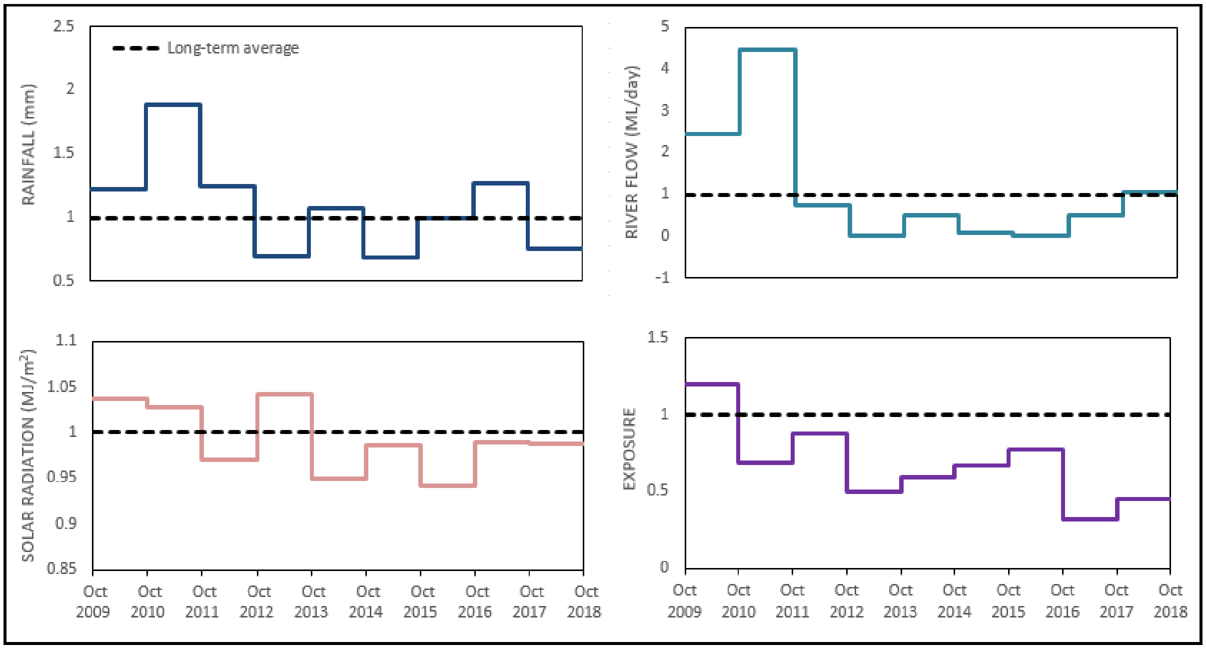


Figure 2. Change in climate variables as a proportion of the long-term average in Karumba. See Section 3.4 for detailed climate data for the Karumba region.

The Karumba seagrass monitoring program forms part of a broader seagrass program that examines the condition of seagrasses in the majority of Queensland commercial ports and a component of TropWATER's broader seagrass assessment and research program. Seagrass at other monitoring locations on Western Cape York and Torres Strait were generally in good condition in 2018. Locations along the east coast of Queensland monitored as part of this program such as coastal seagrasses in Abbot Point, Cairns and Gladstone have shown signs of improvement in 2013 - 2018 following declines prior to this period. However some other locations such as Mourilyan Harbour have yet to recover and remain in a vulnerable condition. For full details of the Queensland ports seagrass monitoring program see www.jcu.edu.au/portseagrassqld

Table of Contents

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 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).

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. It is useful information for planning and implementing port development and maintenance programs so they have a minimal impact on seagrasses. The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

Figure 3 Location of Queensland Port Seagrass assessment sites

The program not only delivers key information for the management of port activities to minimise impacts on seagrasses but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. The program has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses and 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 www.jcu.edu.au/portsseagrassqld

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. The Far North Queensland Ports Corporation Limited (FNQPCL), trading as Ports North (PN), 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 is potentially affected by port activities.

Ports North has recognised that seagrasses form a key ecological habitat in the Karumba region and have continued the long-term seagrass monitoring program established for the port in 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. 2001a). Following this, a long-term seagrass monitoring (LTSM) strategy for the Port of Karumba was developed.

Results of the LTSM 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 which may include, for example, land runoff and dredging impacts, and provides a simple assessment of condition to confirm that port activities are not impacting the seagrass. The LTSM 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 the results of the November 2018 annual seagrass monitoring survey. In addition to the monitoring meadow assessments, this report also presents the results of a wider survey of seagrass to Elbow Bank; opposite the annual monitoring meadow. It has been three years since seagrass beyond the Alligator Bank monitoring meadow have been examined. The objectives of the program were to:

1. Map the distribution of seagrasses in the Alligator Bank monitoring meadow between the Norman and Bynoe River;
2. Monitor the seagrass species composition and density within the monitoring meadow;
3. Monitor the seed bank and reproductive capacity of the annual monitoring meadow on Alligator Bank;
4. Conduct an expanded survey to include intertidal seagrass on Elbow bank to provide updated information on seagrass distribution and density in the wider port area;
5. Assess changes in the seagrass meadows by comparing results with previous Karumba monitoring surveys, and place observed changes within a regional and state wide context of other seagrass monitoring programs.

1.3 Sampling approach

The sampling approach for the expanded 2018 Karumba seagrass survey was based on the need 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 that are established for the Karumba long-term seagrass monitoring program as well as other seagrass monitoring programs established in Queensland Ports including Weipa, Cairns, Mourilyan Harbour, Townsville, Gladstone, Mackay, Thursday Island and Abbot Point (see Rasheed & Taylor 2008; Rasheed et al 2005; Rasheed et al. 2001b; Roelofs et al. 2001).

2 METHODS

2.1 Sampling Methods

The Port of Karumba seagrass survey was conducted from the 28th- 29th November 2018. The survey area included the intertidal banks of Alligator Bank and Elbow Bank within the Karumba port limits. A complete background site description and detailed methodology of the monitoring program are available in previous reports (Rasheed et al. 1996; Rasheed et al. 2001a; McKenna & Rasheed 2011).

The boundary of seagrass meadows were mapped from aerial (helicopter) surveys conducted during the spring low tide when the seagrass meadows were exposed. Waypoints were recorded around the edge of the meadow using a global positioning system (GPS) and were digitised on to a Geographic Information System (GIS) base map.

Seagrass meadow characteristics were collected at seagrass habitat characterisation sites scattered randomly within the mapped meadow boundary. The number of sites placed in the meadow was based on a power analysis taking into account within meadow variability (Unsworth et al. 2009). Seagrass habitat characteristics including seagrass species composition, above-ground biomass, epiphytes, algae and dugong feeding activity were recorded at each sampling site from a helicopter hovering within a metre of the ground when the meadow was exposed at low tide.

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 utilised in surveys throughout Queensland and peer reviewed on several occasions (e.g. Rasheed et al. 2008; Rasheed & 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 relative proportion of each seagrass species within each survey quadrat was also recorded.

Sampling of the seagrass seed bank (i.e. seeds stored in the sediments) and other seagrass reproductive structures (fruit and flowers) was conducted within the monitoring meadow. A Van Veen sediment grab ($0.0625m^{-2}$) was used to collect samples at sites randomly scattered throughout the meadow. Seagrass and sediment/seed samples were sorted by passing the sample through a 1mm sieve. Any seagrass seeds in the 1mm fraction were identified and counted for each site. The 1mm mesh size was small enough to retain seeds of *Halodule uninervis* and fruits and flowers of *Halodule uninervis* and *Halophila ovalis*. Seeds of *Halophila ovalis* were not measured because their small size allows them to pass through the sieve mesh and require 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 species distribution and density. Satellite imagery of the Karumba region with information recorded during the monitoring surveys was combined to assist with mapping seagrass meadows. Three seagrass GIS layers were created in ArcMap:

- ***Habitat characterisation sites*** – site data containing above-ground biomass (for each species), sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.
- ***Seagrass meadow biomass and community types*** – area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). Density categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 1 and 2).

- ***Seagrass landscape category*** – area data showing the seagrass landscape category determined for each meadow (Figure 4).

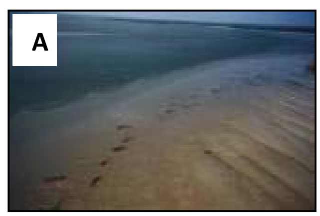
Table 1. Nomenclature for seagrass community types in the Port of Karumba.

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. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density 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.

The seagrass meadow boundary was assigned a mapping precision estimate (in metres) based on mapping methodology utilised for that meadow (Table 3). Mapping precision was assumed to be ±5 m for the monitoring meadow due to the error associated with the GPS fixes for survey sites. The mapping precision estimate was used to calculate a range of meadow area for the monitoring meadow and was expressed as a meadow reliability estimate (R) in hectares.

Table 3. Mapping precision and methodology for seagrass meadows.

Mapping precision	Mapping methodology
± 5 m	All meadow boundaries mapped in detail by GPS using aerial helicopter survey; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent aerial or satellite imagery aided in mapping.

2.3 Seagrass meadow condition index

A condition index was developed for the Karumba seagrass monitoring meadow based on changes in mean above-ground biomass, total meadow area and species composition, and expanded on the previous index that was applied in the 2014 Karumba report (see Sozou et al. 2015). Meadow condition was divided into one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor) by comparing the condition of the current meadow against the baseline conditions. The flow chart in Figure 5 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation methods.

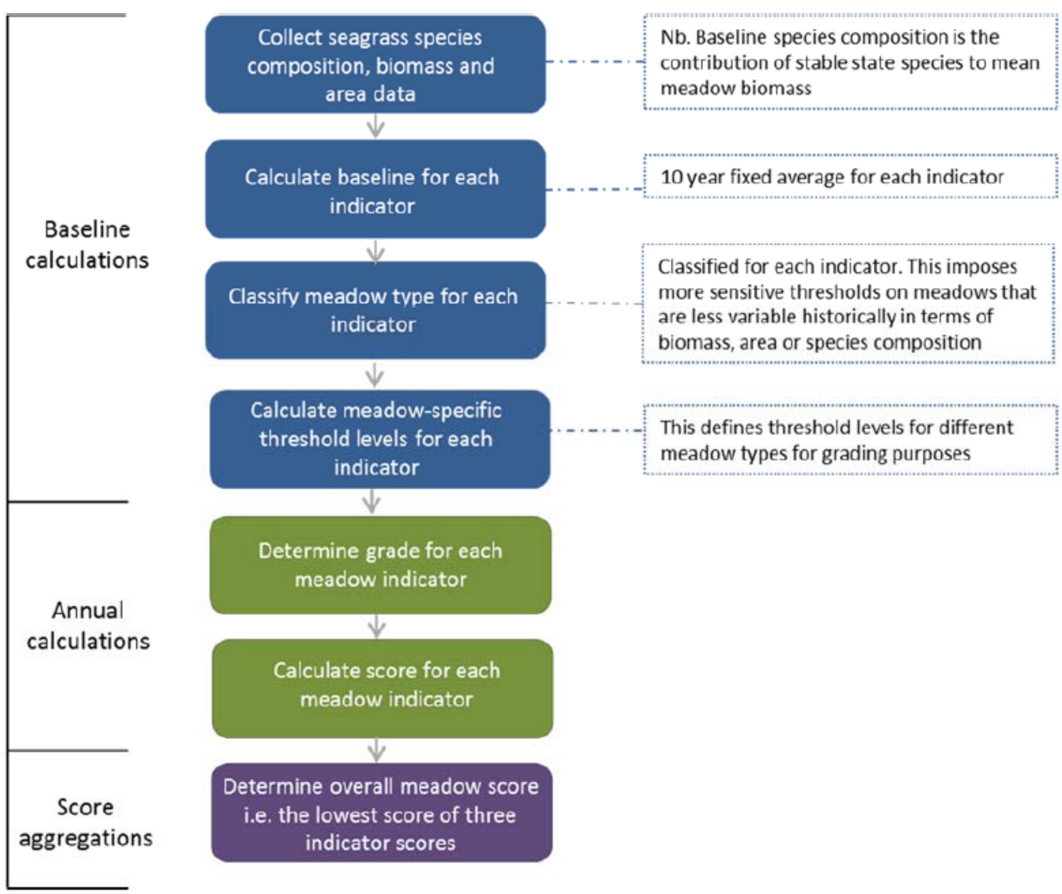


Figure 5. Flow chart to develop Port of Karumba grades and scores.

3 RESULTS

3.1 Seagrass Species in the Port of Karumba

A total of 164 seagrass habitat characterisation sites were surveyed in the Karumba annual monitoring and expanded whole of port limit survey in November 2018, with seagrass present at 80% of sites. Two seagrass species were present in both the annual monitoring meadow on Alligator Bank and the meadow surveyed on Elbow Bank. *Halodule uninervis* (narrow leaf form) was the dominant species recorded across both banks and accounted for approximately 99.75% of above-ground seagrass biomass on Alligator Bank, and 95.26% on Elbow Bank, while *Halophila ovalis* accounted for the remaining biomass of 0.25% and 4.74% respectively (Figure 6 and 9).

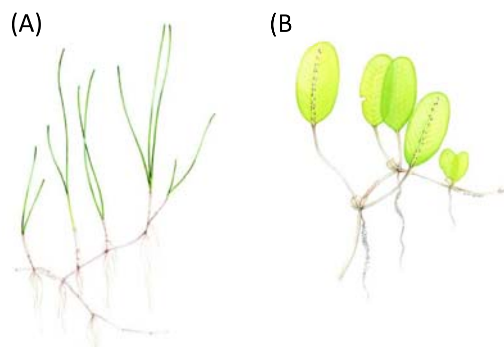


Figure 6. Seagrass species found in Karumba: (A) *Halodule uninervis* (Forsk.) Aschers. in Boissier, Family Cymodoceaceae (narrow leaf form); (B) *Halophila ovalis* (R. Br.) Hook.ƒ, Family Hydrocharitaceae.

3.2 Seagrass in the Annual Monitoring Meadow (Alligator Bank)

3.2.1 Seagrass distribution, density and reproductive capacity

Annual monitoring results show seagrass in the Port of Karumba were in a "satisfactory" condition in 2018 with an overall score of 0.60 (Table 4 & 7). Mean above-ground biomass (density) was 2.02 $\pm$ 0.18 g DW m^{-2}, leading to biomass achieving a condition index score of "satisfactory" (Table 6; Figure 9). The distribution (area) of seagrass across Alligator Bank was classified as stable with the total area of the monitoring meadow reaching 1320.5 $\pm$ 14.7 ha (Table 5; Figure 9). This placed the area of seagrass in the Karumba monitoring meadow into the "very good" category (Figure 9).

While biomass was low, seagrass maintained a continuous landscape cover within the meadow boundary. The species composition was dominated by *Halodule uninervis* (narrow) with *Halophila ovalis* forming a minor component. In 2018 the species composition score was categorised as "very good" (Table 2; Figure 9).

A total of 18 sites were sampled for seeds and reproductive structures within the monitoring meadow. *Halodule uninervis* seeds and pieces of seed pericarp (outer casing of seeds) were found throughout the meadow (Figure 10). Mean *Halodule uninervis* seed density for the meadow was 74 $\pm$ 16 seeds m^{-2} and the density of pericarp pieces 67 $\pm$ 19 pieces m^{-2} (Figure 11). No fruits or flowers of either seagrass species were found at the time of the survey (Figure 11).

Dugong feeding trails (DFTs) were observed at 29% of the survey sites examined and were spread throughout the monitoring meadow (Figure 8).

3.2.2 Comparison with previous monitoring surveys

In 2018 overall seagrass condition fell below a rating of "good" for the first time since 2003 (Table 4; Figure 8). The decline in overall condition to a "satisfactory" rating was due to reduced biomass of seagrass with the other score indicators, seagrass area and species composition, remaining in a "very good" condition.

Meadow biomass decreased between 2017 and 2018 by 77.3%, and resulted in the third lowest biomass recorded in the 25 year history of seagrass monitoring at Karumba. The decrease in seagrass biomass was comparatively uniform across the entire meadow as opposed to being localised to the Bynoe River end, which has occurred previously in the program when meadow biomass declined (Figure 12).

Despite the decline in biomass in 2018, seagrass meadow area was in a very good condition and has remained at this level for the last 15 years, well above the baseline (10 year) average (Figure 9).

Halodule uninervis has consistently been the dominant species in the meadow since monitoring began in 1994 with the species composition being relatively stable throughout the program (Figure 9). In 2018, *Halodule uninervis* comprised 99.8% of the seagrass biomass with *Halophila ovalis* making up the remainder. This is an increase from 2016 and 2017 which were slightly lower at 93.2% and 95.2% respectively. Species composition has remained in a condition state of "good" or higher since monitoring began in 1994, and has been classed as "very good" since 2006 (Figure 9).

Measures of the density of seeds in the seagrass seed bank (seeds stored in the sediment) have varied greatly since seed and pericarp (broken pieces of seed casing) sampling began in 2003, as has the distribution of the reproductive structures within the meadow (Figure 10 & 11). In 2018, seed density for *Halodule uninervis* was above the long-term average, however this was a decrease of 56% from the highest ever recorded seed density in 2017 (168 ± 47 seeds m^{-2}) (Figure 11). Pericarps were also above the long-term average in 2018 (Figure 11). Flowers and fruits were absent at the time of the 2018 survey for both *Halodule uninervis and Halophila ovalis* (Figure 11). Flowering presence has been highly variable between years as may be expected during one off annual surveys, considering the variable timing of flowering combined with the short lived nature of flowering structures. Consequently it is difficult to use this information to infer much about meadow resilience from one off surveys, unlike seeds, which are relatively long lived, and can remain viable for several years in the sediment once produced.

Throughout the entire monitoring program Dugong Feeding Trails (DFTs) have consistently been observed within the meadows. In 2018 DFTs were present at 29% of the sites which is a considerable drop from the 66% of sites in 2017 but still within range of the recent years (27% and 50% in 2016 and 2015 respectively) (Figure 7; Figure 8).

Figure 7. Example of Dugong Feeding Trails within a meadow

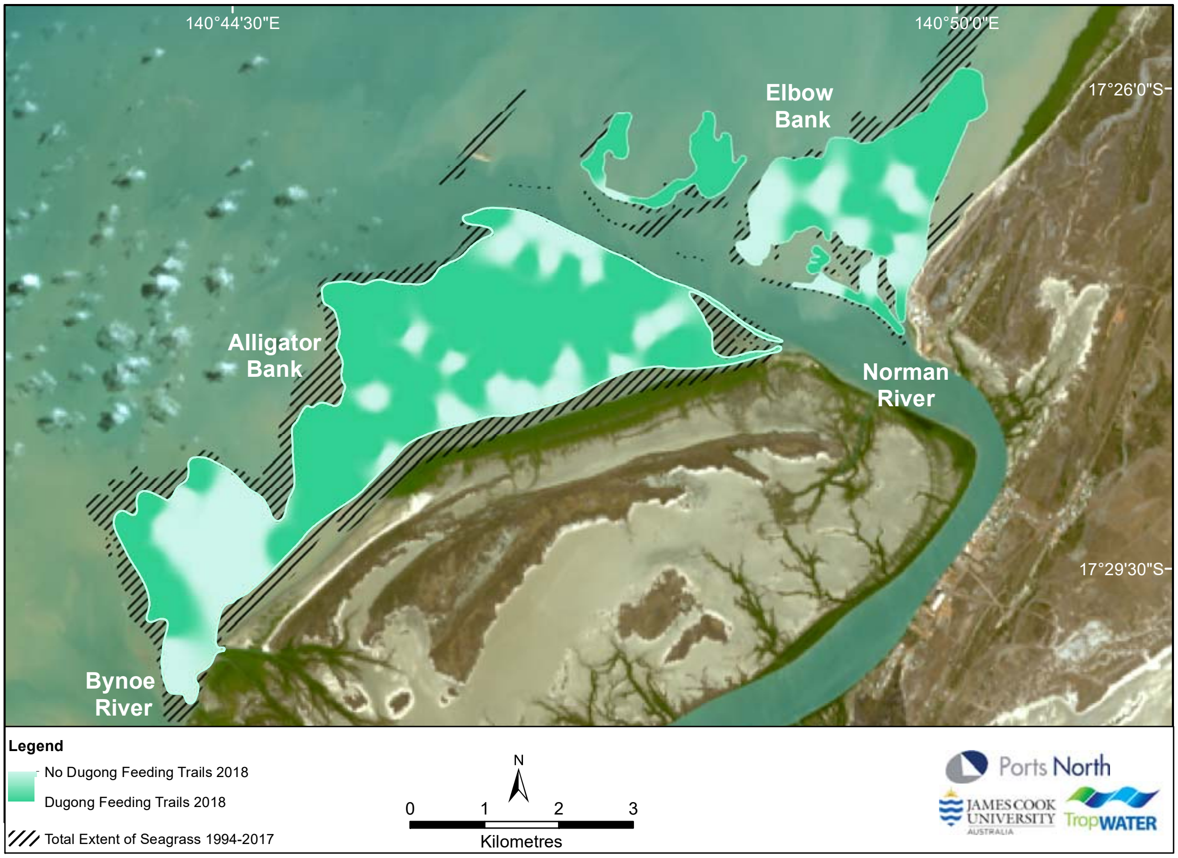


Figure 8. Dugong feeding trails present across the monitoring meadow and Elbow Bank in 2018

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for Karumba.

Meadow	Biomass	Area	Species Composition	Overall Meadow Score
Karumba	0.60	1	1	0.60

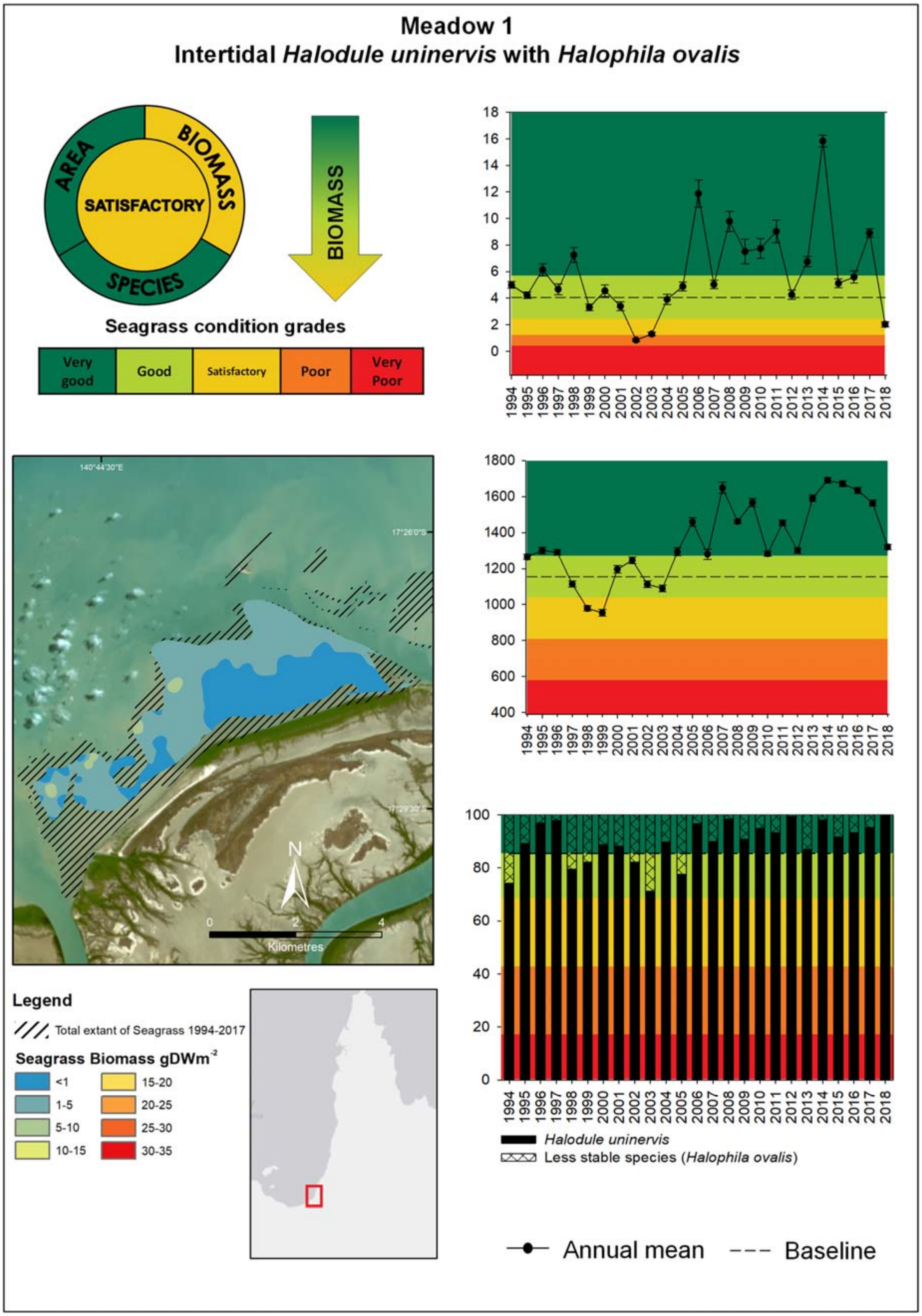


Figure 9. Changes in biomass, area and species composition for the Karumba seagrass monitoring meadow from 1994 to 2018 (biomass error bars = SE; area error bars = "R" reliability estimate).

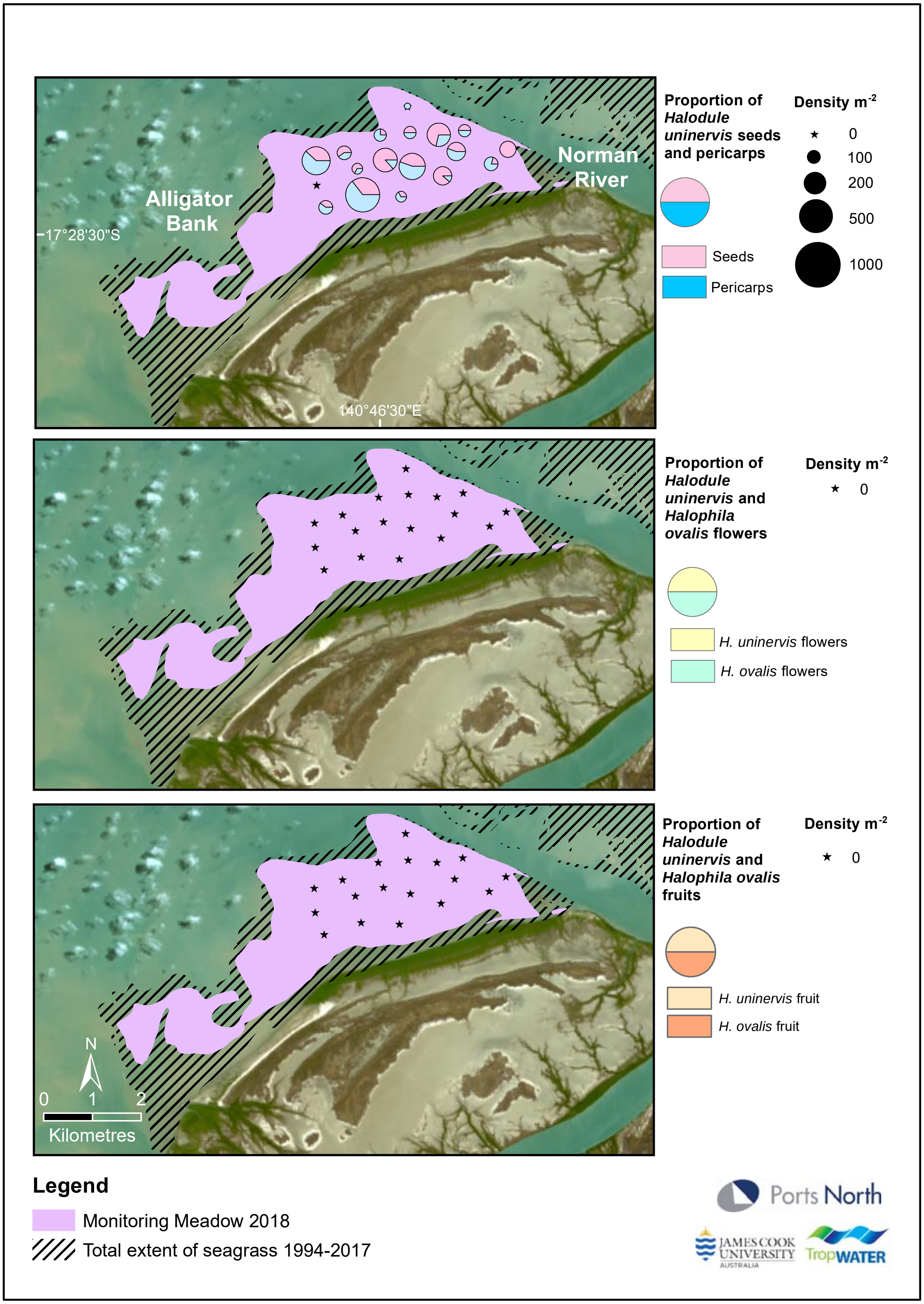


Figure 10. Density of *Halodule uninervis* seeds and pericarps, and *Halodule uninervis* and *Halophila ovalis* flowers and fruits November 2018.

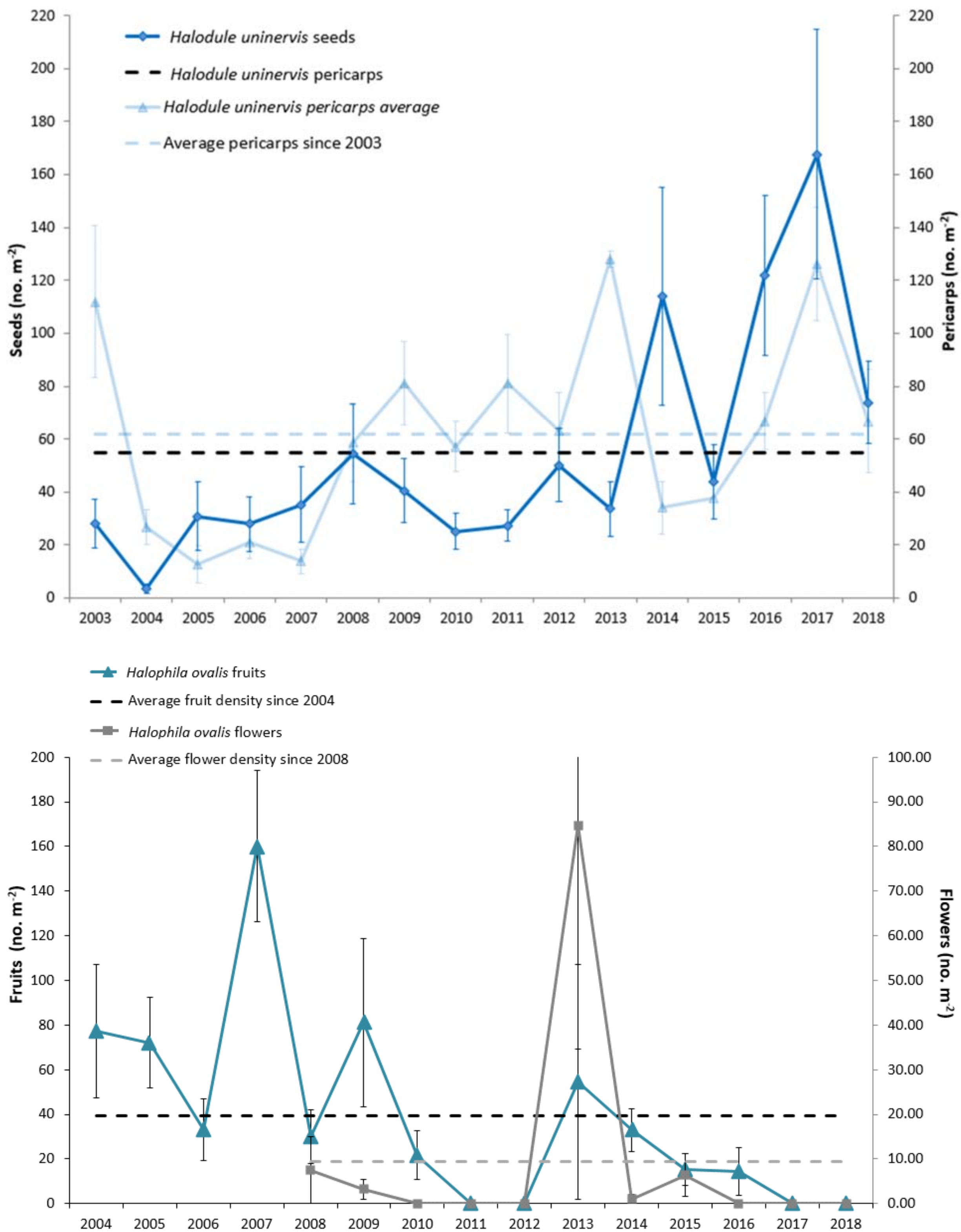


Figure 11. Mean density (± SE) of (A) *Halodule uninervis* seeds and pericarp pieces, and (B) *Halophila ovalis* fruits sampled within the monitoring meadow.

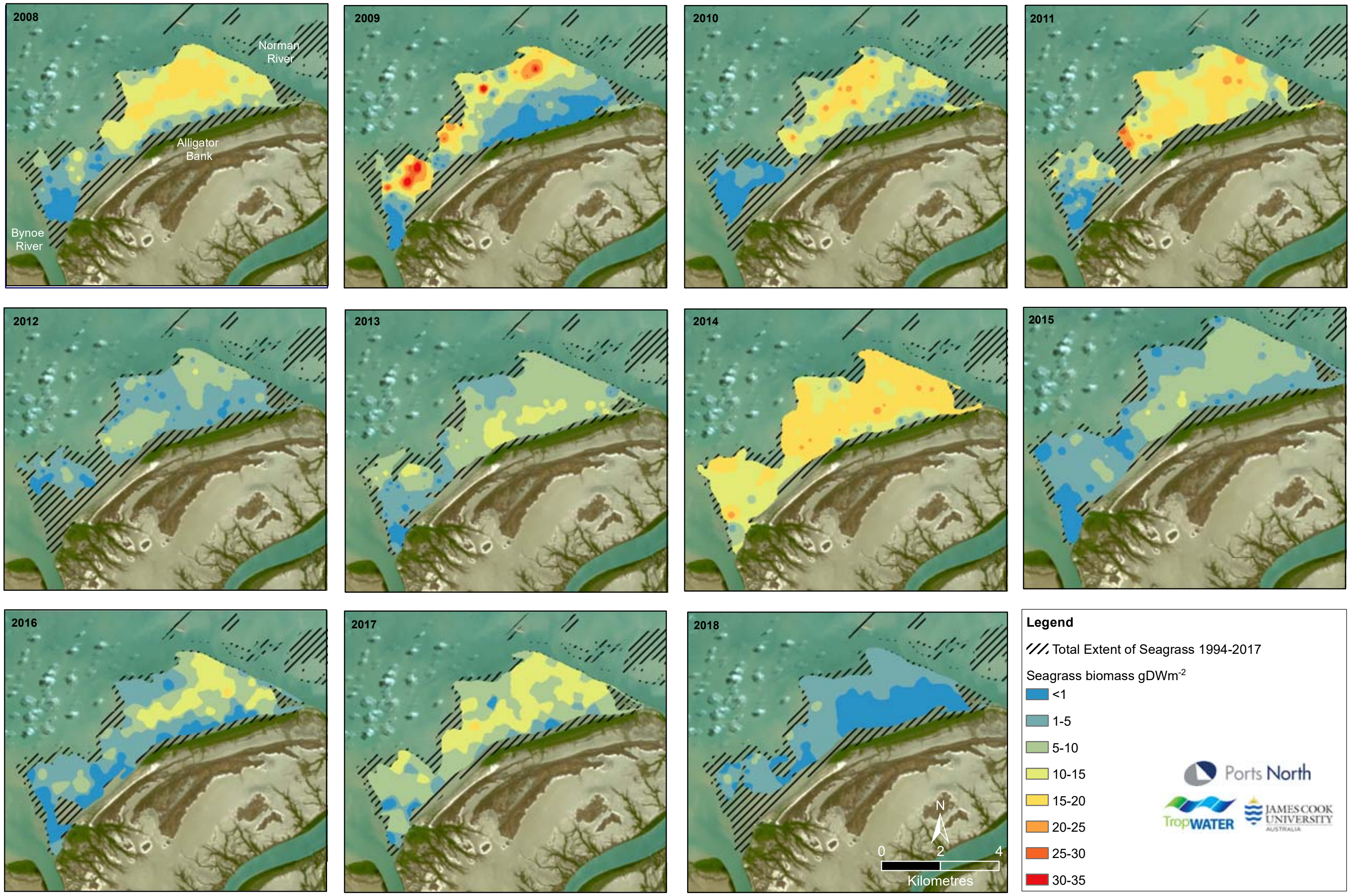


Figure 12. Changes in biomass and area in the Port of Karumba seagrass monitoring 2008 to 2018.

3.3 Seagrass in the broader Port of Karumba

In 2018 seagrasses in the broader Karumba port limits (beyond the Alligator Bank monitoring meadow) were surveyed. As in previous whole of port surveys (October 1994, October 1997 and September 2015 (see Rasheed et al. 2001a, Sozou et al. 2016)), large areas of intertidal seagrass were found (Figure 12 & 14).

A total of 44 habitat characterisation sites were assessed within the mapped boundary of Elbow Bank seagrass meadows in 2018. Similar to 1994, 1997 and 2015 *Halodule uninervis* and *Halophila ovalis* were the two species present and formed a large area of seagrass in several fragmented meadows across the bank. The seagrass landscape within these fragment meadows had a continuous cover (Figure 13).

Seagrass biomass (density) on Elbow Bank in 2018 was 1.32 ± 0.19 g DW m^{-2}, which was lower than previously recorded values in 1994, 1997 and 2015 (3.36 ± 0.30 g DW m^{-2} , 6.99 ± 0.46 g DW m^{-2} and 2.36 ± 0.41 g DW m^{-2} respectively) (Table 5). The area of seagrass on Elbow Bank in 2018 was the second highest recorded (543 ha in 2018 compared with 152 ha in 1994, 422 ha in 1997 and 571 ha in 2015) (Table 5).

Dugong feeding trails were recorded at 36.4% of sites on Elbow Bank (Figure 8) which is higher than the 33% recorded in 2015.

Table 5. Table of Area (ha) and Mean Biomass (g DW m^{-2}) of Elbow Bank seagrass monitoring surveys 1994, 1997, 2015 & 2018.

Area (ha)			
1994	**1997**	**2015**	**2018**
152	422	571	543
Mean Biomass ± SE (g dw m^{-2})			
3.36 ± 0.30	6.99 ± 0.46	2.36 ± 0.41	1.32 ± 0.19

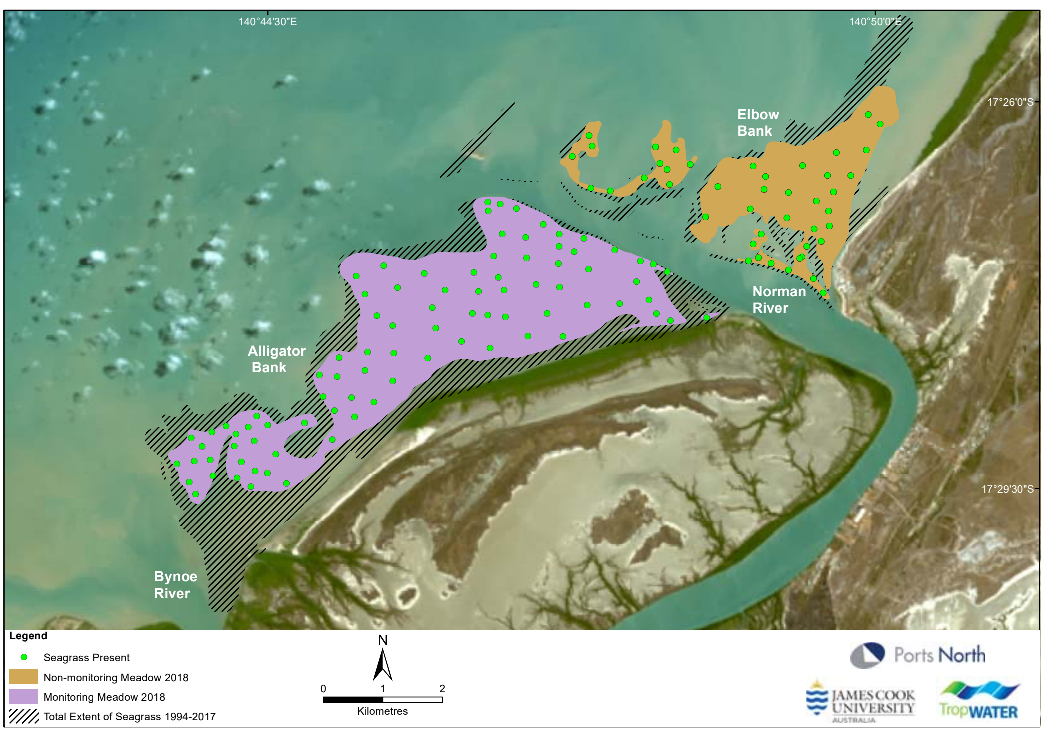


Figure 13. Monitoring and non-monitoring seagrass meadow in the Port of Karumba showing seagrass presence/absence at Elbow Bank in 2018

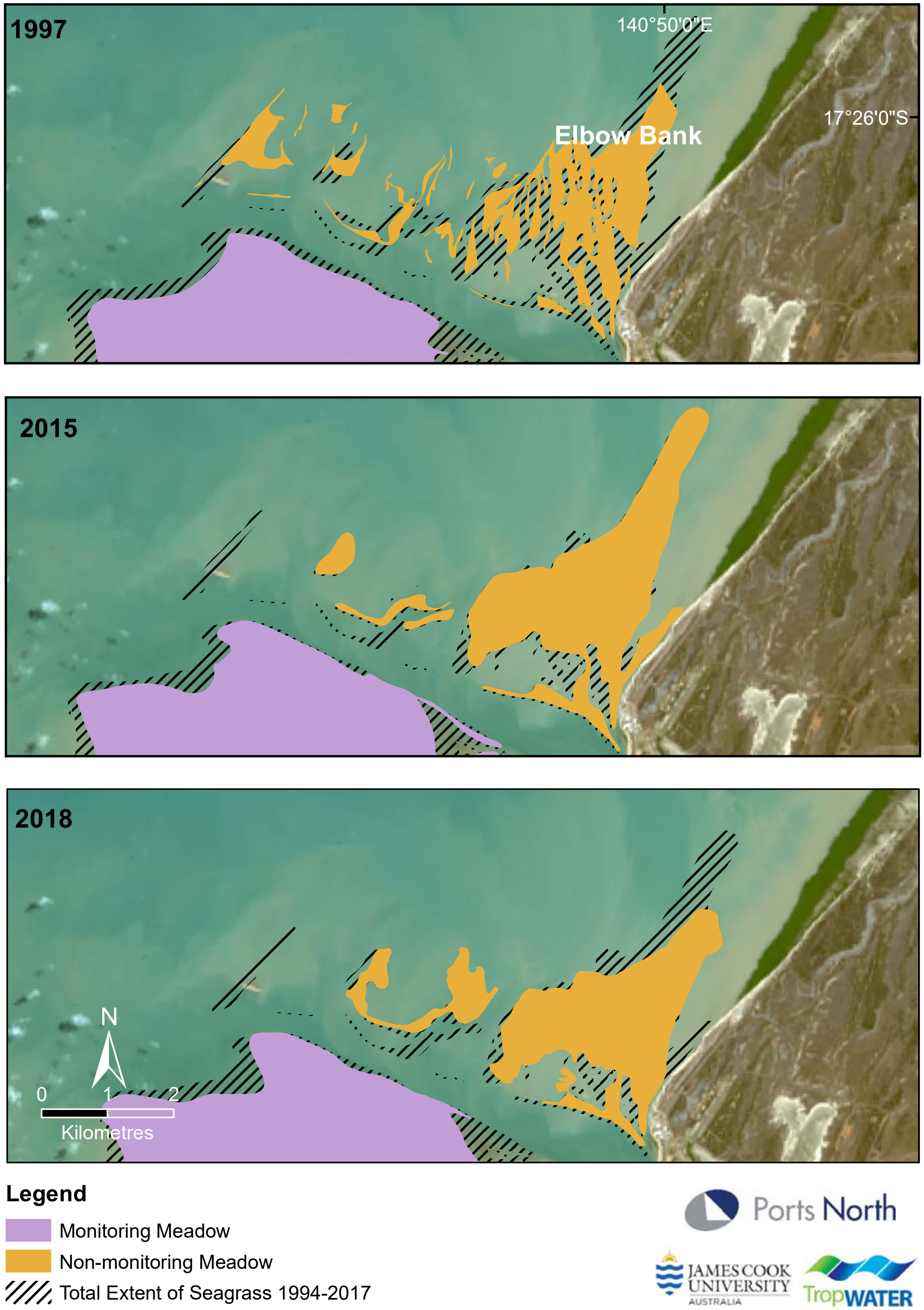


Figure 14. Comparative map of seagrass distribution on Elbow Bank for years 1997, 2015 and 2018.

3.4 Karumba climate patterns

Rainfall

Total annual rainfall for the Normanton area in the twelve months prior to the survey (November 2018) was 594 mm and was below the long-term average rainfall for the area (Figure 15). Light rainfall of 20.4 mm occurred during the survey month (November) with only 41 mm between April and October 2018 (Figure 16).

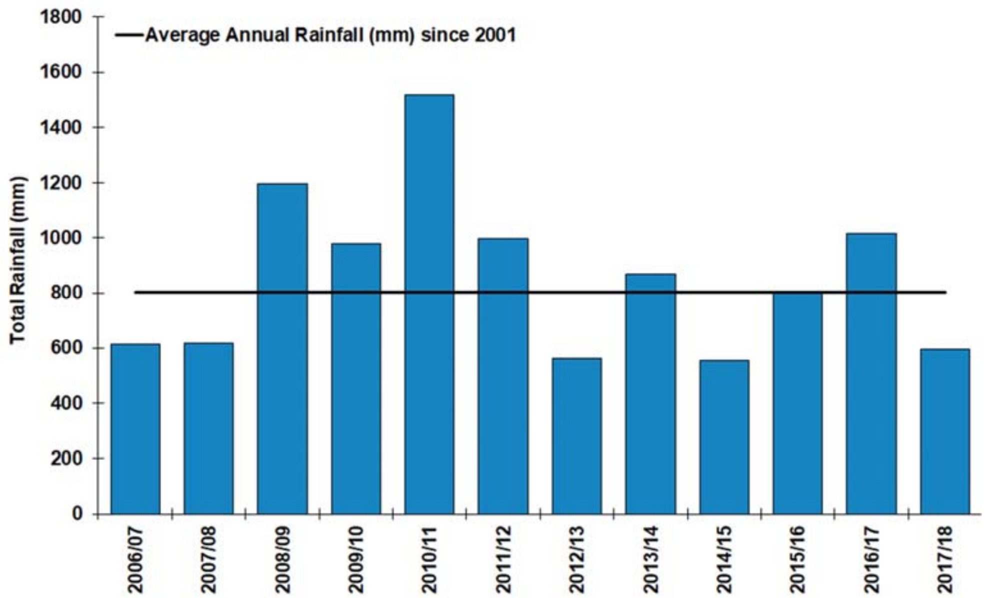


Figure 15. Total annual rainfall (mm) recorded at Normanton Airport, 2006-2018. Twelve month year (2017/18) is twelve months prior to survey. Source: Bureau of Meteorology (BOM), Station 029063, available at www.bom.gov.au

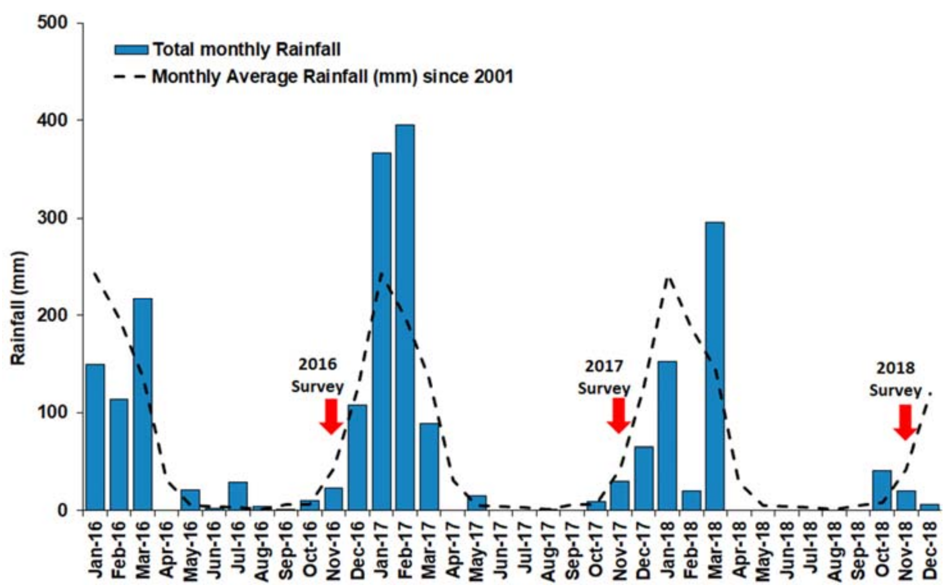


Figure 16. Total monthly rainfall (mm) recorded at Normanton Airport, January 2016 - December 2018. Source: BOM, Station 029063, available at www.bom.gov.au

River flow (Norman River)

In 2018 the Norman River experienced its first substantial flow events since 2011. While this only resulted in total annual river flow being slightly above average (Figure 17), nearly the entire annual flow occurred during flood events over 2 months in March and April 2018 (Figure 18). Total annual river flow 12 months prior to the seagrass survey month was 1,852,738 Mega Litres. River flow output was minimal over the dry season (May-Oct) (Figure 16).

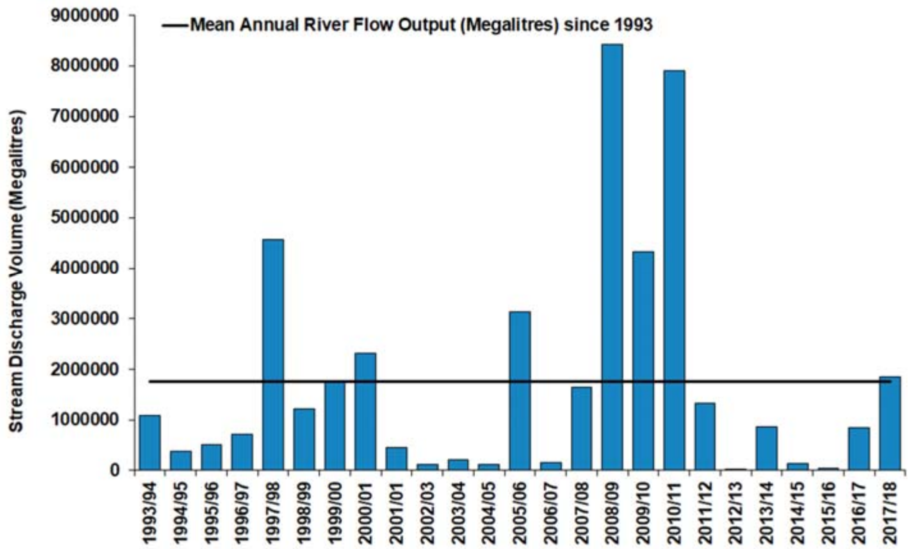


Figure 17. Annual water flow (Megalitres) for the Norman River recorded at Glenore Weir, 1993-2018. Twelve month year (2017/18) is twelve months prior to survey. Source: QLD Department of Environment and Resource Management, Station 916001B, available at http://watermonitoring.derm.qld.gov.au/host.htm

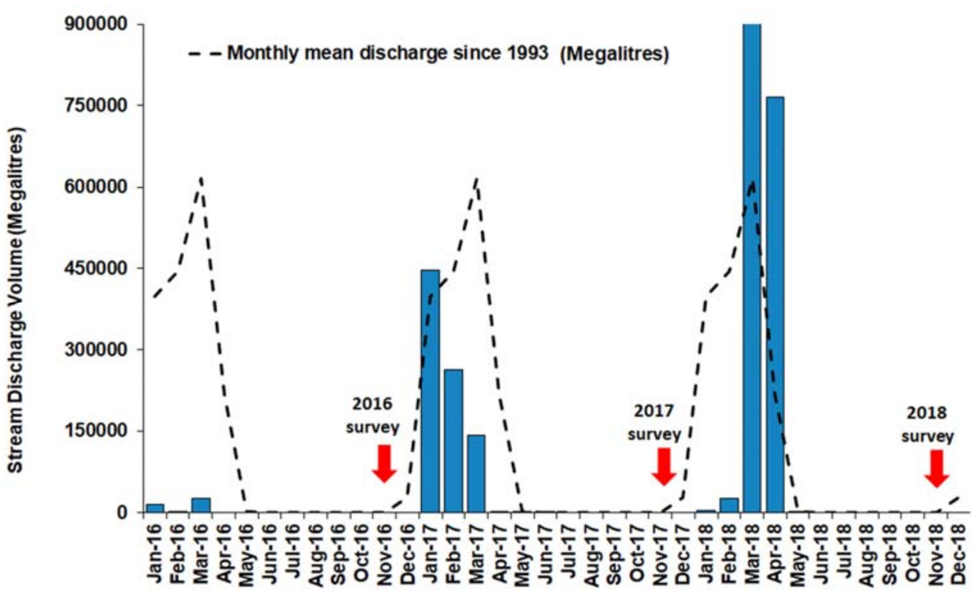


Figure 18. Monthly water flow (Megalitres) for the Norman River recorded at Glenore Weir, January 2016 - December 2018. Source: QLD Department of Environment and Resource Management, Station 916001B, available at http://watermonitoring.derm.qld.gov.au/host.htm

Air Temperature

Air temperature for 2017/18 was below average for the area with a mean annual daily maximum temperature of 33.5°C (Figure 19). 2012/13 is the hottest year recorded since 2001 at 34.6°C.

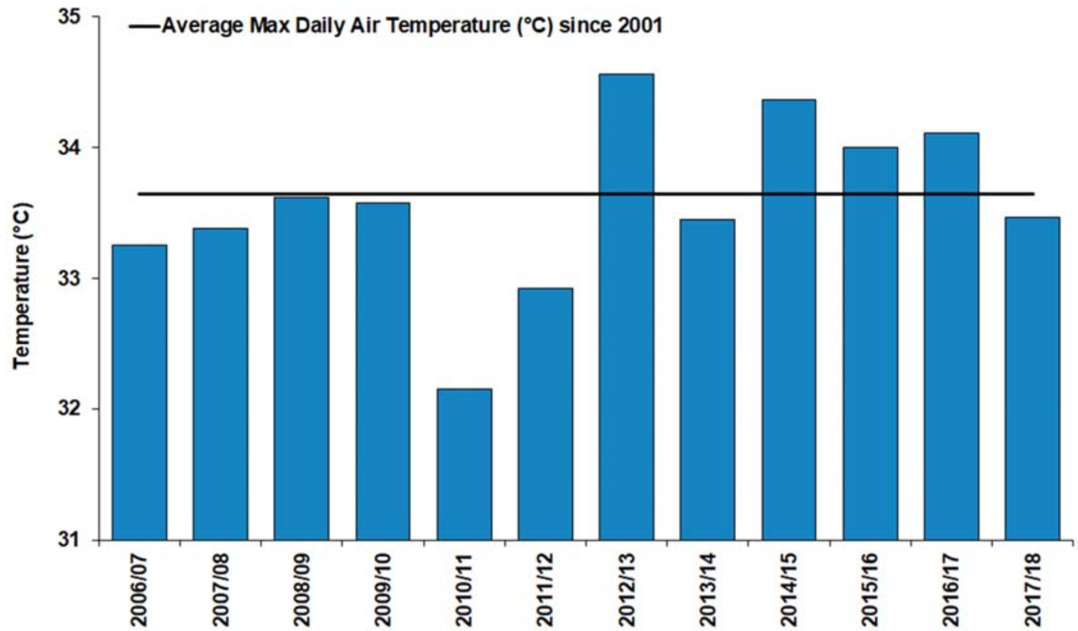


Figure 19. Mean annual maximum daily air temperature (°C) recorded at Normanton Airport, 2006-2018. Twelve month year (2017/18) is twelve months prior to survey. Source: BOM, station 029063, available at www.bom.gov.au

Daily Global Solar Exposure

Daily global 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. Solar exposure in the Normanton area was below average in 2017/18 at 21.99 MJ m^{-2} (megajoules per square metre) (Figure 20). Solar exposure at Normanton for 12 months prior to the survey tended to follow the average monthly solar exposure trend, with an exception to December 2017 which went above average and January and March 2018 which fell below the average (Figure 21).

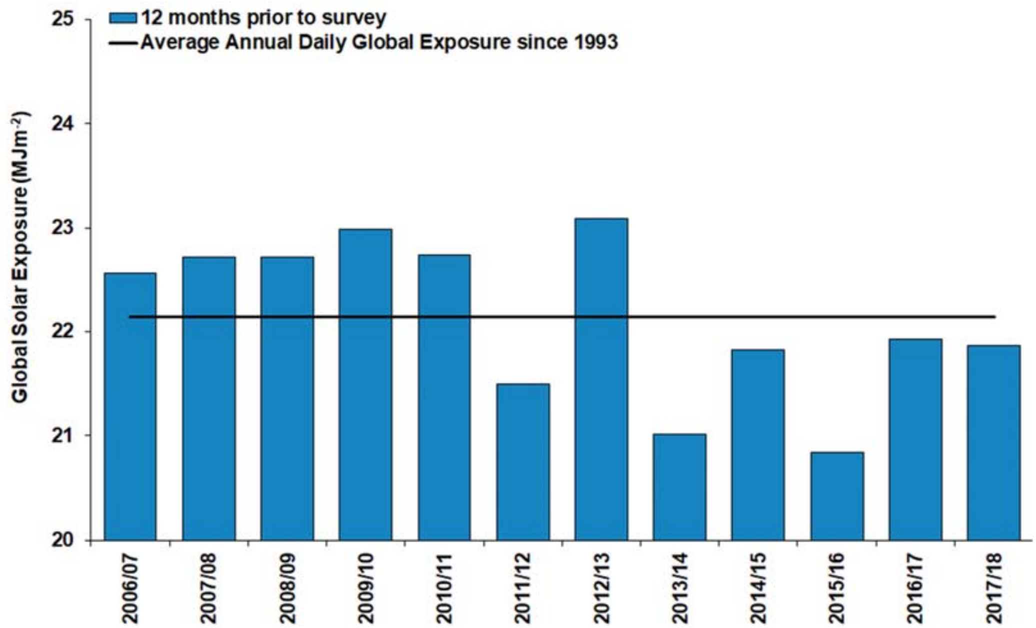


Figure 20. Mean annual daily global exposure (MJ m^{-2}) recorded at Normanton Airport, 2000-2015. Twelve month year (2014/15) is twelve months prior to survey. Source: BOM, Station 029063, available at www.bom.gov.au

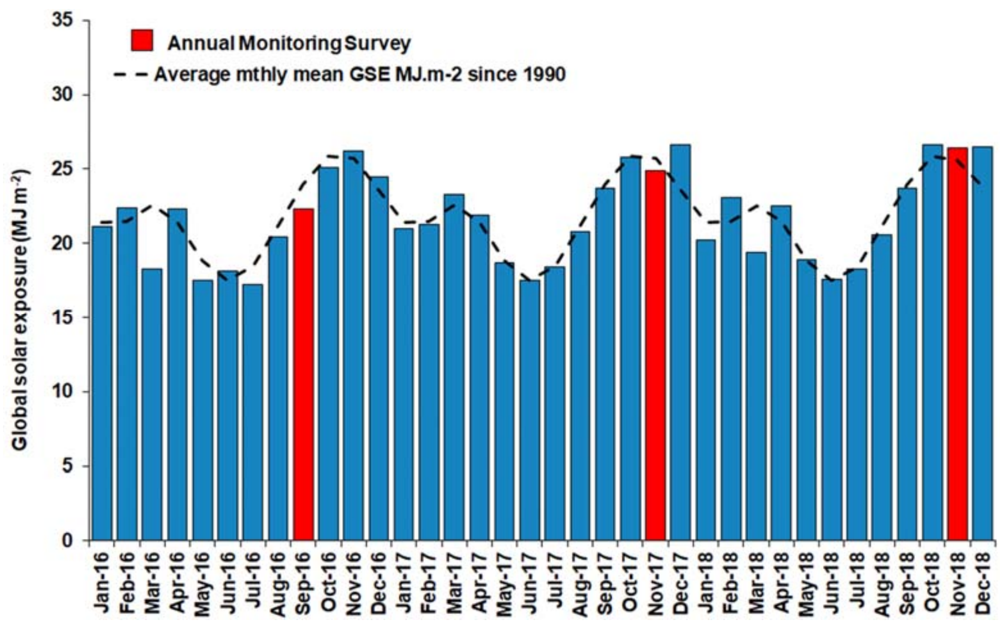


Figure 21. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Normanton Airport, January 2013-September 2015. Source: BOM, Station 029063, available at www.bom.gov.au

Tidal Exposure of Seagrass Meadows

Annual day time exposure to air of intertidal seagrass meadows were below the long-term average, with the intertidal banks being exposed to air during daylight hours for a total of 84 hours in the 12 months prior to the survey (Figure 22). From 2010 to 2018, exposure has remained well below the long term average (Figure 22). The total number of hours that Alligator Bank was exposed in the 3 months prior to the survey was also well below average, reducing the likelihood that seagrasses were exposed to high levels of exposure related stress (Figure 23).

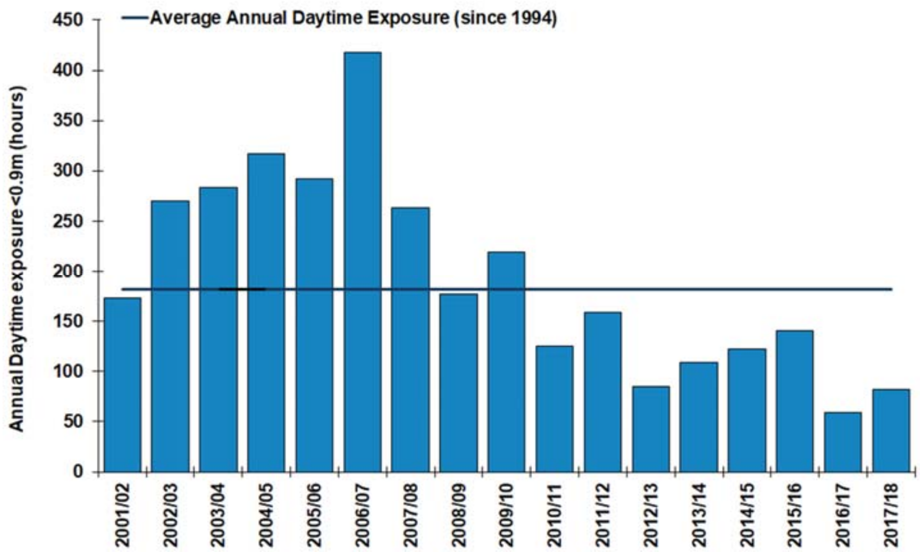


Figure 22. Annual daytime exposure (total hours) of seagrass meadows on Alligator Bank, Karumba; 2001-2018. Twelve month year is twelve months prior to survey. Source: Maritime Safety Queensland, 2018. *Assumes intertidal banks become exposed at a tide height of 0.9m above Lowest Astronomical Tide.

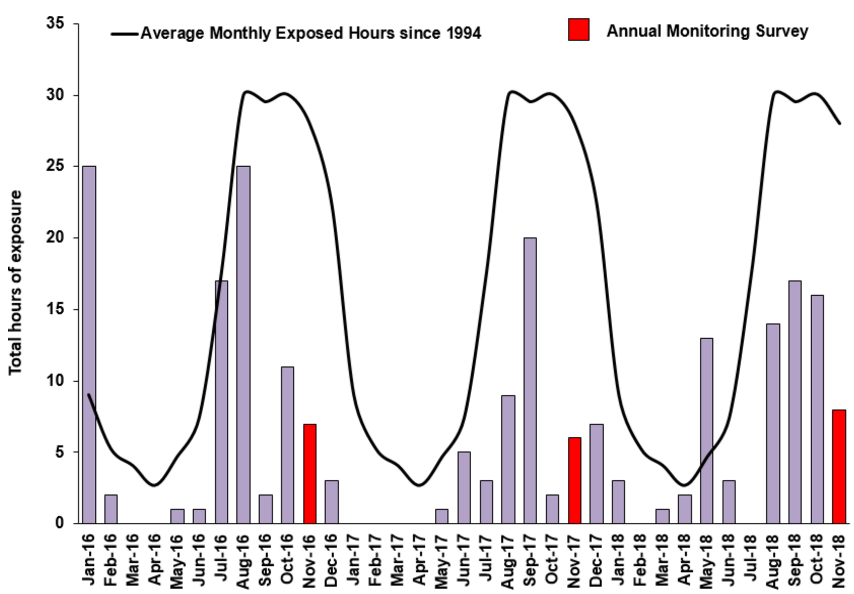


Figure 23. Total monthly hours of daytime exposure from 2016 to survey month in 2018. Source: Maritime Safety Queensland, 2018. *Assumes intertidal banks become exposed at a tide height of 0.9m above Lowest Astronomical Tide.

4 DISCUSSION

Seagrasses in the Port of Karumba were in a satisfactory condition in 2018, a reduction in overall rating following several years of good to very good condition. This change in seagrass condition was due to a substantial decline in biomass from the high levels recorded over the past decade with the other two seagrass score indicators, species composition and meadow area remaining in very good condition. Seagrass biomass declines were likely linked to the first substantial flows and flooding events of the Norman River for several years during March and April 2018 rather than any local anthropogenic or port related causes. Despite the biomass declines seagrasses remained within their previously recorded footprint and maintained a store of seeds within the sediments (seed-bank) from which rapid recovery of lost biomass is possible if favourable environmental conditions for seagrass growth occur in 2019. Seagrasses within the broader port limits also occurred across similar areas to previous whole of port surveys that have been conducted and dugong feeding trails were observed across all of the seagrass meadows in Karumba.

Climate conditions such as river flow, temperature and long-term tidal exposure cycles have been identified as strongly influencing changes in seagrass biomass and distribution in Karumba meadows (Rasheed & Unsworth 2011). In March and April 2018 substantial flows and flooding of the Norman River were recorded for the first time since 2011. The flooding and flow events of the Norman River associated with Tropical Cyclone Nora were the most likely cause of the observed seagrass biomass declines. Other environmental conditions such as tidal exposure and temperature that can impact on seagrasses remained favourable for seagrass growth during 2018 and there were no substantial changes to port operations or coastal developments in the area during 2018. During extreme flooding and river flow events seagrass meadows can be impacted by changes in salinity, an influx of pollutants and primarily through high levels of turbidity, which reduce the available light to support seagrass photosynthesis and growth (Campbell & McKenzie 2004; Waycott et al. 2007; Cardoso et al. 2008; Rasheed et al. 2014; Mckenna et al. 2015).

Light availability is one of the more important environmental factors controlling seagrass distribution and the depth at which it will grow (Longstaff & Dennison 1999; Dennison et al. 1993; Ralph et al. 2007; Chartrand et al. 2012). Longstaff and Dennison (1999) found that *Halodule uninervis* in Karumba experiences an extremely variable light climate (periods of high light and no light) and an average light availability well below what is found for other *Halodule* species. In Karumba the reduction in biomass recorded in 2018 may well be a legacy of impacts to the light environment earlier in the year, although without in-situ monitoring of the light environment and other water quality parameters it's not possible to demonstrate definitive links. The reduction in the amount of *Halophila ovalis* in the species composition is likely a reflection of *Halophila ovalis's* low resilience to relatively short periods of environmental conditions that can impact seagrass growth, in particular low light (Longstaff & Dennison 1999). This is due to *Halophila* being structurally small with limited carbohydrate stores to sustain growth after light levels drop below their requirements (Longstaff et al. 1999, Lee et al. 2007).

Such events may not be entirely negative for seagrasses as increased runoff and water flow can be favourable long-term due to the reintroduction of essential nutrients into coastal seagrass meadows which may have been previously lacking (Short 1987; Udy et al. 1999; Waycott et al. 2005). This phenomenon has been identified in Karumba where analysis has shown a positive relationship between increased river flow in the previous nine months and seagrass biomass (Rasheed & Unsworth 2011). However it is likely to be a complex balance between the extent of the initial negative effects of flood events on seagrasses and any longer term positive outcomes from nutrient enhancement.

While seagrass resilience to future impacts was likely lower in 2018 than in previous years the maintenance of seagrass across the historical footprint of its distribution and the presence of the seedbank means the Karumba seagrass meadows were likely to be able to increase in biomass and recover should growing conditions be favourable during 2019. Such meadow recovery has been documented in Karumba previously following a similar seagrass decline in 2002. Queensland seagrasses are able to recover rapidly through vegetative growth where adult plants remain to initiate recovery (Rasheed 1999; 2004) and the seedbank provides a locally available source of propagules should adult plants be lost. *Halodule uninervis* seeds were found throughout the meadow, with seed density above the long-term average. *Halodule* can form persistent seed banks due to their small and poorly dispersed long lived seeds (Inglis 2000) which remain viable while dormant in the sediment for up to several years (Rasheed 2004).

The results of the 2018 survey show seagrasses in Karumba remained in a satisfactory condition with changes linked to climate/weather conditions rather than localised anthropogenic activities. Despite maintaining an ability for rapid recovery under favourable conditions, their resilience to future impacts was likely to be reduced compared to recent years, and subsequent to this survey extensive flooding in the southern Gulf of Carpentaria has been recorded associated with Tropical Cyclone Owen at the beginning of 2019. It is unclear how Karumba's seagrasses have fared following these subsequent floods, particularly as seagrasses were already in a reduced state at the end of 2018.

These meadows offer substantial ecosystem services such as habitat and food sources dugong, fisheries nursery habitat, through to coastal protection, carbon sequestration and nutrient cycling which leads to improved water quality and human health (Scott et al. 2018). Given the importance of such meadows the Karumba monitoring program provides important insights into the functioning of coastal marine areas locally and in the broader southern Gulf of Carpentaria.

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6 APPENDICES

Appendix 1 – Seagrass Score Calculation

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 4 and Figure 22).

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 5). Meadow area was classified as either highly stable, stable, variable, or highly variable (Table 5). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table 6. 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%	-

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 6).

Table 7. 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		

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).

Score calculations for meadow condition required calculating the biomass, area and species composition for that year (described in Section 2.3.1), allocating a grade for each indicator by comparing 2017 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 7). 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 8. Score range and grading colours used in the 2017 Port of Karumba 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 22). 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 22). 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 22).

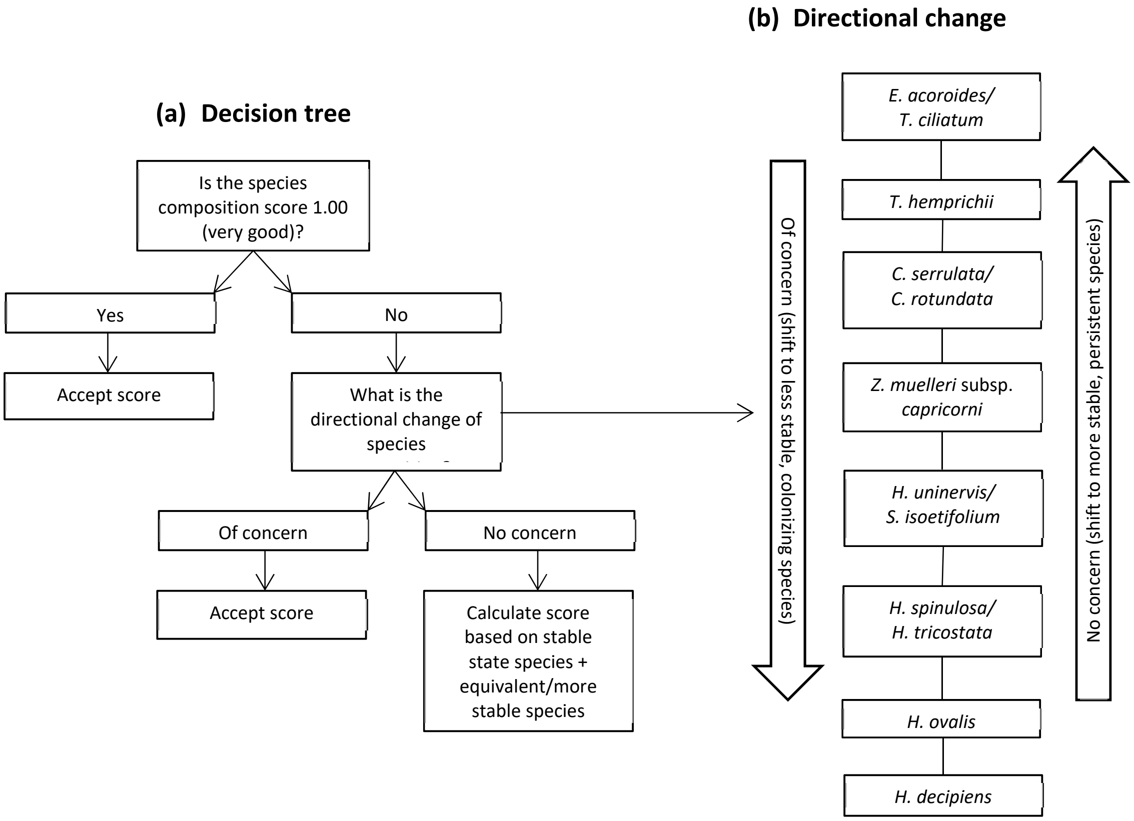

Figure 25. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in the Port of Karumba.

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).

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}):

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

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:

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

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:

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

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):

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

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