PORT OF KARUMBA LONG-TERM ANNUAL SEAGRASS MONITORING: NOVEMBER 2017

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

Report No. 18/04

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KEY FINDINGS

1. Seagrasses in the Port of Karumba were in a very good condition in 2017. All indicators for seagrass condition were well above long-term averages with area, biomass and species composition classified as very good.

2. Reproductive capacity in 2017 was high with the highest density of *Halodule uninervis* seeds measured since sampling began.

3. Generally favourable local and regional climate conditions likely created a suitable environment for seagrass growth and stability in the Port of Karumba.

4. Dugong continue their regular use of the area with feeding trails found throughout the monitoring meadow.

5. Results indicate that the marine environment in Karumba was in a good condition with seagrasses likely to be resilient to port and non-port related pressures during 2018.
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 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 sections 2.3 of this report for further details).

Seagrasses in the Port of Karumba were in a very good condition in 2017 with density, distribution, species composition and *Halodule uninervis* seed banks all above the long-term average (Figure 1). Seagrass in the monitoring meadow was dominated by dense *Halodule uninervis* with continuous seagrass coverage (Figure 9). Dugong feeding trails were found throughout the monitoring meadow.

This survey also found the highest recorded density of *Halodule uninervis* seeds in the sediment seed-bank since seed monitoring began as part of the program in 2003. The seeds were distributed throughout the meadow and provided further evidence of the likely high resilience to impacts for Karumba’s seagrass meadows.

Climate conditions in the Karumba area between the 2016 and 2017 surveys were favourable for seagrass growth, with below-average air exposure and river discharge likely linked to seagrass condition, despite slightly above average rainfall for the 12 months prior to the survey (Figure 2).
Results indicate that seagrasses in Karumba were likely to be in a highly resilient condition to port or non-port related pressures during 2018 with a robust standing crop of seagrass and a healthy store of seeds in the sediment seed-bank at the end of 2017.

The Karumba seagrass monitoring forms part of a broader seagrass program that examines the condition of seagrasses in the majority of Queensland commercial ports and a component of James Cook University (JCU) TropWATER’s broader seagrass assessment and research program. Seagrass condition elsewhere in the Gulf of Carpentaria was in a good condition (Weipa), with coastal seagrass along the east coast of Queensland also generally showing signs of improvement from 2013-2017 following declines prior to this period. For full details of the Queensland ports seagrass monitoring program see [www.jcu.edu.au/portseagrassqld](http://www.jcu.edu.au/portseagrassqld)
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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 and Duarte 2000). 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 and 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.

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 Port of Karumba is located at the mouth of the Norman River and is primarily a service port, handling cargo, commercial fishing and live cattle exports. Prior to the suspension of mining operations in 2016, the port also managed lead and zinc exports. 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 periodic dredging in the port and for managing and monitoring Karumba’s port.
environment. Seagrass meadows are the key marine habitat that occurs 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. 2001b). 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 2017 annual seagrass monitoring survey. The objectives of the program were to:

1. Map the distribution of seagrasses on 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 monitoring meadow on Alligator Bank;
4. Incorporate results into a Geographic Information System (GIS);
5. Assess changes in the seagrass meadow 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 2017 Karumba seagrass survey was to provide continued monitoring of seagrasses including distribution, density, species composition and reproductive capacity, and to establish a report card on the state of seagrasses in the Port of Karumba. 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 including Weipa, Cairns, Mourilyan Harbour, Townsville, Gladstone, Mackay, Thursday Island and Abbot Point (see Rasheed and Taylor 2008; Rasheed et al. 2005; Rasheed et al. 2001a; Roelofs et al. 2001).
2 METHODS

2.1 Sampling Methods

The Port of Karumba seagrass survey was conducted from the 10th-11th November 2017. The survey area included the annual monitoring meadow on the intertidal banks of Alligator Bank. A complete background site description and detailed methodology of the monitoring program are available in previous reports (Rasheed et al. 2001b; Rasheed et al. 1996).

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, benthic type and dugong feeding activity were recorded at each sampling site from a helicopter hovering within less than 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 Mellors 1991; Kirkman 1978). This method has been utilised in surveys throughout Queensland and peer reviewed on several occasions (e.g., Rasheed et al. 2008). The method involves an observer ranking above-ground seagrass biomass within three randomly placed 0.25m² 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 (0.0625m²) 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 1 mm sieve. Any seagrass seeds in the 1 mm 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 identify 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.

<table>
<thead>
<tr>
<th>Community type</th>
<th>Species composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species A</td>
<td>Species A is 90-100% of composition</td>
</tr>
<tr>
<td>Species A with Species B</td>
<td>Species A is 60-90% of composition</td>
</tr>
<tr>
<td>Species A with Species B/Species C</td>
<td>Species A is 50% of composition</td>
</tr>
<tr>
<td>Species A/Species B</td>
<td>Species A is 40-60% of composition</td>
</tr>
</tbody>
</table>

Table 2. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in the Port of Karumba.

<table>
<thead>
<tr>
<th>Density</th>
<th>Mean above-ground biomass (g DW m⁻²)</th>
<th>Halodule uninervis (narrow)</th>
<th>Halophila ovalis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Moderate</td>
<td>1 - 4</td>
<td>1 - 5</td>
<td></td>
</tr>
<tr>
<td>Dense</td>
<td>&gt; 4</td>
<td>&gt; 5</td>
<td></td>
</tr>
</tbody>
</table>

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. Additional sources of mapping error were embedded within the meadow reliability estimates.

**Table 3.** Mapping precision and methodology for seagrass meadows.

<table>
<thead>
<tr>
<th>Mapping precision</th>
<th>Mapping methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 5 m</td>
<td>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.</td>
</tr>
</tbody>
</table>

### 2.3 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in the Port of Karumba 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). The flow chart in Figure 5 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation methods.

![Flow chart to develop Port of Karumba grades and scores.](image-url)
2.4 Seed data analysis

The density of the *Halodule uninervis* seed bank and *Halophila ovalis* fruits and flowers, were compared among years (2003-2017). The effect of year on the number of seeds, fruits and flowers per grab was modelled using a zero inflated Poisson regression model. Data exploration protocols prior to all analyses followed Zuur et al. (2010) and included checks for zero inflation. Overdispersion due to the large number of zeros in each dataset was corrected with the use of zero inflated models in R version 3.3.1 (Abdelrhman 2003) using the `gamlss` package (Rigby and Stasinopoulos2005). For each analysis the model was compared against the null model with the best-fit model determined using the lowest Akaike’s Information Criterion (AIC) (Burnham and Anderson 2002). Statistical significance of year in each best fit model was tested using likelihood-ratio-test-based backward selection with the “drop1” function in R.
3 RESULTS

3.1 Seagrass species, distribution and density

A total of 97 seagrass habitat characterisation sites were surveyed in the Port of Karumba annual monitoring survey in November 2017. Annual monitoring results show that seagrass were overall in a very good condition with a score of 0.95 (Table 4). Seagrass was present at 100% of sites, with two species of seagrass present in the monitoring meadow on Alligator Bank; *Halodule uninervis* (narrow leaf form) and *Halophila ovalis* (Figure 6). Species composition was classified as stable and single species dominated by *Halodule uninervis*, accounting for 95.2% of above-ground biomass, while *Halophila ovalis* formed the minor component for the remaining 4.8% (Figure 8). The meadow was considered dense and consisted of continuous seagrass cover across the bank.

The total area of the monitoring meadow was $1564.2 \pm 15.81$ ha and was classified as stable. Biomass was classified as variable with a total above-ground biomass of $8.9 \pm 0.31$ g DW m$^{-2}$. Biomass, area and species composition all achieved a condition index of very good in 2017. (Figure 9).

![Figure 6](image1.png)

**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.f, Family Hydrocharitaceae.

Dugong feeding trails were observed across the meadow and recorded at 66% of survey sites (Figure 7 and Figure 8).

![Figure 7](image2.png)

**Figure 7.** Dugong feeding trails across the Port of Karumba monitoring meadow.
Figure 8. Dugong feeding trails present across the Karumba seagrass monitoring meadow 2017.
3.2 Comparison with previous annual monitoring surveys

Annual monitoring shows seagrasses in the Port of Karumba were in a very good condition in 2017 (Figure 9; Table 4). Both area and species composition were in a very good condition whilst the biomass increased from last year to also receive a very good score. While condition in 2017 was very good the area, species composition and biomass remained below the peak levels that were achieved in 2014 (Figure 9).

During the history of monitoring, the distribution of biomass throughout the meadow has varied, with hotspots of high biomass often occurring in different locations from year to year (Figure 12). Biomass toward the Bynoe River end of the meadow has tended to be lower than the rest of the meadow during the history of the monitoring program, but in 2017 biomass was much more evenly distributed across the meadow (Figure 12).

*Halodule uninervis* has consistently been the dominant species in the meadow since monitoring began in 1994 with species composition relatively stable throughout the program (Figure 9). In 2017, *H. uninervis* made up 95.2% of the species composition an increase from 2015 and 2016 which were slightly lower at 91.7% and 93.2% respectively. Species composition has not dropped below a condition of good since monitoring began in 1994, and not below a condition of very good since 2006 (Figure 9).

The area of the meadow has been well above the baseline long-term average since 2003 with a corresponding condition score of very good. The highest recorded area was during the 2014 survey at 1691.67 ± 15.21 (Figure 9).

The meadow’s reproductive output has varied substantially since monitoring of reproductive structures began in 2003. In 2017 the mean density of *Halodule uninervis* seeds across the meadow was the highest ever recorded (168 ± 47 seeds m⁻²) ($\chi^2_{(1)} = 176.7, p<0.001$) and pericarp (seed casing) density the second highest (126 ± 21 pieces m⁻²) ($\chi^2_{(1)} = 14.4, p<0.001$) (Figures 10 & 11). Unlike seeds, flowers and fruits were absent at the time of the 2017 survey for *Halophila ovalis* and present at only one site for *Halodule uninervis* (Figure 10). Flowering presence has been highly patchy between years and the variable nature of the timing of flowering combined with the short lived nature of flowers means it is difficult to use this information to infer much about meadow resilience from one off surveys. This is contrast to *Halodule uninervis* seed banks in the sediment, which are long lived, and can remain viable for several years once produced.

Dugong feeding trails (DFT’s) have consistently been observed throughout the meadow, with the 2017 survey recording DFT’s at more sampling sites than in other recent surveys (66% of sites compared to 27% and 50% in 2016 and 2015 respectively) (Figure 12).

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

<table>
<thead>
<tr>
<th>Meadow</th>
<th>Biomass</th>
<th>Area</th>
<th>Species Composition</th>
<th>Overall Meadow Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karumba</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Figure 9. Changes in biomass, area and species composition for the Karumba seagrass monitoring meadow from 1994 to 2017 (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 2017.
Figure 11. Mean density (± SE) of (A) *Halodule uninervis* seeds and pericarp pieces sampled within the monitoring meadow. *Grab data converted to per m² for graphical representation.*
Figure 12. Changes in biomass and area in the Port of Karumba seagrass monitoring 2007 to 2017.
3.3 Karumba climate patterns during monitoring

Rainfall

Total annual rainfall for twelve months prior to the survey month in November 2017 was just above average for the Normanton area at 1007.2 mm, an increase from the last two survey years (Figure 13). Months leading up to the survey followed similar dry season trends excluding May and October 2017, which experienced slightly above average rainfall. Rainfall was below average for the survey month, November 2017. Of note was substantially higher than average monthly rainfall for January and February 2017, 9 months prior to the seagrass survey (Figure 14).

Figure 13. Total annual rainfall (mm) recorded at Normanton Airport, 2005-2016. Twelve month year (2016/17) is twelve months prior to survey. Source: Bureau of Meteorology (BOM), Station 029063, available at www.bom.gov.au

Figure 14. Total monthly rainfall (mm) recorded at Normanton Airport, January 2015- December 2017. Source: BOM, Station 029063, available at www.bom.gov.au
**River flow (Norman River)**

For the sixth consecutive year annual river flow output for the Norman River has been below average. Twelve months before the survey, river flow output reached 850880 megalitres, similar to levels in 2013/14 (Figure 15). No river flow output was recorded between July 2017 and the survey. The only months in the year prior to the survey with slightly above average river flow output were January and June 2017 (Figure 16).

![Figure 15](http://watermonitoring.derm.qld.gov.au/host.htm)


![Figure 16](http://watermonitoring.derm.qld.gov.au/host.htm)

**Figure 16.** Monthly water flow (Megalitres) for the Norman River recorded at Glenore Weir, January 2015-December 2017. 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 the Normanton area was above average for the third consecutive year at 34.1°C. The area has shown a trend of relatively high temperatures compared to previous years prior to 2013 (Figure 17).

![Average Max Daily Air Temperature (°C) since 2001](image)

**Figure 17.** Mean annual maximum daily air temperature (°C) recorded at Normanton Airport, 2005-2017. Twelve month year (2016/17) 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. Daily global solar exposure was below the average for the area for the fourth year at 21.93 MJ m\(^{-2}\) (megajoules per square metre) (Figure 18). Mean monthly daily global exposure followed similar monthly average trends leading up to the survey (Figure 19).

![Daily Global Solar Exposure](image)

**Figure 18.** Mean annual daily global exposure (MJ m\(^{-2}\)) recorded at Normanton Airport, 2005-2017. Twelve month year (2016/17) is twelve months prior to survey. Source: BOM, Station 029063, available at www.bom.gov.au

![Mean Monthly Daily Global Solar Exposure](image)

**Figure 19.** Mean monthly daily global solar exposure (MJ m\(^{-2}\)) recorded at Normanton Airport, January 2015-December 2017. Source: BOM, Station 029063, available at www.bom.gov.au
**Tidal Exposure of Seagrass Meadows**

Annual tidal exposure twelve months prior to the survey was the lowest recorded since 1994 with the intertidal meadow exposing for a total of 50 hours (Figure 20). For the three months prior to the survey the intertidal bank exposed for a total of 31 hours and leading up to the survey one month prior exposed for 2 hours, less than the previous monitoring year (Figure 21).

![Average Annual Daytime Exposure (since 1994)](image1)

**Figure 20.** Annual daytime exposure (total hours) of seagrass meadows on Alligator Bank, Karumba; 1994-2017 Twelve month year is twelve months prior to survey. Source: Maritime Safety Queensland, 2016. *Assumes intertidal banks become exposed at a tide height of 0.9m above Lowest Astronomical Tide.

![Total monthly daytime exposure (total hours) in one and three month prior to the annual survey month 1994-2017.](image2)

**Figure 21.** Total monthly daytime exposure (total hours) in one and three month prior to the annual survey month 1994-2017. Source: Maritime Safety Queensland, 2017. *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 very good condition in 2017 with biomass, area and species composition all well above the baseline long-term average. These three seagrass indicators have been above the long-term average for the past 10 years and this, combined with the seed bank being at the highest density recorded in the program, means Karumba’s seagrasses are likely to have a high resilience to potential impacts and stressors during 2018.

Changes in seagrass biomass and distribution in Karumba are strongly influenced by climate conditions such as river flow, temperature and long-term tidal exposure cycles (Rasheed and Unsworth 2011). The good health of seagrasses in Karumba in recent years is likely due to favourable local climate conditions for seagrass growth. In 2017 these conditions were particularly beneficial with the low recorded level of daytime air exposure of the meadow substantially reducing the risk of thermal and desiccation stresses to seagrasses during the year. In other areas of the Gulf of Carpentaria studies have shown that increased air exposure of intertidal seagrass meadows linked to long term natural tidal cycles was strongly correlated with seagrass loss and the appearance of “burnt” seagrass leaves through temperature and desiccation stress (Unsworth et al. 2012). The generally dry conditions and low flow of the local rivers in recent years also meant that Karumba’s seagrasses have avoided the negative impacts associated with flooding such as high levels of turbidity reducing available light, changes to salinity and influx of pollutants from runoff (McKenna et al. 2015; Rasheed et al. 2014; Cardoso et al. 2008; Waycott et al. 2007; Campbell and McKenzie 2004).

Previous analysis in Karumba has also shown that while large scale flooding and rainfall can be detrimental to seagrasses, good seagrass condition is correlated with moderate river flow events particularly when they occur early in the year (Rasheed & Unsworth 2011). It is thought that river flow may be important in supplying essential nutrients in coastal seagrass meadows where nutrients are limiting (Waycott et al. 2005; Udy et al. 1999; Short 1987). While it has been more than 6 years since an above average flow the Norman River, the three months between January and March 2017 saw the first substantial flows of the Norman River in several years which may have provided a pool of nutrients for seagrasses. However without monitoring sediment nutrients it’s difficult to say definitively if nutrient supply is impacting seagrass growth in Karumba.

Species with small and poorly dispersed seeds such as *Halodule uninervis* are more likely to form persistent seed banks (Inglis 2000). *Halodule* seeds were found dispersed across the meadow in 2017 with the highest seed bank density recorded since reproductive sampling began in 2003. The large increase in seed numbers in the 2016 and 2017 surveys indicates that the meadow has a good capacity to remain resilient and to recover from climate and anthropogenic disturbances in the future. Unlike the long lived *Halodule* seeds, the presence of flowers taken from a one off sampling event is not likely to be a strong indicator of meadow resilience. This is due to the variability in the timing of flowering events combined with the comparatively short lived presence of flowering structures in the seagrass meadow.

The monitoring program at Karumba has demonstrated that seagrass distribution, density, composition and health can be influenced and impacted by a range of environmental conditions (Rasheed and Unsworth 2011). Results of the latest monitoring survey found seagrasses in Karumba were in a very good condition with the health of seagrass and seed bank density in Karumba likely explained by favourable climate conditions. Seagrasses in 2017 were in a highly resilient state with a healthy adult population and the densest seed bank recorded in the monitoring program to date. The Karumba monitoring program continues to be an excellent indicator of environmental change, as well as a guide to the capacity for resilience of seagrass meadows to future natural and anthropogenic impacts. The 2017 program results indicate that Karumba’s marine environment was in good condition, and continues to be an important feeding ground for dugongs.
5 REFERENCES


6 APPENDICES

Appendix 1.

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

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highly stable</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Species composition</td>
<td></td>
</tr>
</tbody>
</table>

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 6. 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.

<table>
<thead>
<tr>
<th>Seagrass condition indicators/ Meadow class</th>
<th>Seagrass grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A Very good</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td>Stable</td>
<td>&gt;20% above</td>
</tr>
<tr>
<td>Variable</td>
<td>&gt;40% above</td>
</tr>
<tr>
<td>Area</td>
<td></td>
</tr>
<tr>
<td>Highly stable</td>
<td>&gt;5% above</td>
</tr>
<tr>
<td>Stable</td>
<td>&gt;10% above</td>
</tr>
<tr>
<td>Variable</td>
<td>&gt;20% above</td>
</tr>
<tr>
<td>Highly variable</td>
<td>&gt;40% above</td>
</tr>
<tr>
<td>Species composition</td>
<td></td>
</tr>
<tr>
<td>Stable and variable; Single species dominated</td>
<td>&gt;0% above</td>
</tr>
<tr>
<td>Stable; Mixed species</td>
<td>&gt;20% above</td>
</tr>
<tr>
<td>Variable; Mixed species</td>
<td>&gt;20% above</td>
</tr>
</tbody>
</table>

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 1.
Table 7. Score range and grading colours used in the 2017 Port of Karumba report card.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Score Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>A</td>
<td>Very good</td>
<td>≥0.85</td>
</tr>
<tr>
<td>B</td>
<td>Good</td>
<td>≥0.65</td>
</tr>
<tr>
<td>C</td>
<td>Satisfactory</td>
<td>≥0.50</td>
</tr>
<tr>
<td>D</td>
<td>Poor</td>
<td>≥0.25</td>
</tr>
<tr>
<td>E</td>
<td>Very poor</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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 22. (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 ($B_{\text{diff}}$) between the 2015 biomass value ($B_{2015}$) and the biomass value of the lower threshold boundary for the “good” grade ($B_{\text{good}}$):

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

Where $B_{\text{good}}$ 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 ($B_{\text{range}}$) in that grade:

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

Where $B_{\text{good}}$ 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 ($B_{\text{prop}}$) that $B_{2015}$ takes up:

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

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

$$\text{Score}_{2015} = L_{B_{\text{good}}} + (B_{\text{prop}} \times \text{SR}_{\text{good}})$$

Where $L_{B_{\text{good}}}$ is the defined lower bound (LB) score threshold for the good grade, i.e. 0.65 units.