Port of Karumba long-term annual seagrass monitoring 2024

February 2025 | Report No. 25/03

Authored by: Abbi Scott and Michael Rasheed

Port of Karumba long-term annual seagrass monitoring 2024

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) James Cook University

Cairns Phone: (07) 4232 1830 Email: seagrass@jcu.edu.au

TropWATER@jcu.edu.au

Web: www.jcu.edu.au/tropwater/

The report may be cited as
Scott A & Rasheed M (2025) Port of Karumba Long-term Annual Seagrass Monitoring 2024, Centre for Tropical Water & Aquatic Ecosystem Research Publication Number 25/03, James Cook University, Cairns

Contacts
For more information contact: seagrass@jcu.edu.au

ACKNOWLEDGEMENTS

This project was funded by Ports North.

KEY FINDINGS

Seagrass Condition 2024

POOR

1. The October 2024 Karumba seagrass survey recorded a decline in seagrass condition to poor for the second time since the baseline was established. Seagrass biomass was the lowest recorded, and the meadow area was the second smallest on record.

2. River flow and rainfall in the preceding wet season were above average for the second consecutive year, following multiple years of below-average levels. This combined with high levels of tidal exposure in April 2024 were likely to have combined to drive the observed seagrass declines.

3. A substantial decline in seagrass biomass was observed across most of the meadow, resulting in a poor condition. This low biomass seagrass was still dominated by the more stable species *Halodule uninervis*.

4. Meadow area decreased by more than one-third, placing it in a satisfactory condition.

5. The seagrass meadow on Elbow Bank was also surveyed and the area dropped dramatically from 567 ha in 2021 to just 1 ha in 2024.

6. No dugong feeding trails were observed in the seagrass meadow.

7. Above average numbers of *Halodule uninervis* seeds and pericarps were found, indicating a stable seed bank is present in the meadow.

8. The declines observed in both Karumba seagrass meadows in 2024 are a cause for concern, however the meadow has demonstrated capacity to recover from similar declines in the past.

IN BRIEF

Seagrasses have been monitored annually in the Port of Karumba since 1994. Each year, the monitoring meadow between the Norman and Bynoe Rivers at Alligator Bank (Figure 1) is assessed for changes in biomass (density), distribution (area), species composition, and reproductive capacity (seed bank, fruits and flowers). Changes to area, biomass and species composition are assessed using a seagrass condition index (see section 2.4 for further details).

In 2024 seagrasses in the broader port limits were also surveyed as part of expanded surveys conducted every three years in the monitoring program. This included intertidal areas on Elbow Bank (Figure 1).

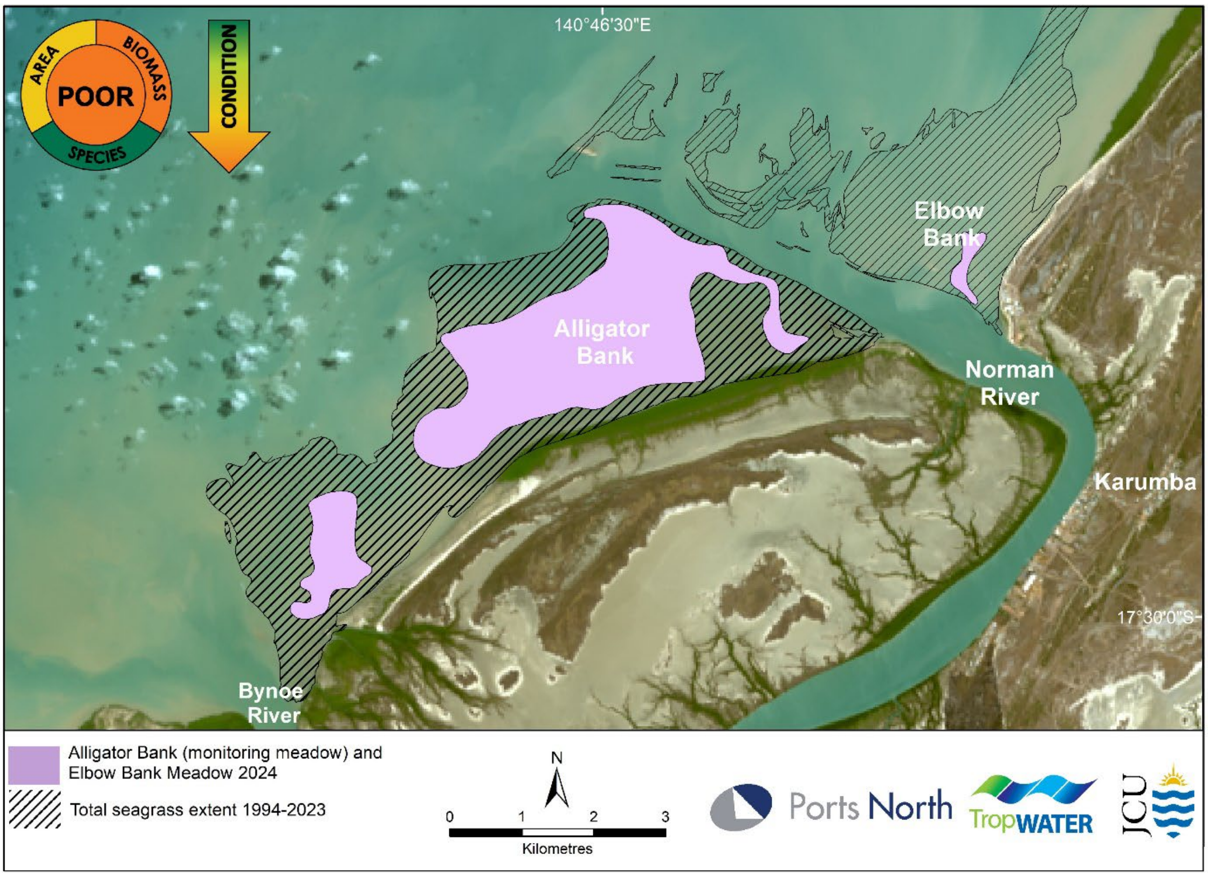

FIGURE 1. SEAGRASS CONDITION AT ALLIGATOR BANK, KARUMBA, 2024.

In 2024, seagrass in the Alligator Bank monitoring meadow dropped to a poor condition for the first time since the baseline condition was established (Figure 1). This decline in condition was driven by a record-low seagrass biomass, the lowest recorded since surveys began in 1994. Additionally, the meadow area decreased to a satisfactory condition, with the second smallest area on record. Despite these declines, species composition remains in very good condition, with the meadow dominated by the more stable species *Halodule uninervis*. There were above average numbers of *Halodule uninervis* seeds and pericarps (seed casings) in the below-ground seed bank, indicating there is a heathy seed bank present, which is supporting meadow maintenance and recovery. No dugong feeding activity was observed in the Alligator Bank or Elbow Bank meadows in 2024.

The meadow on Elbow Bank has declined dramatically in area in 2024, covering just 1 ha. Seagrass biomass in this meadow in 2024 is slightly higher than in 2021, however this represents just six sites where seagrass was present.

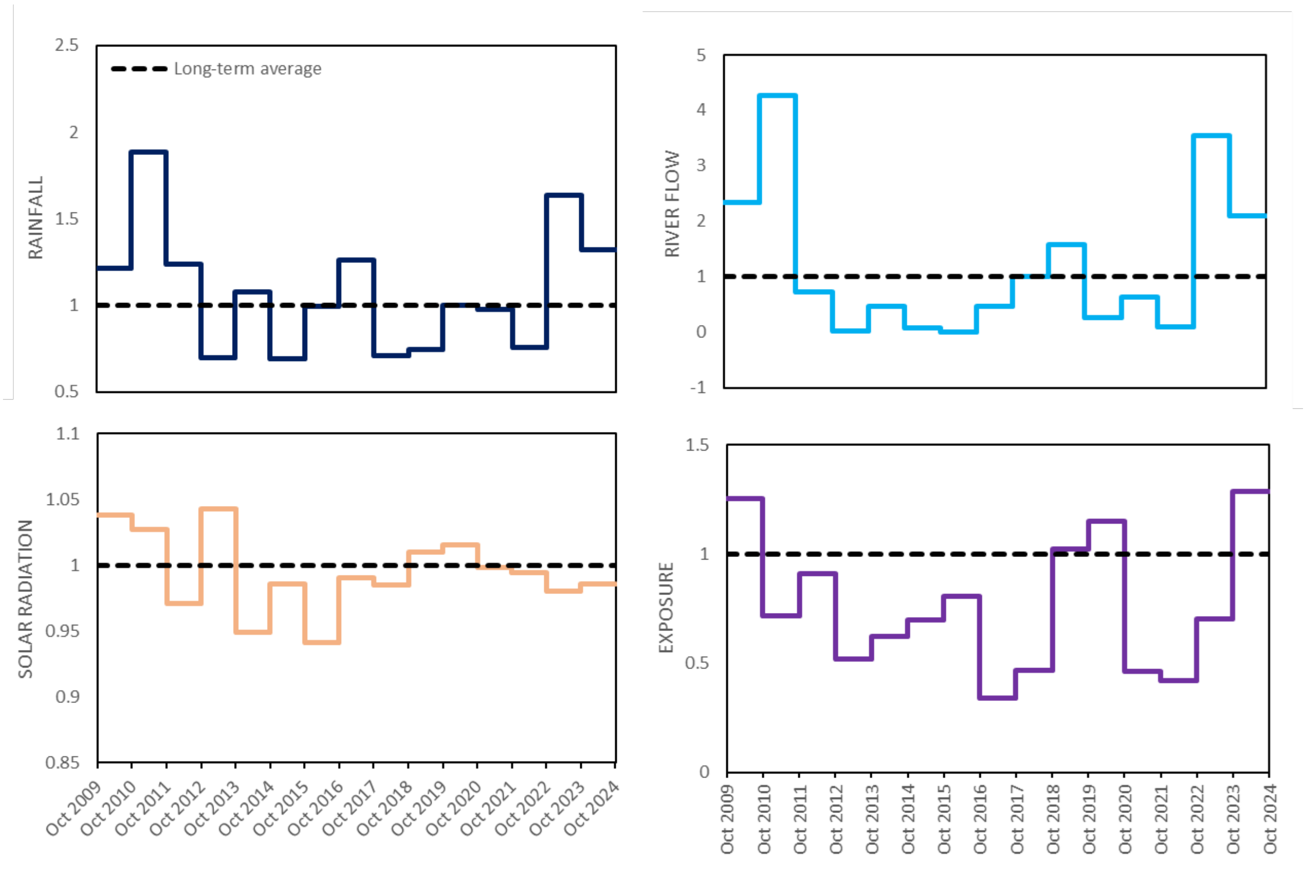

FIGURE 2. CHANGE IN CLIMATE VARIABLES AS A PROPORTION OF THE LONG-TERM AVERAGE IN KARUMBA. SEE SECTION 3.5 FOR DETAILED CLIMATE DATA.

Seagrass in Karumba declined to poor condition in 2024, this may have been driven by extensive flooding and river flow in 2023 followed by above average rainfall, river flow and exposure in 2024 (Figure 2). The drop in condition is a concern, particularly with the very low biomass recorded, however the presence of a healthy seed bank may provide some resilience and support future recovery. Karumba seagrass monitoring is part of a broader seagrass program that examines the condition of seagrasses in the majority of Queensland commercial ports and areas of high anthropogenic activity and is a component of TropWATER's broader seagrass assessment and research program. Overall seagrass condition in Weipa (the closest monitoring location to Karumba) was good in 2024. For full details of the Queensland ports seagrass monitoring program, see https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

TABLE OF CONTENTS

1 INTRODUCTION

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

1.1 QUEENSLAND PORTS SEAGRASS MONITORING PROGRAM

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

FIGURE 3. LOCATION OF QUEENSLAND PORT SEAGRASS ASSESSMENT SITES.

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

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

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

1.2 KARUMBA SEAGRASS MONITORING PROGRAM

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

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

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

This report presents results from the October 2024 monitoring survey. The objectives of the survey were:

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

2 METHODS

2.1 SAMPLING APPROACH

The 2024 survey was designed to provide updated information on seagrass habitats within the Port of Karumba, including seagrass distribution, density and species composition. The sampling method used followed those established for the Karumba long-term seagrass monitoring program as well as other seagrass programs established in Queensland Ports including Weipa, Cairns, Mourilyan Harbour, Townsville, Gladstone, Mackay, Thursday Island and Abbot Point.

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

2.2 SAMPLING METHODS

The Karumba seagrass survey was conducted on 23rd - 24th October 2024. The survey area covered the intertidal area of Alligator Bank and Elbow Bank. Detailed monitoring program methods are available in previous reports (Rasheed et al. 1996; Rasheed et al. 2001; McKenna and Rasheed 2011).

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

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

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

Sampling of the seagrass seed bank (seeds stored in the sediments) and other seagrass reproductive structures (fruit and flowers) was conducted at 18 sites within the Alligator Bank monitoring meadow. A Van Veen sediment grab (0.0625m^{-2}) was used to collect samples at sites haphazardly scattered throughout the meadow. Seagrass and sediment/seed samples were sorted by passing the sample through a 1 mm sieve. Any seagrass reproductive structures in the 1 mm fraction were identified and counted. The 1 mm mesh size was small enough to retain seeds/pericarps of *H. uninervis* and fruits and flowers of *H. uninervis* and *H. ovalis*. Seeds of *H. ovalis* were not measured because their small size allows them to pass through the sieve mesh and requires a microscope to locate them.

2.3 HABITAT MAPPING AND GEOGRAPHIC INFORMATION SYSTEM

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

2.3.1 Site layer

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

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

2.3.2 Biomass interpolation

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

2.3.3 Meadow Layer

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

- Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass ± standard error (SE), meadow area (hectares) ± reliability estimate (R), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1, 2), meadow landscape category (Figure 4).
- Sampling method and any relevant comments.

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

TABLE 1. SEAGRASS MEADOW COMMUNITY TYPE NOMENCLATURE IN THE PORT OF KARUMBA.

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

TABLE 2. SEAGRASS MEADOW DENSITY CATEGORIES BASED ON MEAN ABOVE-GROUND BIOMASS RANGES FOR EACH SPECIES IN THE PORT OF KARUMBA.

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

Isolated seagrass patches

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

Aggregated seagrass patches

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

Continuous seagrass cover

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

FIGURE 4. SEAGRASS MEADOW LANDSCAPE CATEGORIES: (A) ISOLATED SEAGRASS PATCHES, (B) AGGREGATED SEAGRASS PATCHES, (C) CONTINUOUS SEAGRASS COVER.

2.4 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 (see Carter et al. 2023 for full details). Seagrass condition for each indicator at Abbot Point was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50% (Carter et al. 2023).

2.5 ENVIRONMENTAL DATA

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

- Tidal data was provided by Maritime Safety Queensland (MSQ) (© The State of Queensland Department of Transport and Main Roads 2023, Tidal Data) for Karumba (www.msq.qld.gov.au). Predicted data were used for five days in August and three days in September 2020 where the tidal guage was not working.
- Data for rainfall (mm), air temperature (°C), and global solar exposure (MegaJoules, MJ m^{-2}) were obtained for the nearest weather station from the Australian Bureau of Meteorology (BOM) (Normanton Airport, Station #029063; http://www.bom.gov.au/climate/data/).
- Norman River flow data (megalitres; ML) was obtained from the Queensland Government (Glenore Weir, Station #916001B; https://water-monitoring.information.qld.gov.au/).

2.6 SEAGRASS REPRODUCTION ANALYSIS

Halodule uninervis seeds and pericarps in the sediment were compared among years (2003-2023) using a negative binomial regression model in R (version 3.6.2) using the *MASS* package (Venables and Ripley 2002). Data exploration protocols prior to all analyses followed Zuur et al. (2010) and included checks for zero inflation and overdispersion. Statistical significance of year in each model was tested using a likelihood ratio test. Statistical analyses could not be performed on *H. uninervis* and *H. ovalis* fruit and flower counts due to the large number of zeros in the data; this data is presented graphically instead.

3 RESULTS

3.1 SEAGRASS SPECIES

Seagrass was present at 99 of the 200 sites surveyed in the Alligator bank monitoring meadow in 2024, and at seven of the 123 sites on Elbow Bank. Two seagrass species were present in Karumba: *Halodule uninervis* (narrow leaf form) was the dominant species recorded and accounted for approximately 92% of above-ground seagrass biomass in the meadow, while *Halophila ovalis* accounted for the remaining 8% (Figures 5 and 6).

(A) (B)

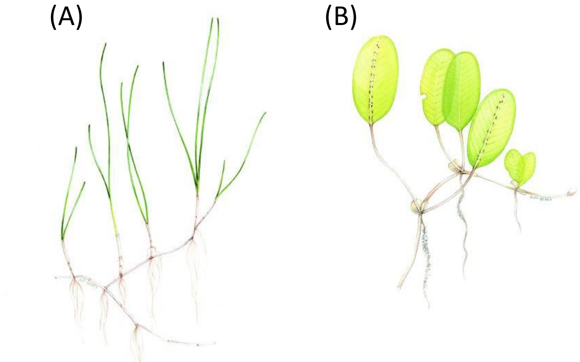

FIGURE 5. SEAGRASS SPECIES FOUND IN KARUMBA: (A) *HALODULE UNINERVIS*, FAMILY CYMODOCEACAE (NARROW LEAF FORM); (B) *HALOPHILA OVALIS*, FAMILY HYDROCHARITACEAE.

3.2 SEAGRASS CONDITION IN THE ALLIGATOR BANK MONITORING MEADOW

Seagrass in the Alligator Bank monitoring meadow was in a poor condition in 2024 (Table 3, Figure 6). This is after the meadow was in very good condition from 2021-23 with all indicators in very good condition. Above-ground biomass was the lowest recorded since surveys began and declined from 10.6 $\pm$ 0.6 g DW m^{-2} in 2023 to 0.79 $\pm$ 0.09 g DW m^{-2} in 2024, resulting in a poor condition for the first time since 2002 (Table 3, Figure 6). Meadow area decreased substantially from 1280 $\pm$ 14 ha in 2023 to 860 $\pm$ 12 ha in 2024, this was the second smallest meadow area recorded and resulted in a drop in condition to satisfactory (Table 3, Figures 6 and 7). Seagrass species composition remained in very good condition, with the meadow 92% dominated by the more stable species *H. uninervis* in 2024, a slight decrease from 96% in 2023 (Table 3, Figure 6).

TABLE 3. GRADES AND SCORES FOR SEAGRASS INDICATORS (BIOMASS, AREA AND SPECIES COMPOSITION) FOR KARUMBA.

Meadow	Biomass	Area	Species Composition	Overall Meadow Condition
Alligator Bank	0.29	0.53	0.92	0.29

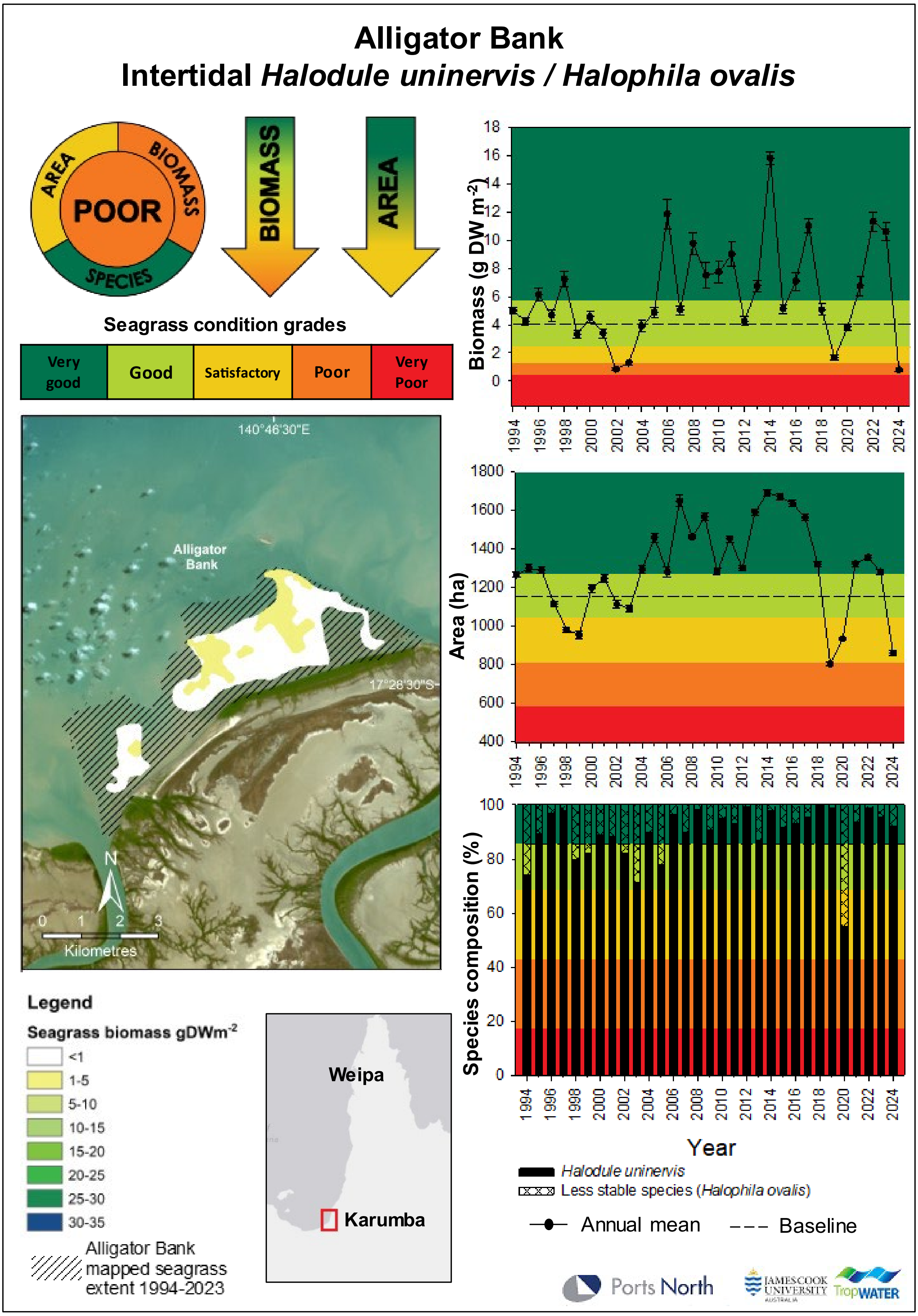

FIGURE 6. CHANGES IN BIOMASS, AREA AND SPECIES COMPOSITION FOR THE KARUMBA SEAGRASS MONITORING MEADOW FROM 1994 TO 2024 (BIOMASS ERROR BARS = SE; AREA ERROR BARS = "R" RELIABILITY ESTIMATE).

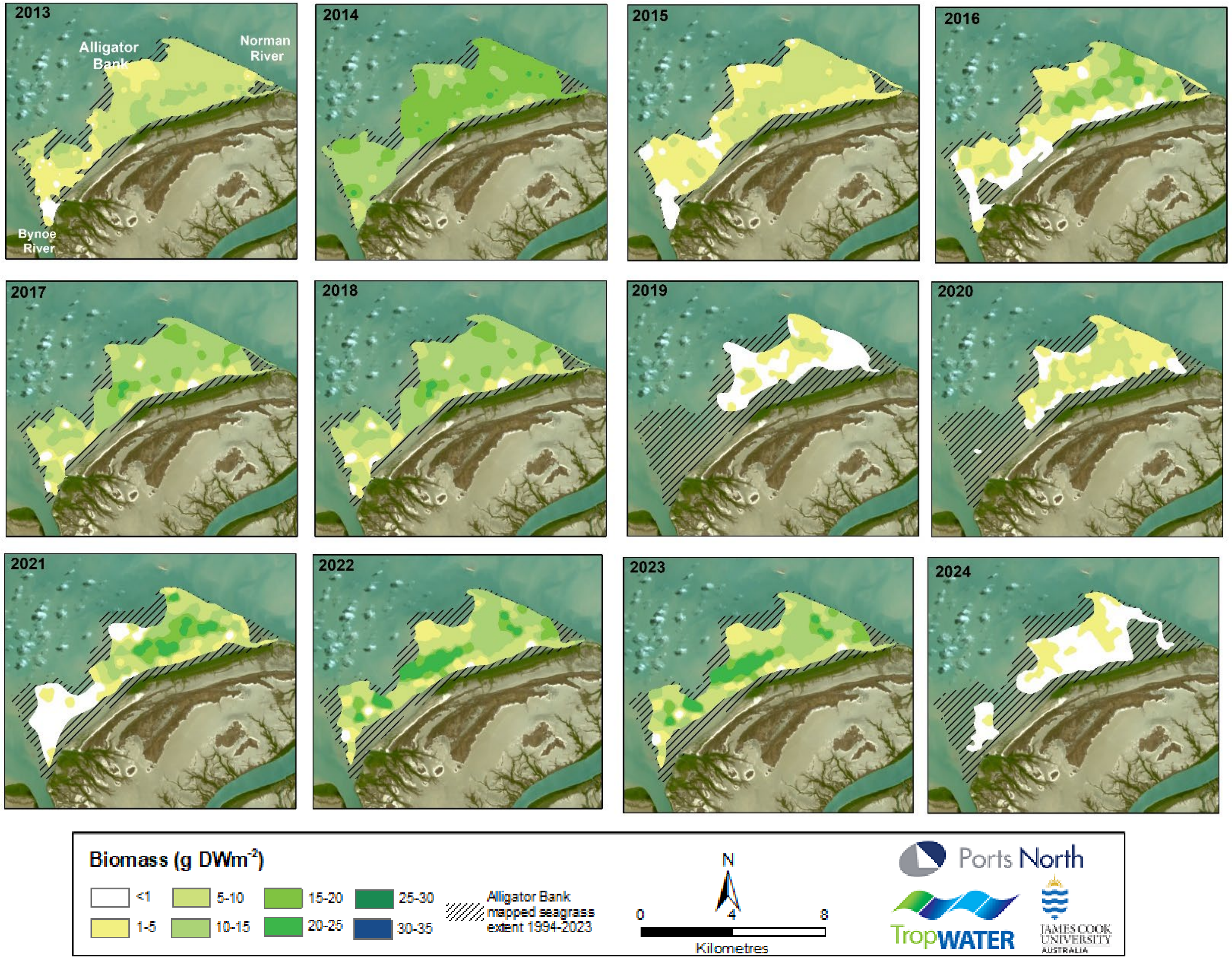

FIGURE 7. BIOMASS AND AREA CHANGE IN THE ALLIGATOR BANK MONITORING MEADOW, 2013 TO 2024.

3.3 SEAGRASS IN THE BROADER PORT OF KARUMBA

In 2024 seagrasses in the broader Karumba port limits (beyond the Alligator Bank monitoring meadow) were surveyed. In previous broader surveys; October 1994, October 1997, September 2015 and November 2018, 2021 (see Rasheed et al. 2001a, Sozou et al. 2016, Van de Wetering et al. 2019, Scott et al. 2022), large areas of intertidal seagrass were found on Elbow Bank, however in 2024 there was only one hectare of mapped seagrass meadow, and one site with seagrass present outside of this (Figure 8, Table 4).

A total of six habitat characterisation sites were assessed within the mapped boundary of the Elbow Bank seagrass meadow in 2024. Similar to previous surveys, *Halodule uninervis* and *Halophila ovalis* were the two species present.

Seagrass biomass on Elbow Bank in 2024 was 1.05 ± 0.43 g DW m^{-2}, which was slightly higher than 2021, however this biomass was across the smallest area recorded, declining from 567 ha in 2021 to just 1 ha in 2024 (Table 4). Dugong feeding trails were not recorded on Elbow Bank, despite previous surveys having observed presence of dugong feeding trails, with over 30% of sites having feeding trails in 2018 and 2015.

Table 4. Table of Area (ha) and Mean Biomass (g DW m^{-2}) of Elbow Bank seagrass monitoring surveys 1994, 1997, 2015, 2018, 2021 & 2024.

Area (ha)					
1994	**1997**	**2015**	**2018**	**2021**	**2024**
152	422	571	543	567	1
Mean Biomass ± SE (g dw m^{-2})					
3.36 ± 0.30	6.99 ± 0.46	2.36 ± 0.41	1.32 ± 0.19	0.98 ± 0.37	1.05 ± 0.43

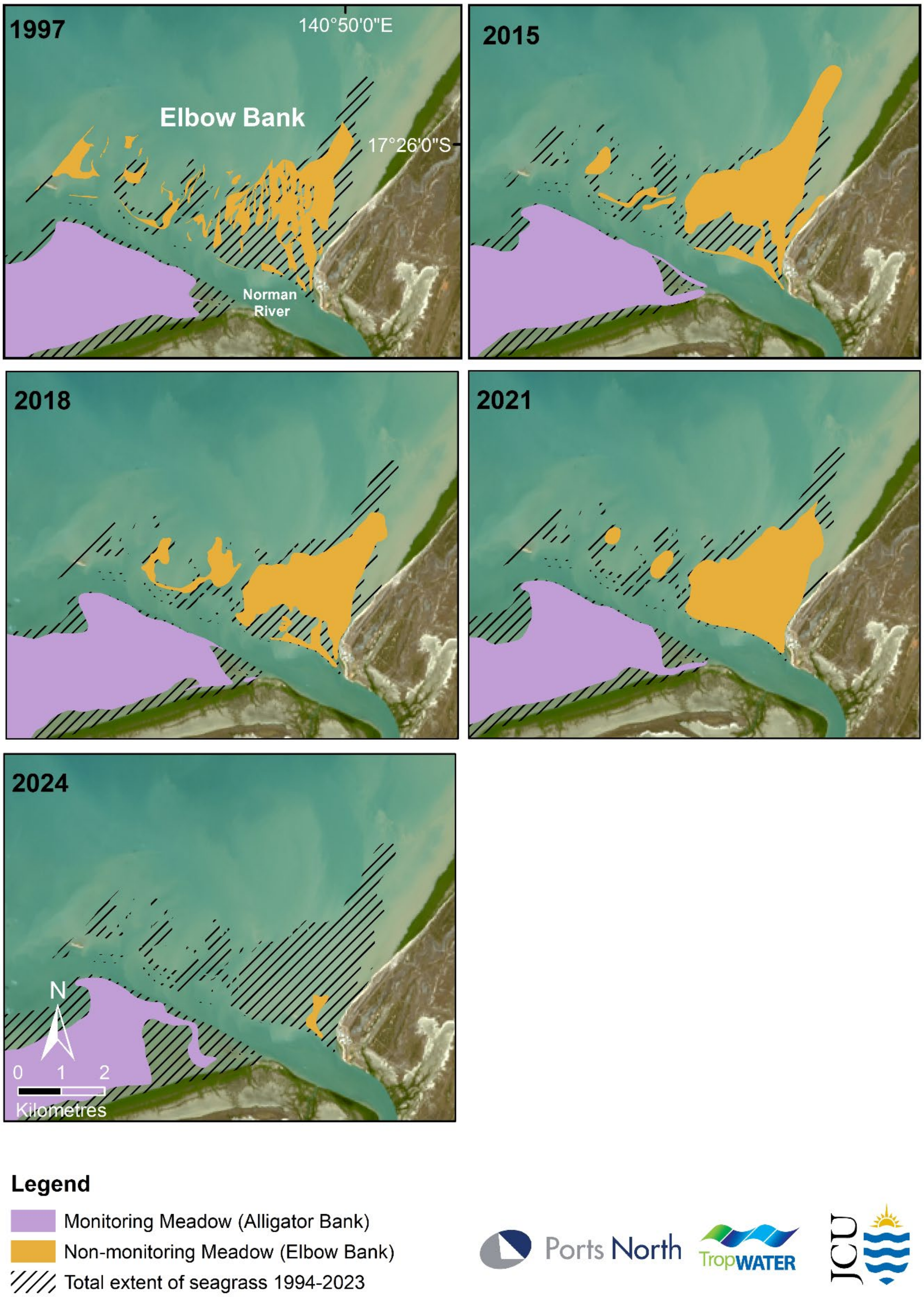

Figure 8. Aera change in the Elbow Bank non-monitoring meadow from 1997 - 2024

3.4 COMPARISON WITH PREVIOUS MONITORING SURVEYS

Seagrass condition in Karumba declined to poor in 2024, after recovering from the first ever poor condition recorded here in 2019, this is the lowest score recorded for the meadow and is driven by very low biomass (Table 3, Figure 6). All seagrass indicators declined from 2023, with only species composition maintaining a very good condition.

Above-ground biomass was ten times lower than in 2023, this dramatic decline to the lowest recorded biomass since surveys began caused a drop in condition to poor (Figure 6). Average meadow above-ground biomass decreased by 9.81 g DW m^{-2} from 2023 to 2024 (Figures 6 and 9). The loss of biomass from the meadow occurred around all of the shoreward edges, with a fragmentation of the meadow also observed (Figure 7).

Seagrass meadow area decreased by over a third in 2024, and declined to a satisfactory condition, this was the second lowest area recorded and represented a dramatic loss of the meadow and fragmentation of the Alligator Bank seagrass meadow (Figures 6 and 7).

Seagrass species composition score maintained a very good condition despite a slight decline in 2024. The meadow was dominated by the more stable species *H. uninervis*, making up 94% of biomass in the meadow (Figure 6).

2023 2024

FIGURE 9: COMPARISON BETWEEN SEAGRASS BIOMASS IN THE ALLIGATOR BANK MONITORING MEADOW IN 2023 AND 2024

3.5 SEAGRASS REPRODUCTIVE CAPACITY

Halodule uninervis seeds and pericarps (outer casings of seeds) were found throughout the monitoring meadow in 2024 (Figure 11), with a mean density of 113 seeds m^{-2} and 175 pericarps m^{-2} across the meadow, well above the long-term average (Figure 11A). *Halodule uninervis* seed density varied significantly among years at the .05 level (Chi square=89, df=20, p=<0.001) when compared against the NULL model, post-hoc analysis showed that in 2024 the number of seeds was significantly higher than in 2004 (p=<0.05) but did not differ from any other year (Figure 10A). *Halodule uninervis* pericarp density varied significantly among years at the .05 level (Chi square=205, df=20, p=<0.001) when compared against the NULL model, post-hoc analysis showed that pericarp densities in 2024 were significantly higher than in 2004 – 2007, 2025 and 2021-2022 (p=<0.05) (Figure 11A). Similar to previous years, there were no *H. uninervis* fruits or flowers found in the Alligator Bank meadow at the time of the survey in 2024 (Figure 11B). In October 2024 there were no *H. ovalis* fruits found in the Alligator Bank meadow, this is below average but is similar to many previous years (Figures 10 and 11C).

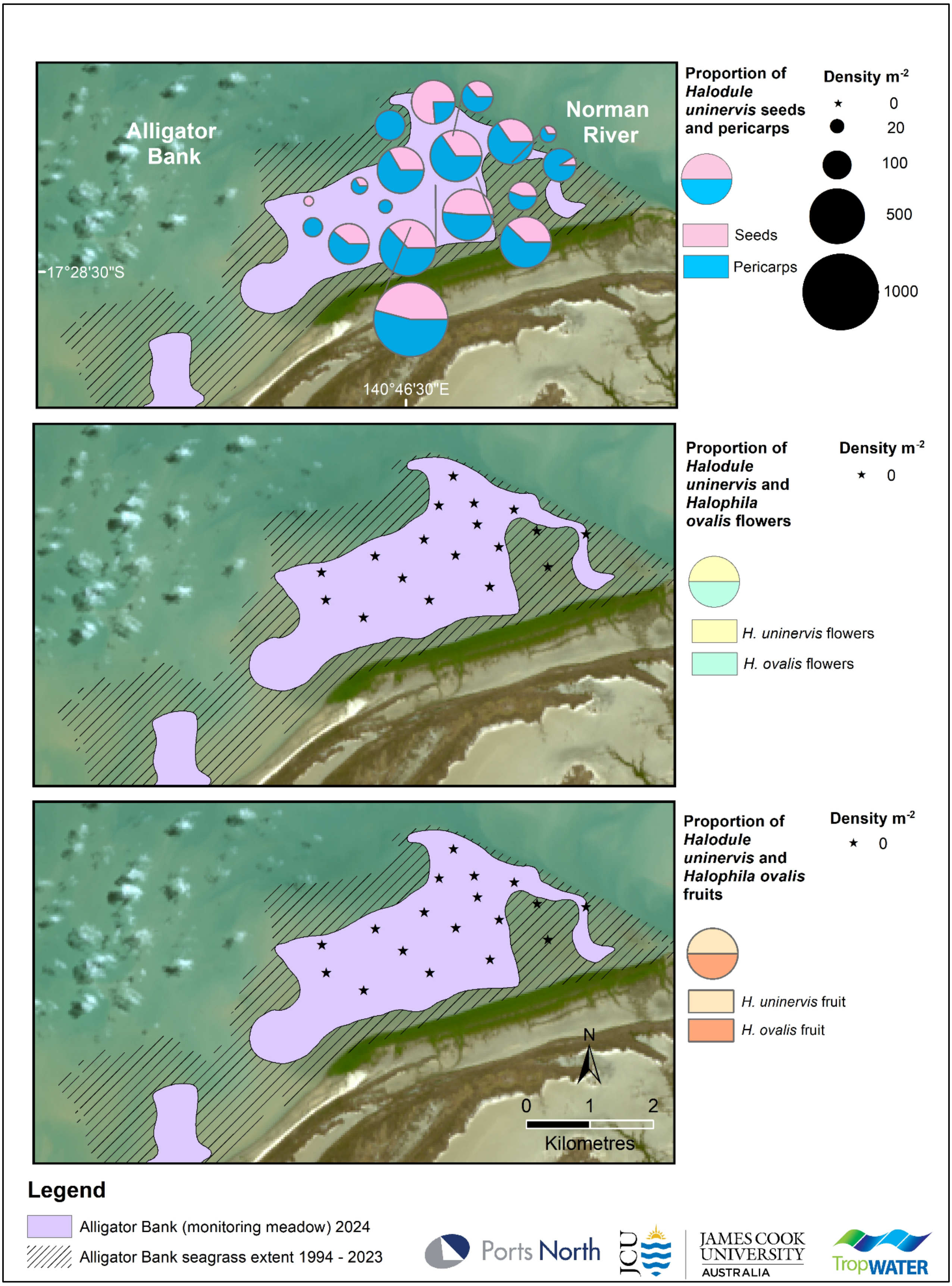

FIGURE 10. DENSITY OF *H. UNINERVIS* SEEDS AND PERICARPS, AND *H. UNINERVIS* AND *H. OVALIS* FLOWERS AND FRUITS IN 2024.

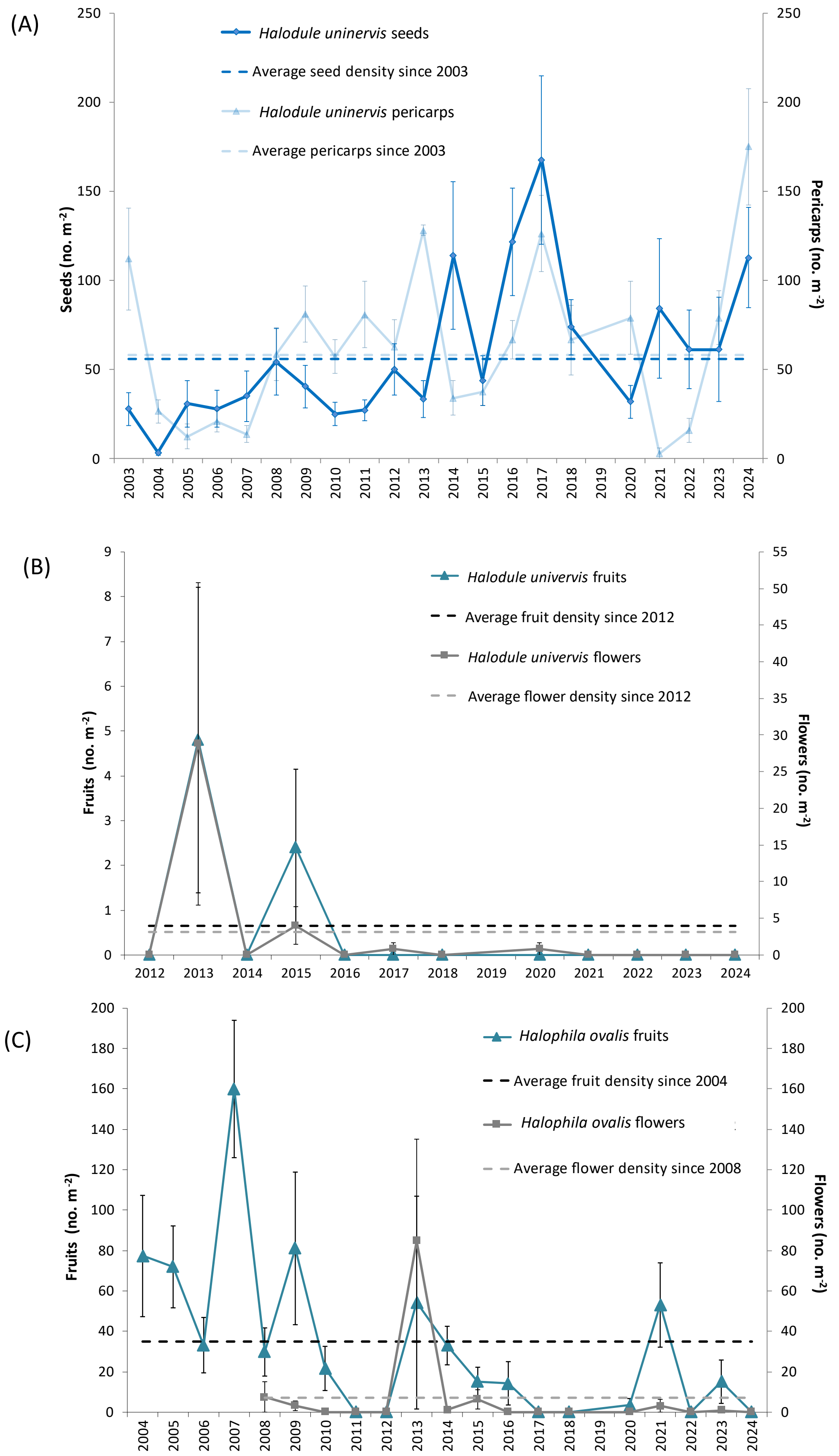

FIGURE 11. MEAN DENSITY (± SE) OF (A) *HALODULE UNINERVIS* SEEDS AND PERICARP PIECES, (B) *H. UNINERVIS* FRUITS AND FLOWERS, AND (C) *HALOPHILA OVALIS* FRUITS SAMPLED WITHIN THE MONITORING MEADOW. DATA FROM 2019 HAVE BEEN EXCLUDED DUE TO A DIFFERENT SAMPLING METHOD USED.

3.6 DUGONG FEEDING ACTIVITY

Dugong feeding trails have been observed within seagrass meadows over the history of the Karumba monitoring program. For the first time, no dugong feeding trails were observed in the Alligator Bank meadow or Elbow Bank meadows in 2024.

3.7 KARUMBA ENVIRONMENTAL CONDITIONS

3.7.1 RAINFALL

Total annual rainfall for the Normanton area in the twelve months prior to the October 2024 survey was 1065 mm, this was well above the average annual rainfall for the area (Figure 12). The majority of the monthly rainfall during the preceding wet season was above average, with rainfall remaining above average in November 2023 and from January - March 2024 (Figure 13). During the survey month there was 6.2 mm of rainfall, just below average, and no rain in the three months prior to this (Figure 13).

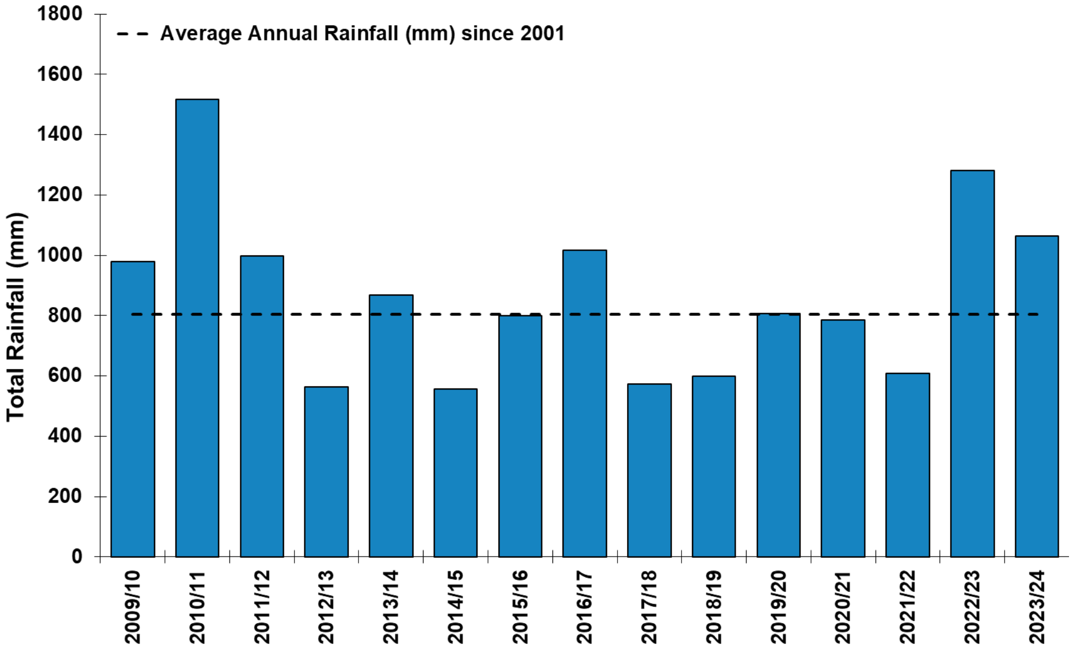

FIGURE 12. TOTAL ANNUAL RAINFALL (MM) RECORDED AT NORMANTON AIRPORT, 2009/10 – 2023/24, IN EACH 12 MONTHS PRIOR TO SEAGRASS SURVEY.

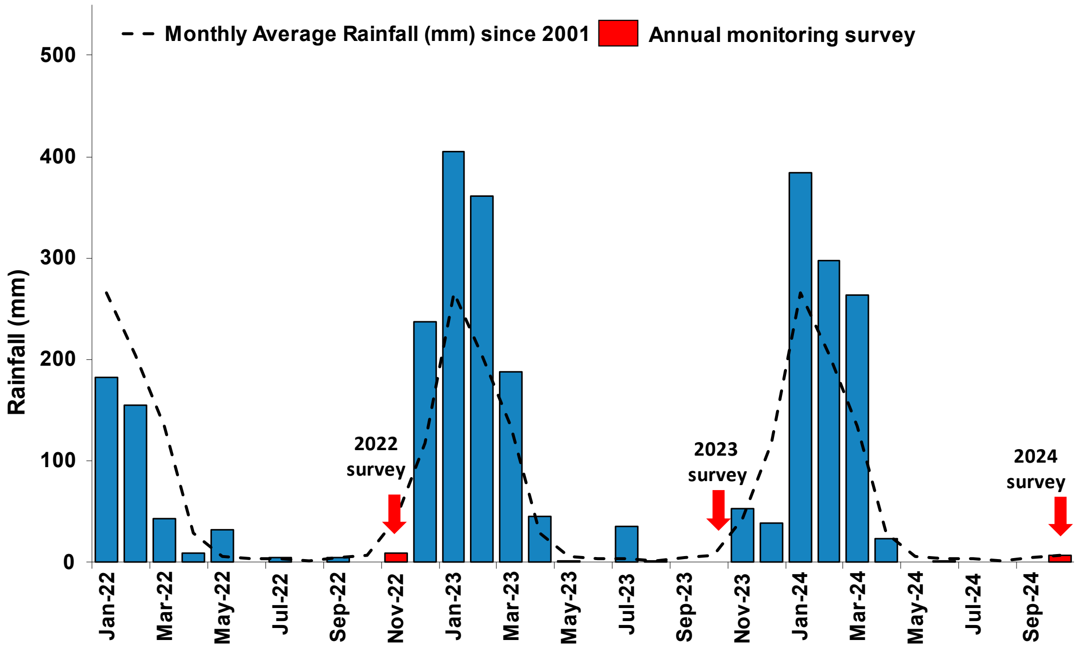

FIGURE 13. TOTAL MONTHLY RAINFALL (MM) RECORDED AT NORMANTON AIRPORT, JANUARY 2022 - OCTOBER 2024.

3.7.2 River Flow

Total annual river flow 12 months prior to the seagrass survey was 3888 GL, the sixth highest volume recorded since 1993/4 and the fourth highest since 2009/10 (Figure 14), this was driven by well above average river flow between January – February 2024 (Figure 15).

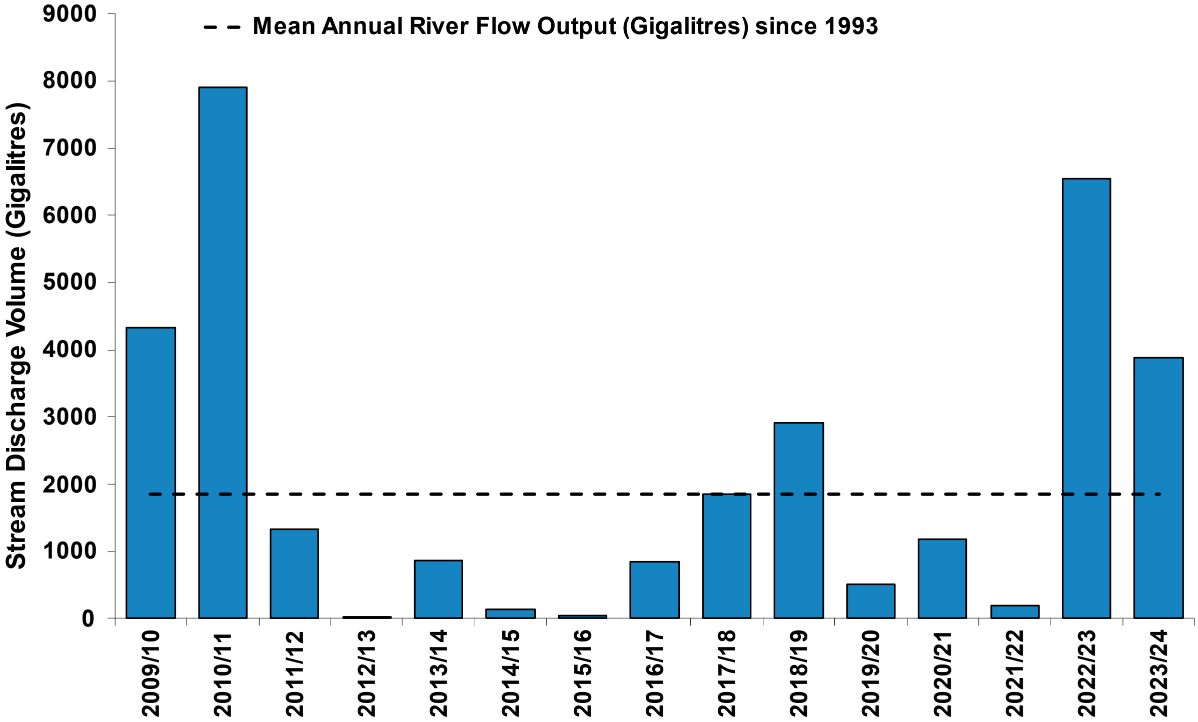

Figure 14. Total Norman River flow (measured as stream discharge volume in Gigalitres, GL) recorded at Glenore Weir, 2009/10 – 2023/24 twelve month year (2023/24) is twelve months prior to survey.

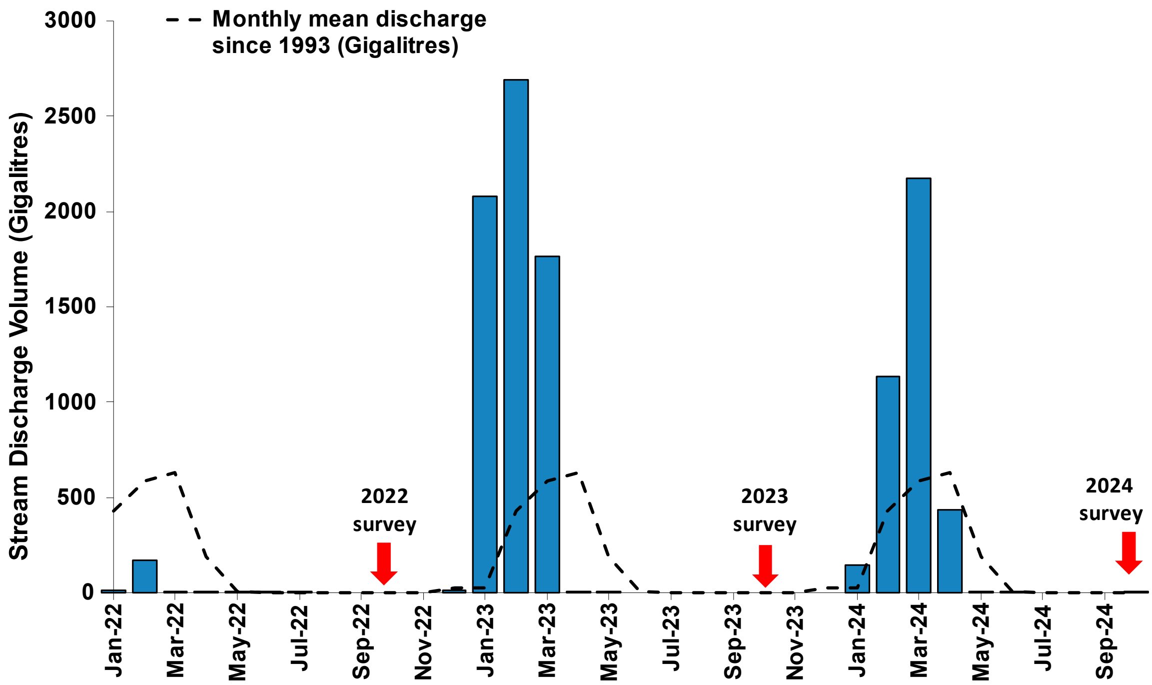

Figure 15. Total Norman River flow (measured as stream discharge volume in Gigalitres) recorded at Glenore Weir, January 2022 - October 2024.

3.7.3 Air Temperature

Air temperature was average in the region in 2023/234 with a mean annual daily maximum air temperature of 33.7°C (Figure 16). Monthly average maximum daily temperatures were close to or above average in the three months prior to the survey, and close to or slightly below average in the 9 months before this with the exception of December 2023 which was above average (Figure 17).

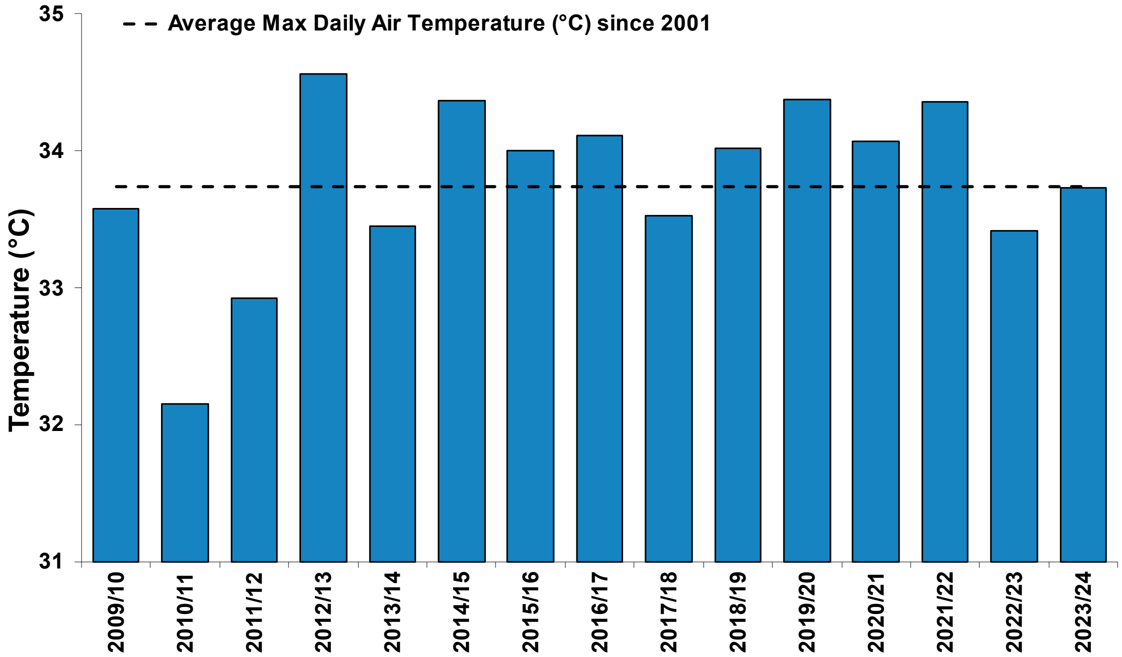

Figure 16. Mean maximum daily air temperature (°C) recorded at Normanton Airport, 2009/10 - 2023/24. Twelve month year (2023/24) is twelve months prior to survey.

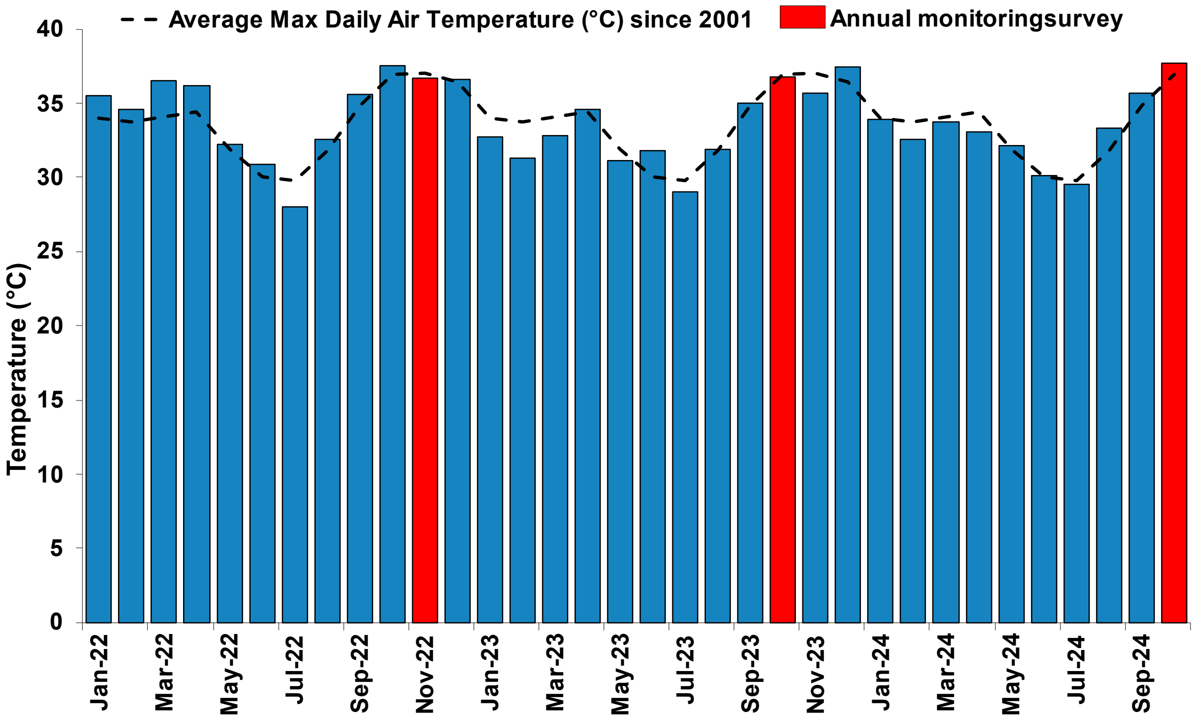

Figure 17. Monthly mean maximum daily air temperature (°C) recorded at Normanton Airport, January 2022 – October 2024.

3.7.4 Daily Global Solar Exposure

Daily global solar exposure is a measure of the total amount of solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Global solar exposure in the Normanton area was slightly below-average in 2023/24 at 21.7 MJ m^{-2} (MegaJoules m^{-2}) (Figure 18), with solar exposure close to the average for most of the 12 months prior to the survey, with above average values in December 2023 and below average values in January and February 2024 (Figure 19).

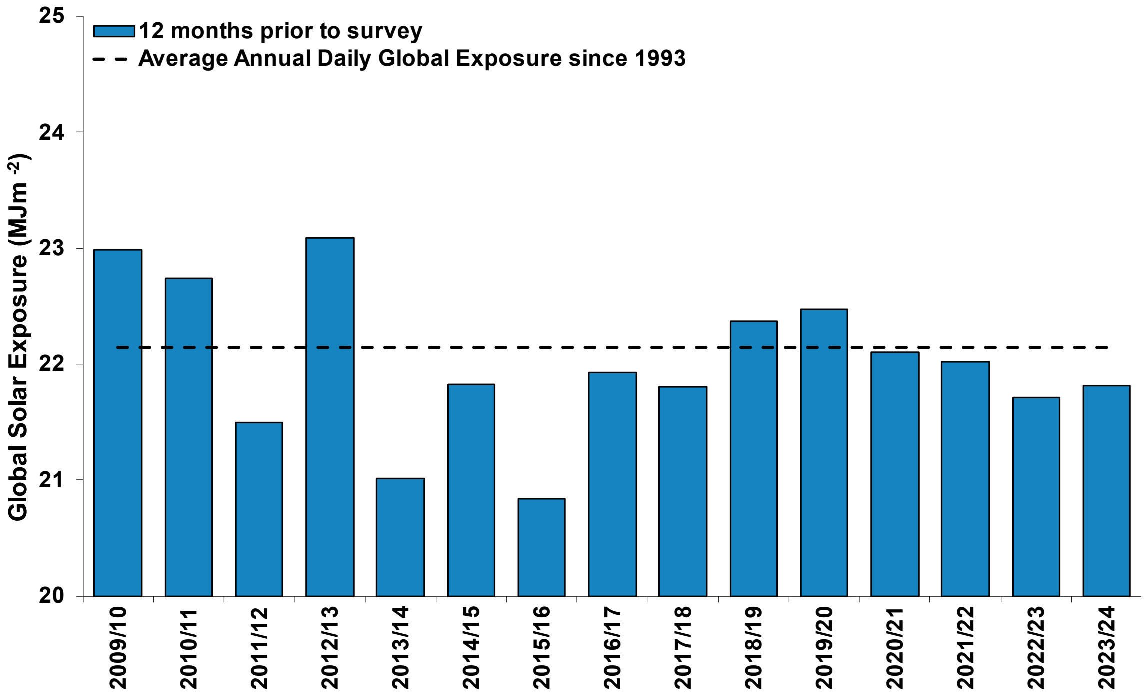

Figure 18. Mean daily global exposure (MegaJoules m^{-2}) recorded at Normanton Airport, 2009/10 – 2023/24. Twelve month year (2023/24) is twelve months prior to survey.

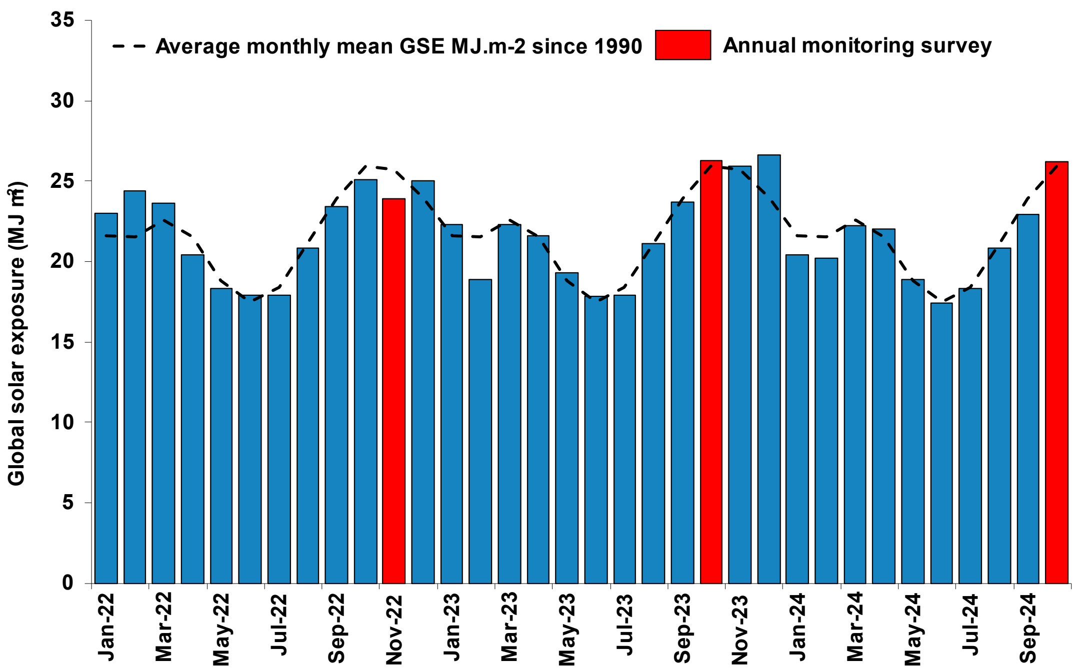

Figure 19. Mean daily global solar exposure (MegaJoules m^{-2}) recorded at Normanton Airport, January 2022-October 2024.

3.7.5 Tidal Exposure of Seagrass Meadows

Annual daytime exposure to air for intertidal seagrass was above-average in 2024 (Figure 20). Intertidal banks were exposed for a total of 225 daytime hours in the 12 months prior to the survey (Figure 21). Monthly daytime exposure to air was well below-average in the survey month and in the year prior to the survey remained close to average, with April 2024 being well above average (Figure 21).

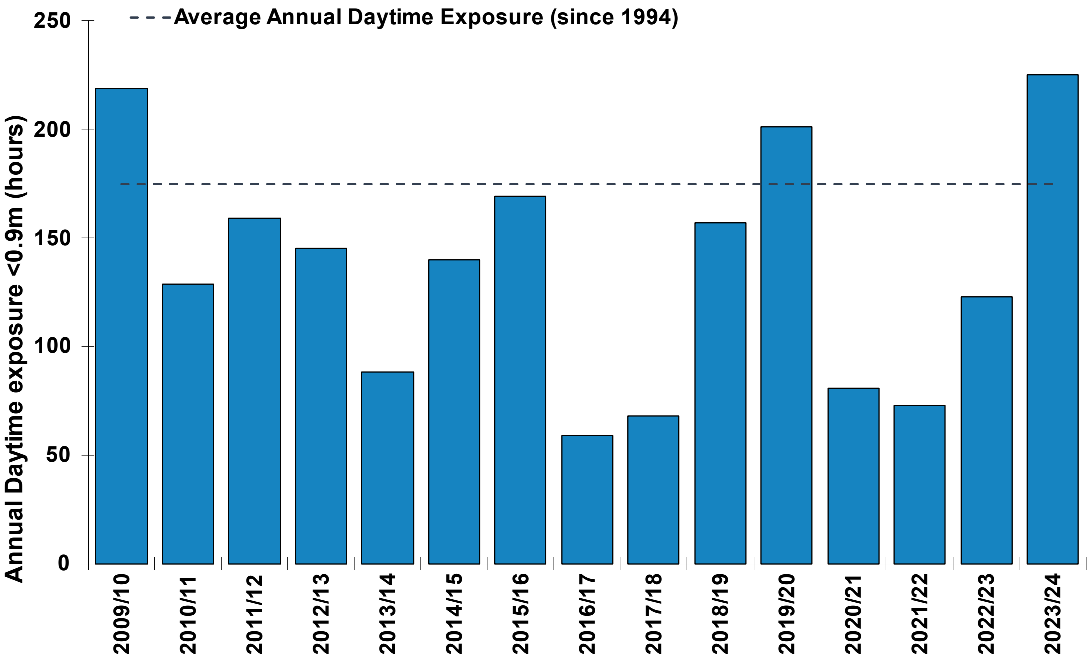

Figure 20. Total hours daytime exposure (annual) of intertidal seagrass in Karumba; 2009/10 – 2023/24. Twelve month year is twelve months prior to survey. *Assumes intertidal banks become exposed at a tide height <0.9m above Lowest Astronomical Tide.

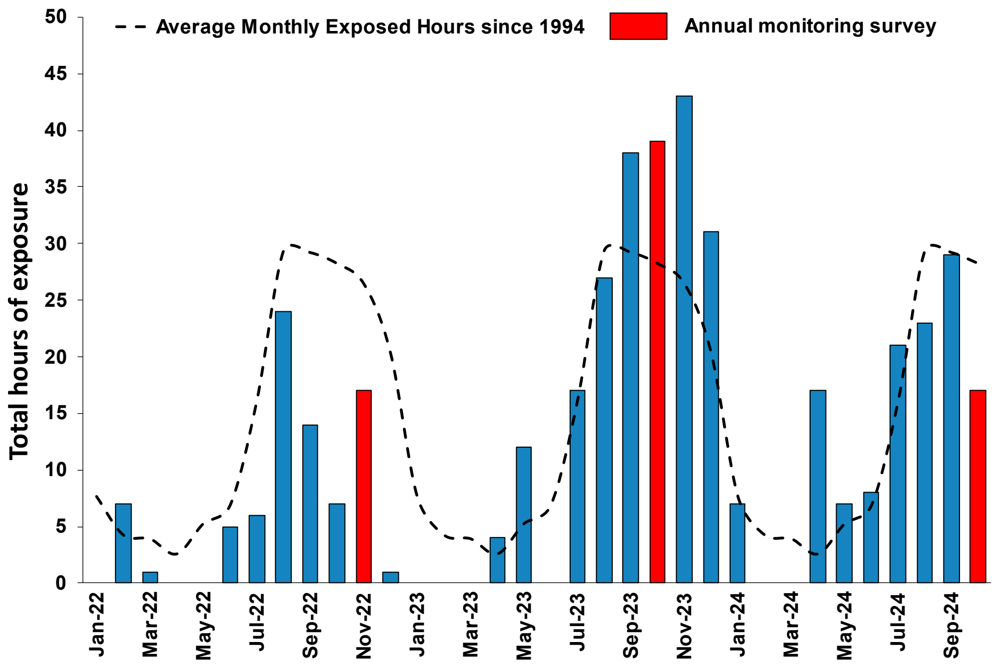

Figure 21. Total hours of daytime exposure (monthly), January 2022 to October 2024. *Assumes intertidal banks become exposed at a tide height <0.9m above Lowest Astronomical Tide.

4 DISCUSSION

In 2024 the Alligator Bank seagrass meadow dropped to a poor condition with the lowest score recorded since monitoring began. This is likely to be due to the cumulative impact of heavy rain and flooding in both the 2022/23 and 2023/24 wet seasons. The low score was primarily driven by a dramatic decline in seagrass biomass, however seagrass area also declined substantially. Similar declines were also seen in the Elbow Bank non monitoring meadow which had low biomass seagrass and the smallest meadow area recorded since monitoring began. For the first time during monitoring surveys, no dugong feeding trails were observed in either seagrass meadow.

Although rainfall and river flow declined in 2023/24 compared to 2022/23, these variables were above average for the second consecutive year. While the flooding generated by this rainfall and river flow did not cause a decline in seagrass in 2023, the multiple years of cumulative flooding pressure could be driving the declines in 2024. These recurring floods can result in physical removal of seagrass, sediment de-stabilisation and the increased runoff can cause burial. Floods may also lead to large freshwater pulses reducing salinity over the seagrass meadows and result in extended periods of high turbidity and reduced light which can all negatively affect seagrasses (Campbell and McKenzie 2004, Waycott et al. 2007, McKenna et al. 2015). During the 2024 survey we observed a layer of fine sediment over the banks, this was particularly evident on Elbow Bank (Figure 22). This may demonstrate that the sediment that comes from the catchment in high rainfall and flooding events is being retained in the system and could be resuspended. These high levels of sediment could reduce light levels for seagrasses and drive meadow scale declines.

FIGURE 22: FINE SEDIMENT OVER THE ELBOW BANK MEADOW

The scale of sediment movement and resuspension in the water column can be seen in satellite imagery (Figure 23). In 2023 and 2024 these conditions led to widespread flooding in Karumba and throughout the Gulf of Carpentaria, satellite imagery shows extensive flood plumes in the area at the end of March 2023 and April 2024, these plumes are more extensive and present later than previous years (Figure 23). This may have caused light levels to be reduced for longer, potentially exceeding the shading tolerance of *H. uninervis*, this species has a high degree of tolerance to light deprivation, however pulsed turbidity events of more than 38 days can lead to seagrass loss (Longstaff and Dennison, 1999). River flow, temperature and long-term tidal exposure cycles have been identified in past research as strongly influencing changes in seagrass biomass and distribution in Karumba (Rasheed and Unsworth 2011). In 2023 the impact of flooding on the seagrass meadow was minimal, however multiple years of disturbance have led to declines in seagrass condition. Although biomass was very low, the seagrass community remained similar to previous years with the meadow dominated by the more stable species *Halodule uninervis.*

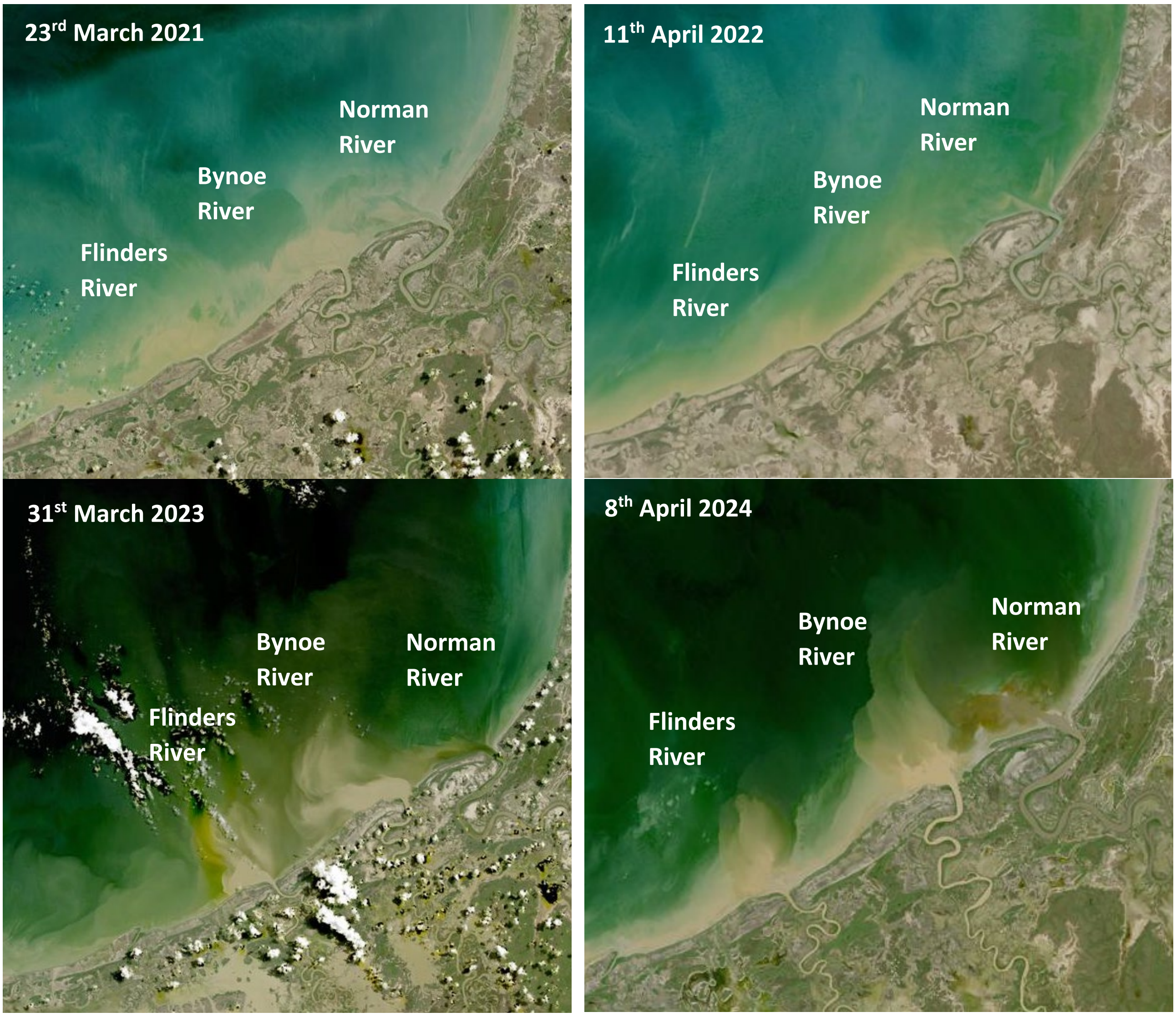

FIGURE 23. NASA LANDSAT OPERATIONAL LAND IMAGER SURFACE REFLECTANCE AND TOA BRIGHTNESS DAILY GLOBAL 30M SATELLITE IMAGE FROM 2021 - 2024 . SOURCE: HTTPS://WWW.EARTHDATA.NASA.GOV/

Seed densities in the Karumba Alligator Bank monitoring meadow were once again above average in 2024, increasing from the previous year. The number of pericarps (seed casings) increased dramatically, indicating some of these seeds are germinating, which could drive meadow recovery going forward. No *H. uninervis* fruits or flowers were found in the meadow at the time of the survey, consistent with previous surveys since 2016. *Halophila ovalis* fruits and flowers were present in low numbers in 2023, consistent with previous surveys.

The very good meadow condition in 2021 and 2022 and presence of the below-ground seed bank in 2022, likely conferred a high level of resilience leading into the 2022/23 wet season and allowed the meadow to remain in very good condition in 2023 despite high rainfall and river flow. The seagrass was likely to have good energy stores to withstand extended periods of low light as well as a substantial source of propagules to allow rapid recovery from any declines after the floods. Prior to the flood related decline in 2019, the Alligator Bank meadow was in a good or very good condition from 2004 to 2017, maintaining this score even in high rainfall years, showing it can be resilient in years of higher rainfall and river flow if area and biomass leading into the wet season are high, as they were in 2023. A meadow with high biomass, a stable seagrass community and a seed bank present is likely to be more resilient, meaning it can absorb disturbances and is able to recover from them (Unsworth et al. 2015). However multiple years or extended periods of severe weather and flooding may have limited the capacity of the seagrass to recover, and eroded resilience of the meadow as has occurred previously in the monitoring program.

The seagrass meadow at Alligator Bank has recovered from these types of declines in the past. Previously, flooding and severe weather have resulted in significant losses of seagrass in this meadow resulting in the poorest condition recorded in over a decade in 2019, which took several years to recover from. Flooding of the Norman River in 2018/19 caused large-scale declines of seagrass biomass and area in Karumba. These flooding and flow events created a persistent turbid plume that reduced light levels and resulted in seagrass loss (Shepherd et al. 2020, Van De Wetering et al. 2019). In 2020, more favourable conditions allowed the meadow to begin to recover, achieving a satisfactory condition. In 2021 and 2022 conditions were once again favourable allowing continued improvement in condition and recovery of the Alligator Bank seagrass meadow to a very good condition. This demonstrates that if conditions are favourable, the meadow has the capacity to recover from large scale losses.

Seagrasses provide a wide range of important ecosystem services and the decline of meadow condition in Karumba will also cause declines in the provision of a range of these services (Nordlund et al. 2016, Scott et al. 2018). For example, Karumba seagrasses are an important nursery ground for prawns and fish (Rasheed et al. 1996) and feeding ground for megaherbivores such as dugong. However, all these services rely on a structurally complex seagrass meadow and cannot be delivered by the very low biomass seagrass present in the 2024 survey.

The seagrass at Karumba is the only substantial area of seagrass for dugong feeding between Mornington Island and the Archer River in the southern Gulf of Carpentaria (Rasheed et al. 1996). The loss of seagrass here means it is unlikely to be a viable feeding area and dugongs may have moved to other areas. In 2024 no dugong feeding trails could be observed in the low biomass seagrass here, this is the first time since surveys began that no dugong feeding trails have been found in the meadow. This could be because the trails are harder to see in the low biomass seagrass, or more likely because this low biomass seagrass doesn't support dugongs and they have moved to other meadows.

In 2024 seagrass condition in the Alligator Bank seagrass meadow at Karumba declined substantially, likely due to multiple years of severe weather and flooding. The drop in area and biomass are a cause for concern, however the presence of a healthy seed bank shows the meadow may have the capacity to recover. The flooding in this region after the time of this survey in February 2025 is likely to present additional stress for the seagrass at Karumba and the potential for further declines.

5 REFERENCES

Abal, E. and Dennison, W. 1996. 'Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia'. *Marine and Freshwater Research.* **47**: 763-771.

Carter, A. B., Coles, R., Jarvis, J. C., Bryant, C. V., Smith, T. M. and Rasheed, M. A. 2023. A report card approach to describe temporal and spatial trends in parameters for coastal seagrass habitats. Scientific Reports, **13**: 2295

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

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W. and Batiuk, R.A. 1993. 'Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health', *BioScience.* **43(2):** 86-94.

Erftemeijer, P.L.A. and Lewis, R.R.R. (2006) 'Environmental impacts of dredging on seagrasses: A review'. *Marine Pollution Bulletin.* **52:** 1553-1572.

Hemminga, M.A. and Duarte, C.M. 2000. '*Seagrass Ecology'.* Cambridge University Press, pp.298.

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G. A., Scanes, P., McKenzie, L., O'Brien, K.R., Lyons, M., Ferguson, A., Maxwell, P., Glasby, T. and Udy, J. (2015). 'Unravelling complexity in seagrass systems for management: Australia as a microcosm'. *Science of the Total Environment*. **534,** 97–109.

Kirkman, H. 1978. 'Decline of seagrass in northern areas of Moreton Bay, Queensland', *Aquatic Botany.* **5:** 63-76.

Longstaff, B. J. and Dennison W. C. 1999. 'Seagrass survival during pulsed turbidity events: the effects of light deprevation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*'. *Aquatic Botany.* 65:105 - 121

McKenna, S.A. and Rasheed, M.A. 2011. 'Port of Karumba Long-Term Seagrass Monitoring, October 2010, Cairns'. DEEDI Publication, Fisheries Queensland, 21 pp.

McKenna, S.A. and Rasheed, M.A. 2013. 'Port of Karumba Long-Term Seagrass Monitoring, October 2012'. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 30 pp.

McKenna, S.A., Jarvis, J.C., Sankey, T., Reason, C.L., Coles, R.G. and Rasheed, M.A. 2015, '*Declines of seagrasses in a tropical harbour, North Queensland, Australia, are not the result of a single event'. Journal of Biosciences.* **40(2):** 389-398.

Mellors, J.E. 1991. 'An evaluation of a rapid visual technique for estimating seagrass biomass'. *Aquatic Botany*. **42:** 67-73.

Nordlund, L.M., Koch, E.W., Barbier, E.B. and Creed, J. C. 2016. 'Seagrass ecosystem services and their variability across genera and geographical regions'. *PLoS One.* **11:** 1–23.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Randall Hughes, A., Kendrick, G.A., Judson, K.W., Olyarnik, S., Short, F.T., Waycott, M. and Williams, S.L. 2006. 'A global crisis for seagrass ecosystems'. *Bioscience.* **56:** 987-996.

Rasheed, M.A., Lee Long, W.J., McKenzie, L.J., Roder, C.A., Roelofs, A.J. and Coles, R.G. 1996. 'Port of Karumba Seagrass Monitoring, Baseline Surveys - Dry-season (October) 1994 and Wet-season (March) 1995'. Brisbane: Ports Corporation of Queensland. 49 pp.

Rasheed, M.A., Roelofs, A.J., Thomas, R. and Coles, R.G. 2001. 'Port of Karumba Seagrass Monitoring - First 6 Years', EcoPorts Monograph Series, Ports Corporation of Queensland, Brisbane. 38 pp.

Rasheed, M.A., Dew, K.R., McKenzie, L.J., Coles, R.G., Kerville, S.P. and Campbell, S.J. 2008. 'Productivity, carbon assimilation and intra-annual change in tropical reef platform seagrass communities of the Torres Strait, north-eastern Australia'. *Continental Shelf Research.* **28:** 2292-2303.

Rasheed, M.A. and Unsworth, R.K.F. 2011. 'Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future'. *Marine Ecology Progress Series.* **422:** 93-103.

Rasheed, M.A., McKenna, S.A., Carter, A. and Coles, R.G. 2014. 'Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia'. *Marine Pollution Bulletin.* **83:** 491-499.

Reason C.L., York P.H. & Rasheed M.A. 2022. 'Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2021'. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication 22/03, Cairns.

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

Scott, A.L., York, P.H., Duncan, C., Macreadie, P.I., Connolly, R.M., Ellis, M.T., Jarvis, J.C., Jinks, K.I., Marsh, H. and Rasheed, M.A. 2018. 'The Role of Herbivory in Structuring Tropical Seagrass Ecosystem Service Delivery'. *Frontiers in Plant Science*. **9:** 127.

Shepherd, L.J., Wilkinson, J.S., Carter, A.B. and Rasheed, M. A. 2020. 'Port of Karumba long-term annual seagrass monitoring 2019'. Centre for Tropical Water & Aquatic Ecosystem Research Publication Number 20/10, James Cook University. Cairns, 26 pp.

Taylor H.A., McKenna, S.A. & Rasheed, M.A. 2014. 'Port of Karumba Long-term Seagrass Monitoring, November 2013'. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns, 25 pp.

Tol, S.J., Jarvis, J.C., York, P.H., Grech, A., Congdon, B.C. and Coles, R.G. 2017. Long distance biotic dispersal of tropical seagrass seeds by marine mega-herbivores. *Scientific Reports.* 1–8.

Unsworth, R.K.F., McKenna, S.A. and Rasheed, M.A. 2009. 'Port of Karumba Long Term Seagrass Monitoring, October 2008'. DPI&F Publication PR09-4227 (DPI&F, Northern Fisheries Centre, Cairns). 25 pp.

Unsworth, R.K.F, Collier, C. J., Waycott, M., Mckenzie, L. and Cullen-Unsworth, L.C. 2015. A framework for the resilience of seagrass ecosystems. *Marine Pollution Bulletin*. **100:** 34-46.

Van De Wetering, C., Scott, A.L. and Rasheed, M.A. 2019. 'Port of Karumba Long-term Annual Seagrass Monitoring: November 2018'. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. 28pp.

Venables, W.N. and Ripley, B.D. 2002. 'Modern Applied Statistics with S'. Fourth Edition. Springer, New York. ISBN 0-387-95457-0.

York, P.H., Carter, A., Chartrand, K.M., Sankey, T.L., Wells, J.N. and Rasheed, M.A. 2015. 'Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program'. *Scientific Reports.* **5:** 1-9.