SEAGRASS HABITAT OF MOURILYAN HARBOUR: Annual Monitoring Report – 2018

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Report No. 19/14

June 2019
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A Report for Far North Queensland Ports Corporation Limited (Ports North)

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Prepared by Jaclyn Wells, Carissa Reason & Michael Rasheed
KEY FINDINGS

Seagrass Condition 2018

Very poor

1. This report compiles the findings of aerial survey conducted on 8th October 2018 and boat work conducted on 4th and 7th December 2018.

2. Seagrass returned to some intertidal and subtidal monitoring meadows in Mourilyan Harbour following the complete collapse of seagrass in 2017. However, due to extremely low biomass and reduced meadow area the overall seagrass condition remains very poor.

3. The larger foundation species *Zostera muelleri* subsp. *capricorni* and *Halodule uninervis* remain absent in monitoring meadows since 2009/2010, with recovery in four out of five monitoring meadows in 2018 due to the return of small colonising *Halophila* species.

4. The broader harbour area was also re-surveyed to update the overall seagrass distribution. An additional 7.5 ha of seagrass was mapped outside of annual monitoring meadows, an increase from the previous whole of harbour survey in 2015. This update found:
   a. Small aggregated and isolated patches of *Enhalus acoroides* as well as greater areas of *Halophila* species outside of the monitoring areas.
   b. A strip of *Halodule uninervis* that had increased in area and biomass from previous years.

5. Mourilyan Harbour remains the only location among our long-term monitoring sites in the wet and dry tropics regions where no recovery of the high biomass foundation species has occurred following region-wide declines leading up to 2011.

6. The recovery of foundation species is likely inhibited by the absence of a viable seedbank within monitoring meadows and a lack of a nearby seagrass stock from which seagrass can regenerate. It is likely that assisted restoration will be required to re-establish *Zostera muelleri* subsp. *capricorni*. 
IN BRIEF

Seagrasses in Mourilyan Harbour have been monitored annually since 2000 following initial assessments conducted between 1993 and 1996. Each year a subset of 5 seagrass meadows (annual monitoring meadows) representing the range of different seagrass community types found in Mourilyan Harbour are assessed for changes in biomass, aerial coverage and species composition. These indicators are used to develop a seagrass condition index (see section 2.5.1 of this report for further details). This report also includes an extended survey encompassing all seagrasses within the harbour to capture the health and condition of the whole system.

In 2018 seagrass returned to both intertidal and subtidal long-term monitoring meadows following the complete collapse of seagrass in 2017 (Figure 2). The overall seagrass condition was classified as very poor. The return of seagrass to four out of the five monitoring meadows was due to small colonising species of *Halophila* with the larger foundation species, *Zostera muelleri* subsp. capricorni and *Halodule uninervis* remaining absent from monitoring meadows since 2009/2010.

Small aggregated and isolated patches of *Enhalus acoroides* and a larger strip of *Halodule uninervis* were mapped outside of the monitoring meadows as well as greater areas of *Halophila* spp. as part of the updated whole of harbour survey (Figure 2).

The lack of recovery for the high biomass foundation seagrass species in Mourilyan Harbour remains unique among other locations in the wet and dry tropics region where seagrass monitoring occurs annually (Figure 3). Climate related declines were documented throughout the Queensland coast from 2009 -2011, with all locations showing recovery of foundation species and meadow area since that time, including nearby Cairns Harbour *Z. muelleri* subsp. *capricorni* meadows as well as Townsville seagrasses which are now in good condition. Initial surveys of the Mourilyan Harbour seedbank found very low densities of seeds of foundation species, but seeds have been completely absent since 2015. Without a seedbank and no nearby source for dispersal of new propagules, it is uncertain how these meadows will re-establish naturally. It is increasingly likely that some form of assisting recovery through a restoration project will be necessary.

Mourilyan Harbour seagrasses face a range of potential natural and anthropogenic threats from the Moresby River catchment. Coastal developments and ports and shipping activity in the Harbour have remained relatively unchanged over the last decade with no maintenance dredging required or major changes to port infrastructure or shipping activity occurring. Future activities and development in the Moresby River, its catchment and the Harbour should consider the current poor state of seagrass and their vulnerability to impacts. Assessing the likelihood of recovery or restoration success for seagrasses would be significantly improved with good water quality monitoring data for the end of the catchment in Mourilyan Harbour, which is currently unavailable.
Figure 2. Seagrass condition for Mourilyan Harbour seagrass meadows in 2018.
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1 INTRODUCTION

Seagrasses provide a range of 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 also show measurable responses to changes in water quality, making them ideal indicators to monitor the health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993).

1.1 Queensland ports seagrass monitoring program

The majority of Queensland’s commercial ports have a long-term seagrass monitoring and assessment program. The program was developed by the Seagrass Ecology Group at James Cook University’s (JCU) Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) (formerly part of the Department Agriculture and Fisheries) in partnership with the various Queensland port authorities. A common program methods and rationale provides a network of seagrass monitoring locations comparable across the State (Figure 3).

A strategic long-term assessment and monitoring program for seagrass provides port managers and regulators with key information to ensure effective management of seagrass habitat. This information is often central to planning and implementing port development and maintenance programs that ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass. The program also has provided significant advances in the science and knowledge of tropical seagrass ecology. This includes the development of tools, indicators, and thresholds for the protection and management of seagrass, and an understanding of the drivers of seagrass change.

For more information on the program and reports from other monitoring locations, see www.jcu.edu.au/portseagrassqld.

1.2 Mourilyan Harbour Monitoring Program

Following initial surveys conducted between 1993 and 1996, an annual seagrass monitoring program was established in 2000 consisting of a sub-set of five representative meadows in the port (the annual monitoring meadows). The monitoring meadows represent the range of seagrass species, habitat types (intertidal and subtidal) and meadow community types identified within the port limits. This long-term monitoring has helped define the natural variation for seagrass communities and some of the links between seagrass change and climate.

The annual monitoring program is conducted between October and December and provides an assessment of seagrass health, condition and resilience to inform port management. An updated whole of harbour survey of all the seagrasses within the broader port area was conducted in 2015 and 2018 to capture the health and condition of the whole system.
This report discusses the findings of the 2018 annual monitoring and broader whole of harbour survey, including:

- Maps of seagrass distribution, abundance and species composition within the long-term annual monitoring meadows and within the broader whole of harbour area;
- Assessments of seagrass condition in the monitoring meadows within the context of historical seagrass conditions and discussion of the observed changes in a regional and state-wide context;
- Comparison with previous whole of harbour surveys of the extent and composition of seagrass meadows not included in annual monitoring meadows;
- Discussion of the implications of monitoring results in relation to the overall health of the marine environment in the harbour and provide advice for management.
2 METHODS

2.1 Field surveys

Survey and monitoring methods followed the established techniques for TropWATER’s Queensland-wide seagrass monitoring programs. The annual seagrass survey was conducted in October and December 2018 during the seasonal peak of seagrass condition. In addition to the annual monitoring survey, mapping was extended to update the broad distribution of Mourilyan seagrasses that was last conducted in 2015. The survey involved mapping and assessing:

- The 5 annual monitoring meadows that are assessed annually within the harbour;
- All intertidal and subtidal areas extending from the seaward entrance to the port to the south side of Lily Island, including portions of Amrit and Walter Creeks (Figure 7).

Intertidal meadows (Bradshaw, Lily, Seaforth Edge, Seaforth Bank) were surveyed at low tide using a helicopter. GPS was used to map the position of meadow boundaries and sites were scattered haphazardly within each meadow. Sites were surveyed as the helicopter hovered less than one metre above the substrate (Figure 4a). Shallow subtidal meadows (the Channel meadow and some deeper sites off the Seaforth Bank and Seaforth Edge meadows) were sampled by boat using camera drops and van Veen grab (Figure 4b, c). Subtidal sites were positioned at ~100 - 500 m intervals running perpendicular from the shoreline, or where major changes in bottom topography occurred, and extended offshore beyond the edge of each meadow. Random sites also were surveyed within each meadow. The details recorded at each site are listed in Section 2.3.1.

Figure 4: Seagrass monitoring methods in 2018. (a) helicopter survey of intertidal seagrass, (b, c) boat-based camera drops and van Veen grab for subtidal seagrass.

2.2 Seagrass biomass estimates

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (Mellors 1991; Kirkman 1978). At each site a 0.25 m² quadrat was placed randomly with three replicates. An observer assigned a biomass rank to each quadrat while referencing a series of quadrat photographs of similar seagrass habitats where the above-ground biomass had previously been measured. Two separate ranges were used - low biomass and high biomass. The percentage contribution of each species to each quadrat’s biomass also was recorded.

At the survey’s completion, the observer ranked a series of calibration quadrat photographs representative of the range of seagrass biomass and species composition observed during the survey. These calibration quadrats had previously been harvested and the above-ground biomass weighed in the laboratory. A separate regression of ranks and biomass from the calibration quadrats was generated for each observer and applied to the biomass ranks recorded in the field. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (g DW m⁻²) for each of the three replicate quadrats per site. Site biomass, and the biomass of each species, is the mean of the three replicates.
2.3 Geographic Information System

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.4®. Three GIS layers were created to describe seagrass in the survey area: a site layer, biomass interpolation layer and meadow layer.

2.3.1 Site layer
The site (point) layer contains data collected at each site, including:
- Site number
- Temporal details – Survey date and time.
- Spatial details – Latitude, longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
- Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); dugong feeding trail (DFT) presence/absence.
- Sampling method and any relevant comments.

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

2.3.3 Meadow layer
The meadow (polygon) layer provides summary information for all sites within each meadow, including:
- Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys.
- Temporal details – Survey date.
- Habitat information – Mean meadow biomass ± standard error (SE), meadow area (hectares) ± reliability estimate (R) (Table 1), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 2, 3), meadow landscape category (Figure 5).
- Sampling method and any relevant comments.

Meadow boundaries were constructed using GPS marked meadow boundaries where possible, seagrass presence/absence site data, field notes, and aerial photographs taken during helicopter surveys. Meadow area was determined using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 1). Mapping precision ranged from 1 m for intertidal seagrass meadows with boundaries mapped by helicopter to ±30 m for subtidal meadows with boundaries mapped by distance between sites with and without seagrass. The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Meadows were described using a standard nomenclature system developed for Queensland’s seagrass meadows. Seagrass community type was determined using the dominant and other species’ percent contribution to mean meadow biomass (for all sites within a meadow) (Table 3). Community density was based on mean biomass of the dominant species within the meadow (Table 2).

2.4 Environmental data

Environmental data were collated for the 12 months preceding each survey. Tidal data was provided by Maritime Safety Queensland (MSQ) (© The State of Queensland (Department of Transport and Main Roads) 2017, Tidal Data) for Mourilyan (MSQ station #063012A; www.msq.qld.gov.au). Total daily rainfall (mm) was obtained for the nearest weather station from the Australian Bureau of Meteorology (Innisfail station #032025; http://www.bom.gov.au/climate/data/). Johnstone River water flow data (total monthly
Megalitres; ML) was obtained from the Department of Natural Resources and Mines (station #112101B; https://water-monitoring.information.qld.gov.au/). Riverflow data is unavailable for the Moresby River.

**Table 1.** Mapping precision and methodology for seagrass meadows in Mourilyan Harbour.

<table>
<thead>
<tr>
<th>Mapping precision</th>
<th>Mapping methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 1-5 m</td>
<td>Meadow boundaries determined from helicopter; Patchy cover of seagrass throughout meadow; High density of mapping and survey sites;</td>
</tr>
<tr>
<td>± 30 m</td>
<td>Some intertidal meadow boundaries determined from helicopter; Most meadow boundaries determined from camera/grab surveys only; Patchy cover of seagrass throughout meadow; Moderate density of survey sites; Recent aerial photography aided in mapping.</td>
</tr>
</tbody>
</table>

**Table 1.** Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in Mourilyan Harbour.

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

**Table 3.** Nomenclature for community types in Mourilyan Harbour.

<table>
<thead>
<tr>
<th>Community type</th>
<th>Species composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species A</td>
<td>Species A is &gt;90-100% of composition</td>
</tr>
<tr>
<td>Species A with Species B (2 species present)</td>
<td>Species A is &gt;60-90% of composition</td>
</tr>
<tr>
<td>Species A with mixed species (&gt;2 species)</td>
<td>Species A is 40-60% of composition</td>
</tr>
<tr>
<td>Species A/Species B</td>
<td></td>
</tr>
</tbody>
</table>
### Isolated seagrass patches
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

### Aggregated seagrass patches
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

### Continuous seagrass cover
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

**Figure 5.** Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

### 2.5.1 Seagrass 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 each meadow was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). Overall meadow condition is the lowest indicator score where this is driven by biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The flow chart in Figure 6 summarises the methods used to calculate seagrass condition. See Appendix 1 and 2 for full details of score calculation.
Figure 6. Flow chart to develop Mourilyan Harbour grades and scores.
3 RESULTS

3.1 Seagrasses in Mourilyan Harbour

A total of 380 sites were surveyed in the 2018 annual monitoring and broader whole of harbour survey (Figure 7). Four seagrass species from two families were observed (Figures 8 and 9). A total area of 24 ± 9 ha was mapped within the annual monitoring meadows, approximately 30 ha below the long-term average (Figure 1). An additional 8 ± 2 ha of seagrass habitat was mapped in the broader whole of harbour area.

![Map of Mourilyan Harbour showing seagrass presence/absence and monitoring meadows.](image)

**Figure 7.** Seagrass presence/absence at sites surveyed within the whole of harbour survey area, 2018.
Figure 8. Mourilyan Harbour seagrass distribution and community type for all seagrass meadows mapped in 2018.
3.2 Seagrass condition for annual monitoring meadows

Seagrass returned to four of the five annual monitoring meadows in Mourilyan Harbour following the complete absence of seagrass in 2017, however extremely low biomass and restricted meadow areas continue to drive the overall condition score of very poor (Table 6). Individual monitoring meadow condition improved for the large subtidal *Halophila decipiens* Channel meadow due to improvements in all three individual indicators (biomass, area and species composition) (Meadow 5; Figure 14). The remaining three monitoring meadows showed improvement mainly in area and species composition (Table 6; Figures 11 – 13). Only the Bradshaw meadow remained absent in 2018 (Meadow 1; Figure 10).

<table>
<thead>
<tr>
<th>Meadow</th>
<th>Biomass Score</th>
<th>Area Score</th>
<th>Species Composition Score</th>
<th>Overall Meadow Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Bradshaw</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>2 - Lily</td>
<td>0.01</td>
<td>1.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>3 - Seaforth Bank</td>
<td>0.02</td>
<td>0.57</td>
<td>1.00</td>
<td>0.02</td>
</tr>
<tr>
<td>4 - Seaforth Edge</td>
<td>0.00</td>
<td>0.21</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5 - Channel</td>
<td>0.73</td>
<td>0.38</td>
<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Overall Score for the Port of Mourilyan</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.08</strong></td>
</tr>
</tbody>
</table>

Table 2. Grades and scores for seagrass indicators (biomass, area and species composition) for the Mourilyan Harbour annual monitoring meadows 2018. Overall meadow score is the lowest of the biomass or area scores, or where species composition is the lowest score it makes up 50% of the score with the other 50% from the next lowest indicator (see Appendix 1 and Table A3 for a full description of scores and grades).
The subtidal *H. decipiens* meadow in the Channel (Meadow 5) was the only individual monitoring meadow to improve its condition in 2018 from very poor to poor (Figure 14). Following the complete collapse of seagrass in 2017 this meadow has recovered to over 11 ha, (similar recoveries were observed in 2001 and 2011) (Figure 15). Biomass increased to just under the long-term average (1.1 g DW m$^{-2}$) and was in good condition (Figure 14). The Channel meadow has historically been a mix of *H. decipiens*, *H. ovalis* and *H. uninervis* until 2009 when the meadow disappeared. Since 2010 the meadow has been comprised of *Halophila* spp. only (Appendix 3).

Recovery of seagrass meadow area in Mourilyan Harbour has nearly exclusively been due to the small colonising species *H. ovalis* and *H. decipiens*. The higher biomass, foundation species *Z. muelleri* subsp. *capricorni* and *H. uninervis* remain absent from the monitoring meadows. The *Z. muelleri* subsp. *capricorni* that dominated meadows at Bradshaw Island and Lily Island (Meadows 1 and 2) before 2010 has yet to recover (Appendix 3). *H. uninervis* was found within the Channel (Meadow 5) as well as sporadically on Seaforth Bank until 2008. The presence of *H. uninervis* in the adjacent intertidal meadow mapped as part of the whole of harbour survey in 2018 (See section 3.3) may aid the recovery of this species to the Channel meadow. The intertidal Bradshaw meadow (Meadow 1) remains completely absent for the eighth successive year (Figure 10).

The nearby intertidal *H. ovalis* meadow on Seaforth Bank (Meadow 3) has recovered with over 10 ha, the largest area since 2011, although biomass remains extremely low (< 0.1 g DW m$^{-2}$) (Figure 12). Directly adjacent is the intertidal *H. ovalis* meadow on Seaforth Edge (Meadow 4), which has returned as two patches of *H. ovalis* (Figure 13). Biomass and area remain well below the long-term average in both of these meadows (Figures 12 and 13).

Isolated patches of *E. acoroides* were found near Lily Island and Seaforth Bank meadow in the same location as previous years (Figure 8). Biomass and species change calculations for these meadows were performed excluding the contribution of *E. acoroides*. The focus of monitoring at these meadows is to track changes in *Z. muelleri* subsp. *capricorni*, however the presence of the much larger *E. acoroides* in some isolated patches had the potential to mask changes to *Z. muelleri* subsp. *capricorni* between years. This was due to the random site locations occasionally falling on one of these isolated patches.
Figure 10. Changes in biomass, area and species composition for the Bradshaw Island meadow from 1993 – 2018 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.
Figure 11. Changes in biomass, area and species composition for the Lily Island meadows from 1993 – 2018 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.
Figure 12. Changes in biomass, area and species composition for Seaforth Bank meadow from 1993 – 2018 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.
Figure 13. Changes in biomass, area and species composition for the Seaforth Edge meadow from 1993 – 2018 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.
Figure 14. Changes in biomass, area and species composition for the Channel meadow from 1993 – 2018 (biomass error bars = SE; area error bars = “R” reliability estimate). The community type in bold at top represents the baseline community type. CR = calculation restriction due to seagrass absence.
Figure 15. Change in seagrass distribution over time (2007-2018) in Mourilyan Harbour.
3.3 Seagrasses in the whole of harbour area

In addition to the five long-term monitoring meadows assessed annually (see Section 3.2), 11 seagrass meadows were mapped within the whole of Mourilyan Harbour area (Figure 8). These included several small meadows of isolated or aggregated patches of *Halophila* spp. and a continuous intertidal meadow of *H. uninervis* on the sandbanks to the west of the main channel near the mouth of Walter Creek. The *H. uninervis* meadow was also found during the previous whole of harbour survey, and it has increased from a light cover of seagrass with a meadow biomass of 0.56 ± 0.15 g DW m\(^{-2}\) in 2015 to a dense meadow of 5.8 ± 1.35 g DW m\(^{-2}\) in 2018 (Figure 8).

The small *E. acoroides* meadow to the north of Lily Island described in 2015 has developed into a much longer stretch of *H. ovalis* in 2018, though one small patch of *E. acoroides* remains on the edge of the mangroves (Figure 8). No *H. ovalis* meadows were found elsewhere around Lily Island in the previous whole of harbour survey, however several isolated patches as well as an expansion of the Lily monitoring meadow (Meadow 2) outside of the annual monitoring meadow footprint were mapped in 2018.

The 2018 re-mapping of all seagrass habitat within the whole of Mourilyan Harbour shows an increase of 4.2 ha in the total seagrass distribution compared to the previous whole harbour survey in 2015 (Figure 16). In contrast the total area of the annual monitoring meadows was slightly lower (approximately 1.7 ha) in 2018 than in 2015. Species were similar in both surveys. The *Halophila* spp. meadows had similar biomass in 2015 as in 2018. The *H. uninervis* meadow had substantially increased in biomass in 2018 compared with 2015. This is a positive sign for the recovery of the larger species within Mourilyan Harbour and may also aid recovery within the adjacent annual monitoring meadows in the future. Total seagrass area in the harbour however remained substantially lower in both 2018 and 2015 compared with earlier surveys that encompassed the whole harbour in 1993 and 2001 (Figure 16). Consistent with the trends in the annual monitoring meadows since 2009.

![Figure 16. Comparison of total seagrass area (hectares) in the broader Mourilyan Harbour region in 1993, 2001, 2015 and 2018.](image-url)
3.4 Mourilyan Climate Patterns

3.4.1 Rainfall
Total annual rainfall in Mourilyan Harbour during the twelve months preceding the 2018 survey was below the long-term average annual rainfall (3549 mm) since 2013 (Figure 16). Rainfall spiked above average in March 2018 with (1346 mm) and December 2018 with (853 mm) and remained near or below average for the rest of the year (Figure 17).

![Figure 16. Total annual rainfall (mm) recorded in the twelve months prior to survey, at Innisfail, 2001 – 2018. Source: Bureau of Meteorology, Station 032025, available at: www.bom.gov.au.](image1)

![Figure 17. Total monthly rainfall (mm) recorded at Innisfail, January 2017 – December 2018. Source: Bureau of Meteorology, Station 032025, available at: www.bom.gov.au.](image2)
3.4.2 River Flow
River flow data for the Moresby River which flows directly into Mourilyan Harbour is not available. River flow of the South Johnstone River (in Innisfail to the north of Mourilyan Harbour) for twelve months prior to the survey was above the long-term average (808 gigalitres) with 1011 gigalitres following three years below the long-term average (Figure 18). River flow output was above average from January through July 2018, with particularly high spikes in February – April 2018 (Figure 19).

![Mean Annual River Flow Output since 1994 (Gigalitres)](image)


![Monthly water flow (gigalitres) for the South Johnston River recorded at Upstream Central Mill, January 2016 – December 2018](image)

3.4.3 Air Temperature and Daily Global Solar Exposure

Mean annual maximum daily air temperature of 28.2°C recorded at Innisfail in 2018 was well above the longterm average of 27.9°C (Figure 20). Daily global solar exposure is a measure of the total amount of solar energy falling on a horizontal surface. The values are usually highest in clear, sunny conditions during the spring/summer prior to the wet season and lowest during winter. Solar exposure in the twelve months leading up to the survey was above average for the second year at 20 MJ m⁻² (Figure 21).

![Average Max Daily Air Temperature (°C) since 1968](image)

**Figure 20.** Mean annual maximum daily air temperature (°C) recorded at Innisfail in the twelve months prior to survey, 2000 – 2018. Source: Bureau of Meteorology, Station 032025, available at: [www.bom.gov.au](http://www.bom.gov.au).

![Average Daily Global Exposure since 1990](image)

**Figure 21.** Mean annual daily global solar exposure (MJ m⁻²) recorded at Innisfail in the twelve months prior to survey, 2000 – 2018. Source: Bureau of Meteorology, Station 032025, available at: [www.bom.gov.au](http://www.bom.gov.au).
3.4.4 Tidal Exposure of Seagrass Meadows

Total annual daytime exposure of intertidal seagrass meadows in 2018 (150 hours) remained the same as 2017 and was well below the long-term average (179 hours) (Figure 22). Daytime exposure of Mourilyan Harbour intertidal banks was just over the long-term average for the first six months of the year, and apart from the survey month October 2018 well below average for the second half of the year, (Figure 23).

Figure 22. Annual daytime tidal exposure (total hours)* of seagrass meadows in Mourilyan Harbour in the twelve months prior to survey; 2000 - 2018. Source: Maritime Safety Queensland, 2019. * Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.

Figure 23. Total monthly daytime tidal exposure (total hours)* in Mourilyan Harbour; January 2017 – December 2018. Source: Maritime Safety Queensland, 2019.* Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.
The one and three month time intervals preceding the survey are most likely to influence the growth of seagrass. In the month preceding the survey, the total numbers of hours that intertidal banks were exposed was much greater than it was in that same time interval prior to the survey since 2011, (Figure 24). Tidal exposure in the three months preceding the survey was the greatest since 2012 (Figure 24).

**Figure 24.** Total monthly daytime tidal exposure (total hours)* in Mourilyan Harbour in the one and three months prior to the annual survey 2003 – 2018. Source: Maritime Safety Queensland, 2019.* Assumes intertidal banks become exposed at a tide height of 0.8m above Lowest Astronomical Tide.
4 DISCUSSION

Seagrasses in Mourilyan Harbour annual monitoring meadows remain in very poor condition. While there has been recovery of area in annual monitoring meadows through colonising species, seagrass meadows in the harbour have yet to return to pre-cyclone disturbance levels despite several years of favourable climate conditions. The larger foundation species $Z.\ muelleri$ subsp. $capricorni$ and $H.\ uninervis$ remain absent from the annual monitoring meadows. The whole of harbour survey conducted in 2018 found several patches of $E.\ acoroides$ throughout the harbour and a large strip of $H.\ uninervis$ adjacent to the Channel, potentially enabling recovery of this species in the nearby monitoring meadow. However $Z.\ muelleri$ subsp. $capricorni$ has not been detected anywhere in the harbour since 2009, and the best opportunity for recovery of this important fisheries nursery habitat can only be through a restoration intervention.

The recovery of intertidal and subtidal annual meadows due to $Halophila$ spp. was expected as these small, early colonisers are typically the first to return following disturbance (Rasheed 2004). Their return, as well as increased meadow coverage in the whole of harbour, suggests that in the year leading up to the 2018 survey local conditions were suited to the growth of seagrass, where sources of seeds or propagules were available. The climate conditions appear to have been favourable for the last several years. Total annual rainfall has been below average since 2013, with river flow generally the same. Temperature was above average but unlikely to be at levels that would pose a problem to the seagrass species present in the harbour (Campbell et al. 2006). Tidal exposure has been well below the long-term average since 2009, indicating that sustained declines are unlikely to have been due to desiccation or thermal stress (Unsworth et al. 2012).

Catchment water quality issues could be playing a significant role in inhibiting seagrass recovery. The Environmental factors which may contribute to poor condition of seagrasses are the ones which are not measured in-situ in Mourilyan Harbour; water quality, light availability and nutrient conditions. No data is available for the Moresby River, which flows directly into Mourilyan Harbour and is likely a major contributing factor to the environmental health of the harbour. Seagrass meadows have been highly variable in their distribution over the last several years, however the continued presence of at least some seagrass on the intertidal banks and the quick recovery following collapse suggests that environmental conditions are not responsible, and that the impediment to recovery lies in recruitment of seeds and/or availability of propagules from which meadows can re-establish.

Seagrass meadows have historically been highly variable in Mourilyan Harbour. Declines in density and distribution in 2002/2003, largely attributed to local climate and flooding events (Sankey, Rasheed and Unsworth 2009; McKenna et al 2008), appeared to be confined to intertidal meadows while subtidal seagrasses remained relatively stable. The declines were attributed to high solar irradiance and temperatures causing stress to seagrasses (Thomas and Rasheed 2004), and were observed in other Queensland locations during this time. Seagrass collapse between 2008 and 2011 was likely a result of severe La Niña weather events, and impacts from Cyclone Larry (2006) and Cyclone Yasi (2011) that also affected seagrasses on a regional scale (McKenna et al. 2015; Rasheed et al. 2014). While these impacts were documented along the coast, the trajectory of recovery has been quite different for Mourilyan Harbour compared with nearby monitoring locations such as Cairns and Townsville. In these locations, the foundation species in monitoring meadows were reduced to small remnant patches or to severely restricted meadow distributions (Jarvis et al 2014; Davies et al 2014). Cairns has shown significant recovery in meadow area and by 2018, a seagrass seed bank for the foundation species $Z.\ muelleri$ subsp. $capricorni$ was found in the port (Rasheed et al 2019). Townsville seagrasses have reached the second highest combined meadow area recorded and species composition returned to pre-cyclone disturbance levels with the return of the larger, foundation species (Bryant et al 2019).

The degree to which recovery is possible for Mourilyan Harbour is limited by the availability of a viable seed bank and a source of new seagrass propagules. The trajectory of recovery is also affected by the initial impact, and subsequent severe weather events. While Mourilyan, Cairns and Townsville have suffered severe meadow collapse, the complete disappearance of foundation species in Mourilyan by 2010 left no remnant
adult plants to facilitate rapid recovery. Tropical Cyclone Yasi in 2011 would only serve to further reduce the already diminished seagrass condition in Mourilyan Harbour. Without a standing stock to replenish underground seed stores, the seed bank has been depleted and since 2014 no *Z. muelleri* subsp. *capricorni* seeds have been detected in the harbour (Reason and Rasheed 2017). If any *Z. muelleri* subsp. *capricorni* seeds do remain buried in the sediment, it is very unlikely that they would still be viable given the time that has elapsed. Studies of the seedbank in Cairns Harbour have shown greatly reduced viability within 18 months of seagrass loss (Jarvis et al. 2013). A combination of a relatively closed estuary and considerable distances to other potential donor meadows (Cairns or Townsville are the nearest major *Z. muelleri* subsp. *capricorni* meadows) indicate that recruitment via dispersal from outside sources is unlikely.

### 4.1 Implications for Management of the Harbour

The loss of the high fisheries nursery value *Z. muelleri* subsp. *capricorni* seagrass meadows remains the biggest issue in the management of the marine environment of Mourilyan Harbour. During baseline assessments in 1993 these seagrass meadows were found to support high numbers of juvenile prawn species of commercial importance including tiger and endeavour prawns as well as a variety of juvenile fish of species valuable to recreational fisheries (McKenzie et al. 1996). The loss of these key nursery grounds is likely to have flow on effects to the local ecology of the harbour. After several years of absence and little prospect of natural recovery the case for assessing and trialling restoration of *Z. muelleri* subsp. *capricorni* in Mourilyan Harbour is compelling. The Bradshaw Island meadow has had a long history of supporting this species and covers a relatively small area, it would provide an ideal site for a project to trial both seed and vegetative methods of restoration in tropical Queensland.

While the recovery of colonising species to both intertidal and subtidal monitoring meadows is a positive sign for seagrasses in Mourilyan Harbour, the region remains highly vulnerable. Future development activities in the Moresby River and its catchment may impact on the vulnerability of the seagrasses and ongoing management strategies need to include protection of seagrasses and ensuring their recovery and long-term viability.
5 REFERENCES


APPENDICES

Appendix 1. Seagrass Condition Index

Baseline Calculations
Baseline conditions for seagrass biomass, meadow area and species composition were established from annual means calculated over the first 10 years of monitoring (1993/94 – 2005/06). The 1993/94 – 2005/06 period incorporates a range of conditions present in Mourilyan Harbour, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events (McKenna et al. 2007). This will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). In 2016 an additional rule was applied: where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Grade and Score Calculations section and Figure A1).

Meadow Classification
A meadow classification system was developed for the three condition indicators (biomass, area, species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass, area and species composition was classified as either stable or variable (Table A1). One further classification for meadow area was added in the 2016 reporting year: highly stable (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

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

<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>&lt; 40%</td>
</tr>
<tr>
<td>Area</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Species composition</td>
<td>&lt; 40%</td>
</tr>
</tbody>
</table>

Threshold Definition
Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).
Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

<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>

Grade and Score Calculations
A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows within a port, and among all the ports monitored by TropWATER (Table A3, see Carter et al. 2015 for a detailed description).

Score calculations for each meadow’s condition required calculating the biomass, area and species composition for that year (see Baseline Calculations section), allocating a grade for each indicator by comparing 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 A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period.
**Table A3.** Score range and grading colours used in the 2018 Mourilyan Harbour report card.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Score Range</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Very good</td>
<td>≥0.85</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Good</td>
<td>≥0.65</td>
<td>&lt;0.85</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Satisfactory</td>
<td>≥0.50</td>
<td>&lt;0.65</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Poor</td>
<td>≥0.25</td>
<td>&lt;0.50</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Very poor</td>
<td>0.00</td>
<td>&lt;0.25</td>
<td></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 A1). If this was the case, then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from Z. muelleri subsp. capricorni to H. ovalis). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between H. uninervis and Z. muelleri), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from H. decipiens to H. uninervis or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning S. isoetifolium further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows (Rasheed 2004); and (2) separating and ordering the Halophila genera by species. Shifts between Halophila species are ecologically relevant; for example, a shift from H. ovalis to H. decipiens, may indicate declines in water quality and available light for seagrass growth as H decipiens has a lower light requirement (Collier et al. 2016) (Figure A1).
Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition in Mourilyan Harbour.

Score Aggregation
A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years’ annual report. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change acknowledges that species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the
overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such as food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a “0” score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lower of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in Mourilyan Harbour as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Abbot Point, Mackay, Hay Point, Port Curtis, Torres Strait, Weipa and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across Gladstone (and the other locations), where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Overall Mourilyan Harbour grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The meadow classification process applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Port grades are therefore more sensitive to changes in stable than variable meadows.
Appendix 2. Example of calculations meadow condition scores

An example of calculating a meadow score for an area in satisfactory condition.

1. Determine the grade for the 2018 (current) area value (i.e. satisfactory).

2. Calculate the difference in area ($A_{\text{diff}}$) between the 2018 area value ($A_{2018}$) and the area value of the lower threshold boundary for the satisfactory grade ($A_{\text{satisfactory}}$):

   $$A_{\text{diff}} = A_{2018} - A_{\text{satisfactory}}$$

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

3. Calculate the range for area values ($A_{\text{range}}$) in that grade:

   $$A_{\text{range}} = A_{\text{good}} - A_{\text{satisfactory}}$$

   Where $A_{\text{satisfactory}}$ is the upper threshold boundary for the satisfactory grade.

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

4. Calculate the proportion of the satisfactory grade ($A_{\text{prop}}$) that $A_{2018}$ takes up:

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

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

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

   Where $LB_{\text{satisfactory}}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.
Appendix 3. Detailed species composition of monitoring meadows

## Appendix 4a. Area changes: 1993 – 2018

Seagrass monitoring meadow area (ha) in Mourilyan Harbour, 1993-2018 (±R = reliability estimate).

<table>
<thead>
<tr>
<th>Meadow (ID no.)</th>
<th>Jan 1993 ±1.9</th>
<th>Dec 1994 ±0.8</th>
<th>Jan 1995 ±0.9</th>
<th>Dec 1996 ±0.4</th>
<th>Dec 2000 ±0.5</th>
<th>Dec 2001 ±0.4</th>
<th>Dec 2002 ±0.5</th>
<th>Dec 2003 ±0.4</th>
<th>Nov 2004 ±0.5</th>
<th>Nov 2005 ±0.5</th>
<th>Oct Dec 2007 ±0.5</th>
<th>Oct Dec 2008 ±0.5</th>
<th>Nov 2009 ±0.5</th>
<th>Oct Nov 2010 ±0.5</th>
<th>Oct Nov 2011 ±0.5</th>
<th>Oct 2012 ±0.5</th>
<th>Dec 2013 ±0.5</th>
<th>Sept 2014 ±0.5</th>
<th>Oct 2015 ±0.5</th>
<th>Oct 2016 ±0.5</th>
<th>Oct 2017 ±0.5</th>
<th>Oct Dec 2018 ±0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bradshaw (1)</td>
<td>3.7 ±1.9</td>
<td>2.5 ±0.8</td>
<td>2.7 ±0.9</td>
<td>3.4 ±0.4</td>
<td>3.0 ±0.5</td>
<td>4.1 ±0.5</td>
<td>3.6 ±0.4</td>
<td>3.3 ±0.5</td>
<td>3.0 ±0.5</td>
<td>2.7 ±0.5</td>
<td>3.4 ±0.5</td>
<td>3.0 ±0.5</td>
<td>2.4 ±0.4</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td>Lily (2)</td>
<td>0.9 ±0.4</td>
<td>1.0 ±0.5</td>
<td>0.8 ±0.3</td>
<td>1.1 ±0.2</td>
<td>1.4 ±0.3</td>
<td>1.8 ±0.3</td>
<td>1.0 ±0.4</td>
<td>1.2 ±0.4</td>
<td>0.5 ±0.2</td>
<td>0.4 ±0.2</td>
<td>0.4 ±0.2</td>
<td>1.74 ±0.3</td>
<td>0.4 ±0.2</td>
<td>NP</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
<td>0.283 ±0.16</td>
</tr>
<tr>
<td>Seaforth Bank (3)</td>
<td>22.1 ±4.0</td>
<td>27.5 ±5.5</td>
<td>23.1 ±6.0</td>
<td>19.7 ±7.1</td>
<td>15.6 ±2.8</td>
<td>29.8 ±0.5</td>
<td>NP</td>
<td>6.3 ±2.2</td>
<td>13.1 ±2.6</td>
<td>4.0 ±1.1</td>
<td>1.9 ±1.3</td>
<td>0.9 ±0.7</td>
<td>NP</td>
<td>25.1 ±1.4</td>
<td>0.6 ±0.1</td>
<td>0.02 ±0.01</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td>Seaforth Edge (4)</td>
<td>2.6 ±1.8</td>
<td>3.0 ±1.4</td>
<td>3.3 ±2.1</td>
<td>3.4 ±3.3</td>
<td>NP</td>
<td>5.2 ±4.2</td>
<td>2.9 ±1.2</td>
<td>0.2 ±0.1</td>
<td>3.3 ±0.9</td>
<td>3.3 ±0.7</td>
<td>1.5 ±0.8</td>
<td>0.1 ±0.0</td>
<td>NP</td>
<td>2.1 ±0.9</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>0.47 ±0.20</td>
</tr>
<tr>
<td>Channel (5)</td>
<td>20.0 ±5.63</td>
<td>37.1 ±6.4</td>
<td>55.4 ±9.2</td>
<td>30.3 ±18.8</td>
<td>NP</td>
<td>34.1 ±9.8</td>
<td>25.7 ±10.4</td>
<td>28.8 ±14.1</td>
<td>38.4 ±15.3</td>
<td>47.8 ±13.9</td>
<td>40.8 ±11.1</td>
<td>21.9 ±7.6</td>
<td>27.8 ±7.6</td>
<td>NP</td>
<td>0.11 ±0.0</td>
<td>12.0 ±9.0</td>
<td>25.9 ±15.9</td>
<td>7.5 ±6.3</td>
<td>53.2 ±18.9</td>
<td>25.70 ±12.33</td>
<td>11.39 ±7.1</td>
<td>11.18 ±7.37</td>
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<tr>
<td>Total (ha) COMBINED</td>
<td>49.6 ±13.8</td>
<td>71.3 ±14.7</td>
<td>85.6 ±18.6</td>
<td>57.4 ±29.1</td>
<td>20.2 ±7.8</td>
<td>74.0 ±17.7</td>
<td>35.0 ±13.1</td>
<td>34.5 ±14.9</td>
<td>52.4 ±19.4</td>
<td>68.5 ±18.2</td>
<td>48.1 ±13.0</td>
<td>29.6 ±10.5</td>
<td>32.4 ±9.1</td>
<td>2.7 ±0.6</td>
<td>0.51 ±0.3</td>
<td>47.3 ±12.0</td>
<td>27.7 ±16.4</td>
<td>8.0 ±6.5</td>
<td>53.2 ±18.9</td>
<td>25.70 ±12.33</td>
<td>11.67 ±7.26</td>
<td>NP</td>
</tr>
</tbody>
</table>

NP - seagrass not present.
Appendix 4b. Above-Ground Biomass changes: 1993 – 2018

Mean above-ground biomass (g DW m\(^{-2}\)) of seagrass for monitoring meadows in Mourilyan Harbour, 1993-2018.

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<tbody>
<tr>
<td>Bradshaw (1)</td>
<td>37.8 ±11.5</td>
<td>45.1 ±3.5</td>
<td>49.2 ±2.9</td>
<td>59.4 ±5.4</td>
<td>17.5 ±1.3</td>
<td>35.8 ±5.3</td>
<td>32.1 ±2.0</td>
<td>21.5 ±3.4</td>
<td>59.3 ±6.9</td>
<td>34.1 ±3.6</td>
<td>46.5 ±4.1</td>
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<td>15.5 ±2.9</td>
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<tr>
<td>Lily (2)</td>
<td>16.1 ±10</td>
<td>30.4 ±4.5</td>
<td>29.4 ±2.0</td>
<td>29.8 ±2.9</td>
<td>7.6 ±0.5</td>
<td>5.5 ±1.5</td>
<td>20.6 ±3.0</td>
<td>5.0 ±2.3</td>
<td>12.3 ±3.6</td>
<td>0.1 ±0.1</td>
<td>2.4 ±0.8</td>
<td>2.8 ±0.6</td>
<td>4.3 ±2.9</td>
<td>0.03 ±0.01</td>
<td>0.57 ±0.13</td>
<td>0.37 ±0.01</td>
<td>0.03 ±0.01</td>
<td>0.4 ±0.2</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>0.17 ±0.004</td>
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<tr>
<td>Seaforth Bank (3)</td>
<td>0.9 ±0.2</td>
<td>0.7 ±0.2</td>
<td>1.1 ±0.2</td>
<td>3.0 ±0.5</td>
<td>0.2 ±0.05</td>
<td>2.4 ±0.4</td>
<td>0.3 ±0.2</td>
<td>NP</td>
<td>0.5 ±0.1</td>
<td>0.02 ±0.005</td>
<td>0.06 ±0.02</td>
<td>NP</td>
<td>0.02 ±0.006</td>
<td>NP</td>
<td>0.3 ±0.06</td>
<td>0.03 ±0.01</td>
<td>0.1 ±0.1</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>0.01 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Seaforth Edge (4)</td>
<td>1.8 ±0.4</td>
<td>2.0 ±0.5</td>
<td>1.6 ±0.2</td>
<td>3.3 ±0.8</td>
<td>NP</td>
<td>2.1 ±0.4</td>
<td>1.6 ±0.2</td>
<td>0.02 ±0.02</td>
<td>1.2 ±0.3</td>
<td>0.1 ±0.1</td>
<td>NP</td>
<td>1.1 ±0.03</td>
<td>NR</td>
<td>2.5 ±0.8</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NR</td>
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<td></td>
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<tr>
<td>Channel (5)</td>
<td>0.4 ±0.1</td>
<td>1.8 ±0.6</td>
<td>1.4 ±0.2</td>
<td>2.7 ±0.6</td>
<td>NP</td>
<td>0.6 ±0.1</td>
<td>1.0 ±0.1</td>
<td>0.8 ±0.2</td>
<td>1.0 ±0.2</td>
<td>1.2 ±0.4</td>
<td>2.3 ±0.5</td>
<td>2.5 ±0.3</td>
<td>1.5 ±0.3</td>
<td>NP</td>
<td>1.94 ±0.1</td>
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<td>2.1 ±0.3</td>
<td>2.4 ±0.2</td>
<td>0.87 ±0.24</td>
<td>0.70 ±0.27</td>
<td>NP</td>
<td>1.03 ± 0.44</td>
</tr>
</tbody>
</table>

NR (Not recorded) - seagrass present but too sparse to record biomass; NP - seagrass not present.