Great Barrier Reef Water Quality Protection Plan – Marine Monitoring Program

Intertidal Seagrass

Draft FINAL REPORT

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Project 1.1.3 Condition trend and risk in coastal habitats: Seagrass Indicators, distribution and thresholds of potential concern.
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Executive summary

- The dominant species of seagrass present along the east coast of Queensland within the monitoring sites were *Halophila ovalis*, *Halodule uninervis* and *Zostera capricorni*. *Halophila ovalis* occurred ubiquitously, *Halodule uninervis* was found at nine of the 11 locations monitored, while *Zostera capricorni* was collected from five locations. Although *Zostera* communities are found all along the coast of Queensland, they only dominant southern intertidal meadows and are not common or representative of intertidal meadows in the north (www.seagrasswatch.org). Tissue nutrient and reproductive assessments were restricted to these dominant species.

- Seagrass cover and abundance was generally low in 2006 compared to previous years, however levels in April 2007 show recovery.

- Seagrass biomass across the monitored sites was lower in 2006 than in 2007.

- *Halodule uninervis* was the most sexually active species at locations in the north, and *Zostera capricorni* in the south. This reflects the dominance of these species in the respective regions. Nearly all locations had reproductive structures or seeds present, with the exception of Green Island, where asexual growth dominates. Other locations where reproductive structures were absent, the presence of a seed bank (albeit often small) confirmed sexual growth.

- Flowers occurred more often during the monsoon in the most northern regions (Cape York and Far North Queensland). However in central regions (Burdekin Dry Tropics and Mackay Whitsundays), although flowers occurred throughout the year, they were more prevalent in the Dry Season. In the southern regions where *Zostera capricorni* dominated, spathes were only present in the Dry Season and flowers only occurred in the Monsoon.

- Seeds were more common at coastal than offshore locations. The region with the greatest seed banks was Burdekin Dry Tropics followed by Mackay Whitsundays and Far North Queensland NRMs. With the exception of Cape York, the size of seed banks did not change significantly between seasons within regions.

- Levels of adsorbed ammonium within the seagrass rhizosphere were similar between years, however the levels of adsorbed phosphate were lower in 2006.

- Sediment N:P ratios were generally below one depicting a sediment pool that has a higher proportion of phosphate than nitrogen.

- Plant tissue nutrients (%C, %N, %P) were higher in 2006, and plant tissue nutrient ratios displayed stronger spatial patterns than temporal patterns.

- Examination of plant tissue C:N and C:P ratios was able to differentiate between coastal and reef seagrass habitat types inferring a distinction between low light, and comparatively higher light environments.
- *Halophila ovalis* recorded low tissue N:P ratios inferring nitrogen limitation throughout the region, possibly a consequence of a high nitrogen demand due to its rapid growth strategies and turnover rates.

- The structurally larger seagrasses (*Halodule uninervis, Zostera capricorni*) had tissue N:P ratios that inferred they were nutrient replete.

- Within canopy temperature were not unusually high compared to pervious years of monitoring and no extreme peaks in maximum temperatures recorded above 40°C during the past 12 months.
1. Introduction

A key component of the RQWPP is the implementation of a long-term water quality and ecosystem monitoring program in the Great Barrier Reef lagoon. The Great Barrier Reef Marine Park Authority (GBRMPA) has responsibility for implementation of this program. The Queensland Department of Primary Industries & Fisheries (DPI&F) have been contracted to provide the intertidal seagrass monitoring component.

The key aims of this component of the programme are to:

a. Detect long-term trends in seagrass abundance, community structure, distribution, reproductive health and nutrient status from representative intertidal seagrass meadows in relation to large river inputs (provided by other programmes) into the GBRWHA.

b. Detect long-term trends in levels of ecologically significant nutrient pollutants from representative intertidal seagrass meadows in relation to large river inputs into the GBRWHA.

c. To work closely with and involve community partners (Seagrass-Watch) to ensure broad acceptance and ownership of the RWQPP by the Queensland and Australian community.

Background

There are nearly 6,000 km² of seagrasses in waters shallower than 15 metres, relatively close to the coast, and in locations that can potentially be influenced by adjacent land use practices. Monitoring of the major marine ecosystem types most at risk from land based sources of pollutants is being conducted to ensure that any change in their status is identified. Seagrass monitoring sites have been located as close as practically possible (dependent on historical monitoring and location of existing meadows) to river mouth and inshore marine water quality monitoring programs to enable correlation and concurrently collected water quality information.

One of the paramount requirements of the RWQPP monitoring program, apart from being scientifically robust, is that its findings must have broad acceptance and ownership by the North Queensland and Australian community. It was identified very early in development of the RWQPP, that the existing Seagrass-Watch program was an excellent opportunity on which the inshore seagrass monitoring component could be based. It was designed such that the ongoing community volunteer monitoring activities were enhanced through;

- Value adding by collecting other information by scientists in the field,
- Where community groups can not monitor DPI&F staff and FFS trained personnel collect the data.

DPI&F has developed long-term collaboration/partnerships with individuals, community groups and government organizations participating in the Seagrass-Watch program to help monitor and collect samples for long-term condition and trend assessment of Queensland’s seagrass resources. Volunteers collect quantitative data on seagrasses and their associated fauna by means of simple yet scientifically rigorous monitoring techniques. For detailed
reports on each location/region, visit the long-term monitoring section of the website at www.seagrasswatch.org.

In late 2004 all existing Seagrass-Watch data was supplied to Glenn De’ath (AIMS) for independent review. De’ath (2005) analysed the available Seagrass-Watch dataset to estimate expected performance of the monitoring program. He included data from 2000–2004 at 63 sites in 29 locations in 6 regions (Cooktown, Cairns, Townsville, Whitsundays, Hervey Bay, Great Sandy Strait). Results concluded that the Seagrass-Watch monitoring is providing valuable information about temporal trends and spatial differences, with changes in seagrass cover occurring at various spatial and temporal scales. The monitoring showed recovery in the Hervey Bay Region, from ~3% cover in 2000 increasing to ~17% cover in 2004. The report recommended that the value of the monitoring would be greatly enhanced by adding more widely spread regions to the surveys.

There are 15 species of seagrass in the GBRWHA. A high diversity of seagrass habitats is provided by extensive bays, estuaries, rivers and the 2600 km of Great Barrier Reef with its reef platforms and inshore lagoon. They can be found on sand or muddy beaches, on reef platforms and in reef lagoons, and on sandy and muddy bottoms down to 60 metres or more below MSL. There is in excess of 5,000 km² of coastal seagrass meadows in eastern Queensland waters shallower than 15 metres and it is likely that approximately 40,000km² of the seafloor in the GBRWHA deeper than 15 metres has some seagrass (Coles et al. 2003a). This represents about 36% of the total recorded area of seagrass in Australia.

Seagrasses in the GBRWHA can be split into four major habitat types: estuary/inlet, coastal, reef and deepwater (Carruthers et al. 2002) (Figure 1). All but the outer reef habitats are significantly influenced by seasonal and episodic pulses of sediment laden, nutrient rich river flows, resulting from high volume summer rainfall. Cyclones, severe storms, wind and waves as well as macro grazers (fish, dugongs and turtles) influence all habitats in this region to varying degrees. The result is a series of dynamic, spatially and temporally variable seagrass meadows.

Figure 1. General conceptual model of seagrass habitats in north east Australia (from Carruthers et al. 2002)

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Methodolgy

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures.]

Sites were monitored as scheduled (Table 1). This included the original 22 sites and four additional sites to broaden the coverage of offshore intertidal sites as per recommendation of the SAP 06. Offshore sites were successfully established and sampled at Dunk Island in April 2007. Difficulty in locating suitable meadows at Hamilton Island and Great Keppel resulted in only one site being sampled respectively at each location. An evaluation of the suitability and further reconnaissance of these meadows is required, as at the time of sampling the meadows were very sparse and a significant number of zero % covers were returned.

A description of all the data collected to date under the monitoring contract has been collated by NRM region site, parameter, and the number of samples collected per sampling period is listed in Table 3. The presence of the targeted seagrass species at monitoring sites is listed in Table 3.

Inter-tidal seagrass monitoring

Survey methodology followed Seagrass-Watch standard methodology (www.seagrasswatch.org, McKenzie et al., 2004, 2005a, b; see also www.seagrasswatch.org). At each sampling location, sampling includes two sites nested in location and three 50m transects nested in each site. A site is defined as a 50m x 50m area within a relatively homogenous section of a representative seagrass community/meadow (McKenzie et al 2000). Community-based monitoring at the sites identified for the Reef Plan MMP long-term intertidal monitoring in late dry and late monsoon of each year is supervised on-site by a qualified and trained scientist. Monitoring conducted outside these months, is conducted by trained community volunteers. An additional six sites at offshore intertidal locations as per Table 1 were scoped for inclusion (recommendation of the SAP 2006), during the late Monsoon Season (2007). Sites are monitored for seagrass cover and species composition. Additional information is collected on canopy height, algae cover and epiphyte cover and macrofaunal abundance. An assessment of Halodule uninervis reproductive health is also conducted via seedbank monitoring.

Monitoring of within canopy temperatures was also recorded at all established sites with an additional temperature loggers placed at Dunk Island sites and Hamilton Island.

Edge mapping

Mapping the edge of the seagrass meadow within 100m of each monitoring site was conducted at all sites in the October 2006 and April 2007 monitoring periods. Training and equipment (GPS) were provided to personnel involved in the edge mapping.
Table 1. Seagrass-Watch sites selected for Reef Plan MMP intertidal seagrass long-term monitoring

<table>
<thead>
<tr>
<th>GBR region</th>
<th>NRM Board</th>
<th>Catchment</th>
<th>Seagrass monitoring location</th>
<th>Site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Seagrass community type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far Northern</td>
<td>Cape York</td>
<td>Endeavour</td>
<td>Cooktown Coastal intertidal</td>
<td>AP1</td>
<td>15° 36.5</td>
<td>145° 19.143</td>
<td>H. uninervis/H. ovalis with Cymodocea/T. hemprichii</td>
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<td>AP2</td>
<td>15° 36.525</td>
<td>145° 19.108</td>
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<td></td>
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<td>Russell / Mulgrave Johnstone</td>
<td>Green Island Offshore intertidal</td>
<td>GI1</td>
<td>16° 45.789</td>
<td>145° 58.31</td>
<td>C. rotundata/T. hemprichii with H. uninervis/H. ovalis</td>
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<td></td>
<td>GI2</td>
<td>16° 45.776</td>
<td>145° 58.501</td>
<td>C. rotundata/T. hemprichii with H. uninervis/H. ovalis</td>
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<td>Cairns Coastal intertidal</td>
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<td>YP1</td>
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<td>145° 30.744</td>
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<td>YP2</td>
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<td>Tully</td>
<td>Mission Beach Coastal intertidal</td>
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<td>146° 5.61</td>
<td>H. uninervis</td>
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<td></td>
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<td></td>
<td>LB2</td>
<td>17° 57.674</td>
<td>146° 5.612</td>
<td>H. uninervis</td>
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<td></td>
<td>Dunk Island Offshore intertidal</td>
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<td>DI1</td>
<td>17° 56.6496</td>
<td>146° 8.4654</td>
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<td>DI2</td>
<td>17° 56.7396</td>
<td>146° 8.4624</td>
<td>H. uninervis with T. hemprichii/C. rotundata</td>
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<td>Burdekin</td>
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<td>Magnetic island Offshore intertidal</td>
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<td>MI1</td>
<td>19° 10.734</td>
<td>146° 50.468</td>
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<td>MI2</td>
<td>19° 10.612</td>
<td>146° 49.737</td>
<td>H. ovalis with C. serrulata &amp; T. hemprichii/H. uninervis</td>
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<td>Townsville Coastal intertidal</td>
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<td>SB1</td>
<td>19° 11.046</td>
<td>146° 45.697</td>
<td>H. uninervis with H. ovalis &amp; Zostera/H. spinulosa</td>
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<td>BB1</td>
<td>19° 11.028</td>
<td>146° 40.951</td>
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<td>Central</td>
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<td>Proserpine</td>
<td>Whitsundays Coastal intertidal</td>
<td>PI2</td>
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<td>148° 41.586</td>
<td>H. uninervis/H. ovalis with Zostera &amp; H. spinulosa</td>
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<td>PI3</td>
<td>20° 16.248</td>
<td>148° 41.844</td>
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<td>Mackay / Whitsunday</td>
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<td>Whitsundays Offshore intertidal</td>
<td>HM1</td>
<td>20° 20.7396</td>
<td>148° 57.5658</td>
<td>H. uninervis with H. ovalis</td>
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<td>Pioneer</td>
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<td></td>
<td>SI1</td>
<td>21° 23.76</td>
<td>149° 18.2</td>
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<td></td>
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<td>SI2</td>
<td>21° 23.712</td>
<td>149° 18.276</td>
<td>Zostera capricorni</td>
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<td></td>
<td>Fitzroy</td>
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<td>RC</td>
<td>22° 22.953</td>
<td>150° 12.685</td>
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<td>22° 23.926</td>
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<td>GK1</td>
<td>to be established</td>
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<td>Gladstone Coastal intertidal</td>
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<td>23° 46.005</td>
<td>151° 18.052</td>
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<td>UG1</td>
<td>25° 18.053</td>
<td>152° 54.409</td>
<td>Zostera capricorni with H. ovalis &amp; H. uninervis</td>
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<td>UG2</td>
<td>25° 18.197</td>
<td>152° 54.364</td>
<td>Zostera capricorni with H. ovalis</td>
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</tbody>
</table>
Table 2. Number of samples collected at each monitoring site per parameter for each sampling event (Late Dry Season (2006) late Monsoon Season (2007)). Activities include: SG = seagrass cover & composition, SM = seed monitoring, TN=tissue nutrients, SN=sediment nutrients, EM=edge mapping, RH=reproductive health, Temperature loggers deployed, # = supplementary activity, shaded cell=completed *after locating seagrass at this location, not enough time to sample

<table>
<thead>
<tr>
<th>Sector</th>
<th>Region</th>
<th>Catchment</th>
<th>Monitoring location</th>
<th>Late Dry Season (2006)</th>
<th>Late Monsoon Season (2007)</th>
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<td>SG SM TN SN EM RH</td>
<td>SG SM TN SN EM RH</td>
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<td>Cape York</td>
<td>Endeavour</td>
<td>Cooktown</td>
<td>33 30 3 5 ✓ 15</td>
<td>33 30 N/A N/A ✓</td>
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<td>Russell / Mulgrave</td>
<td>GI1</td>
<td>33 30 3 5 ✓ 15</td>
<td>33 30 N/A N/A ✓</td>
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<td>Mackay / Whitsunday</td>
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Table 3. Presence (■) of Halophila ovalis, Halodule uninervis and Zostera capricorni in monitoring locations sampled in Reef Plan MMP, for plant tissue and reproductive health. * indicates presence adjacent, but not within, 50m x 50m site. + only found at Picnic Bay

<table>
<thead>
<tr>
<th>GBR region</th>
<th>NRM Board</th>
<th>Catchment</th>
<th>Seagrass monitoring location</th>
<th>H. ovalis</th>
<th>H. uninervis</th>
<th>Z. caprcorni</th>
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<tr>
<td>Far Northern</td>
<td>Cape York</td>
<td>Endeavour</td>
<td>Cooktown</td>
<td>■</td>
<td>■</td>
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<td>Daintree</td>
<td>Russell / Mulgrave</td>
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<td>Wet Tropics</td>
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<td>Tully</td>
<td>Luger Bay</td>
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<td>Dunk Island</td>
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<tr>
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<td>Herbert</td>
<td>NA</td>
<td>Townsville</td>
<td>■</td>
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<tr>
<td>Burdekin</td>
<td>Burdekin</td>
<td>Magnetic Island</td>
<td>■</td>
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<td>Proserpine</td>
<td>Whitsundays</td>
<td>■</td>
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<tr>
<td>Mackay</td>
<td></td>
<td></td>
<td>Whitsunday Islands</td>
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<tr>
<td>Whitsunday</td>
<td>Pioneer</td>
<td>Mackay</td>
<td>■</td>
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<tr>
<td>Southern</td>
<td>Fitzroy</td>
<td>Shoalwater Bay</td>
<td>■*</td>
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<td></td>
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<td>■*</td>
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<td></td>
<td>Mary</td>
<td>Hervey Bay</td>
<td>■*</td>
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</tbody>
</table>

Seagrass reproductive health (status)
Seagrass reproductive health was assessed from samples collected in the late dry 2006 at locations identified in Table 2. Samples were processed according to standard methodologies.

In the field, 15 haphazardly placed cores of seagrass were collected from an area adjacent, of similar cover and species composition, to each Seagrass-Watch monitoring site.

In the laboratory, reproductive structures (spathes, fruit, female flower or male flowers) of plants from each core were identified and counted for each samples and species. If Halodule uninervis seeds (brown green colour) were still attached to the rhizome, they were counted as fruits. Seed estimates are not recorded for Halophila ovalis due to time constraints (if time is available post this first pass of the samples, fruits will be dissected and seeds counted). For Zostera capricorni, the number of spathes are recorded, male and female flowers and seeds will be counted during dissection if there is time after this initial pass of the samples. Apical meristems were not recorded- as they were too damaged by the collection process to be able to be identified correctly. All flowers and spathes and fruits /fruitti bodies were kept and re-frozen in the site bags for revalidation if required (see QAQC).
Seagrass tissue nutrient

In late dry season October 2006, tissue nutrient (*Halodule uninervis*, *Halophila ovalis* and *Zostera capricorni*) samples were collected from the monitoring sites where present as indicated Table 3.

Three haphazardly placed 0.25m² quadrats were harvested from an area adjacent, of similar cover and species composition, to each Seagrass-Watch monitoring site. Leaves were separated from the below ground material in the laboratory and epiphytic algae removed by scraping. A re-evaluation of the laboratory techniques, including sub-sampling, expedited the processing time. Samples were oven dried at 60°C to a constant weight and dried samples of leaves will be homogenized by milling to fine powders.

Nitrogen and phosphorus were extracted using a standardized selenium Kjeldahl digest and the concentrations determined with an automatic analyser using standard techniques at a Queensland Health and Scientific Services, (QHSS - a NATA certified laboratory). %C was determined by atomic absorption, also at QHSS. C:N:P will be calculated using atomic weights.

Sediment nutrient

To sample sediment nutrients, five replicate sediment cores (50mL) were collected from each monitoring site for measurement of adsorbed nutrients. Samples were placed on ice then refrigerated. Adsorbed exchangeable ammonium (NH$_4^+$) was extracted using KCl. Previous analyses had shown that within site variability was negligible, therefore bulking of sediment cores before extraction was considered acceptable (after discussion with D. Haynes) representing quite a savings on analyses.

To extract adsorbed phosphate (PO$_4^{3-}$), the Olsen/ Colwell/Bicarbonate method was used. This technique is not affected by pH, and potentially strips all adsorbed PO$_4^{3-}$ from the sediments. Although this has the potential to overestimate the PO$_4^{3-}$ that is bioavailable to the seagrass, it was used to represent the total phosphorus pool and to compare with previous research studies and datasets.

Chemical analyses of all inorganic nutrients were determined using a Skalar segmented flow auto-analyser, using standard water quality techniques.

Replicate samples (3) of saturated sediment cores were collected at each site at the time of nutrient sampling. Cores were collected in ‘cut-off’ 50 mL syringes and rubber stoppered. The volume of each core was measured from the syringe gradations. The intact core was weighed (g), dried in an oven (80°C, 48 h) and then reweighed to determine weight loss.

Particle size density ($p_s$) and porosity ($\Phi$) was calculated (Eq 1, Eq 2) by converting adsorbed nutrients units ($\mu$molkg$^{-1}$) to equivalent units ($\mu$molL$^{-1}$ sediment) to enable the molar ratios of the total sediment nutrient pool to be calculated.
Equation 1:
\[ p_s = \frac{(\text{Dry sample wt} - \text{Syringe weight})}{(\text{Volume} - ((\text{Wet sample wt} - \text{Dry sample wt})/\text{dw}))} \]
\[ \text{where } \text{dw} = \text{specific gravity of water} = 1.025 \]

Equation 2:
\[ \Phi = \frac{H/1.025}{H/1.025 + ((1-H)/p_s)} \]
\[ \text{where } H = \text{proportion of water} - (\text{wet weight} - \text{dry weight})/\text{wet weight} \]
\[ \text{and } p_s = \text{particle size density} \]

QA/QC procedures

Sampling Design

Site marking

Each selected intertidal seagrass site was permanently marked with plastic star pickets at the 0m and 50m points of transect 2. Labels identifying the sites and contact details for the program were attached to these pickets. Positions of 0m and 50m points for all three transects at a site were also noted using GPS (Table 1). This ensures that the same site was monitored each event.

Seagrass Cover and Species Composition

The collection of data by Seagrass-Watch volunteers necessitates a high level of training to ensure that the data is of a standard that can be used by management agencies. Technical issues concerning quality control of data are important especially when the collection of data is by people not previously educated in scientific methodologies. By using simple and easy methods, Seagrass Watch ensures completeness (the comparison between the amount of valid or useable data originally planned to collect, versus how much was collected). Standard seagrass cover calibration sheets are used to ensure precision (the degree of agreement among repeated measurements of the same characteristic at the same place and the same time) and consistency between observers and across sites at monitoring times. Ongoing standardisation of observers is achieved by on-site refreshers of standard percentage covers by all observers prior to monitoring and through ad hoc comparisons of data returned from duplicate surveys (e.g., either a site or a transect will be repeated by scientist – preferably the next day and unknown to volunteers). Any discrepancy in these duplicates is used to identify and subsequently mitigate bias. For the most part however uncertainties in percentage cover or species identification are mitigated in the field via direct communication (as at least one experienced observer are always present), or the collection of voucher specimens (to be checked under microscope and pressed in herbarium) and the use of a digital camera to record images (protocol requires at least 27% of quadrats are photographed) for later identification and discussion. Coordinators are advised of errors in data identified through the Seagrass-Watch QAQC.

Seagrass reproductive health

After processing, samples are retained for future verification if required.
Laboratory Analysis

Sediment samples are sent to the QHSS for analysis. Sample receipting, handling, analysis and data reporting at QHSS will be based on NATA certified methods. QHSS holds NATA accreditation (Corporate Accreditation Number 41) for constituents of the environment including soil, sediments, waters and wastewaters. (Note that details of QHSS accreditation can be found at the NATA website http://www.nata.asn.au/). The NATA accreditation held by QHSS includes a wide variety of QA/QC procedures covering the registration and identification of samples with specific codes and the regular calibration of all quantitative laboratory equipment required for the analysis. QHSS has developed appropriate analytical techniques including QA/QC procedures and detection of nutrients. These procedures include blanks, duplicates where practical, and internal use of standards for quality assurance.

Seagrass Tissue Nutrient

Samples (0.25-0.40gm), standards and quality control samples are taken through the whole digestion process using a Kjeldahl Digestion Mix (potassium sulfate/sulfuric acid/copper sulfate). The digestion is automated using block digesters programmed to give a final digestion temperature of 360°C for a period of 2 hours and is based on procedures (with quite a few modifications to allow analysis for freshwater, saline waters and sediments) described in Standard Methods 1998 – 4500-Norg D.

After digestion, analyses for Total Kjeldahl Nitrogen (TKN) and Total Kjeldahl Phosphorus (TKP) are performed simultaneously using a segmented flow instrument (BRAN+LUEBBE). For TKN, NH₃ is analysed based on Standard Methods 1998 (20th Edition) – 4500- NH₃ H (it should be noted sodium salicylate is used in lieu of phenol). For TKP the analysis is based on the ascorbic acid reduction of phosphomolybdate for FRP (Standard Methods 1998 (20th Edition) – 4500-P). N:P ratios are calculated using atomic weights. These processes are all carried out at the QHSS Quality Assured and NATA certified laboratory (Accreditation No: AN 41).

The nutrient state of a meadow was also characterised by gNseagrassm⁻² and gPseagrassm⁻² calculated as % plant tissue nutrient biomass (gDWm-2) = g Nutrientseagrassm⁻². This measure will then be converted to μmolL⁻¹ sediment to enable comparisons between the plant and sediment nutrient pools.

Sediment Nutrient

To enable comparison with published results on sediment and nutrient dynamics in coastal intertidal seagrass of north eastern tropical Australia (see Mellors 2003 and Mellors et al 2005) the cores are analysed for extractable inorganic ammonium, and phosphate in the following manner and methods. All cores are homogenized to provide a depth-integrated sample and then bulked to provide an averaged sampled for that site.

Adsorbed exchangeable ammonium is extracted using KCl (Rayment and Higginson, 1993). Phosphate will be extracted using the Colwell method (Colwell, 1963; Mengel and Kirkby, 1987; Rayment and Higginson, 1993), as this method is not affected by pH and is more appropriate for alkaline soils pH>7.8 (Baker and Eldershaw, 1993). This technique will provide information on the amount of adsorbed PO that was bio-available to the seagrass. The chemical determination for the extracted phosphate is based on the method of Murphy and Riley (in Rayment and Higginson, 1993).
Each batch of samples are run with a reagent blank and a sample fortified with a known concentration of the analytes to give a concentration in the sediment. An internal standard, is added to all samples, fortified sample, reagent blank and standards before quantification. Certified reference standards are used for instrument calibration with a standard being run every 10 samples.

**Data Management**

DPI&F has systems in place to manage the way data is collected, organised, documented, evaluated and secured. The Seagrass-Watch program collects and collates all data in a standard format. DPI&F has implemented a quality assurance management system to ensure that data collected by volunteers is organised and stored and able to be used easily.

All data (datasheets & photographs) received are entered onto a relational database on a secure server in Cairns at the Northern Fisheries Centre. Receipt of all original data hardcopies is documented and filed within the DPI&F Registered Management System, a formally organised and secure system. Seagrass-Watch HQ (DPI&F) operates as custodian of data collected from other participants and provides an evaluation and analysis of the data for reporting purposes. Access to the IT system and databases is restricted to only authorised personnel. Provision of data to a third party is only on consent of the data owner/principal.

Seagrass-Watch HQ (DPI&F) performs a quality check on long-term monitoring data submitted as part of Seagrass-Watch QA/QC. Seagrass-Watch HQ provides validation of data and attempts to correct incidental/understandable errors where possible (e.g., blanks are entered as -1 or if monospecific meadow percentage composition =100%). Validation is provided by checking observations against photographic records to ensure consistency of observers and by identification of voucher specimens submitted.

In accordance with QA/QC protocols, Seagrass-Watch HQ advises observers via an official data error notification of any errors encountered/identified and provides an opportunity for correction/clarification (this may include additional training). Any data considered unsuitable (e.g., nil response to data notification within 30 days) is removed from the database.

**Statistical analysis**

At the Scientific Advisory Panel meeting in April 2007, the Panel agreed that a statistician should be employed to assist all proponents of the Marine Monitoring Program of the Reef Water Quality Protection Plan. Until the statistician is employed we intend to analyze the data as has been conducted previously (described briefly below).

**Seagrass Cover and species composition**

Quadrat measures will be pooled across each site for each sampling period. Running averages of cover will be assessed against latest year of sampling to determine changes in seagrass cover for each site.

**Sediment physical characteristics**

All sediment physical characteristic variables were analysed using a General Analysis of Variance with Location and Year as factors and Site nested within Location. Normality of the data will be checked using standardised residual plots. Where data shows non-normal tendencies, the variables will be transformed accordingly. GenStat® will be used to detect data
outliers (i.e. observations having unusually large residual values that fell outside the range of the response data and the model design). Where there are outliers in the data, analysis will be re-run excluding outliers to determine if there is any influence on the ANOVA outcome. Results of previous analyses indicated that variation within locations was negligible compared to the differences between locations. Hence, Sites can be considered as replicates. Results will be reported for locations and graphed as mean (x) as calculated by the ANOVA ± 95% Confidence Interval (CI) based on the pooled variance also determined by the ANOVA.

Due to the new reporting requirements for this year: Presentation of results based on NRM regions (Cape York, Far North Queensland, Burdekin, Mackay/Whitsunday, Fitzroy and Burnett-Mary) with graphs, tables, and photographs as required, results from the analyses on each NRM region will need to be assessed due to small size. Sample size at location was comprised further by bulking sediment samples at the site level. This action was agreed to in discussion with the funding body, to physically rather than statistically average the sediment cores (bulk sampling) for each location. This decision was based on the outcomes of the initial ANOVA that showed variation within Location was negligible. Whilst this was appropriate for analysing data on a GBR scale, it poses certain challenges at the NRM scale. In NRM regions where two or more locations are monitored the data was analysed using ANOVA with Location and Year as treatments and Year only for NRMs with only one site being monitored. Site is no longer nested within Location to give the residual enough degrees of freedom to be tested against the treatment terms.

**Seagrass tissue nutrients**

Residual maximum likelihood (REML analysis) showed that differences in tissue nutrients between species was highly significant (p<0.001). However, two of the species (*Halodule uninervis* and *Zostera capricorni*) were almost confounded with location, therefore nutrient data was analysed separately for each species. Analysing species separately is further supported by the knowledge that all seagrasses do not have the same environmental requirement or responses to environmental conditions as proposed by the “Seagrass Functional Form Model” (Walker et al. 1999).

Seagrass variables were analysed using Analysis of Variance (ANOVA) with Location and Year as treatments and Sites nested within Location as the blocking structure at the GBR scale and as previously mentioned with no blocking at the NRM scale. Normality of the data was checked using standardised residual plots. Transforming the data had no effect on the residual plots as the plots were heavily influenced by outliers. Analyses were re-run leaving out the outliers to ascertain their influence on the analysis outcome. Outliers were not deleted for analysis but their influence on the analyses is reported. Because of the variable nature of this data results are reported for sites and graphed as mean (x) ± CI(95%)

**Reproductive effort**

Reproductive effort was calculated as the number of reproductive structures per node (leaf cluster emerging from the rhizome) as each of the three species examined (*Halophila ovalis*, *Halodule uninervis* and *Zostera capricorni*) have different reproductive structures. For comparative purposes only the presence of a reproductive structure per node was counted rather than the relative number of flowers, fruits or seeds. The number of nodes counted reflects the number of shoots found in the core. Thus cores with larger numbers of nodes contained more shoots. The average number of reproductive structures per node reflects the per unit area occurrence of reproductive output and this is the reproductive effort (i.e. average
number of flowers per core). The production of flowers and fruit were analysed with respect to the sediment nutrient loads and tissue nutrient concentrations. Correlations were performed in SPSS® and presented as Pearson correlation coefficients (p).

Unfortunately, at time of printing, no results for the reproductive component of the monitoring had been completed.

**Reporting Approach**

Results and discussion of monitoring is presented firstly in a GBRWHA general overview, and then by the Natural Resource Management Regions identified in the GBRWHA area. These discrete regions have been used for stratifying issues of land and catchment based resource management and used to report downstream impacts on the reef environment such as from the affect of water quality. There are 56 Natural Resource Management regions identified in Australia, 15 are in Queensland and six are part of the coastal processes of the GBRWHA.

These regions are mostly based on catchments or bioregions using assessments from the National Land and Water Resources Audit. Regional plans have been developed for each of these setting out the means for identifying and achieving natural resource management targets and detailing catchment-wide activities addressing natural resource management issues including land and water management, biodiversity and agricultural practices. Seagrass habitat data forms part of these targets and activities.

Within each region, estuarine and coastal habitat boundaries were delineated based on the Queensland coastal waterways geomorphic habitat mapping, Version 2 (1:100 000 scale digital data) (Heap et al 2001). Reef habitat boundaries were determined using the AUSLIG (now the National Mapping Division of Geosciences Australia) geodata topo basemap (1:100 000 scale digital data).

Conceptual diagrams have been used to illustrate the general seagrass habitats type in each region. Symbols/icons have been used in the conceptual diagrams to illustrate major controls, processes and threats/impacts (Figure 2).
Figure 2. Key to symbols used for conceptual diagrams.
2. Results

Cape York NRM

Background
Cape York Peninsula is considered an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. (http://www.nrm.gov.au/state/qld/cape-york/publications/report-card/index.html). The majority of the land is relatively undeveloped and therefore water entering the lagoon is perceived to be of a high quality. Mining, agriculture, shipping tourism and commercial and recreational fishing are the major economic activities. All have potential to expand in this region and with this expansion the possible increase in pollutants.

Of the seagrass habitats types identified for the GBR (Figure 1), Reef Plan MMP monitoring of intertidal seagrass meadows within this NRM is on a fringing reef platform. These habitats in the Cape York NRM region support diverse seagrass assemblages. Approximately 3% of all mapped seagrass meadows in the Cape York region are located on fringing-reefs (Coles et al. 2007). On fringing-reefs, physical disturbance from waves and swell and associated sediment movement primarily control seagrass growing in these habitats (Figure 3). Shallow unstable sediment, fluctuating temperature, and variable salinity in intertidal regions characterize these habitats. Sediment movement due to bioturbation and prevalent wave exposure creates an unstable environment where it is difficult for seagrass seedlings to establish or persist.
Seagrass cover and composition

The monitoring sites at Archer Point were located on a fringing reef platform in a protected section of bay adjacent to Archer Point, fringed by mangroves, approximately 15km south of Cooktown. The sites were dominated by *Halodule uninervis* and *Halophila ovalis* and seagrass cover was between 20% in winter and 35% in spring (Figure 4). Although sites were only 50m apart, AP2 had slightly more *Cymodocea* and *Thalassia* present. Species composition remained relatively stable over the past 12 months (Figure 6).

![Figure 4](image1.png)

Figure 4. Seagrass abundance (% cover) at Archer Point, coastal intertidal fringing-reef habitat, sites pooled.

Seagrass cover was significantly lower in October 2006 than in previous late dry seasons, and the meadow appears to have generally declined in abundance since monitoring was established in 2003 (Figure 4).

Since monitoring was established at AP1 in 2003, seagrass cover has generally followed a seasonal trend with higher abundance in late spring/early summer (Figure 5). However, no seasonal trend is apparent at AP2 due to the paucity of data.

![Figure 5](image2.png)

Figure 5. Mean percentage seagrass cover (all species pooled) (± Standard Error) for Cape York Seagrass-Watch long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.
Figure 6. Mean percentage cover for each seagrass species at Archer Point monitoring sites (+ Standard Error). NB: if no sampling conducted then x-axis is clear.

**Seagrass biomass**

*Halophila ovalis* and *Halodule uninervis* were present in harvested biomass samples for both years, however the amount of plant material in the *Halophila ovalis* samples was insufficient for nutrient analysis. *Cymodocea serrulata* was also present but from only one site (consequently no statistical analyses done on this species).
In general, seagrass biomass (above and below ground) declined between 2005 and 2006 for all species. Both above and below ground declined significantly for *Halophila ovalis* \((\rho < 0.001\text{ and } \rho = 0.008,\text{ respectively})\). Biomass declines for *Halodule uninervis* were significant for above ground biomass \((\rho = 0.016)\) and marginally non-significant for below ground biomass \((\rho = 0.055)\) (Figure 7). Above:below ground biomass ratios did not differ significantly between 2005 and 2006 for either species \((Halophila ovalis \rho = 0.379; \ Halodule uninervis \rho = 0.983)\)

![Figure 7. Seagrass biomass for each species at Archer Point (mean ± CI as determined by the ANOVA).](image)

**Seagrass reproductive health**

Shoot production as counted by the number of nodes per core varied both spatially and temporally \((\rho < 0.001\text{ and } \rho < 0.001,\text{ respectively})\). *Z. capricorni* shoots were only present in Dry Season 2005. For both *H. uninervis* and *H. ovalis* the number of shoots per core was generally lower in the Dry Season than the Monsoon (Figure 8).

![Figure 8. The number of nodes per core for all species (a) and for each of the three targeted species (b) at coastal intertidal monitoring sites, Archer Point. Error bars are + S.D.](image)

Sexual reproduction was evident either as flowers (male and female for both *H. ovalis* and *H. uninervis*) or as a seed bank at both sites. No reproductive structures were present for the *Z. capricorni* sampled in Dry Season 2005.
The number of reproductive structures per core (flowers and/or fruits) varied over the sampling period, but was generally dominated by *H. uninervis* (Figure 9). Fruits were only present during the Dry Season. *H. ovalis* flowers (mainly male) were present only at site AP1 at the beginning of sampling. Total reproductive effort across all species was dominated by the presence of *H. uninervis* (Figure 9).

![Graph](image1)

Figure 9. **Total reproductive effort for all species combined (a) and for the three targeted seagrass species (b) (reproductive effort = the number of reproductive structures per core).**

A seed bank was present, however it did not appear to be persistent (Figure 10). No seeds were found during the monsoon (Figure 10), when the presence of flowers or fruits in cores was highest.

![Graph](image2)

Figure 10. **Seed bank abundance at both sampling sites. (Seed bank is represented as the total number of seeds per m² sediment surface).**

**Seagrass meadow edge mapping**

Edge mapping was conducted within a 100m radius of both Archer Point Seagrass-Watch monitoring sites in September/October and March/April of each year (see Appendix 6.1). Over the past 12 months, the meadow at AP1 and AP2 expanded shoreward, increasing the overall area of seagrass present within the mapping boundaries (Figure 11, Table 4). This expansion of the meadow, resulted in all monitoring transects for both sites occurring within the main meadow (Appendix 1, Maps 1 and 2).
Figure 11. Percentage of area (100m radius of monitoring site) covered by seagrass at each monitoring site.

Table 4. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline.

<table>
<thead>
<tr>
<th>Monitoring Site</th>
<th>October 2005</th>
<th>April 2006</th>
<th>October 2006</th>
<th>April 2007</th>
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<tbody>
<tr>
<td>AP1</td>
<td>3.667</td>
<td>3.330</td>
<td>3.843</td>
<td>4.212</td>
</tr>
<tr>
<td></td>
<td>(-9.2%, decrease seaward)</td>
<td>(4.8%, increase shoreward)</td>
<td>(14.9%, increase shoreward)</td>
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<tr>
<td>AP2</td>
<td>3.710</td>
<td>3.139</td>
<td>3.5865</td>
<td>4.0367</td>
</tr>
<tr>
<td></td>
<td>(-15.4, decrease seaward)</td>
<td>(-3.3, increase shoreward)</td>
<td></td>
<td>(8.8%, decrease seaward)</td>
</tr>
</tbody>
</table>

Sediment nutrients

Levels of NH₄⁺ did not differ significantly between years possibly due to the more variable nature of the data collected in 2005. Average levels ranging between 186.1 – 204.6 µM Lₖₑ₅⁻¹. In contrast levels of adsorbed PO₄³⁻ were significantly lower in 2006 than in 2005 (p = <0.001) (Figure 12). While NH₄⁺ levels were not significantly different they were sufficiently lower in 2006 to account for the non-significant result for N:P ratios between years (Figure 13). The sediment N:P ratios within this seagrass meadow describes a nutrient pool that is greater in adsorbed PO₄³⁻ than NH₄⁺.

Figure 12. Sediment adsorbed ammonium and phosphate concentrations at Archer Point in 2005 and 2006 (mean ± CI as determined by the ANOVA).
Figure 13. Sediment N:P ratios at Archer Point in 2005 and 2006 (mean ± CI as determined by the ANOVA).

Tissue nutrients
Statistical analysis of tissue nutrients for *Halophila ovalis* between years was not possible, as %C, %N and %P were not determined in 2005. Despite this, nutrient ratios were calculated for this species in 2005. In 2006 there was insufficient plant material for Kjeldahl digestion, consequently not even nutrient ratios could be determined for this species. No further statistical analyses were undertaken for this species.

Plant tissue %C was not significantly different between years for *Halodule uninervis* despite mean %C in 2005 being 29.6%C and in 2006, 40.2%C (Figure 14). *Cymodocea serrulata* recorded a tissue %C of 37% (Figure 14).

![Figure 14. Seagrass tissue %C for each year and seagrass species at Archer Point.](image)

Significant increases in %N and %P between years were detected for *Halodule uninervis* (Figure 15). %N increased from 1.57% in 2005 to 2.83% in 2006. %P increased from 0.11%P to 0.19%P. *Cymodocea serrulata* recorded plant tissue nutrient levels of 1.5%N and 0.15%P (Figure 15).

![Figure 15. Seagrass tissue %N and %P for each year at Archer Point. Halodule uninervis (solid) Cymodocea serrulata (striped).](image)

There were no significant effects with regard to tissue nutrient ratios for *Halodule uninervis*.
Though not significant, the C:N for *Halodule uninervis* decreased (Figure 16), in 2006 as did C:P (Figure 16). N:P ratios increased marginally from 32.10:1 to 33.79:1 in 2006.

Figure 16. *Plant Tissue Ratios for each year and seagrass species at Archer Point.*
Far North Queensland NRM

The Far North Queensland NRM includes the wet tropics catchment region and covers 22,000 km2 (NRM 2007e). Land use practices include primary production such as cane and banana farming, dairying, beef, cropping and tropical horticulture. Others uses within the region include fisheries, mining, tourism and World Heritage areas. Declining water quality, due to sedimentation combined with other forms of pollutants, the disturbance of acid sulphate soils, and point source pollution have been identified as a major concern to the health of coastal estuary and marine ecosystems of which seagrass meadows are a major component (FNQ NRM Ltd and Rainforest CRC 2004). Of the seagrass habitats identified for Northeast Australia RWQPP monitoring occurs within two habitats: Coast and Reef.

Reef Plan monitoring occurs at two coastal seagrass habitat locations: Yule Point, in the north and Lugger Bay to the south. The seagrass meadows at Yule Point and Lugger Bay are located on naturally dynamic intertidal sand banks, protected by fringing reefs. These meadows are dominated by *Halodule uninervis* with some *Halophila ovalis* and are often exposed to regular periods of disturbance from wave action and consequent sediment movement. The sediments in these locations are relatively unstable restricting seagrass growth and distribution. A dominant influence of to these coastal meadows is terrigenous runoff from seasonal rains (Figure 17). The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these monitored meadows.

![Figure 17](image17.jpg)

Figure 17. Conceptual diagram of coastal habitat (<15m) in the Far North Queensland region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (See Figure 2 for icon explanation).
Monitoring of reef habitats occurs at two locations: Green Island, and Dunk Island. The Dunk Islands sites were only recently established (April 2007). Monitoring at Green Island occurs on the large intertidal reef-platform south west of the cay. The meadow is dominated by *Cymodocea rotundata* and *Thalassia hemprichii* with some *Halodule uninervis* and *Halophila ovalis*. The sites at Dunk Island have been scoped and found to be an adequate replicate for intertidal reef seagrass habitat in this region. To date only Seagrass-Watch monitoring has occurred at this site.

Shallow unstable sediment, fluctuating temperature, and variable salinity in intertidal regions characterize these habitats. Physical disturbance from waves and swell and associated sediment movement primarily control seagrass growing in these habitats (Figure 18). Reef seagrass habitats in the region are often adjacent to areas of high tourism use and boating activity with propeller and anchor scarring impacts. Globally, nutrient concentrations are generally low in reef habitats due to the coarse nature of the sediments coral sand. In these types of carbonate sediments the primary limiting nutrient for seagrass growth is generally phosphate (Short *et al.* 1990; Fourqurean *et al.* 1992; Erftemeijer and Middelburg 1993). This is due to the sequestering of phosphate by calcium carbonate sediments. In this region seagrass meadows inhabiting the near shore inner reefs and fringing reefs of coastal islands inhabit a mixture of terrigenous and carbonate sediments, such as Green Island. Seagrasses at this location have been shown to be nitrogen limited (Udy *et al.* 1999).

![Figure 18](image_url)

**Figure 18.** Conceptual diagram of reef habitat (<15m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing: general habitat, seagrass meadow processes and threats/impacts (See Figure 2 for icon explanation).

**Seagrass cover and composition**

The seagrass at Yule Point and Lugger Bay were representative of coastal (inshore) seagrass communities in the region, and dominated by *Halodule uninervis* and *Halophila ovalis*. The Yule Point meadows appear to have changed relatively little since 1967, when den Hartog (1970) photographed the area and described the species present and sediment condition. *Zostera capricorni* was reported from YP1 in 2002, and was absent during the period of the Reef Plan MMP until April 2007, when isolated plants were found inshore, within the 100m radius of the monitoring site. At Lugger Bay the meadow is only exposed as very low tides (<0.4m), and seagrass cover was generally low (< 10%), which is similar to observations in the early 90’s at this location (Mellors *et al.* 2005). The decline of seagrass at Lugger Bay in 2006 appears a consequence of severe TC Larry, which crossed the coast 50km north of the location on 20 March 2006. In April 2007, the cover had increased in excess of the April 2006
values. No significant changes in species composition were observed at either of the locations (Figure 19).

Figure 19. Mean percentage cover for each seagrass species at Townsville Seagrass-Watch long-term monitoring sites (+ Standard Error). NB: if no sampling conducted then x-axis is clear.
Seagrass cover from the start of monitoring at Yule Point in 2000, has changed little from year to year (Figure 20).

![Graph showing seagrass cover from 2000 to 2007 at Yule Point and Lugger Bay.](image)

**Figure 20.** Changes in seagrass abundance (% cover) of coastal intertidal *Halodule uninervis* meadows monitored in the Wet Tropics region from 2000 to 2007.

Seagrass cover over the past 12 months at Yule Point appeared to follow a seasonal trend with higher abundance in the early months of the year (Figure 21).

![Graph showing seasonal seagrass cover at Yule Point for 1999-2007.](image)

**Figure 21.** Mean percentage seagrass cover (all species pooled) (± Standard Error) at Yule Point long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.

No seasonal trends in seagrass cover were apparent over the past 12 months at Lugger Bay, due to the paucity of data and possibly a consequence of the meadow recovering after significant losses in early 2006 (Figure 22).
Figure 22. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Lugger Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.

Above left: Dugong feedings trails at Yule Point. Above right: monitoring seagrass cover at Lugger Bay

Seagrass monitoring site GI2 on the reef flat, Green Island.

Green Island and Dunk Island sites were on offshore reef-platforms. Dunk Island is a continental island offshore from Mission Beach and sites were only established in April 2007. Seagrass species at Dunk Island sites included *H. uninervis* and *H. ovalis* with *T. hemprichii* and *C. rotundata* (Figure 16). Green Island is on a mid shelf reef, approximately 27 km north east of Cairns. The sites are located south west of the cay and dominated by *C. rotundata* and *T. hemprichii* with some *H. uninervis* and *H. ovalis*. The sites appeared to follow a seasonal pattern in abundance, with high cover in the summer and low cover in winter, and no significant changes in species composition were observed (Figure 19, Figure 23 and Figure 24).
Seagrass monitoring sites DI1 (above left) and DI2 (above right) at Dunk Island: meadows located on the shallow reef flat between Dunk Island and Kumboola Island.

Seagrass biomass

Seagrasses are represented by *Halophila ovalis* and *Halodule uninervis* at all locations monitored in the Far North Queensland NRM region. Additionally *Cymodocea serrulata*, *Cymodocea rotundata* and *Thalassia hemprichii* were collected from Green Island. Of these minor species (by biomass samples composition) only *Thalassia hemprichii* will be reported on as it was consistently present in samples from both Green Island sites and both years.
Biomass measures for *Halophila ovalis* were quite variable depending on Location and Year. This was reflected in a significant interaction term for above ground biomass ($\rho = 0.037$) and a significant Location effect with below ground biomass ($\rho = 0.008$) (Figure 25). Green Island had significantly more below ground biomass than the other two locations monitored in this NRM (Figure 25). Differences between years were verging on significance ($\rho = 0.059$). *Halodule uninervis* biomass did not differ significantly between location or between years. *Thalassia hemprichii* (Green Island only) significantly decreased in above ground biomass between 2005 and 2006 ($\rho = 0.038$) (Figure 26).

![Figure 25. *Halophila ovalis* biomass measures for Location and year for the Far North Queensland NRM (mean ± CI as determined by the ANOVA)](image)

![Figure 26. *Thalassia hemprichii* above ground biomass for 2005 and 2006 at Green Island](image)

**Seagrass reproductive health**

Shoot production as counted by the number of nodes per core varied both spatially and temporally ($\rho < 0.001$ and $\rho < 0.001$, respectively) and reflects the differences in meadow species composition and structure of the meadows examined (Figure 27). For both the targeted species *H. uninervis* and *H. ovalis*, the number of shoots per core was generally higher in the Dry Season than the Monsoon at Green Island and Lugger Bay (Figure 27). However this pattern was not consistent across all sites in the region (Figure 27).
Figure 27. The number of nodes per core for all species (a) and for each of the three targeted species (b) at all intertidal monitoring sites in the region. Error bars are + S.D.

Sexual reproduction was evident either as flowers (male and female for both *H. ovalis* and *H. uninervis*) or as a seed bank at all sites. However, no flower or fruits have been present at Lugger Bay sites since monitoring began. The number of reproductive structures per core (flowers and/or fruits) varied over the sampling period (Figure 28). *H. uninervis* was the most sexually active species, and dominated the total reproductive effort across the region (Figure 28). *H. uninervis* flowers and fruits were only evident during the monsoon. *H. ovalis* flowers occurred only on Green Island and only in the last 12 months (October 2006 and April 2007) during both the Dry Season and Monsoon; no fruits were present across the region.

Figure 28. Total reproductive effort or all species combined (a) and for the three targeted seagrass species (b) (reproductive effort = the number of reproductive structures per core).

Seeds were more often common at coastal sites than offshore sites. A persistent and abundant seed bank was present at Yule Point, however few seeds were present at Lugger Bay during 2006 (Figure 29). No seeds have been found at Green Island sites, although a small seed bank exists at Dunk Island (Figure 29). In general, seed banks did not differ in size between season ($p=0.514$).
Figure 29. Seed bank abundance at coastal (a) and offshore (b) monitoring sites. (Seed bank is represented as the total number of seeds per m² sediment surface).

Seagrass meadow edge mapping

Edge mapping was conducted within a 100m radius of all Seagrass-Watch monitoring sites in October/November and March/April of each year (Table 5). Both sites at Yule Point were negatively impacted by the occurrence of drainage channels in 2006. However by April 2007 the channels had moved out of monitoring sites and seagrass recovered (see Appendix 1, Maps 3 and 4). There were no detectable differences in the edge mapping data of the seagrass meadows at Green Island between 2006 and 2007 (Figure 30, Appendix 1, Maps 3, 5 and 9).

At Lugger Bay, the distribution of the seagrass meadow continued to decline from April 2006 to October 2006, however by April 2007 the meadow had begun to recover, although not the same distribution as the 2005 baseline Figure 25, Appendix 1, Map 7 and 8).

Table 5. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.

<table>
<thead>
<tr>
<th>Monitoring Site</th>
<th>October 2005</th>
<th>April 2006</th>
<th>October 2006</th>
<th>April 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP1</td>
<td>1.326</td>
<td>1.789</td>
<td>1.768</td>
<td>2.452</td>
</tr>
<tr>
<td></td>
<td>(34.9% increase shoreward)</td>
<td>(33.3% decrease overall)</td>
<td>(84.9% increase overall)</td>
<td></td>
</tr>
<tr>
<td>YP2</td>
<td>3.596</td>
<td>4.120</td>
<td>3.697</td>
<td>3.735</td>
</tr>
<tr>
<td></td>
<td>(14.6% increase shoreward)</td>
<td>(2.8% decrease seaward)</td>
<td>(3.9% increase shoreward)</td>
<td></td>
</tr>
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<td>GI1</td>
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<td>5.319</td>
<td>5.266</td>
<td>5.266</td>
</tr>
<tr>
<td></td>
<td>(1.2%, increase shoreward)</td>
<td>(0.2% decrease seaward)</td>
<td>(0.2%, no change)</td>
<td></td>
</tr>
<tr>
<td>GI2</td>
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<td>4.647</td>
<td>4.674</td>
<td>4.605</td>
</tr>
<tr>
<td></td>
<td>(0.3%, negligible)</td>
<td>(0.9%, negligible)</td>
<td>(-0.6%, negligible)</td>
<td></td>
</tr>
<tr>
<td>LB1</td>
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<td>1.085</td>
<td>0.453</td>
<td>0.953</td>
</tr>
<tr>
<td></td>
<td>(-35.2%, decrease landward)</td>
<td>(-73%, decrease overall)</td>
<td>(-43.1%, increase overall)</td>
<td></td>
</tr>
<tr>
<td>LB2</td>
<td>1.801</td>
<td>1.448</td>
<td>0.561</td>
<td>1.167</td>
</tr>
<tr>
<td></td>
<td>(-19.6%, decrease landward)</td>
<td>(-68.8%, decrease overall)</td>
<td>(-35.2%, increase overall)</td>
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<tr>
<td>DI2</td>
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<td>NA</td>
<td>3.972</td>
</tr>
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</table>
Figure 30. Percentage of area (100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Cairns locations.

Figure 31. Percentage of area (100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Mission Beach locations.

Sediment nutrients

Mean levels of NH$_4^+$ for this region ranged from 367 µmol L$^{-1}_{sed}$ (Green Island 2005) to 117 µmol L$^{-1}_{sed}$ (Yule Point 2005) (Figure 26). Levels did not differ significantly between years or locations. Levels of adsorbed PO$_4^{3-}$ differed between Locations and Years ($\rho = 0.002$). Differences between locations are evident with Green Island levels exceeding those of the other locations. Differences between years were also apparent with a significant decrease in adsorbed levels of PO$_4^{3-}$ at all locations in 2006 (Figure 26). This decline in adsorbed PO$_4^{3-}$ is reflected in the significant increase in sediment N:P ratios in 2006 ($\rho = 0.024$, Figure 27). During this sampling period, sediment N:P ratios ranged from 0.669 (Lugger Bay (N>P)) to 0.262 (Green Island N<P) (Figure 27).
Figure 32. Adsorbed ammonium and phosphate for locations within Far North Queensland NRM.

Figure 33. Sediment N:P for intertidal seagrass meadows within Far North Queensland

Tissue nutrients

There is no data analysis on tissue nutrients for *Halophila ovalis*. This is because there were no records for %C, %N and %P due to the samples being contaminated during the grinding process with silica beads in 2005. Despite this, nutrient ratios were calculated for this species in 2005. No significant differences were detected for nutrient ratios (C:N, N:P, C:P) for this species within and across the monitoring sites of this NRM region.

A significant interaction between Location and Year was detected tissue %C for *Halodule uninervis*. Locations were significantly different from each other and also between years (\( \rho = <0.001 \)). A general increase in %C was detected for 2006 with a dramatic increase at both Lugger Bay and Yule Point (Figure 28). This same pattern was detected for %N (\( \rho = 0.004 \)) and for %P for this species (\( \rho = 0.014 \)) (Figure 29). *Thalassia hemprichii* at Green Island showed increases in tissue nutrient content in 2006 (37.22%C; 2.1%N, 0.1567). The only significant increase detected was that of %N for this species (\( \rho = 0.026 \), Figure 30).
Plant tissue ratios for *Halodule uninervis* for C:P and C:N showed only significant location effects (C:P, $p = 0.005$; C:N, $p = 0.016$). Both C:P and C:N had significantly higher ratios at Green Island than the other two locations. C:P ratios ranged from 610:1 (Green Island) to 336.1 (Lugger Bay) (Figure 31), while C:N ranged from 24.3 (Green Island) down to 13.1 at Lugger Bay (Figure 32). In contrast N:P for *Halodule uninervis* did not vary significantly between locations or year, even though an overall increase in the N:P for the region was recorded for 2006 (FNQ N:P, 29:1).
Figure 38. *Halodule uninervis* C:N for monitored sites within the FNQ NRM.

N:P and C:N did not vary significantly between years for *Thalassia hemprichii*, however C:N decreased significantly between 2005 (28.11:1) and 2006 (20.81:1) ($\rho = 0.22$, Figure 33).

Figure 39. *Thalassia hemprichii* C:N ratios for 2005 and 2006

**Within meadow canopy temperature**

Temperature loggers were deployed at all locations monitored in the region, however at two locations (Lugger Bay and Dunk Island) this did not occur until April 2007. Within canopy temperature data was retrieved from three locations (Figure 34). The loggers deployed at Dunk Island could not be relocated as the pegs had been removed or lost.
Mean temperatures were generally within the 23 – 31°C range, with highest mean temperatures in the late dry and monsoon seasons. Extreme temperatures (41°C) were recorded in January and February, 2004 and 2005 respectively (Figure 35). The maximum temperatures were also recorded in October-November 2005 and 2006, and March-April 2006 and 2007. Temperatures at the coastal and reef-platform locations generally follow a similar pattern.
Figure 41. Monthly mean and maximum within seagrass canopy temperatures (°C) at coastal (Yule Point) and fringing-reef (Green Island) intertidal meadows within the Far North Queensland region.
Burdekin Dry Tropics

Background

The Burdekin Dry Tropics region, includes an aggregation of the Black, Burdekin, Don, Haughton and Ross River catchments and includes several smaller coastal catchments, all of which empty into the Great Barrier Reef lagoon (NRM 2007a). Because of its geographical location, rainfall in the region is lower than other regions within tropical Queensland. Annual rainfall averages approximately 1,150 mm from on average 91 rain days. However, there is considerable variation from year-to-year due to the sporadic nature of tropical lows and storms. Approximately 75% of the average annual rainfall is received during December to March (Scheltinga and Heydon 2005).

Major threats to seagrass meadows in the region include: coastal development (reclamation; changes to hydrology, water quality declines (particularly nutrient enrichment or increased turbidity); downstream effects from agricultural (including sugarcane, horticultural, beef), industrial (including refineries) and urban centres (Scheltinger and Heydon 2005; Haynes et al. 2001). All four generalised seagrass habitats are present within the Burdekin Dry Tropics region, and Reef Plan monitoring occurs at both coastal and reef seagrass habitat locations.

The coastal sites are located on naturally dynamic intertidal sand flats and are subject to sand waves and erosion blowouts moving through the meadows. The Bushland Beach and Shelley Beach area is a sediment deposition zone, so the meadow must also cope with incursions of sediment carried by long shore drift. The meadows are frequented by dugongs and turtles as witnessed by feeding trials and scars. These meadows are also visited regularly by recreational fishers. Sediments within this habitat are mud and sand that have been delivered to the coast during the episodic peak flows of the creeks and rivers (notably the Burdekin) in this area. While episodic riverine delivery of freshwater nutrients and sediment is a medium time scale factor in structuring these coastal seagrass meadows, it is the wind induced turbidity of the costal zone that is likely to be a major short term driver (Figure 42). In these shallow coastal areas waves generated by the prevailing SE trade winds are greater than the depth of water, maintaining elevated levels of suspended sediments, limiting the amount of light availability for photosynthesis during the trade season. Intertidal seagrasses can survive this by photosynthesizing during periods of exposure, but must also be able to cope with desiccation. Another significant feature in this region is the influence of ground water.
The Reef habitats are mainly represented by fringing reefs on the many continental islands within this area. Most fringing reefs have seagrass meadows growing on their intertidal flats. Nutrient supply to these meadows is by terrestrial inputs via riverine discharge, re-suspension of sediments and groundwater supply (Figure 43). The meadows are typically composed of zones of seagrasses. *Cymodocea serrulata* and *Thalassia hemprichii* often occupy the lower intertidal/subtidal area, blending with *Halodule uninervis* (wide leaved) in the middle intertidal region. *Halophila ovalis* and *Halodule uninervis* (narrow leaved) inhabit the upper intertidal zone. Studies from overseas have often implicated phosphate as the nutrient most limiting to reefal seagrasses (Short *et al.* 1990; Fourqurean *et al.* 1992). Experimental studies on reef top seagrasses in this region however, have shown seagrasses to be nitrogen limited primarily with secondary phosphate limitation, once the plants have started to increase in biomass (Mellors 2003). In these fringing reef top environments fine sediments are easily resuspended by tidal and wind generated currents making light availability a driver of meadow structure.
Seagrass cover and composition

Both Bushland Beach and Shelley Beach were dominated by *Halodule uninervis* with varying amounts of *Halophila ovalis*. There were no detected changes in species composition. Seagrass cover appears to have increased at Bushland Beach over the past 12 months, although cover at Shelley Beach continued to decline (Figure 44).

Figure 44. Mean percentage cover for each seagrass species at sites in the Burdekin region (+ Standard Error). NB: if no sampling conducted then x-axis is clear.
Although seagrass cover has fluctuated both within and between years at Bushland Beach, the overall pattern indicates a generally increase (Figure 45). Shelley Beach (SB1) appeared to follow a similar trend, until 2006, when the cover decreased.

**Figure 45. Change in seagrass abundance (percentage cover) at coastal intertidal meadows in the Burdekin Dry Tropics region.**

Seagrass-Watch participants monitoring Bushland Beach (BB1).

Since monitoring was established, both Bushland Beach and Shelley Beach have shown a seasonal pattern in seagrass cover, high in summer and low in winter (Figure 46).

**Figure 46. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Townsville coastal long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.**
Offshore reef habitats are monitored on the fringing reef flats of Magnetic Island. Picnic Bay was dominated by *Halodule uninervis* with *Halophila ovalis* and the adjacent Cockle Bay was dominated by *Halophila ovalis* with *Cymodocea serrulata*/*Thalassia hemprichii*/*Halodule uninervis* (Figure 44). Seagrass cover at both sites appears to have increased since monitoring was established in 2005 (Figure 47), however due to the paucity of data, it is difficult to describe a seasonal pattern in seagrass cover with sufficient certainty (Figure 48).

Figure 47. Change in seagrass abundance (percentage cover) at intertidal meadows on fringing reef platforms in the Burdekin Dry Tropics region.

Seagrass-Watch participants monitoring Picnic Bay (MI1, above left) and Cockle Bay (MI2, above right) on Magnetic Island.

Figure 48. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Magnetic Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.
Seagrass biomass

*Halophila ovalis* and *Halodule uninervis* represented the predominant species within the collected biomass samples. *Thalassia hemprichii* and *Cymodocea serrulata* were also present in minor amounts in samples collected from the reef tops at Magnetic Island. As these species were not represented consistently in the biomass samples no statistical analyses were undertaken.

The above ground biomass of *Halophila ovalis* declined marginally at Magnetic Island in 2006 but increased marginally at Townsville sites (Figure 49). Both locations recorded declines in below ground biomass for 2006 for this species. These observations were reflected in changes in the above:below ground ratios for these sites and years. These observations were not statistically significant.

The above ground biomass of *Halodule uninervis* declined significantly at both locations with 2006 recorded the lower biomass between the two years ($p = 0.006$, Figure 49). The samples of below ground biomass were quite variable, and whilst there was an observed decline in 2006, it was not significant. Changes in above:below ground biomass reflected the changes in biomass but as the rate of change was different between locations no significant outcome for this parameter was observed.

![Figure 49. Above ground biomass for Halophila ovalis and Halodule uninervis at coastal (Townsville) and offshore (Magnetic Island) RWQPP monitoring sites within the BDT NRM for 2005 and 2006.](image)

Seagrass reproductive health

Shoot production as counted by the number of nodes per core varied both spatially and temporally ($p<0.001$ and $p<0.001$, respectively) and reflects the differences in meadow species composition and structure of the meadows examined (Figure 50). There was no consistent pattern in abundance of nodes and season for either of the targeted species *H. uninervis* and *H. ovalis* (Figure 50).
Sexual reproduction was evident either as flowers (male and female for both *H. ovalis* and *H. uninervis*) or as a seed bank at all sites. In the region, both *H. ovalis* and *H. uninervis* generally flowered in the Dry season. The presence of *H. uninervis* flowers also highly correlated with fruit abundance, although fruits sometimes were present throughout 2006. The only exception to this pattern was at the coastal site of Shelly Beach (SB1) where both flowers and fruits occurred over the entire monitoring period. This was possibly the consequence of greater disturbance at this site (see mapping section below). The offshore Cockle Bay site (MI2) on Magnetic Island, had lowest sexual activity within the region (Figure 51, Figure 52), although this may be a consequence of the lower composition of the targeted species at this site.

Seeds were more often common at coastal sites than offshore sites (Figure 52). A persistent and abundant seed bank was present at both coastal sites (Bushland Beach and Shelly Beach) (Figure 52). The abundance of seeds at Bushland Beach has continued to increase over the past six years, and is strongly correlated with seagrass abundance. In general, seed banks did not differ in size between season ($\rho=0.667$).

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**Figure 50.** The number of nodes per core for all species (a) and for each of the three targeted species (b) at all intertidal monitoring sites in the region. Error bars are $+\text{S.D.}$.

**Figure 51.** Total reproductive effort for all species combined (a) and for the three targeted seagrass species (b) (reproductive effort $=\text{the number of reproductive structures per core}$).
Seagrass meadow edge mapping

Edge mapping was conducted within a 100m radius of all Seagrass-Watch monitoring sites in September/October and March/April of each year (Table 6). Some meadows changed species or edges within the mapping area, but were outside the 50m x 50m monitoring sites (Appendix 1). For example, at Cockle Bay (MI2, Magnetic Island) the seagrass within the monitoring site remained similar; however the edges of the meadows and the presence of sparse *Halophila ovalis* differed slightly in October 2006 and April 2007 compared to previous (Appendix 1). Alternatively, there was a slight decrease in distribution of the Bushland Beach (BB1) meadow, the result of large gaps (possibly blowouts) forming in the seaward portion of the meadow (Appendix 1).

The most dramatic changes over the past 12 months occurred in the meadow at Shelley Beach (SBI) and Picnic Bay (MI1) (Table 6, Figure 53). In October 2006 the Shelley Beach meadow was significantly fragmented due to “blowouts”. This resulted in relatively few of the sampling quadrats falling with the meadow (Appendix 1). In April 2007 the meadow had recovered and the site was once again within a continuous meadow. The meadow however, had not fully recovered to baseline distribution. At Picnic Bay, the overall extent of the meadow had contracted, however this only had a relatively minor impact of the sampling site (MI1).

Table 6. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.

<table>
<thead>
<tr>
<th>Monitoring Site</th>
<th>October 2005</th>
<th>April 2006</th>
<th>October 2006</th>
<th>April 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI1</td>
<td>2.933</td>
<td>3.398</td>
<td>1.723</td>
<td>2.587</td>
</tr>
<tr>
<td></td>
<td>(15.9%, increase shoreward)</td>
<td>(-41.2% decrease seaward)</td>
<td>(-11.8%, increase shoreward)</td>
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</tr>
<tr>
<td>MI2</td>
<td>4.104</td>
<td>4.342</td>
<td>4.112</td>
<td>4.141</td>
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<td>(5.8, increase shoreward)</td>
<td>(0.2, negligible)</td>
<td>(0.9, increase shoreward)</td>
<td></td>
</tr>
<tr>
<td>BB1</td>
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<td>5.312</td>
<td>5.312</td>
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<tr>
<td></td>
<td>(no change)</td>
<td>(no change)</td>
<td>(no change)</td>
<td>(-3.7, decrease seaward)</td>
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<td>2.861</td>
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<tr>
<td></td>
<td>(-19.1 decrease seaward)</td>
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<td>(-8.5 increase shoreward)</td>
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</tr>
</tbody>
</table>
Figure 53. Percentage of area (within 100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Townsville and Magnetic Island locations.

Sediment nutrients

Mean levels of NH$_4^+$ for this region ranged from 528 µmols L$_{sed}^{-1}$ (Magnetic Island 2005) to 196 µmols L$_{sed}^{-1}$ (Magnetic Island 2006). Levels did not differ statistically between years or locations even though there was a general decrease in levels of adsorbed NH$_4^+$ between 2005 (418 µmols L$_{sed}^{-1}$) and 2006 (223 µmols L$_{sed}^{-1}$) (Figure 54). Levels of adsorbed PO$_4^{3-}$ differed significantly between years ($\rho < 0.001$) and marginally between locations ($\rho = 0.070$). Level of adsorbed PO$_4^{3-}$ were consistently higher at Magnetic Island (1029 µmols L$_{sed}^{-1}$) than Townsville (791 µmols L$_{sed}^{-1}$) with dramatic decreases in levels between years (2005, 1378 µmols L$_{sed}^{-1}$; 2006, 442 µmols L$_{sed}^{-1}$, Figure 54). This decrease in levels of adsorbed PO$_4^{3-}$ is reflected in the increase in N:P ratios for the region, which were marginally non-significant ($\rho = 0.051$, Figure 55).

Figure 54. Sediment ammonium and phosphate levels for the monitored sites within the BDT NRM for 2005 and 2006.

Figure 55. Between year differences for N:P region for the BDT NRM
Tissue nutrients and nutrient ratios

The results of %C, %N and %P statistical analyses for Halophila ovalis requires circumspect interpretation, as the interaction term between Location and Year could not be analyzed due to a lack of sufficient degrees of freedom. This anomaly occurred due to no records being available for either of the Townsville sites in 2005. This was further compounded by the lack of sufficient biomass at one of the Townsville sites. Interpretation of the main treatment effects is still prudent in view of discussing differences between years and between locations within this NRM. Analyses of tissue nutrient ratios for this species were not affected, and a full ANOVA was performed.

Differences between Halophila ovalis %C between Magnetic Island and Townsville sites were non-significant. Values in 2006 for Halophila ovalis %C (36.89) were higher than that recorded for 2005 (29.20) (Figure 56). Halodule uninervis %C was not significantly different between locations but was significantly different between years with overall percentages being higher in 2006 (39.8%C) than in 2005 (32.9 %C) (Figure 56).

Significant differences were detected for both Location and Year for Halophila ovalis %N with Townsville sites recording higher %N than Magnetic Island (\( \rho = 0.002 \), Figure 57) with 2006 recording high %N than 2005 (\( \rho =0.32 \), Figure 57). Whilst no significant difference was detected for Halodule uninervis %N between locations or years, there was a general increase in %N from 2005 (2.14) to 2006 (2.70) (Figure 57).

No significant differences were detected for tissue %P, or any tissue nutrient ratios for either species.
Within meadow canopy temperature

Within canopy temperature was monitored at coastal and reef-platform locations (Figure 58), and generally follow a similar pattern. Mean temperatures were mostly within the 22 – 30°C range, with highest mean temperatures in the January to March period. Extreme temperatures (41°C) were recorded in February 2004. Maximum temperatures peaked several times throughout the year, generally in February-March, June-July and October-November (Figure 59).
Figure 58. Within seagrass canopy temperature (°C) at coastal (Bushland Beach and Shelley Beach) and offshore (Magnetic Island) intertidal meadows within the Far North Queensland region over the 2006/2007 monitoring period.
Figure 59. Within seagrass canopy temperature (°C) at intertidal meadows in a coastal and a fringing-reef habitat within the Burdekin Dry Tropics region.

Light at meadow canopy

Light loggers were deployed at two sites (one coastal and one offshore) in the region to determine if the data recorded would be suitable for future monitoring of light availability. Trials were conducted, to determine suitable time intervals to measure both daily and monthly patterns of light availability at the seagrass canopy and whether differences existed between coastal and offshore locations.

The loggers were successfully deployed for up to one month, although beyond this time the level of fouling compromised the data quality. Recording intervals of 30 minutes were found to be suitable. From the preliminary trials, light was only available to plants during the low phase of the tidal cycle during the daylight hours at both coastal and offshore sites (Figure 60 and Figure 61 respectively). More light was available at the offshore sites for a longer time period, possibly a consequence of clearer waters compared to the coast. As the light sensors were not calibrated to PAR, the amount of light available has not yet been accurately determined.

Figure 60. Daily light profile at the canopy over a daily tidal cycle at Bushland Beach 17 April 2007. Yellow symbol is light intensity, blue symbol is sea level (m).
Figure 61. Daily light profile at the canopy over a daily tidal cycle during a spring tide (a) and neap tide (b) at Cockle Bay (Magnetic Island), 26 April 2007 and 20 May 2007 respectively. Yellow symbol is light intensity; blue symbol is sea level (m).

From the light data collected over a month, it is apparent that the availability of light differences greatly between coastal and offshore locations (Figure 62).
Figure 62. Uncalibrated light intensity profile at Bushland Beach (BB1) and Cockle Bay (MI2) from 15 April 2007 to 20\textsuperscript{th} May 2007.
Mackay – Whitsunday

The Mackay Whitsunday region comprises an area of almost 940,000 ha. It includes the major population centres of Mackay, Proserpine, Airlie Beach and Sarina, and encompasses the Proserpine, O’Connell, Pioneer and Plane Creek river systems (NRM 2007d). The region’s climate is humid and tropical with hot wet summers and cool dry winters. Annual rainfall varies significantly with as much as 3000 mm a year in elevated sections of the coastal ranges. Most (~70%) of the region’s rainfall occurs between December and March. Average daily temperatures for Mackay range between 23° and 31°C in January and 11° and 22°C in July. The south-easterly trades are the prevailing winds, with occasional gale force winds occurring during cyclonic and other storm events. (Mackay Whitsunday Natural Resource Management Group Inc 2005). The major industries in the Mackay Whitsunday region are agriculture and grazing, tourism, and fishing and aquaculture. Reef Plan monitoring sites are located on three of the generalised seagrass habitats represented in the region, including estuarine, coastal and reef.

Estuarine seagrass habitats in the Mackay Whitsunday region tend to be intertidal on the large sand/mud banks of sheltered estuaries. Run-off through the catchments connected to these estuaries is variable, though the degrees of variability is moderate compared to the high variability of the Burdekin and the low variability of the Tully (Brodie 2004). Seagrass in this habitat must cope with extremes of flow, associated sediment and freshwater loads from December to April when 80% of the annual discharge occurs (Figure 63).

Coastal seagrass habitats are found in areas such as the leeward side of inshore continental islands and in north opening bays. These areas offer protection from the south-easterly trades. Potential impacts to these habitats are issues of water quality associated with urban, marina development and agricultural land use (Figure 64). Monitoring sites of intertidal coastal
Seagrass habitat are located on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay.

Seagrass cover and composition

The coastal seagrass monitoring sites were located on intertidal sand/mud flats adjacent to Cannonvale in southern Pioneer Bay. The meadows cover approximately 60ha and were dominated by *Halodule uninervis* and *Zostera capricorni* mixed with *Halophila ovalis*. Species composition remained stable over the monitoring period and total abundance indicated natural seasonal patterns (Figure 66). Percent cover at this location has remained
relatively stable (trend line, Figure 67), even though fluctuations are apparent between years indicating disturbance regimes at longer time periods than annually (Figure 68).

Figure 66. Mean percentage cover for each seagrass species at Seagrass-Watch long-term monitoring sites in the Mackay Whitsunday region (+ Standard Error). NB: if no sampling conducted then x-axis is clear.
Figure 67. Change in seagrass abundance (percentage cover) at the coastal intertidal meadows at Pioneer Bay, in the Mackay Whitsunday region.

Figure 68. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Pioneer Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.

The estuarine monitoring sites are located on an intertidal sand/mud bank in Sarina Inlet south of Mackay. This site is dominated by *Zostera capricorni* with some *Halophila ovalis* (Figure 66). Seagrass cover in April 2006 was significantly lower than that recorded in September/October 2005 but was similar to cover recorded in April 2005 (Figure 69). As the dataset for this location is limited, it is not possible to determine if this is a natural/seasonal fluctuation in seagrass abundance (Figure 70).
Figure 69. Change in seagrass abundance (percentage cover) at intertidal meadows located in estuaries in the Mackay Whitsunday region.

Figure 70. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Sarina Inlet long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.

In April 2007, a site was examined on the fringing reef of Catseye Bay (Hamilton Island) during a reconnaissance visit. Although the visit confirmed the presence of intertidal seagrass, a further trip is required to determine if the meadow is large enough to contain two Seagrass-Watch sites and sustain the destructive sampling for seagrass nutrient samples. This reconnaissance trip also confirmed the southern most extent of *Thalassodendron ciliatum* in the Pacific Ocean.
Seagrass biomass

*Halophila ovalis, Halodule uninervis, and Zostera capricorni* were found in biomass samples for 2005 and 2006. *Zostera capricorni* occurred consistently across years and locations. The biomass of *Halophila ovalis* was minimal compared to that of *Zostera capricorni*. The presence of *Halodule uninervis* tended to be variable between years and locations.

Above and below ground biomass for *Halophila ovalis* and *Halodule uninervis* was significantly different between locations. On both sampling occasion (2005 and 2006) biomass of these species was greater at Pioneer Bay (Figure 71 and Figure 72). A decline in *Zostera capricorni* biomass from Sarina Inlet between 2005 and 2006, to levels below that at Pioneer Bay, resulted in a significant interaction between Location and Year for both above-ground ($\rho = 0.004$) and below ground biomass ($\rho = 0.017$) (Figure 73). None of these significant effects were reflected in the above:below ground biomass ratios for any of the species analysed. Ratios for all three species at each location and year indicated that the majority of seagrass biomass is the rhizomes and roots.

![Hamilton Island reef flat at Catseye Bay](image)

**Figure 71.** Above-ground biomass for *Halophila ovalis* and *Halodule uninervis* for 2005 and 2006 at RWQPP sites within the Mackay Whitsunday NRM.
Seagrass reproductive health

Shoot production as counted by the number of nodes per core varied both spatially and temporally ($p<0.001$ and $p<0.001$, respectively) and reflects the differences in meadow species composition (Figure 74). Species composition at Sarina Inlet sites (SI1 and SI2) varied over the monitoring period, a consequence of significantly declines in early 2006. Although no consistent pattern in node abundance occurred across all sites with season, slightly more nodes of *H. ovalis* and *Z. capricorni* occurred during the Dry Season at most coastal sites (Figure 74).
Sexual reproduction was evident either as flowers (male and female for both *H. ovalis* and *H. uninervis*) or as a seed bank at most sites. Hamilton Island was only sampled in Monsoon’07 and no reproductive structures were present. The number of reproductive structures per core (flowers and/or fruits) varied over the sampling period (Figure 75). *H. ovalis* and *H. uninervis* flowers occurred at both coastal sites in Pioneer Bay (PI2 and PI3) over the monitoring period. Reproductive structures only occurred twice at Sarina Inlet sites: *H. ovalis* male and female flowers at SI1 in Dry Season 2006, and a *H. uninervis* male flower at SI2 in monsoon’07.

A persistent seed bank is present at all coastal sites in the region (Figure 76). Seed banks have not been examined at Hamilton Island. The seed bank at PI2 however, appears to be declining over the past three years, and significantly lower than in 2001/2002 (Figure 76). In general, seed banks did not differ in size between season (p=0.991).
Seagrass meadow edge mapping

Edge mapping was conducted within a 100m radius of all Seagrass-Watch monitoring sites in September/October and March/April of each year (Table 7, Appendix 1).

Over the past 12 months, the meadow at Pioneer Bay has expanded shoreward, the edge of the meadow at Sarina Inlet decreased seaward into the SI2 monitoring site and resulted in loss of seagrass in one of the three transects monitored (Figure 77, Appendix 1, Map 17). Site SI1 however, remained within the main meadow and there were no noticeable edge effects.

Table 7. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.

<table>
<thead>
<tr>
<th>Monitoring Site</th>
<th>October 2005</th>
<th>April 2006</th>
<th>October 2006</th>
<th>April 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI2</td>
<td>3.432</td>
<td>3.534</td>
<td>3.812</td>
<td>4.193</td>
</tr>
<tr>
<td></td>
<td>(3.0%, increase shoreward)</td>
<td>(11.1%, increase shoreward)</td>
<td>(22.2%, increase shoreward)</td>
<td></td>
</tr>
<tr>
<td>PI3</td>
<td>2.432</td>
<td>2.026</td>
<td>3.891</td>
<td>4.418</td>
</tr>
<tr>
<td></td>
<td>(-16.7%, Decrease shoreward)</td>
<td>(60%, increase shoreward)</td>
<td>(81. %, increase shoreward)</td>
<td></td>
</tr>
<tr>
<td>HM1</td>
<td>NA</td>
<td>NA</td>
<td>0.144</td>
<td></td>
</tr>
<tr>
<td>SI1</td>
<td>3.374</td>
<td>1.726</td>
<td>4.425</td>
<td>4.092</td>
</tr>
<tr>
<td></td>
<td>(-48.8%, decrease seaward)</td>
<td></td>
<td>(31.2%, increase shoreward)</td>
<td>(21.0%, increase shoreward)</td>
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<tr>
<td>SI2</td>
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<td>2.46</td>
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<td>3.536</td>
</tr>
<tr>
<td></td>
<td>(-34. %, decrease shoreward)</td>
<td></td>
<td>(-1.8%, decrease seaward)</td>
<td>(-5.6%, decrease seaward)</td>
</tr>
</tbody>
</table>
Figure 77. Percentage of area (100m radius of monitoring site) covered by seagrass at each coastal (Pioneer Bay) and estuarine (Sarina Inlet) monitoring locations.

Sediment nutrients

Mean levels of adsorbed NH$_4^+$ for this region ranged from 343 µmols L$^{-1}$ sed$^{-1}$ (Pioneer Bay, 2006) to 128 µmols L$^{-1}$ sed$^{-1}$ (Sarina Inlet 2005). Levels differed significantly between locations ($\rho = 0.012$). Pioneer Bay sediments recorded consistently higher adsorbed NH$_4^+$ than those at Sarina Inlet (Figure 78). Levels of adsorbed PO$_4^{3-}$ differed between Location ($\rho = 0.002$) and Year ($\rho = 0.002$). Pioneer Bay had higher levels of adsorbed PO$_4^{3-}$ than did Sarina Inlet (Figure 79). Differences between years were also apparent with a significant decrease in adsorbed levels of PO$_4^{3-}$ at all locations in 2006 (Figure 79). This decline in adsorbed PO$_4^{3-}$ during 2006 is reflected by the significant interaction between Location and Year for sediment N:P ratios ($\rho = 0.017$). During this sampling period, sediment N:P ratios ranged from 0.617 (Sarina Inlet - N>P) to 0.152 (Pioneer Bay - N<P) (Figure 80).

Figure 78. Absorbed ammonium levels for 2005 and 2006 at RWQPP seagrass sites for the Mackay-Whitsunday NRM.
Figure 79. Adsorbed phosphate levels for 2005 and 2006 at RWQPP seagrass sites for the Mackay-Whitsunday NRM.

Figure 80. Sediment N:P ratios for 2005 and 2006 for RWQPP seagrass sites, Mackay Whitsunday NRM

Tissue Nutrients

The results of %C, %N and %P statistical analyses for *Halophila ovalis* requires circumspect interpretation, as the interaction term between Location and Year could not be analyzed due to a lack of sufficient degrees of freedom. This anomaly occurred due to no records being available for three out of the four Mackay Whitsunday sites in 2005. Regardless, interpretation of the main treatment effects is still prudent in view of discussing differences between years and between locations within this NRM for this species. Analyses of tissue nutrient ratios for this species were not affected, and a full ANOVA was performed. Samples for Halodule uninervis and Zostera capricorni were not affected and a full statistical treatment was undertaken for these species.

There were no significant outcomes for *Halophila ovalis* %C, %N and %P. There was a strong location effect due to *Halodule uninervis* not being present in the 2005 Sarina Inlet samples. This coupled with a marked increase in %C between years resulted in a significant interaction (Location x Year) effect ($\rho = 0.006$) (Figure 81a). This effect was also reflected in the significant statistical outcomes for %N (Location x Year, $\rho = 0.029$) and also for %P (Location x Year, $\rho = 0.029$) (Figure 81b).
A significant interaction term was detected for *Zostera capricorni* %C ($\rho = 0.003$). This was due to Pioneer Bay recording the lowest %C in 2005 to recording the highest levels in 2006 (Figure 82a). An analogous outcome for the same reasons as described above for %C was also apparent for %N (Location x Year $\rho = 0.028$, Figure 82) and %P (Location x Year $\rho = 0.49$, Figure 82b).

No significant outcomes in relation to plant tissue ratios for *Halophila ovalis* were detected. Significant interaction terms were returned for all plant tissue nutrient ratio analyses for *Halodule uninervis*. This outcome was influenced heavily by the absence of *Halodule uninervis* in samples from Sarina Inlet in 2005. In 2006 plant tissue ratios were quite similar at each location being monitored (Figure 83).
For *Zostera capricorni*, C:N ratios were significantly higher in 2005 than they were in 2006 ($\rho = 0.046$, Figure 84a). Plant N:P ratios were also significantly higher in 2006 than 2005 ($\rho = 0.017$, Figure 84b). There was a significant interaction between Location and year in regard to C:P plant tissue ratios as *Zostera capricorni* C:P ratios at Pioneer Bay increased while those at Sarina Inlet decreased (Figure 84b).

**Within meadow canopy temperature**

Temperature loggers were deployed at all locations monitored in the region, however this did not occur at Hamilton Island until April 2007. Within canopy temperature data was retrieved from three locations (Figure 85). Discontinuity in the data reflects either loss or failure of loggers.

Mean within canopy temperature monitored at Pioneer Bay were within the 20 – 30°C range, with highest mean temperatures in the February periods. Extreme temperatures (>40°C) were not recorded in the region. Although data over the last 12 months is limited, they do not indicate temperatures greater than in previous years (Figure 86).
Figure 85. Within seagrass canopy temperature (°C) at coastal (Pioneer Bay), estuarine (Sarina Inlet) and offshore (Hamilton Island) intertidal meadows within the Mackay Whitsunday region over the 2006/2007 monitoring period.
Figure 86. Within seagrass canopy temperature (°C) at intertidal meadows in a coastal habitat within the Mackay Whitsunday region.
Fitzroy

The Fitzroy region covers an area of nearly 300,000 km². It extends from Nebo in the north to Wandoan in the south, and to the Gemfields in the west and encompasses the major systems of the Fitzroy, Boyne, and Calliope rivers as well as the catchments of the smaller coastal streams of the Capricorn and Curtis Coasts (NRM 2007c). The Fitzroy River is the largest river system running to the east coast of Australia. The Boyne and Calliope Rivers drain the southern part of the region, entering the GBRWHA lagoon at Gladstone. The region covers ten percent of Queensland’s land area and is home to approximately 200,000 people. It is one of the richest areas in the state in terms of land, mineral and water resources and supports grazing, irrigated and dryland agriculture, mining, forestry and tourism land uses. (Fitzroy Basin Association 2004). Agricultural production constitutes the largest land use in Central Queensland, with nearly 90% of the land under agricultural production. Concomitant with this land use is the usual concern of the quality of the water that is entering the GBRWHA lagoon. While streams further north deliver water to the lagoon every year, about once per decade the Fitzroy floods to an extent that affects the Reef. However, the smaller annual flows deliver sediments and nutrients affecting coastal habitats.

The Fitzroy NRM region experiences a tropical to subtropical humid to semi arid climate. Annual median rainfall throughout the region is highly variable, ranging from about 600 mm annually at Emerald to more than 800 mm along the coast, and over 1000mm in the north, where coastal ranges trap moist on-shore airflow. Most rain falls in the summer, with many winters experiencing no rain at all. Because of the tropical influence on rainfall patterns, heavy storms can trigger flash flooding, and occasional cyclones wreak havoc.

Reef Plan monitoring sites within this NRM are in contrast to each other, occurring on coastal or estuarine seagrass habitats. Coastal sites are monitored in Shoalwater Bay, and are located on the large intertidal flats of the north western shores of Shoalwater Bay. The remoteness of this area (due to its zoning as a military exclusion zone) represents a near pristine environment, removed from anthropogenic influence. The other monitored location is within Gladstone Harbour estuary: a heavily industrialized port. Additional sites for intertidal seagrass meadows on Great Keppel Island were scoped in May. During this reconnaissance, only one site was located. Further investigation into suitable sites is required if a non-coastal seagrass meadow is to be monitored in this NRM.

The Shoalwater Bay monitoring sites are located in a bay which is a continuation of an estuarine meadow that is protected by headlands. A feature of the region is the large tidal amplitudes and consequent strong tidal currents (Figure 87). As part of this tidal regime large intertidal banks are formed which are left exposed for many hours. Pooling of water in the high intertidal, results in small isolated seagrass patches 1-2m about MSL.
Figure 87. Conceptual diagram of coastal habitat in the Fitzroy region – major control is pulsed light, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (See Figure 2 for icon explanation).

Estuarine seagrass habitats in the southern Fitzroy region tend to be intertidal, on the large sand/mud banks in sheltered areas of the estuaries. Tidal amplitude is not as great as in the north and estuaries that are protected by coastal islands and headlands support meadows of seagrass. These habitats feature scouring, high turbidity and desiccation linked to this large tide regime, and are the main drivers of distribution and composition of seagrass meadows in this area (Figure 88). These southern estuary seagrasses (Gladstone) are highly susceptible to impacts from local industry and inputs from the Calliope River. The Gladstone region is highly industrial with the world’s largest alumina refinery, Australia’s largest aluminium smelter and Queensland’s biggest power station. In addition, Port Curtis is Queensland’s largest multi-cargo port with 53 million tonnes of cargo passing through the port in 2006.

Figure 88. Conceptual diagram of estuary habitat in the Fitzroy region – major control variable rainfall and tidal regime: general habitat, seagrass meadow processes and threats/impacts (See Figure 2 for icon explanation).

Seagrass cover and composition

Seepcies composition different greatly between coastal and offshore sites. Sites monitored in Shoalwater Bay, are dominated by Zostera capricorni with some Halodule uninervis (Figure 89). Percent cover appears to be on the increase, driven by a large increase in cover in late 2005. More recent data though not as high as the 2005 data still shows seagrass cover to be higher than when monitoring first commenced in early 2002 (Figure 90, Figure 91).
Figure 89. Mean percentage cover for each seagrass species at Seagrass-Watch long-term monitoring sites in the Fitzroy Region (+ Standard Error). NB: if no sampling conducted then x-axis is clear.
Gladstone Harbour sites were located in a large Zostera capricorni dominated meadow (Figure 89) on the extensive intertidal Pelican Banks south of Curtis Island. Seagrass distribution decreased significantly across the region in early 2006, however the meadow has significantly recovered in cover at GH1 and to a lesser extent at GH2 (Figure 89).
Seagrass-Watch participants estimating seagrass cover at intertidal sites on Pelican Banks south of Curtis Island, Gladstone Harbour.

The monitoring sites at Great Keppel Island (GK3) was only recently established, and differed from the coastal sites as it was composed of *H. uninervis* on sand substrate (Figure 89).

### Seagrass Biomass

*Zostera capricorni* was the dominant species in the samples collected from this NRM. *Halophila ovalis* was also present in the majority of samples. *Halodule uninervis* was also present but not consistently. Its presence varied according to year and site, accordingly no statistical analysis was performed with this species for this NRM region.

No statistically significant differences were observed for *Halophila ovalis* biomass parameters. There was however a general trend of increasing *Halophila* biomass at the sites monitored in this NRM, Gladstone Harbour recording higher biomass than Shoalwater (Figure 92a). *Zostera capricorni* above ground biomass was significantly lower in 2006 than it was in 2005 ($\rho = 0.11$) (Figure 92b). Whilst this occurred at both sites the decrease was notable at Gladstone Harbour for this species (Figure 92b). This had no effect on the above: below ground ratios for either species.

![Figure 92](image)

**Figure 92.** Above and below ground biomass for (a) *Halophila ovalis* and (b) *Zostera capricorni* at monitoring sites in the Fitzroy NRM.
Seagrass reproductive health

Shoot production as counted by the number of nodes per core varied both spatially and temporally ($p<0.001$ and $p<0.001$, respectively) (Figure 93). *H. uninervis* was limited in present across the region, only occurring at WH1 and GK3. *H. ovalis* nodes were generally more abundant during the Monsoon. There was no apparent pattern in abundance of *Z. capricorni* nodes with season (Figure 93).

Sexual reproduction was evident either as flowers (male for *Z. capricorni* and both male and female for *H. ovalis*), fruits or spathes at all sites. The number of reproductive structures per core (flowers and/or fruits) varied over the sampling period (Figure 94). *Z. capricorni* was the most sexually active species, and dominated the total reproductive effort across the region (Figure 94). *Z. capricorni* flowers only occurred in the Monsoon, however spathes only occurred in the Dry Season. *H. ovalis* flowers and fruits only occurred in the Monsoon. No *H. uninervis* reproductive structures were present, however this is not unexpected at it was only minor component of meadow composition across the region. No seeds were found at any of the Shoalwater Bay, Great Keppel or Gladstone Harbour sites.

Figure 93. The number of nodes per core for all species (a) and for each of the three targeted species (b) at all intertidal monitoring sites in the region. Error bars are + S.D.

Figure 94. Total reproductive effort or all species combined (a) and for the three targeted seagrass species (b) (reproductive effort = the number of reproductive structures per core).
Seagrass edge mapping

Edge mapping was conducted within a 100m radius of all Seagrass-Watch monitoring sites in September/October and March/April of each year (Table 8, see Appendix 1). The meadow at Gladstone Harbour which was absent in early 2006, had recovered in distribution by October 2006. Over the past 12 months, the meadows at all site remained relatively stable, with only a slight decrease at GH2 due to a drainage channel appearing within 100m of the monitoring site (Figure 95).

Table 8. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.

<table>
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<th>Monitoring site</th>
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<th>October 2006</th>
<th>April 2007</th>
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<tr>
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<td>5.38</td>
<td>5.38</td>
<td>5.396</td>
<td>5.384</td>
</tr>
<tr>
<td></td>
<td>(No change)</td>
<td>(No change)</td>
<td>(0.3% increase shoreward)</td>
<td>(0.01% increase shoreward)</td>
</tr>
<tr>
<td>WH1</td>
<td>5.397</td>
<td>5.397</td>
<td>5.397</td>
<td>5.397</td>
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<td>(No change)</td>
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</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>(-100% Meadow absent)</td>
<td>(Meadow recovered)</td>
<td>(Meadow recovered)</td>
<td></td>
</tr>
<tr>
<td>GH2</td>
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<td>5.394</td>
<td>5.174</td>
</tr>
<tr>
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<td>(4.3%)</td>
<td>(0.01%)</td>
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<tr>
<td>GK3</td>
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<td>0.691</td>
</tr>
</tbody>
</table>

Figure 95. Percentage of area (100m radius of monitoring site) covered by seagrass at each monitoring site at Shoalwater Bay and Gladstone Harbour locations.

Sediment nutrients

Levels of NH$_4^+$ µmols L$_{sed}^{-1}$ were significantly different between locations ($\rho = 0.04$). Shoalwater Bay over the last two years recorded higher levels of adsorbed NH$_4^+$ than that recorded from Gladstone Harbour (Figure 96). Significant treatment effects were detected for levels of adsorbed levels of PO$_4^{3-}$. Shoalwater Bay recorded higher levels than Gladstone Harbour (Location $\rho = 0.040$). Both sites recorded significant decreases during 2006 of PO$_4^{3-}$ µmols L$_{sed}^{-1}$ (Year $\rho <0.001$, Figure 96).
Figure 96. Sediment ammonium and phosphate levels for the monitored sites within the Fitzroy NRM for 2005 and 2006.

This significant decrease of adsorbed PO$_4^{3-}$ in 2006 was reflected by a significant Year effect on sediment N:P ratios with 2006 recording a higher ratio than 2005 ($\rho = 0.002$, Figure 97).

Figure 97. Sediment N:P ratios for RWQPP sites within the Fitzroy NRM.

**Plant tissue nutrients**

The results of %C, %N and %P statistical analyses for *Halophila ovalis* requires circumspect interpretation, as the interaction term between Location and Year could not be analyzed due to a lack of sufficient degrees of freedom. This anomaly occurred due to no records being available for either of the Shoalwater sites in 2005. This was further compounded by the lack of sufficient biomass at one of the Shoalwater sites. Interpretation of the main treatment effects is still prudent in view of discussing differences between years and between locations within this NRM. Analyses of tissue nutrient ratios for this species were not affected, and a full ANOVA was performed.

There were no statistically significant treatment effects for this species for either %C, %N or %P. In general terms though, *Halophila ovalis* in Gladstone harbour was consistently higher in %C (Figure 98), %N (Figure 99) and %P (Figure 100) than that recorded for Shoalwater. A general trend of increasing tissue nutrients was observed in 2006. The same could not be said for *Zostera capricorni*. Significant yearly effects were detected for %C ($\rho = 0.005$, Figure 98) and %P ($\rho = 0.019$, Figure 100) for this species. Both %C and %P were higher in 2006. Though not significant there was an increase in %N tissue in the 2006 samples of *Zostera capricorni* (Figure 99).
The only statistically significant change in any of the plant tissue ratio was the *Zostera capricorni* N:P ratio. There was a significant location effect, with Gladstone recording higher N:P ratios ($\rho = 0.026$, Figure 101). This is consistent with higher plant tissue nutrients recorded for this location. Though not significant a similar pattern was also observed for *Halophila ovalis*. 

Figure 98. Tissue %C for *Halophila ovalis* and *Zostera capricorni* for RWQPP sites within the Fitzroy NRM.

Figure 99. Tissue %N for *Halophila ovalis* and *Zostera capricorni* for RWQPP sites within the Fitzroy NRM.

Figure 100. Tissue %P for *Halophila ovalis* and *Zostera capricorni* for RWQPP sites within the Fitzroy NRM.
Figure 101. *Plant tissue ratio N:P for the representative species monitored in the Fitzroy*
Burnett Mary

The Burnett-Mary region covers an area of 88,000 km² and supports a population of over 257,000 people, largely in the main centres of Bundaberg, Maryborough, Gympie and Kingaroy. The region is comprised of a number of catchments including the Baffle Creek, Kolan, Burnett, Burrem and Mary Rivers (Burnett Mary Report card 2004). Only the northern most catchment, the Baffle Basin, is within the GBRWHA. Meadows in this Basin generally face low levels of anthropogenic threat, and it is proposed to establish a Reef Plan MMP monitoring location at Rodd’s Bay, within the Baffle Basin of Burnett Mary NRM. Currently, the only location that is monitored within this NRM is at Urangan (Hervey Bay). This site is adjacent to the Urganan marina and in close proximity to the Mary River.

Estuarine habitats occur in bays that are protected from the south easterly-winds and consequent wave action. The seagrasses in this area must survive pulsed events of terrestrial run-off, sediment turbidity and drops in salinity. Estuary seagrasses in the region are susceptible to temperature related threats and desiccation due to the majority being intertidal (Figure 102).

Seagrass cover and species composition

The Urangan sites in 2005 were dominated by *Zostera capricorni* with minor components of *Halophila ovalis* and some *Halodule uninervis* (Figure 103). In early 2006 the meadow declined and seagrass was absent until April 2007, when a few isolated plants were found scattered across the intertidal banks. Since monitored was established at this location in 1998,
the meadow has come and gone on an irregular basis. Due to these changes, no clear seasonal pattern is apparent (Figure 104).

Figure 103. Mean percentage cover for each seagrass species at Seagrass-Watch long-term monitoring sites in the Burnett Mary Region (+ Standard Error). NB: if no sampling conducted then x-axis is clear.
Figure 104. Changes in above-ground biomass and distribution of estuarine intertidal Zostera meadows monitored in the Mary/Burnett region from 2002 to 2006.

Intertidal seagrass meadows at Urangan in August 2005 (left) and March 2007 (right).

Seagrass biomass

*Halophila ovalis* and *Zostera capricorni* were the two species collected from this intertidal location. *Halophila ovalis* was present in 2005 samples but absent in 2006. The variability in biomass samples between Urangan sites during 2005 was too great for the ANOVA to detect a significant change in biomass between years (Figure 105a). A similar decline was observed for *Zostera capricorni* biomass though at statistically detectable levels for only above ground biomass (ρ = 0.007, Figure 105b).

Seagrass reproductive health

Shoot production as counted by the number of nodes per core was very low in 2006 and no nodes were present in 2007 (Figure 106). *Z. capricorni* was the dominant species present at...
this site. Although *H. ovalis* was present on the monitoring site, no nodes were present in the reproductive samples collected from the area immediately adjacent.

![Graph](image1)

**Figure 106.** The number of nodes per core for all species (a) and for each of the three targeted species (b) at all intertidal monitoring sites in the region. Error bars are ± S.D.

No reproductive structures occurred in these meadows over the last 12 months (Figure 107). Similarly, no seeds have been found at either of the Urangan monitoring sites.

![Graph](image2)

**Figure 107.** Total reproductive effort or all species combined (a) and for the three targeted seagrass species (b) (reproductive effort = the number of reproductive structures per core).

**Edge mapping**

As the meadow at Urangan has not recovered in the last 12 months, no meadow edges/boundaries could be mapped (Table 9). In April 2007, only a few isolated plants were found scattered across the intertidal banks. Apart from the baseline mapping, no edge maps have been produced (Appendix 1).
Table 9. Area (ha) of seagrass meadow being monitored within 100m radius of site. Value in parenthesis is % change from October 2005 baseline, and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>October 2005</th>
<th>April 2006</th>
<th>October 2006</th>
<th>April 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>UG1</td>
<td>5.266</td>
<td>0</td>
<td>0 (meadow absent)</td>
<td>0 (meadow absent)</td>
</tr>
<tr>
<td>UG2</td>
<td>5.326</td>
<td>0</td>
<td>0 (meadow absent)</td>
<td>0 (meadow absent)</td>
</tr>
</tbody>
</table>

Sediment Nutrients

There was a substantial decrease in sediment nutrient concentrations at Urangan for 2006 (Figure 108). Due to the large amount of variability between the samples collected (particularly the samples in 2005) only adsorbed PO$_4^{3-}$ was shown to be statistically significant ($p = 0.038$, Figure 108). Analysis on N:P ratios were also affected by the large variance and were also non-significant even though, N:P ratios decreased from 0.75 (2005) to 0.47 (2006), reflecting the large decreases in adsorbed NH$_4^+$ observed in 2006 (Figure 109).

![Figure 108. Levels of adsorbed sediment nutrients at Urangan, during 2005 and 2006.](image1)

![Figure 109. Sediment N:P for Urangan, 2005 and 2006.](image2)

Tissue nutrients

There was no data analysis on tissue nutrients or ratios for *Halophila ovalis*. This is because there were no records for %C, %N and %P in 2005 and a lack of plant material due to the absence of this species in 2006.
Biomass samples for *Zostera capricorni* were so small they had to be combined to supply enough material for Kjeldahl digestion. Although this allowed for an estimate of plant tissue nutrients for the location there is no variability around this estimate for the 2006 nutrient samples. Interpretation of these results should bear this in mind.

In 2005 %C of *Zostera capricorni* was 26.1%C and in 2006 it was 29.5%C (Figure 110). Estimates of %N and %P for 2005 were 1.44%N and 0.12%P compared to 1%N and 0.074%P in 2006 (Figure 111).

![Figure 110. Estimates of %C for Zostera capricorni at Urangan for 2005 and 2006.](image)

![Figure 111. Estimates of %N and %P for Zostera capricorni at Urangan for 2005 and 2006](image)

All plant tissue ratios were significantly higher in 2006 (N:P, $\rho = 0.03$; C:N, $\rho = 0.025$, Figure 112; C:P, $\rho = 0.005$, Figure 113). These results must be viewed with caution as even the analysing laboratory noted that the size of the material presented for analysis was marginal for the Kjeldahl technique for estimating %N and %P.

![Figure 112. Plant tissue ratios N:P, C:N for Zostera capricorni at Urangan.](image)
Within canopy temperature

Within canopy temperature was monitored at Urangan over the past 12 months (Figure 114). Discontinuity in the data reflects the late replacement of the logger before the memory was full. Within canopy temperature monitored at Urangan was within the 15 – 30°C range, with highest mean temperatures in the February periods. Extreme temperatures (>40°C) were not recorded in the region.

Figure 114. *Within seagrass canopy temperature (°C) at Urangan intertidal meadow over the 2006/2007 monitoring period.*
3. Discussion

Seagrasses form critical ecosystems in the north eastern Australian coastal waters and deserve similar attention from management agencies, researchers and the public as do the better known coral and fish populations. Their role in fisheries production and in sediment accumulation and stabilisation is well known but their role is much more diverse, spanning from directly providing food and filtering nutrients from the water, through to a role in carbon sequestration (Spalding et al., 2003).

The six NRM regions that abut the GBR lagoon are affected by different climate regimes, demographic and catchment groupings and are unequal in size and coastline. This requires some care when making between region comparisons. Particularly as locations/seagrass habitat type within these NRM regions are at least as important as the region in understanding how a seagrass meadow may respond to external pressures.

The types of influences/pressures on seagrass differ for each region. Our conceptual models synthesise the key driving influences and pressures and conceptual models are a powerful way of visualising how each system works. Anthropogenic affects are far more important in regions such as the Wet Tropics with its port activities and intensive coastal agriculture. This region is well monitored and loss or any change at least in shallow waters would be quickly noticed. North on the Cape, such impacts are less likely but changes could occur over time that would not be noticed due to the lack of the spatial extent of monitoring in this region.

Intertidal seagrass monitoring (Seagrass–Watch program) has demonstrated that despite some temporary losses, intertidal seagrass in Queensland remain in relatively good condition (Coles et al. 2007; www.seagrasswatch.org).

Seagrass cover and distribution

The Reef Plan MMP used some existing Seagrass-Watch sites, included additional sites sampled from 2005 and new sites established in 2007. The distribution of seagrass species monitored in this programme is representative of the intertidal meadows in GBRWHA (Coles et al. 2007; Lee Long et al., 1993). While Zostera communities are found all along the coast of Queensland this species predominates in southern intertidal meadows.

Declines in seagrass abundance were reported at several southern and one northern location in 2006. The southern locations (Sarina Inlet, Gladstone Harbour and Hervey Bay) were dominated by Zostera capricorni communities, while the northern location (Mission Beach) was dominated by Halodule uninervis. The declines observed between October 2005 and April 2006 generally fit the accepted model of seasonal variation. The un-expected severity of the declines in intertidal Zostera meadows in Gladstone and other southern/central Queensland locations however may be related to atypical variations of climate such as rainfall, wind and water temperature occurring in the region between October 2005 and April 2006.

Studies of tropical and subtropical seagrass communities have found distinct seasonal patterns with maximum cover usually occurring in spring/summer and minima in winter (McKenzie, 1994; Lanyon and Marsh, 1995). This seasonal pattern is likely to be driven by a combination of climatic and environmental parameters, particularly rainfall, water and air temperature, and solar irradiance (Mellors et al., 1993; McKenzie, 1994). Generally seagrass cover decreased between the October 2005 monitoring and the October 2006, but to a level which is within the
boundaries of fluctuations that have been observed for these meadows that have been monitored over a number years (Coles et al 2007, www.seagrasswatch.org). Since the October 2006 monitoring, the meadow at Mission Beach, which was affected by Cyclone Larry appears to be recovering (Figure 19, Figure 20, Figure 31). The same cannot be said for Urangan, however this meadow has declined severely in the past, and appears to follow a pattern of loss and recovery (~ 18 months to three years for full recovery, Campbell and McKenzie 2004) which we would expect to continue. Other Seagrass-Watch monitoring sites adjacent to Urangan and the mouth of the Mary River also report patterns of loss and recovery (www.seagrasswatch.org). Intertidal Zostera dominated meadows in the greater region (within Great Sandy Strait), corroborate these findings.

The decline in intertidal seagrass across the Gladstone region between 2005 and 2006 (Mckenzie et al 2006) also appears to be recovering but hasn’t recovered to levels recorded in October 2005. Unlike the reported declines in seagrasses in Hervey Bay, there is not a reliable long term understanding of the natural background range of changes likely to be expected in Gladstone and a longer data set is needed for interpretation. These finding are all corroborated by the biomass data except at Lugger Bay for Halodule uninervis where the biomass was so variable that no significant difference between years could be detected. Recovery at Lugger Bay has been purely by vegetative reproduction and possible fragment recruitment to the area, as no seed bank is evident at this location.

Percent cover from the entire Seagrass-Watch data set when all sites within the GBRWHA are combined by habitat type, shows since 1998 a flat trend for inter-tidal coastal seagrass at around a 20% cover level, a decline in recent years in estuary inter-tidal and an increase in percent cover for reef platform seagrasses (Figure 115). The changes that have occurred are likely to be related to exposure at low tide and temperature and drying effects and are unlikely to be long term effects. Within these overall trends there are some location specific exceptions.

![Graphs showing seagrass cover over time for different habitats](image)

Figure 115. All Seagrass-Watch data sets within the GBRWHA combined by habitat type since monitoring commenced.
The only notable change in species composition occurred at Pioneer Bay in the Mackay/Whitsunday region. This meadow is becoming more *Zostera* dominated, and the sediments more mud dominated. This is likely to be a normal successional event.

Adsorbed nutrient levels were within the range recorded from previous studies (Mellors *et al.*, 2005, McKenzie *et al.* 2006). Adsorbed ammonium levels did not differ between years. Phosphate levels were lower than those recorded in 2005. All N:P ratios for this reporting period were below one characterizing the sediments as having a large phosphate pool relative to its nitrogen pool.

Examination of the plant tissue nutrient ratios and their deviation from the “Seagrass Redfield Ratio” (500:30:1, Atkinson and Smith 1983) distinguished coastal meadows from reef top meadows. This distinction is based on the premise that values below the “Redfield Ratio” especially that of C:N and C:P characterize seagrasses living in low light, high nutrient environments (sic. coastal) as opposed to comparatively lower nutrient higher light environments(sic. reef) (Atkinson and Smith 1983, Duarte 1990, Johnson *et al.* 2006).

C:N ratios and C:P ratios for *Halodule uninervis* showed a general distinction between coastal and reef top locations (Table 10). Coastal sites, generally had C:N, and C:P ratios below 16.7:1 and 500:1 respectively making a distinction between turbid (Neckles 1993), nutrient rich conditions (Atkinson and Smith 1983) and not so turbid and lower nutrient environments. The exception to this was Shoalwater which had a C:N of 21:1 and Urangan and Gladstone Harbour where no data for *Halodule uninervis* was available. Establishment of light loggers at these locations, will allow this observation to be tested for seagrass meadows within GBRWHA.

<table>
<thead>
<tr>
<th>Coastal</th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yule Point</td>
<td>Archer Point</td>
</tr>
<tr>
<td>Lugger Bay</td>
<td>Green Island</td>
</tr>
<tr>
<td>Townsville</td>
<td>Dunk Island</td>
</tr>
<tr>
<td>Pioneer Bay</td>
<td>Magnetic Island</td>
</tr>
<tr>
<td>Sarina Inlet</td>
<td>Hamilton Island</td>
</tr>
<tr>
<td>Shoalwater Bay</td>
<td></td>
</tr>
<tr>
<td>Gladstone Harbour</td>
<td></td>
</tr>
<tr>
<td>Urangan</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. *Classification of RWQPP locations*

In general terms this pattern was mirrored by the spatial variation in C:N ratios for *Halophila ovalis* i.e separating coastal *Halophila ovalis* from reef top *Halophila ovalis*. This distinction could not be applied to *Halophila ovalis* C:P. All C:P ratios were below 500:1. This is more likely to be a reflection of the limited amount of investment this species puts into its architectural structure.

This C:N distinction did not apply to *Zostera capricorni* (rarely is *Zostera capricorni* found on a reef flat), where all ratios were above 20:1. C:P ratios, however, did separate the *Zostera capricorni* sites within the Mackay Whitsunday region from those of the Fitzroy and Burnett Mary region. Ratios for *Zostera capricorni* within the Mackay Whitsunday area placed these seagrasses in a high nutrient, low light environments, which adequately portrays conditions at Pioneer Bay and Sarina Inlet. The long exposure times of the meadows in the Fitzroy region
due to the large tidal amplitude may constitute a higher light environment for this species. This species is known to photosynthesize effectively while exposed (Pollard and Greenwood 1993). In turbid conditions the ability to photosynthesize (sic. increase carbon production) longer while exposed would be similar to living in conditions of better light attenuation.

The N:P ratio is more useful than C:N and C:P when investigating changes in nutrients, because they are not so reliant on structural carbon, thus reducing inter-plant variability (Johnson et al., 2006). N:P in excess of 30:1 is considered to be evidence of P limitation and ratios less than 30-25:1 are considered to show N limitation (Duarte, 1990). Based on this premise, Halophila ovalis at all locations/NRM regions within the GBRWHA is Nitrogen limited. N:P for this species ranged from 3.5:1 (Shoalwater Bay) to 20:1 (Gladstone Harbour).

Examination of the N:P ratios for Zostera capricorni and Halodule uninervis revealed that only the seagrasses at Shoalwater were Nitrogen limited. At other locations where Zostera was present the N:P ratios inferred that these seagrasses were nutrient replete. Only two locations had seagrasses showing Phosphate limitation; Halodule uninervis at Archer Point and Yule Point. All other locations where this species was present had ratios 25-30:1 inferring they were nutrient replete.

In view of the evidence presented here, seagrass meadows do not appear to be in a eutrophic state, in fact the seagrass species inhabiting these meadows are in a nutrient replete state or are nitrogen limited. Despite this (adequate nutrients available) there was a noted decline in seagrass biomass. This evidence points towards something other than nutrients driving the dynamics of seagrasses within this region. The most likely parameter is light. Whilst this decline in biomass was matched by the decline in seagrass cover between October 2005 and October 2006, the Seagrass-Watch database indicates that this decrease is within the limits of previously recorded declines.

Seagrasses are viewed as a habitat type – a seagrass meadow – but the plants belong in three separate taxonomic families and make up 15 separate species. Each of these species fills an individual ecological niche and may use different approaches to colonisation, survival growth and recovery. There are at least four different growth strategies among the species in the GBRWHA. In addition in some locations plants may be sexually reproductive but the same species in another location may grow purely by asexual expansion from a single clone. Each of these strategies and combination of strategies affects the plant and meadow response to natural environmental and anthropogenic influence. The loss of an area of seagrass meadow may be the result of an external influence, simply a plant clone senescing, or a combination of those factors.

Adding to this complexity is the range of habitat types seagrasses have colonised in the GBRWHA. They can be found on reef edges exposed to waves, on reef platforms, at 60 metres deep on coralline sands in the reef lagoon, on sandy coastlines both inter-tidal and sub-tidal, and in estuaries colonising muddy banks and the edges of mangrove creeks. They are found from the tip of Cape York more or less continuously to the southern boundary of the GBRWHA a distance along the coast of some 2000 kilometres.

Because of this complexity reviewing the status and health of seagrasses that are present in the GBRWHA and interpreting changes or trends, is scale dependent in time and space. Locations may respond differently to local influences, and seasonal influences in biophysical factors such as temperature and light, which influence the extent and biomass of seagrasses
through an annual cycle. Different species and species groups may respond differently to these biophysical factors and some locations may respond dramatically to a combination of biophysical events. Seagrass exposed at low tide in the tropics can be used as an example. A very low tide in the day time during summer combined with high temperatures and a drying wind can lead to a sudden dying of leaf material and a dramatic loss of biomass in a meadow at least for a relatively short time.

Results from the DPI&F monitoring programs indicate that at the scale of the GBRWHA, seagrass meadows were in a “healthy” state and have been relatively stable over the past 20 years. However within this overall “stability” seagrasses have fluctuated, most often as a response to climate and at smaller localized scales there have been some acute event related changes. These fluctuations do not appear to represent long term trends in a particular direction they are simply fluctuations. How these meadows respond in the future to changes in water quality will require a larger data of coupled sampling between seagrass and nutrient parameters. The addition of monitoring PAR at these seagrass meadows (future direction of RWQPP intertidal seagrass monitoring) will only improve our understanding of the drivers that shape these dynamics intertidal meadows of the GBRWHA.

Finally there is a very poor understanding of meadow resilience. While resilience factors are complex – they may include the previous history of the meadow, species mix, genome types, availability of viable seed banks, reproductive ability, nutrient availability, sediment type and a variety of location specific factors – they are essential in understanding the “performance” of a meadow under stressful conditions. There are long term data sets that show the range of fluctuations that can occur but the limits to successful recovery and the processes that support recovery are poorly understood. Without this information it is difficult to model scenarios such as the effect of climate change in a meaningful way.

4. Conclusions

There are considerable pressures on seagrass meadows along the urban coast from river discharge water quality and urban and industrial development. With increasing urban and catchment development further research is will be required to understand the synergistic effects between high nutrient availability and exposure to pollutants, and between water quality parameters and other disturbances or factors that influence health and production of seagrass.

At the spatial scales of locations and sites, there is considerable variability in meadow cover but at a GBRWHA scale there is no evidence of sustained losses or gains where monitoring is occurring. Most changes are possibly linked to short term environmental events.

Current nutrient states of the seagrasses that inhabit the coastal regions of the GBRWHA appear to be in either nutrient replete or nitrogen limited. Though nutrient supply is adequate, small biomass declines were noted across the regions. Collecting information of PAR within these meadows will lessen our information gaps and increase our ability to populate scenario models with parameters that will better reflect GBRWHA environment.

The seagrass monitoring component of the Reef Plan MMP within the GBRWHA has been successful in monitoring seagrass condition at a variety of locations and habitats. It is one of the most comprehensive seagrass programs outside the east coast of north America. Some regions however are less well monitored than others and this needs to be addressed.
5. References


Scheltinga DM and Heydon L (eds.) (2005). Report on the Condition of Estuarine, Coastal and Marine Resources of the Burdekin Dry Tropics Region. Commissioned by the


Appendix 1

Edge maps of the seagrass meadow within 100m of each monitoring site conducted at all sites in the Dry Season and Monsoon of each year.
Archer Point (Cooktown)

AP1
12 October 2005

AP2
28 April 2006

Legend
- **Main meadow**
- **Patchy meadow**

Points are start & end of transects. Codes = site+transect+quadrat distance, e.g., AP1150=site AP1, transect 1, distance 50m.


© The state of Queensland through the DPI&F (2007).
Archer Point (Cooktown)

AP2
12 October 2005

Legend

- **Main meadow**
- **Patchy meadow**

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., AP2150=site AP2, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Yule Point (Cairns)
Site: YP1

1 October 2005

29 March 2006

3 November 2006

15 April 2007

Legend

- Halodule uninervis meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., YP1150=site YP1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Yule Point (Cairns)
Site: YP2

1 October 2005

29 March 2006

3 November 2006

15 April 2007

Legend

- Halodule uninervis meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., YP2150=site YP2, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Green Island (Cairns)

13 October 2005

24 April 2006

20 October 2006

16 April 2007

Legend

C. rotundata/T. hemprichii meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., GI1150=site GI1, transect 1, distance 50m.

Green Island (Cairns)

GI2

13 October 2005

24 April 2006

Legend

- C. rotundata/T. hemprichii meadow

Points are start & end of transects. Codes = site+transect+quadrat distance, e.g., GI2150=site GI2, transect 1, distance 50m.

Lugger Bay (Mission Beach)

LB1
16 September 2005

26 April 2006

Legend

Halodule uninervis meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., LB1150=site LB1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Lugger Bay (Mission Beach)

LB2
16 September 2005

Legend

- Halodule uninervis meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., LB2150=site LB2, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Dunk Island (Mission Beach)

DI1
18 April 2007

Legend
- main meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., DI1150=site DI1, transect 1, distance 50m.


DI2
18 April 2007
Bushland Beach (Townsville)

BB1
1 October 2005

23 April 2006

07 October 2006

14 April 2007

Legend

- Main meadow
- Patchy meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., BB1150=site BB1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Shelley Beach (Townsville)

SB1
15 October 2005

Legend

- Green: Main meadow
- Light green: Patchy meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., SB1150=site SB1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Picnic Bay (Magnetic Island, Townsville)

MI1
12 October 2005

Legend

- H. uninervis (main meadow)
- Sparse H.uninervis/H.ovalis

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., MI1150=site MI1, transect 1, distance 50m.

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Magnetic Island (Townsville)

MI2
12 October 2005

24 April 2006

08 October 2006

19 April 2007

Legend

- main meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., MI2150=site MI2, transect 1, distance 50m.

Pioneer Bay (Whitsundays)

PI2
17 September 2005

PI2
04 October 2006

PI3
17 April 2007

Legend

Water
Patchy H. ovalis meadow
Main meadow

Points are start & end of transects. Codes = site+transect+quadrat distance, e.g., PI1150=site PI1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Pioneer Bay (Whitsundays)

PI3
17 September 2005

26 April 2006

04 October 2006

17 April 2007

Legend

- Water
- Patchy H. ovalis meadow
- Main meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., PI3150=site PI3, transect 1, distance 50m.


© The state of Queensland through the DPI&F (2007).
Legend

- Halophila/Halodule meadow
- Cymodocea/Thalassia meadow

Points are start & end of transects.

Codes = site+transect+quadrat distance, e.g., HM1150=site HM1, transect 1, distance 50m.


© The state of Queensland through the DPI&F (2007).
Sarina Inlet (Mackay)

SI2
19 September 2005

26 March 2006

05 October 2006

15 April 2007

Legend

- Zostera capricorni meadow

Points are start & end of transects.

Codes = site+transect+quadrat distance,
e.g., SI2150=site SI2, transect 1, distance 50m.

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ecosystem monitoring programs - Reef Water Quality

© The state of Queensland through the DPI&F (2007).
Shoalwater Bay

RC1
18 September 2005

RC1
28 March 2006

03 October 2006

01 May 2007

Legend

- Zostera capricorni meadow

Points are start & end of transects. Codes = site+transect+quadrat distance, e.g., RC1150=site RC1, transect 1, distance 50m.


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Shoalwater Bay

WH1

17 September 2005

04 0 8 0 1 2 0 1 6 020
04 October 2006

RC1

Legend

Zostera capricorni meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., WH1150=site WH1, transect 1, distance 50m.

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Great Keppel Island

GK3
15 May 2007

Legend
- seagrass
- water

Points are start & end of transects. Codes = site+transect+quadrat distance, e.g., GK1150=site GK1, transect 1, distance 50m.

Legend

- Zostera capricorni meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., GH1150=site GH1, transect 1, distance 50m.

© The state of Queensland through the DPI&F (2007).
Points are start & end of transects. 
Codes = site+transect+quadrat distance, 
e.g., GH1150=site GH1, transect 1, distance 50m. 
© The state of Queensland through the DPI&F (2007).
Urangan (Hervey Bay)

UG1
30 October 2005

Legend

- Zostera capricorni meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance,
e.g., UG1150=site UG1, transect 1, distance 50m.

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Urangan (Hervey Bay)

Legend

- Green: Zostera capricorni meadow

Points are start & end of transects.
Codes = site+transect+quadrat distance, e.g., UG2150=site UG2, transect 1, distance 50m.

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