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MARINE MONITORING PROGRAM

Annual Report for inshore seagrass monitoring

2013 - 2014

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Seagrass-Watch

JAMES COOK UNIVERSITY
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Acronyms & Abbreviations Used In This Report

CV	coefficient of variation
DAFF	Department of Agriculture, Fisheries and Forestry
DERM	Department of Environment and Resource Management
Fisheries QLD	Fisheries Queensland (DAFF)
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
JCU	James Cook University
km	kilometre
m	metre
MMP	Marine Monitoring Program
NRM	Natural Resource Management
Paddock to Reef	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program
SE	Standard Error
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
QPSMP	Queensland Ports Seagrass Monitoring Program

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River discharge data provided by the State of Queensland (Department of Natural Resources and Mines) 2014. The conceptual diagram symbols are courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science. Climate data courtesy of the Australian Bureau of Meteorology, and tide data courtesy Maritime Safety Queensland, Department of Transport and Main Roads.

Executive summary

The Marine Monitoring Program (herein referred to as the MMP) undertaken in the Great Barrier Reef (GBR) lagoon assesses the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan) and the Australian Government's initiative, formerly known as Reef Rescue. Established in 2005 to help assess the long-term status and health of GBR ecosystems, the MMP is a critical component in assessing improvements in regional water quality as land management practices are improved across Reef catchments. The program forms an integral part of the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (P2R program) supported through Reef Plan. This report details the results of sampling that has occurred under the MMP to assess the status and identify responses to the environmental drivers of trends in the inshore seagrass ecosystems of the GBR lagoon.

The inshore seagrass ecosystem monitoring component of the MMP assessed seagrass abundance (percentage cover), community structure, distribution, reproductive health, and nutrient status from inshore seagrass meadows at 21 locations throughout the GBR. Within each of the Natural Resource Management regions (Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary), monitoring locations included each of the major seagrass habitat types where possible (estuarine, coastal, reef, subtidal reef). Locations were predominately lower littoral (only exposed to air at the lowest of low tides), hereafter referred to as intertidal, although four locations also included shallow subtidal meadows.

Prior to 2011, inshore seagrass meadows along the developing coast of the GBR were in a vulnerable condition with declining trajectories. This was the result of multiple years of above average rainfall and climate-related impacts. The extreme weather events of early 2011 resulted in further substantial decline in inshore seagrass meadows throughout much of the GBR. As a critical component of the GBR inshore ecosystems, the seagrass losses had significant flow-on effects to dugong and green turtle populations (Meager and Limpus 2012), which are highly dependent on certain seagrasses as their primary food supply.

An important component of assuring the long-term maintenance and viability of GBR seagrass ecosystems, is to understand and enhance the key features of their resilience. Ecological resilience includes resistance to disturbance (resistance) and capacity to recover (recovery) and determines the capacity of a system to maintain its function when affected by disturbances (Folke *et al.* 2004; Bernhardt and Leslie 2013; Unsworth *et al.* In Press). These attributes are also important in GBR seagrass meadows faced with multiple cumulative stressors, including the chronic effects of poor water quality, and it is therefore helpful to consider monitoring results in the context of resistance and recovery attributes. The attributes of seagrasses that are indicative of resistance include: abundance, species composition, genetic diversity, and storage reserves, and continuity (or spatial extent) (Unsworth*, et al.* In Press). Furthermore, recovery is facilitated by reproductive output, seed banks and species composition. In 2013-14, the majority of seagrass meadows across the GBR remained in a vulnerable state, with weak resistance (low abundance and low diversity, or abundance dominated by colonising species) and a low capacity to recover (both low seed bank and low reproductive effort).

In 2013-14, the indicators of seagrass resilience continued to improve for meadows along the GBR developing coast, although still remained in a vulnerable and poor state (particularly in the Wet Tropics and southern NRM regions). The indicators of this improvement were: increasing abundance (% cover) at 71% of sites (predominately intertidal coast and reef habitats); 80% of meadows expanding in area or remaining unchanged/at their maximum extent; and increasing composition of foundation species at 87% of sites. Of concern, however, is that resilience continued to remain low and the indicators of this were: 49% of sites with lower than GBR average composition of foundational species; the absence of seed banks at 42% of sites and declining seed banks at another

22% of sites; 58% of sites with lower than average daily light, particularly across the Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions; increasing epiphyte loads with above GBR averages at 42% sites; and nutrient enrichment at 44% sites and of these, 11% with either high or elevated nitrogen. Elemental ratios of tissue nutrients indicate some meadows in the Wet Tropics, Burdekin and Fitzroy regions have degraded water quality with an excess of nutrients compared to light availability.

The region with the greatest improvement in abundance (% cover) during 2013-14 was the Burdekin NRM, while the Fitzroy NRM was the only region to experience declines. Greatest increases in abundance were measured across subtidal habitats, however, only four subtidal meadows are monitored and all occur in the Wet Tropics and Burdekin regions. Seagrass meadow expansion in 2013-14 was not as great as during the previous monitoring period, increasing only 5% in overall extent, however, meadows have continued to undergo a state change with foundation seagrass species becoming increasing more prevalent. Improvement in seed banks, particularly in the Burdekin and Mackay Whitsunday regions, coupled with the increased reproductive effort, suggests GBR estuarine and coastal meadows have an improved capacity to recover from disturbances. However, seed banks in reef subtidal habitats may become limited as a result of low reproductive effort and lack of replenishment. Daily incident light reaching the top of the seagrass canopy was at or below average for meadows in the southern Wet Tropics, Burdekin, Burnett Mary and Fitzroy regions, but above average in the northern Wet Tropics and Mackay-Whitsunday regions. The number of days light was below the threshold for positive seagrass growth in 2013-14, was either equal to or slightly less than the long-term average for subtidal and intertidal meadows, respectively. Overall, these results indicate that light conditions were less than optimum.

Climatic conditions during 2013-14 were less conducive for seagrass growth than in recent years in Cape York and the Wet Tropics, as a result of higher rainfall and greater wind. Above median discharges from rivers, likely exposed meadows to plumes of turbid sediment-laden water, and more days of stronger winds resuspended benthic sediments, limiting light during the main seagrass growing season. The Burdekin and Burnett Mary regions were drier, but the higher winds coupled with warmer temperatures and higher tidal exposure would have been less conducive for seagrass growth in some meadows, due to elevated heat and desiccation stress. In the central regions (Mackay Whitsunday and Fitzroy) climatic conditions were more favourable, particularly as the majority of inshore meadows occur within wind sheltered bays and estuaries.

Across the GBR NRM regions, the seagrass report card scores improved during 2013-14 in the Burdekin, Mackay Whitsunday and Burnett Mary, but remained relatively unchanged in the others. It should be noted, however, that seagrass across most of the regions are still recovering from multiple years of climate related impacts which has likely left a legacy of reduced resilience. Overall, the status of the inshore seagrass meadows of the GBR improved in 2013-14 compared to the previous 2 years, but remained in a **poor state** (Table 1). Current rates of recovery, as well as examples taken from previous localised impacts (Birch and Birch 1984; Campbell and McKenzie 2004b) indicate that a return to a moderate or good condition could occur within 2 more years (i.e. >5 years from impact), as long as conditions remain favourable.

Table 1. *Report card for seagrass status for the GBR and each NRM region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).NB: includes new locations established in 2012.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	43	8	36	29
Wet Tropics	24	12	34	23
Burdekin	51	60	69	60
Mackay Whitsunday	18	25	31	25
Fitzroy	22	8	47	26
Burnett Mary	10	0	77	29
GBR	39	19	43	**34**

1 Introduction

Long-term water quality and ecosystem monitoring in the inshore Great Barrier Reef (GBR) lagoon is undertaken through the Marine Monitoring Program. The Great Barrier Reef Marine Park Authority (GBRMPA) has responsibility for implementation of this program. James Cook University (JCU) were contracted to provide the inshore seagrass monitoring component. The key aims were to:

- Report on the abundance and species composition of seagrass (including edge mapping) in the late dry season of 2013 and the late monsoon season of 2014 at inshore intertidal and subtidal locations,
- Report on the reproductive health of the seagrass species present at inshore intertidal and subtidal locations,
- Report on tissue nutrient concentrations (carbon, nitrogen and phosphorus) and epiphyte loads of foundation seagrass species (genus *Halodule, Zostera, Cymodocea*) at each inshore intertidal and subtidal location,
- Report on spatial and temporal patterns in light, turbidity and temperature at sites where autonomous loggers are deployed,
- Report on seagrass community and environment status and trends, and
- Integrate reporting on GBR seagrass status including production of seagrass report card metrics for use in an annual Paddock to Reef report card.

Seagrasses are an important component of the marine ecosystem of the Great Barrier Reef. The ecosystem services provided by seagrass ecosystems makes them a high conservation priority (Cullen-Unsworth and Unsworth 2013). Certain seagrasses are the primary food for marine green turtles and dugongs, which are seagrass specialists (Read and Limpus 2002; Arthur *et al.* 2008; Marsh *et al.* 2011;). Seagrass form highly productive habitats for a large number of invertebrates, fish and algal species (Carruthers *et al.* 2002), which are of commercial (e.g. prawns) and subsistence (e.g. holothurians) fisheries importance (Coles *et al.* 1993; Cullen-Unsworth and Unsworth 2013). Nutrient cycling in seagrass meadows makes them one of the most economically valuable ecosystems in the world (Costanza *et al.* 1997) and the retention of carbon within their sediments contributes significantly to Blue Carbon sequestration (Fourqurean *et al.* 2012; Unsworth *et al.* 2012a).

Much of the connectivity in reef ecosystems depends on intact and healthy non-reef habitats, such as seagrass meadows (Waycott *et al.* 2011). These non-reef habitats are particularly important to the maintenance and regeneration of populations of reef fish such as Emperor fish (*Lethrinus spp*) and Tuskfish (*Choerodon spp*) (Unsworth *et al.* 2014). In addition, the incorporation of carbon within seagrass tissues can affect local pH and increase calcification of coral reefs, thereby mitigating the effects of ocean acidification (Fourqurean*, et al.* 2012; Unsworth*, et al.* 2012a). Therefore, monitoring changes in seagrasses meadows not only provides an indication of coastal ecosystem health, but also improves our capacity to predict changes to adjacent reefs, mangroves and associated resources upon which coastal communities depend (Heck *et al.* 2008).

Chronic declines in inshore water quality in the GBR since European settlement have led to dramatic ecological shifts in many GBR marine ecosystems (De'ath and Fabricius 2010; Roff *et al.* 2013). Multiple pressures are the cause of this decline, including intensive use of the GBR catchments for agriculture and grazing, and coastal development for urban centres and commercial ports (Brodie *et al.* 2013). Flood plumes, in particular, bring the terrestrially sourced pollutants into the GBR dispersing them over the sensitive ecosystems including seagrass meadows (summarised in Schaffelke *et al.* 2013).

Approximately 3,063 km^2 of coastal seagrass meadows has been mapped in Great Barrier Reef World Heritage Area (GBRWHA) in waters shallower than 15m, and in locations that can potentially be influenced by adjacent land use practices (McKenzie *et al.* 2010). An additional 31,778 km^2 of the sea floor within the GBRWHA is seagrass habitat (Coles *et al.* 2009). This represents more than 50% of the total recorded area of seagrass in Australia (Green and Short 2003) and between 6% and 12% globally (Duarte *et al.* 2005) making the Great Barrier Reef's seagrass resources globally significant. The predominantly inshore distribution of seagrass meadows in the GBR makes them particularly susceptible to the direct effects of flood plumes as well as chronic water quality decline.

Tropical seagrass ecosystems of the GBR are a complex mosaic of different habitat types comprised of multiple seagrass species (Carruthers *et al.* 2002). There are 15 species of seagrass in the GBR (Waycott *et al.* 2007) and high diversity of seagrass habitat types is provided by extensive bays, estuaries, rivers and the 2600 km length of the 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 Mean Sea Level (MSL). Seagrasses in the GBR can be separated 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.

The seagrass ecosystems of the GBR, on a global scale, would be for the most part categorised as being dominated by disturbance-favouring opportunistic species (e.g. *Halophila*, *Halodule* and *Zostera*), which typically have low standing biomass and high turnover rates (Carruthers *et al.* 2002, Waycott *et al.* 2007). In more sheltered areas, including in reef top or inshore protected areas, more stable and persistent species are found, although these are still relatively responsive to disturbances (Carruthers *et al.* 2002, Waycott *et al.* 2007, Collier and Waycott 2009).

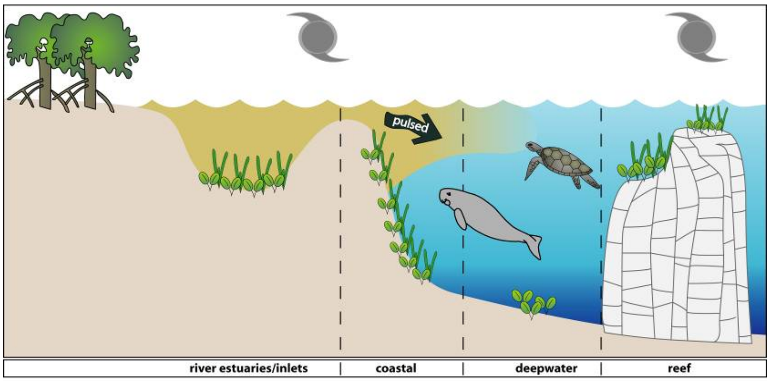

Figure 1. *General conceptual model of seagrass habitats in north east Australia (from Carruthers et al., 2002)*

The requirements for the formation of healthy seagrass meadows are relatively clear as they are photosynthetic plants occupying a marine habitat. They require adequate light, nutrients, carbon dioxide, suitable substrate for anchoring along with tolerable salinity, temperature and pH (Waycott and McKenzie 2010; Collier *et al.* 2014b). As seagrasses are well recognised as indicators of integrated environmental pressures, monitoring their status and trend can provide insight into the condition of the surrounding environment (e.g. Dennison *et al.* 1997). In low nutrient, oligotrophic systems there is typically high light availability for the plants, while in high nutrient, eutrophic ecosystems there is little light reaching the benthos (Johnson *et al.* 2006). Monitoring of C:N:P ratios may be advantageous for the early detection of changes in nutrient regimes for environmentally sensitive seagrasses (Johnson*, et al.* 2006; Waycott and McKenzie 2010). Observations of trends in indicators such as C:N:P ratios or changes in seagrass meadow composition provide insight into the responses of seagrasses to environmental change (Waycott and McKenzie 2010). We have developed a matrix of comparison for these indicators (Table 2) and have evidence of seagrass responses in most categories. This framework provides a structure for acknowledging and interpreting the variety of indicators being used to detect different types of environmental change.

Table 2. *Response stages of seagrass meadows to external stressors and the indicator responses observed in GBR monitored seagrass meadows (adapted from Waycott and McKenzie 2010).*

Indicator	***Sub-lethal*** (ecophysiological)	***State change*** (whole plant and population scale)	***Population decline*** (whole meadow scale)
Tissue nutrients	Ratios of key macronutrients change to indicate relative excesses (i.e. C:N, C:P, N:P)	Limited by species, variable upper threshold	-
Isotope ratios ($\delta^{13}C$, $\delta^{15}N$)	Ratios change with demand ($\delta^{13}C$) and environmental conditions ($\delta^{15}N$)		
Chlorophyll concentrations	Rapid short term changes observed	Limited by species variable upper threshold	-
Storage carbohydrates	Sugars and starch in rhizomes depleted as photosynthetic C-fixation is reduced		
Production of reproductive structures including seeds	-	Reduced flowering and fruiting, loss of seeds for meadow recovery seen as high variability among sites	Threshold reached where no reproduction occurs
Change in plant morphology	-	Reduction in leaf area	Threshold reached
Community structure	-	Change in species composition	Loss of species
Change in species abundance (population structure)	-	Change in abundance of species (i.e. % cover)	Reduction in effective population size
Change in meadow area	-	-	Reduction (or increase) in total meadow area
Recovery time from loss	Limited or no change	Measurably delayed	Potentially no recovery if threshold reached

There are also many scales at which indicators respond, ranging from sub-lethal (physiological), through to meadow-scale (or state change) losses (Figure 2, Table 1). These indicators also respond at different temporal scales, with sublethal, physiological indicators able to respond from seconds to months, while the meadow-scale effects usually take many months to be detectable. A robust monitoring program benefits from having a suite of indicators that can indicate sub-lethal stress that forewarns of imminent loss, as well as indicators of meadow-scale changes, which are necessary for interpreting broad ecological changes. Indicators included in the MMP span this range of scales, in particular for indicators that respond from weeks (tissue nutrients, isotopes), through to months (abundance and reproduction), and even years (abundance and meadow extent).

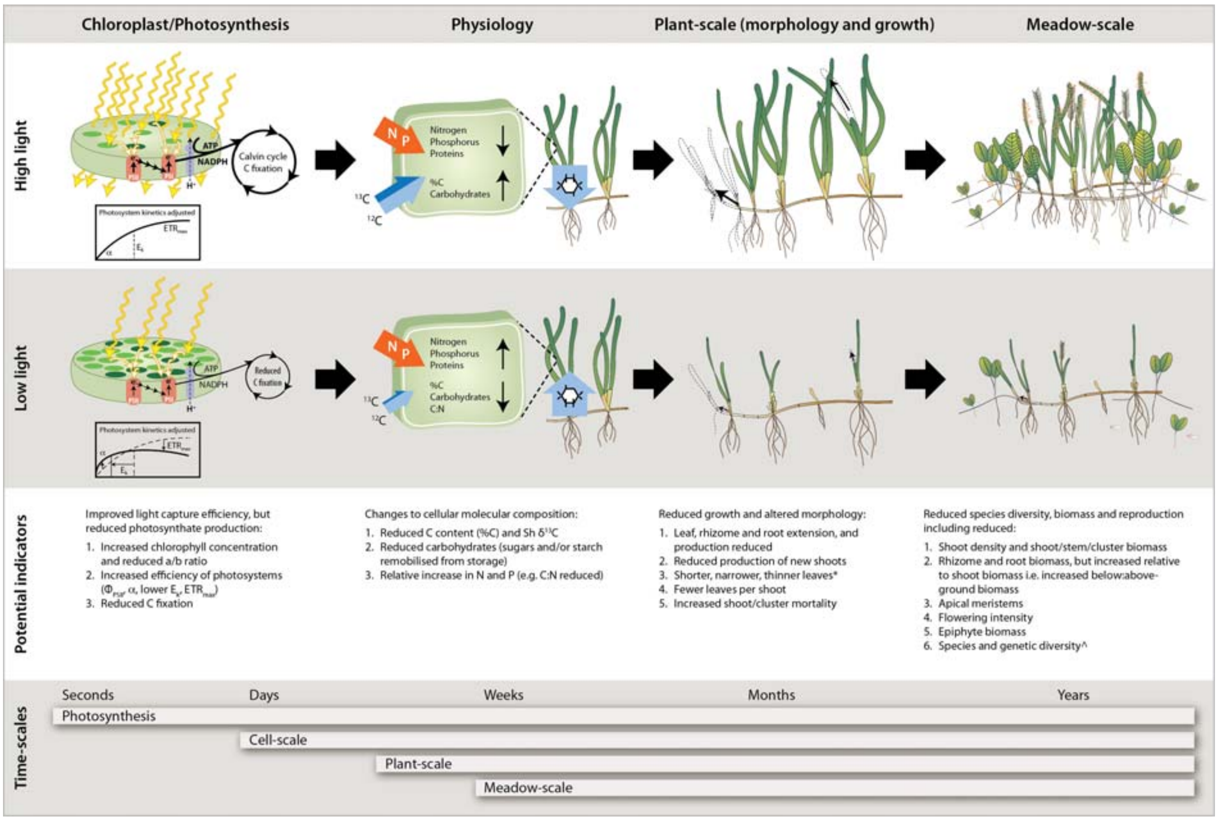

Figure 2. *Conceptual diagram of the current understanding of the of seagrass response pathway under low light conditions separated by photosynthetic, other physiological, plant-scale (growth and morphology) and meadow-scale variables. The timescales at which the responses to light reduction generally occur are indicated at the base of the diagram. from McMahon et al. (2013).*

To understand the status and trends of GBR inshore seagrass ecosystems, a suite of indicators were monitored in representative meadows across the range of habitats and regions. Sub lethal indicators such as seagrass leaf tissue nutrient ratios (C:N:P) and isotopes (e.g. $\delta^{13}C$, $\delta^{15}N$) provided insight into the light and nutrient status of the inshore environment. The abundance, community structure, and reproductive health of the meadows indicated the state of the plants/population and forewarned of imminent loss. The relative distribution was also monitored to indicate meadow-scale changes, which were necessary for interpreting broad ecological changes of population decline. In concert with the indicators, a number of environmental drivers (e.g. light availability, temperature) and modifiers (e.g. herbicides) were monitored.

This report presents data from the tenth period of monitoring inshore seagrass ecosystems of the Great Barrier Reef under the MMP (undertaken from June 2013 to May 2014; hereafter called “2013-14”).

2 Methods summary

In the following, an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the methods used in the MMP, including quality assurance and quality control procedures, is available in Appendix 1.

2.1 Sampling design & site selection

The sampling design was selected to detect changes in inshore seagrass meadows in response to improvements in water quality associated with specific catchments or groups of catchments (Region) and to disturbance events.

One of the paramount requirements at the onset of the Marine Monitoring Program, apart from being scientifically robust, was that its findings must have broad acceptance and ownership by the North Queensland and Australian community. It was identified very early in development of Reef Rescue (a component of Reef Plan), that existing long-term monitoring programs (e.g. Seagrass-Watch) and legacy sites provided an excellent opportunity on which to base the inshore seagrass monitoring component. In late 2004 all data collected within the GBR region as part of existing monitoring programs were supplied to a Senior Statistician at AIMS for independent review. De'ath 2005) examined the available datasets to estimate expected performance with regard to detecting long-term changes (including estimates of precision for annual mean, differences in means and linear trends) of the monitoring program. Seagrass data included in the analyses was collected from 2000–2004 and across 63 sites in 29 locations from Cooktown to Hervey Bay. Results concluded that the existing spatial and temporal coverage of monitoring was providing valuable information about long-term trends and spatial differences, with changes in seagrass cover occurring at various spatial and temporal scales. The report recommended that the value of the monitoring would be greatly enhanced by adding more widely spread locations.

The meadows monitored within the MMP were selected by the GBRMPA, using advice from expert working groups. The selection of meadows was based upon two primary considerations:

1. meadows were representative of seagrass habitats and seagrass communities across each region (based on Lee Long *et al.* 1993, Lee Long *et al.* 1997a, Lee Long *et al.* 1998; McKenzie *et al.* 2000a; Rasheed *et al.* 2003; Campbell *et al.* 2002; Goldsworthy 1994)
2. sampling locations where possible included legacy sites (e.g. Seagrass-Watch, MTSRF) or sites where seagrass research had been focused (e.g. Dennison *et al.* 1995; Thorogood and Boggon 1999; Udy *et al.* 1999; Haynes *et al.* 2000a; Inglis 2000; Campbell and McKenzie 2001; Mellors 2003; Campbell and McKenzie 2004b; Mellors *et al.* 2004; Limpus *et al.* 2005; McMahon *et al.* 2005; Mellors *et al.* 2005; Lobb 2006).

Meadows were selected using mapping surveys across the regions prior to site establishment. Ideally mapping was conducted immediately prior to site positioning, however in most (60% of) cases it was based on historic (>5yr) information. The final constraint on site selection was that the Minimum Detectable Difference (MDD) had to be below 20% (at the 5% level of significance with 80% power) (Bros and Cowell 1987). Representative meadows were those which covered the greater extent of the resource, were generally the dominant seagrass community type and were within GBR average abundances (based on Coles *et al.* 2001a; Coles *et al.* 2001c, 2001b, 2001d). To account for spatial heterogeneity of meadows within habitats, two sites were selected at each location.

From the onset, inshore seagrass monitoring for the MMP was focused primarily on intertidal seagrass meadows due to:

- accessibility and cost effectiveness (limiting use of vessels and divers)
- Work Place Health and Safety due to dangerous marine animals (e.g., crocodiles, box jellyfish and irukandji)
- occurrence of meadows in estuarine, coastal and reef habitats across the entire GBR, and
- provides an opportunity for community involvement, ensuring broad acceptance and ownership of Reef Plan by the Queensland and Australian community.

Although considered intertidal within the MMP, the meadows chosen for monitoring were in fact lower littoral (rarely exposed to air). The long-term median annual daylight exposure (the time intertidal meadows are exposed to air during daylight hours) was 1.7% (all meadows pooled) (Table 39). This limited the time monitoring could be conducted to the very low spring tides within small tidal windows (mostly 1-4hrs per day for 3-6 days per month for 6-9 months of the year). Traditionally, approaches developed for monitoring seagrass to assess changes in water quality were developed for subtidal meadows typified by small tidal ranges (e.g., Florida = 0.7m, Chesapeake Bay = 0.6m) and clear waters where the seaward edges of meadows were only determined by light (EHMP 2008). Unfortunately, depth range monitoring in subtropical/tropical seagrass meadows has not been as successful as initially expected (e.g. Moreton Bay) and seagrass meadows within the Great Barrier Reef lagoon do not conform to traditional ecosystem models because of the systems complexity (Carruthers*, et al.* 2002), including:

- a variety of habitat types (estuarine, coastal, reef and deepwater);
- a large variety of seagrass species with differing life history traits and strategies;
- tidal amplitudes spanning 3.42m (Cairns) to 10.4m (Broad Sound) (www.msq.qld.gov.au; Maxwell 1968);
- a variety of sediment substrates, from terrigenous with high organic content, to oligotrophic calcium carbonate;
- turbid nearshore to clearer offshore waters;
- grazing dugongs and sea turtles influencing meadow community structure and landscapes;
- near absence of shallow subtidal meadows south of the Whitsundays due to the large tides which scour the seabed.

Subtidal meadows across the GBR are predominately dominated by *Halophila* species and are highly variable in abundance and distribution (Lee Long *et al.* 2000). Due to this high variability they are generally not recommended for monitoring as the Minimum Detectable Difference (MDD) is very poor at the 5% level of significance with 80% power (McKenzie *et al.* 1998). Predominately stable lower littoral meadows of foundation species (e.g., *Zostera*) are best for determining significant change/impact (McKenzie *et al.* 1998). Nevertheless, where possible, shallow (<1.5m below Lowest Astronomical Tide) subtidal monitoring has been conducted since October 2009 at locations in the Burdekin and Wet Tropics regions. These sites were chosen as they were dominated by species similar to adjacent lower littoral meadows.

Due to the high diversity of seagrass species across the GBR, it was decided in consultation with GBRMPA to direct monitoring toward the foundation seagrass species across the seagrass habitats. A foundation species is the dominant primary producer in an ecosystem both in terms of abundance and influence, playing central roles in sustaining ecosystem services (Angelini *et al.* 2011). The activities of foundation species physically modify the environment and produce and maintain habitats that benefit other organisms that use those habitats. For the seagrass habitats assessed in the MMP, the foundation seagrass species were those species which typified the habitats both in abundance and structure when the meadow was considered in its steady state (Figure 3**Error! Reference source not found.**) (Kilminster *et al.* 2015). The foundation species were all di-meristematic leaf-replacing forms.

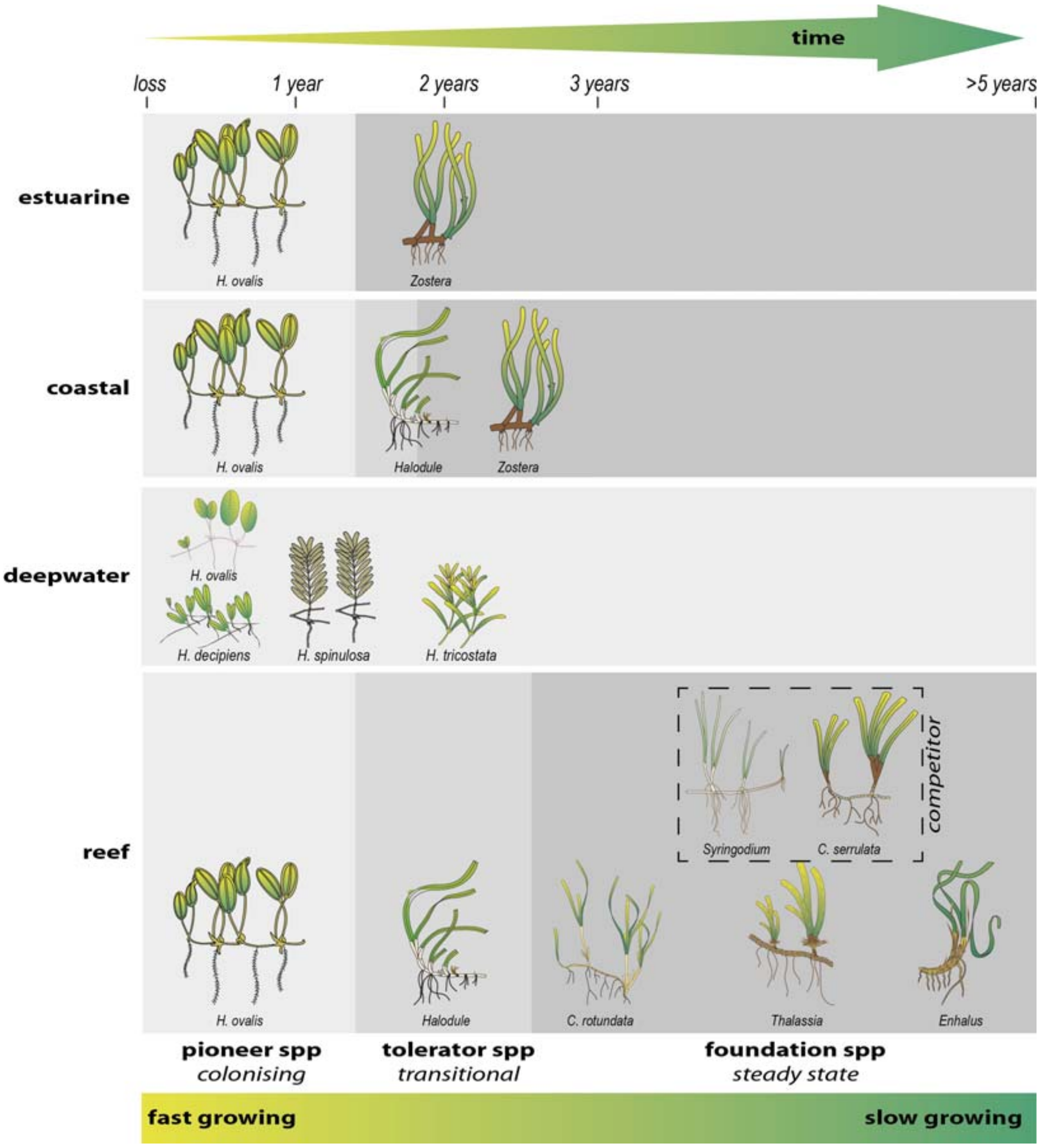

Figure 3. *Illustration of seagrass recovery after loss and the categories of successional species over time.*

The timing of the monitoring within the MMP was decided by the GBRMPA, using advice from expert working groups. As the major period of runoff from catchments and agricultural lands was the tropical wet season/monsoon (December to April), monitoring was focussed on the late dry (growing) season and late wet season to capture the status of seagrass pre and post wet.

Seagrass monitoring methods were conducted as per McKenzie *et al.* (2010). In early 2012, additional monitoring sites were established in the Cape York region north of Cooktown and within Bowling Green Bay (Burdekin region), with financial support from Reef Plan operations (Regional Services, DAFF). Forty five sites were monitored during the 2013-14 monitoring period (Table 4). This included eight coastal, four estuarine and nine reef locations (i.e. two-three sites at each location). At the reef locations in the Burdekin and Wet Tropics, intertidal sites were paired with a subtidal site (Table 4). A description of all data collected during the sampling period under the monitoring contract has been collated by Natural Resource Management (NRM) region, site, parameter, and the number of samples collected per sampling period is listed in Table 26. The seagrass species present at each monitoring site (including foundation seagrass species) is listed in Table 5.

2.2 Seagrass monitoring

2.2.1 Seagrass abundance, composition and distribution

Field survey methodology followed standardised protocols (detailed in McKenzie *et al.* (2003) and Appendix 1). At each location, with the exception of subtidal sites, sampling included two sites nested (within 500m of each other) in a location. Subtidal sites were not replicated within locations. Intertidal sites were defined as a 50m x 50m area within a relatively homogenous section of a representative seagrass community/meadow (McKenzie *et al.,* 2000). The sampling strategy for subtidal sites was modified to sample along 50m transects 2-3 m apart (aligned along the depth contour) due to logistics of SCUBA diving in waters of poor visibility. Monitoring at sites in the late dry (September/October 2013) and late monsoon (March/April 2014) of each year was conducted by a qualified and trained scientist. Monitoring conducted outside these periods was also conducted by a trained scientist, and at 3 locations (Magnetic Island, Townsville and Pioneer Bay) was assisted by volunteers. At each site, during each survey, observers recorded the percent seagrass cover within a 50 cm × 50 cm quadrat every 5 m along three 50m transects, placed 25m apart. Additional information was collected at the quadrat level, although only included as narrative in this report, including: seagrass canopy height of the dominant strap leaved species; macrofaunal abundance; abundance of burrows, as an measure of bioturbation; presence of herbivory (e.g. dugong and sea turtle); a visual/tactile assessment of sediment composition (see McKenzie 2007); and observations on the presence of superficial sediment structures such as ripples and sand waves to provide evidence of physical processes in the area (see Koch 2001b).

Regularly mapping the distribution of entire meadows was beyond the funding available for the project. To provide an indication of meadow distribution, mapping the edges of meadows within 100m of each site was used to determine if changes in seagrass abundance were the result of seascape changes (e.g. the meadow shrinking/increasing in distribution or aggregation / isolation of patches) or the shoots increasing/decreasing in density, or both. Mapping the edge of the seagrass meadow within 100m of each monitoring site was conducted in the late dry and late monsoon monitoring periods (for detail of mapping approach, see Appendix 1.1.5). Extent of seagrass within the mapping area was compared against each site's baseline (first measure).

Seagrass species were identified as per Waycott *et al.* (2004). Species composition was further categorised into life history traits and strategies. Plants have a range of adaptive features incorporated into life histories, which can be distinguished along a continuum of strategies (Gadgil and Solbrig 1972). At the extremes of the continuum are the *r*- and K-strategists as defined by MacArthur and Wilson (1967). Plants species with the traits that are thought to characterise *r*-selection are the generalist species - ruderal species or weeds - opportunistically colonise highly disturbed sites, commonly in abundance, relying on fast and adaptable clonal growth, regular and flexible sexual reproduction and a persistent, abundant seed bank (MacArthur and Wilson 1967; Grime 1979). In stable or predictable environments, K-selection predominates as the ability to compete successfully for limited resources is crucial and populations of K-selected organisms typically are very constant and close to the maximum that the environment can bear (unlike *r*-selected populations, where population sizes can change much more rapidly). K-strategist (also referred to as foundational or climax) species allocate resources to vegetative adaptation to resist stress or competition.

Seagrass species within each monitoring location were classified into broad *r*- or K-strategist species for each habitat type (as per **Error! Reference source not found.** and Carruthers*, et al.* 2002). For example, in estuarine and reef habitats, *Zostera* and *Thalassia* are considered to be a K-strategists, being perennial and using the carbohydrate reserve in their rhizomes for maintenance if their leaves are removed (Dawes 1981). Conversely, *Halophila ovalis* displays characteristics of an *r*-strategist with high reproductive output and little investment in competition or maintenance (Rasheed 2004).

However, as *Zostera*, and also *Halodule*, can act as both an *r*- or K-specialist during meadow expansion/recovery phase (after loss) and depending on the environment within which they persist (Harrison 1979), expert elucidation was required to classify which category they aligned. After categorisation, the long-term average proportion of K-strategist (foundational) species in each meadow monitored was determined for each GBR seagrass habitat type (Table 3), excluding during the following periods:

- the period of time when meadows underwent major decline i.e. >80% loss of cover (or below 20th percentile);
- the period after meadow loss (absence) when a meadow was in recovery mode:
    a. 24 months post estuary or coastal meadow loss, (Campbell and McKenzie 2004a; McKenzie *et al.* 2010b);
    b. 5 years post reef meadow loss (Birch and Birch 1984).

Table 3. *Long-term average proportion (±SE) of K-strategist species in each GBR seagrass habitat type. (refer* Figure 3***Error! Reference source not found.****)*

Seagrass habitat	average proportion K-strategist species	Seagrass genus
estuary	0.95 ±0.01	*Zostera*
coast	0.84 ±0.014	*Zostera, Halodule*
reef - intertidal	0.85 ±0.02	*Cymodocea, Thalassia, Zostera*
reef - subtidal	0.87 ±0.03	*Halodule*

Table 4. *MMP inshore seagrass long-term monitoring sites. NRM region from www.nrm.gov.au. * = intertidal, ^=subtidal.*

GBR region	NRM region (*Board*)	Catchment	Monitoring location	Site		Latitude		Longitude		Seagrass community type
Far Northern	Cape York		Shelburne Bay *coastal*	SR1*	Shelburne Bay	11°	53.233	142°	54.851	*H. ovalis with H. uninervis/T. hemprichii*
				SR2*	Shelburne Bay	11°	53.251	142°	54.938	*H. ovalis with H. uninervis/T. hemprichii*
			Piper Reef *reef*	FR1*	Farmer Is.	12°	15.352	143°	14.020	*T. hemprichii with C. rotundata/H. ovalis*
				FR2*	Farmer Is.	12°	15.448	143°	14.185	*T. hemprichii with C. rotundata/H. ovalis*
		Normanby	Stanley Island *reef*	ST1*	Stanley Island	14°	8.576	144°	14.680	*H. ovalis/H. uninervis with T. hemprichii/C. rotundata*
				ST2*	Stanley Island	14°	8.547	144°	14.588	*H. ovalis/H. uninervis with T. hemprichii/C. rotundata*
			Bathurst Bay *coastal*	BY1*	Bathurst Bay	14°	16.082	144°	13.961	*H. uninervis with H. ovalis/T. hemprichii/C. rotundata*
				BY2*	Bathurst Bay	14°	16.062	144°	13.896	*H. uninervis with H. ovalis/T. hemprichii/C. rotundata*
		Annan	Cooktown *reef*	AP1*	Archer Point	15°	36.500	145°	19.143	*H. univervis/ H. ovalis* with *Cymodocea/T. hemprichii*
				AP2*	Archer Point	15°	36.525	145°	19.108	*H. univervis/H. ovalis* with *C. rotundata*
Northern	Wet Tropics (*Terrain NRM*)	Daintree	Low Isles *reef*	LI1*	Low Isles	16°	23.11	145°	33.88	*H.ovalis/H.uninervis*
				LI2^	Low Isles	16°	22.97	145°	33.85	*H.ovalis/H.uninervis*
		Barron Russell -Mulgrave Johnstone	Yule Point *coastal*	YP1*	Yule Point	16°	34.159	145°	30.744	*H. uninervis* with *H. ovalis*
				YP2*	Yule Point	16°	33.832	145°	30.555	*H. uninervis* with *H. ovalis*
			Green Island *reef*	GI1*	Green Island	16°	45.789	145°	58.31	*C. rotundata/T. hemprichii* with *H. uninervis/H. ovalis*
				GI2*	Green Island	16°	45.776	145°	58.501	*C. rotundata/T. hemprichii* with *H. uninervis/H. ovalis*
				GI3^	Green Island	16°	45.29	145°	58.38	*C. rotundata/ H. uninervis/C.serrulata/S.isoetifolium*
		Tully	Mission Beach *coastal*	LB1*	Lugger Bay	17°	57.645	146°	5.61	*H. uninervis*
				LB2*	Lugger Bay	17°	57.674	146°	5.612	*H. uninervis*
			Dunk Island *reef*	DI1*	Dunk Island	17°	56.6496	146°	8.4654	*H. uninervis* with *T. hemprichii/ C. rotundata*
				DI2*	Dunk Island	17°	56.7396	146°	8.4624	*H. uninervis* with *T. hemprichii/ C. rotundata*
				DI3^	Dunk Island	17°	55.91	146°	08.42	*H. uninervis / H. ovalis/H.decipiens/C. serrulata*
Central	Burdekin (*NQ Dry Tropics*)	Burdekin	Magnetic island *reef*	MI1*	Picnic Bay	19°	10.734	146°	50.468	*H. uninervis* with *H. ovalis & Zostera/T. hemprichii*
				MI2*	Cockle Bay	19°	10.612	146°	49.737	*C. serrulata/ H. uninervis* with *T. hemprichii/H. ovalis*
				MI3^	Picnic Bay	19°	10.734	146°	50.468	*H. uninervis* with *H. ovalis & Zostera/T. hemprichii*
			Townsville *coastal*	SB1*	Shelley Beach	19°	11.046	146°	45.697	*H. uninervis* with *H. ovalis*
				BB1*	Bushland Beach	19°	11.028	146°	40.951	*H. uninervis* with *H. ovalis*
			Bowling Green Bay *coastal*	JR1*	Jerona (Barratta CK)	19°	25.380	147°	14.480	*H. uninervis* with *Zostera/H. ovalis*
				JR2*	Jerona (Barratta CK)	19°	25.281	147°	14.425	*H. uninervis* with *Zostera/H. ovalis*
	Mackay Whitsunday (*Reef Catchments*)	Proserpine	Whitsundays *coastal*	PI2*	Pioneer Bay	20°	16.176	148°	41.586	*H. uninervis/ Zostera* with *H. ovalis*
				PI3*	Pioneer Bay	20°	16.248	148°	41.844	*H. uninervis* with *Zostera/H. ovalis*
			Whitsundays *reef*	HM1*	Hamilton Island	20°	20.7396	148°	57.5658	*H. uninervis* with *H. ovalis*
				HM2*	Hamilton Island	20°	20.802	148°	58.246	*Z. muelleri* with *H. ovalis/H. uninervis*
		Pioneer	Mackay *estuarine*	SI1*	Sarina Inlet	21°	23.76	149°	18.2	*Z. muelleri* with *H. ovalis (H. uninervis)*
				SI2*	Sarina Inlet	21°	23.712	149°	18.276	*Z. muelleri* with *H. ovalis (H. uninervis)*
Southern	Fitzroy (*Fitzroy Basin Association*)	Fitzroy	Shoalwater Bay *coastal*	RC1*	Ross Creek	22°	22.953	150°	12.685	*Zostera muelleri* with *H. ovalis*
				WH1*	Wheelans Hut	22°	23.926	150°	16.366	*Zostera muelleri* with *H. ovalis*
			Keppel Islands *reef*	GK1*	Great Keppel Is.	23°	11.7834	150°	56.3682	*H. uninervis* with *H. ovalis*
				GK2*	Great Keppel Is.	23°	11.637	150°	56.3778	*H. uninervis* with *H. ovalis*
		Boyne	Gladstone Harbour *estuarine*	GH1*	Gladstone Hbr	23°	46.005	151°	18.052	*Zostera muelleri* with *H. ovalis*
				GH2*	Gladstone Hbr	23°	45.874	151°	18.224	*Zostera muelleri* with *H. ovalis*
	Burnett Mary (*Burnett Mary Regional Group*)	Burnett	Rodds Bay *estuarine*	RD1*	Rodds Bay	24°	3.4812	151°	39.3288	*Zostera muelleri* with *H. ovalis*
				RD2*	Rodds Bay	24°	4.866	151°	39.7584	*Zostera muelleri* with *H. ovalis*
		Mary	Hervey Bay *estuarine*	UG1*	Urangan	25°	18.053	152°	54.409	*Zostera muelleri* with *H. ovalis*
				UG2*	Urangan	25°	18.197	152°	54.364	*Zostera muelleri* with *H. ovalis*

Table 5. *Presence of foundation (■) and other (☐) seagrass species in monitoring locations sampled in MMP for plant tissue and reproductive health. Habitat type is classified as Reef, Coast, and Estuary following the classification of Carruthers, et al. 2002.*

NRM Region	Catchment	Seagrass Monitoring location	Habitat type		*C. rotundata*	*C. serrulata*	*E. acoroides*	*H. decipiens*	*H. ovalis*	*H. spinulosa*	*H. uninervis*	*S. isoetifoilium*	*T. hemprichii*	*Z. muelleri*
Cape York		Shelburne Bay	Coast	intertidal					☐		■		■	
		Piper Reef	Reef	intertidal	■				☐				■	
	Normanby	Stanley Reef	Reef	intertidal	■		■		☐		■	☐	■	
		Bathurst Bay	Coast	intertidal	■				☐		■	☐	■	
	Annan	Archer Point	Reef	intertidal	■	☐	■		☐		■		■	☐*
Wet Tropics	Daintree	Low Isles	Reef	Intertidal					☐		■		■	
				subtidal					☐		■			
	Russell - Mulgrave, Johnstone	Yule Point	Coast	Intertidal					☐		■			☐*
		Green Island	Reef	intertidal	■	☐			☐		■		■	
				subtidal	■	■			☐		■	☐	■	
	Tully	Lugger Bay	Coast	intertidal					☐		■			
		Dunk Island	Reef	intertidal	■	■			☐		■		■	
				subtidal		■		☐	☐		■			
Burdekin	Herbert, Burdekin	Magnetic Island	Reef	intertidal	■	■			☐		■	☐	■	☐*
				subtidal		■		☐	☐	☐	■			
		Townsville	Coast	intertidal		☐			☐		■			■
		Bowling Green Bay	Coast	intertidal					☐		■			■
Mackay Whitsunday	Proserpine	Pioneer Bay	Coast	intertidal					☐	☐	■			■
		Hamilton Island	Reef	intertidal					☐		■	☐		■
	Pioneer	Sarina Inlet	Estuary	intertidal					☐		☐			■
Fitzroy	Fitzroy	Shoalwater Bay	Coast	intertidal					☐		■			■
		Keppel Islands	Reef	intertidal					☐	☐	■			■
	Boyne	Gladstone	Estuary	intertidal					☐		☐*			■
Burnett Mary	Burnett	Rodds Bay	Estuary	intertidal					☐		☐			■
	Mary	Hervey Bay	Estuary	intertidal					☐		☐			■

** indicates presence adjacent, but not within, 50m x 50m site.*
Zostera muelleri = Zostera muelleri subsp. *capricorni, as revision of Zostera capricorni (Jacobs et al. 2006) resulted in classification to subspecies.*

2.2.2 Seagrass reproductive health

Seagrass reproductive health was assessed from samples collected in the late dry 2013 and late monsoon 2014 at locations identified in Table 26. Samples were processed according to standard methodologies (see Appendix 1).

In the field, 15 haphazardly placed cores (100mm diameter x 100mm depth) of seagrass were collected from an area adjacent (of similar cover and species composition) to each monitoring site. In the laboratory, reproductive structures (spathes, fruits, female and male flowers) of plants from each core were identified and counted for each samples and species. Reproductive effort was calculated as number of reproductive structures (fruits, flowers, spathes; species pooled) per core for analysis.

Seeds banks and abundance of germinated seeds were sampled according to standard methods (McKenzie *et al.* 2010a) by sieving (2mm mesh) 30 cores (50mm diameter, 100mm depth) of sediment collected across each site and counting the seeds retained in each. For *Zostera muelleri*, where the seed are <1mm diameter, intact cores (18) were collected and returned to the laboratory where they were washed through a 710µm sieve and seeds identified using a hand lens/microscope.

2.3 Seagrass environment monitoring

2.3.1 Seagrass tissue nutrients

In late dry season (October) 2013, foundational seagrass species leaf tissue nutrient samples were collected from each monitoring site (Table 26, Table 5). For nutrient status comparisons, collections were recommended during the growth season (e.g. late dry when nutrient contents are at a minimum) (Mellors*, et al.* 2005) and at the same time of the year and at the same depth at the different localities (Borum *et al.* 2004). Shoots from three haphazardly placed 0.25m^2 quadrats were collected from an area adjacent (of similar cover and species composition) to each monitoring site. Leaves were separated from the below ground material in the laboratory and epiphytic algae removed by gently scraping. Dried and milled samples were analysed according to McKenzie*, et al.* 2010a. Elemental ratios (C:N:P) were calculated on a mole:mole basis using atomic weights (i.e., C=12, N=14, P=31).

Analysis of tissue nutrient data was based upon the calculation of the atomic ratios of C:N:P. The ratios of the most common macronutrients required for plant growth has been used widely as an indicator of growth status, in phytoplankton cultures this known as the familiar *"Redfield"* ratio of 106C:16N:P (Redfield *et al.* 1963). Seagrass and other benthic marine plants possess large quantities of structural carbon, resulting in ''seagrass Redfield ratios'' estimated to be between 550:30:1 (Atkinson and Smith 1983) and 474:24:1 (Duarte 1990). The magnitude of these ratios and their temporal changes allow for a broad level understanding of the physical environment of seagrass meadows. Like phytoplankton, seagrasses growing in eutrophic waters have C:N:P ratios that reflect elevated nitrogen and phosphorus levels (Duarte 1990). Plants residing in nutrient poor waters show significantly lower N:P ratios than those from nutrient rich conditions (Atkinson and Smith 1983). Comparing deviations in the ratios of carbon, nitrogen and phosphorous (C:N:P) retained within plant tissue has been used extensively as an alternative means of evaluating the nutrient status of coastal waters (Duarte 1990).

Changing C:N ratios have been found in a number of experiments and field surveys to be related to light levels, as leaves with an atomic C:N ratio of less than 20, may suggest reduced light availability when N is not in surplus (Abal *et al.* 1994; Grice *et al.* 1996; Cabaço and Santos 2007; Collier *et al.* 2009). The ratio of N:P is also a useful indicator as it is a reflection of the *"Redfield"* ratios (Redfield*, et al.* 1963), and seagrass with an atomic N:P ratio of 25 to 30 can be determined to be 'replete' (well supplied and balanced macronutrients for growth) (Atkinson and Smith 1983; Fourqurean *et al.* 1997; Fourqurean and Cai 2001). When N:P values are in excess of 30, this may indicate P-limitation and a ratio of less than 25 is considered to show N limitation (Atkinson and Smith 1983;Duarte 1990; Fourqurean *et al.* 1992b; Fourqurean and Cai 2001). The median seagrass tissue ratios of C:P is approximately 500 (Atkinson and Smith 1983), therefore deviation from this value is also likely to be indicative of some level of nutrient enriched or nutrient limited conditions. A combination of these ratios can indicate seagrass environments which are impacted by nutrient enrichment. Plant tissue which has a high N:P and low C:P indicates an environment of elevated (saturated) nitrogen.

Investigations of the differences in each individual tissue ratio within each of the species revealed that although tissue nutrient concentrations were extremely variable between locations and between years, by pooling species within habitat types trends were apparent (McKenzie and Unsworth 2009). As seagrass tissue nutrient ratios of the foundation species were generally not significantly different from each other at a site within each sampling period (McKenzie and Unsworth 2009), the tissue nutrient ratios were pooled at the request of the GBRMPA to assist with interpretation of the findings.

To identify the sources of the nitrogen and provide insight into the occurrence of carbon limitation associated with light limitation, leaf tissue were also analysed for nitrogen and carbon stable isotope ratios (δ^{15}N and δ^{13}C).

There are two naturally occurring atomic forms of nitrogen (N). The common form that contains seven protons and seven neutrons is referred to as ^{14}N, and a heavier form that contains an extra neutron is called ^{15}N: with 0.3663% of atmospheric N in the heavy form. Plants and animals assimilate both forms of nitrogen, and the ratio of ^{14}N to ^{15}N compared to an atmospheric standard (δ^{15}N) can be determined by analysis of tissue on a stable isotope mass spectrometer using the following equation:

$$\delta^{15}\mathrm{N}\ (‰) = \left(\frac{\left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{sample}}\right) - \left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}\right)}{\left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}\right)} \right) \times 1{,}000$$

Seagrasses are passive indicators of δ^{15}N enrichment, as they integrated the signature of their environment over time throughout their growth cycle. The various sources of nitrogen pollution to coastal ecosystems often have distinguishable ^{15}N/^{14}N ratios (Heaton 1986), and in regions subject to anthropogenic inputs of nitrogen, changes in the δ^{15}N signature can be used to identify the source and distribution of the nitrogen (Costanzo 2001). Nitrogen fertilizer, produced by industrial fixation of atmospheric nitrogen results in low to negative δ^{15}N signatures (i.e. δ^{15}N ~0 - 1‰) (Udy and Dennison 1997a). In animal or sewage waste, nitrogen is excreted mainly in the form of urea, which favours conversion to ammonia and enables volatilization to the atmosphere. Resultant fractionation during this process leaves the remaining ammonium enriched in ^{15}N. Further biological fractionation results in sewage nitrogen having a δ^{15}N signature greater than 9 or ~10‰ (Lajtha and Marshall 1994; Udy and Dennison 1997b; Dennison and Abal 1999; Abal *et al.* 2001; Costanzo *et al.* 2001). Septic and aquaculture discharge undergo less biological treatment and are likely to have a signature closer to that of raw waste (δ^{15}N ~5‰) (Jones *et al.* 2001).

Similar to N, there are two naturally occurring atomic forms of carbon (C), ^{13}C and ^{12}C, which are taken up during photosynthesis where ^{12}C is the more abundant of the two, accounting for 98.89% of carbon. The ratio that ^{13}C is taken up relative to ^{12}C varies in time as a function of productivity, organic carbon burial and vegetation type. A measure of the ratio of stable isotopes ^{13}C:^{12}C (i.e. δ^{13}C) is known as the isotopic signature, and reported in parts per thousand (per mil, ‰):

$$\delta^{13}\mathrm{C} = \left[\left(\frac{\left(^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{sample}}\right)}{\left(^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{standard}}\right)} \right) - 1 \right] \times 1{,}000$$

where the standard is an established reference material.

Experimental work has confirmed that seagrasses from high light, high productivity environments demonstrate (less negative) isotopic enrichment: i.e. low %C, low C:N, in contrast, more negative δ^{13}C, may indicate that light is limited (Grice*, et al.* 1996; Fourqurean *et al.* 2005).

2.3.2 Epiphyte and macroalgae abundance

Epiphyte and macroalgae cover were measured according to standard methods (McKenzie*, et al.* 2010a). The total percentage of leaf surface area (both sides, all species pooled) covered by epiphytes and percentage of quadrat area covered by macroalgae, were measured each monitoring event. Values were compared against the GBR long-term average (1999-2010) calculated for each habitat type.

Increased epiphyte (the plants growing on the surfaces of slower-growing seagrass leaves (Borowitzka *et al.* 2006) loads may result in shading of seagrass leaves by up to 65%, reducing photosynthetic rate and leaf densities of the seagrasses (Sand-Jensen 1977; Tomasko and Lapointe 1991; Walker and McComb 1992; Tomasko *et al.* 1996; Frankovich and Fourqurean 1997; Ralph and Gademann 1999; Touchette 2000). In seagrass meadows, increases in the abundance of epiphytes are stimulated by nutrient loading (e.g. Borum 1985; Silberstein *et al.* 1986; Neckles *et al.* 1994; Balata *et al.* 2008) and these increases in abundance have been implicated as the cause for declines of seagrasses during eutrophication, because of the associated decrease in light reaching the seagrass blade (e.g. Orth and Moore 1983; Cambridge *et al.* 1986).

Given the observed relationships between nutrient loading and the abundance of epiphytes observed in seagrass ecosystems from around the world, and the perceived threat to water quality owing to human population, the abundance of epiphytes in seagrass meadows may prove to be a valuable indicator for assessing both the current status and trends of the GBR seagrass meadows. However, preliminary analysis of the relationship between seagrass abundance and epiphyte cover collected by the RRMMP and MTSRF did not identify threshold levels beyond which loss of abundance occurred (McKenzie 2008) suggesting further research and analysis.

2.3.3 Within seagrass canopy temperature

Autonomous iBTag™ submersible temperature loggers were deployed at all sites identified in Table 26**Error! Reference source not found.**. The loggers recorded temperature (accuracy 0.0625°C) within the seagrass canopy every 30-90 minutes. iBCod™22L submersible temperature loggers were attached to the permanent marker at each site above the sediment-water interface.

2.3.4 Seagrass canopy light

Submersible Odyssey™ photosynthetic irradiance autonomous loggers were attached to permanent station markers at 20 intertidal and 4 subtidal seagrass locations from the Cape York region to the Burnett Mary region (Table 26). Detailed methodology for the light monitoring (including cosine correction factors) can be found in Appendix 1. Measurements were recorded by the logger every 15 - 30 minutes. Automatic wiper brushes cleaned the optical surface of the sensor every 15 minutes to prevent marine organisms fouling.

The deployment durations were variable, with some deployed since 2008 under a different program (e.g. MTSRF); however the light monitoring was expanded and incorporated into the MMP in late 2009. Data were patchy for a number of intertidal sites because visitation frequency was low (3- 6 months), which increases the risk of light logger or wiper unit failure and increases the gap in data if loggers do fail. Furthermore, there are some sites that are frequently accessed by the public and tampering is suspected in the disappearance of some loggers. For subtidal sites, and their associated intertidal sites (Picnic Bay, Dunk Island, Green Island and Low Isles, 8 sites in total), the logger replacement time was every 6 weeks so data gaps were reduced.

Loggers were calibrated against a certified reference Photosynthetically Active Radiation (PAR) sensor (LI-COR™ LI-192SB Underwater Quantum Sensor) using a stable light source (LiCor) enclosed in a casing that holds both the sensor and light source at a constant distance. Calibration is repeated after each deployment period of 6 weeks to 6 months.

Autonomous iBTag™ submersible temperature loggers and submersible Odyssey™ photosynthetic irradiance autonomous logger deployed at Green Island.

Light data measured as instantaneous irradiance ($\mu mol\ m^{-2}\ s^{-1}$) was converted to daily irradiance (I_d, $mol\ m^{-2}\ d^{-1}$). I_d is highly variable in shallow coastal systems, being affected by incoming irradiance, the tidal cycle as well as water quality (Anthony *et al.* 2004). This high variability makes it difficult to ascertain trends in data. To aid with the visual interpretation of trends, I_d was averaged over a 28-day period (complete tidal cycle). 28 days is also biologically meaningful, as it corresponds to the approximate duration over which leaves on a shoot are fully replaced by new leaves and it is the approximate time over which shoot density and biomass starts to decline following reductions in light (Collier *et al.* 2012a). 28-day averaged I_d are presented graphically against draft thresholds with different values for northern and southern communities as the dominant species and habitat types vary from north to south. Thresholds applied in the northern GBR (5 $mol\ m^{-2}\ s^{-1}$) were developed for *Halodule uninervis*-dominated communities during episodic seagrass loss (Collier *et al.* 2012b). The threshold applied to southern GBR communities were developed for *Zostera muelleri* dominated communities over a 2-week rolling average using a range of experimental and monitoring approaches (Chartrand *et al.* 2012). These working thresholds describe light levels associated with short-term changes in seagrass abundance.

Also discussed, I_d is relative to estimated minimum light requirements (MLR). MLR describes the light required for the long-term survival of seagrass meadows (Dennison 1987). It is frequently calculated from measurement of annual light availability at the deepest edge of seagrass meadow, beyond which seagrasses cannot survive. MLR is difficult to determine in the dynamic seagrass meadows of the GBR, which often have poorly defined meadow boundaries, and these boundaries vary over intra-annual cycles. Therefore, MLR were estimated based on the average range in MLR for other 'blady' tropical species from the same genera (e.g. *Halodule, Thalassia*). MLR are usually reported as percent of surface irradiance (SI), even though this not the most meaningful representation of light requirements. The average MLR of 15-25% SI for tropical blady species (summarized in Lee *et al.* 2007) was converted to I_d using surface light data from Magnetic Island, Dunk Island, Green Island and Low Isles, which has been recorded at these sites since 2008. From this we estimate that the MLR equivalent to 15-25% SI is 4.7 to 7.9 mol photons $m^{-2}\ d^{-1}$. *Halophila* species typically have a much lower MLR, around 5-10% SI (Lee*, et al.* 2007), which is equivalent to 1.5 to 2.9 $mol\ m^{-2}\ d^{-1}$ at the monitoring sites for which we have surface light data. There are other species that possibly have higher MLR than the range given here; for example, *Zostera muelleri* is thought to have an MLR greater than 30% (Longstaff 2002). There is similarity between the working light thresholds and the MLR, reflecting the sensitivity of the dominant coastal seagrasses, to perturbations in their light environment.

Table 6. *Minimum light requirements (MLR) derived from the literature (15-25%) were converted to daily irradiance from surface light at sites where surface light is also monitored.*

Site	**Average daily irradiance (mol m^{-2} d^{-1})** **15% SI**	 **25% SI**
Low Isles	4.5	7.4
Green Island	4.9	8.2
Dunk Island	4.9	8.1
Magnetic Island	4.6	7.7
AVERAGE	**4.7**	**7.9**

2.3.5 Rhizosphere sediment herbicides

At request of DAFF, sediment (approximately 250ml) for herbicide analysis was collected at selected monitoring sites in the Cape York and Burdekin regions (identified in Table 26). Along each of the three transects at each site, approximately 20ml of sediment was collected every 5m to a depth approximately equal to the depth of the rhizome layer (5cm). Three homogenised samples (one per each transect) were collected per site (detailed procedures are outlined in McKenzie*, et al.* 2010a). Frozen samples were then sent for analysis. Extraction, clean-up and analysis of the sediments for herbicides were conducted according to NATA approved methods developed by QHSS.

2.3.6 Tidal exposure

The majority of meadows monitored within the MMP are located in shallow turbid waters where the duration of emersion and exposure has been shown to be important environmental drivers of seagrass change (Unsworth *et al.* 2012b). In the inshore waters of the GBR, where turbidity is naturally high, seagrasses are often restricted exclusively to the intertidal zone, as the periods around and even during exposure may provide critical windows of sufficient light for positive net photosynthesis (Pollard and Greenway 1993). However, during tidal exposure, these intertidal seagrasses are susceptible to high irradiance, potentially high UV-A and UV-B, thermal stress and desiccation (Erftemeijer and Herman 1994; Stapel *et al.* 1997; Björk *et al.* 1999; Campbell *et al.* 2006). Research on upper intertidal *Enhalus acoroides* meadows in the northern Gulf of Carpentaria (Weipa), reported strong correlative evidence that long-term tidal cycles coinciding with daylight and high solar radiation are linked to this long-term variability and seagrass decline (Unsworth*, et al.* 2012b). To determine if the tidal exposure regime may be increasing stress on seagrass and driving decline, tidal height observations were accessed from Maritime Safety Queensland and duration of annual exposure (hours) was determined for each meadow (i.e. monitoring site) based on the meadows height relative to the Lowest Astronomical Tide (Appendix 2, Table 39).

2.3.7 Climate and river discharge

Maximum daily air temperature, total daily rainfall, 3pm wind speed and average daily cloud cover (average of 9am and 3pm total cloud) was accessed from the Australian Bureau of Meteorology from meteorological stations which were proximal to monitoring locations. The 3pm wind speed (km h^{-1}) dataset was selected (cf. 9am dataset), as winds along the GBR coast are predominately south-easterly with typically increasing late morning into the afternoon, due to increased atmospheric mixing in the later part of the day (a consequence of the Earth's surface heating) (Coppin *et al.* 2003; Whinney 2007).

As the height of locally produced, short-period wind-waves can be the dominant factor controlling suspended sediment on inner-shelf of the GBR (Larcombe *et al.* 1995; Whinney 2007), the number of days wind speed exceeded 25km hr^{-1} was used as a surrogate for elevated resuspension pressure on inshore seagrass meadows. When wind speeds and wave heights increase above average (>20 km h^{-1} and 0.3m), they have been reported to elevate inshore turbidity in the GBR (Browne *et al.* 2013). Moderate sea state with winds >25km hr^{-1} can elevate turbidity by three orders of magnitude in the inshore coastal areas of the GBR (Orpin *et al.* 2004). Periods of rapidly increasing turbidity, to >20 NTU, following wind-driven resuspension events (>20 km h^{-1}) have also been reported (Browne*, et al.* 2013). Concurrent with the elevated turbidity, is the movement of sand particles and the formation of ripples and sand waves, which can destabilise seagrass meadows and restrict seedling establishment (Koch 2001a).

The presence of inshore seagrass meadows along the GBR places them at high risk of exposure to plume waters from adjacent watersheds and there is a growing body of evidence that exposure to flood plumes may be a significant forcing factor in structuring inshore seagrasses communities of the GBR (Collier *et al.* 2014a). As river discharge volumes are a precursor to the formation of flood plumes, we have used the river discharge volumes as a surrogate for the presence of plumes impacting inshore seagrass meadows. Daily river discharge data (ML day^{-1}) was accessed from the online water monitoring data portal (watermonitoring.derm.qld.gov.au) provided courtesy State of Queensland (Department of Natural Resources and Mines).

2.4 Data analyses

In this report results are presented to reveal temporal changes in seagrass community attributes and key environmental variables. Generalised additive mixed effects models were also fitted to seagrass attributes for each habitat, to identify the presence and consistency of trends, using the gamm4 (Wood 2006; Wood and Scheipl 2014) package in R 3.1.2 (R Core Team 2014). Generalized additive mixed effects models (GAMMs; Wood 2006) were used to decompose the irregularly spaced time series into its trend cycles (long-term) and periodic (seasonal) components.

GAMMs are an extension of additive models (which allow flexible modelling of non-linear relationships by incorporating penalized regression spline types of smoothing functions into the estimation process), in which the degree of smoothing of each smooth term (and by extension, the estimated degrees of freedom of each smoother) is treated as a random effect and thus estimable via its variance as with other effects in a mixed modelling structure (Wood 2006). The results of these analyses are graphically presented in a consistent format for both, environmental variables and biological variables: Predicted trends were plotted as bold blue lines, the confidence intervals of these trends delimited by blue shading; the observed trends at each survey reef were plotted in the background as thin grey lines.

Within and between year differences in seagrass community attributes and key environmental variables was also examined. Prior to analysis (e.g. ANOVA) percent cover data was ArcSin square root transformed. Where data for the majority of months failed a normality test (Shapiro-Wilk), a non-parametric Kruskal-Wallis One Way ANOVA on Ranks was performed. A Tukeys pairwise multiple comparison was conducted post hoc to identify differences between sampling events.

Non-linear regressions and polynomials were used (at the request of past reviewers) to show trends in seagrass abundance (% cover) over time; 95% confidence intervals and R-squared were used to indicate to level of variance is explained by the model.

Regression analysis was used to examine the relationship between seagrass abundance and light within regions, as light has been shown to be one of the strongest explanatory variables in the loss of seagrass during flood-related seagrass loss events (2008-2011) (Collier et al 2011). The regression analysis and determination of the 95% confidence intervals were performed in R (R core development team) using the Car library. Data used were daily light (total light received during the one day) and abundance (percent cover) data from 2008 to 2014, which includes a period of seagrass loss (2008-2011) and recovery (2011-2014). Change in cover was calculated as change from one sampling event to the next (typically 3 month intervals) and if abundance was less than 1% and remained less than 1% this was classified as undetectable change and assigned a “0%” change in abundance.

Due to the seagrass declines experienced over the last 4 years and the large numbers of "zero" results, the data for many meadows failed the assumptions of normality and homogeneity of variance despite using several data transformations. Also, the majority of meadows have been in a "recovery mode" since the losses, which has restricted multivariate analysis. Analysis is currently underway to more fully interrogate the temporal and covariate components of the data as the time series of observations lengthen. As this is continuing, results are not completed and are planned for inclusion in future reports.

2.5 Reporting Approach

Results and discussion of monitoring is presented firstly in a GBR general overview and then by the NRM regions identified in the GBR 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 effect of water quality. There are 56 NRM regions identified in Australia, 15 are in Queensland and six are part of the coastal processes of the GBR. 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.

The data is presented in a number of ways depending on the indicator and section of the report:

- Report card scores are presented at the start of each section. These are a numerical summary of the status within the region relative to a regional baseline (described further below).
- Raw data is presented for metrics with low variation (temporal and spatial), such as tissue nutrients
- Normalised data are presented for highly variable data, in which the inherent variation among sites makes it very difficult to plot and visualise long-term trends. These include epiphyte and macroalgae , within canopy light data (z-score transformed)
- Trend analysis (GAMM plots) are also used (for the first time in this 2013-14 report) to explore the long-term temporal trends in biological and environmental indicators. These provide visual (and statistically robust) overviews of trends and include raw data as background to the plots. GAMM analysis also over-comes the inherent spatial variability in the parameters by exploring trends and providing confidence intervals of the trends. However, they may also show slightly different trends in some instances to the raw or normalised data, so are included in this report as supporting additional plots.

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 topographic 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 (Appendix 1, Figure 127).

2.6 Report card

Three indicators (presented as unitless scores) were selected by the GBRMPA, using advice from expert working groups and the Paddock to Reef Integration Team, for the seagrass report card:

1. seagrass abundance (cover)
2. reproductive effort
3. nutrient status (seagrass tissue C:N ratio)

Seagrass abundance (% cover) is used to indicate the state of the seagrass to resist stressors, reproductive effort to indicate the potential for the seagrass to recover from loss, and the nutrient status to indicate the condition of the environment in which the seagrass are growing in recognition of seagrass' role as a bioindicator of environmental (including water quality) health.

The molar ratios of seagrass tissue carbon relative to nitrogen (C:N) were chosen as the indicator for seagrass nutrient status as an atomic C:N ratio of less than 20, may suggest either reduced light availability or nitrogen enrichment. Both of these deviations may indicate reduced water quality. Examination of the molar ratios of seagrass tissue carbon relative to nitrogen (C:N) between 2005 and 2008 explained 58% of the variance of the inter-site seagrass cover/abundance (McKenzie and Unsworth 2009).

The methods for calculation of scores was chosen by the Paddock to Reef Integration Team (i.e. not the authors of this report) and all report card scores are transformed to a five point scale from 0 to 100 as directed to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). *Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.*

2.6.1 Seagrass abundance

The status of seagrass abundance (% cover) was determined using the seagrass abundance guidelines developed by McKenzie (2009). The seagrass abundance measure in the MMP is the average % cover of seagrass per monitoring site. Individual site and subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on % cover data collected from individual sites and/or reference sites (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference site conditions.

After discussions with GBRMPA scientists and the Paddock to Reef integration team, the seagrass guidelines were further refined by allocating the additional categories of very good (median abundance at or above 75th percentile), and very poor (median abundance below 20th or 10th percentile and declined by >20% since previous sampling event). Seagrass state was then rescaled to a five point scale from 0 to 100 to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.

Table 7. *Seagrass percentage cover guidelines ("the seagrass guidelines") for each site/location and the subregional guidelines (bold) for each NRM habitat. Values in light grey not used. ^ denotes regional reference site, * from nearest adjacent region.*

NRM region	site/ location	Habitat	percentile guideline			
			10th	20th	50th	75th
Cape York	AP1^	reef intertidal	11	16.8	18.9	23.7
	AP2	reef intertidal	11		18.9	23.7
	FR	reef intertidal		16.8	18.9	23.7
	ST	reef intertidal		16.8	18.9	23.7
	NRM	***reef intertidal***	***11***	***16.8***	***18.9***	***23.7***
	SR*	coastal intertidal		6.6	12.9	14.8
	BY*	coastal intertidal		6.6	12.9	14.8
	NRM	***coastal intertidal****	***5***	***6.6***	***12.9***	***14.8***
Wet Tropics	LB	coastal intertidal		6.6	12.9	14.8
	YP1^	coastal intertidal	4.3	7	14	15.4
	YP2^	coastal intertidal	5.7	6.2	11.8	14.2
	NRM	***coastal intertidal***	***5***	***6.6***	***12.9***	***14.8***
	DI	reef intertidal	27.5		37.7	41
	GI1^	reef intertidal	32.5	38.2	42.7	45.5
	GI2^	reef intertidal	22.5	25.6	32.7	36.7
	LI1	reef intertidal	27.5		37.7	41
	NRM	***reef intertidal***	***27.5***	***31.9***	***37.7***	***41.1***
	DI3	reef subtidal	22	26	33	39.2
	GI3^	reef subtidal	22	26	33	39.2
	LI2	reef subtidal	22	26	33	39.2
	NRM	***reef subtidal***	***22***	***26***	***33***	***39.2***
Burdekin	BB1^	coastal intertidal	16.3	21.4	25.4	35.2
	SB1^	coastal intertidal	7.5	10	16.8	22
	JR	coastal intertidal		*15.7*	*21.1*	*28.6*
	NRM	***coastal intertidal***	***11.9***	***15.7***	***21.1***	***28.6***
	MI1^	reef intertidal	23	26	33.4	37
	MI2^	reef intertidal	21.3	26.5	35.6	41
	NRM	***reef intertidal***	***22.2***	***26.3***	***34.5***	***39***
	MI3	reef subtidal	22	26	33	39.2
	NRM	***reef subtidal***	***22****	***26****	***33****	***39.2****
Mackay Whitsunday	SI	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	**10.8***	**18***	**34.1***	**54***
	PI2^	coastal intertidal	18.1	18.7	25.1	27.6
	PI3^	coastal intertidal	6.1	7.6	13.1	16.8
	NRM	***coastal intertidal***	**12.1**	**13.15**	**19.1**	
	HM	reef intertidal	22.2		34.5	39
	NRM	***reef intertidal***	***22.2****	***26.2****	***34.5****	***39****
Fitzroy	GH	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	10.8*	18*	34.1*	
	RC1^	coastal intertidal	18.6	20.6	24.4	34.5
	WH1^	coastal intertidal	13.1	14.4	18.8	22.3
	NRM	***coastal intertidal***	15.85	17.5	21.6	28.4
	GK	reef intertidal	22.2		34.5	39
	NRM	***reef intertidal***	***22.2****	***26.2****	***34.5****	***39****
Burnett Mary	RD	estuarine intertidal		18	34.1	54
	UG1^	estuarine intertidal	10.8	18	34.1	54
	UG2	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8***	***18***	***34.1***	***54***

Table 8. *Scoring threshold table to determine seagrass abundance status. low = 10th or 20th percentile guideline (Table 7). NB: scores are unitless.*

description	category	score	status
very good	75-100	100	80 - 100
good	50-75	75	60 - <80
moderate	low-50	50	40 - <60
poor	<low	25	20 - <40
very poor	<low by >20%	0	0 - <20

2.6.2 Seagrass reproductive effort

The reproductive effort of seagrasses provides an indication of the capacity of seagrasses to recover from the loss of an area of seagrass through the recruitment of new plants, i.e. the resilience of the population (Collier and Waycott 2009). Given the high diversity of seagrass species that occur in the GBR coastal zone (Waycott *et al.* 2007), their variability in production of reproductive structures (e.g. Orth *et al.* 2006), a metric that incorporates all available information on the production of flowers and fruits per unit area is the most useful.

The production of seeds also reflects a simple measure of the capacity of a seagrass meadow to recover following large scale impacts (Collier and Waycott 2009). As it is well recognized that coastal seagrasses are prone to small scale disturbances that cause local losses (Collier and Waycott 2009) and then recover in relatively short periods of time, the need for a local seed source is considerable. In the GBR, the production of seeds comes in numerous forms and seed banks examined at MMP sites are limited to foundational seagrass species (seeds >0.5mm diameter). At this time, seed banks have not been included in the metric for reproductive effort, but methods for future incorporation are currently being explored.

Using the annual mean of all species pooled in the late dry and comparing with the long-term (2005-2010) average for GBR habitat (coastal intertidal = 8.22±0.71, estuarine intertidal = 5.07±0.41, reef intertidal = 1.32±0.14), the reproductive effort was scored as the number of reproductive structures per core and the overall status determined (Table 9) as the ratio of the average number observed divided by the long term average.

Table 9. *Scores for late dry monitoring period reproductive effort average against long-term (2005-2010) GBR habitat average. NB: scores are unitless.*

description	***Reproductive Effort monitoring period / long-term***	***ratio***	***score***	***0-100 score***	***status***
very good	≥4	4.0	4	100	80 - 100
good	2 to <4	2.0	3	75	60 - <80
moderate	1 to <2	1.0	2	50	40 - <60
poor	0.5 to <1	0.5	1	25	20 - <40
very poor	<0.5	0.0	0	0	0 - <20

2.6.3 Seagrass nutrient status.

As changing leaf C:N ratios have been found in a number of experiments and field surveys to be related to available nutrient and light levels (Abal*, et al.* 1994; Grice*, et al.* 1996; Cabaço and Santos 2007; Collier*, et al.* 2009) they can be used as an indicator of the light that the plant is receiving relative to nitrogen availability or N surplus to light. With light limitation, seagrass plants are unable to build structure, hence the proportion of carbon in the leaves decreases relative to nitrogen.

Experiments on seagrasses in Queensland have reported that at an atomic C:N ratio of less than 20, may suggest reduced light availability relative to nitrogen availability (Abal*, et al.* 1994; AM Grice*, et al.*, 1996;). The light availability to seagrass is not necessarily an indicator of light in the water column, but an indicator of the light that the plant is receiving as available light can be highly impacted by epiphytic growth or sediment smothering photosynthetic leaf tissue. However, C:N must be interpreted with caution as the level of N can also influence the ratio in oligotrophic environments (Atkinson and Smith 1983; Fourqurean*, et al.* 1992b). Support for choosing the elemental C:N ratio as the indicator also comes from preliminary analysis of MMP data in 2009 which found that the C:N ratio was the only nutrient ratio that showed a significant relationship (positive) with seagrass cover at coastal and estuarine sites. Seagrass tissue C:N ratios explained 58% of the variance of the inter-site seagrass cover data (McKenzie and Unsworth 2009). Using the guideline ratio of 20:1 for the foundation seagrass species, C:N ratios were categorised on their departure from the guideline and transformed to a 0 to 100 score using:

Equation 1 $$\overline{R} = (\mathrm{C:N} \times 5) - 50$$

NB: C:N ratios >35 scored as 100, C:N ratios <10 scored as 0

The score was then used to represent the status to allow integration with other components of the report card (Table 10).

Table 10. *Scores for leaf tissue C:N against guideline to determine light and nutrient availability. NB: scores are unitless.*

description	C:N ratio range	value	Score ($\overline{R}$)	status
very good	C:N ratio >30*	30	100	80 - 100
good	C:N ratio 25-30	25	75	60 - <80
moderate	C:N ratio 20-25	20	50	40 - <60
poor	C:N ratio 15-20	15	25	20 - <40
very poor	C:N ratio <15*		0	0 - <20

2.6.4 Seagrass index

The seagrass index is average score (0-100) of the three seagrass status indicators chosen for the MMP. Each indicator is equally weighted as we have no preconception that it should be otherwise. To calculate the overall score for seagrass of the Great Barrier Reef (GBR), the regional scores were weighted on the percentage of GBRWHA seagrass (shallower than 15m) within that region (Table 11). *Please note: Cape York omitted from the GBR score in P2R reporting prior to 2012 due to poor representation of inshore monitoring sites throughout region*.

Table 11. *Area of seagrass shallower than 15m in each NRM region (from McKenzie et al. 2010c) within the boundaries of the Great Barrier Reef World Heritage Area.*

NRM	Area of seagrass (km^2)	% of GBRWHA
Cape York	1,843	0.60
Wet Tropics	201	0.07
Burdekin	551	0.18
Mackay Whitsunday	154	0.05
Fitzroy	241	0.08
Burnett Mary	73	0.02
GBRWHA	**1,220**	**1.00**

3 Results & Discussion

3.1 GBR Summary

The greatest extent of seagrass in the GBRWHA is located in the deeper waters (>15m) of the lagoon (Coles *et al.* 2009a), however, these meadows are relatively sparse, structurally smaller, higher dynamic, composed of *r*-strategist species, and not as productive as inshore seagrass meadows for fisheries resources (McKenzie et al. 2010; Derbyshire *et al.* 1995). In contrast, the most abundant seagrass meadows are those in the shallower waters of the GBR inshore areas where habitat and growth requirements are met. These inshore meadows are structurally larger, composed of foundational species, store more carbon in their sediments, of higher fisheries importance, and the main feeding pastures for dugong and green sea turtle (Watson *et al.* 1993; Sheppard *et al.* 2009 Lanyon *et al.* 1989; McKenzie*, et al.* 2010c; Lavery *et al.* 2013). It is these meadows that occur at the frontline of runoff and inshore water quality deterioration.

The long-term average seagrass percent cover at each of the inshore intertidal seagrass habitats of the GBR (prior to 2011) was 13.9% for estuarine, 16.5% for coastal, 22.7% for reef and 17.2% for subtidal reef (McKenzie *et al.* 2012c). Post the extreme weather events of 2011, the abundances of GBR inshore seagrass declined to the lowest recorded since monitoring was established. In the 2013-14 monitoring period, although the overall seagrass score increased (Figure 4), 61% of the MMP sites examined remained classified as poor or very poor in abundance (below the guidelines) in late monsoon 2014, with an annual average abundance (all sites and sampling events) of 11.2% for estuarine, 11.2% for coastal, 14.9% for reef and 21.5% for subtidal reef.

During 2013-14, seagrass abundances improved in all habitats across the GBR; with greatest increases at subtidal sites (although only 4 subtidal sites are only monitored and all occur in the Wet Tropics and Burdekin regions). The region with the greatest improvement during 2013-14 was the Burdekin NRM, while the Fitzroy NRM was the only region to experience declines in seagrass abundance. Seagrass meadows expansion in 2013-14 was not as great as the previous monitoring period, increasing only 5% in overall extent (cf. 18% in 2012-13).

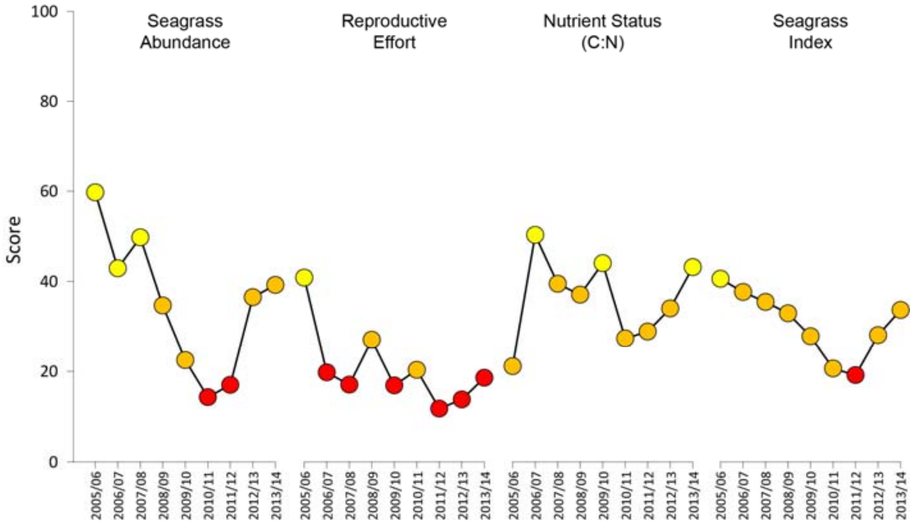

Figure 4. *GBR report card scores (regions pooled) for each indicator and total seagrass index over the life of the MMP. Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20). NB: Scores are unitless.*

Seagrass species richness differed between locations and habitats in the GBR Region, with inshore reef habitats more specious than meadows at coastal or estuarine habitats. However, since 2011, meadows monitored in the GBR have undergone a state change being firstly dominated by a greater than average proportion of colonising (*r*-strategist) seagrass species, until the current monitoring period when the foundation (K- strategist) seagrass species have been more successful.

Reproductive effort increased at all habitats in 2013-14 relative to the previous year, particularly in the Burdekin and Mackay Whitsunday regions, and was higher in coastal and estuary habitats (respectively). Similarly, seed banks increased to there highest abundances in 2013-14. This suggests that coupled with the increased reproductive effort, GBR estuarine and coastal meadows in 2013-14 have an improved capacity to recover from disturbances, although seed bank in reef subtidal habitats may become limited as a result of low reproductive effort and lack of replenishment.

Variable light conditions prevailed in 2013-14 (i.e. below the long-term average), which may have created stress to the plants, particularly subtidal, possibly slowing recovery in some meadows. Daily incident light reaching the top of the seagrass canopy was at or below average for meadows in the southern Wet Tropics, Burdekin, Burnett Mary and Fitzroy regions, however, above average in the northern Wet Tropics and Mackay Whitsunday regions. The number of days light was below the threshold for positive seagrass growth in 2013-14, was either equal to or generally less than the long-term average for subtidal and intertidal meadows, respectively.

Seagrass leaf tissue nutrients for foundation species across the majority of GBR habitats and locations in late 2013 suggested P, and to an extent N, surplus to C requirements. There was a marginal improvement in leaf tissue C:N:P ratios in 2013, mainly from the Burdekin region southwards, however, nutrient status scores remained poor in Cape York, Wet Tropics and Mackay Whitsunday. The high tissue nutrient concentrations measured across most coastal locations were likely a consequence of the high N, where the primary source of N was either from sewage or fertiliser.

Epiphyte cover on seagrass leaves increased across GBR habitats in 2013-14, either increasing above or remaining at long-term averages intertidal estuary and reef meadows. Macroalgae abundance remained low and changed little during 2013-14.

Within canopy seawater temperatures across the GBR were higher than the long-term (10 year) average over the 2013-14 monitoring period (Figure 26): the warmest in 8 years. Seagrasses in the Cape York NRM region experienced extreme (>40°C) seawater temperatures and the greatest number of days in the GBR where sea temperatures exceeded 35°C, followed by Mackay Whitsunday. Water temperatures >40°C can reduce photosynthetic efficiency within 1-2 hours of exposure for some species (e.g. *H. ovalis*), and induce mortality and reduce growth rates after repeated (6 days) exposure, such as those occurring at low tide (Campbell*, et al.* 2006; Collier and Waycott 2014,). While water temperature exceeding 35°C does not impact photosynthetic efficiency in most GBR seagrass species, some species, such as *Z. muelleri* which occurs in the Mackay Whitsunday region, reduce growth rates after prolonged (5 days) exposure to 35°C due to higher rates of respiration caused by elevated temperatures (Campbell*, et al.* 2006; Collier *et al.* 2011).

Climate conditions were variable across the GBR inshore seagrass meadows during 2013-14. In Cape York and the Wet Tropics, climatic conditions were less conducive for seagrass growth than recent years, as a result of higher rainfall and greater wind; resulting in above median discharges from rivers, which would have exposed meadows to plumes of turbid sediment laden water, and more days of stronger winds, which would have resuspended benthic sediments and limited light during the main seagrass growing season. In the Burdekin and Burnett Mary, the regions were drier, but the higher winds coupled with warmer temperatures and higher tidal exposure would have been less conducive of seagrass growth in some meadows as it would have elevated heat and desiccation stress. In the central regions (Mackay Whitsunday and Fitzroy) climatic conditions were more conducive, particularly as the majority of inshore meadows are within bays and estuaries sheltered for winds.

Across the GBR NRM regions, the seagrass report card scores improved during 2013-14 in the Burdekin, Mackay Whitsunday and Burnett Mary, while scores in the other region remained relatively unchanged (Figure 5, Table 12, Table 13). It should also be noted, however, that seagrass across most of the regions are still recovering from multiple years of climate-related impacts which has likely left a legacy of reduced resilience to future impacts.

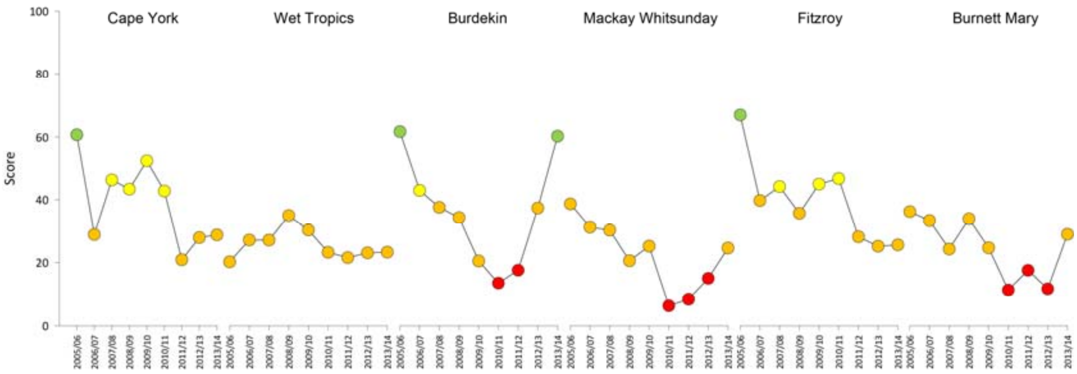

Figure 5. *Report card of seagrass index/status for each NRM region (averaged across indicators). Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20). NB: Scores are unitless.*

Table 12. *Report card for seagrass status for the GBR and each NRM region: June 2013 – May 2014. Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20). NB: Scores are unitless.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	43	8	36	29
Wet Tropics	24	12	34	23
Burdekin	51	60	69	60
Mackay Whitsunday	18	25	31	25
Fitzroy	22	8	47	26
Burnett Mary	10	0	77	29
GBR	39	19	43	**34**

Table 13. *Report card for seagrass status for each habitat in each NRM region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20). NB: Scores are unitless.*

NRM region	**Habitat**	Abundance	Reproductive Effort	C:N Ratio	**Seagrass Index**
Cape York	coastal intertidal	63	0	36	33
	reef intertidal	29	17	35	27
Wet Tropics	coastal intertidal	21	0	16	13
	reef intertidal	28	10	40	26
	reef subtidal	22	25	46	31
Burdekin	coastal intertidal	44	19	39	34
	reef intertidal	50	63	69	60
	reef subtidal	75	100	100	92
Mackay Whitsunday	estuarine intertidal	13	25	39	26
	coastal intertidal	33	0	23	19
	reef intertidal	0	50	31	27
Fitzroy	estuarine intertidal	34	25	33	31
	coastal intertidal	8	0	67	25
	reef intertidal	6	0	41	16
Burnett Mary	estuarine intertidal	10	0	77	29

3.1.1 Status of the seagrass community

In the 2013-14 monitoring period, although the overall seagrass abundance score improved (Figure 4), 60% of the MMP sites examined remained classified as poor or very poor in abundance (below the guidelines) in late monsoon 2014, with an annual average abundance (all sites and sampling events) of 11.23 ±1.27% for estuarine, 11.21 ±1.3% for coastal, 14.93 ±1.59% for reef and 21.48 ±2.56% for subtidal reef.

Seagrass abundance at meadows monitored in the MMP declined from 2005-06 until 2012-13, after which abundances increased (Figure 6). Based on the average score against the seagrass guidelines (determined at the site level), the abundance of inshore seagrass in the GBR over the 2013-14 period remained in a **poor** state (all sites and seasons pooled, unweighted) (Figure 6).

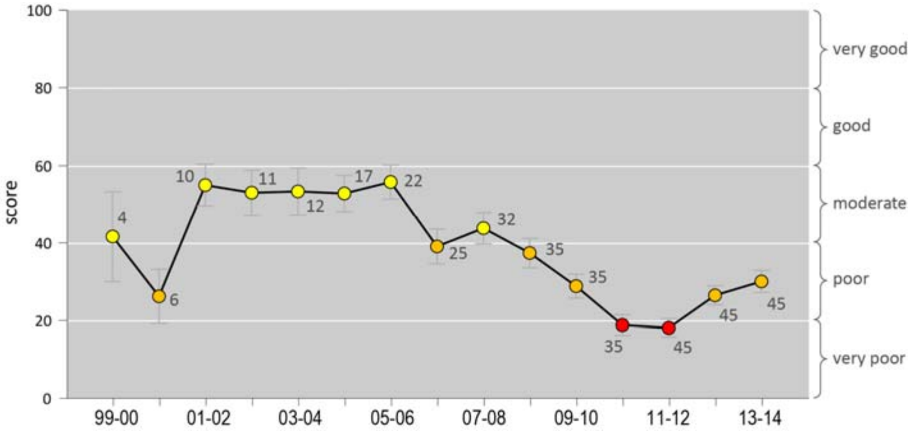

Figure 6. *Average seagrass abundance score (all sites and seasons pooled) for the GBR (±Standard Error) for each monitoring period from 1999 to 2014. Median percentage cover at a site for each monitoring event was scored relative to each site's guideline value, taking into account species and habitat. NB: score is unit less. Numbers indicate total sites contributing to the score.*

The only region where the seagrass abundance score declined in 2013-14 from the previous monitoring period was the Fitzroy NRM (Figure 7). The region with the greatest improvement during 2013-14 was the Burdekin NRM (Figure 7).

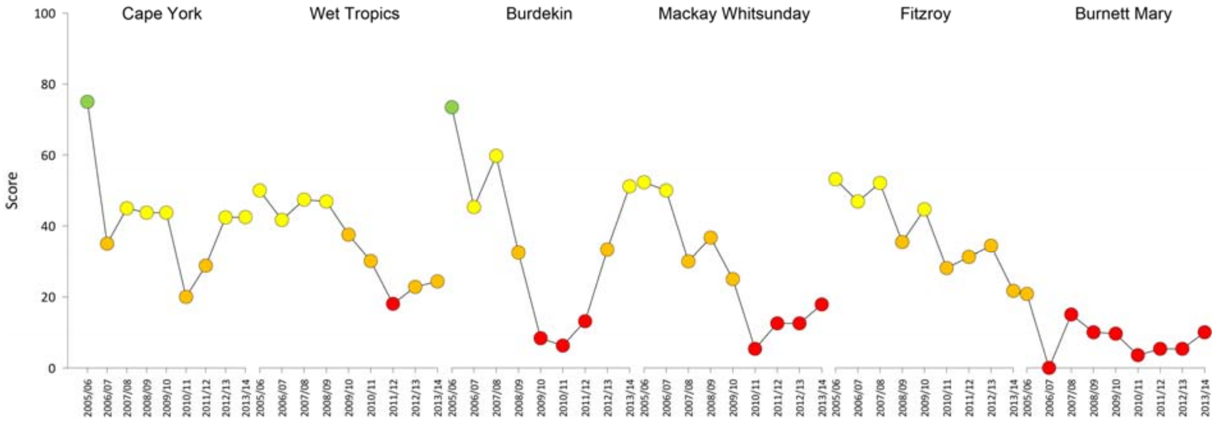

Figure 7. *Regional report card scores for seagrass abundance over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20). NB: Scores are unitless.*

Seagrass abundance scores have fluctuated within regions at habitats since monitoring was established. The most variable GBR seagrass habitat in abundance score (since 2005) was intertidal reef (CV=100.6%), followed closely by intertidal coast (CV=93.4%), subtidal reef (CV=83.1%) and lastly intertidal estuary (CV=68.4%) (Table 14).

Table 14. *Long-term report card for seagrass abundance status for each habitat in each NRM region: June 2005 – May 2014. Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20). Overall GBR score is weighted (see Table 11). NB: Scores are unitless.*

NRM region	Habitat	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Cape York	coastal intertidal							63	81	63
	reef intertidal	75	35	45	44	44	20	14	22	29
Wet Tropics	coastal intertidal	38	30	55	70	54	46	7	13	21
	reef intertidal	72	58	43	35	35	19	17	21	28
	reef subtidal			0	33	23	27	34	37	22
Burdekin	coastal intertidal	88	31	34	25	11	6	5	29	44
	reef intertidal	59	59	75	31	6	9	25	41	50
	reef subtidal			100	50	8	0	8	31	75
Mackay Whitsunday	estuarine intertidal	40	25	20	25	6	0	13	25	13
	coastal intertidal	63	88	54	63	63	8	13	13	33
	reef intertidal		25	6	13	6	6	13	0	0
Fitzroy	estuarine intertidal	25	13	44	25	42	34	47	53	34
	coastal intertidal	81	81	100	75	81	31	25	25	8
	reef intertidal			13	6	13	13	6	6	6
Burnett Mary	estuarine intertidal	21	0	15	10	10	4	5	5	10
GBR		**60**	**43**	**50**	**35**	**22**	**14**	**17**	**36**	**39**

The average seagrass % cover for the 2013-14 monitoring period was 13.62 ±1.6% (sites and habitats pooled). This remains below the GBR long-term average and the GBR historical baseline (Table 15). The long-term average seagrass percent cover for the GBR was 17.8 ±2.1% prior to 2011 (Table 15) (due to the extreme weather events in 2011 and associated seagrass losses, values post 2010 were excluded). The highest long-term average % cover for GBR seagrass habitats was reef intertidal, and the lowest estuarine intertidal (Table 15). The long-term average cover for GBR subtidal seagrass habitats was 17.2 ±2.9%, however, this was only over a period of 3 years prior to 2011 (Table 15). Since 1999, the percentage cover values for the GBR were mostly below 25% cover, and depending on habitat, only occasionally extend beyond 50% (Figure 8). These long-term percentage cover values were similar to the GBR historical baselines, where surveys from Cape York to Hervey Bay (between November 1984 and November 1988) reported most (three-quarters) of the percent cover values fell below 50% cover (Figure 9, Lee Long, *et al.* 1993). The findings negate the assumption that seagrass meadows of the GBR should have abundances closer to 100% before they are categorised as good.

Table 15. *Long-term (1999-2010) average seagrass percent cover for monitored GBR habitats (sites pooled) and GBR baseline surveys. *individual meadows.*

habitat	average % cover	number of sites/meadows*	duration	data source
estuarine intertidal	13.9 ±1.8	8	Nov99-Nov10	McKenzie *et al.* 2012b
coastal intertidal	16.5 ±1.9	16	Sep99-Oct10	McKenzie, *et al.* 2012b
reef intertidal	22.7 ±2.4	17	Nov01-Dec10	McKenzie, *et al.* 2012b
reef subtidal	17.2 ±2.9	4	Jan08- Dec10	McKenzie, *et al.* 2012b
GBR long-term	17.8 ±2.1		Sep99- Dec10	
Cape York to Cairns	32.6 ±1.2	115*	Nov84	Coles, *et al.* 2001c
Cairns to Bowen	19.3 ±1.2	122*	Oct-Nov87	Coles, *et al.* 2001a
Bowen to Water Park Pt	14.9 ±1.2	113*	Mar-Apr87	Coles, *et al.* 2001b
Water Park Pt to Hervey Bay	24.4 ±1.4	60*	Oct-Nov88	Coles, *et al.* 2001d
GBR historic baseline	22.6 ±1.2		Nov84-Nov88	

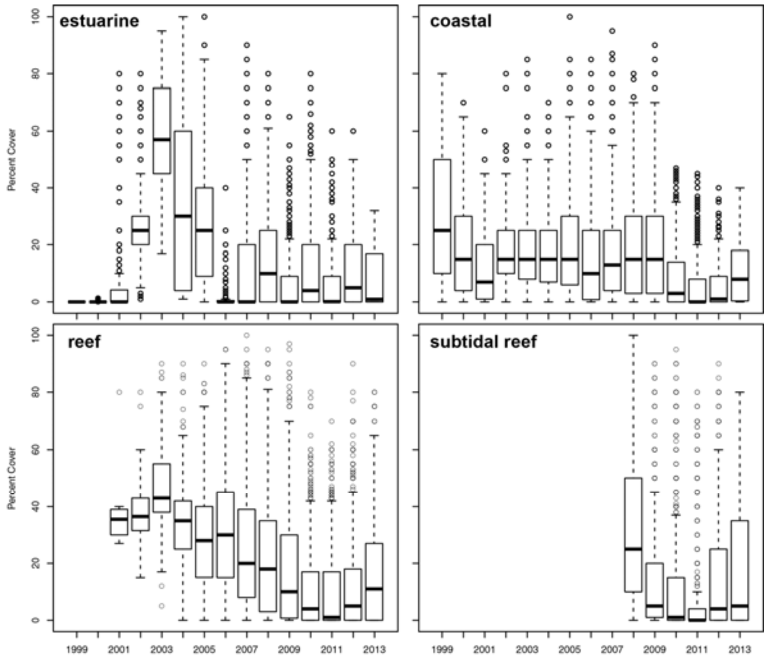

Figure 8. Seagrass percent cover measures per quadrat from meadows monitored from July 1999 to July 2013 (sites and habitats pooled). *The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the black dots represent outlying points.*

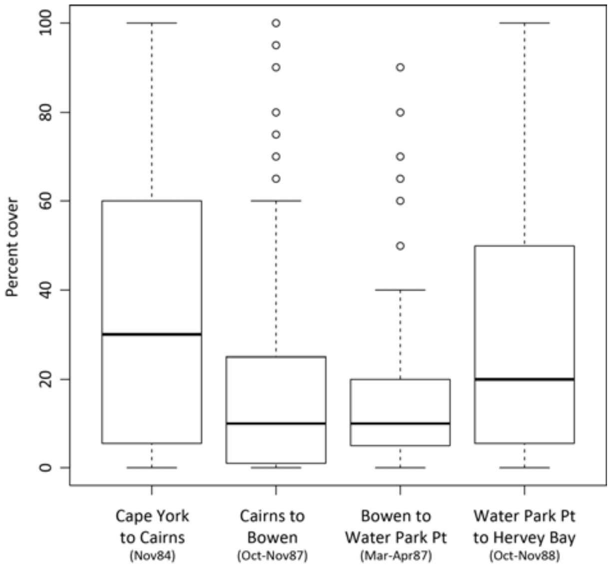

Figure 9. *Seagrass percent cover measures per quadrat from meadows examined during the GBR historical baseline surveys 1984 - 1988.The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the black dots represent outlying points.*

Long-term total seagrass abundance (percent cover) across the inshore GBR was generally higher in reef than coastal and estuarine habitats (Figure 10). Over the past decade, the patterns of seagrass abundance in each GBR habitat have differed (Figure 11, Figure 12), however both reef (including intertidal and subtidal) and coastal habitats show declining trajectories from 2009 to 2011. Seagrass trends have fluctuated in estuary habitats, most often at smaller localised scales where there have been some acute event related changes (McKenzie*, et al.* 2012c).

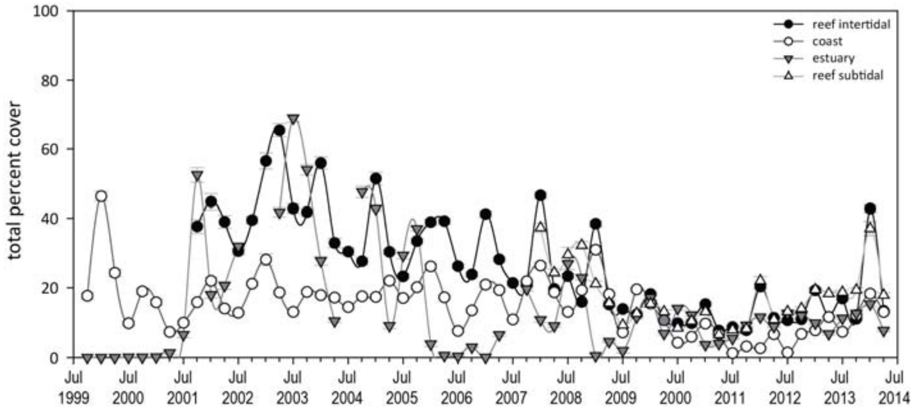

Figure 10. *Seagrass percent cover for each GBR habitat (locations pooled ±SE) across all sampling events from late dry 1999 to late monsoon 2014.*

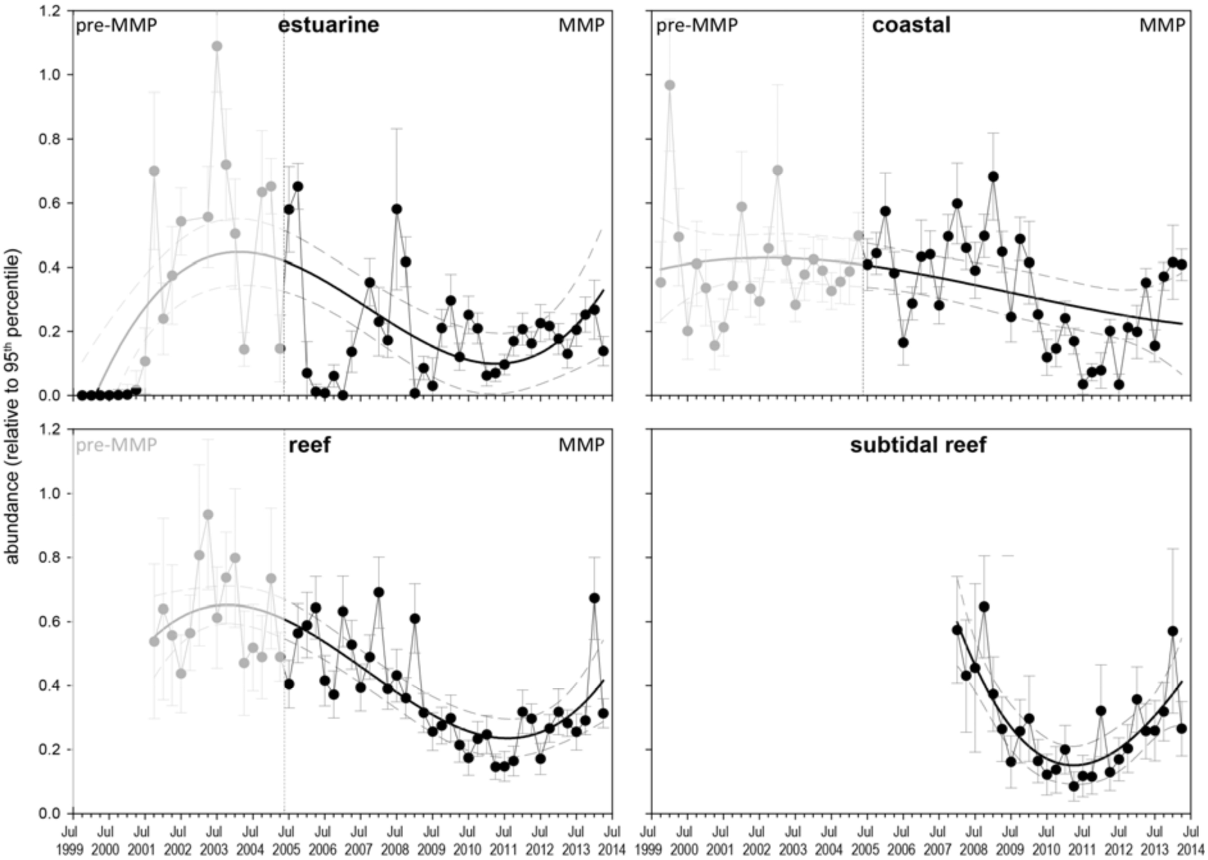

Figure 11. *Generalised trends in seagrass abundance for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data. Data prior and post implementation of the RRMMP displayed. Trendline is 3rd order polynomial, 95% confidence intervals displayed, estuarine (8 sites) r^2 = 0.32, coastal (16 sites) r^2 = 0.16, reef (17 sites) r^2 =0.63, subtidal reef (4 sites) r^2 =0.65.*

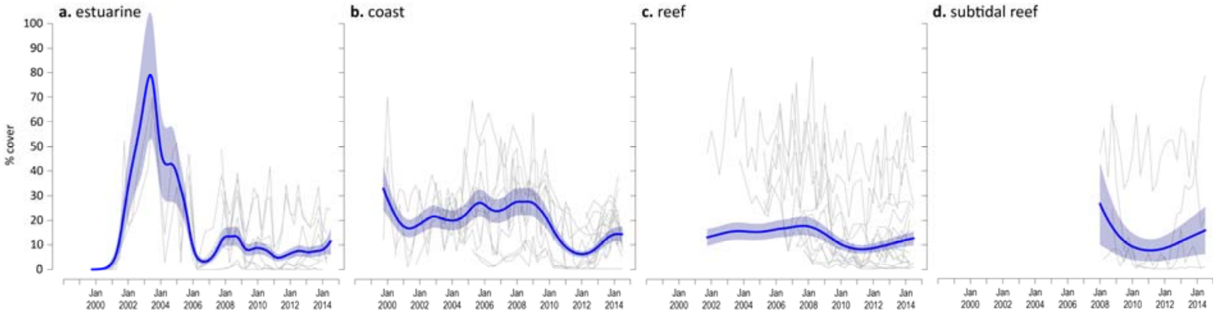

Figure 12. *Trends in seagrass abundance (% cover) for each habitat type across the GBR. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations.*

Since monitoring was established in 2005, GBR seagrass meadow extent at the monitoring sites has declined and subsequently increased on two occasions. The first decline event was in early 2006, recovering within 2 years, and the second was in early 2011, with recovery continuing in 2013-14 (Figure 13). These declines were a consequence of extreme weather and subsequent flooding events. Seagrass meadows in 2013-14 did not expand as greatly as the previous monitoring period, increasing in extent by only 5% overall (cf. 18% in 2012-13).

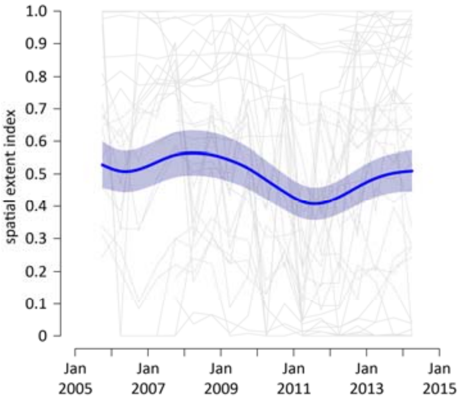

Figure 13. *Trend in meadow spatial extent (% cover) for inshore monitoring sites at all locations and habitats across the GBR. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites.*

Between 2011 and 2013, increases in seagrass meadow extent appears primarily a consequence of the proliferation of *r*-strategist (colonising) seagrass species such as *Halophila ovalis*. However, over the 2013-14 monitoring period, recovery has favoured K-strategist (foundation) species, with the most substantial increases in the subtidal habitats (Figure 14).

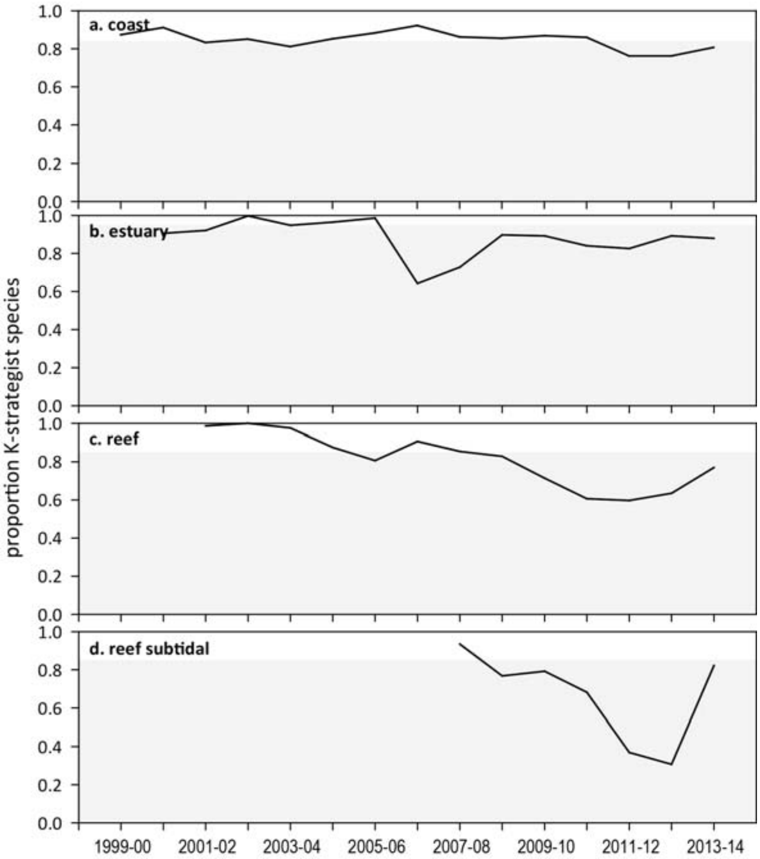

Figure 14. *Proportion of total seagrass abundance composed of K-strategist (foundation) species in a) coastal intertidal, b) estuary intertidal, c) reef intertidal and d) reef subtidal habitats (sites pooled) for the GBR (regions pooled) each monitoring period. Shaded area illustrates average proportion of K-strategist species in each habitat type (refer* Table 3*).*

Reproductive effort across the GBR, representing per area estimates of the number of reproductive structures produced by any seagrass species during the sampling period, was higher in estuary habitats over the long-term, than coastal and reef habitats (Figure 15). Reproductive effort increased at all habitats in 2013-14 relative to the previous year and was higher in coastal and estuary habitats (respectively) (Figure 15).

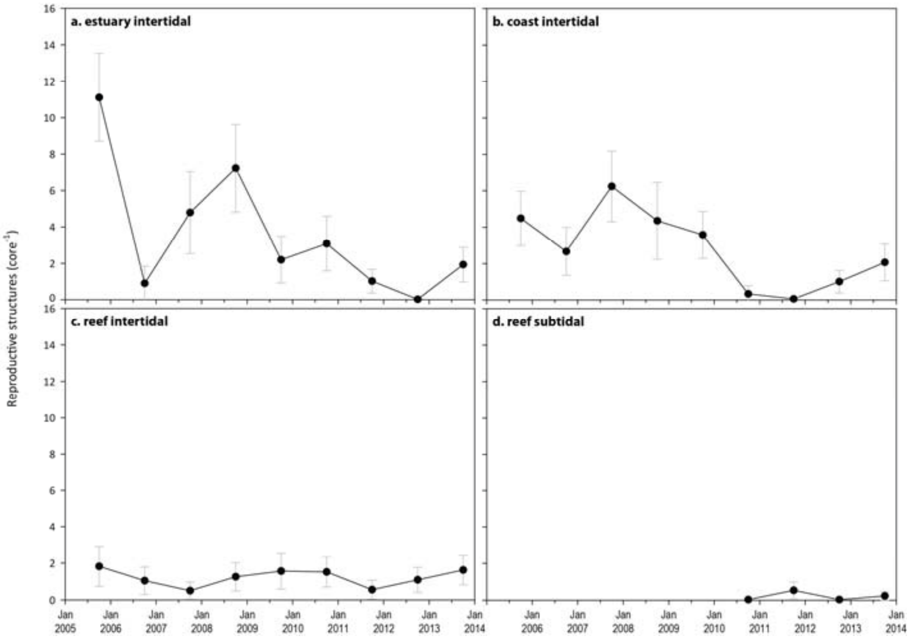

Figure 15. *Seagrass reproductive effort (number of reproductive structures produced by all seagrass species) during the late dry of each monitoring period, for a) estuary intertidal; b) coast intertidal; c) reef intertidal; d) reef subtidal.*

Reproductive effort across the GBR NRM regions during 2013-14 improved in the Wet Tropics, Mackay Whitsunday and Fitzroy (Figure 16). With the exception of the Burdekin and Mackay Whitsunday, reproductive efforts in all other regions was classified as very poor in 2013-14 (Figure 16).

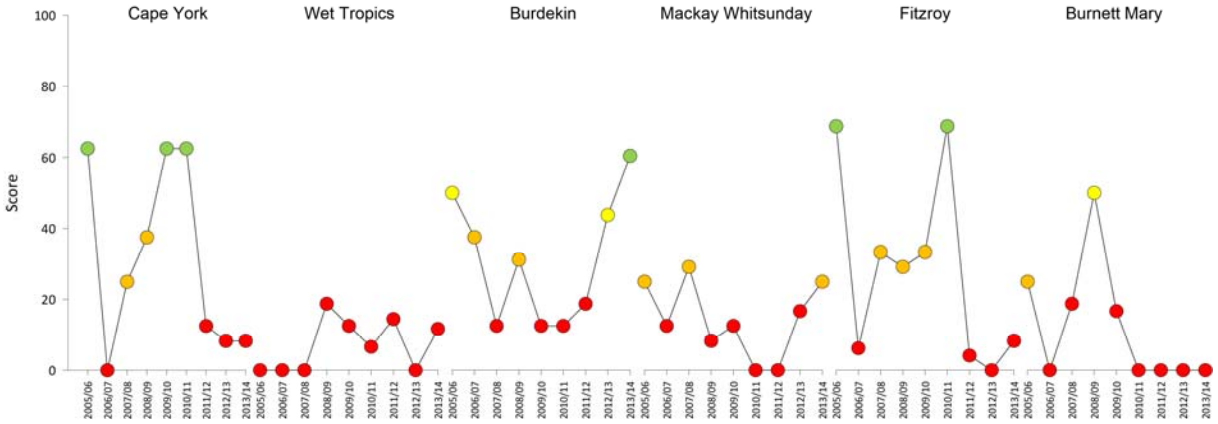

Figure 16. *Regional report card scores for seagrass reproductive effort over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Seagrass reproductive effort scores have fluctuated across regions and habitats over the greater monitoring period. The most variable GBR seagrass habitat in reproductive effort score since monitoring was established was intertidal coast (CV=155.8%) and the least variable was subtidal (72.9%) (Table 16)

Table 16. *Long-term report card for seagrass reproductive status for each habitat in each NRM region: 2005 –2013. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20). Overall GBR score is weighted (see Table 11).*

NRM region	**Habitat**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Cape York	coastal intertidal	63	0	25	38	63	63	13	0	0
	reef intertidal								17	17
Wet Tropics	coastal intertidal	0	0	0	0	6	0	0	0	0
	reef intertidal	0	0	0	38	19	20	10	0	10
	reef subtidal						0	33	0	25
Burdekin	coastal intertidal	50	25	25	38	0	0	0	13	19
	reef intertidal	50	50	0	25	25	25	38	75	63
	reef subtidal									100
Mackay Whitsunday	estuarine intertidal	50	13	25	0	0	0	0	0	25
	coastal intertidal	0	13	38	13	38	0	0	0	0
	reef intertidal			25	13	0	0	0	50	50
Fitzroy	estuarine intertidal	100	0	50	63	25	75	13	0	25
	coastal intertidal	38	13	50	25	25		0	0	0
	reef intertidal			0	0	50	63	0	0	0
Burnett Mary	estuarine intertidal	25	0	19	50	17	0	0	0	0
GBR		**41**	**20**	**17**	**27**	**17**	**20**	**12**	**14**	**19**

Seed banks across the inshore GBR meadows were higher in late dry and greater in coastal than reef or estuarine habitats over the long-term (8 years) (Figure 17). Coastal seed banks declined between 2008 and 2011, but have been increasing since (Figure 17b). Similarly, seed banks have increased to their highest abundances in 2013-14, since monitoring commenced (Figure 17a). This suggests that coupled with the increased reproductive effort, GBR estuarine and coastal meadows in 2013-14 have an improved capacity to recover from disturbances. Although the increased seed bank in reef subtidal habitats (Figure 17d) during 2013-14 suggests an improved capacity to recover from disturbances, the banks may become limited as a result of low repro effort and lack of replenishment.

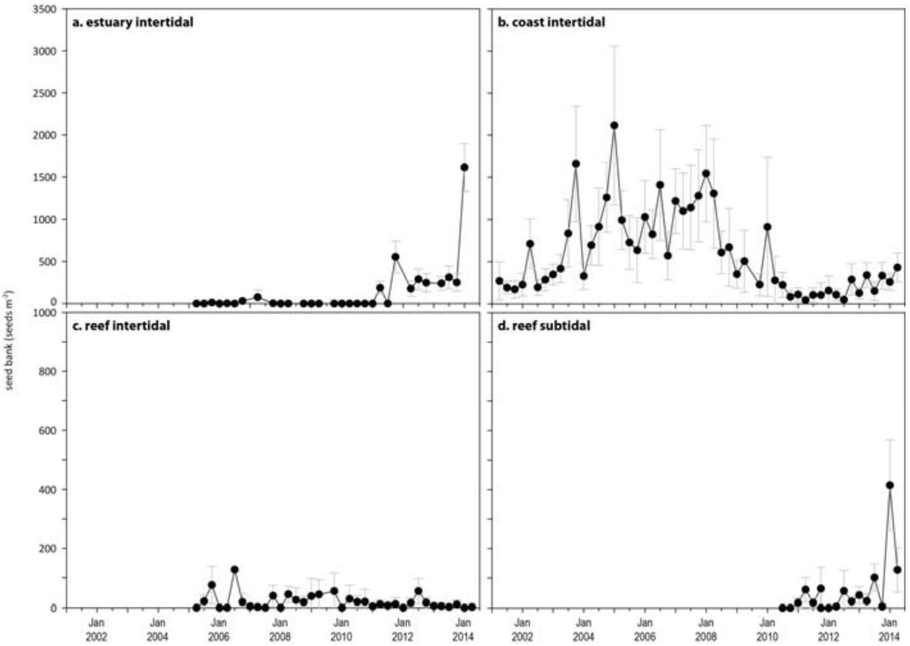

Figure 17. *Average seeds banks (seeds per square metre of sediment surface, all sites and species pooled) in GBR seagrass habitats: a) estuary intertidal; b) coast intertidal; c) reef intertidal; d) reef subtidal.*

3.1.2 Status of the seagrass environment

Seagrass tissue nutrients

Tissue nutrient concentrations differed both across and within habitats between years. It was necessary at some sites (refer Table 5) to pool across foundation species as the presence of individual species has not remained constant over time at all locations since monitoring was established. As tissue nutrient ratios between co-occurring foundation species are not significantly different (McKenzie*, et al.* 2012b), by pooling across species and habitat types, some trends are apparent.

Leaf tissue nutrient concentrations (%N and %P) increased from 2006 to 2010 and reached their highest in 2010 or 2011 across all habitats (species pooled). At the individual, macroscopic level, increased leaf growth, production, shoot height, blade length and width, and biomass are the most commonly reported responses to increased nutrients (Romero *et al.* 2006); i.e. seagrasses allocate more biomass in leaf tissues under high-nutrient availability. However, since 2011 leaf tissue nutrient concentrations (%N and %P) have continued to decrease (Figure 18). The decreased %N the seagrass leaves could suggest a decrease in the N source (reduced river discharge), or it may suggest allocation to other plant organs. Cut from here on? For example, 2011-2013 was a period of meadow recovery (e.g. clonal expansion), where internal nutrient demand may favour from the leaf blade to the basal meristem and transport from intercalary shoots to apical shoots (Romero*, et al.* 2006). Clonal expansion abated in 2013-14, however, the decreases in leaf tissue %N may be in response to increased reproductive output (e.g. reproductive effort and seed production) measured across several of the GBR meadows. Seagrass reproduction represents a substantial nitrogen investment and there is some suggestion that nutrients can also modify allocation of energy and resources to flowering (Romero*, et al.* 2006).

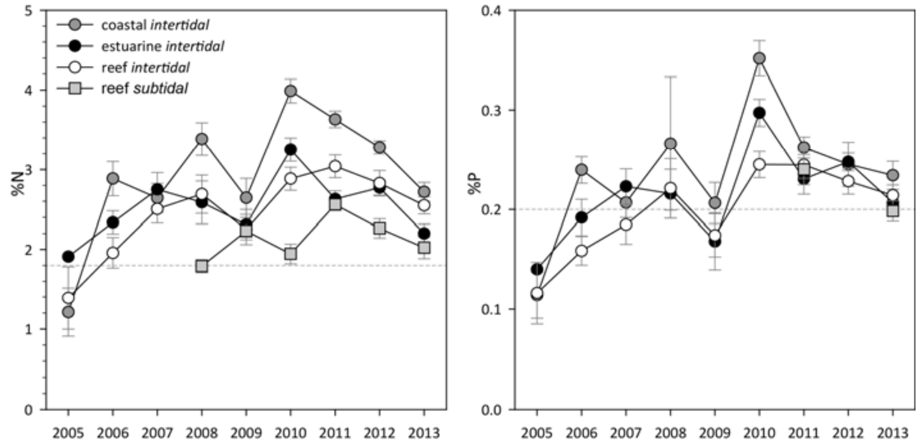

Figure 18. *Median tissue nutrient concentrations (±Standard Error) in seagrass leaves for each habitat type (species pooled) over the entire monitoring program. Dashed lines indicate global median values of 1.8% and 0.2% for tissue nitrogen and phosphorus, respectively (Duarte 1990).*

Since 2005, median tissue nitrogen concentrations for all habitats have exceeded the global value of 1.8% (Duarte 1990; Schaffelke *et al.* 2005) (Figure 18). With the exception of subtidal seagrass, median leaf tissue phosphorus concentrations for all habitats remained above the global value of 0.2% (Duarte 1990; Schaffelke*, et al.* 2005) in 2013 (Figure 18). These findings indicate that nutrients were unlikely to be limiting seagrass growth, however, some concerns have been raised as to accuracy of the global tissue nutrient values (Schaffelke*, et al.* 2005). Furthermore, nutrient levels were unlikely to be physiologically "toxic", as this tends to occur only at very high nutrient concentrations (Burkholder *et al.* 2007).

Tissue nutrient ratios provide information on nutrient availability in the environment relative to demand from growth. In particular, an atomic C:N ratio <20 in Queensland seagrass species, may suggest reduced light availability, and therefore, reduced photosynthetic C incorporation (Abal*, et al.* 1994; Grice*, et al.* 1996). However, the level of N can also influence the ratio in oligotrophic environments (Atkinson and Smith 1983; Fourqurean*, et al.* 1992b). Since 2007, all three intertidal habitat types (coast, reef and estuary) had C:N ratios <20, however, after 2011, the ratios have been gradually increasing (Figure 19, Table 17) indicating increased light availability (which is confirmed to have increased since 2011 through light monitoring, see below). This is further supported by the improvement in the δ^{13}c values (more negative) in late 2013 in reef subtidal and coast intertidal habitats (Figure 22). The increased C:N in 2013 (Figure 19) may also have resulted from reduced N availability; both this and higher light levels are consistent with lower annual discharge since 2011. At reef subtidal habitats, C:N ratios declined below 20 from 2009 to 2011, but increased above 20 for the last 2 monitoring periods suggesting a return to N limitation at reef subtidal sites; however, this trend was being driven predominantly by conditions at the subtidal site in the Burdekin NRM region.

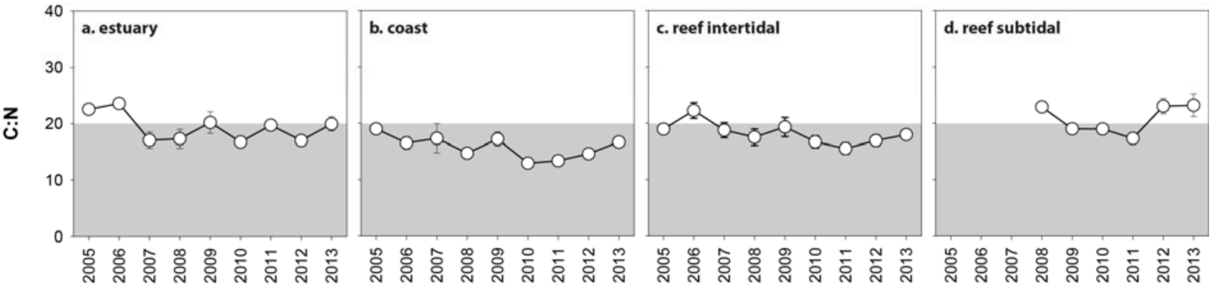

Figure 19. *Elemental ratios (atomic) of seagrass leaf tissue C:N for each habitat each year (foundation species pooled). Horizontal dashed line on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

Seagrass nutrient status scores (using only C:N) across the GBR NRM regions, improved from the Burdekin southwards, but changed little in Cape York and declined in the Wet Tropics (Figure 20). Overall, nutrient status scores remained poor in Cape York, Wet Tropics and Mackay Whitsunday (Figure 20).

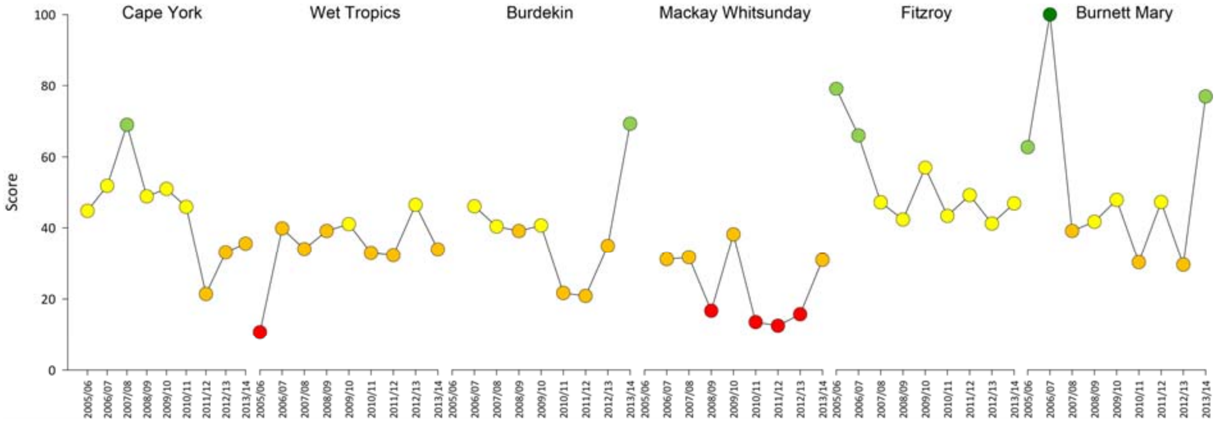

Figure 20. *Regional report card scores for seagrass leaf tissue nutrient status (C:N) over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Table 17. *Long-term report card for seagrass leaf tissue nutrient status (C:N) for each habitat in each NRM region: 2005 –2013. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20). Overall GBR score is weighted (see Table 11).*

NRM region	Habitat	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Cape York	coastal intertidal								30	36
	reef intertidal	45	52	69	49	51	46	21	36	35
Wet Tropics	coastal intertidal	11	10	21	6	25	7	4	7	16
	reef intertidal		70	46	47	50	40	38	40	40
	reef subtidal				64	48	52	54	93	46
Burdekin	coastal intertidal		30	27	27	19	6	14	26	39
	reef intertidal		62	54	51	64	28	28	42	69
	reef subtidal					39	30		37	100
Mackay Whitsunday	estuarine intertidal		23	30	26	43	9	12	19	39
	coastal intertidal		39	38	18	41	12	14	14	23
	reef intertidal			27	7	30	20	11	14	31
Fitzroy	estuarine intertidal		58	46	37	67	66	85	62	33
	coastal intertidal	79	74	75	65	69	41	46	41	67
	reef intertidal			20	25	34	23	17	21	41
Burnett Mary	estuarine intertidal	63	100	39	42	48	30	47	30	77
GBR		**21**	**50**	**39**	**37**	**44**	**27**	**29**	**34**	**43**

Intertidal seagrass habitats across the GBR were consistently rich in phosphorus (P) relative to carbon with C:P ratios below 500 (Figure 21). Furthermore, as for C:N, there has been a slight increase in C:P since 2010 or 2011 across all intertidal habitats, again indicating a reduction in supply of nutrients (through riverine discharge), relative to demand. In 2013, N:P ratios in the leaf tissue changed little from the previous year in the estuarine and reef habitats (Figure 21). Coast and reef habitats had N:P ratios between 25 and 30, indicating seagrass to be nutrient replete (well supplied and balanced macronutrients for growth), and potentially nutrient saturated. In 2013, no habitat had leaf tissue N:P ratios above 30, which if coupled with the low C:P ratios could have suggested elevated N in the environment. . Conversely, the leaf tissue molar N:P ratios remaining below 25 in estuary and reef subtidal habitats, suggests enrichment in P or N deficiency (Figure 21). The ratio of ^{15}N to ^{14}N ($\delta^{15}N$) can indicate the source of nutrients; however, there has been no significant change in $\delta^{15}N$, but it has been measured for just 3 years (i.e. post-2011).

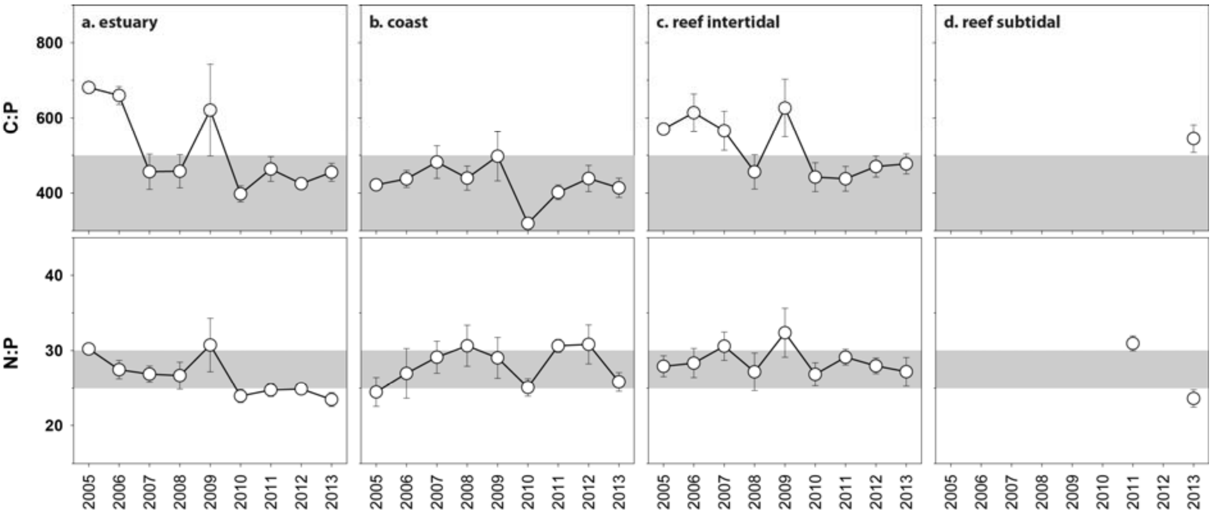

Figure 21. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for each habitat each year (foundation species pooled) (± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Horizontal dashed line on the C:P panel at 500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

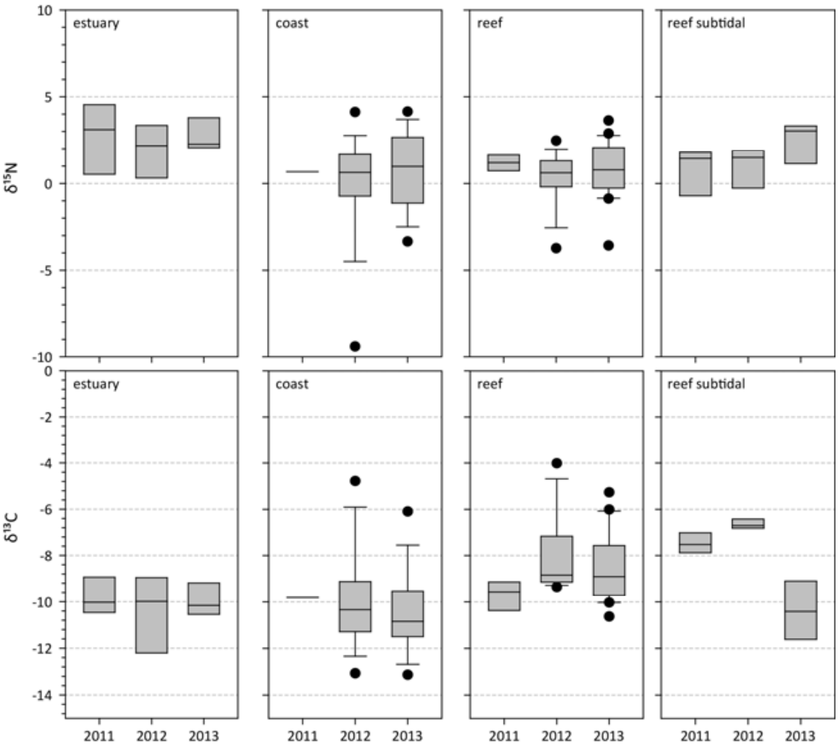

Figure 22. *Seagrass leaf tissue $\delta^{13}C$ and $\delta^{15}N$ concentrations from each GBR seagrass habitat (locations pooled) in the late dry 2011 and 2013. The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the black dots represent outlying points.*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaves across the GBR was higher in the wet than the dry season across all seagrass habitats in 2013-14. Epiphyte cover at intertidal estuary and reef habitats increased in 2013-14, but remained below the GBR long-term average (Figure 23). Similarly, epiphyte cover increased in coastal and subtidal reef habitats in 2012-13, but were above the GBR long-term average (Figure 23).

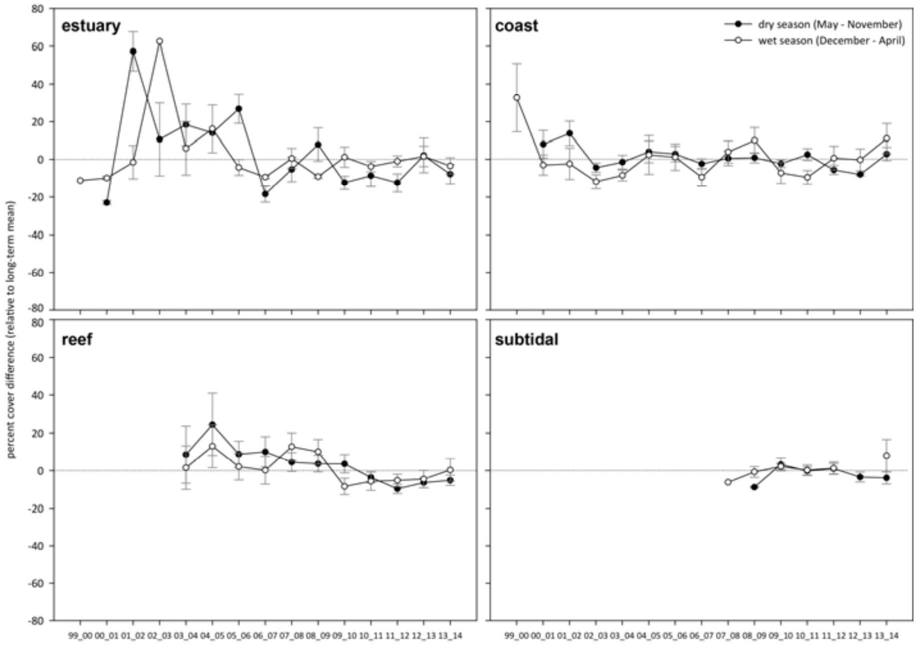

Figure 23. *Epiphyte abundance (% cover) relative to the long-term average for each GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 16.2 ±8.4% coastal=15.1 ±3.1%, reef = 20.2 ±3.3%, subtidal= 7.7 ±1.6%.*

Macroalgae abundance changed little and remained low either at or below the GBR long-term average during the 2013-14 monitoring period (Figure 24).

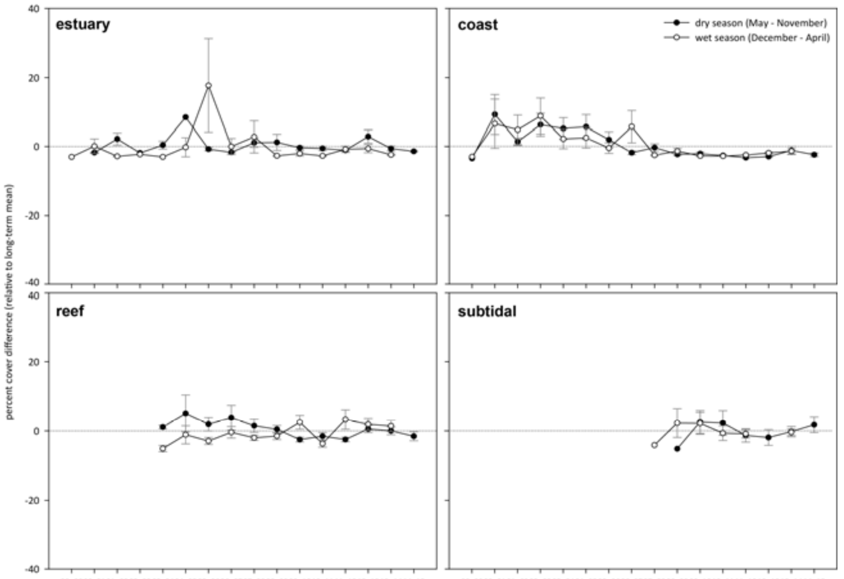

Figure 24. *Macroalgae abundance (% cover) relative to the long-term average for each inshore GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 2.5 ±1.0%, coastal=3.2 ±1.4%, reef = 6.2 ±1.8%, subtidal = 4.7 ±2.0%.*

Within canopy seawater temperature

Within seagrass canopy seawater temperature data were reported for the period of September 2003 to May 2014. Over the 2013-14 monitoring period, seagrasses in the Cape York NRM region (all locations pooled) experienced the greatest number of days (49 days) in the GBR where sea temperatures exceeded 35°C. The GBR region with next highest days of exceedance was Mackay Whitsunday with 44 days. The only region to experience extreme (>40°C) seawater temperatures in 2013-14 was the Cape York NRM region (40.5°C at Bathurst Bay on 14 October 2013). Since monitoring was established, the number of days when seawater temperatures exceeded 35°C was on average greater in the Wet Tropics, followed by Burdekin, Fitzroy, Cape York, Burnett Mary and Mackay Whitsunday respectively (Figure 25).

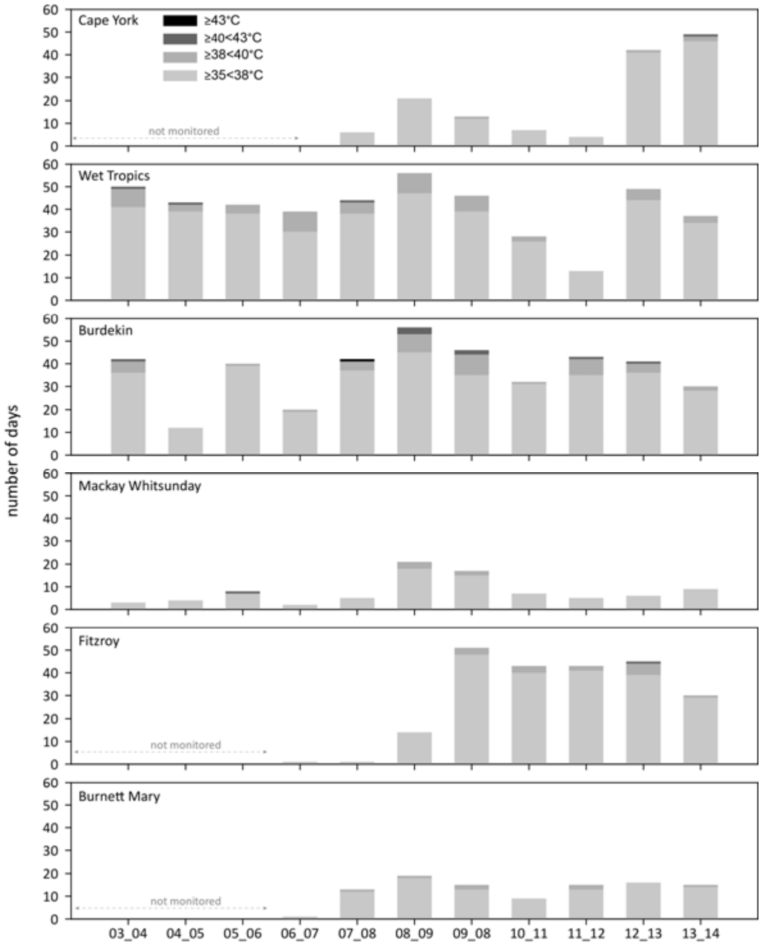

Figure 25. *Number of days when inshore intertidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region.Thresholds adapted from Campbell, et al. 2006; Collier, et al. 2012b.*

Within canopy seawater temperatures were highest than the long-term (10 year) average over the 2013-14 monitoring period (Figure 26); the warmest in 8 years. The warmest period since MMP monitoring commenced was 2005-06 and the coolest was 2011-12 (Figure 26)

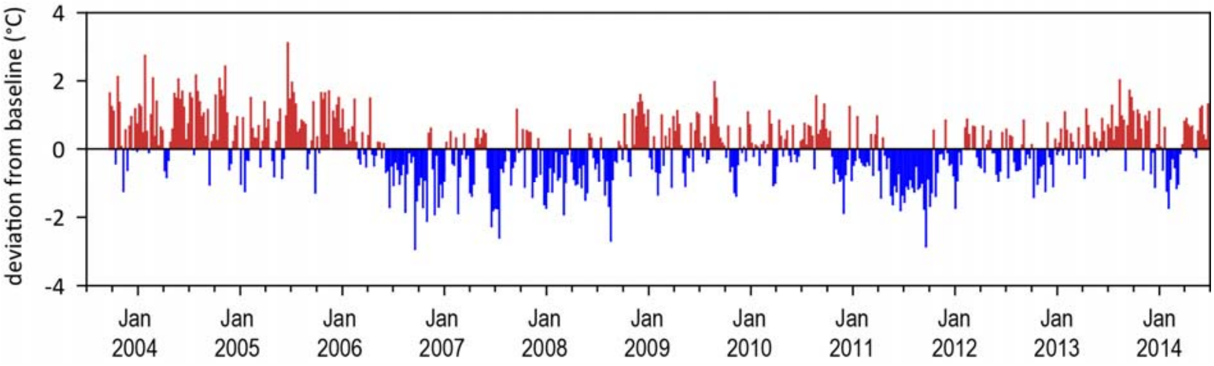

Figure 26. *Inshore intertidal sea temperature deviations from baseline for GBR seagrass habitats 2003 to 2014. Data presented are deviations from 10-year mean weekly temperature records (based on records from September 2003 to June 2014). Weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations.*

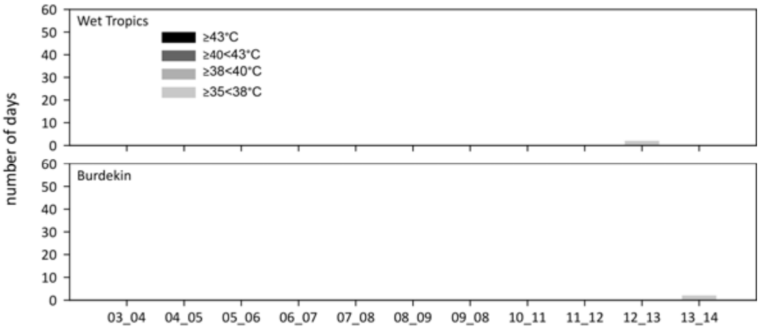

Figure 27. *Number of days when inshore subtidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region. Thresholds adapted from Campbell, et al. 2006; Collier, et al. 2012b.*

Light and turbidity

Daily incident light (I_d, mol m^{-2} d^{-1}) reaching the top of the seagrass canopy in the GBR at intertidal sites in 2013-14 (14.3 mol m^{-2} d^{-1}) was higher than the long-term average (13.5 mol m^{-2} d^{-1}) (Figure 28), when the recently added Cape York sites (first full year of data was in 2013-14) were included in the annual average. Without the additional Cape York sites, the average for 2013-14 (13.6 mol m^{-2} d^{-1}) was similar to the long-term average. At subtidal sites (which only occur in the northern GBR) in 2013-14, mean I_d was slightly lower (6.3 mol m^{-2} d^{-1}) compared to the long-term average (7.5 mol m^{-2} d^{-1}). There was, however, some variability with northern sites in the southern Wet Tropics, Burdekin, Burnett Mary and Fitzroy regions having average or lower than average light levels in 2013-14 compared to the long-term mean. In contrast, daily light in the northern Wet Tropics and Mackay Whitsunday regions were above average. Highest I_d occurred at the Hamilton Island (18.8 mol m^{-2} d^{-1}), Great Keppel Island (17.5), Low Isles (17.9 mol m^{-2} d^{-1}) and the Cape York meadows. Midge Point also recorded a high I_d, however data were only available for September to March, which is biased towards higher light times of year. The lowest I_d occurred at Bushland Beach (5.1 mol m^{-2} d^{-1}) followed by Shelley Beach (7.8 mol m^{-2} d^{-1}) in the Burdekin region, Pelican Banks in Gladstone Harbour (9.9 mol m^{-2} d^{-1}) and Urangan (8.5 mol m^{-2} d^{-1})in the Fitzroy and Burnett Mary regions, respectively.

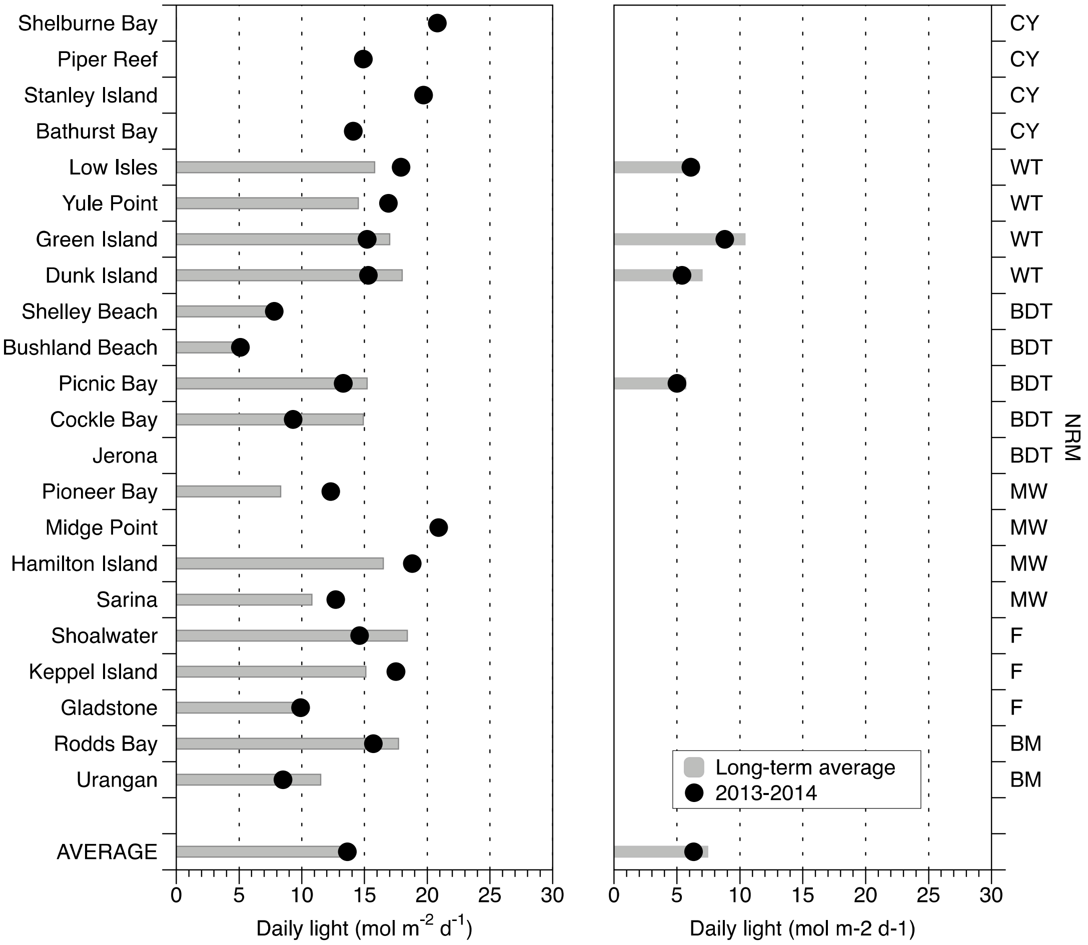

Figure 28. *Average daily light for all intertidal (left) and subtidal (right) sites including the long-term average and the value for the 2013-14 reporting period. NRM regions: WT= Wet Tropics, BDT = Burdekin; M-W = Mackay Whitsunday; F = Fitzroy; BM = Burnett Mary.*

Daily light in shallow habitats can be affected by water quality, cloudiness and the depth of the site, which affects the frequency and duration of exposure to full sunlight at low tide (Anthony*, et al.* 2004; Fabricius *et al.* 2012); however, the differences in I_d among seagrass medaows is largely a reflection of site-specific differences in water quality. For example, turbidity at Green Island (1.6 NTU) was lower than at Picnic Bay (2.52 NTU) (See Appendix 2, Figure 185, Figure 188), and these correspond to mean I_d in 2013-14 of 8.8 mol m^{-2} d^{-1} and 5.0 mol m^{-2} d^{-1} at the same sites, respectively (i.e. light is the inverse of turbidity). In the past year, there was an increase in chlorophyll concentration at Green Island, increasing from 0.38 ug L^{-1} (long-term average) to 0.59 ug L^{-1} (2013-14). Turbidity data are not available for other seagrass monitoring sites. The spatial and temporal variability in I_d, NTU and chlorophyll a is also consistent with spatial patterns in water quality observed at larger spatial scales by remote sensing (Devlin et al 2013) and by *in situ* water quality measurements at reef sites (Schaffelke et al 2013) confirming the role of water quality in the observed patterns of canopy incident light.

Threshold exceedance (number of days less than 5mol m^{-2} d^{-1}, for northern *Halodule uninervis* dominated, meadows and <6 mol m^{-2} d^{-1} for southern *Zostera muelleri* dominated meadows) was generally lower than the long-term average at intertidal sites. Thresholds were exceeded on fewer days (13% of days) compared to the long-term mean (19% of days). For subtidal sites in 2013-14 threshold exceedance was similar in 2013-14 (28% days) compared to the long-term mean (27% of days).

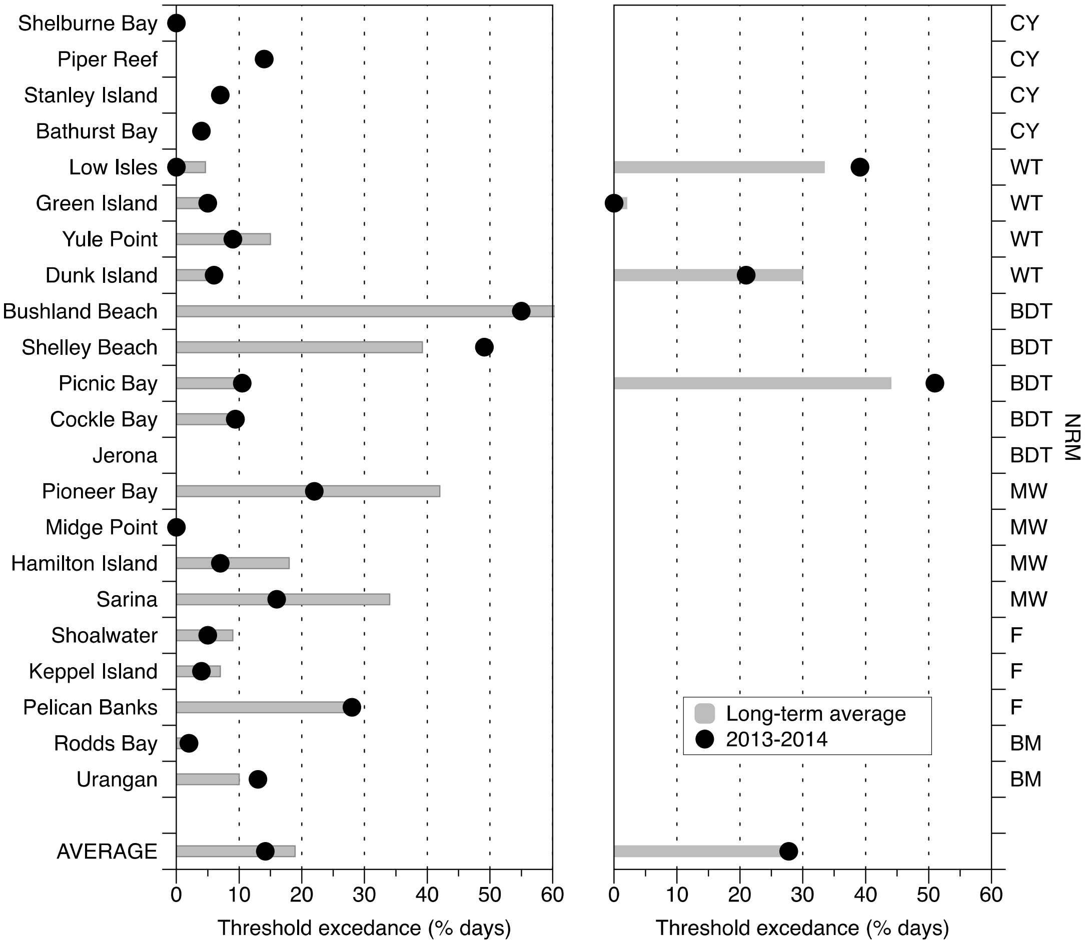

Figure 29. *Threshold exceedance for all intertidal (left) and subtidal (right) locations including the long-term average and the value for the 2013-14 reporting period. Thresholds adapted from Collier, et al. 2012b for northern GBR Halodule uninervis-dominated meadows and Chartrand, et al. 2012 for southern GBR Zostera muelleri dominated meadows.*

Long-term trends demonstrate that the peak in canopy light occurs in September to December as incident solar irradiation reaches its maximum (Figure 30). In 2013-14 the highest light levels were reached in October 2013. The lowest light levels often occured in the wet season, in particular during January to April and in 2013-14, the lowest light levels occurred in February 2014. A break-down of long-term trends by habitat (Figure 31) demonstrates strong seasonal variability in all habitats.

Figure 30. *GBR-wide (locations pooled) normalised daily light data (28-day rolling average). Daily light data were z-score transformed for each site and then averaged (mean) across all sites in the GBR.*

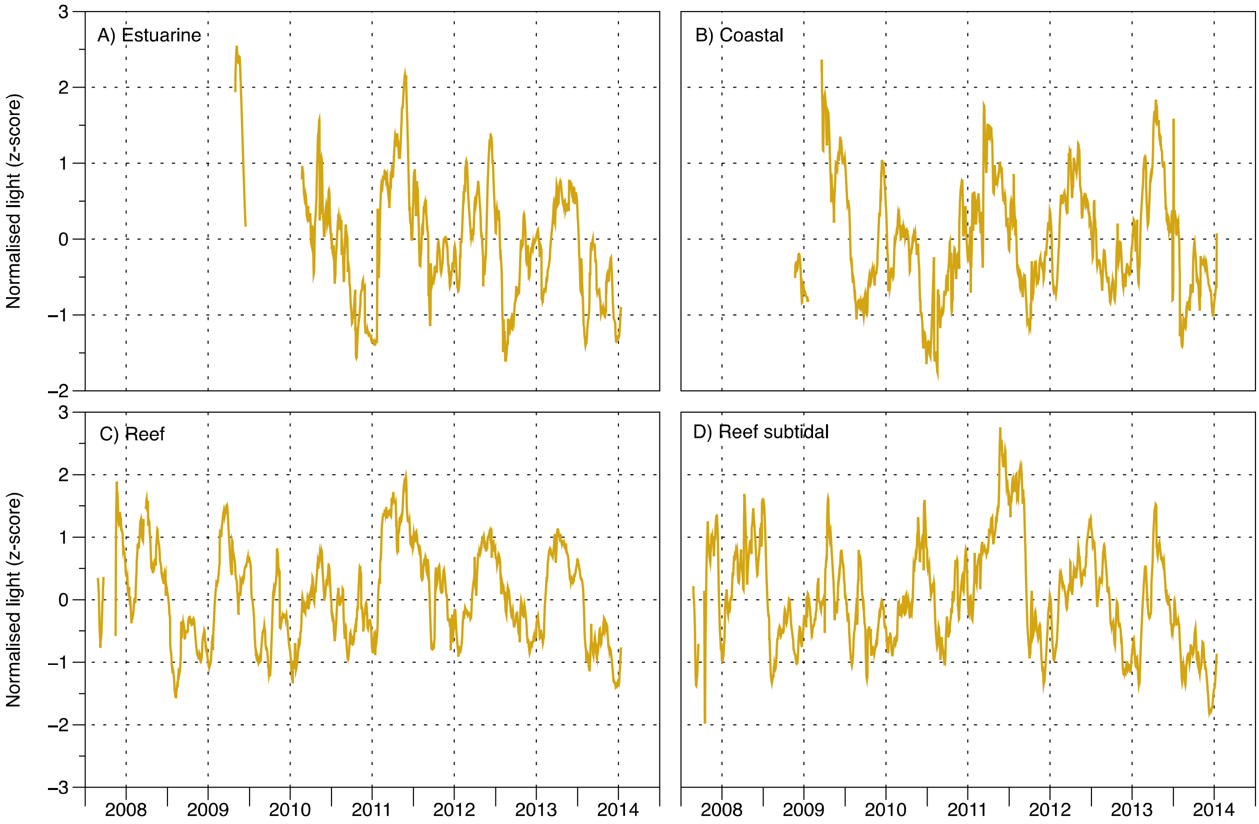

Figure 31. *Normalised (z-score) daily light data (28-day rolling average) for inshore GBR searass habitats: (A) intertidal estuarine, (B) intertidal coastal, (C) intertidal reef; and (D) subtidal reef. Daily light data were z-score transformed for each site and then averaged (mean) across all sites within each habitat type.*

3.2 Cape York

3.2.1 2013-14 Summary

Waters entering the GBR lagoon from Cape York catchments are perceived to be of a high quality, as the majority of the land is undeveloped, including indigenous country, national park or inactive cattle leases. Seagrass growth on reef habitats in the region appears primarily controlled by physical disturbance from waves/swell and associated sediment movement. Similarly, the dominant influence at coastal habitats is exposure to wind/wave disturbance, but with temperature extremes and pulsed terrigenous runoff from seasonal rains.

One location in Cape York (Archer Point) has been monitored since 2005, with sites further north being monitored from 2011, only after the climatic events that caused declines throughout the developing GBR coast. This makes it more difficult to assess long-term trends in Cape York. Seagrass abundance, as well as changes in abundance since 2012-13 varied among sites within the region in 2013-14. Seagrass abundance at reef habitats increased, but remained in a poor state, which coupled with a higher proportion of colonising species may suggest weaker ecosystem resistance to perturbations. The low seed bank and very poor reproductive effort at reef sites further indicates a low capacity to recover following disturbance, which suggests reef meadows remain in a vulnerable state. Although similarly composed of greater than average proportion of colonising/pioneering species, coastal seagrass meadows may have greater resistance on account of their good abundance. The greater seed banks in coastal meadows also suggests a higher capacity to recover following disturbance, although poor reproductive effort may indicate seed bank limitation in the near future. From analysis of seagrass leaf tissue nutrients in late 2013, there was some suggestion of higher available N, from N_2 fixation or fertiliser, in reef habitats. Epiphyte abundance increased in 2013-14, possibly a consequence of higher available N, but macroalgae remained below GBR long-term average.

No extreme within canopy seawater temperatures were experienced over the monitoring period and annual daytime tidal exposure was the lowest in 3 years (below median). Daily light was abundant throughout the year, however, there is some suggestion it may have been lower than the previous monitoring period. Meteorological conditions, in general, were less favourable for seagrass growth with higher rainfall and rougher seas. The higher rainfall was associated with TC Ita, which resulted in above median discharges from the rivers which would have exposed meadows to plumes of turbid, sediment laden water. This may also explain the traces (below reportable limit) of Diuron present at Bathurst Bay. Also, the rougher seas may have mobilised inshore sediments resulting in some physical disturbance of the seabed and possibly reduced light levels for some periods. On account of their moderate abundance, it appears seagrass across the Cape York NRM region were able to resist the impaired environmental conditions of 2013-14, and rather than decline, the regional seagrass state improved slightly over the last 12 months, but remains **poor** (Table 18).

Table 18. *Report card for seagrass status (community & environment) for the Cape York region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
estuarine intertidal		*not monitored*		
coastal intertidal	63	0	36	33
reef intertidal	29	17	35	27
subtidal		*not monitored*		
Wet Tropics	43	8	36	**29**

3.2.2 Background

Cape York Peninsula is the northernmost extremity of Australia. From its tip at Cape York it extends southward in Queensland for about 800 km, widening to its base, which spans 650 km from Cairns (east) to the Gilbert River (west). The largest rivers empty into the Gulf of Carpentaria on the west, however there are several significant catchments which empty into the GBR. Major catchments of the region include the Macmillian, Olive, Pascoe, Lockhart, Stewart, Normanby, Jeannie, and Annan Rivers (Figure 32).

The region has a monsoonal climate with distinct wet and dry seasons with mean annual rainfall ranging from 1715 mm (Starke region) to 2159 mm (Lockhart River airport). Most rain falls between December and April. Mean daily air temperatures in the area range between 19.2 – 32.1°C. The prevailing winds are from the south east and persist throughout the year (Earth Tech 2005).

Cape York Peninsula is an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. The majority of the land is relatively undeveloped, therefore water entering the GBR lagoon is perceived to be of a high quality. Cattle station leases occupy about 52% of the total area, mostly located in central Cape York Peninsula but only around 33% are active leases. Indigenous land comprises about 22%, with a significant area of the West coast being held under Native title and other areas being under native title claim. The remainder is mostly declared as National Park including joint management areas with local traditional owners or under other conservations tenures e.g. nature refuges, conservation areas, wildlife reserves . Mining, agriculture, and commercial and recreational fishing are the major economic activities. All these activities have the potential to expand in this region and with this expansion the risk of increased pollutants.

Approximately 60% of the maximum habitable area of seagrass mapped in the shallow waters (<15m) of the GBR occurs in the Cape York NRM (McKenzie*, et al.* 2010c). Of this, approximately 95% is inshore coastal and fringing reef (Coles *et al.* 2007). The most extensive seagrass distribution occurs in the shallow waters of the Starke region, and in Bathurst, Princess Charlotte, Shelburne and Margaret Bays. Thirteen species of seagrass have been identified from this region (Coles *et al.* 1985; Lee Long*, et al.* 1993; Rasheed *et al.* 2005). Only reef and coastal seagrass habitats were monitored.

Reef habitats in the Cape York 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). In these environments, physical disturbance from waves and swell and associated sediment movement primarily control seagrass growth (Appendix 2, Figure 128). Shallow unstable sediment, fluctuating temperature, and variable salinity also 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.

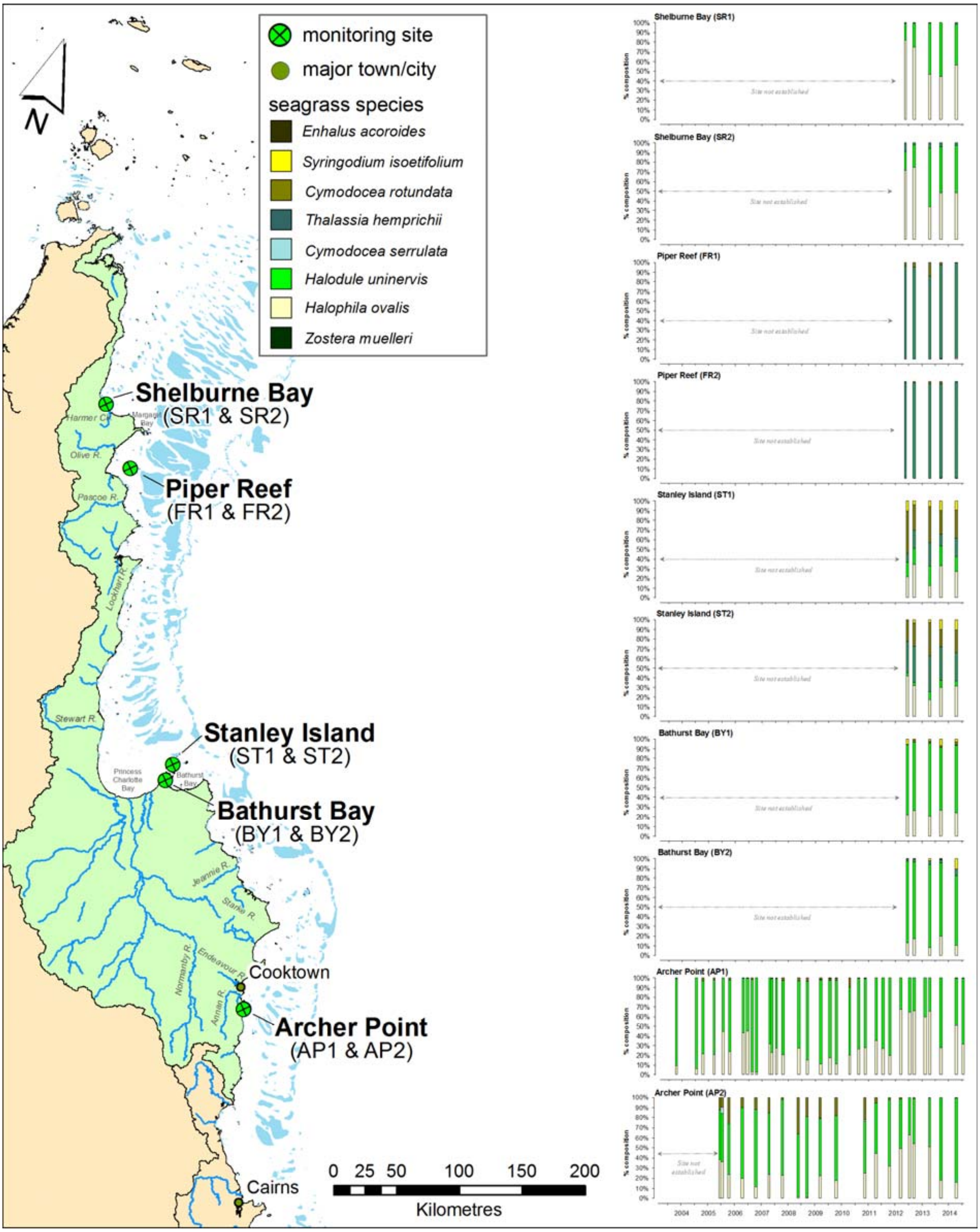

Figure 32. *Location of the Cape York region monitoring sites and seagrass species percent composition at each site since 2003. Please note: replicate sites within 500m of each other.*

Seagrass meadows on inshore reef habitats were monitored at 3 locations, from the north of the region (12.25°S), to the south (15.6°S) (Figure 32). The most southern location (Archer Point) includes a legacy site which has been monitored over the longest time period for the region. The sites at Archer Point were located in a sheltered section of bay adjacent to Archer Point, fringed by mangroves, approximately 15km south of Cooktown (Figure 32). There are two major rivers within the immediate area: the Endeavour and the Annan River. The Endeavour River is the larger of the two river systems and has a catchment area of approximately 992 km^2. The Annan River is located approximately 5 km south of Cooktown and extends inland from Walker Bay. The Annan River catchment area is approximately 850 km^2 (Hortle and Person 1990).

The other two reef habitat locations were included for monitoring from early 2012: Stanley Island and Piper Reef. Stanley Island is within the Flinders Island group north of Bathurst Bay (Figure 32). The site is a fringing reef site also fringed with mangroves. The islands are influenced by the Princess Charlotte Bay catchment which has four river systems, the Normanby, Marrett, Bizant and North Kennedy Rivers. Piper Reef is approximately 45km north west of Portland Roads, 15 km off the mainland coast (Figure 32). It is influenced by coastal waters from the Olive and Pascoe Rivers along with the Temple Bay catchment. There are minor land use activities in these catchments with some small level housing on the Pascoe River at the Wattle Hills settlement.

In early 2012, coastal seagrass habitat locations paired with the new reef habitat locations, were also included for monitoring, they included: Bathurst Head (paired with Stanley Island) and Shelburne Bay (paired with Piper Reef). The coastal seagrass meadows at Bathurst Head and Shelburne Bay are located on naturally dynamic sand banks. 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. A dominant influence to these coastal meadows is exposure to wind/wave disturbance and terrigenous runoff from seasonal rains (Appendix 2, Figure 129).

Bathurst Head is located just east of Combe Point in the Bathurst Bay area to the east of Princess Charlotte Bay (Figure 32). It is a coastal location fringed by mangroves on the eastern edge of the bay. The sites are within 20km of the mouths of the Normanby and Margaret Rivers. The Normanby River is the fourth largest river system flowing into the Great Barrier Reef. The catchment area covers 24,228 km^2 and consists of one of Queensland’s largest conservation areas, extensive cattle grazing country (75% of the catchment), and rich agricultural land at Lakeland Downs (Reef Water Quality Protection Plan Secretariat 2011). Less than 5% of the catchment has been cleared (Reef Water Quality Protection Plan Secretariat 2011). Grazing densities are generally low on Cape York Peninsula (~1 beast/40 ha), however, the productive pastures in the Normanby catchment can have densities from ~1 beast/20 ha to >1 beast/5 ha (Cotter 1995).

Shelburne Bay is located 112 km north of Lockhart River and 122 km southeast of Bamaga on the east coast of the GBR. The bay has a limited catchment with only Harmer Creek discharging directly into it, and the MacMillan River discharging into the adjacent Margaret Bay. The catchment contains one of the least disturbed parabolic sand dunes areas in the world and is made up of seasonal wetlands and sand ridges. There are no current land use activities occurring in this catchment. The area is prone to extreme weather with the cyclone database stating that 47 cyclones have tracked within 200km of Shelburne Bay between 1906 and 2007. The monitoring site at Shelburne Bay is approximately 5 km west of the mouth of Harmer Creek mouth.

3.2.3 Status of the seagrass community

Seagrass abundance and composition

The seagrass abundance score across the region remained moderate in 2013-14 (Figure 33). Seagrass abundance at intertidal reef habitats declined from 2003 to 2012, and although improved in cover since, remains in a poor state. Seagrass abundance at coastal habitats was in a very good state in 2012-13, however it has declined to a good state in 2013-14. Meadows across the region were composed of a greater than average proportion of *Halophila ovalis*, an *r*-strategist species, which coupled with poor abundance may suggest weaker ecosystem resistance in some meadows.

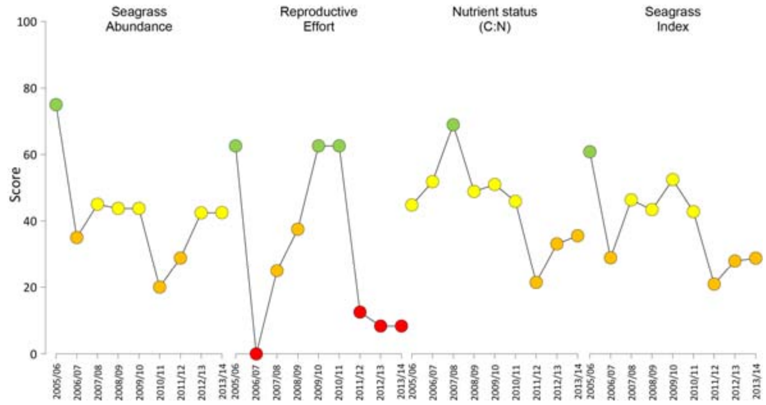

Figure 33. *Report card of seagrass status indicators and index for the Cape York NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20).*

The long-term average seagrass cover at reef habitats in the Cape York NRM region varied little between seasons: 13.3% in the late dry and 14.9% in late monsoon season. Seagrass abundance in 2013-14 remained similar at far northern meadows (Piper and Stanley Reefs), but was approximately 40% higher at Archer Point than the previous monitoring period (Figure 34): a consequence of higher abundances in April 2014.

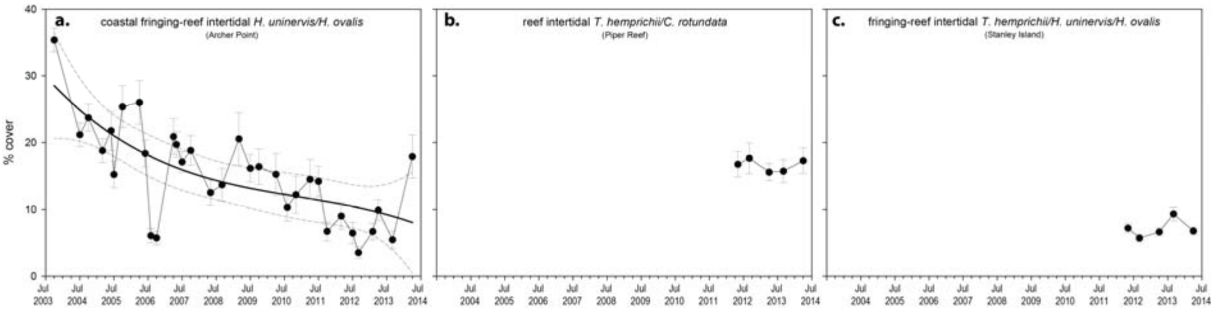

Figure 34. *Seagrass abundance (% cover ± Standard Error) at inshore intertidal reef habitats (replicate sites pooled) in the Cape York NRM. Trendline for Archer Point is 3rd order polynomial, 95% confidence intervals displayed,* $r^2 = 0.51$.

In the late monsoon 2014, meadows in Cape York reef habitats with the highest seagrass abundance were at Piper Reef (21.9 ±2.5% at site FR2), followed by Archer Point (19.8 ±3.4% at site AP2). In 2013-14 seagrass abundance continued to increase across reef habitat meadows, from declines observed in 2011/12. Since monitoring was established at Archer Point (AP1) in 2003, seagrass cover has generally followed a seasonal trend with higher abundance in late dry period (McKenzie*, et al.* 2012c). The seasonal trend at other meadows was less apparent.

Seagrass abundance at coastal habitats in the northern and central sections of eastern Cape York NRM region slightly increased in 2013-14 (Figure 35), although no long-term patterns were apparent due to the limited dataset. In 2013-14, seagrass abundances at Shelburne Bay increased above the 20th percentile guideline for most meadows, however, at Bathurst Bay they were above the 50th percentile guideline (Figure 35, Table 27).

Cape York reef meadows were dominated by *Thalassia hemprichii*, *Cymodocea rotundata, Halodule uninervis* and *Halophila ovalis* with varying amounts of *Syringodium isoetifolium* and *Enhalus acoroides* (Figure 34). At Archer Point (the location of the longest dataset), species composition has varied since sampling began in 2003 with the composition of *Halophila ovalis* fluctuating seasonally with increases in the late monsoon.

Seagrass at coastal habitats in the eastern Cape York NRM region were located on large shallow sand banks and dominated by *H. ovalis*/*Halodule uninervis*. At Bathurst Bay in the central section of Cape York, adjacent to Princess Charlotte Bay, meadows were dominated by *Halodule uninervis* (Figure 32). Five seagrass species were present in the Bathurst Bay meadows, whereas only three species were present at Shelburne Bay (Figure 32). As the dataset is limited, no temporal trends were apparent.

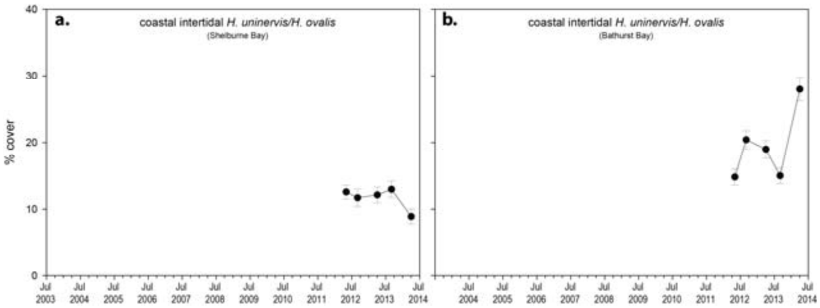

Figure 35. *Seagrass abundance (% cover ± Standard Error) at inshore intertidal coastal habitats (sites pooled) in the Cape York NRM region.*

Seagrass meadows in the Cape York NRM region were composed of a greater than average proportion of *r*-strategist species, particularly over the last 3 monitoring periods (Figure 36). This suggests the meadows are dynamic in nature and have experienced perturbations in recent years. The increase in foundation / K-strategist species in reef meadows in 2013-14 suggests improved ecosystem resistance, however, this may be compromised by the reduced abundance (% cover).

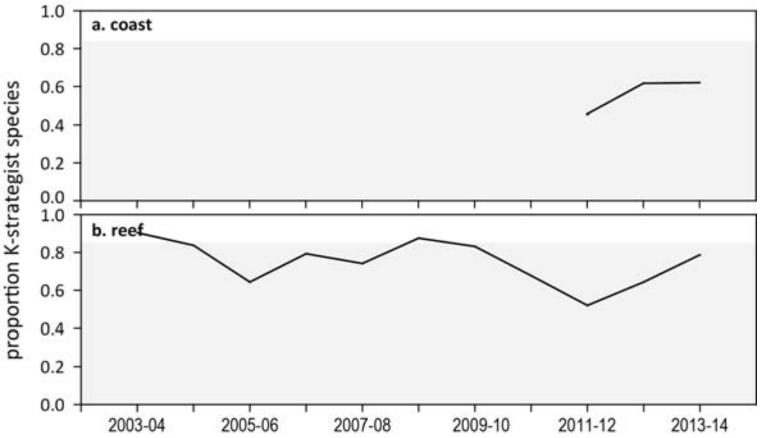

Figure 36. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Cape York region.Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in October 2013 and April 2014 to determine if changes in abundance were a consequence of the meadow edges changing (Appendix 1, Table 36). Prior to 2012, the only meadow extent mapping in the Cape York NRM region was conducted at Archer Point. The meadows within 100m of the monitoring sites on the reef flat at Archer Point have fluctuated within and between years (Figure 37), primary due to changes in the landward edge and appearance of a drainage channel from an adjacent creek (data not presented). Post 2011, additional reef meadows and coastal meadows in the Cape York NRM region were included MMP. Overall, the slight increase in extent measured in throughout 2012-13 continued throughout 2013-14 at all reef and coastal sites (Figure 37; Appendix 2, Table 36).

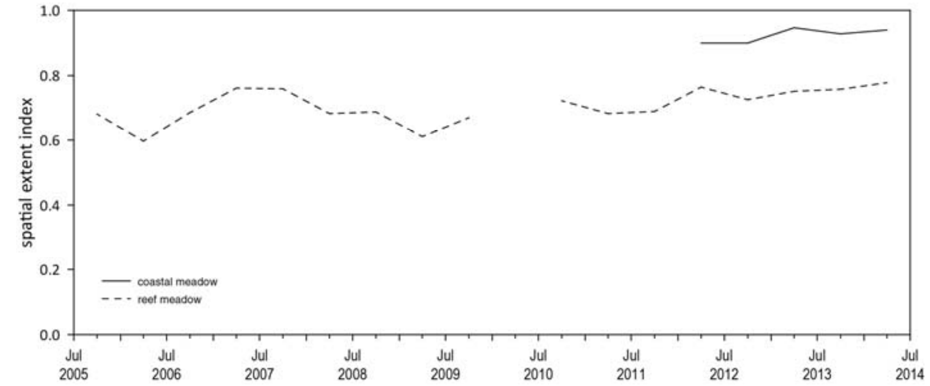

Figure 37. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each habitat and monitoring period across the eastern Cape York NRM region.*

Seagrass reproductive status

Seagrass seed banks in Cape York meadows were often larger in the late dry than late monsoon (Figure 38). Seed banks were also higher at coastal than reef habitats (Figure 38). A seed bank of predominately *Halodule uninervis* persists at reef habitat meadows (Figure 38), however late dry abundances in 2013-14 were similar to 2012-13; the lowest since monitoring was established. Although *Cymodocea* plants were present across reef meadows, no seeds have been found since monitoring commenced. Total reproductive effort was greater in reef habitats, and was similar to the previous monitoring period; remaining below the peak in 2009 (Figure 38).

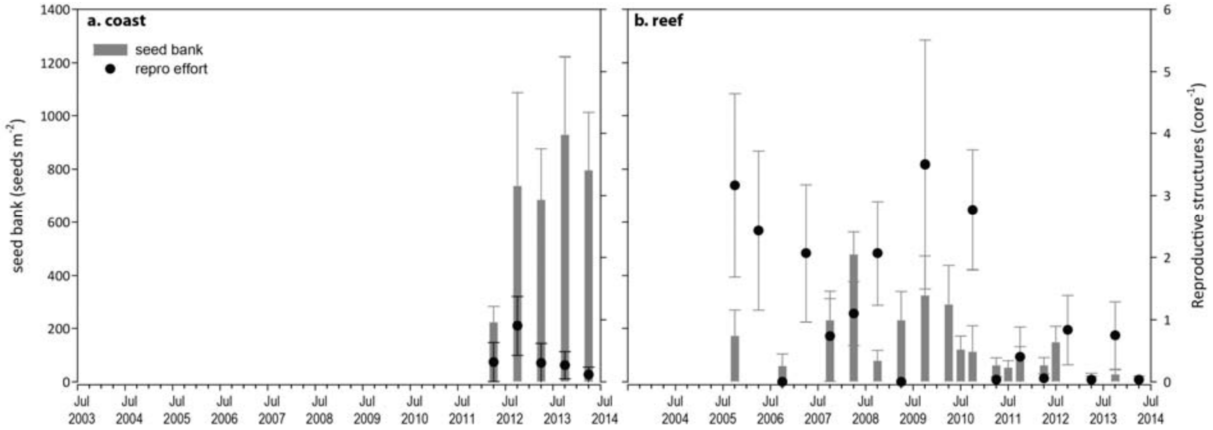

Figure 38. *Seed banks and reproductive effort at inshore intertidal coastal (a) and reef (b) habitats in the Cape York region (species and sites pooled). Seed banks presented as the total number of seeds per m^2 sediment surface. Reproductive effort for late dry season presented as the average number of reproductive structures per core.*

The low seed bank and poor reproductive effort at reef meadows indicates a low capacity to recover following disturbance. Alternatively, at coastal meadows, the greater seed bank suggests a higher capacity to recover, but the poor reproductive effort may indicate seed bank limitation in the near future.

In a further exploration of the biological response variables using long-term trends analysis (GAM), seagrass abundance (% cover) was relatively stable since 2011 (Figure 39a). However, the overall trend in reproductive effort shows some ongoing decline, which may be biased by the addition of new sites since 2011 (Figure 39b). The long-term trend in sees banks has remained relatively stable (Figure 39c).

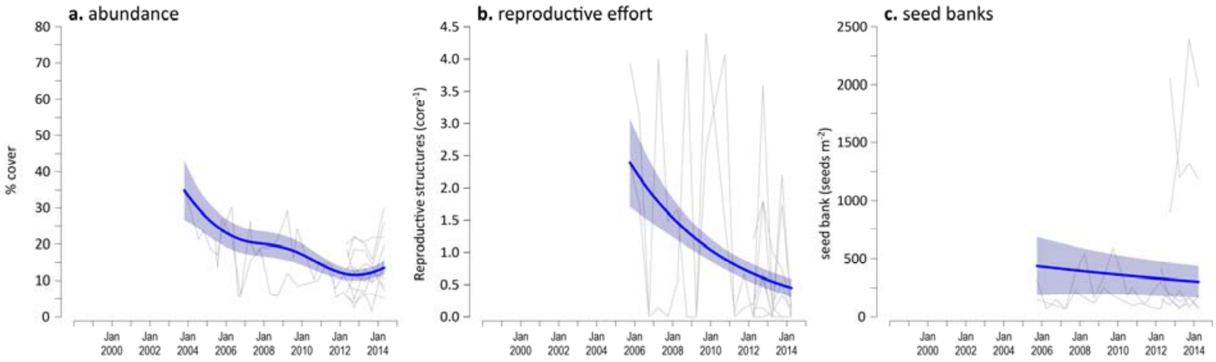

Figure 39. *Seagrass abundance, reproductive effort and seed bank trends in the Cape York region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles individual sites at all locations and habitats.*

3.2.4 Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf molar C:N ratios were below 20 at all Cape York habitats and locations in late dry season 2013 (Figure 40). Although molar C:N ratios for the foundation seagrass species (*Halodule uninervis* and *Cymodocea serrulata*) at Archer Point increased in late dry season 2012 from the lowest recorded levels in 2011, they remained below 20 and declined slightly in 2013 (Appendix 2, Figure 141c). With the exception of *Zostera muelleri* at Archer Pt, δ^{13}C values for foundation species at all habitats during the 2013 late dry (growing) season were above (isotopically heavier) the global average or within global ranges (Appendix 2, Table 37), suggesting sufficient carbon available for growth. The isotopically lighter δ^{13}C values (below the global average) for *Zostera muelleri* in the reef habitat at Archer Point, may be a consequence of Z. *muelleri* growing adjacent to mangroves and experiencing either shading or higher epiphytic cover (data not available).

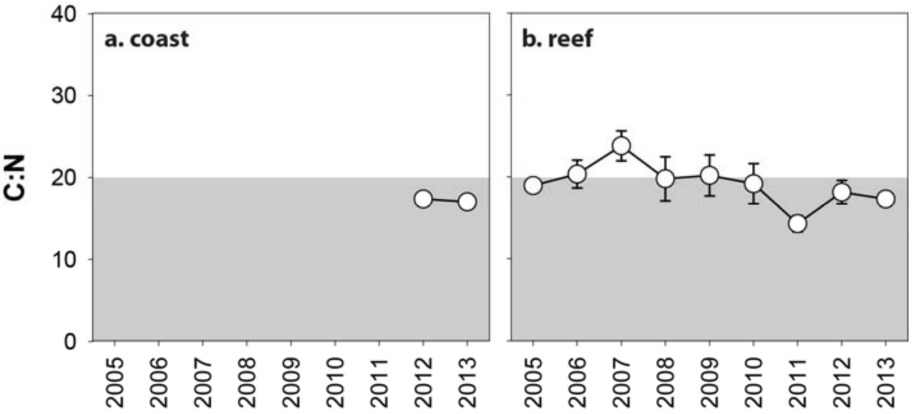

Figure 40. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation species in inshore intertidal coastal (a) and reef (b) habitats in the Cape York region from 2005 to 2013 (species pooled) (mean and SE displayed). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

Seagrass leaf molar C:P ratios in 2013 were <500 for coastal habitats, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 41; Appendix 2, Figure 142). However, at reef habitats, with the exception of Stanley Island, seagrass leaf molar C:P ratios in 2013 were >500, indicating that the plants were growing in a nutrient poor environment with a relatively small P pool (Figure 41; Appendix 2, Figure 141).

N:P ratios for the foundation species increased slightly overall at reef habitats since the previous monitoring period (Figure 41); predominately due to the larger increase at Archer Pt (Appendix 2, Figure 141). Conversely, ratios decreased at coastal habitats in 2013, but remained between 25 and 30, indicating the plants remained replete (well supplied and balanced macronutrients for growth)(Figure 41).

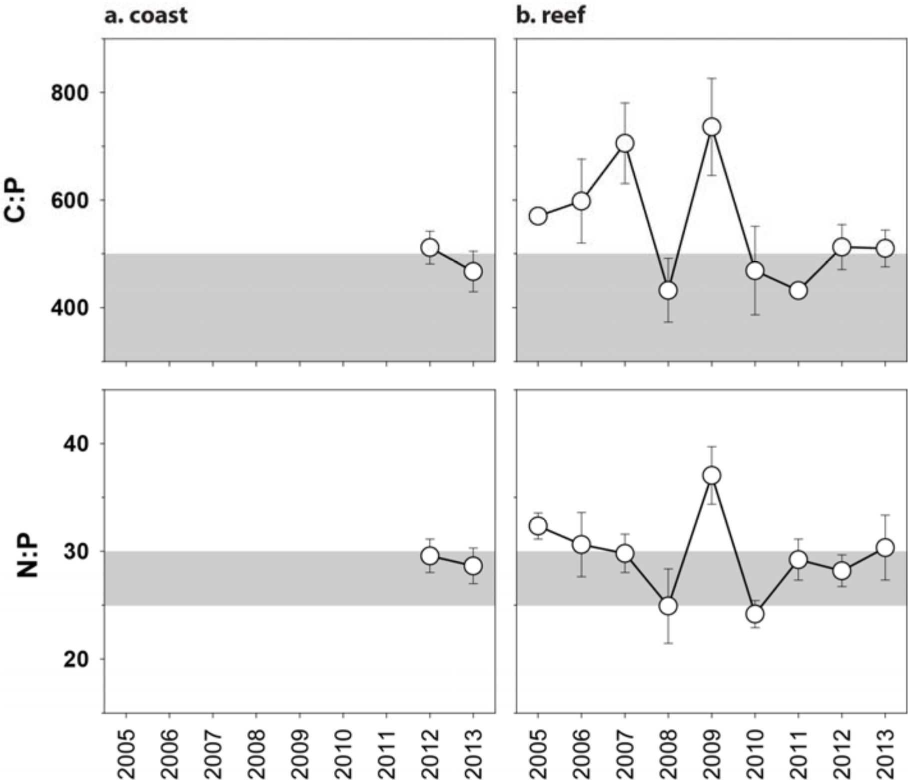

Figure 41. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation species in inshore intertidal reef (a, c) and coastal (b, d) habitats in the Cape York region from 2005 to 2013 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

There was some suggestion of higher available N at Cape York reef habitats in the northern and southern Cape York region during the late dry season 2013, as there was a slight decrease in C:N ratios (not light related), N:P ratios increased above 30 (Figure 41), and δ^{15}N values in the leaf tissues were between 0.5‰ and 1.5‰ (Appendix 2, Table 37), suggesting the primary source of N was from N_2 fixation or fertiliser. The highest average δ^{15}N values in the leaf tissues from the region in 2013 were measured in *Thalassia* (1.46‰) at Piper Reef, followed by *Halodule* (0.89‰) at Archer Point. These δ^{15}N values were lower than those measured in 2012, where the highest values were from *Syringodium* (1.99‰) and *Halodule* (1.5‰) at Stanley Island and *Zostera* (1.84‰) at Bathurst Bay: all within the central section of the Cape York region.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades over the long-term was generally higher in the wet season at coastal habitats and in the dry season at reef habitats (Figure 42). During 2013-14, epiphyte abundances were 3-4 times the GBR long-term average at coastal habitats in the north of the region (i.e. Shelburne Bay), but well below the GBR long-term average in the central (Bathurst Bay)

(Appendix 2, Figure 149). Epiphyte abundances at reef habitats were higher in 2013-14 than the GBR long-term average and the previous monitoring period (Figure 42; Appendix 2, Figure 150).

Percentage cover of macroalgae was variable between years, but appears to have increased over the last two monitoring periods and was above the GBR long-term average for reef habitats throughout 2013-14 (Figure 42; Appendix 2, Figure 150). Macroalgae cover increased above the GBR long-term average for coastal habitats for the first time in 3 years (Figure 42).

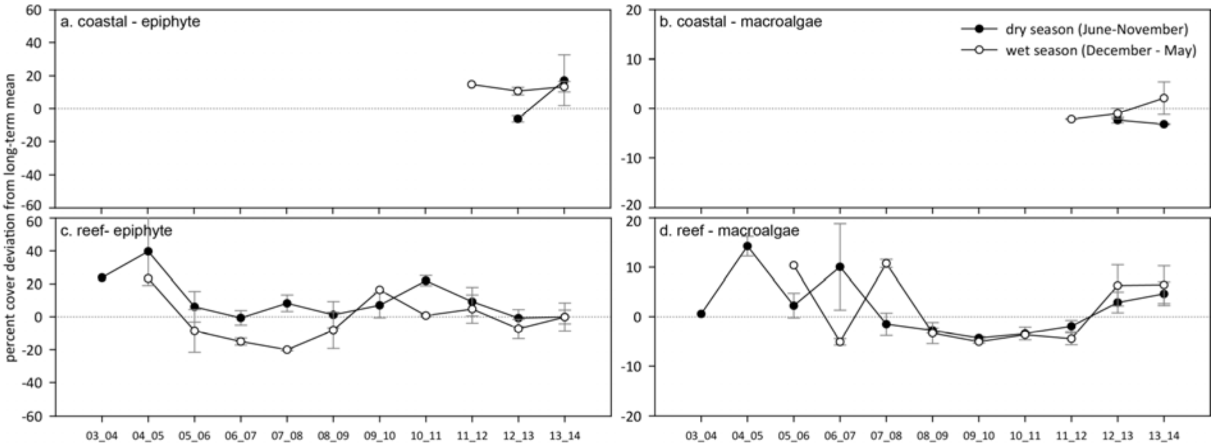

Figure 42. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore GBR intertidal seagrass habitat (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated between and within years, however, the long-term trend demonstrates a decline from 2004 to 2008 (Figure 43) (a period when seagrass cover was in a moderate to good state), after which it has been gradually increasing; possibly in association with the higher available N. Similarly, macroalgae cover decreased from 2004 to 2009, after which it has remained low and stable (Figure 43).

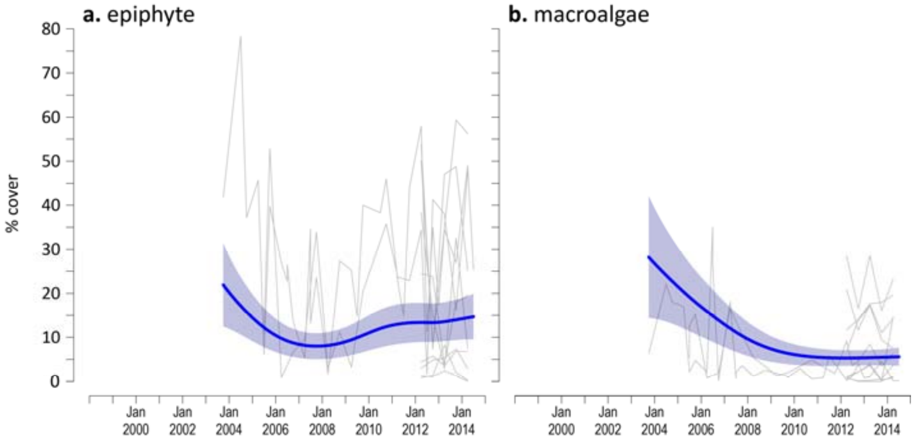

Figure 43. *Epiphyte and macroalgae cover trends in the Cape York region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Archer Point during daylight over the 2013-14 monitoring period was the lowest in 3 years; below the long-term median (69.5 hours) (Appendix 2, Table 39, Figure 164). This would have alleviated any desiccation stress on the plants over the year. As data was currently unavailable at the time of production of this report, levels of exposure at other intertidal sites in the far northern section of Cape York could not be calculated, but it would not be unreasonable to assume were similarly lower in 2013-14 (as all tide heights are relative to the same standard port (Appendix 2, Table 39)).

Rhizosphere sediment herbicides

Although Diuron was present in the sediments of the seagrass meadows at Bathurst Bay in the late monsoon 2014, herbicide levels were below reportable limits sites. No herbicides were detected in the north and central Cape York region in the late monsoon 2014 (Appendix 2, Table 40). Archer Point sediments were not examined for the presence of herbicides.

Within canopy sea temperature

Autonomous temperature loggers were deployed at all locations over the monitoring period. The longest dataset was from Archer Point, as other sites were established in May 2012 (Appendix 2, Figure 172). High temperatures (>35°C) were recorded from October to December 2013 across the region, with the highest temperature (40.5°C) recorded at 1:30pm on the 14 October 2013 at Bathurst Bay (Figure 44a); the highest ever recorded in the region. A greater number of days (49 days) where the sea water temperatures exceeded 35°C was experienced in 2013-14 (cf. 42 in 2012-13). At Archer Point, temperatures were 2.1°C warmer on average than the previous period and slightly above the long-term over the 2013-14 monitoring period. At other locations in the north of the region, temperatures during 2013-14 were similar to 2012-13.

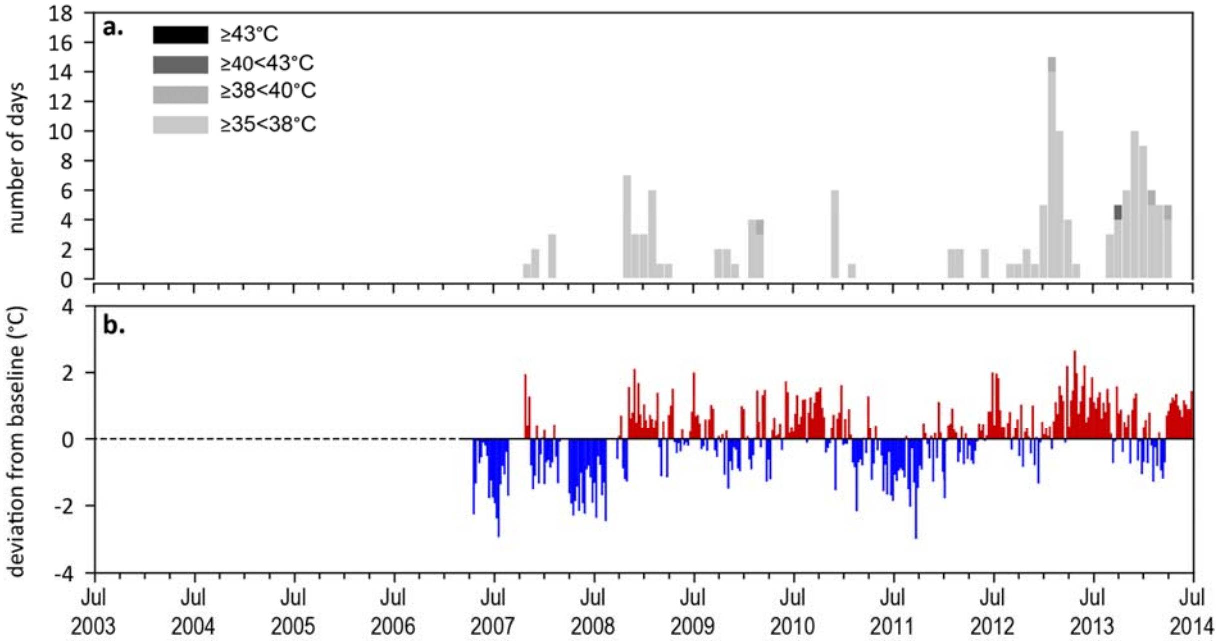

Figure 44. *Inshore sea temperature for intertidal seagrass habitats in the Cape York NRM region from April 2007 to June 2014: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations at Archer Point from 7-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations). Dashed line represents period when monitoring not established.*

Canopy incident light

Daily light levels in the Cape York NRM region follow a seasonal pattern in which light peaks during the late dry season, and then declines sharply with the onset of the wet season (Figure 45; Appendix

2, Figure 180). There is some suggestion that daily light levels were lower over 2013-14 compared to the previous monitoring event (Figure 45), however, as light monitoring data is limited, it is difficult to be certain.

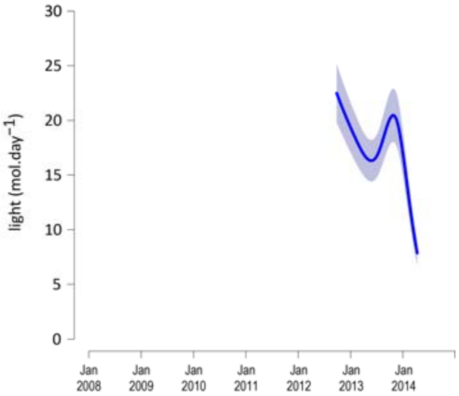

Figure 45. *Seagrass canopy light trend in the Cape York region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

Regional climate and river discharge

The most significant climate event to impact seagrass meadows in the Cape York NRM region occurred in early April 2014, with severe Tropical Cyclone Ita (Category 4). Tropical Cyclone Ita was the strongest tropical cyclone to impact Queensland since TC Yasi three years prior; making landfall at about 2200hrs on the evening of Friday April 11th near Cape Flattery in the southern section of the Cape York NRM region. However, an aerial reconnaissance flight conducted from the Jeannie River to Cape Bedford on 30 April 2014 reported no substantial impacts to seagrass in the areas directly affected by the path of Tropical Cyclone Ita (McKenzie *et al.* 2014b). Shallow coastal meadows showed some minor evidence of impact, but the low level of impact was a consequence of a high tide at the time TC Ita crossed the coast and landward origin of the most destructive winds (McKenzie*, et al.* 2014b).

In general, climate over the 2013-14 monitoring period was cooler, wetter, and with clearer skies than the long-term average meteorological conditions. The mean maximum daily air temperatures recorded in during 2013-14 were similar (e.g. Cooktown, Cape Flattery) or 0.4°C cooler (Lockhart R.) than 2012/13 and between 0.2 -0.4°C cooler than the decade average (Appendix 2, Figure 192, Figure 193, Figure 194). The highest recorded daily maximum air temperature in 2013-14 was 38.0°C at Cooktown, cooler than the 2012-13 maximum of 38.6°C, but the same as the decadal mean.

Mean annual monthly cloud cover in 2013-14 was higher than the previous period, but 16% lower than the decadal average. Mean monthly wind speeds in 2013-14 were 20.4 km.hr^{-1} in the north and 22.5 km.hr^{-1} in the south, which was 1% lower and 2% higher than the long-term average, in the north and south respectively. However, in 2013-14, there were 76 days in the north (cf. 59 days in 2012-13) and 112 days in the south (cf. 122 days in 2012-13) where winds were greater than 25 km.hr^{-1} (Appendix 2, Figure 195), which would have mobilised and resuspended sediments in shallow inshore waters for up to 30% of the year, reducing available light and destabilised the seabed.

The 2013-14 monitoring period was wetter than average with a total rainfall of 2069mm and 1745mm (north and south, respectively). This was 36% higher than the previous years rainfall, and 14% higher than the decadal mean annual rainfall. As a consequence, the discharge from the northern rivers of the Cape York region in 2013-14 was above the long-term median (Appendix 2, Table 41, Figure 214), which would have exposed inshore meadows to plumes of turbid, sediment laden waters.

3.3 Wet Tropics

3.3.1 2013-14 Summary

The Wet Tropics includes two World Heritage Areas, however increases in intensive agriculture, coastal development and declining water quality have been identified as significant across the region. Seagrass monitoring was conducted on coastal and nearshore reef habitats. A dominant influence on these habitats is disturbance from wave action, sediment movement, elevated temperatures as well as seasonal terrigenous runoff. Nutrient concentrations are also generally low in reef habitats due to the carbonate nature of the sediments.

Seagrass in the region remain in a vulnerable state, with weaker resistance and a lower capacity to recover from major disturbances. Although seagrass abundance and extent increased over the last 12 months at intertidal coast and reef habitats, they remained in a poor state. Similarly, subtidal meadows remaining in a poor state, however, they declined in both abundance and extent. The increased proportion of foundation/K-strategist species in the majority of meadows across the region suggests improved ecosystem resistance. Green Island seagrasses remain more abundant and diverse than other sites in the wet tropics, although slight declines in abundance over recent years may weaken their ability to tolerate major disturbances. Seed banks across the region remained unchanged and reproductive effort remained very poor, although slightly improved from the previous monitoring period. This indicates that meadows in the region may take longer to recover following disturbance and may be at risk from chronic impacts.

Analysis of seagrass leaf tissue suggests low but sufficient light for growth, which may be consequence of decreasing daily light or increasing epiphyte cover. Daily light was above the threshold required for positive growth in 2013-14, but has been progressively decreasing over the last couple of years. High available N was measured remaining across the meadows and higher chlorophyll-a concentrations were measured at subtidal meadows. δ^{15}N values in the leaf tissue were higher than previously measured, suggesting the primary source of N was influenced by anthropogenic N sources such as fertiliser.

Seagrasses in the south of the region experienced slightly warmer sea temperatures in 2013-14, while those in the north were cooler. No extreme temperatures (>40°C) which would result in high stress to plants were measured in 2013-14, but the hottest seawater temperature in 3 years occurred at Yule Point in November 2013 (39.6°C). Overall, seawater temperatures in 2013-14 were less stressful to intertidal seagrass, as the number of days above 35°C were a third lower than the previous monitoring period and below median annual daytime tidal exposure would limit heat and desiccation stress.

Climatic conditions in the region over the monitoring period were less conducive to seagrass growth than recent years. Although air temperatures were slightly cooler in the north of the region than the south, overall 2013-14 was a wetter, cloudier and windier than average year. The greater rainfall resulted in above median discharges from rivers, which would have exposed meadows to plumes of turbid sediment laden water, and high winds for much of the year would have mobilised inshore sediments resulting in some physical disturbance of the seabed and reduced light levels. Overall the status of seagrass condition in the Wet Tropics NRM region has remained unchanged and **poor** in 2013-14 (Table 19).

Table 19. *Report card for seagrass status (community & environment) for the Wet Tropics region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
estuarine intertidal	*not monitored*			
coastal intertidal	21	0	16	**13**
reef intertidal	28	10	40	**26**
subtidal	22	25	46	**31**
Wet Tropics	24	12	34	**23**

3.3.2 Background

The Wet Tropics region covers 22,000 km^2 and land use practices include primary production such as cane and banana farming, dairying, beef, cropping and tropical horticulture (Commonwealth of Australia 2013e). Approximately 6.5% of the maximum habitable area of seagrass mapped in the shallow waters (<15m) of the GBR occurs in the Wet Tropics NRM (McKenzie*, et al.* 2010c). The most extensive areas of seagrass in this region occur around Low Isles, Cairns Harbour, Green Island, Mourilyan Harbour and the Hinchinbrook Island area (between Dunk Island and Lucinda) (Coles*, et al.* 2007). Thirteen seagrass species have been recognised for this region (Lee Long*, et al.* 1993). Nearshore seagrass meadows are situated on sand and mud banks and mostly dominated by *Halodule uninervis* with some *Halophila* in the northern and southern areas. Intertidal meadows in Cairns Harbour and southern Hinchinbrook channel are dominated by *Zostera muelleri*. Shallow subtidal coastal meadows consist of *Halodule uninervis* and *Halophila* communities mostly along sheltered coasts and harbours (e.g. Cairns Harbour and Mourilyan Harbour). *Cymodocea* spp., *Thalassia* and a suite of *Halophila* species tend to dominate island habitats in the region (e.g. Dunk Island and northern Hinchinbrook Island). Only reef and coastal seagrass habitats are currently monitored.

Coastal seagrass habitats were monitored at Yule Point in the north and Lugger Bay in the south of the region. The seagrass meadows at Yule Point and Lugger Bay occur on shallow sand banks, protected by fringing reefs. Coastal seagrass 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 habitats are relatively unstable restricting seagrass growth and distribution. A dominant influence of these meadows is terrigenous runoff from seasonal rains (Appendix 2, Figure 130). The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these coastal meadows.

Reef seagrass habitats were monitored at Low Isles, Green Island and Dunk Island. Low Isles is located in the north of the region and the monitoring sites were paired intertidal and subtidal (not replicated) (Figure 46). Low Isles is an inshore reef located 15km south east of the Daintree River mouth. Low Isles refers to the two islets of Low Isles reef: Low Island (the cay) and Woody Island (predominantly *Rhizophora* forest). The intertidal site was located near the northern edge of the reef platform between Low Island and Woody Island. This area is dominated by *Halodule uninervis* and *Halophila ovalis*. The subtidal site was approximately 250 north of the intertidal site, in the eastern edge of the anchorage (Low Isles lagoon), and was dominated by *Halophila ovalis* and *Halodule uninervis.*

Green Island is a mid shelf reef located 26km north east of Cairns and the Barron River mouth, in approximately the centre of the Wet Tropics region (Figure 46). Monitoring at Green Island occurs on the large reef-platform and in the shallow lagoon to the south west and north west of the cay, respectively. The meadows are dominated by *Cymodocea rotundata* and *Thalassia hemprichii* with some *Halodule uninervis* and *Halophila ovalis*. The seagrass meadows at Green Island have been the focus of research since the 1980's and monitoring includes a legacy site (GI1).

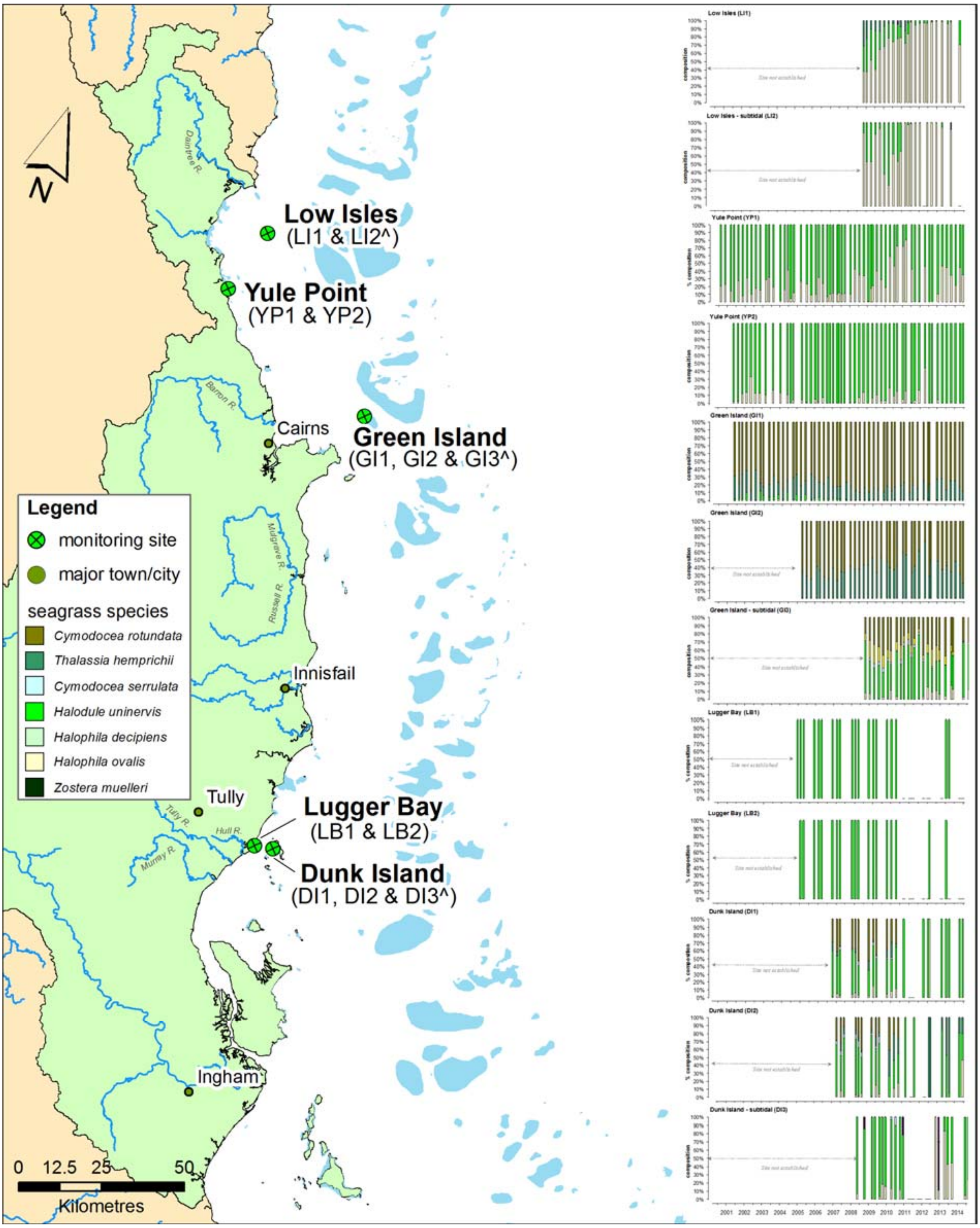

Figure 46. *Location of Wet Tropics region long-term monitoring sites and seagrass species composition at each site. Please note: replicate sites within 500m of each other; ^ denotes subtidal site.*

Dunk Island is an inshore continental island located in the southern section of the region (Figure 46). Intertidal monitoring sites are located on the sand spit between the main island and Kumboola Island. The subtidal site is located in the lee of the island, in front of the former Dunk Island resort.

Shallow unstable sediment, fluctuating temperature, and variable salinity in shallow regions characterise reef habitats. Physical disturbance from waves and swell and associated sediment movement primary forcing factors which control seagrass growing in these habitats (Appendix 2, Figure 131). 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 coral sand sediments. In these carbonate sediments the primary limiting nutrient for seagrass growth is generally phosphate (Short *et al.* 1990; Fourqurean *et al.* 1992a; Erftemeijer and Middelburg 1993). This is due to the sequestering of the phosphate by the calcium carbonate. 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 in the 1990's were shown to be nitrogen limited (Udy*, et al.* 1999).

3.3.3 Status of the seagrass community

Seagrass abundance and composition

The seagrass abundance score across the region was rated as poor in 2013-14 (Figure 47). Seagrass abundance at coastal habitats increased over the last 12 months, but remained in a poor state. Seagrass at reef habitats remained in a stable but also poor state. With the exception of Green Island, the greater proportion of colonising/pioneering species in the majority of meadows across the region may suggest weaker ecosystem resistance. Green Island seagrasses remain more abundant and diverse than other sites in the Wet Tropics, although slight declines in abundance over recent years may weaken their ability to tolerate major disturbances.

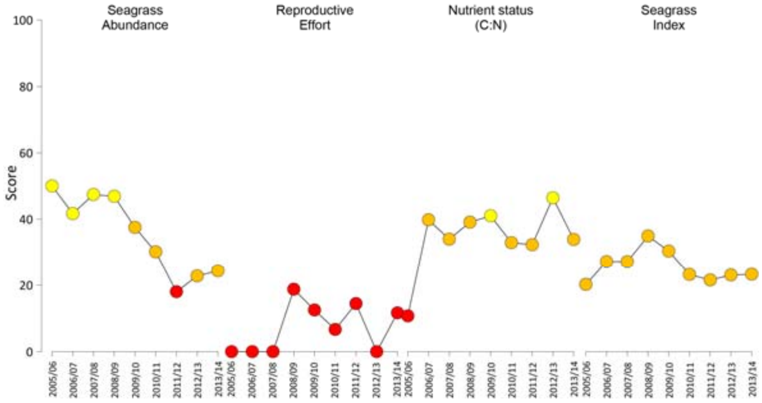

Figure 47. Report card of seagrass status indicators and index for the Wet Tropics NRM region *(averages across habitats and sites). Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

The long-term average seagrass cover at coastal habitats in the Wet Tropics NRM region varied greatly between seasons: 6.1 ±0.1% in the dry and 10.6 ±0.3% in the monsoon season. Seagrass abundance over the 2013-14 monitoring period increased at Yule Point, nearly doubling the 2012-13 abundances, but remained very poor at Lugger Bay (Figure 48). The seagrass meadows at Lugger Bay have fluctuated greatly since monitoring was established in late 2004, primarily from acute disturbances such as tropical cyclones. Seagrass cover declined in early 2010 and was completely lost in early 2011 following Tropical Cyclone Yasi. A few isolated shoots/plants established at Lugger Bay in late dry 2012, but they have failed to recolonise.

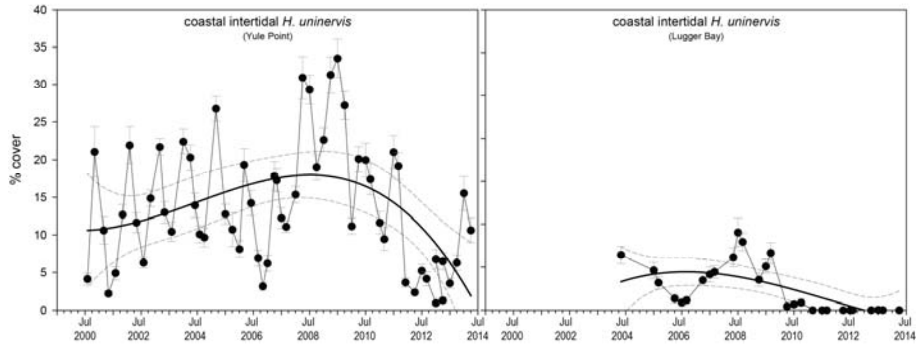

Figure 48. *Changes in seagrass abundance (% cover ±Standard Error) at inshore intertidal coastal habitats in the Wet Tropics region, 2000 - 2014. Trendline is 3rd order polynomial (95% confidence intervals displayed) where Yule Pt r^2 = 0.23 and Lugger Bay r^2 = 0.41).*

Reef intertidal seagrass abundances (% cover) were not only higher at Green Island than other locations over 2013-14, Green Island was the only location to increase (Figure 49). The decline in intertidal seagrass at Low Isles observed in early 2013, continued throughout 2013-14, while intertidal seagrass abundance changed little at Dunk Island (remaining <1%). The greatest change in seagrass abundance across the region in 2013-14 was in the subtidal habitats at all the reef locations, with marked declines coinciding with the wet season in early 2014 (Figure 49).

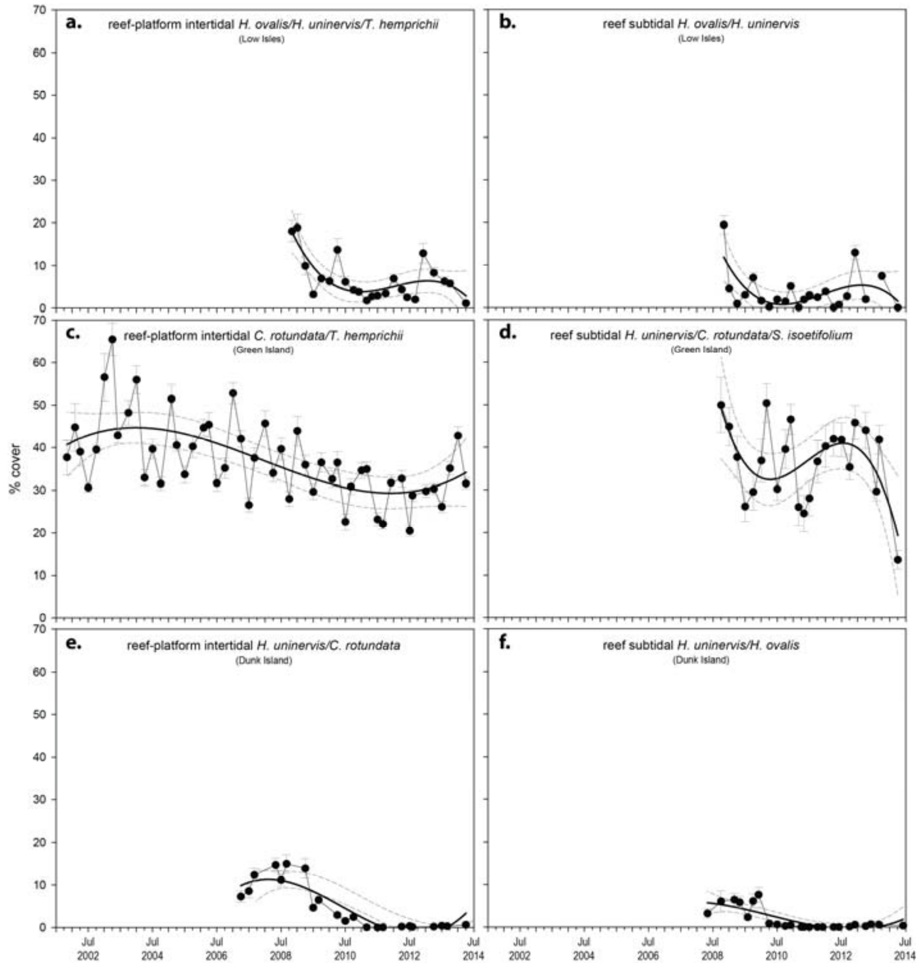

Figure 49. *Changes in seagrass abundance (% cover ±Standard Error) for inshore intertidal and subtidal reef habitats (left and right respectively) in the Wet Tropics region, 2001 - 2013: trendline is 3rd order polynomial (95% confidence intervals displayed), a-b) Low Isles, intertidal r^2 = 0.58 and subtidal r^2 = 0.38; c-d) Green Island, intertidal r^2 = 0.39 and subtidal r^2 = 0.36; and e-f) Dunk Island, intertidal r^2 = 0.81 and subtidal r^2 = 0.63. Subtidal sites not replicated.*

The seagrass at Yule Point and Lugger Bay were representative of coastal (inshore) seagrass communities in the region and were dominated by *Halodule uninervis* and *Halophila ovalis* (Figure 46). The proportion of foundation (K-strategist) species in the Yule Point meadows was above average for GBR coastal habitats during 2013-14 (Figure 50), which suggests the meadows were recovering with improved ecosystem resistance, particularly with increasing abundance.

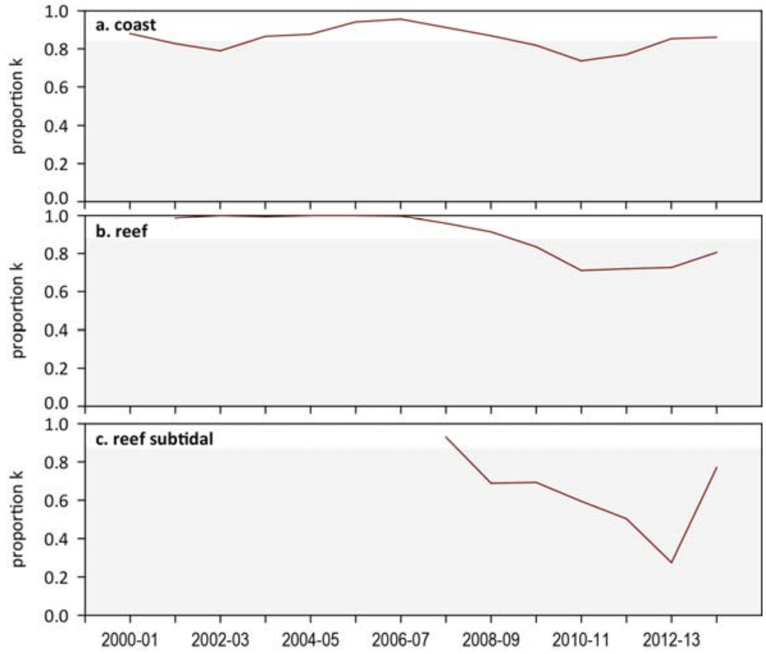

Figure 50. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Wet Tropics region, 2001 - 2014. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

The seagrass meadows at Low Isles, Green Island and Dunk Island are typical of reef seagrass communities in the region and were dominated by *Cymodocea rotundata*, *C. serrulata* Thalassia *hemprichii* and *Halodule uninervis* (Figure 46). However, between 2009 and 2012, with the exception of Green Island, both intertidal and subtidal meadows were composed of a greater than average proportion of *r*-strategist species (Figure 50). This suggested the meadows had experienced perturbations in recent years. Over the 2013-14 monitoring period, the proportion of K-strategist species increased, suggesting improved ecosystem resistance, however, the poorer abundances in early 2014 may compromise resilience.

Seagrass meadow edge mapping was conducted within a 100m radius of all intertidal monitoring sites in October/November and March/April of each year to determine if changes in site abundance were a consequence of the meadow edges changing (Appendix 2, Table 36). The meadows within 100m of coastal monitoring sites have fluctuated within and between years (Figure 51), primarily due to losses and subsequent recolonisation, but are gradually improving. Intertidal meadows on reef habitats similarly continued to improve (greater extent) over the last 3 years, however, subtidal meadows have declined in extent over the past 18 months (Figure 51; Appendix 2, Table 36)

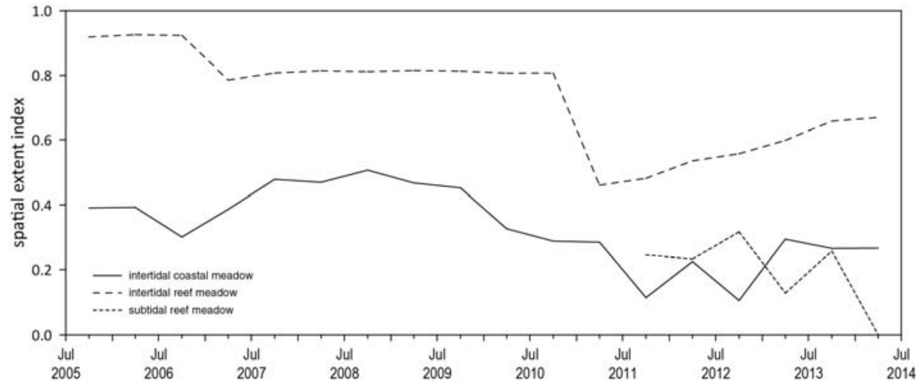

Figure 51. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Wet Tropics region.*

Annual monitoring for Ports North reported unprecedented declines in biomass and distribution of estuarine meadows in the Ports of Cairns and Mourilyan Harbours since 2009 (Jarvis *et al.* 2014; York *et al.* 2014). However, recovery in the estuarine port habitats has been slower than observed in most coastal and reef habitats monitored across the region as part of the MMP. An assessment of 6 meadows (predominately aggregated patches) in Cairns Harbour and Trinity Inlet between October and December 2013, reported only 1 meadow had markedly increased in the abundance (visual estimate of biomass) and extent, while recovery in the others was minor, if any (Jarvis*, et al.* 2014). The authors suggest the presence of a seed bank (albeit reduced) may facilitate further recovery, however, in combination with the overall poor condition of seagrass in 2013, they conclude the seagrasses are likely to be highly vulnerable to further impacts (Jarvis*, et al.* 2014).

Similarly, an assessment of 5 seagrass meadows in Mourilyan Harbour in October-November 2013 reported seagrass in a poor state with 2 of the monitoring meadows absent and a further 2 with biomass (visual estimate of biomass) and area (extent) well below the historical long term average (York*, et al.* 2014). All meadows in the harbour were composed of *Halophila* species, as the foundation species (*Zostera muelleri*) was absent for the fourth consecutive year. The authors attributed the lack of recovery, despite improved growing conditions in 2012-13, was likely due to a lack of seagrass propagules (York*, et al.* 2014).

Seagrass reproductive status

Seed banks and reproductive effort across the region remained unchanged over the monitoring period (Figure 52). A *Halodule uninervis* seed bank persists at Yule Point, however, it has substantially reduced since October 2010. The very small *Halodule uninervis* seed bank which was present at both Dunk Island and Lugger Bay in 2012-13, has since been depleted. Reproductive effort also remained very poor across the region, indicating meadows will take longer to recover following disturbance and may be at risk from repeated impacts.

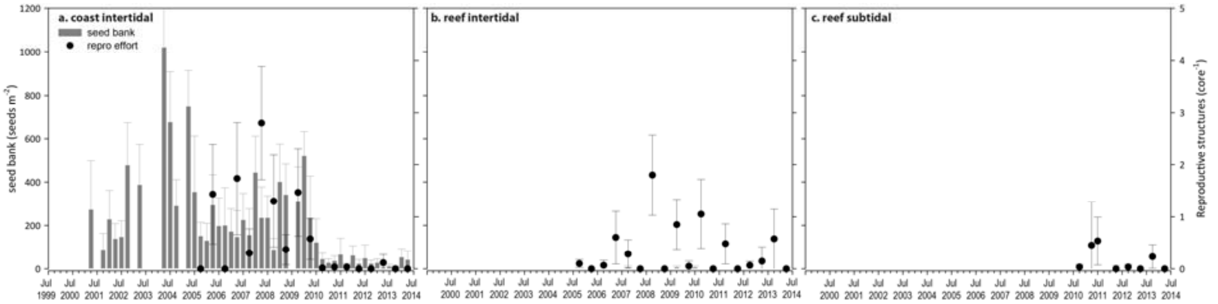

Figure 52. *Seed bank and late dry season reproductive effort for inshore intertidal coast and reef habitats in the Wet Tropics region, 2001 - 2014.Seed banks presented as the total number of seeds per m^2 sediment surface, and reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

An examination of the long term trends across the Wet Tropics NRM region (all habitats pooled) suggests seagrass abundance (% cover) has improved little since declining in 2009 (Figure 53a), and that reproductive effort has continued to declines (Figure 53b). The long-term trend indicates seeds banks have persisted, but remain low (Figure 53c).

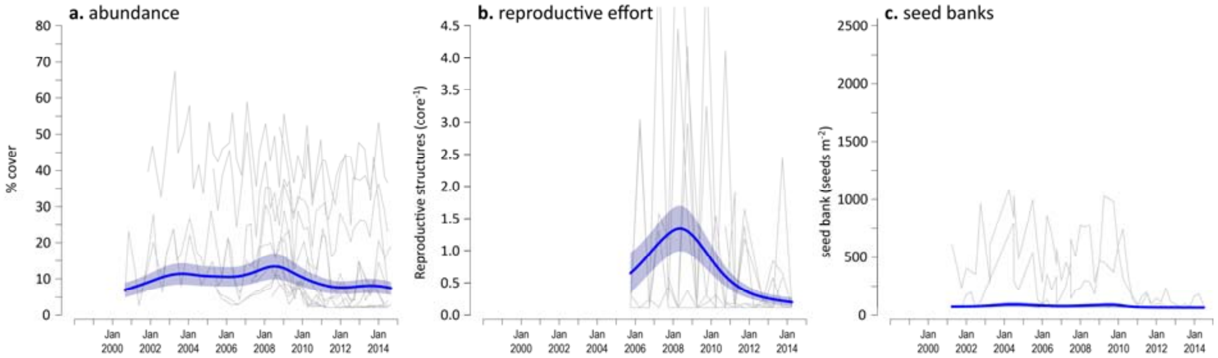

Figure 53. *Seagrass abundance, reproductive effort and seed bank trends in the Wet Tropics region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

3.3.4 Status of the seagrass environment

Seagrass tissue nutrients

In 2013, C:N ratios in the leaves of the foundation seagrass species were below 20 across all habitats and locations (Figure 54; Appendix 2, Figure 143). Seagrasses in reef habitats (intertidal and subtidal) had higher leaf molar C:N ratios than those in coastal habitats (Figure 54), which has remained consistent across all years of monitoring. C:N ratios have remained relatively unchanged across all intertidal seagrass habitats over the last 2-3 years (Figure 54; Appendix 2, Figure 143a, Figure 143b). Following the sharp increased at Green Island in 2012, C:N ratios declined below 20 for the first time in 2013-14, since monitoring commenced in 2008 (Appendix 2, Figure 143c).

δ^{13}C values for foundation species at all habitats during the late dry (growing) season were mostly below (isotopically lighter) the global average, but within global ranges (Appendix 2, Table 37), suggesting low but sufficient carbon available for growth. The only species which may indicate some light limitation was possibly *Thalassia hemprichii* in the intertidal reef habitat of Green Island, as δ^{13}C concentrations have become progressively isotopically lighter: below the global average (Appendix 2, Table 37). This, however, may be a consequence of slightly higher epiphyte cover and lower leaf turnover of *T. hemprichii* (McKenzie, unpublished data).

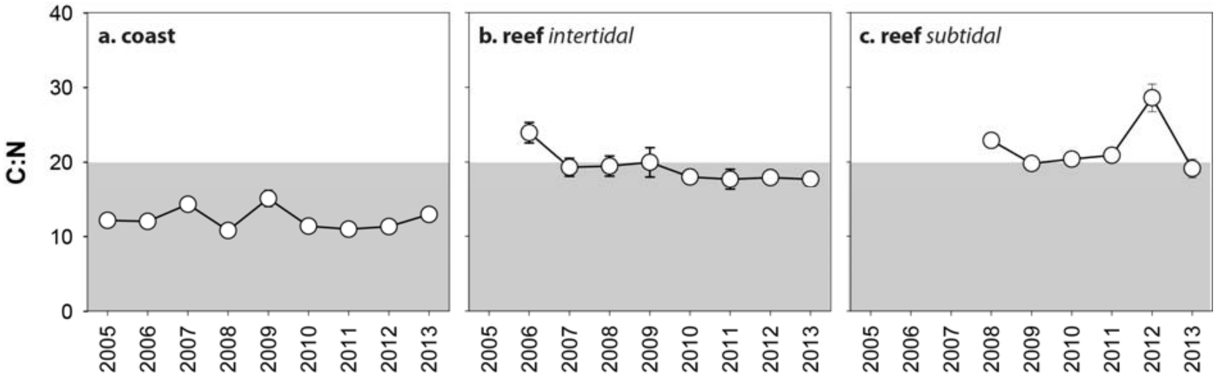

Figure 54. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore intertidal habitat in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line indicate reduced light availability and/or N enrichment.*

Seagrass leaf molar C:P ratios in 2013 were <500 for intertidal reef and coastal habitats, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 54; Appendix 2, Figure 144, Figure 145). Subtidal reef habitats had C:P ratios >500, however, due to the lack of data, no comparison is possible over time (Appendix 2, Figure 146). N:P ratios for the foundation species across all habitats were between 25-30, indicating the plants were replete (well supplied and balanced macronutrients for growth) with high N (Figure 55).

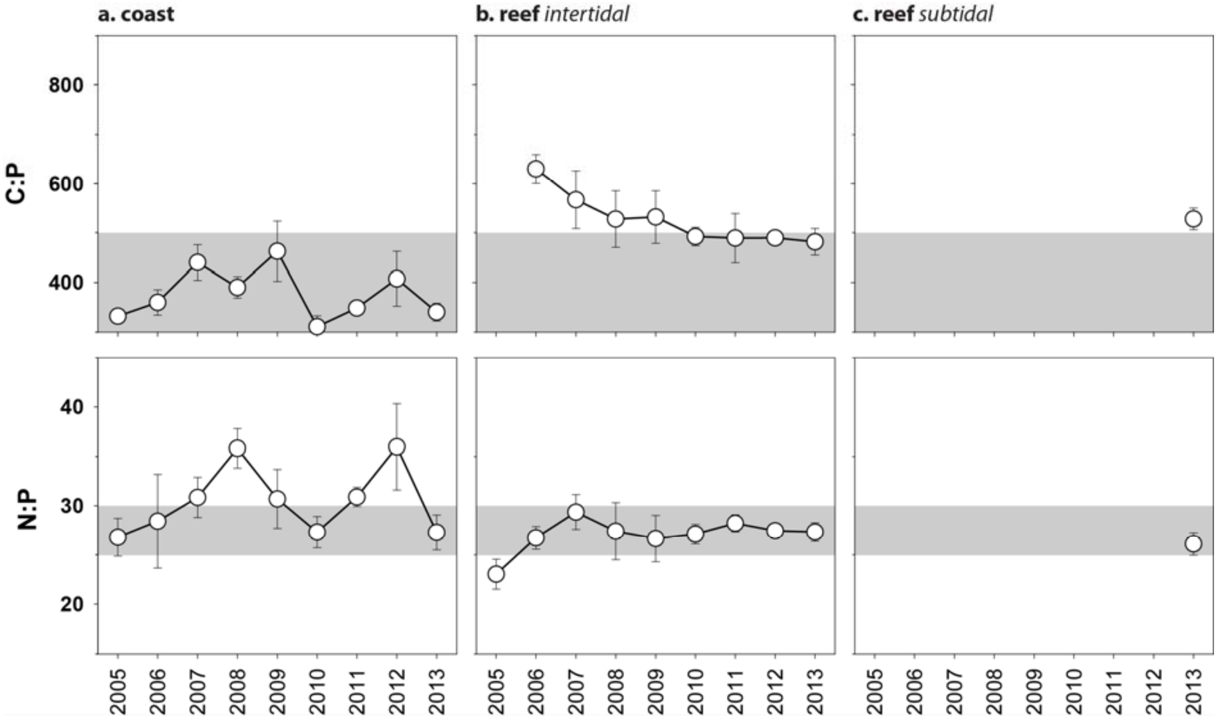

Figure 55. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore intertidal habitat in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

The $\delta^{15}N$ values in the leaf tissue of all foundation seagrass species across reef habitats (intertidal and subtidal) were higher in 2013-14 than previous measured in the MMP, suggesting that their primary source of N was influenced by anthropogenic N sources such as fertiliser (Appendix 2, Table 37). From the analysis of the leaf tissue of the foundation seagrass species, it appears that although available N is high, the lower C:N ratios in 2013-14 were most likely a consequence of reducing light availability.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades was generally higher in the wet season across all habitats in the Tropics NRM region (Figure 56). Epiphyte abundance varied across habitats and locations, but was much higher in the more extensive/continuous meadows at Green Island and Yule Point (Appendix 2, Figure 151, Figure 152,Figure 153). Epiphyte abundances at Green Is and Yule Pt in 2013-14 were not only above the GBR long-term average for reef and coastal habitats, respectively, they were also the highest abundances since monitoring commenced (Appendix 2, Figure 151, Figure 152). With the exception of the subtidal habitats, percentage cover of macroalgae remained stable between years across both coastal and reef intertidal habitats, either below or at the GBR average (Figure 56; Appendix 2, Figure 151,Figure 152). Macroalgae abundances increased above the GBR average at the subtidal habitats of Low Isles and Green Is over the 2013-14 period (Figure 56; Appendix 2, Figure 153).

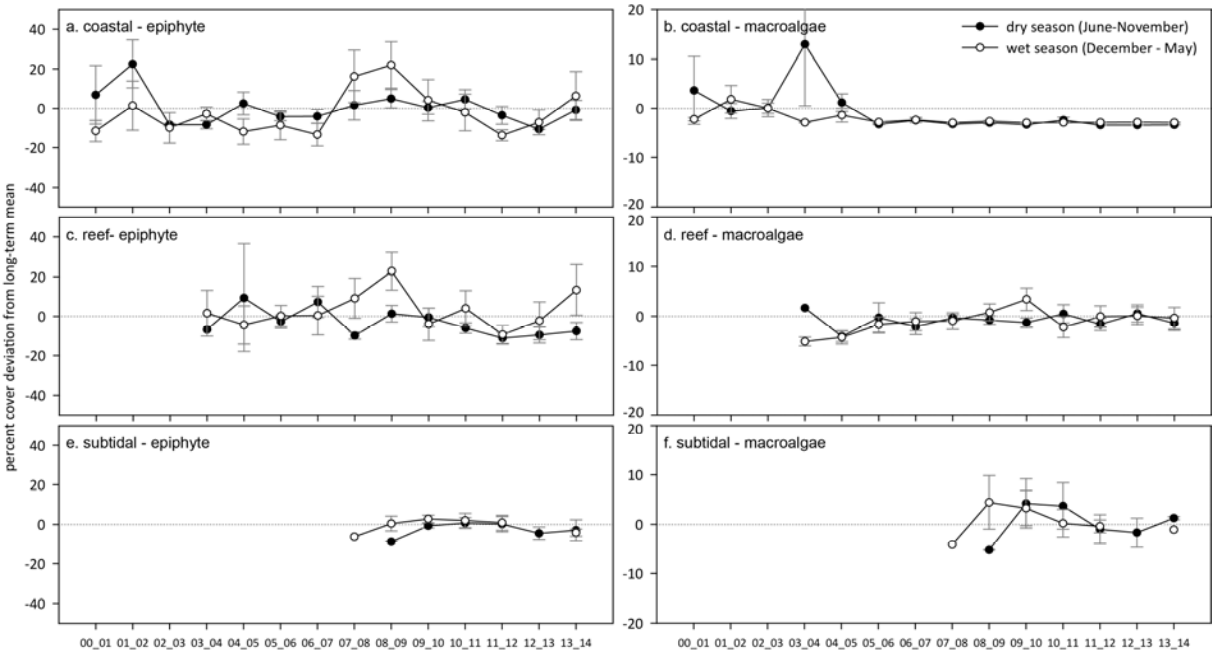

Figure 56. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore seagrass habitat in the Wet Tropics region, 2001 - 2013 (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated greatly between and within years, however, the long-term trend demonstrates an increase from 2007 to 2009 (Figure 57) (a period when seagrass cover was in a moderate to good state), followed by a decrease until mid 2012, after which it has been gradually increasing; possibly in association with the higher available N. Macroalgae cover has been less variable over the long-term, decreasing since monitoring was established to persist in a low and stable state (Figure 57).

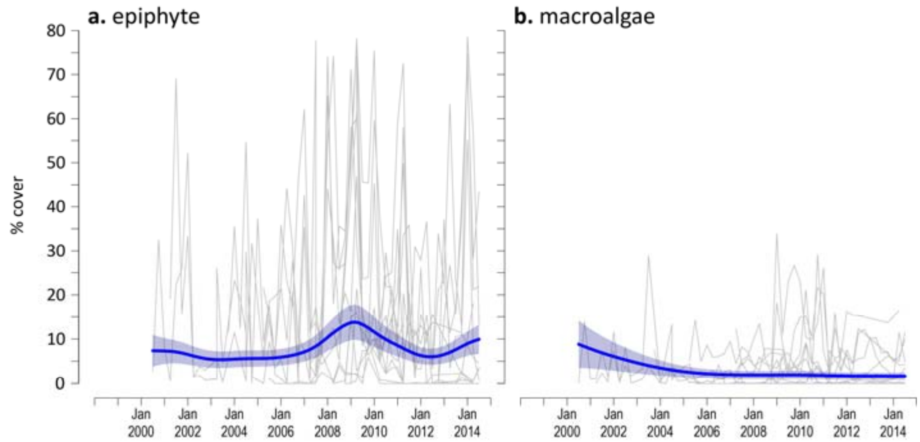

Figure 57. *Epiphyte and macroalgae cover trends in the Wet Tropics region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Wet Tropics reef habitats during daylight over the 2013-14 monitoring period were mostly below long-term medians (Appendix 2, Table 39). Intertidal meadows on the reef flat at Low Isles had the greatest number of hours exposed (167hrs) of all reef meadows monitored during the 2013-14 period, however, this was the fifth consecutive year the total hours exposed was below the long-term annual median (178.5hrs) (Appendix 2, Figure 165). This was followed by Green Island, where the hours exposed during daylight (105hrs and 135hrs for GI1 and GI2 respectively) in 2013-14 was the sixth consecutive year the total hours exposed was below the long-term annual median (113hrs and 151hrs for GI1 and GI2 respectively) (Appendix 2, Figure 165). The least exposed reef meadows were those in the south of the region at Dunk Island. At the shallower site (DI1) the meadows exposed for only 73hrs in 2013-14; which was the second consecutive year exposure was below the long term median (75hrs). At the deeper Dunk Island site (DI2), although the meadows only exposed for 45hrs in 2013-14, it was above the long-term median (44hrs) for the second consecutive year (Appendix 2, Figure 165).

The annual exposure of intertidal seagrass meadows at Wet Tropics coastal habitats during daylight over the 2013-14 monitoring period were all below long-term medians (Appendix 2, Table 39). The shallowest meadows (highest level of exposure) were in the north of the region at Yule Point, where 2013-14 was the fifth consecutive year the amount of daytime exposure (164hrs at YP1 and 97hrs at YP2) was below the long-term annual median (170hrs and 97hrs for YP1 and YP2, respectively) (Appendix 2,Figure 166). The lower levels of daytime exposure for intertidal seagrass meadows in all habitats across the region would have provided a more conducive environmental conditions for seagrass growth in 2013-14.

Within canopy temperature

Temperature loggers were deployed within the seagrass canopy throughout the monitoring period at all intertidal and subtidal locations monitored in the region (Appendix 2, Figure 173, Figure 174). Annual average within canopy sea temperatures were slightly cooler in the north and warmer in the south of the region over 2013-14 than the previous 2012-13 monitoring period. Seagrass meadows in the region experienced up to 37 days of seawater temperatures above 35°C, which was also less than the previous period (cf. 54 days) (Figure 58). This may have resulted in increased growth rates and higher C demand, where periods of light limitation may have resulted in plant stress. Water temperature at subtidal sites was less variable (Appendix 2, Figure 174), with no extremes compared to intertidal sites as the deeper water column (2 - 4m) is well mixed and isn't as readily affected by air temperature and heat transfer. No extreme temperatures (>40°C) were measured in 2013-14, but the hottest sea temperature in 3 years occurred at Yule Point on 30 November 2013 (39.6°C). Although the warmest month across the region was January 2014, the month with the greatest temperature stress to seagrasses would have been in December 2013 when there were 9 days above 35°C (Figure 58). Overall, 2013-14 was an on average year for seawater temperatures, relative to the long-term (10year).

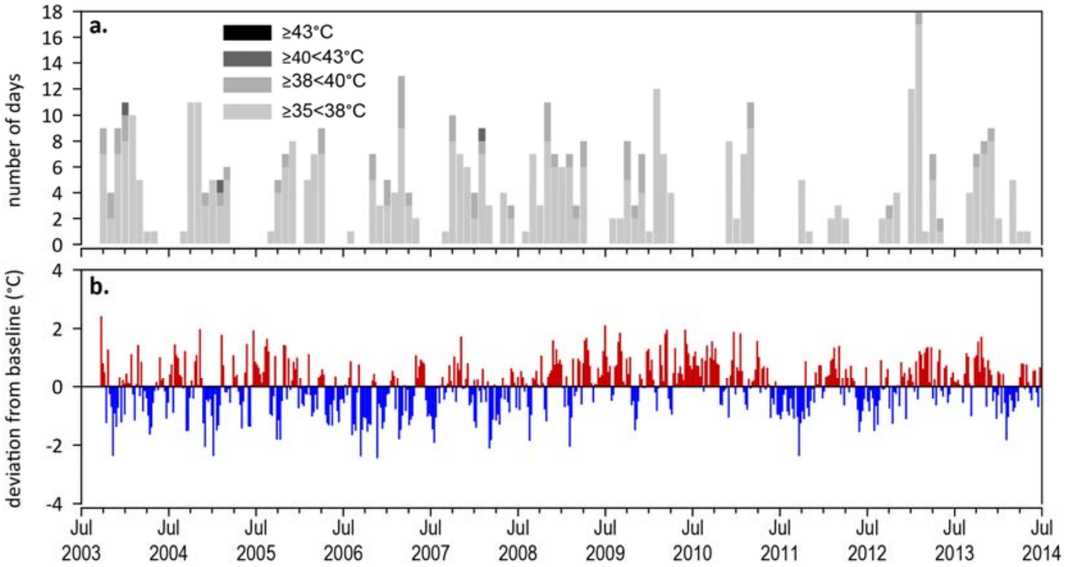

Figure 58. *Inshore sea temperature monitoring for intertidal habitats in the Wet Tropics region, September 2003 to June 2014: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

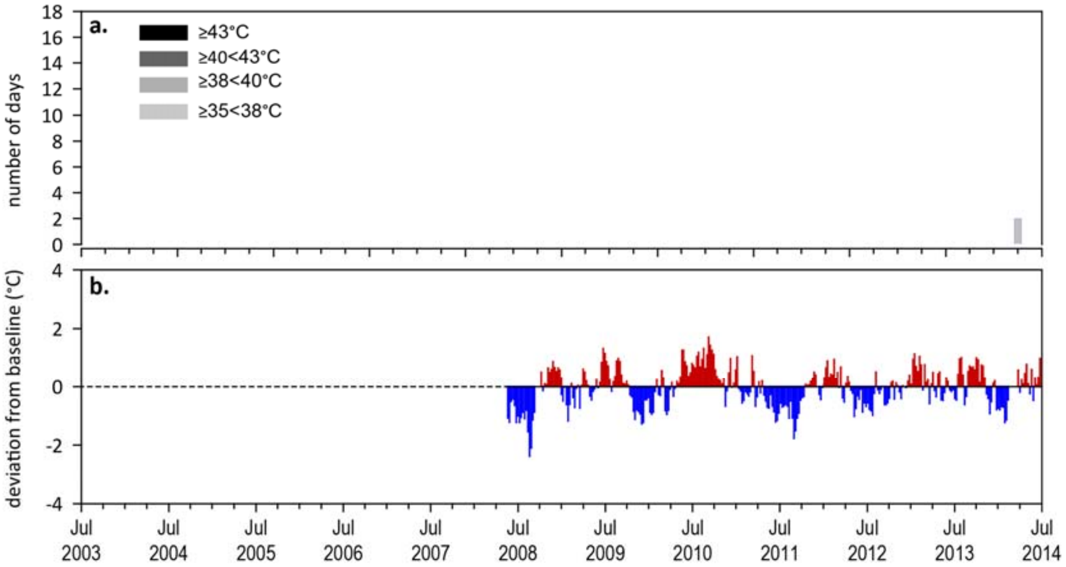

Figure 59. *Inshore sea temperature monitoring for subtidal habitats in the Wet Tropics region, May 2008 to June 2014: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

Canopy incident light

Daily light levels in the Wet Tropics follow a seasonal pattern in which light peaked during the late dry season (typically September to December), and then declined sharply during the onset of the wet season (around January to February), and remained low during the wet season, and into winter. This period of low light coincides with the "senescent season" for seagrasses of the GBR. In 2013-14, the peak light levels were reached early (September), and quickly dropped, remaining low throughout the reporting year. On average, daily light levels were equal to the long-term average (16.3 mol m^{-2} d^{-1}) for intertidal sites, and were lower than average at subtidal sites (6.3 mol m^{-2} d^{-1} for 2013-14 compared to 7.5 mol m^{-2} d^{-1}). Intertidal sites have consistently high light levels (Appendix 2, Figure 181, Figure 182, Figure 183, Figure 184) and amongst subtidal sites, Green Island has the highest light levels (Figure 28), despite being lower than average. Chlorophyll concentration was also high at the Green Island subtidal site (GI3) throughout 2013-14 (Appendix 2, Figure 185), and inshore wet season water quality data also indicated "green" water in the Wet Tropics in 2013-14 (Devlin et al, In prep). Daily light data for each location within the Wet Tropics are presented in the Appendix 2 (Figure 181, Figure 182, Figure 183, Figure 184).

Figure 60. *Standardised daily light (28 day rolling average) for seagrass habitats in the Wet Tropics region, 2008 - 2014 (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

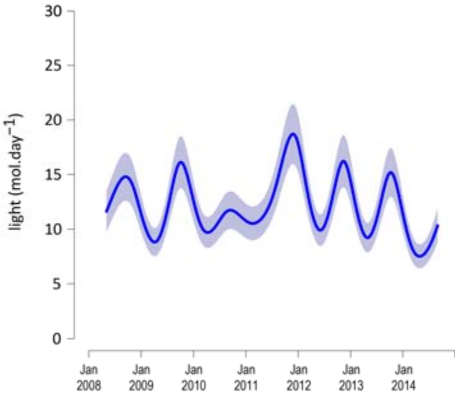

Figure 61. *Seagrass canopy light trend in the Wet Tropics region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

Incoming irradiance reaching the seagrass leaf is a strong driver of changes in seagrass abundance, meadow distribution and the colonization depth of meadows (Collier et al 2011, Abal and Dennison, 1996), because reductions in light reduce photosynthetic rates and the energetic surplus of the seagrass plants. At the subtidal GBR monitoring sites, daily light levels, frequency of exceedance of low light thresholds and the hours of light saturating irradiance were strong explanatory variables in the loss of seagrass during flood-related seagrass loss events (2008-2011) (Collier et al 2011). However, during the recovery period (2011-2014), light levels have been a poor predictor of changes in seagrass abundance. This is due mostly to the poor relationship between light and changes in abundance during the recovery phase when other factors, such as recruitment processes, determine changing abundance. Recruitment processes include recolonisation from existing or new propagules or seeds, changes in species composition and meadow expansion. The exception to this is at Green Island sites (Table 20). The meadows at Green Island did not decline in abundance in 2008-2011 when most other meadows did, nor has it undergone a period of recovery. Under these relatively stable conditions, there is a statistically significant relationship between changes in abundance and light at both the subtidal (GI3, *p*=0.019) and intertidal (GI2, *p*=0.002) sites. As data availability increases we may me able to model the relationship at the other intertidal site GI1, where the *p*-value was 0.06, with more confidence. The Green Island sites did not show the same significant level of prediction for changes in seagrass abundance and threshold exceedance (Table 20). This is likely due to the infrequent exceedance of thresholds at these sites. At other sites where thresholds are more frequently exceeded, there was also a poor relationship between the frequency that thresholds were exceeded and changes in abundance, presumably because of the recruitment dynamics as described above.

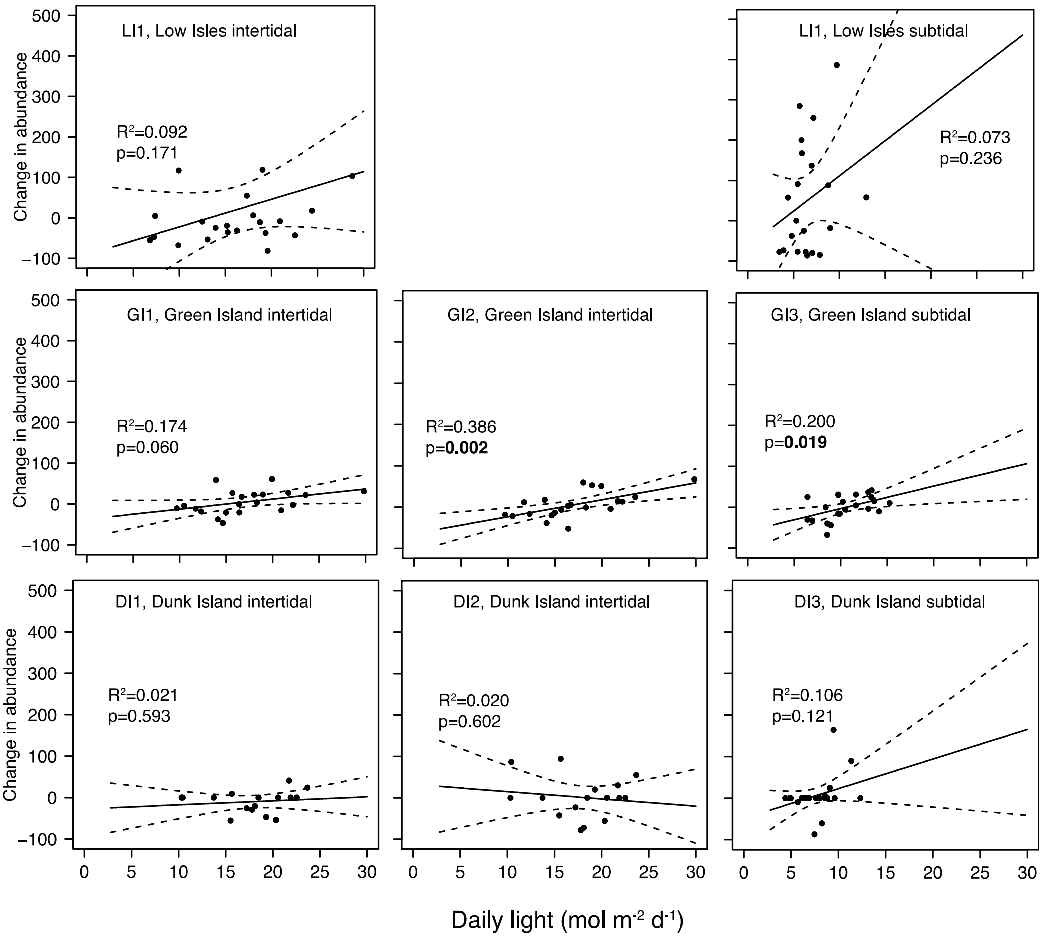

Figure 62. *Daily light and changes in abundance (mean percent cover) at Wet Tropics sites from 2008-2014. Mean daily light (mol m^{-2} d^{-1}) was calculated for the same period over which changes in abundance were calculated, typically 3 months. Sites with data starting in 2009 or 2010 have not been included in this analysis.*

Table 20. *Summary statistics for regression analysis of mean daily light (mol m^{-2} d^{-1}) and changes in abundance at Wet Tropics sites.*

WT site	**Intercept**	**Light** (slope)	**Std Err**	R^2	***p***
LI1	-90.611	6.830	4.807	0.092	0.171
LI2	-63.85	17.49	14.28	0.073	0.236
GI1	-37.339	2.472	1.237	0.174	0.060
GI2	-64.210	4.095	1.185	0.386	0.002
GI3	-58.386	5.493	2.153	0.200	0.019
DI1	-27.327	0.972	1.775	0.021	0.593
DI2	32.462	-1.758	3.293	0.020	0.602
DI3	-48.469	7.131	4.422	0.106	0.121
Threshold exceedance (% days below 5 mol m^{-2} d^{-1})					
LI1	34.475	-2.015	2.387	0.034	0.409
LI2	141.177	-2.793	1.401	0.173	0.060
GI1	11.230	-1.267	1.030	0.074	0.234
GI2	12.685	-1.354	1.148	0.068	0.148
GI3	9.713	-0.744	0.483	0.101	0.138
DI1	-10.801	0.150	1.342	0.001	0.913
DI2	-8.726	1.565	2.454	0.028	0.534
DI3	38.49	-1.08	0.56	0.145	0.067

Regional climate and river discharge

Although air temperatures were slightly cooler in the north of the region than the south, overall 2013-14 was a wetter, cloudier and windier than average year.

The mean maximum daily air temperatures recorded across the region were cooler in 2013-14 than the previous decade. In the north of the region (Low Isles, Yule Pt and Green Is.) temperatures were also cooler than the previous monitoring period, whereas in the south (Dunk Is. and Lugger Bay)they were warmer (Appendix 2, Figure 196, Figure 197, Figure 198). The highest recorded daily maximum air temperature in 2013-14 was 37.2°C at Low Isles in January 2014. Cloud in the north of the region was lower than the south for much of the 2013-14 monitoring period. Although lower in north, it remained above the decadal and long-term averages (Appendix 2, Figure 196, Figure 197, Figure 198). Conversely, in the south, although higher than the previous monitoring period, cloud cover in 2013-14 was slightly below (<5%) the decadal average. Average wind speeds were stronger across the region in 2013-14 than previous monitoring period, as well as the decadal and long-term averages. This resulted in nearly half the year experiencing winds >25 km hr^{-1}; the highest in over a decade at Low Isles (Appendix 2, Figure 199). The greater number of windier days would have mobilised and resuspended inshore sediments, resulting in reduced light availability from the elevated turbidity, and destabilising plants or preventing establishment of seedlings.

During 2013-14 it was wetter than average period relative to both the 2012-13 and long-term averages. Compared to the previous period, the north experienced 43% more rainfall, while the south had only 2% more (Appendix 2, Figure 196, Figure 197, Figure 198).

Several major rivers discharge into the coastal waters of the Wet Tropics and during floods their plumes extend to locations where seagrass monitoring sites occur. Discharged waters from Wet Tropics rivers travel predominately north (Furnas 2003). During flood events, intertidal and inner reefs can be inundated by waters laden in nitrogen and phosphorus species for periods of days to several weeks in the monsoon (Devlin *et al.* 2001). The higher rainfall in the north of the region resulted in Daintree River discharges 2-3 times the long-term median (Table 41). Similarly, above median discharges were reported from most of the major rivers in the southern Wet Tropics in 2013-14 (Appendix 2, Table 41, Figure 215). These above median discharges would have resulted in plumes of sediment and herbicide laden water which would have increased stressors, making conditions less favourable for seagrass growth.

3.4 Burdekin

3.4.1 2013-14 Summary

Inshore seagrass meadows in the Burdekin region are primarily structured by wind induced turbidity (resuspension) in the short term and by episodic riverine delivery of nutrients and sediment in the medium time scale. Disturbance from wave action, sediment movement and elevated temperatures are also dominant influences. Nutrient loadings in reef habitats are generally low: primarily nitrogen limited with secondary phosphate limitation. Rainfall in the region is lower than other regions within tropical Queensland.

Seagrass meadows in the Burdekin NRM region continued to increase in abundance over 2013-14, similar to the previous monitoring period at all habitats. These were the highest abundances recorded in the last five years, with the greatest improvement in subtidal meadows. Similarly, annual QPSMP) showed that there was substantial recovery in meadow area and biomass in October 2013, however, seagrass condition remained below the 2007 baseline (Davies *et al.* 2014).

Seed bank density and reproductive effort were increased at reef subtidal sites, which indicates a high capacity to recover following disturbance. In contrast at reef intertidal sites, the seed bank and reproductive effort remains low indicating a lower capacity to recover following disturbance in the immediate future. At coastal sites, the seed bank and reproductive effort remains small, but is increasing. In particular, the seed bank remains an order of magnitude lower than historical densities, suggesting an improved but none-the-less concerning capacity to recover, as meadows may be at risk if there is another sizeable impact.

The C:N ratio of seagrass leaves continued to increase in 2013-14. This indicates that photosynthetic C incorporation had increased relative to the uptake of nitrogen. Considering that light availability was not particularly high over the past year (see below), the increase in C:N ratio suggests, instead, a reduction in N availability and uptake consistent with lower riverine discharge over the past year. Stable isotope ($\delta^{15}N$) values in the leaf tissue indicates the primary source of the high N was anthropogenically influenced. Epiphyte cover on seagrass blades continued to increase in 2013-14 across habitats, further supporting the indication of high available N in the inshore areas of the region.

Although 2013-14 was a drier year, and below median discharges from the major rivers were experienced, it was also one of the windiest monitoring periods. The number of days with winds strong enough to resuspend benthic sediments were the highest in 7 years. This would have created periods of both physical disturbance and light limitation for the inshore seagrasses. This may explain the below average daily light experienced at coastal and subtidal meadows during 2013-14. Seagrasses across the region experienced average or slightly warmer sea temperatures in 2013-14 than previous; however, no extreme temperatures (>40°C). Furthermore, below median annual daytime tidal exposure would have limited heat and desiccation stress. Burdekin regional seagrass state continued to improve from poor in 2012-13 to **good** in 2013-14 (Table 21).

Table 21. *Report card for seagrass status (community & environment) in the Burdekin region: June 2013 – May 2014. Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
estuarine intertidal	*not monitored*			
coastal intertidal	44	19	39	**34**
reef intertidal	50	63	69	**60**
reef subtidal	75	100	100	**92**
Burdekin	51	60	69	**60**

3.4.2 Background

The Burdekin region, includes an aggregation of the Burdekin, Don, Haughton and Ross River catchments and several smaller coastal catchments, all of which empty into the Great Barrier Reef lagoon (Commonwealth of Australia 2013a). Rainfall is lower than other regions within tropical Queensland with an annual average of approximately 1,150 mm from on average 91 rain days. There is, however, considerable year-to-year variation 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).

Approximately 18% of the maximum habitable area of seagrass mapped in the shallow waters (<15m) of the GBR occurs in the Burdekin NRM region (Table 11, McKenzie*, et al.* 2010c). Intertidal seagrasses and shallow subtidal seagrasses dominate in this region, the majority of which are within coastal habitats (Coles*, et al.* 2007). Extensive seagrass meadows occur in Upstart, Cleveland, and Bowling Green Bays and off Magnetic Island. Twelve species have been found within this region (Lee Long*, et al.* 1993, Lee Long *et al.* 1996a). Deep water (>15m) seagrasses occur in this region but are not as common or dense as occurs in regions further north (Coles*, et al.* 2009a). Most fringing reefs associated with continental islands support moderately dense mixed species meadows (especially *Cymodocea serrulata*), which are not restricted to the confines of fringing reefs, but are also found in sheltered bays at continental islands or coastal localities (Coles*, et al.* 2007).

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 (Scheltinga and Heydon 2005; Haynes *et al.* 2001). All four generalised seagrass habitats are present within the Burdekin region, and MMP monitoring occurs at coastal and reef seagrass habitat locations.

The coastal monitoring sites are located on naturally dynamic shallow sand banks and are subject to sand waves and erosion blowouts moving through the meadows. The Townsville (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 Bowling Green Bay (Jerona) location is adjacent to the mouth of Barratta Creek. 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 (Appendix 2, Figure 132). 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. Another significant feature in this region is the influence of ground water (Stieglitz 2005). The meadows are also frequented by dugongs and turtles as witnessed by abundant grazing trails and patches of cropping .

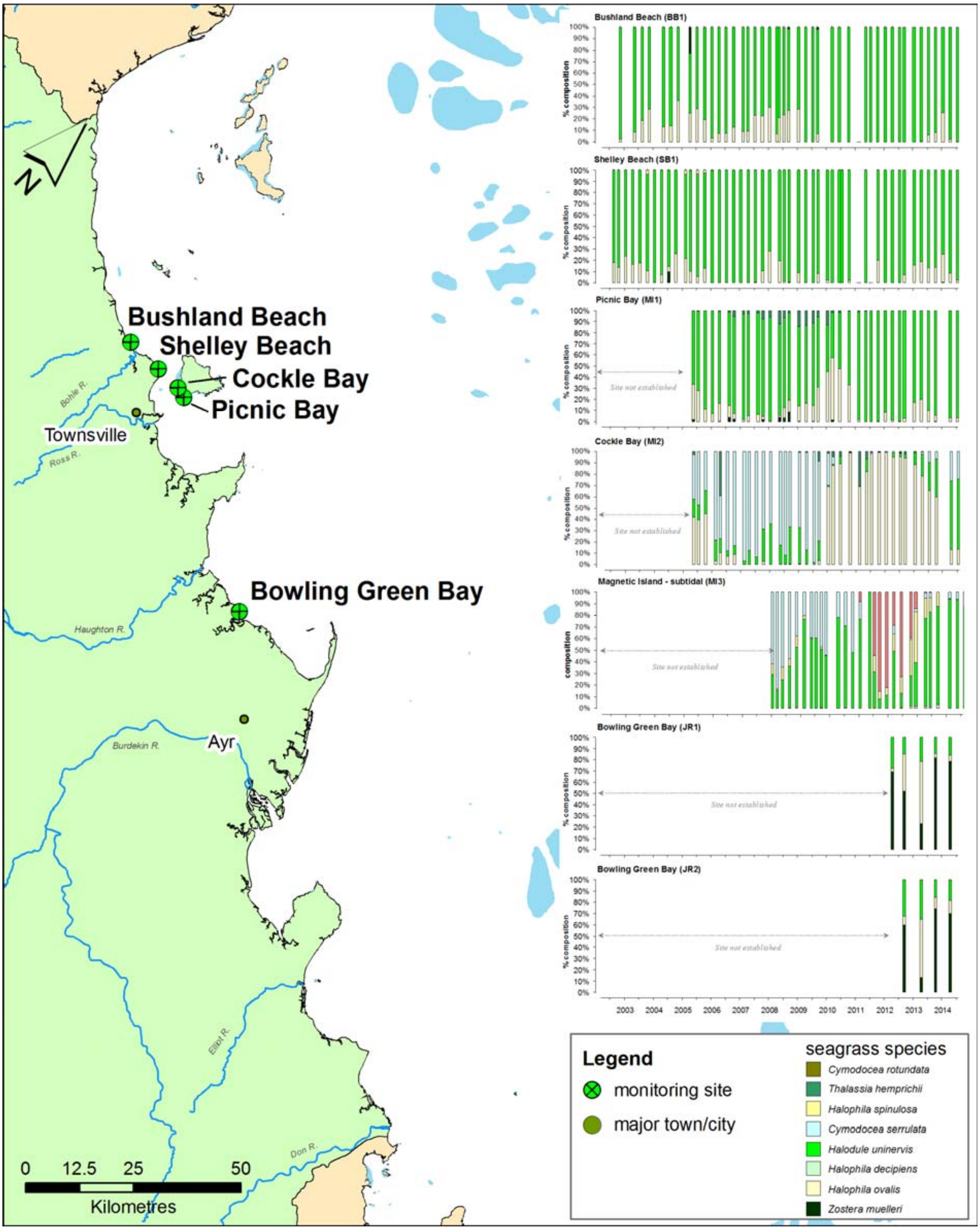

Figure 63. *Location of Burdekin region long-term monitoring sites in coastal (Bushland Beach, Shelley Beach and Bowling Green Bay) and reef (Picnic Bay and Cockle Bay, Magnetic Island) habitats, and the seagrass species composition at each site each monitoring event. Please note: replicate sites within 500m of each other.*

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 shallow banks. Nutrient supply to these meadows is by terrestrial inputs via riverine discharge, re-suspension of sediments and groundwater supply (Appendix 2, Figure 133). The meadows are typically composed of zones of seagrasses: *Cymodocea serrulata, Thalassia hemprichii* and *Halodule uninervis* (wide leaf) often occupy the lower littoral/subtidal area, blending with *Halodule uninervis* (narrow leaved) and *Halophila ovalis* in the upper intertidal zone. Phosphate is often the nutrient most limiting to reefal seagrasses (Short*, et al.* 1990;Fourqurean*, et al.* 1992b). 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.

3.4.3 Status of the seagrass community

Seagrass abundance and composition

Seagrass abundance (% cover) continued to improve over the past 12 months and has near recovered to pre-2011 levels. The overall status for seagrass abundance has also improved from poor in 2012-13 to **good** in 2013-14 (Figure 64).

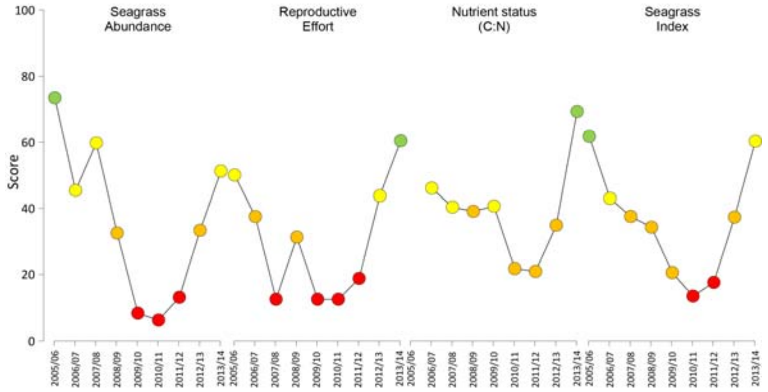

Figure 64. *Report card of seagrass status indicators and index for the Burdekin NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Seagrass meadows in the Burdekin NRM region continued to experience increases in abundance over the 2013-14 period, similar to the previous monitoring period, at coastal, reef and subtidal habitats (Figure 65). These increases resulted in the highest abundances in the last five years.

Since monitoring was established, coastal meadows in the region have displayed a seasonal pattern in abundance; high in monsoon and low in the dry season (McKenzie *et al.* 2012a). This, however, was not apparent over the last 3 years, as seagrass has been recovering from losses experienced in early 2011. Long-term seagrass abundances were generally higher in reef than coastal habitats, however, the seasonal difference (highest abundances are late dry and early monsoon) for each was similar: coastal = 11.4 ±0.3% in the dry and 11.6 ±0.3% in monsoon season; reef = 21.9 ±0.4% in dry and 25.3 ±0.3% in late monsoon; subtidal 16.4 ±0.8% in the dry and 21.2 ±1.1% in monsoon season.

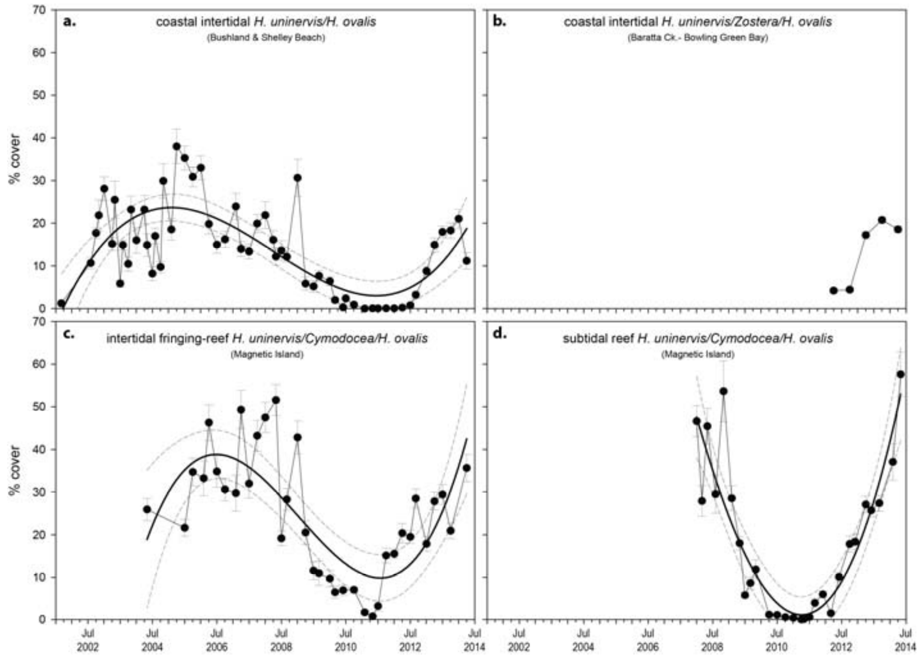

Figure 65. *Changes in mean seagrass abundance (% cover ±Standard Error) at inshore coastal intertidal (a, b), reef intertidal (c) and reef subtidal (d) meadows in the Burdekin region, 2001 - 2012. Trendline is 3rd order polynomial, 95% confidence intervals displayed, coastal intertidal r^2 = 0.54, reef intertidal r^2 = 0.58 and reef subtidal r^2 = 0.84.*

Coastal meadows remained dominated by either *Halodule uninervis* or *Zostera muelleri* with small amounts of *Halophila ovalis* over the 2013-14 period (Figure 63). The dominance of the foundational/K-strategist species, particularly over the last 5 monitoring periods indicates meadow recovery. The increase in K-strategist species in the coastal habitat during the greatest period of disturbance (2011) was unexpected (Figure 66), and this may be a situation where the species (*Halodule uninervis* and *Zostera muelleri*) adapted features aligning with *r*-strategist species traits. However, the increasing proportion of typical K-strategist species overall (all habitats) in 2013-14 suggests some level of stability, which will improve ecosystem resistance.

Intertidal reef habitats on the fringing reef platforms of Magnetic Island, were dominated by either *Halodule uninervis* (e.g. Picnic Bay) or *Halodule uninervis* / *Cymodocea serrulata* (e.g. Cockle Bay). Prior to 2009/10, the meadow at Cockle Bay was dominated by the foundational species *Cymodocea serrulata* and *Thalassia hemprichii* (Figure 63). The subtidal meadows beyond the reef crest on the eastern side of the Picnic Bay also changed from a dense (48% cover) mixed species meadow of *H. uninervis*, *C. serrulata*, and *H. spinulosa* to a *H. uninervis* and *H. decipiens* meadow post-2011 losses. From 2011 to 2013, reef habitats in the Burdekin NRM region were composed of a greater than average proportion of *r*-strategist species, however during the 2013-14 monitoring period a state change occurred with the recovery of the K- strategist (foundation) species dominating (Figure 66). This suggests the meadows have nearly recovered from the severe disturbances in recent years. The greater proportion of K- strategist species also suggests improved ecosystem resistance.

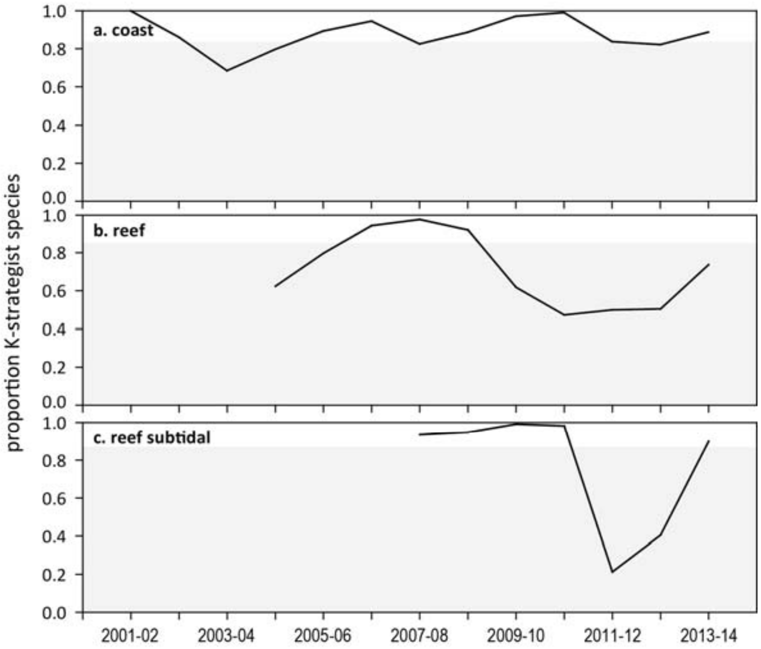

Figure 66. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Burdekin region, 2001 - 2014. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in October/November and March/April of each year to determine if changes in abundance were a consequence of the meadow edges changing (Appendix 2, Table 36). In the two to three years prior to 2011, significant changes occurred across the region with all seagrass meadows reducing in size and changing in landscape from continuous, to patchy, to isolated patches and finally to isolated shoots with the loss of meadow cohesion (Figure 67). This was caused by the high rainfall and riverine discharge that affected much of the GBR. Since 2011, meadow extents have increased in both coastal and reef habitats to pre-2009 levels (Figure 67). In early 2014, however, seagrass extent declined at the subtidal habitat, to the lowest in 2 years but the cause of this decline is not apparent, as all other indicators suggest an improvement in meadow health and resilience.

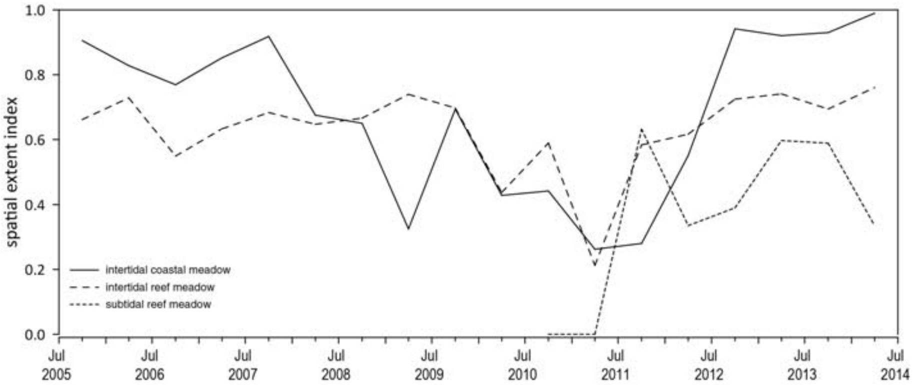

Figure 67. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Burdekin region, 2005 - 2014.*

Apart from the MMP, seagrass monitoring within the Burdekin NRM region is also conducted as part of the Queensland Ports Seagrass Monitoring Program (QPSMP). Findings from QPSMP monitoring locations, reported either recovery or no improvement in 2013. Annual monitoring of 10 seagrass meadows in the Port of Townsville reported the onset of recovery in October 2011, after unprecedented declines in biomass and distribution in 2010, and although substantial recovery was reported in October 2013, seagrass condition remained below the historical baseline (Davies*, et al.*

2014). Increases (visual estimates of biomass and extent) in coastal habitat meadows were primarily a consequence of foundation species recovering; although some meadows were still dominated by colonising species such as *Halophila* (Davies*, et al.* 2014). A whole of port survey conducted in October 2013 (referred to as the 2013 baseline), similarly found seagrass extent and biomass lower than the whole of port survey conducted in October 2007 (referred to as the 2007 baseline) (Davies*, et al.* 2014). Unfortunately, no comparison is made to the GBR historical baseline from 1987 (Coles *et al.* 1992; Coles*, et al.* 2001a).

In the south of the Burdekin NRM region, the findings from quarterly monitoring for the North Queensland Bulk Ports Corporation in the Port of Abbot Point were less clear, as discerning seagrass state at the coastal and subtidal locations is challenged by the extremely dynamic nature of the meadows, often disappearing at the end of the wet season and re-established in the spring. After showing signs of recovering in 2012 (from losses experienced in September 2011), deeper water seagrass once more underwent decline throughout 2013 following the impacts of Tropical Cyclone Oswald (January 2013) (McKenna and Rasheed 2014). The shallower coastal meadows, however, showed initial signs of recovery throughout 2013, with small amounts of Halodule uninervis present at 2 of the 5 meadows monitored (McKenna and Rasheed 2014). A whole of port wet season survey conducted in September 2013 reported the total extent of seagrass had changed little when compared to the 2008 whole of port wet season survey, however, the visually estimated biomass was significantly lower in 2013 (McKenna and Rasheed 2014). The authors suggest recovery may be a limited due to the absence of seed banks or propagules (data not presented) (McKenna and Rasheed 2013).

Seagrass reproductive status

The *Halodule uninervis* seed bank which has persistent at coastal habitats across the region, increased in 2013-14, but remained below 2007 peak size (Figure 68a). A seed bank was absent at reef habitats in 2011-12, but after recovering in 2012-13 was near depleted in 2013-14 (Figure 68b). Subtidal seed banks have continued to improve since 2010, reaching peak size in early 2014 (Figure 68c). Reproductive effort remained good across the region in 2013-14 for reef habitats, but remained very poor at coastal habitats. The greater seed bank and higher reproductive effort at reef subtidal sites indicates a high capacity to recover following disturbance, whereas the smaller seed bank and higher reproductive effort at reef intertidal sites indicates a moderate capacity to recover following disturbance in the immediate future. Alternatively, at coastal sites, the smaller but increasing seed bank and reproductive effort suggest an improved capacity to recover, but meadows may be at risk if there is another sizeable impact in the near future.

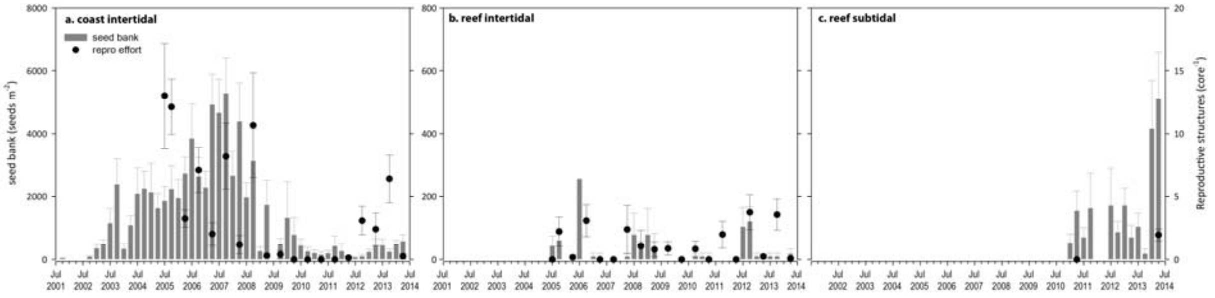

Figure 68. *Seed bank and late dry season reproductive effort at inshore intertidal coast and reef and subtidal reef habitats in the Burdekin region. Seed bank presented as the total number of seeds per m^2 sediment surface, and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled). NB: Y-axis scale for seed banks not differ between habitats.*

An examination of the long term trends across the Burdekin NRM region (all habitats pooled) suggests seagrass abundance (% cover) has near recovered to pre-2011 levels (Figure 69a), and that reproductive effort and seed banks have started recovering. In 2013-14, reproductive effort was approximately a third of what is in 2005-06 (Figure 69b), and seed banks, although well below the peaks of 2006-07, were similar to 2002-03 sizes (Figure 69c).

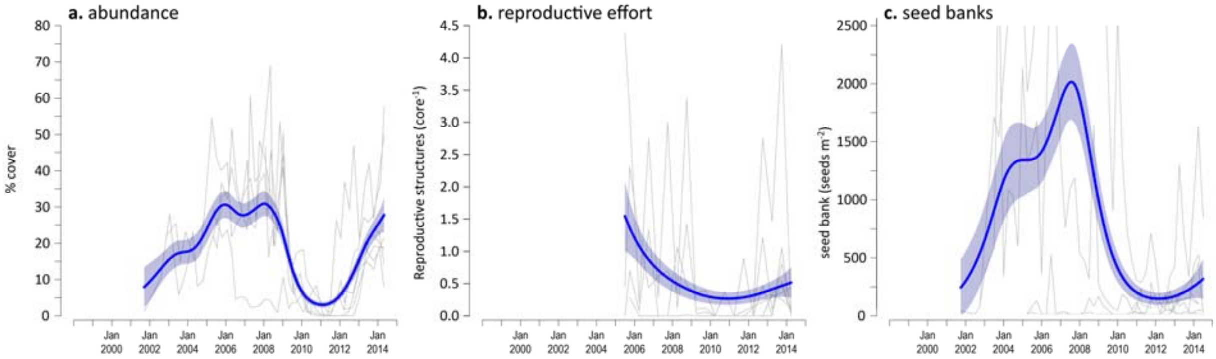

Figure 69. *Seagrass abundance, reproductive effort and seed bank trends in the Burdekin region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

3.4.4 Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf tissue molar C:N ratios increased across the region at all habitats in 2013 (to their highest values since monitoring commenced) and were above 20 for reef intertidal and subtidal (Figure 70). The lowest values were at coastal sites (Townsville). Increasing C:N ratios across the region since 2011 may indicate increasing light availability and/or N depletion. δ^{13}C values for foundation species at all habitats during the late dry (growing) season were either above (isotopically heavier) the global average and within global ranges (Appendix 2, Table 37), suggesting sufficient carbon available for growth. The δ^{15}N values measured across all species and habitats in the region, were the highest since measures commenced in 2011; averaging between 1.5‰ and 3.5‰ (Appendix 2, Table 37). These high δ^{15}N values suggest the primary source of the N across the region was fertiliser and/or sewage.

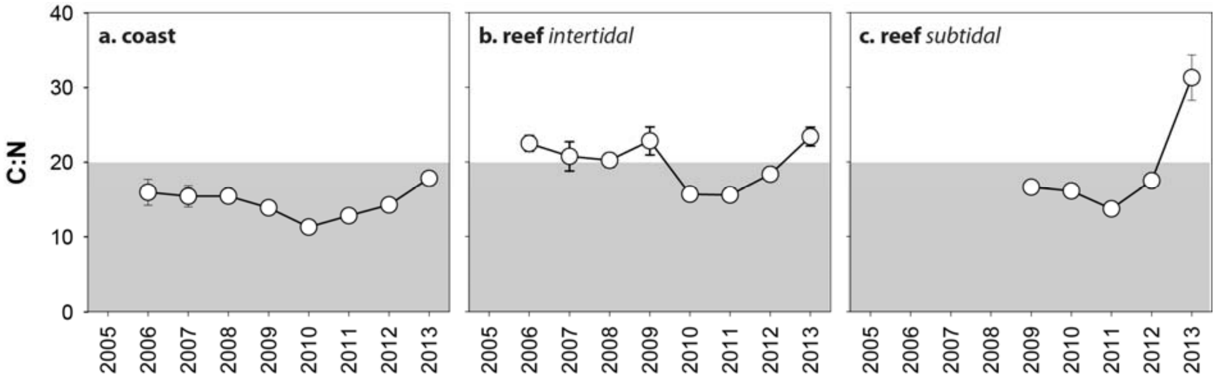

Figure 70. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore habitat in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line indicate reduced light availability and/or N enrichment.*

Seagrass leaf molar C:P ratios increased above 500 in 2013 at reef habitats (intertidal and subtidal), indicating that C incorporation was increasing relative to the uptake of P (Figure 71). C:P ratios at coastal meadows, however, have remained below 500, indicating the habitat remains nutrient rich, containing a large P pool (Figure 71; Appendix 2, Figure 147). N:P ratios for the foundation species decreased the greatest over the 2013-14 period, with ratios below 20, indicating the leaf tissue had a higher proportion of P than N, i.e. N limitation (Figure 71). As N is highly mobile within plants, the N limitation in the leaf tissue may suggest mobilisation of N to other plant organs for either rhizome extension or reproduction. This is supported by the good to very good reproductive effort reported for reef intertidal and subtidal habitats in 2013-14.

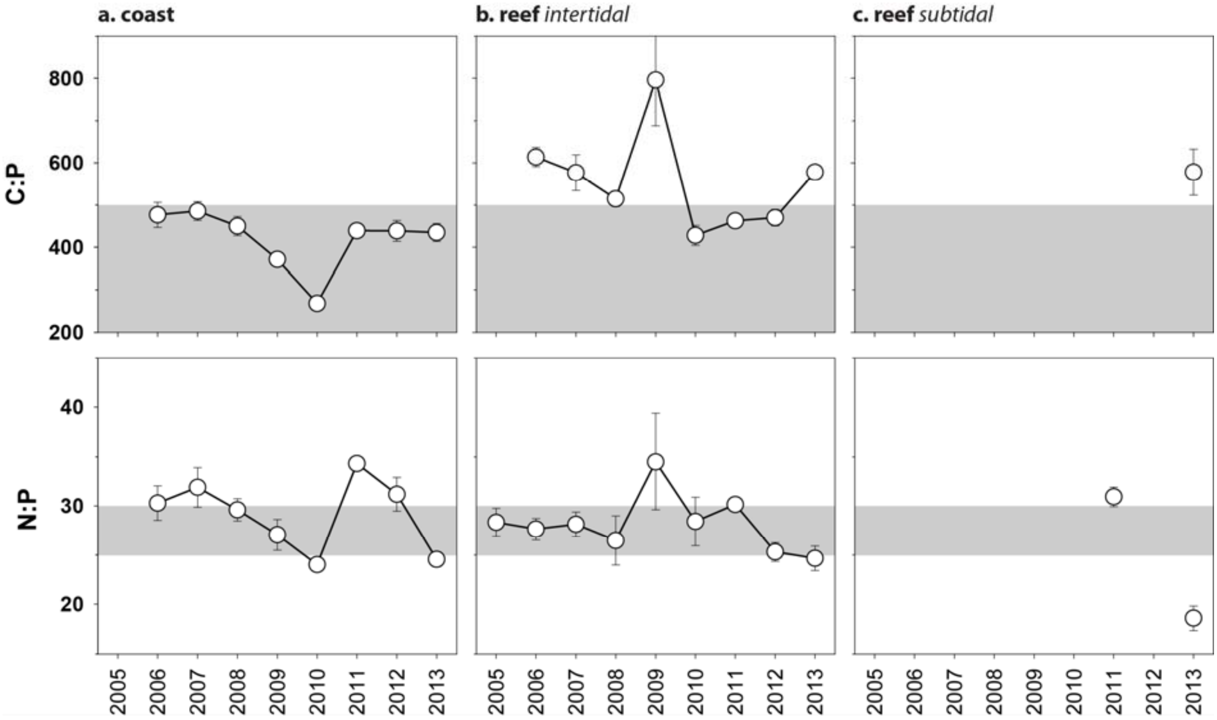

Figure 71. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore intertidal habitat in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues. N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades at coastal meadows were higher in the wet season than the dry (Figure 72; Appendix 2, Figure 154). The greatest change in epiphyte cover was the substantial increase at coastal habitats over the 2013-14 period (Figure 72a); with a sharp peak above the GBR long-term average in the late dry at Bushland Beach/Shelley Beach, but peaking in the late monsoon at Bowling Green Bay (Appendix 2, Figure 154a, Figure 154c, respectively). Percentage cover of macroalgae at coastal habitats changed little over the last 4 years (Figure 72b) with location abundances remaining low and below the GBR long-term average (Appendix 2, Figure 154b, Figure 154d).

Epiphyte cover at intertidal reef habitats has increased over the last three monitoring periods, but in early 2014 remained below the GBR long-term average, close to the long-term mean (Figure 72c; Appendix 2, Figure 155a). Macroalgae was generally higher during the dry season at reef habitats (Figure 72d), and over the last 24 months has increased slightly around the GBR long-term average (Appendix 2, Figure 155b). Epiphyte cover increased substantially at subtidal habitats over the 2013-14 period (Figure 72e), well above GBR long-term average. However, macroalgae cover has remained low (Figure 72f; Appendix 2, Figure 156).

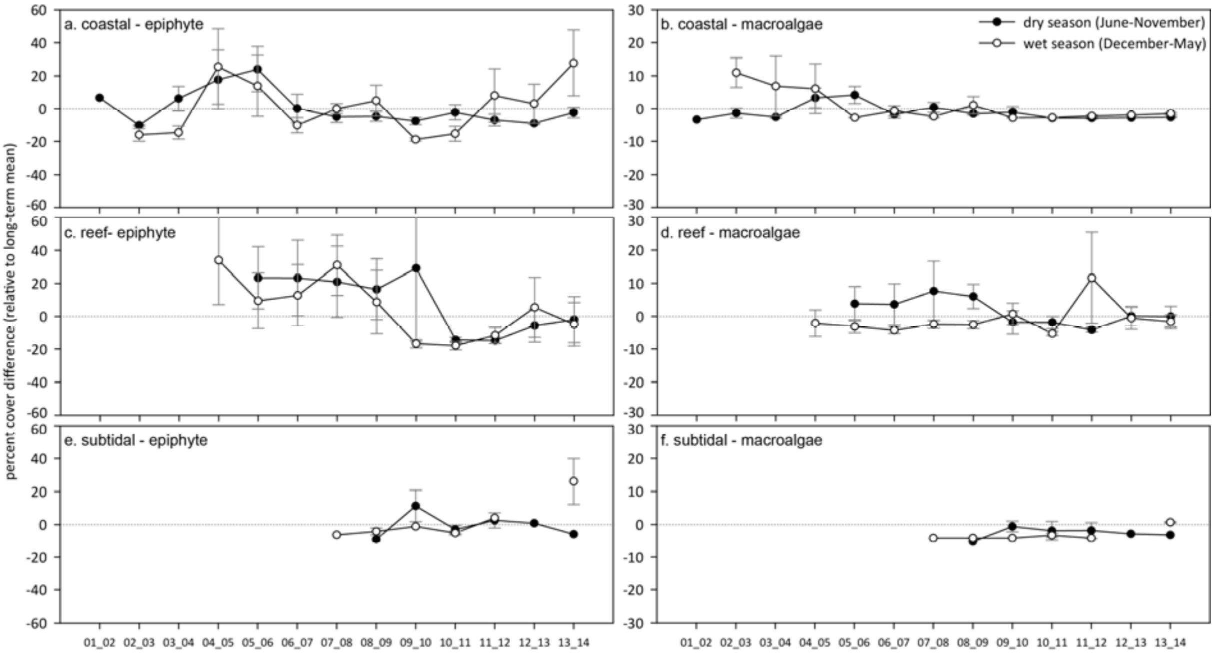

Figure 72. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term GBR average for each inshore seagrass habitat in the Burdekin region (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated greatly since monitoring was established in late 2001, with an initial increase from 2002-2006 (Figure 73a) (a period when seagrass cover was in a moderate to good state), followed by a decrease until early 2011 (a period of above average rainfall and severe storm and cyclone activity), after which it has been gradually increasing; possibly in association with improved light availability and higher available N. Macroalgae cover has been less variable over the long-term, showing a decrease since monitoring was established to persist in a low and stable state (Figure 73b).

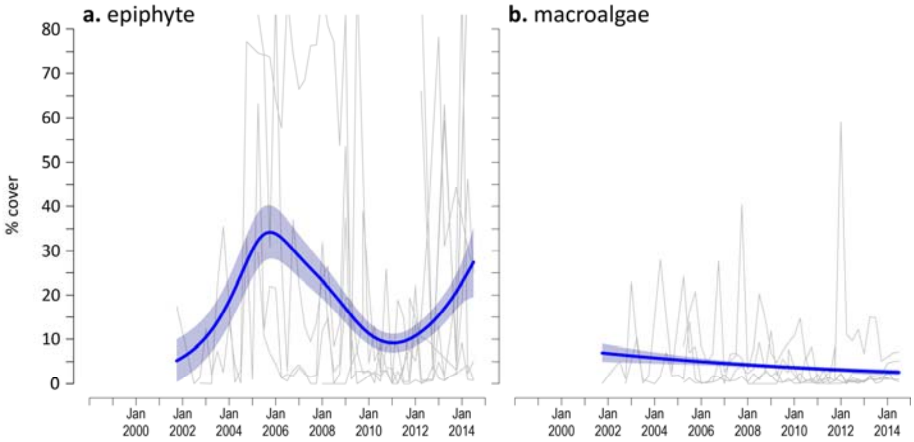

Figure 73. *Epiphyte and macroalgae cover trends in the Burdekin region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Wet Tropics reef habitats during daylight over the 2013-14 monitoring period were mostly below long-term medians (Appendix 2, Table 39). Annual exposure of coastal meadows throughout the region was below the long-term median for the fifth consecutive year (Appendix 2, Figure 167). During 2013-14, the meadows at Bushland and Shelley Beach were exposed the most (71hrs and 60.6hrs at BB1 and SB1, respectively), but less than the previous monitoring period (Appendix 2, Figure 167a, Figure 167b). The other coastal meadows in the region, adjacent to Barratta Creek (Bowling Green Bay), were exposed 90min more in 2013-14 (66hrs 40min) than the previous monitoring period, however, comparison with the long-term is not possible due to the limited dataset (Appendix 2, Figure 167c, Figure 167d).

Although the intertidal meadows on the fringing reef flats at Magnetic Island had the greatest number of hours exposed (131hrs and 113hrs at Picnic Bay and Cockle Bay, respectively) of all meadows (and habitats) monitored across the region during the 2013-14 period, this was the sixth consecutive year the total hours exposed was below the long-term annual median (197hrs) (Appendix 2, Figure 168).

The lower levels of daytime exposure for intertidal seagrass meadows in all habitats across the region would have provided more conducive environmental conditions for seagrass growth in 2013-14.

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows at sites adjacent to the mouth of Barratta Creek (Bowling Green Bay) on the 30th April 2014 (Appendix 2, Table 40). No other sediments in the region were examined for herbicides.

Within canopy seawater temperature

Autonomous temperature loggers were deployed within the seagrass canopy at all coastal and reef sites over the monitoring period, however, the loggers failed at Bowling Green Bay between November 2013 and March 2014 (Appendix 2, Figure 175, Figure 176). Mean seawater temperatures within the seagrass meadows were similar to or slightly above the long-term (10 years) average, for coastal and reef habitats, respectively (Appendix 1, Figure 175, Figure 176). Coastal seawater temperatures were less than half a degree higher at Townsville than Bowling Green Bay. Higher temperatures (>35°C) were recorded from September 2013 and March 2014, however no extreme temperatures (>40°C) were recorded across the region (Figure 74). The highest temperature recorded was at Picnic Bay on the 30 December 2013 when the seawater temperatures remained at 38.8°C for at least 30min between 2-4 pm (Figure 74a, Appendix 2, Figure 175). Overall, seagrass meadows in the region were exposed to 30 days of seawater temperatures above 35°C, which was less than for the previous 12 months (Figure 74). This suggests that 2013-14 was a less stressful year for seagrass in regards to seawater temperatures, ranking 10th over the last 11 years of data.

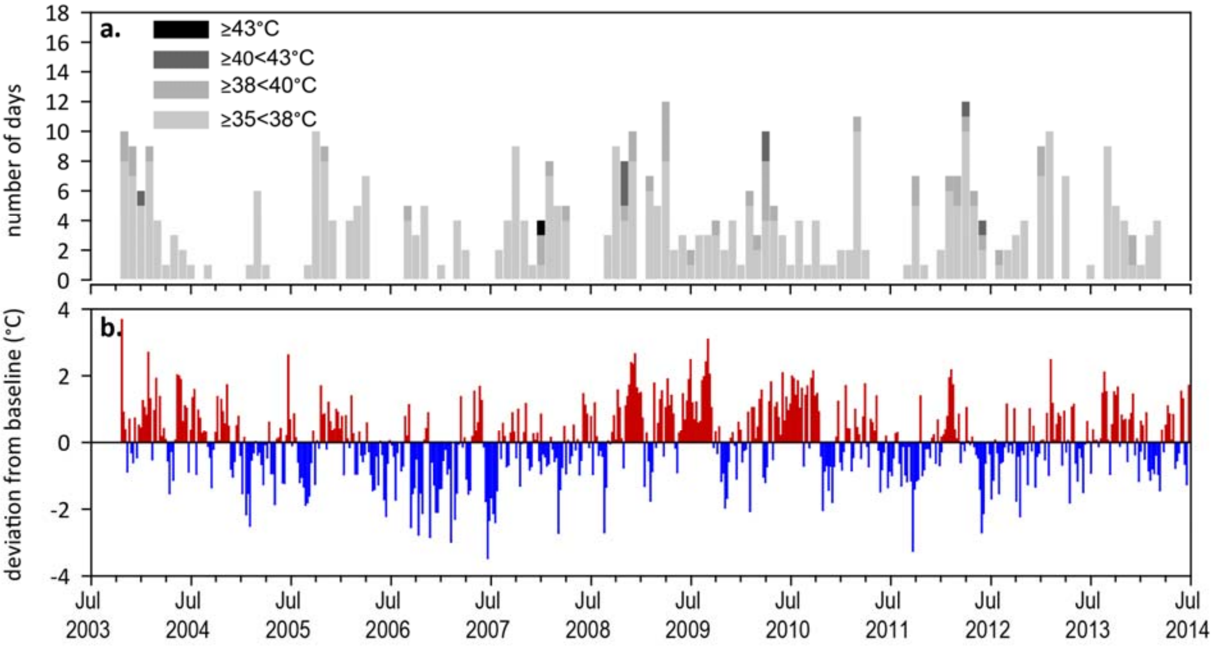

Figure 74. *Inshore intertidal sea temperature at inshore seagrass habitats in the Burdekin region, September 2003 - June 2014: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

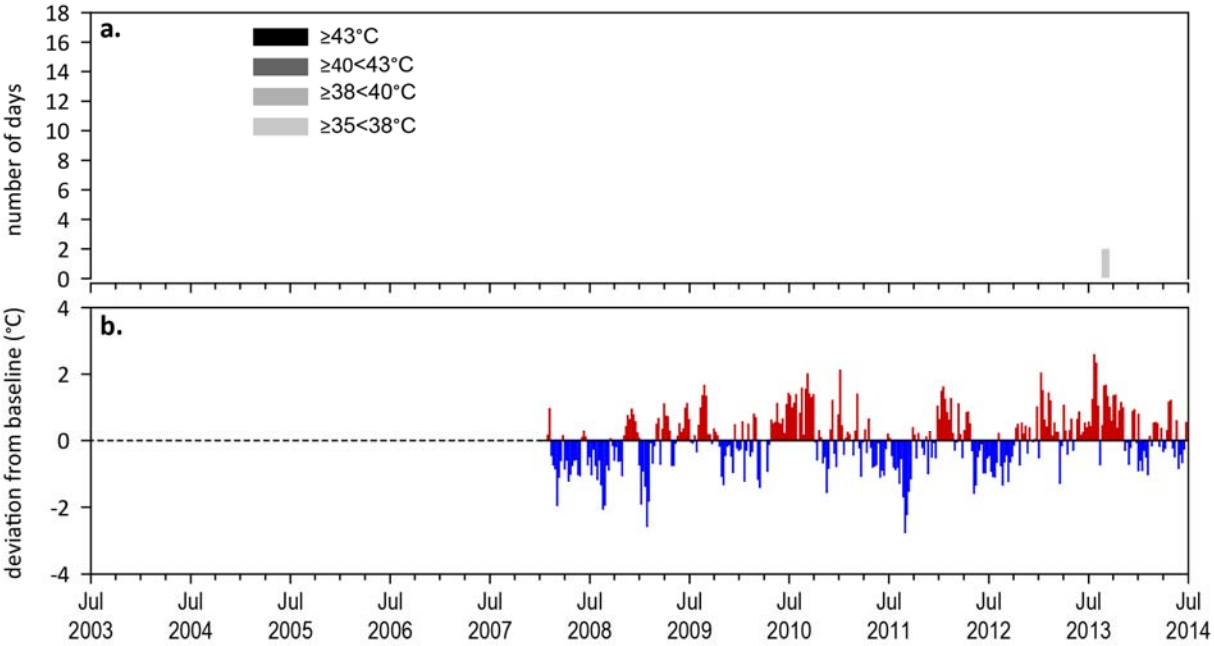

Figure 75. *Inshore sea temperature at inshore subtidal seagrass habitat at Magnetic Island (Burdekin region), January 2008 - June 2014: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 6-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

Canopy incident light and turbidity

Within canopy daily light levels in the Burdekin Dry tropics typically follow seasonal patterns of increase during September to December and declining during the wet season (Figure 76). However, the peaks in light intensity are not as pronounced as they are in the Wet Tropics and light levels do tend to be more variable. On average, daily light levels at the Burdekin NRM region intertidal meadows during 2013-14 (8.9 mol m^{-2} d^{-1}) were considerably lower than the GBR-wide average (14.3 mol m^{-2} d^{-1}) and lower than the long-term average for Burdekin intertidal sites of 10.9 mol m^{-2} d^{-1}. Meadows at Bushland Beach consistently had the lowest light levels (5.1 mol m^{-2} d^{-1} for 2013-14), and the meadows at Magnetic Island (MI1 or MI2), had the highest daily light levels. There is just one subtidal site in the Burdekin region (Picnic Bay, MI3), and daily light was lower in 2013-14 (5 mol m^{-2} d-1) compared to a long-term average (5.7 mol m^{-2} d^{-1}). Daily light for each site within the Burdekin NRM region is presented in the Appendix 2 (Figure 186, Figure 187).

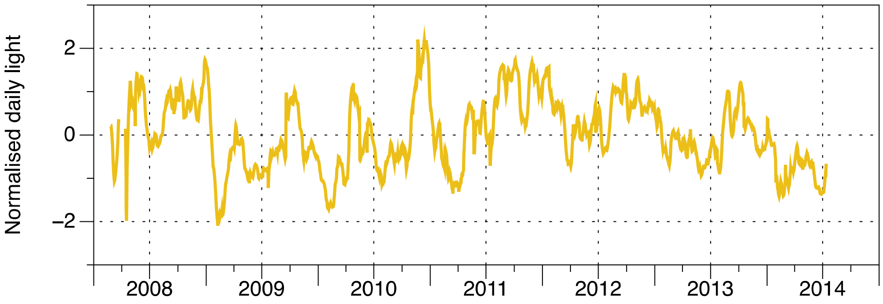

Figure 76. *Standardised daily light (28 day rolling average) for inshore seagrass habitats in the Burdekin region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

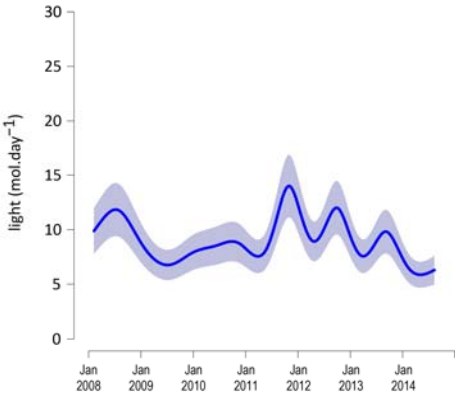

Figure 77. *Seagrass canopy light trend in the Burdekin region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

As described in the Wet Tropics sections, incoming irradiance reaching the seagrass leaf is a strong driver of changes in seagrass abundance, meadow distribution and the colonization depth of meadows (Abal and Dennison 1996; Collier*, et al.* 2012b), because reductions in light reduce photosynthetic rates and the energetic surplus of the seagrass plants. From 2008 to 2014 when there was complete seagrass mortality followed by recovery, light levels have been a poor predictor of changes in seagrass abundance at the subtidal site (MI3). This is due mostly to the poor relationship between light and changes in abundance during the recovery phase when other factors, such as recruitment processes, determine changing abundance. Recruitment processes include recolonisation from existing or new propagules or seeds, changes in species composition and meadow expansion. Furthermore, seagrass abundance remained at <1% (0% change) for one year following the February 2011 complete mortality event. However, a significant relationship was identified at the intertidal site (MI1), where complete mortality did not occur at any stage, however abundance did decline to very low (1% total cover) for 2 sampling events. This has been tested only at sites with light data extending back to 2008, and this analysis will be updated for other Burdekin sites as data sets mature in following years.

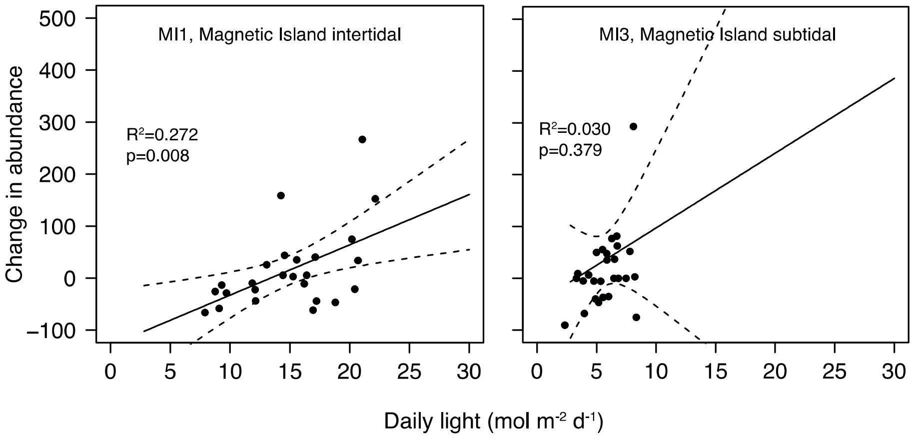

Figure 78. *Daily light and changes in abundance (mean percent cover) at Burdekin sites from 2008-2014. Mean daily light (mol m^{-2} d^{-1}) was calculated for the same period over which changes in abundance were calculated, typically 3 months. NB: Sites with data starting in 2009 or 2010 have not been included in this analysis.*

Table 22. *Summary statistics for regression analysis of mean daily light (mol m-2 d-1) and changes in abundance at Burdekin sites.*

site	**Intercept**	**Light** (slope)	**Std Err**	**R^2**	***p***
MI1	-129.381	9.668	3.299	0.272	0.008
MI3	-47.04	14.43	16.12	0.030	0.379
Threshold exceedance					
MI1	56.036	-3.466	1.343	0.225	0.017
MI3	105.171	-1.607	1.259	0.059	0.213

Regional climate and river discharge

Seagrass meadows across the Burdekin region (Cleveland Bay and Bowling Green Bay) in 2013-14 experienced above average air temperatures and winds, but below average cloud cover and rainfall. Discharges from rivers which would impact nearby meadows were below median, however, the number of days with winds strong enough to resuspend benthic sediments were the highest in 7 years.

The mean maximum daily air temperatures recorded across the region during 2013-14 (Townsville = 29.5°C; Ayr = 29.5°C) were higher than the decadal and long-term (73 year) averages. The highest recorded daily maximum temperature in 2013-14 was 36.1°C in Ayr, but this was lower than the previous 2 monitoring periods (Appendix 2, Figure 200, Figure 201). Cloud cover in the region was similar to the previous monitoring period, but slightly higher (by 8%) than the long term (70 year) average (Appendix 2, Figure 200, Figure 201). Overall, cloud was the fourth lowest for the decade. 2013-14 was a windier than average year for Townsville, with an annual mean wind speed (25.1 km.hr^{-1}) higher than the previous monitoring period, the decade and the long-term. The monitoring period had more days (198) with >25 km.hr^{-1} winds than the last 7 years (Appendix 2, Figure 202). Annual rainfall over the 2013-14 monitoring period (Townsville = 1016mm, Ayr = 658mm) was 30 % higher in Townsville, but approximately 10% below average (for both the decade and long-term) (Appendix 2, Figure 200, Figure 201).

In the Burdekin region, the most significant river impacting seagrass meadows adjacent to Townsville and Bowling Green Bay is the Burdekin. Bowling Green Bay meadows would also be impacted by discharges from smaller catchments via the Haughton River and Barratta Creek. Inshore areas north of the Burdekin River (including Magnetic Island) receive riverine waters every two to three years (Wolanski and Jones 1981; Maughan *et al.* 2008). The Burdekin River has the largest annual exports of sediment, phosphorus and nitrogen of any catchment in the GBR, with an annual discharge of 4.6×10^6 tonnes of fine sediment, 2,030 tonnes of phosphorus and 12,100 tonnes of nitrogen (Brodie *et al.* 2009). During episodic flooding, high concentrations of dissolved nutrients are experienced off Townsville and in Bowling Green Bay, up to 50 km north of the Burdekin River mouth, for periods of up to three weeks (Maughan *et al.* 2008). In 2013-14, however, the lower than average rainfall resulted in below median discharges from the major rivers which would impact seagrass meadows monitored in the Burdekin region (Appendix 2, Table 41, Figure 216). The only river in the region with above median freshwater discharge was the Don in the very south. Monitoring sites are approximately 135km north and outside the primary and secondary plumes (Michelle Devlin, JCU, Pers. Comm.).

3.5 Mackay Whitsunday

3.5.1 2013-14 Summary

Only 5% of the maximum habitable area of seagrass mapped in the shallow waters (<15m) of the GBR occurs in the Mackay Whitsunday NRM region. The majority of these inshore seagrass meadows are within coastal and estuary habitats where the key environmental drivers include exposure to wind driven waves and variable flood runoff during the tropical monsoon. Seagrass meadows are monitored at reef, coastal and estuarine locations in the Mackay Whitsunday region.

During 2013-14 seagrass abundance remained in a very poor state despite slight increases across the region. However, the change in abundance differed among habitat types. In coastal habitats, seagrass abundance continued to increase, while at reef habitats abundance declined. Despite a trend of increasing abundance at estuary habitats after 2011, abundances sharply declined in early 2014. Meadows continued to increase their extent across the region and increased in dominance of the foundational species across all habitats. These changes suggest that meadows may have an improved resistance enabling them to tolerate disturbances. Despite increasing reproductive effort, seed banks declined during 2013-14, which may possibly have been a consequence of germination. This makes them less resilient to disturbances, rendering them with a low capacity to recover.

Leaf tissue C:N ratios continued to increase in all habitats compared to previous years, which indicates a greater level of C incorporation relative to N. Higher than average light levels during the dry season when tissue nutrients are sampled further indicate that higher rates of photosynthetic C incorporation could be contributing to the increasing C:N. Stable isotope (δ^{15}N) values in the leaf tissue were high (>2‰) across all habitats, indicating the primary source of N was possibly sewage and/or fertiliser. Epiphyte cover was variable across habitats, but regionally was unchanged.

Seagrasses across the region experienced above average seawater temperatures and above median annual daytime tidal exposure, which would have elevated heat and desiccation stress in 2013-14. The stresses, however, may be limited as no extreme temperatures (>40°C) which would result in high stress to plants were measured in 2013-14, and only 9 days above 35°C were recorded.

Climatic conditions in the region over the monitoring period were more conducive to seagrass growth than recent years. The year 2013-14 was not only a warmer than average period, but it also had a greater number of windy days and it was also one of the driest in 5-7 years. The low rainfall was in the south of the region, which resulted in below median flows from southern rivers for the first time in 8 years, but in the north discharges from rivers remained above median. As inshore meadows across the region grow mainly in sheltered bays, the impact of winds strong enough to resuspend benthic sediments and limit light for a nearly half of the year would have been reduced. Also, the impact to meadows in the south estuaries would have been minimised by the reduced flooding. This untimately resulted in the overall Mackay Whitsunday regional seagrass state improving from very poor in 2012-13 to **poor** in 2013-14 (Table 23).

Table 23. *Report card for seagrass status (community & environment) in the Mackay Whitsunday region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index^**
estuarine intertidal	13	25	39	**19**
coastal intertidal	33	0	23	**19**
reef intertidal	0	50	31	**27**
Mackay Whitsunday	18	25	31	**25**

3.5.2 Background

The Mackay Whitsunday region comprises an area of almost 940,000 ha and extends from Bowen (Queens Beach) in the north to Clairview (Clairview Bluff) in the south and includes several large continental islands. The region includes the major population centres of Mackay, Proserpine, Airlie Beach and Sarina; encompassing the Proserpine, O’Connell, Pioneer and Plane Creek river systems (Commonwealth of Australia 2013d).

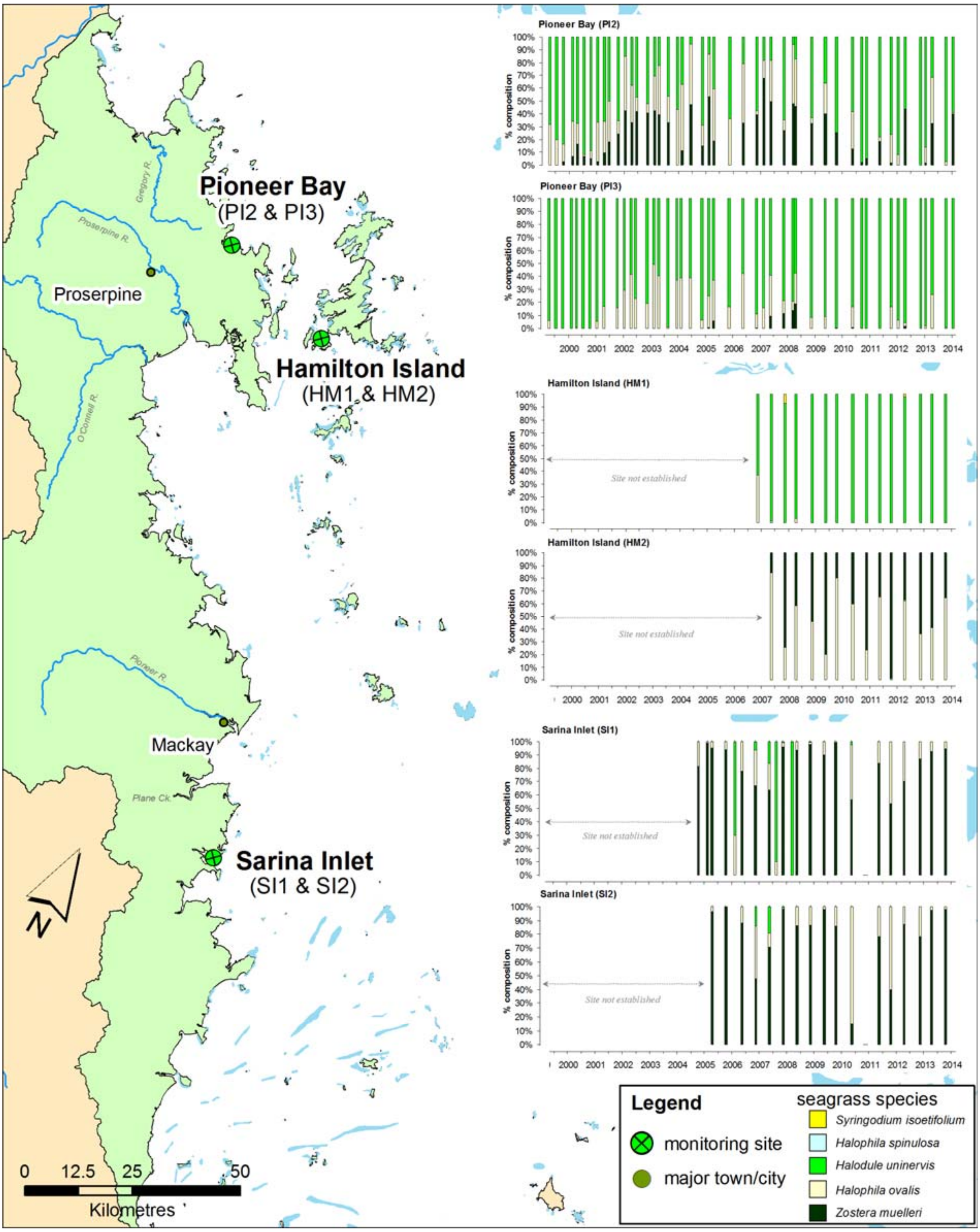

Figure 79. *Location and species composition of each long-term seagrass monitoring site in the Mackay Whitsunday region. Please note: replicate sites within 500m of each other.*

The Great Barrier Reef protects the coastline from predominantly south-easterly winds which often accompany a light south-easterly ocean swell (Mackay Whitsunday Natural Resource Management Group Inc 2005). Coastal waters adjacent to the large rivers and mangrove-lined inlets are generally very turbid and shallow, with predominantly mud sediments. Tidal range in the south of the region is large, and in some places has the effect of creating extensive tidal banks. The region receive rainfall between 500-3000 mm annually, which falls mostly (~70%) from December to March. Average daily temperatures for Mackay range between 23-31°C in January and 11-22°C in July. The major land use of each catchment is livestock grazing, and crops such as sugar cane.

Extensive seagrass meadows occur both on shallow banks and in nearshore subtidal areas in the region. Approximately 448 km^2 of seagrass habitat has been mapped in the Mackay Whitsunday region over the past 3 decades, with 154 km^2 in shallow waters and 293 km^2 in deeper (>15m) waters (McKenzie*, et al.* 2010c). In 1999/2000, 5553 ±1182 hectares of seagrass was mapped from Midge Point in the south to Hydeaway Bay in the north (Campbell*, et al.* 2002). This represented a 40% increase in overall seagrass habitat compared to the 1987 baseline, however losses had occurred at some localities. For a detailed description of seagrass meadows and habitats across the region (see McKenzie and Yoshida 2012).

Twelve species of seagrass have been recorded in the Mackay Whitsundays, representing 80% of the known species found in Queensland waters (McKenzie and Yoshida 2012). The wide range of physical habitats where seagrasses were found undoubtedly contributes to the high species diversity. Habitats include intertidal and subtidal areas of estuary, coastal fringing reef environments and deepwater environments. MMP 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 (Appendix 2, Figure 134).

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 trade winds. Potential impacts to these habitats are issues of water quality associated with urban, marina development and agricultural land use (Appendix 2, Figure 135). Monitoring sites of coastal seagrass habitat were located on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay.

Reef habitat seagrass meadows are found on the shallow fringing reefs adjacent to the mainlands or associated with the many islands in this region. The drivers of these habitats is exposure to waves and temperature extremes (Appendix 2, Figure 136). Major threats would be increased tourism activities including marina and coastal developments.

3.5.3 Status of the seagrass community

Seagrass abundance, composition and extent

Seagrass abundance continued to increase at coastal habitats in 2013-14, however, the increase at estuary habitats over the past 18 months was offset by a sharp decrease in early 2014; the cause of which is not immediately apparent. Seagrass abundances generally declined at reef habitats over the past year and remained in a very poor state. Overall, seagrass abundance improved slightly in 2013-14 but remained in a very poor state.

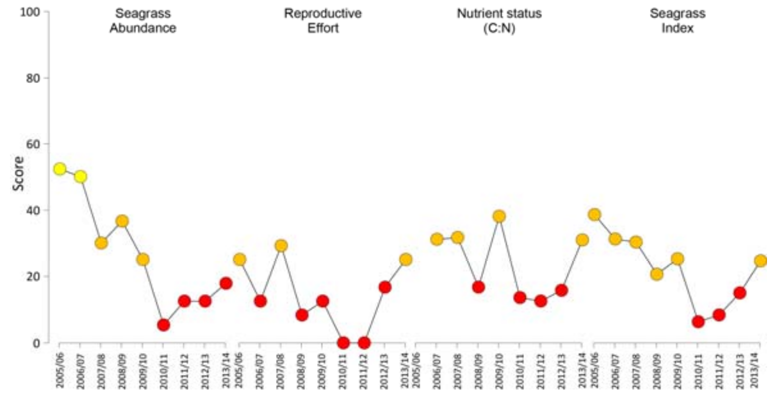

Figure 80. *Report card of seagrass status indicators and index for the Mackay Whitsunday NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20).*

Seagrass species and abundance has fluctuated at the coastal habitats between and within years, indicating disturbance regimes at longer time periods than annually (Figure 81). Seagrass abundance improved at coastal habitats in 2013-14, to the highest abundances in 4 years. The seasonal pattern in abundance, with abundances increasing throughout the year to the monsoon (McKenzie*, et al.* 2012a), was less apparent in the last 2 years in the coastal meadows of Pioneer Bay as the meadows have recovered from the losses experienced in 2010-11 (Figure 81).

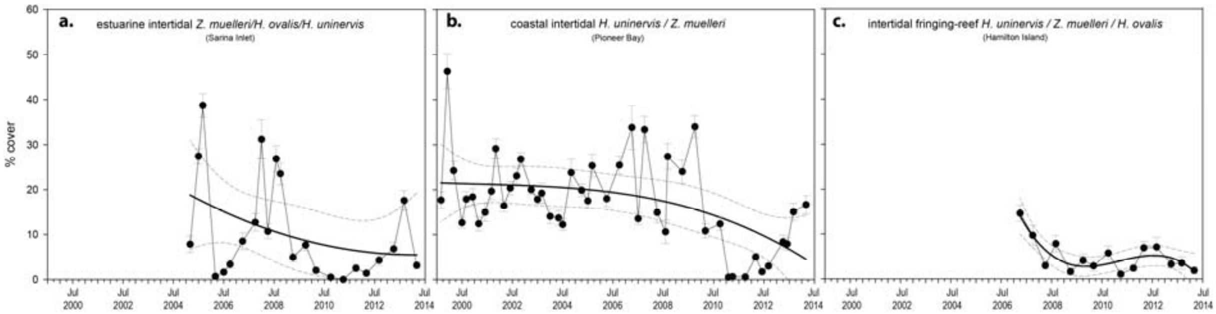

Figure 81. *Changes in seagrass abundance (% cover ±Standard Error) at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2013: a). estuarine, b). coastal, and c). reef. Trendline is 3rd order polynomial, 95% confidence intervals displayed: estuarine* $r^2 = 0.15$*, coastal* $r^2 = 0.26$*, reef* $r^2 = 0.71$*.*

Estuarine meadows improved in abundance (cover) throughout 2013, until early 2014 when they sharply declined (Figure 81a). Seagrass cover has fluctuated greater since monitoring was established in early 2005, with seagrass severely declining in the late wet season of 2006, recovering within 18 months to only decline again in 2008 (Figure 81). Since 2011, seagrass abundance was once again increasing, until it sharply declined for a third time within a decade. Although there is insufficient spread of sampling across months within years, and the meadow state has fluctuated within and between years, the seagrass abundance appears greater in the late dry than late monsoon (Figure 81a).

Seagrass abundance at reef habitats has continued to decline over the last 18 months, after starting to recover from losses experienced in 2011 (Figure 81c).

The most common seagrass species across all habitats in the Mackay Whitsunday NRM region were *Halodule uninervis* and *Zostera muelleri.* Coastal meadows were dominated by *Halodule uninervis* and *Zostera muelleri* mixed with *Halophila ovalis*. Species composition, however, has fluctuating greatly over the past decade at the coastal meadows, with varying amounts of *Z. muelleri* (Figure 79). Since the late monsoon 2011, the seagrass meadows were predominately *H. uninervis* (Figure 79).

Although abundance and species composition in the estuarine meadows has similarly fluctuated over the last 9 years, as a result of meadow loss and recolonising, in 2013-14 they were dominated by *Zostera muelleri* with some *Halophila ovalis* (Figure 79). The species composition of the meadows on the reef habitat have remained relatively steady, with the site at the eastern end of Catseye Bay (HM2) dominated by Z. *muelleri* and the site at the western end (HM1) dominated by *H. uninervis* (Figure 79).

The dominance of the foundational/K-strategist species in meadows across all habitats in the Mackay Whitsunday NRM region continued to improve over the last 2 monitoring periods, suggesting meadows may have an improved ecosystem resistance to tolerate disturbances (Figure 82).

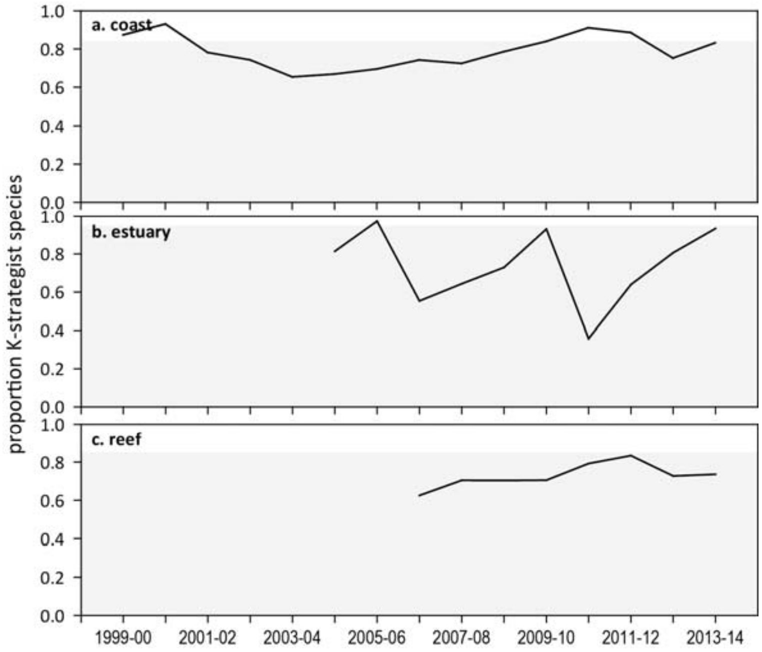

Figure 82. *Proportion of seagrass abundance composed of K-strategist species at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2014. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type*.

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 2, Table 36) to determine if changes in abundance were a consequence of the meadow edges changing. Over the past 12 months, meadows have continued to expand across the region reaching their greatest extents since the losses in 2011 (Figure 83).

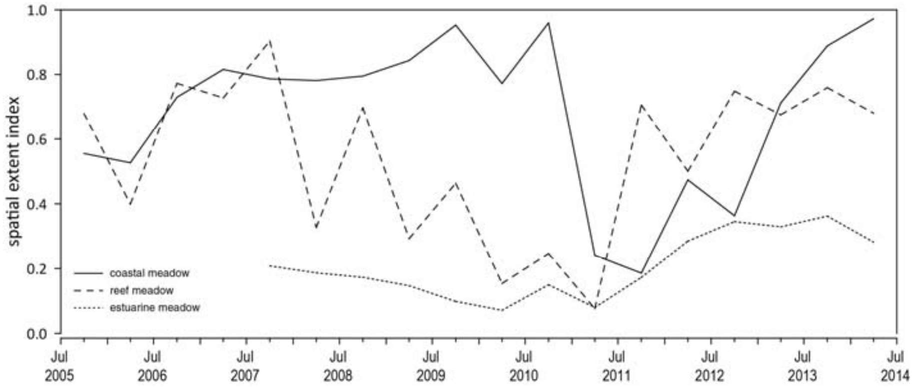

Figure 83. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Mackay Whitsunday NRM region.*

Seagrass reproductive status

Banks of predominately *Halodule uninervis* and some *Zostera muelleri* seeds have varied greatly over the past decade, however, very few seeds have been found in reef habitat meadows. Seed banks were generally greater at coastal than estuary habitats (Figure 84), however, seed banks decreased slightly over the last 12 months relative to the previous monitoring period. Conversely, reproductive effort increased, indicating the meadows may have a reduced capacity to recover from large scale disturbances in the near future.

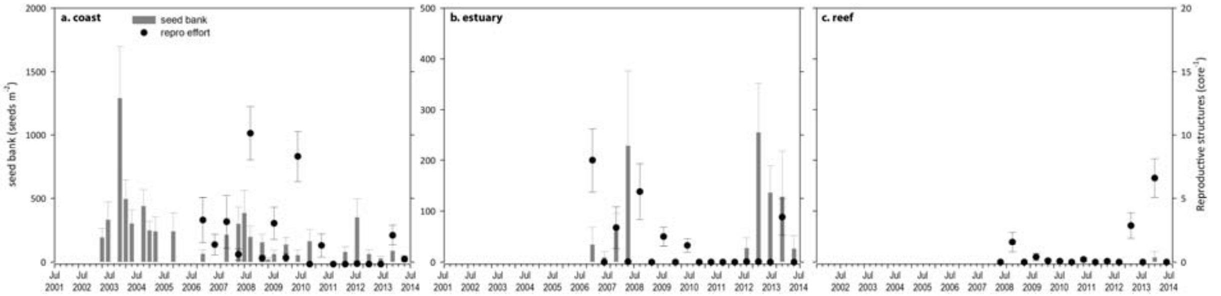

Figure 84. *Seed bank and late dry season reproductive effort at inshore intertidal coast, estuary, and reef habitats in the Mackay Whitsunday region, 2001 - 2014. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled). NB: Y-axis scale for seed banks differs between habitats.*

An examination of the long term trends across the Mackay Whitsunday NRM region (all habitats pooled) suggests seagrass abundance (% cover) is improving, from losses experienced in 2011, but remains well below pre-2009 levels (Figure 85a). Long-term trends also indicate that since 2011, seagrass are allocating significant resources to reproductive structures, which in 2013-14, were approximately half of what they were in 2005-06 (Figure 85b). Seed banks were also relatively small and short lived, well below the peaks of 2006 and 2009 (Figure 85c). Overall this would indicate that seagrass across the region still remaining in a vulnerable state, with a low ability to resistance, and reduced capacity to recover from, large disturbances.

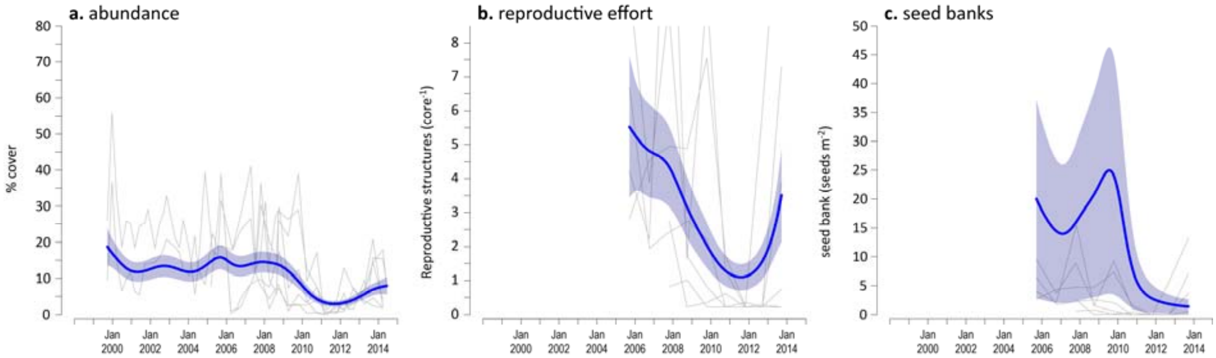

Figure 85. *Seagrass abundance, reproductive effort and seed bank trends in the Mackay Whitsunday region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

3.5.4 Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf molar C:N ratios improved across all habitats in the Mackay Whitsunday region during the 2013 late dry (growing) season, but continue to remain below 20 (Figure 86). In coastal habitats, $\delta^{13}C$ values in *Zostera* leaf tissue remained above (isotopically heavier) the global average in 2013, but decreased in *Halodule* (Appendix 2, Table 37). $\delta^{13}C$ values for foundation species at estuarine and reef habitats during the late dry (growing) season were also below (isotopically lighter) the global average, but within global ranges (Appendix 2, Table 37). Overall, this suggests lower but sufficient carbon available for growth.

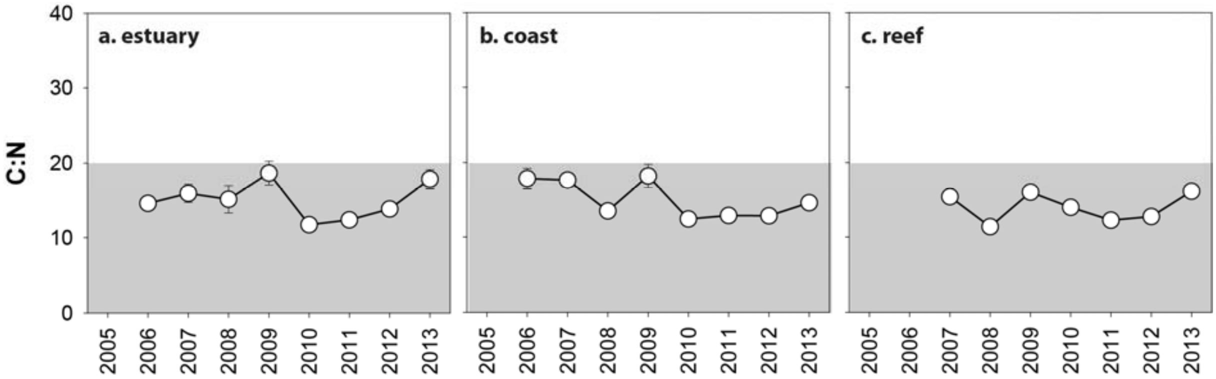

Figure 86. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2013 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

Seagrass leaf molar C:P ratios have remained below 500 for all seagrass habitats over the last 4 years, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 87). N:P ratios for the foundation species also decreased across all habitats in 2013. At estuary and reef habitats, the N:P ratios decreased to <25, but in coastal habitats they remained between 25-30. When coupled with the large P pool, this indicates the greater level of N in coastal environments in 2013; well supplied and balanced macronutrients for growth (high N and P) (Figure 71). Across all habitats, the $\delta^{15}N$ values for the dominant species (*Zostera muelleri*) were above 2‰, and at coastal habitats it was above 4‰, suggesting the primary source of the elevated N was fertiliser or sewage (Appendix 2, Table 37).

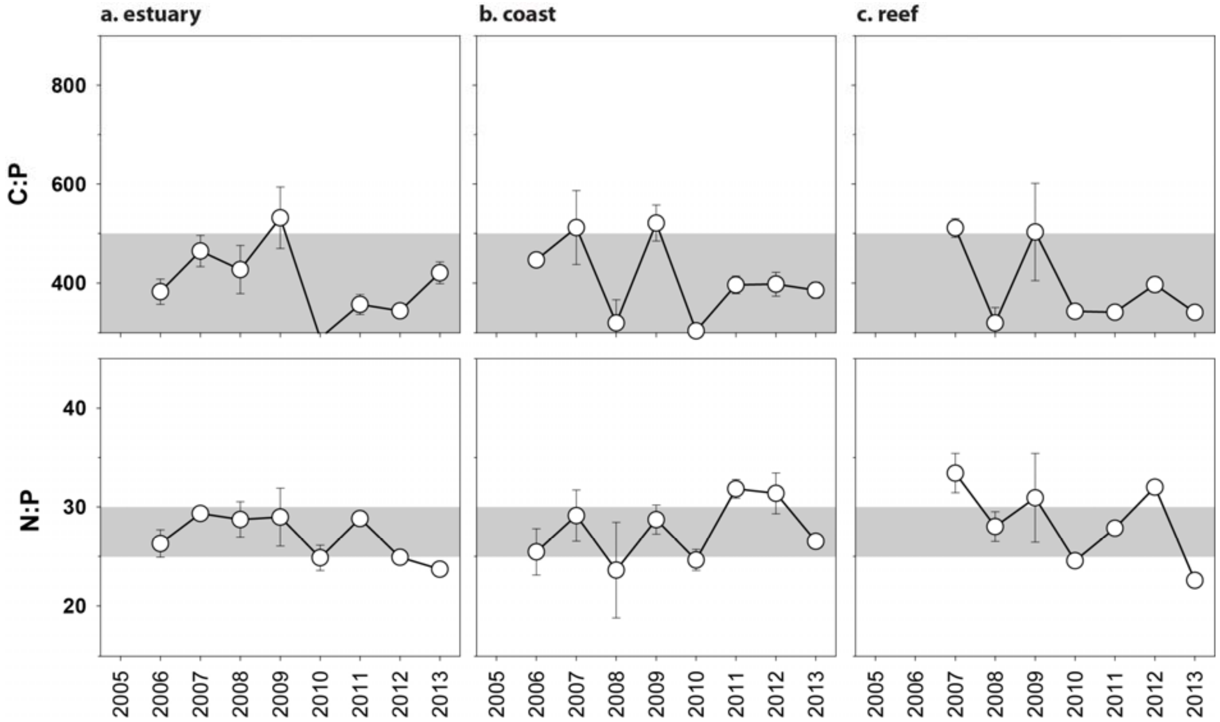

Figure 87. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2013 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades is generally higher in the wet season at coastal habitats, but higher during the dry season at estuary or reef habitats (Figure 88). Epiphyte abundances fluctuated around the long-term (8 year) mean in 2013-14. At estuarine and coastal habitats, epiphyte cover increased well above the GBR long-term average in 2013-14 (Appendix 2, Figure 157, Figure 158), but remained low and below the GBR long-term average at reef habitats (Appendix 2, Figure 159). Epiphyte abundances at coastal habitats during the 2013-14 wet season were not only similar to the previous wet season, but remain some of the higher recorded over the past decade (Figure 88; Appendix 2, Figure 157). Percentage cover of macroalgae remained unchanged and below the GBR long-term average for estuarine and reef seagrass habitats throughout 2013-14 (Appendix 1, Figure 157, Figure 158, Figure 159), but increased in late 2013 at coastal habitats.

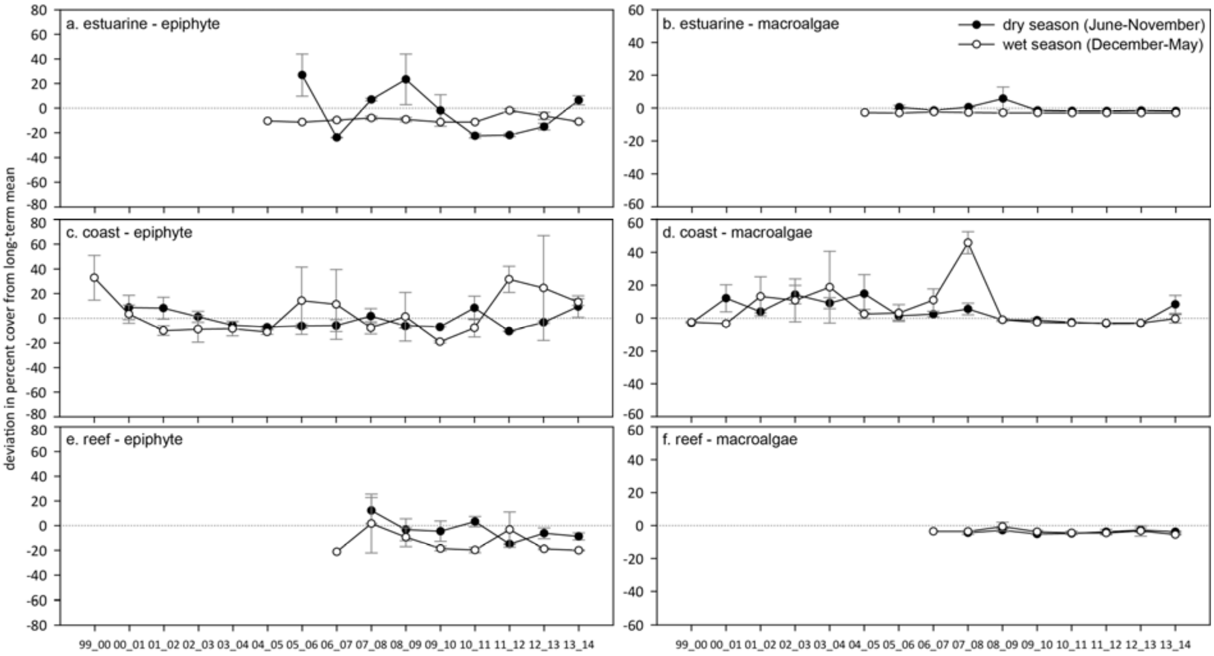

Figure 88. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore intertidal habitat in the Mackay Whitsunday region, 1999 - 2014 (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated between and within years since monitoring was established in late 2000, but the long-term trend indicates a relatively persistent and moderate cover (Figure 89a). Macroalgae were similarly persistent, but appear to "bloom" periodically (every 2-3 years), with reduced abundance since 2009 (Figure 89b). The persistent and higher epiphytic and macroalgae abundance in the Mackay Whitsunday NRM region, were likely in response to high N, as indicated from leaf tissue analysis.

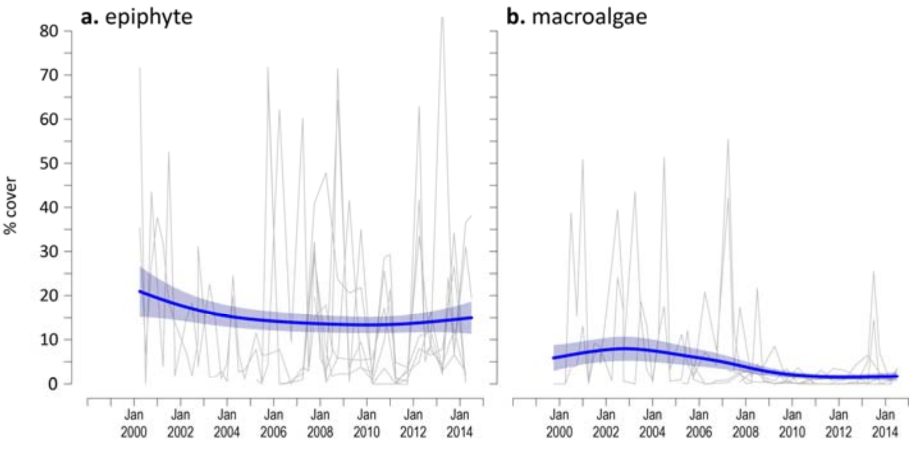

Figure 89. *Epiphyte and macroalgae cover trends in the Mackay Whitsunday region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Mackay Whitsunday habitats during daylight over the 2013-14 monitoring period was higher than the previous monitoring period and were either at or above the long-term median (Appendix 2, Table 39, Figure 169). Of all the intertidal seagrass habitats in the region, the estuarine meadows were exposed the least (22hrs20min) during daylight hours in 2013-14. However, the duration the intertidal estuarine meadows were exposed was greater than the long term median (21hrs) and the highest annual duration in 4 years (Appendix 2, Figure 169). The amount of time that coastal and estuarine habitats were exposed during daylight hours in 2013-14, were similarly above annual median durations (Appendix 2, Table 39). The longest duration of exposure (80hrs 40min) was at one of the coastal meadows in Pioneer Bay (PI2). The higher levels of daytime exposure for intertidal seagrass meadows in all habitats across the region would have provided more stressful environmental conditions for seagrass growth in 2013-14.

Within canopy seawater temperature

Autonomous temperature loggers were deployed at all locations monitored in the region (Appendix 2, Figure 177), however, no data is available from the estuarine sites at Sarina from October 2013 to February 2014 due to logger failure. Within canopy seawater temperatures followed a similar pattern at all habitats over the monitoring period (Appendix 2, Figure 177). 9 days with high temperatures (>35°C) were recorded spread from October 2013 to January 2014, but the highest temperature (37.2°C) for the period was recorded at 2:00pm on the 28 March 2014 at Hamilton Island (Figure 90a). No extreme temperatures (>40°C) were recorded over the last 12 months. Within canopy temperatures in coastal habitats (Pioneer Bay) were on average 0.4°C above the long-term (11 years) average and 0.6°C above the previous monitoring period. In reef intertidal habitats, within canopy temperatures were also above the long-term (7 years) and previous monitoring period by approximately 0.2°C. Overall, the higher temperatures would suggest a slightly more stressful year for seagrass in regards to elevated seawater temperature pressures.

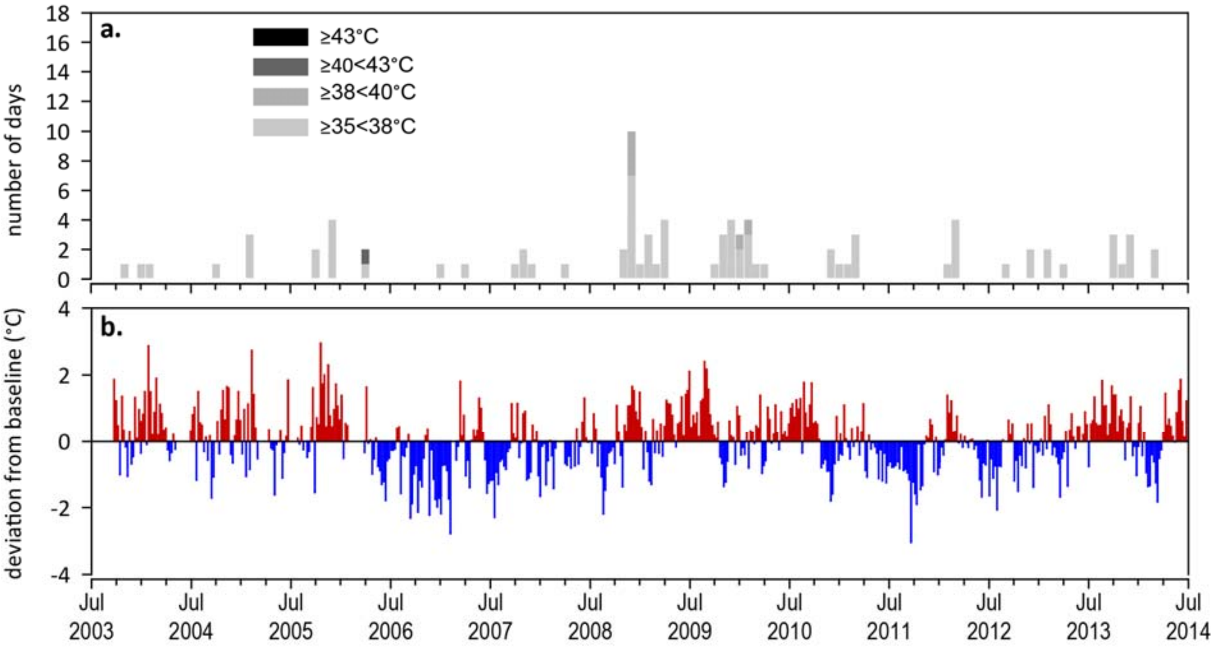

Figure 90. *Inshore sea temperatures within each intertidal seagrass habitat in the Mackay Whitsunday region, September 2003 - June 2014: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

Canopy incident light

Light levels in Mackay-Whitsunday tend to follow a seasonal pattern with a peak in light during the late dry season, however, the peak is not as distinct as in the WT (Figure 91). In 2013-14, light levels were higher than the long-term average being 16.2 mol m^{-2} d^{-1}, compared to a long-term average of

11.9 mol m^{-2} d^{-1}. This increase was driven by rapid recovery of light levels following the wet season low of 2012-13. Hamilton Island had the highest light levels for the Mackay Whitsunday region, and often the highest in the GBR (except Cape York). Daily light for each location within the Mackay Whitsunday NRM region is presented in the Appendix 2 (Figure 189).

Figure 91. *Standardised daily light (28 day rolling average) for inshore intertidal seagrass habitats in the Mackay Whitsunday region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

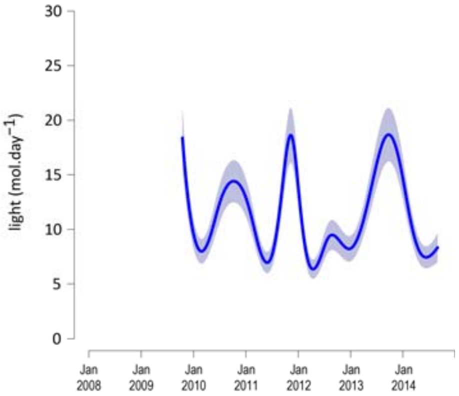

Figure 92. *Seagrass canopy light trend in the Mackay Whitsunday region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

Regional climate and river discharge

Warmer than average climate continued across the Mackay Whitsunday region in 2013-14. The monitoring period was also one of the driest in 5-7 years, and although discharges from rivers in the south of the region were below median for the first time in 8 years, the discharges from rivers in the north remained above median. The region also experienced a greater number of windy days in 2013-14, which would have resulted in resuspension of inshore sediments, reducing water clarity, for a nearly half of the year.

The closest meteorological station to Pioneer Bay is Proserpine airport (27.4km). The mean maximum daily air temperature recorded at Proserpine during 2013-14 was 29.1°C, which was 2.2°C higher than decade average and 0.4°C above the long-term (26 year) average (Appendix 2, Figure 203). The highest recorded daily maximum temperature in 2013-14 was 38°C, which was the second highest in over a decade, preceded only by the previous monitoring period. Above average temperatures were experienced at Hamilton Island and Mackay over the 2013-14 monitoring period (Appendix 2, Figure 204, Figure 205). At Hamilton Island and Mackay (Sarina Inlet), average temperatures were the highest in 4 and 6 years (Hamilton Island = 26.6°C; Mackay = 27.9°C), respectively.

Above average cloud cover was experienced in the north of the region throughout the year. Annual wind speeds in the north of the region (Proserpine = 22.5 km.hr^{-1}) were higher then the previous monitoring period and the long-term (24 year) average, but 19% lower than the decadal average. Wind speeds at Hamilton Island (30.3 km.hr^{-1}) and Mackay (25.7 km.hr^{-1}) were above the previous monitoring period, as well as the decadal and long-term averages (Appendix 2, Figure 206). Overall this resulted in between 121 - 241 days in the north (Proserpine and Hamilton Island) and 185 days in the south (the highest in 7 years) where wind speeds would have resulted in resuspension of inshore sediments from the seabed into the water column, reducing water clarity for a nearly half of the year.

2013-14 was one of the driest in 5-7 years across the region. In the north annual rainfall (Proserpine = 1538mm) was 28% less than decade annual average. At the islands, annual average rainfall (Hamilton = 1483mm) was 18% below the long-term annual average, and in the southern estuaries (Plane Creek = 1671mm), 17% below the decadal but only 3% below the long-term (100yr) annual averages.

Several large rivers discharge into the coastal waters of the Mackay Whitsunday and during floods their plumes extend to locations where seagrass monitoring sites occur. In the north, primary-secondary flood waters from the Proserpine and O'Connell Rivers extend from Repulse Bay to include Hamilton Island (50 km to the north) and secondary-tertiary flood waters extend to Pioneer Bay (85 km to the north) (Collier*, et al.* 2014a). No major river discharges into Sarina Inlet where the estuarine seagrass monitoring sites are located, and there is no flow data available for Plane Creek which flows into the Inlet. However, it could be expected that flows from Sandy Creek or even the Pioneer River during floods could travel south for some extent to expose Sarina Inlet (25-30 km to the south) to primary-secondary plumes.

The period 2013-14 was the first time in 8 years that the volume of freshwater discharged from Sandy Creek and the O'Connell were below median (Appendix 2, Table 41, Figure 217, Figure 218). The Proserpine River experienced above median discharge for the 10th consecutive year. Similarly the discharge from the Pioneer River in 2013-14 was above median. Of the estimated volume discharged from the Pioneer River over the monitoring period (426,441 ML), 70% of the volume discharged occurred between February and April 2014, with the greatest average flows in February (Appendix 2, Figure 217).

3.6 Fitzroy

3.6.1 2013-14 Summary

Seagrass meadows in the Fitzroy region are located mainly on the large shallow sand/mud banks in sheltered areas of the region's estuaries and coasts, or on the fringing reef flat habitats of offshore islands. Environmental drivers of seagrass in these habitats includes high turbidity, desiccation and elevated temperatures (which is linked primarily to the large tide regime). All three seagrass habitat types are monitored in the region.

The regional seagrass abundance declined in 2013-14 but the state remained unchanged as poor. Seagrass abundance at estuarine and coastal habitats declined, while reef habitats remained unchanged. Long-term monitoring at permanent sites within Gladstone Harbour under the Queensland Ports Seagrass Monitoring Program (QPSMP) also reported variable recovery in 2013 (Bryant *et al.* 2014). Substantial recovery was reported in the outer Gladstone Harbour in 2013-14, however, inner harbour sites remained well below pre-2011 levels. Coastal and reef meadows across the region were also composed of a greater than average proportion of *r*-strategist species, which coupled with very poor abundance and very poor reproductive effort suggests a weaker ability to tolerate/resist major disturbances.

Coastal meadows remained relatively stable in extent, allocating resources to production of the greater seed bank, suggesting a higher capacity to recover, however, low reproductive effort in 2013-14 may indicate seed bank limitation in the near future. The estuarine and reef meadows have declined slightly in extent, but the improving reproductive effort and seed banks in the estuarine meadows indicates an improved capacity to recover following any large disturbances. Reef meadows remain vulnerable, and the absence of reproductive effort and a seed bank may indicate that meadows are allocating resources toward vegetative expansion, giving them a very low capacity to recover should they experience major disturbance.

Leaf tissue nutrients, in particular the C:N ratio, showed a variable response compared to previous across the habitat types. C:N increased at coastal and reef sites, indicating an increase in C uptake relative to N, while it declined at estuary site. There was no indication of elevated N in the estuary habitat, although *Zostera muelleri* δ^{15}N values suggests some influence of sewage. Similarly, there was no indication of elevated N at coastal habitats and δ^{15}N values suggested the primary source of N was influenced by fertiliser. Leaf tissue C:N:P ratios at reef habitats suggest decreasing N and some light limitation, although daily light levels were similar to the long-term average.

Climatic conditions in the region over the monitoring period should have been more conducive to seagrass growth than recent years. Although seagrass across the region experienced above average seawater temperatures for the second consecutive year, below median annual daytime tidal exposure would have limited heat and desiccation stress in 2013-14. Also, no extreme temperatures (>40°C) which would result in high stress to plants were measured in 2013-14, and only half the number of days above 35°C were recorded compared to the previous monitoring period. 2013-14 was also one of the driest period in 6-7 years, which resulted in the lowest river discharges in 5 years, which would have minimised light attenuation. Apart from slightly elevated temperatures, the only climatic condition which would impact seagrass was wind, and the greater number of days of strong wind in 2013-14, may have been enough to created periods of physical disturbance coupled with light limitation from resuspend benthic sediments. It should also be noted that seagrass across the region are still in the early stages of recovering from multiple years of climate related impacts which has likely left a legacy of reduced resilience to impacts until they have further recovered. Overall, the Fitzroy regional seagrass state declined in 2013-14, but remained **poor** (Table 24).

Table 24. *Report card for seagrass status (community & environment) for the Fitzroy NRM region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
estuarine intertidal	34	25	33	**31**
coastal intertidal	8	0	67	**25**
reef intertidal	6	0	41	**16**
Fitzroy	22	8	47	**29**

3.6.2 Background

The Fitzroy region covers an area of nearly 300,000 km^2. It extends from Nebo in the north to Wandoan in the south, 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 (Commonwealth of Australia 2013c). 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 GBR 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 (Christensen *et al.* 2006). 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 concern of the quality of the water that is entering the GBR lagoon.

The Fitzroy region experiences a tropical to subtropical humid to semi arid climate. Annual median rainfall throughout the region is highly variable, ranging from about 800 mm to over 1000mm. 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.

The first broad scale survey of seagrass habitat in this region occurred in 1987, followed by more fine scale surveys of Shoalwater Bay (Lee Long *et al.* 1996b), the Dugong Protection Areas of Llewellyn Bay, Ince Bay and the Clairview Region (Coles *et al.* 2002) and Port Curtis to Rodds Bay (Rasheed*, et al.* 2003). Ten species of seagrass have been recorded from this region ranging from the intertidal to a depth of 48m (McKenzie*, et al.* 2010c, Coles*, et al.* 2007). The majority of seagrass in this region exist on large shallow banks flats. Expansive meadows exist on the coastal intertidal flats of Ince Bay, Clairview, Shoalwater Bay and Rodds Bay.

The area of shallow subtidal coastal seagrass habitat in this region is small, as most of the coastline is exposed to south-east winds (Coles*, et al.* 2007). A significant factor contributing to the lack of suitable coastal habitat is the scouring tidal currents and associated high water turbidity in this region which limits light penetration and therefore the depth to which seagrasses can grow. Deepwater seagrasses were generally not found in the central and northern parts of this region, apart from occasional sites in the lee of islands or reefs (Coles *et al.* 2009b).

MMP sites within this region are located in coastal, estuarine or fringing-reef seagrass habitats. Coastal sites are monitored in Shoalwater Bay and are located on the large shallow banks 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 form anthropogenic influence. In contrast, the estuarine sites are located within Gladstone Harbour: a heavily industrialized port. Offshore reef sites are located at Monkey Beach, Great Keppel Island.

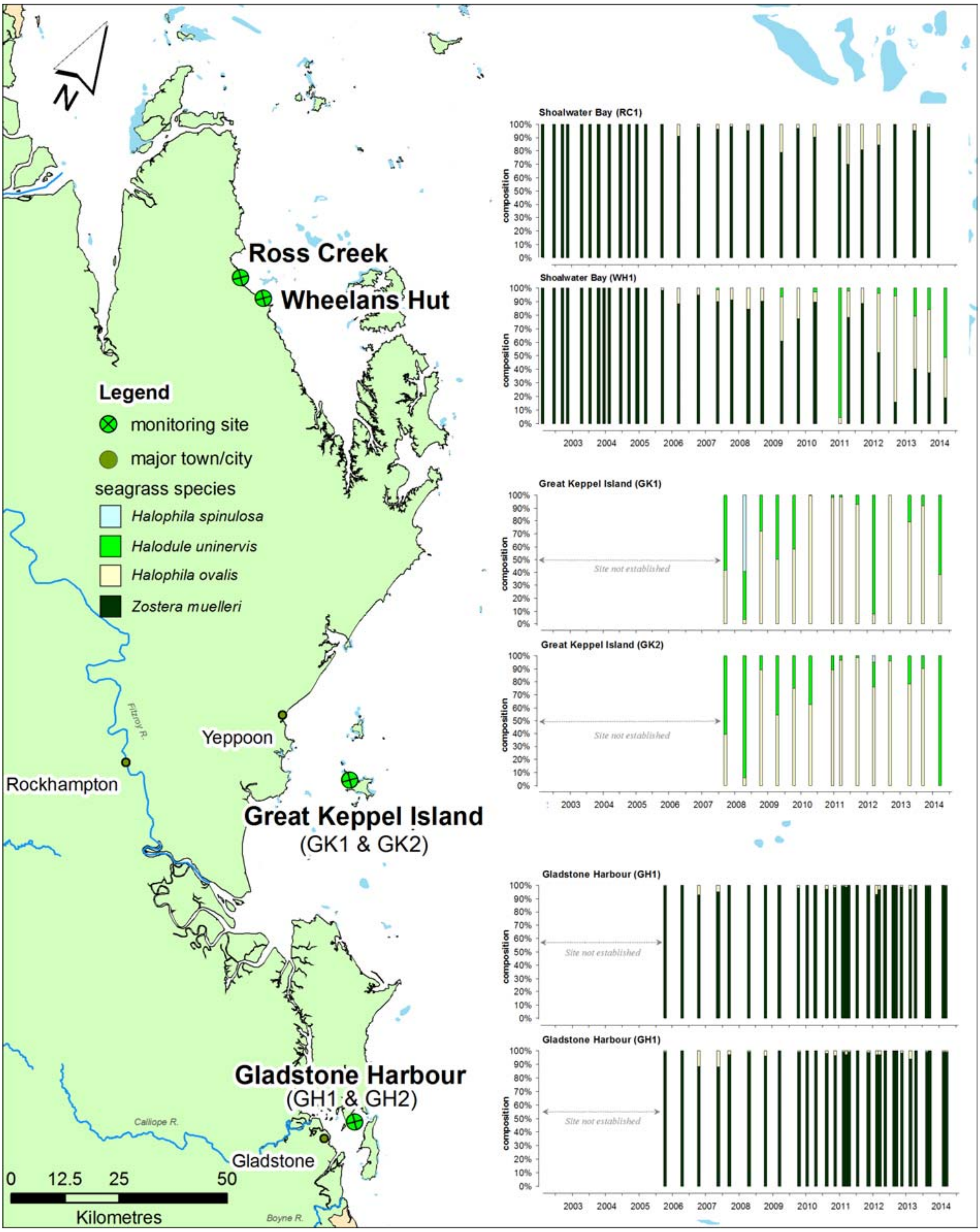

Figure 93. *Location and seagrass species composition of long-term monitoring sites in the Fitzroy region. Please note: some replicate sites within 500m of each other.*

The Shoalwater Bay monitoring sites are located in a bay which is a continuation of an coastal meadow that is protected by headlands. A feature of the region is the large tidal amplitudes and consequent strong tidal currents (Figure 137). 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 above Mean Sea Level (MSL).

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 138). These southern estuary seagrasses (Gladstone, Port Curtis) are highly susceptible to impacts from local industry and inputs from the Calliope River. Port Curtis 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 contains Queensland's largest multi-cargo port (Port of Gladstone) with 50 million tonnes of coal passing through the port annually.

3.6.3 Status of the seagrass community

Seagrass abundance, composition and extent

The regional seagrass abundance declined in 2013-14 but the state remained unchanged as poor. Seagrass abundance and state at estuarine and coastal habitats in the region declined, and remained unchanged at reef. Coastal and reef meadows across the region were also composed of a greater than average proportion of *r*-strategist species, which coupled with very poor abundance and very poor reproductive effort suggests a weaker ability to tolerate/resist major disturbances.

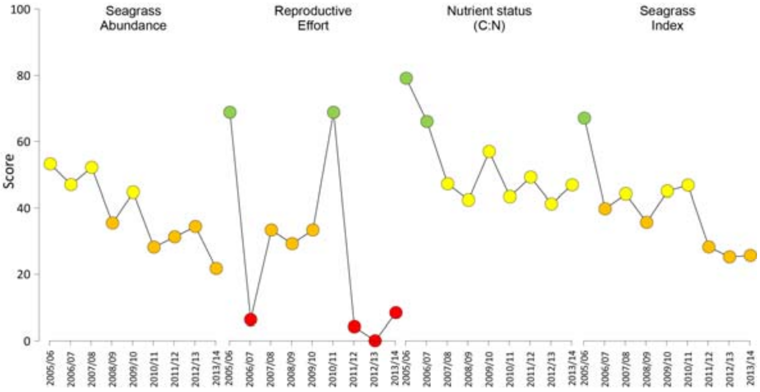

Figure 94. *Report card of seagrass status indicators and index for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Over the 2013-14 monitoring period there was little change (excluding seasonal) in seagrass abundances reef habitats relative to the previous 12 months, however, estuarine and coastal meadows continued to decline in abundance (Figure 95). The long-term average seagrass abundances at coastal habitats in the Fitzroy NRM region were seasonally similar, with late monsoon covers (19.2 ±0.3%) slightly less than those of the late dry (20.8 ±0.4%). In 2013-14, coastal average abundances in the late dry were less than half the long-term (10 year) seasonal average. Estuarine abundances in 2013-14 were within or higher than average (incl. 95% confidence intervals): late dry abundance was near 10% higher than the long term average, while late monsoon was 15% lower.

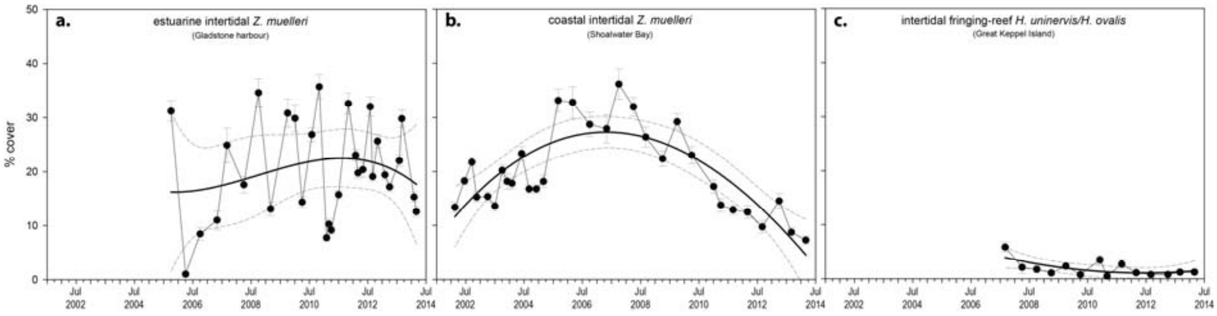

Figure 95. *Changes in seagrass abundance (% cover ±Standard Error) in inshore intertidal habitats of the Fitzroy region, 2001 - 2013: a) estuarine (Gladstone Harbour, b) coastal (Shoalwater Bay) and c) reef (Great Keppel Island). Trendline is 3rd order polynomial, 95% confidence intervals displayed, estuarine r^2 = 0.05, coastal r^2 = 0.65, and reef r^2 = 0.39.*

Coastal meadows monitored in Shoalwater Bay (Ross Creek (RC1) and Wheelans Hut (WH1) remained dominated by *Zostera muelleri,* but over the monitoring period the higher contributions of *Halodule uninervis* and the colonising species *Halophila ovalis* at one of the replicates (WH1) may indicate a level of disturbance across the meadow (Figure 93). The monitoring sites at Great Keppel Island differ greatly from the inshore sites, being generally composed predominately of *H. uninervis* and *H. ovalis* on sand substrate (Figure 93). Over the 2013-14 monitoring period, one of the replicate sites (GK2) was dominated by *H. ovalis*. The estuarine meadows in Gladstone Harbour, located on the extensive intertidal Pelican Banks at the southern end of Curtis Island, remain dominated by *Z. muelleri* and species composition has remained stable (Figure 93).

Seagrass meadows in coastal and reef habitats were of greater than average composition of colonising species, while estuarine habitats were within average compositions for the habitat (Figure 96). This suggests coastal and reef meadows have experienced perturbations in recent years and the greater proportion of *r*-strategist species also suggests weaker ecosystem resistance, particularly for meadows with poor abundance.

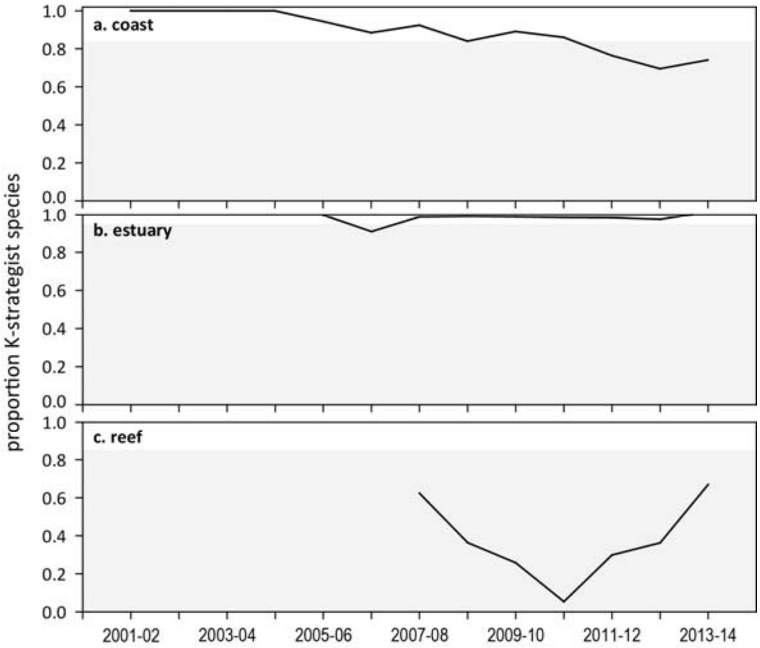

Figure 96. *Proportion of seagrass abundance composed of K-strategist species in inshore intertidal habitats of the Fitzroy region, 2001 - 2014. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 2, Table 36) to determine if changes in abundance were a consequence of the meadow edges changing. The coastal meadows in Shoalwater Bay have remained stable at maximum extent since monitoring began. The estuarine meadows have remained relatively stable over the past 7 monitoring periods, however the meadows at the reef (Great Keppel Island) habitat have varied greatly (Figure 97). The extent of the meadows at Great Keppel Island has remained low since late 2009, and changes appear to be primarily seasonal; increasing in late dry and declining in the late monsoon (Figure 97).

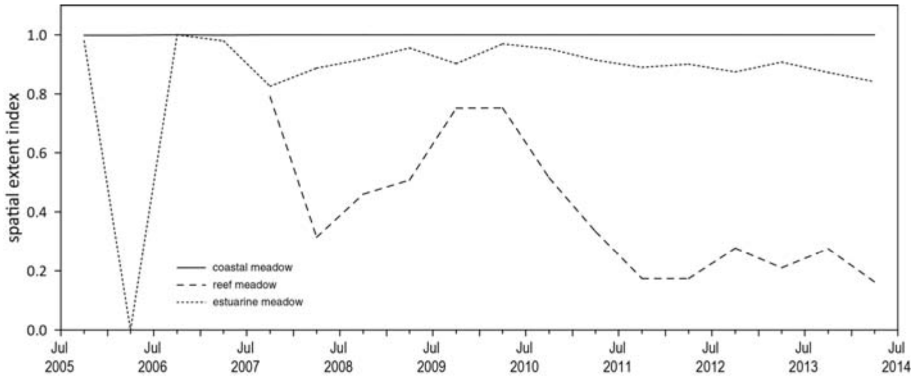

Figure 97. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat across the Fitzroy NRM region, 2005 - 2014.*

Apart from the MMP, seagrass monitoring within the Fitzroy NRM region is also conducted for the Gladstone Ports Corporation Limited as part of the Queensland Ports Seagrass Monitoring Program (QPSMP). Two locations monitored (Pelican Banks north and Rodds Bay) for the Gladstone Ports Corporation Limited are also monitored as part of the MMP.

Long-term monitoring at permanent sites within Gladstone Harbour reported variable recovery in 2013 from the losses which occurred in 2010-11 as a consequence of extreme weather events and associated flooding (Bryant*, et al.* 2014). Substantial recovery was reported in the outer Gladstone Harbour in 2013-14, however, inner harbour sites remained well below pre-2011 levels. During 2013, seagrass at Pelican Banks south declined following Tropical Cyclone Oswald (and subsequent flooding) earlier in the year, and although cover remains low, the presence of a permanent standing crop of seagrass provides mechanisms for seagrass recovery through clonal growth (Bryant*, et al.* 2014). At nearby Facing Island, seagrass recovery over the 2013 growing season was also low compared with 2012 (Bryant*, et al.* 2014).

At inner harbour sites, there have been significant declines in seagrass cover since 2009 with limited recovery (Bryant*, et al.* 2014). The presence of a viable seed bank at Wiggins Island indicates some capacity for seagrass to recover, however, replenishment of the seed bank may be limited if recovery does not progress. At Black Swan, seagrass cover has continued to decline, which may in part be attributed to algal mats that were present over several months at the start of the growing season. Overall, indications are that seagrass should continue to recover across the Harbour if climatic conditions are favourable over the 2014-15 growing season (Bryant*, et al.* 2014).

Seagrass reproductive status

Seed banks have increased in estuary and coast habitats over the last 2-3 monitoring periods, however remain absent in reef habitats in 2013-14 (Figure 98). Reproductive effort, however, is low across all habitats, with a slight increased in estuarine meadows in the late dry 2013. The improving seed banks and reproductive effort at estuary sites indicates an improved capacity to recover following disturbance (Figure 98). Alternatively, at coastal meadows, the greater seed bank suggests a higher capacity to recover, although poor reproductive effort may indicate seed bank limitation in the near future. The absence of reproductive effort and a seed bank at reef habitats (Figure 98), may indicate that meadows are allocating resources toward vegetative expansion rather than seed production or sexual reproduction. This also suggests a very low capacity to recover following disturbance.

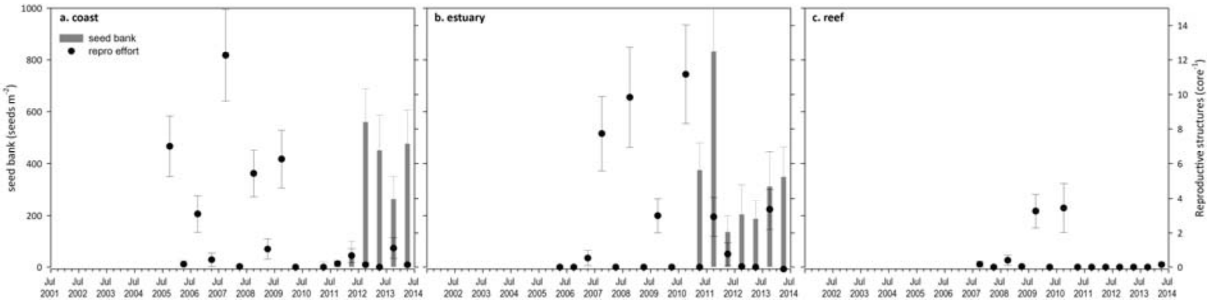

Figure 98. *Seed bank and late dry season reproductive effort for inshore intertidal coastal, estuary and reef habitats in the Fitzroy region, 2001 - 2014. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

An examination of the long term trends across the Fitzroy NRM region (all habitats pooled) suggests seagrass abundance (% cover) slightly increased from 2002 to 2008, but has since progressively declined to baseline abundances (Figure 99a). Long-term trends also indicate that seagrass are progressively allocating less resources to reproductive structures, which in 2013-14, were less than a sixth of what they were in 2005-06 (Figure 99b). Surprisingly, seed banks have improved, peaking immediately following the extreme weather events of 2011 (Figure 99c). Overall this would indicate that seagrass across the region still remain in a vulnerable state, with a low ability to resist and reduced capacity to recover from, large disturbances.

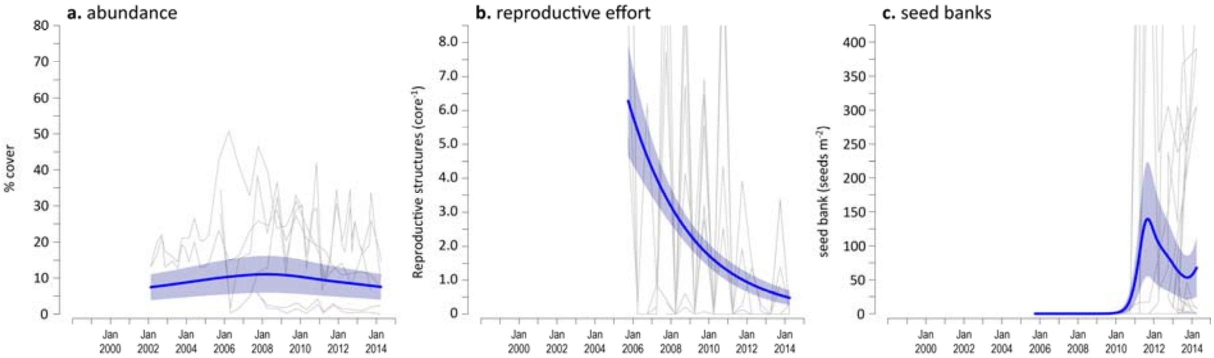

Figure 99. *Seagrass abundance, reproductive effort and seed bank trends in the Fitzroy region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

3.6.4 Status of the seagrass environment

Seagrass tissue nutrients

Seagrass growing in the Fitzroy NRM region appear to differ in the relative compositions of carbon to nitrogen (C:N < 20) depending on habitat (Figure 100). Plants in reef and estuary habitats either remained low or declined in carbon relative to nitrogen in 2013 (seagrass leaf molar C:N ratios <20), which may indicate either reduced light availability or elevated N. At coast habitats, however, the ratio which has remained below 20 for the last three years increased above 20 (Figure 100). $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were either within global ranges or below (isotopically lighter) the global average (Appendix 2, Table 37), suggesting low and possibly limited carbon available for growth.

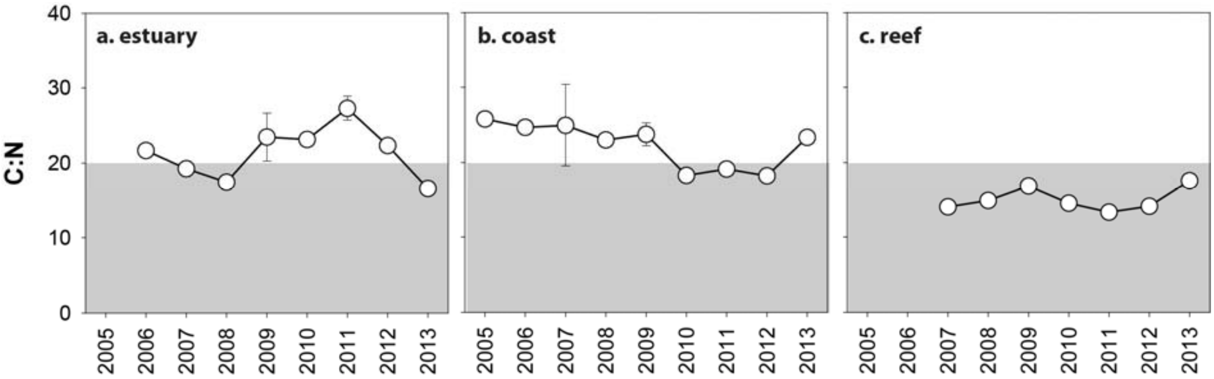

Figure 100. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

All seagrass habitats in the Fitzroy region had seagrass leaf molar C:P ratios below 500 in 2013, indicating nutrient rich habitats (large P pool) (Figure 101). Leaf tissue N:P ratios for foundation species were mixed depending on habitat in late dry 2013. N:P ratios at coastal meadows continued to decrease below 25 (Figure 101); indicating the plants were low (possibly limited) in N relative to P. At reef habitats, N:P ratios also continued to decrease but remained above 25 and <30 in late dry 2013 (Figure 101); indicating decreasing N in the environment but that the plants remained replete (well supplied and balanced macronutrients for growth). Estuarine meadows also remained replete in 2013, but the increase in the N:P indicating an decrease in p (Figure 101).

Although N was high in the leaf tissue of *Zostera muelleri* in the estuary habitat (Gladstone Harbour), there was no indication of elevated N at any habitats in the Fitzroy NRM region in 2013. The $\delta^{15}N$ values in *Zostera muelleri* leaf tissues suggested the primary source of N was either from N_2 fixation or fertiliser in the coastal habitats, but higher concentrations (>2‰) suggests some influence of sewage in the estuary (Appendix 2, Table 37). The C:N:P ratios in *Halodule uninervis* leaf tissue from reef habitats in 2012, suggest some light limitation as N has decreased between 2011 and 2013.

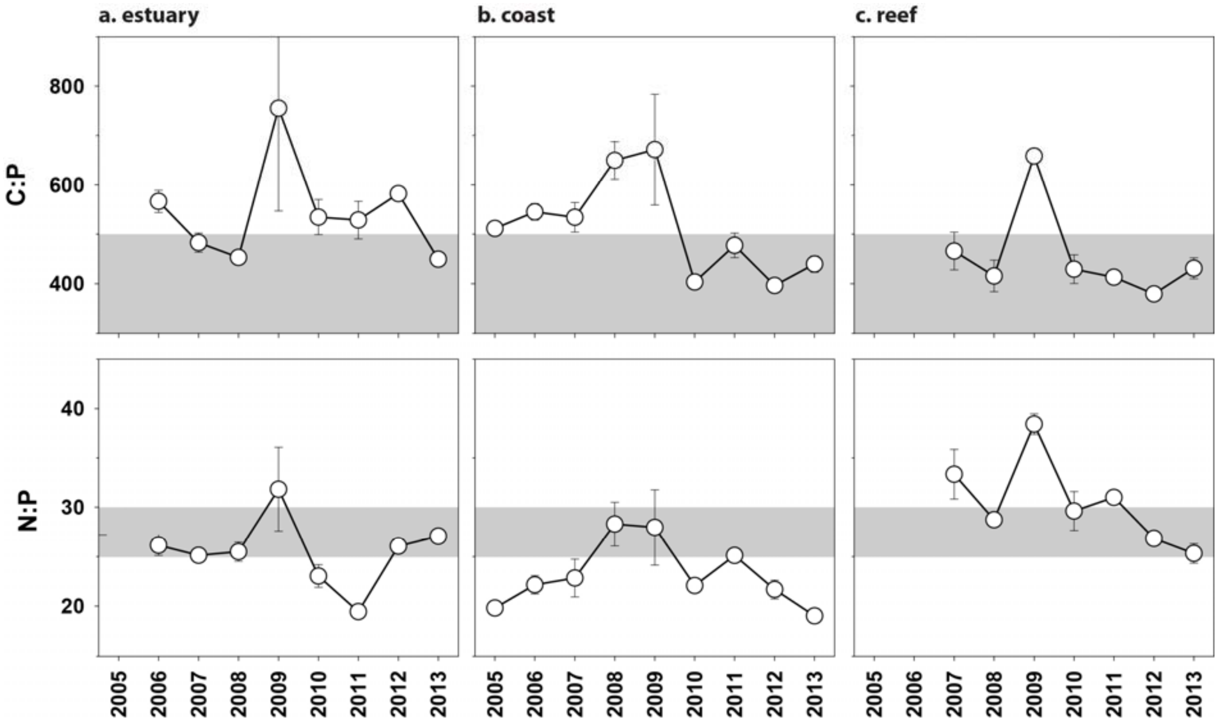

Figure 101. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues. N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Epiphytes and Macroalgae

Epiphyte cover at coast and reef habitats either decreased or remained below the GBR long-term average over the 2013-14 monitoring period (Figure 102; Appendix 2, Figure 161, Figure 163). At estuary habitats, however, epiphyte cover fluctuated seasonally, increasing above the GBR long-term average (Appendix 2, Figure 162). Macroalgae cover remained unchanged at coastal and estuarine meadows in 2013-14 relative to the GBR long-term average, but marginally increased during the late monsoon at Great Keppel Island (reef habitat) (Figure 102; Appendix 2, Figure 163).

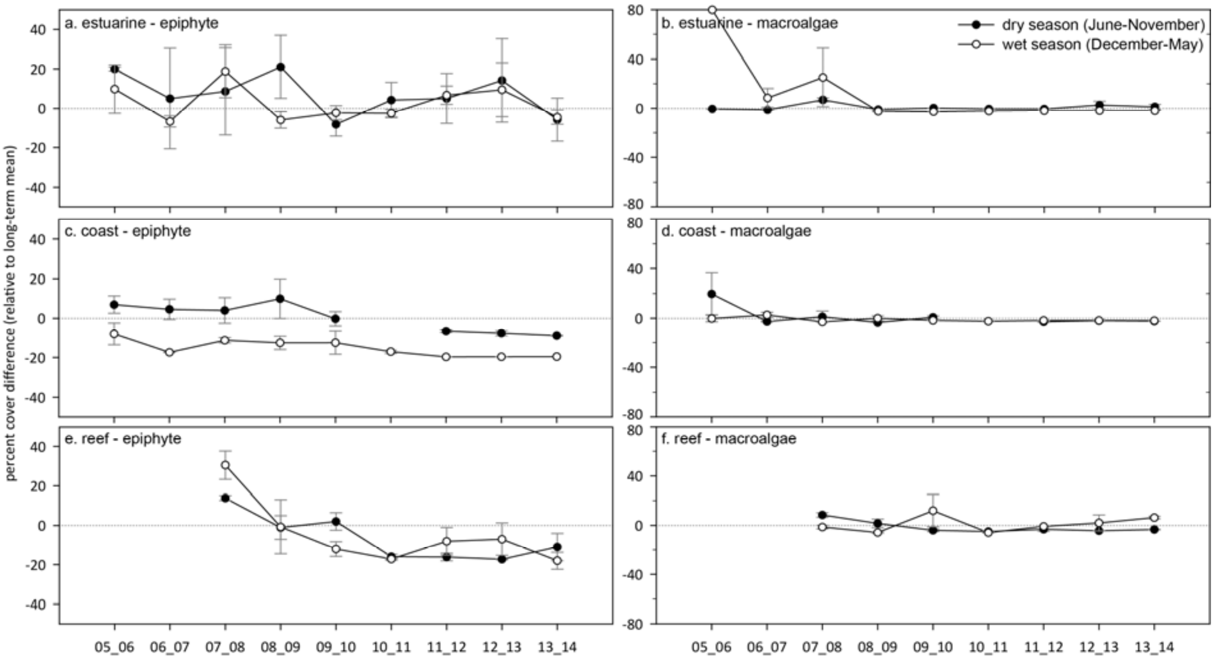

Figure 102. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Fitzroy region, 2005 - 2014 (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated between and within years since monitoring was established in late 2005, but the long-term trend indicates a progressive decline (Figure 103a). Macroalgae have similarly progressively decreased since 2005, but occasionally "bloom" (every 2-3 years) (Figure 103b). The decreasing epiphytic and macroalgae abundance in the Fitzroy NRM region, were likely in response to reduced light, with occasional "blooms" the result of N pulses.

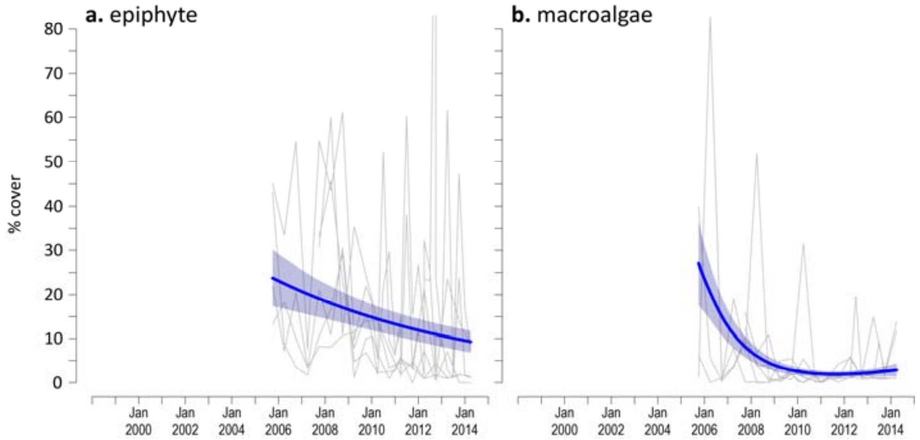

Figure 103. *Epiphyte and macroalgae cover trends in the Fitzroy region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Fitzroy NRM region coastal and reef habitats during daylight over the 2013-14 monitoring period were below long-term medians (Appendix 2, Table 39). However, in 2013-14 the meadows on the intertidal banks of the Gladstone Harbour estuary were exposed for approximately 6 hours above median for the first time in 4 years (Appendix 2, Figure 170). The meadows which were exposed for the longest time during daylight, were in

Shoalwater Bay (226hrs 50min); these were the longest duration of any meadows monitored as part of the MMP (Appendix 2, Table 39). These high expose times are a consequence of the large tides (up to 7.6m) experienced in the area (Maxwell 1968). Overall, the lower or near median levels of daytime exposure for intertidal seagrass meadows across all regional habitats would have provided a more conducive environmental conditions for seagrass growth in 2013-14.

Within meadow canopy temperature

Autonomous temperature loggers were successfully deployed at all monitoring locations over the monitoring period (Appendix 2, Figure 178). The lowest mean temperatures across the region occurred in July/August and highest in January. Average annual temperatures at all habitats across the region were above long-term (8 year) annual averages. At the reef habitats, the average annual temperature in 2013-14 was 0.3°C above both the long-term and 2012-13 annual averages. At coastal habitats (Shoalwater Bay), the annual average temperature was 0.4°C above the long-term and 0.5°C above the previous monitoring period. In the estuary habitats (Gladstone Harbour), the average annual temperature in 2013-14 was similar to the previous year, which resulted in 2 consecutive years with temperatures 0.6°C above the long-term (7 year) annual averages.

High sea water temperatures (>35°C) within the seagrass canopy were recorded from November 2013 to May 2014, with the highest (38.6°C) at Gladstone Harbour on 30 March 2014 (at 3pm) (Appendix 2, Figure 178). This was below the maximum ever recorded in the region (40.9°C, November 2003 to February 2004, Limpus*, et al.* 2005). Sea water temperatures exceeded 35°C for nearly half the number of days in 2013-14 (29 days) compared to the previous year (Figure 104).

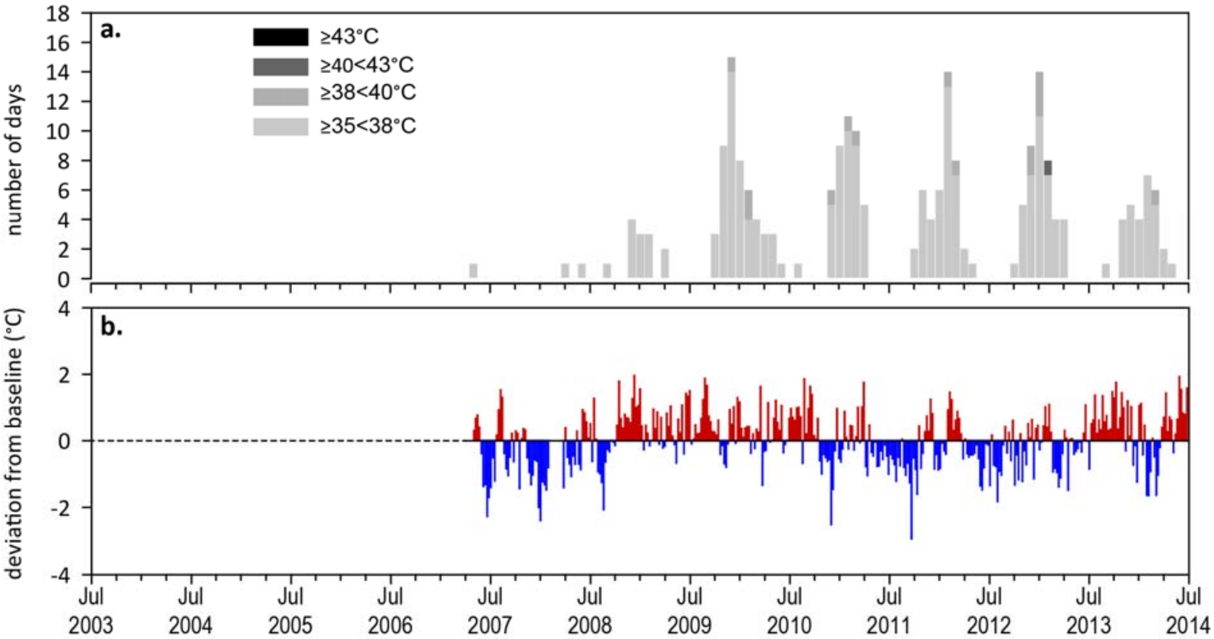

Figure 104. *Inshore sea temperatures for intertidal habitats in the Fitzroy region, September 2003 - June 2014: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 7-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

Canopy incident light

As for the Wet Tropics, light levels in the Fitzroy NRM region have a strong peak in the late dry and early wet season (September to January), followed by sharp declines with the onset of the wet season. During 2013-14, daily light (14 mol m^{-2} d^{-1}) was similar to the long-term average (14.3 mol m^{-2}

d^{-1}). Daily light is consistently lowest at Pelican Banks, in Gladstone Harbour (9.9 mol m^{-2} d^{-1}).). Daily light for each location within the Fitzroy NRM region is presented in the Appendix 2 (Figure 190).

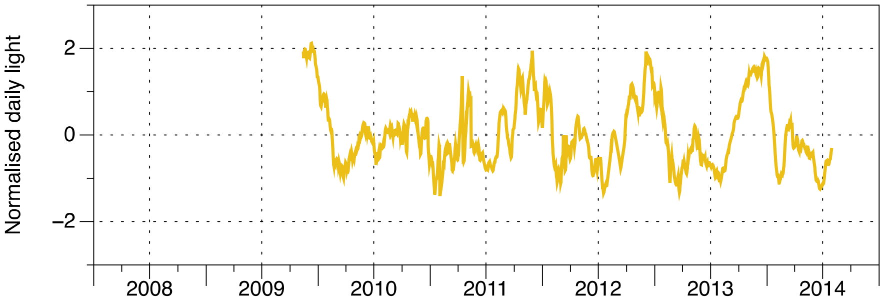

Figure 105. *Standardised daily light (28 day rolling average) for inshore intertidal habitats in the Fitzroy region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites. Some of the Pelican Banks data for provided courtesy of Gladstone Ports Corporation Ltd and Vision Environment Pty Ltd.*

Examination of the long-term trend in daily light shows yearly fluctuations, with the 2013-14 monitoring period one of the highest and longest durations of available light (Figure 106).

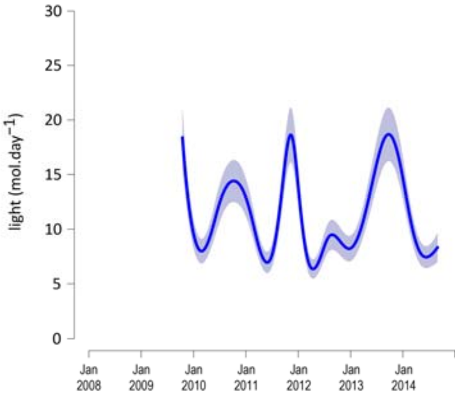

Figure 106. *Seagrass canopy light trend in the Fitzroy region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

Regional climate and river discharge

Seagrass meadows across the region experienced above average annual maximum daily air temperatures (Shoalwater Bay = 28.3°C, Great Keppel Island = 26.1°C, Gladstone Harbour = 28.6°C) over the 2013-14 monitoring period. Annual maximum air temperatures at coastal and reef habitats were 0.7°C higher than the 2012-13 monitoring period, as well as 0.3°C above the decadal and long term averages (Appendix 2, Figure 207, Figure 208, Figure 209). The greatest difference was in estuarine habitats, where average annual air temperature in 2013-14 was 1.0°C and 0.9°C higher than the previous period and long-term (22 years) respectively. These, however, were not the highest for the decade, which was experienced over the 2009-10 across the region.

Wind speeds across the region were higher (~3-5%) than the previous monitoring period and long-term (22 year) annual averages. Seagrass meadows would have experienced approximately 100 days of winds strong enough (>25 km.hr^{-1}) to re-suspend sediments and reduce water clarity (Appendix 2, Figure 210). Annual average wind speeds in 2013-14 were the highest in 5 to 7 years in the south and north respectively.

2013-14 was the driest monitoring period in 6-7 years, with the regions seagrass meadows experiencing below average rainfall. Rainfall across the region was 33% to 54% below the average annual rainfall experienced in the previous monitoring period, in the north and south respectively.

Rainfall in Shoalwater Bay (835mm) was 13% below the annual average, while at Great Keppel Island (1119mm) and Gladstone Harbour (752mm) , totals were 16% below the long-term (22year) annual average.

Several rivers discharge into the coastal waters of the Fitzroy, but the largest by far is the Fitzroy River and during floods its plumes extend 100's of km north to locations where coastal and reef seagrass monitoring sites occur. Primary-secondary flood waters from the Fitzroy River extend into Shoalwater Bay (200 km to the north) and secondary-tertiary flood waters extend out to Great Keppel Island (34 km to the north) (Collier*, et al.* 2014a). The rivers that discharge into Gladstone Harbour are the Calliope and the Boyne, which are within 10 km of the estuarine monitoring sites on Pelican Banks (Port Curtis). During floods, freshwater-primary flood waters extend out to the sites, exposing the seagrass to elevated total suspended solids and Photosystem II (PSII) herbicides (Michelle Devlin, JCU, pers. comm.).

2013-14 was the 1st monitoring period in 5 years where the total discharges from all rivers in the region were below median (Appendix 2, Table 41). Approximately 48% of the volume discharged from the Fitzroy River was between February and April 2014, with the highest volume in February (Appendix 2, Figure 219). For the other rivers, approximately 75% of the volume discharged occurred in March 2015 for the Calliope Rivers, while in the Boyne, discharges were more dispersed, with 11% occurring in June 2013, 10% in November 2013 and 17% in March 2014 (Appendix 2, Figure 220).

3.7 Burnett Mary

3.7.1 2013-14 Summary

Only intertidal estuarine seagrass meadows located in bays protected from SE winds and wave action were monitored in the Burnett Mary NRM region. The main ecological drivers in these environments are exposure to wind waves, elevated temperature, flood runoff and turbidity. Seagrasses are monitored at locations in the north and south of the Burnett Mary Region. Since monitoring was established, the meadows have come and gone on an irregular basis. Seagrass abundance in 2013-14 increased across the region, albeit marginally in the north at Rodds Bay, and the overall rate of change has been positive for the last 5 years. Nevertheless, abundances remained low and in a very poor state. The greater than average proportion of colonising species in the meadows suggests weaker ecosystem resistance, particularly as the meadows were of poor abundance. Meadow extent increased at both locations over the last 12 months, however, seagrass was lost from Rodds Bay monitoring sites in late dry 2013. A *Zostera muelleri* seed bank has persisted across the region since 2011, with the largest bank measured in late dry 2013 at Urangan, indicating a high capacity to recover following disturbance. However, the very low reproductive effort suggests seed bank limitation in the near future.

Zostera muelleri leaf tissue analysis in late 2013, suggested sufficient but possibly low carbon available for growth and that the plants were possibly limited or mobilising/allocating N away from their leaves. Leaf tissue $\delta^{15}N$ value were higher in 2013 than previous, which indicated either fertiliser and/or sewage influence as the primary N source. Epiphyte abundance also increased above the GBR long-term average in 2013-14, possibly a result of high available N.

Although climatic conditions in the region improved over the monitoring period, they were less than conducive to seagrass growth. The drier conditions may have resulted in the lowest river discharges in 7 years, however, the windier and warmer conditions coupled with the above median annual daylight tidal exposure experienced in 2013-14, would have elevated heat and desiccation stress. The below average daily light experienced across the region was like the result of the highest number of stronger wind days in 6 years resuspending benthic sediments and limiting light during the main seagrass growing season. Overall this results in the state of seagrass in the Burnett Mary region increasing only slightly in 2013-14, and remaining **poor** for the 8th consecutive year (Table 25).

Table 25. *Report card for seagrass status (community & environment) for the Burnett Mary NRM region: June 2013 – May 2014. Values are indexed scores scaled from 0-100; 🟩 = very good (80-100), 🟩 = good (60 - <80), 🟨 = moderate (40 - <60), 🟧 = poor (20 - <40), 🟥 = very poor (0 - <20).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
estuarine intertidal	10	0	77	**29**
coastal intertidal	*not monitored*			
Burnett Mary	10	0	77	**29**

3.7.2 Background

The Burnett Mary Region encompasses a land area of more than 56,000 km^2, a marine area of almost 10,000 km^2 and supports a population of over 200,000 people. The region is comprised of a number of catchments including the Baffle Creek, Kolan, Burnett, Burrum and Mary Rivers (Commonwealth of Australia 2013b) (Figure 107). Only the northern most catchment of the Burnett Mary region, the Baffle Basin, is within the GBR and includes the tidal mudflats and mangroves in Rodds Peninsula/Turkey Beach considered ‘near pristine’ (Burnett Mary Regional Group 2005).

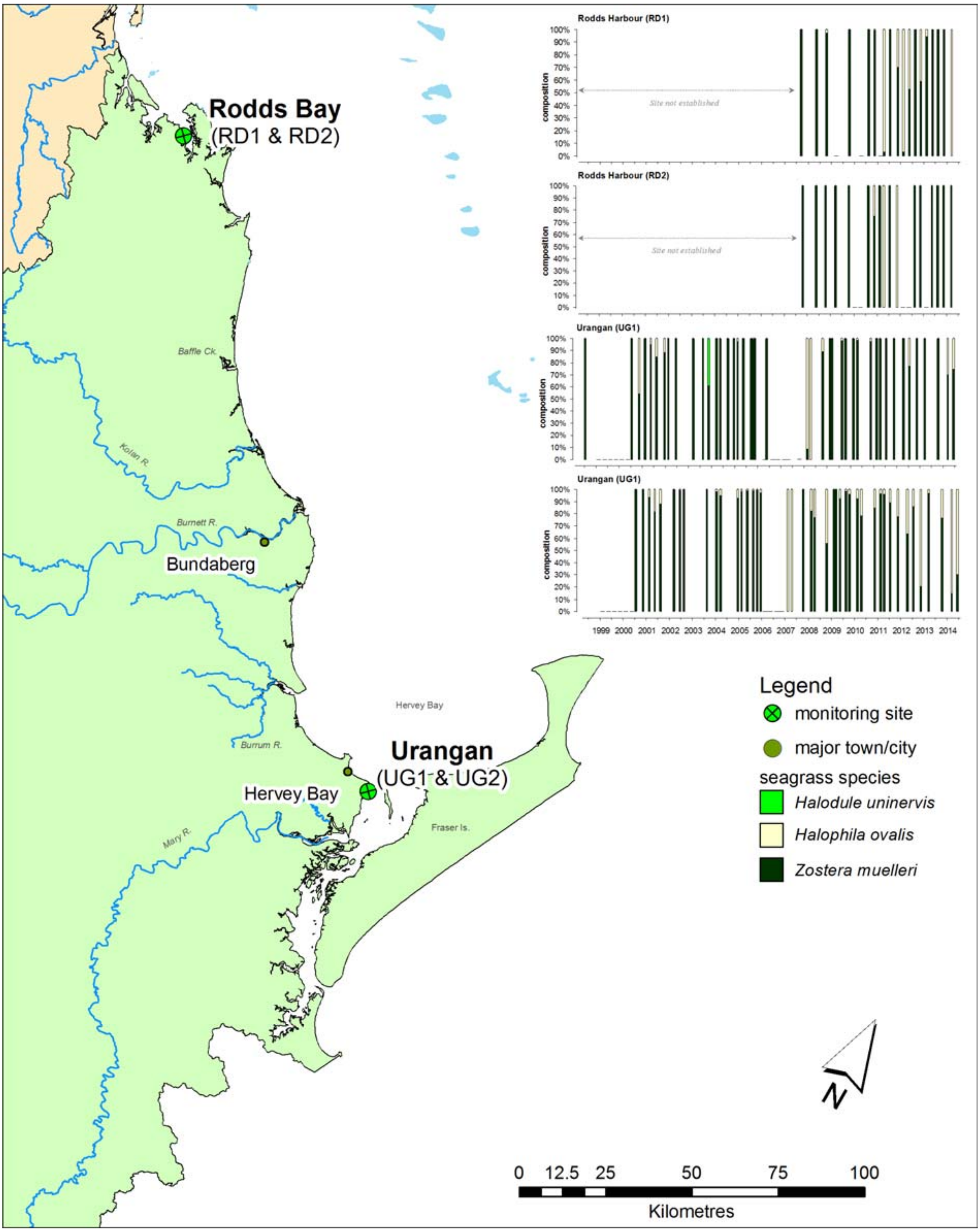

Figure 107. *Location and species composition of long-term monitoring sites in the Burnett Mary region. Please note: replicate sites are within 500m of each other.*

Principal land uses in the Burnett-Baffle area are beef cattle grazing (the largest though currently declining), small crop growers, forestry (including plantations), tourism and fishing (Burnett Mary Regional Group 2010). Other significant land uses include conservation, rural and urban residential development (Prange and Duke 2004). Located in the northern section of the region is Rodds Bay, where freshwater input is minor from seasonal flows in small catchments, and water quality generally good - little organic/inorganic pollution even though Rodds Harbour has elevated natural turbidity and minor increases in sediment loads from grazing and development (Ford 2004). The southern region includes the Mary River catchment (9181km²) and although outside the GBR Marine Park, is highly connected through oceanographic processes and plays a major driver of southern GBR ecosystems (Burnett Mary Regional Group 2013). Grazing predominates and utilises 42% of the land area of the Mary catchment. High rainfall areas to the south and east host the majority of residential development, horticulture, and intensive livestock. Forestry and nature conservation, each of which occupies 18% of the catchment, are the second largest land uses, with intensive anthropogenic uses (residential, manufacturing, services, waste treatment, transport, and services) occupying 13% of the catchment area (Walker and Esslemont 2008). Sediment, total nitrogen and total phosphorus exports from the Mary catchment to the coastal receiving waters are estimated to be 455 kt.yr^{-1}, 1.541 kt.yr^{-1} and 0.344 kt.yr^{-1}, respectively (DeRose *et al.* 2002). Since European settlement, relative erosion rates in some sections of the Western Mary have increased 2 to 7 fold, and 4 to more than 14 fold in the Upper Mary (Esslemont *et al.* 2006).

Seagrass in the region were first broadly surveyed in 1988 (Lee Long *et al.* 1992) with the section north of Rodds Peninsula resurveyed at a finescale in 2002 (Rasheed*, et al.* 2003). Seven seagrass species have been reported in the Burnett Mary NRM region (McKenzie and Yoshida 2008), five within the marine park boundary (Coles*, et al.* 2007). Meadows have been reported throughout the inlets protected from the south easterly winds and oceanic swell, and throughout Hervey Bay and the Great Sandy Strait. No seagrass has been mapped on the exposed coastline between Bustard Head to just north of Hervey Bay. Within the GBRWHA boundaries, the majority of seagrass meadows are within coastal and estuary habitats. South of the GBRWHA boundary in one of the largest single areas of seagrass resources on the eastern Australian seaboard (McKenzie and Yoshida 2008). The southern marine area of the Burnett Mary NRM region includes large meadows in deepwater, coastal (including intertidal and shallow subtidal) and estuarine habitats (McKenzie and Yoshida 2008).

Meadows in the north of the Burnett Mary region generally face low levels of anthropogenic threat, and monitoring sites are located within Rodd’s Bay. The only other location that is monitored within this region is in the south, at Urangan (Hervey Bay). This location is adjacent to the Urangan marina and in close proximity to the mouth of 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 140).

3.7.3 Status of the seagrass community

Seagrass abundance, composition and extent

Only estuarine habitats are monitored in the Burnett Mary NRM region. Since monitoring was established, the meadows have come and gone on an irregular basis.

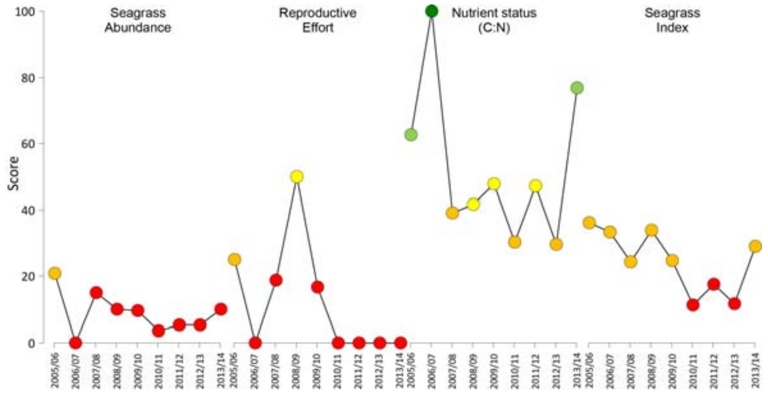

Figure 108. *Report card of seagrass status indicators and index for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (80-100),* 🟩 *= good (60 - <80),* 🟨 *= moderate (40 - <60),* 🟧 *= poor (20 - <40),* 🟥 *= very poor (0 - <20).*

Seagrass abundance in 2012-13 increased across the region, albeit marginally in the north at Rodds Bay, and the overall rate of change has been positive for the last 5 years. Nevertheless, abundances remained low and in a very poor state. When meadows are present, a seasonal pattern is apparent within years across with greater abundance in the late dry season (McKenzie *et al.* 2013).

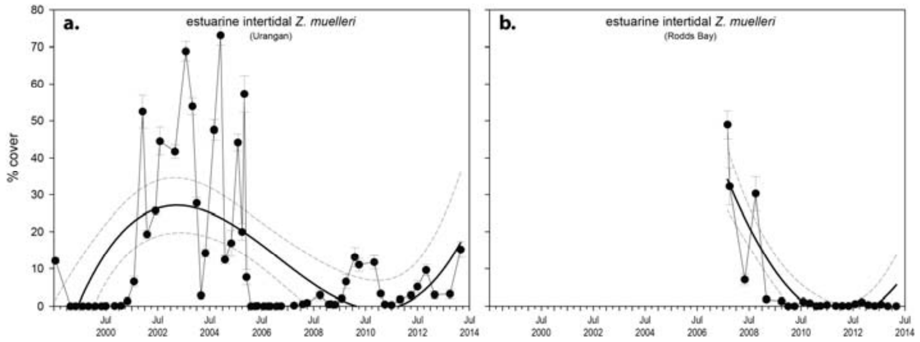

Figure 109. *Changes in seagrass abundance (% cover ±Standard Error) at estuarine meadows in Burnett Mary region from 1999 to 2011. Urangan trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.30. Rodds Bay trendline is 2nd order polynomial, 95% confidence intervals displayed, r^2 = 0.74.*

The estuarine seagrass habitats were dominated by *Zostera muelleri* with varying components of *Halophila ovalis* over the monitoring period (Figure 107). The greater than average proportion of *r*-strategist (colonising) species in the meadows suggests weaker ability to tolerate/resist major disturbances, particularly as the meadows are of poor abundance.

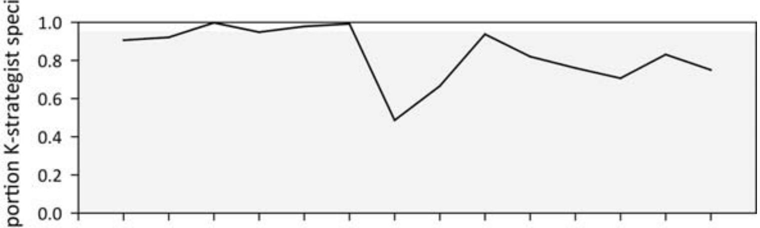

Figure 110. *Proportion of seagrass abundance composed of K-strategist species. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 2, Table 36) to determine if changes in abundance were a consequence of the meadow edges changing. Over the last 12 months the seagrass meadows at both locations decreased slightly (Urangan) or were lost (Rodds Bay) after initially expanding in the previous monitoring period (Figure 111). Expansion of the remnant isolated patches of seagrass increased in early 2014. Overall, meadows in 2013-14 were of slightly less extent than the previous monitoring period, but still remained greater than a 20th of their original extent.

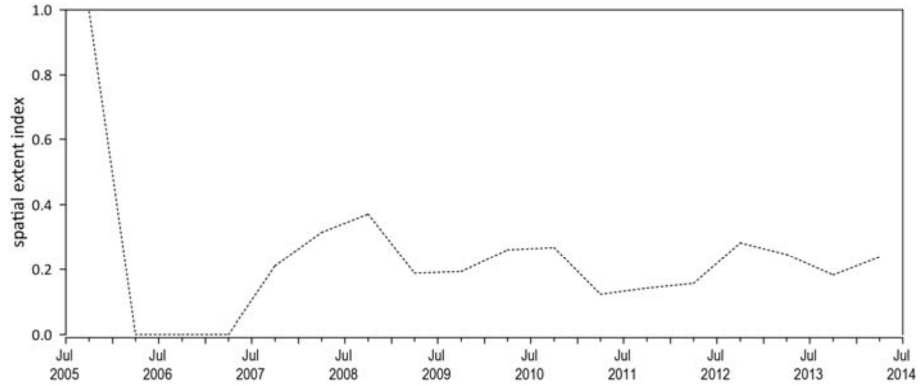

Figure 111. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each habitat and monitoring period across the Burnett Mary NRM region.*

Seagrass reproductive status

Seagrass seed banks in Burnett Mary NRM region meadows differ greatly between seasons in 2013-14 (Figure 112). A *Zostera muelleri* seed bank persisted throughout the year with the largest seed banks since monitoring commenced measured in late 2013 (Figure 112); indicating a high capacity to recover following disturbance. However, the very low reproductive effort suggests seed bank limitation in the near future due to reduced replenishment.

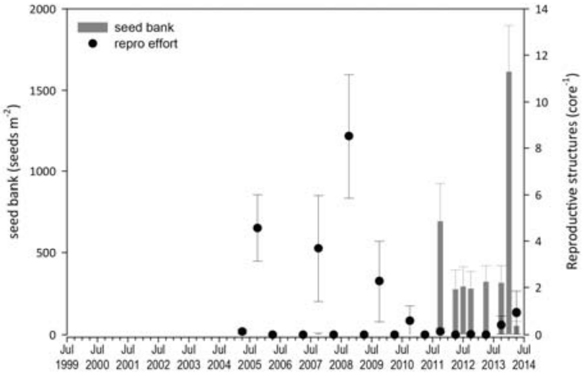

Figure 112. *Burnett Mary estuary seed bank and reproductive effort. Seed bank presented as the total number of seeds per m^2 sediment surface and reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

An examination of the long term trends across the Burnett Mary NRM region suggests estuarine seagrass abundance (% cover) has progressively decreased from 2004 to 2012, until after which the decline appears to have abated (Figure 113a). Long-term trends also indicate that seagrass are progressively allocating less resources to reproductive structures, which in 2013-14, were less than a tenth of what they were in 2005-06 (Figure 113b). Surprisingly, seed banks have improved, peaking immediately following the extreme weather events of 2011 (Figure 113c). Overall this would indicate that seagrass across the region still remaining in a vulnerable state, with a low ability to resistance, and reduced capacity to recover from, large disturbances.

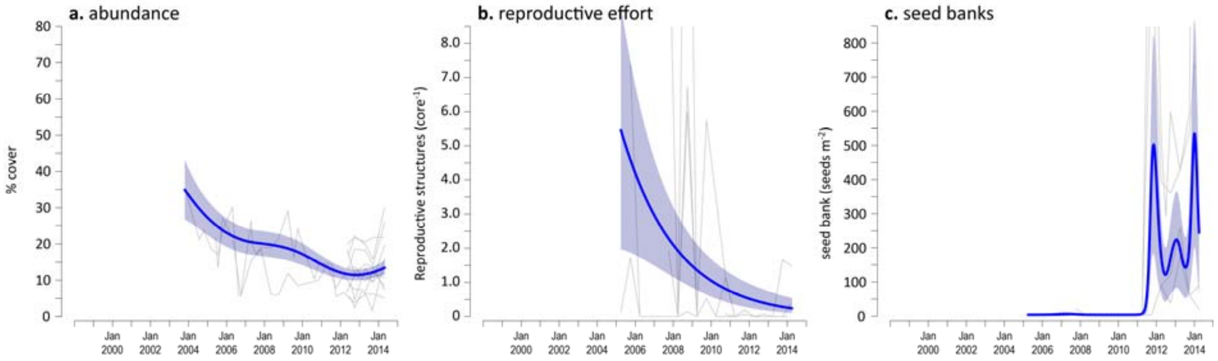

Figure 113. *Seagrass abundance, reproductive effort and seed bank trends in the Burnett Mary region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

3.7.4 Status of the seagrass environment

Seagrass tissue nutrients

In 2013, *Zostera muelleri* leaf molar C:N ratios increased above 20 for the first time in 7 years (Figure 114); primarily due to the higher C:N ratios at Urangan, rather than Rodds Bay (which remained <20) (Appendix 2, Figure 148). δ^{13}C values were within global ranges (Appendix 2, Table 37), suggesting sufficient but possibly low carbon available for growth.

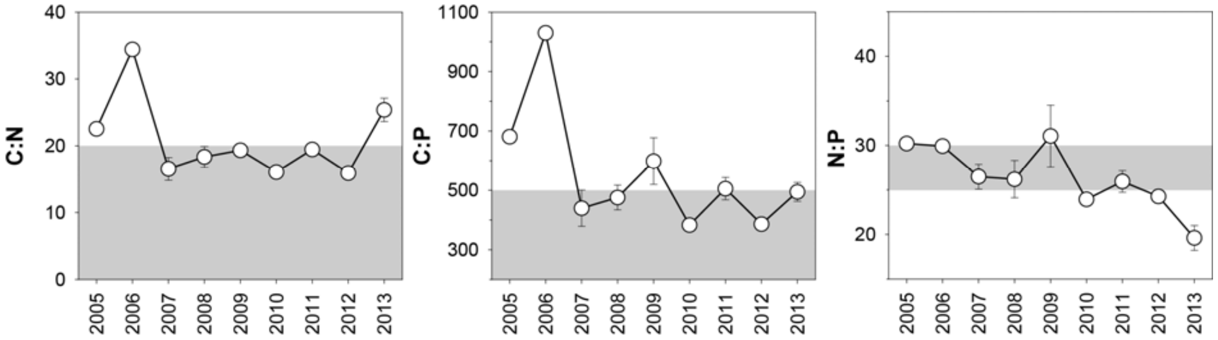

Figure 114. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at estuarine habitats in the Burnett Mary region each year (sites and species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment. Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Zostera muelleri leaf molar C:P ratios in 2012 were <500 for at both locations (Appendix 2, Figure 148), indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 114). N:P ratios for *Zostera muelleri* increased slightly since the previous monitoring period at Rodds Bay, but decreased at Urangan (Hervey Bay) (Appendix 2, Figure 148), indicating the plants remained replete (well supplied and balanced macronutrients for growth) or possibly N limited, respectively (Figure 114). Leaf tissue δ^{15}N values were higher in 2013 than previous (Appendix 2, Table 37) and the levels suggest either fertiliser and/or sewage influence in the primary source of N.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades was higher in the wet season and increased above the GBR long-term average in 2013-14 (Figure 115; Appendix 2, Figure 163). Conversely , percentage cover of macroalgae was higher in the dry season and decreased below the GBR long-term average in 2013-14 (Figure 115; Appendix 2, Figure 163).

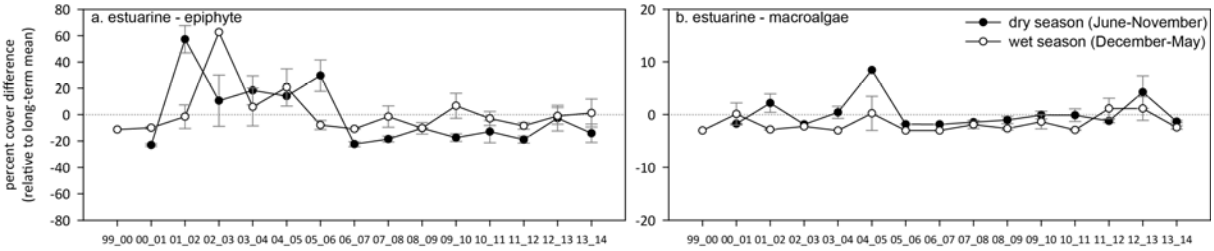

Figure 115. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each seagrass habitat in the Burnett Mary NRM region (sites pooled, ±SE).*

Epiphyte cover on seagrass leaf blades has fluctuated greatly since monitoring was established, with an initial increase from 2000-2003 (Figure 116a), followed by a decrease until early 2007, after which it has been gradually increasing; possibly in association with higher available N. Macroalgae cover has persisted at a very low and relatively stable state (Figure 116b).

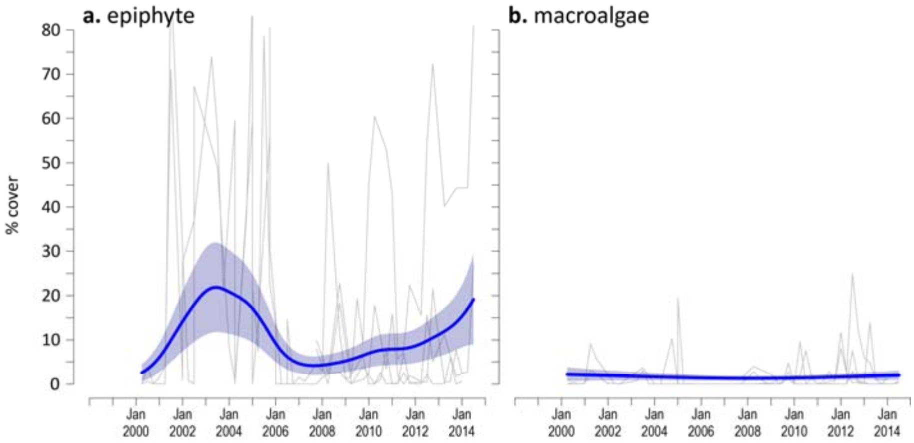

Figure 116. *Epiphyte and macroalgae cover trends in the Burnett Mary region. Trends are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends, grey lines represent observed profiles for individual sites at all locations and habitats.*

Tidal exposure of intertidal seagrass meadows

The annual exposure of intertidal seagrass meadows at Burnett Mary NRM region estuarine habitats during daylight over the 2013-14 monitoring period were mostly above long-term medians (Appendix 2, Table 39). Meadows in the Burnett Mary region which exposed for the longest duration were at Urangan (121 hrs 40min), however, this was the first time in 6 years a meadow has been exposed longer than the annual median (Appendix 2, Figure 171). At Rodds Bay, 2013-14 was the third consecutive year meadows exposed above the annual median (Appendix 2, Figure 171). Overall, Burnett Mary estuarine meadows expose for 1.5 to 3.4% of annual daylight hours (Appendix 2, Table 39), which in 2013-14 would have provided a less than conducive environmental conditions for seagrass growth.

Within canopy temperature

Autonomous temperature loggers were deployed at both locations over the monitoring period (Appendix 2, Figure 179). Within canopy seawater temperatures in the north (Rodds Bay) were 0.5°C higher than the long-term (7 year) and 2012-13 annual averages (Figure 117b). However, in the south of the region, temperatures were 0.5°C and 0.8°C higher than the long-term (9 year) and 2012-23 annual averages. Although fewer days of high temperatures (>35°C) were experienced in 2013-14 compared to 2012-13, the months with high temperatures were in December 2013 and March/April 2014, with the highest temperature (39.3°C) recorded at 2:00pm on the 29 March 2014 at Rodds Bay (Figure 117a).

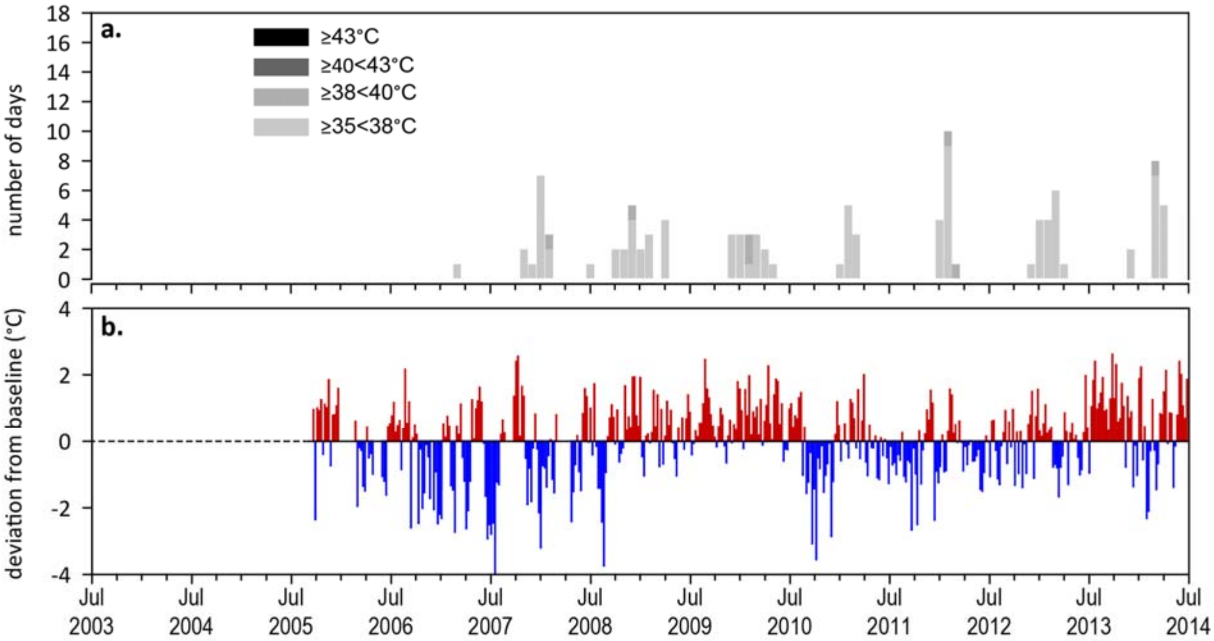

Figure 117. *Inshore sea temperature monitoring September 2005 to June 2014 for seagrass meadows in Burnett Mary NRM region: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from SJ Campbell et al., 2006); b) deviations from 9-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

Canopy incident light

The dataset for the Burnett-Mary NRM region is relatively short, and data gaps are more common due to infrequent site access for logger maintenance. However, there is a strong seasonal peak in daily light in the Burnett-Mary locations, and this peak has been declining since light monitoring began in 2010 (Figure 118, Figure 119). As such, daily light in the Burnett-Mary region in 2013-14 (12.1 mol m^{-2} d^{-1}) was below the long-term average (14.6 mol m^{-2} d^{-1}) and the GBR-wide average (14.3 mol m^{-2} d^{-1}) for this year. Daily light for each location within the Burnett-Mary NRM region is presented in the Appendix 2 (Figure 191).

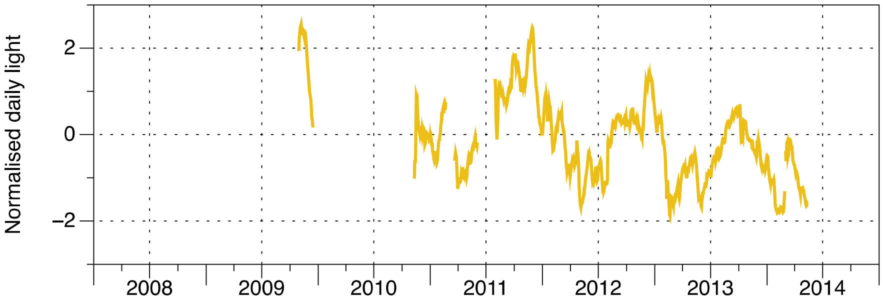

Figure 118. *Standardised (z-score) daily light (28-day rolling average) for all locations (pooled) in the Burnett Mary NRM region. Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

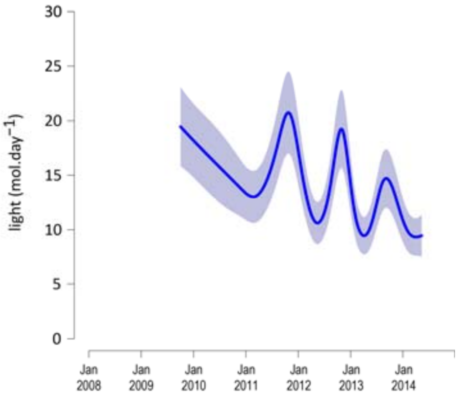

Figure 119. *Seagrass canopy light trend in the Burnett Mary region. Trend represented by blue line with blue shaded area defining 95% confidence intervals of the trend.*

Regional climate and river discharge

Climate across the Mary Burnett NRM region was warmer, windier, and drier than average in 2013-14. The drier conditions resulted in the lowest river discharges in seven years.

Average annual maximum air temperatures across the region were warmer than the previous monitoring period, the decade and the long term. In the north (Seventeen Seventy = 26.0°C) maximum air temperature in 2013-14 were 0.3-0.8°C warmer than the previous monitoring period, the decade and the long term. In the south, average annual maximum air temperatures were higher (Hervey Bay = 26.9°C) than the north, with maximum air temperatures in 2013-14 from 0.7-1.0°C warmer than 2012-13, the averages for the last decade and the long term (15 years) (Appendix 2, Figure 211, Figure 212). Although average temperatures were higher, maximum daily temperatures in 2013-14 (Seventeen Seventy = 32.5°C, Hervey Bay = 32.9°C) were similar to the long term, but 0.5°C to 4.0°C lower than the previous year in the north and south respectively.

Although annual wind speeds across the region in 2013-14 were above average relative to the last decade and the long-term (15 years), in the north (Seventeen Seventy = 23 km.hr^{-1}) they were below those experienced during the previous monitoring period (Appendix 2, Figure 211, Figure 212). In the south, however, wind speeds (Hervey Bay = 20.1 km.hr^{-1}) were 0.7 km.hr^{-1} higher than the previous monitoring period; making 2013-14 the windiest monitoring period with the highest number of days (77 days) with winds above 25 km.hr^{-1} in 6 years (Appendix 2, Figure 213). This would have resulted in rougher seas resuspending sediments and reducing water clarity in the south.

Rainfall across the region during 2013-14 was below average. In the north of the region, rainfall (Seventeen Seventy = 666mm) was the lowest in 7 years; ~40% lower than the last decade and the long-term average. It was an even drier period in the south, with total annual rainfall (Hervey Bay = 563mm) the lowest in 15 years (53% lower than the last decade, 50% lower than the long-term) (Appendix 2, Figure 211, Figure 212). Several large rivers discharge into the coastal waters of the Burnet Mary region and during floods their plumes extend to locations where seagrass monitoring sites are located. In the north, no major rivers discharge directly into Rodds Bay where the estuarine seagrass monitoring sites are located, however it could be expected that flood waters from the Calliope and Boyne Rivers would travel slightly southward exposing Rodds Bay (41 km to the south) to plumes. In the south of the region, the Mary River is the most dominant river and as the Urangan seagrass monitoring sites are located within 14 km of the river mouth, they are frequently impacted (Campbell and McKenzie 2003).

During the 2013-14 monitoring period, total annual discharges from the major rivers which would impact the seagrass monitoring sites were below the long-term medians (Appendix 2, Table 41). This was the first monitoring period in 7 years that the total discharge from the Mary River (361,863 ML) was not above median for the (Appendix 2, Table 41, Figure 220, Figure 221).

4 Conclusions

The report card of inshore seagrass state for the Great Barrier Reef shows that the declines experienced from 2006 to 2012 (from Cooktown south) abated in late 2012 and seagrass state improved, but remained poor in 2013-14 (Figure 120). Long-term monitoring through the MMP and related programs has demonstrated that the tropical seagrass ecosystems of the GBR are a mosaic of different habitat types comprised of multiple seagrass species in which timing and mechanisms that capture their dynamism (i.e. declines and subsequent recovery) are complex and spatially diverse. For example, although some locations in the Wet Tropics and Burdekin regions experienced declines in early 2006 as a consequence of TC Larry, most recovered within 1-2 years, with the exception of the coastal sites in southern Wet Tropics where recovery was protracted. In late 2008, locations in the northern Wet Tropics and Burdekin regions were in a moderate state of health with abundant seagrass and seed banks. In contrast, locations in the southern GBR in Mackay Whitsunday and Burnett Mary regions were in a poor state, with low abundance, reduced reproductive effort and small or absent seed banks. In 2009 with the onset of the La Niña, the decline in seagrass state steadily spread across the Burdekin region and to locations within the Fitzroy and Wet Tropics where discharges from large rivers and associated catchments occurred. The only locations of better seagrass state were those with relatively little catchment input, such as Gladstone Harbour and Shoalwater Bay (Fitzroy region), Green Island (Wet Tropics), and Archer Point (Cape York). By 2010, seagrasses of the GBR were in a poor state with declining trajectories in seagrass abundance, reduced meadow extent, limited or absent seed production and increased epiphyte loads at most locations. These factors would have made the seagrass populations particularly vulnerable to large episodic disturbances, as demonstrated by the widespread and substantial losses documented after the floods and cyclones of early 2011.

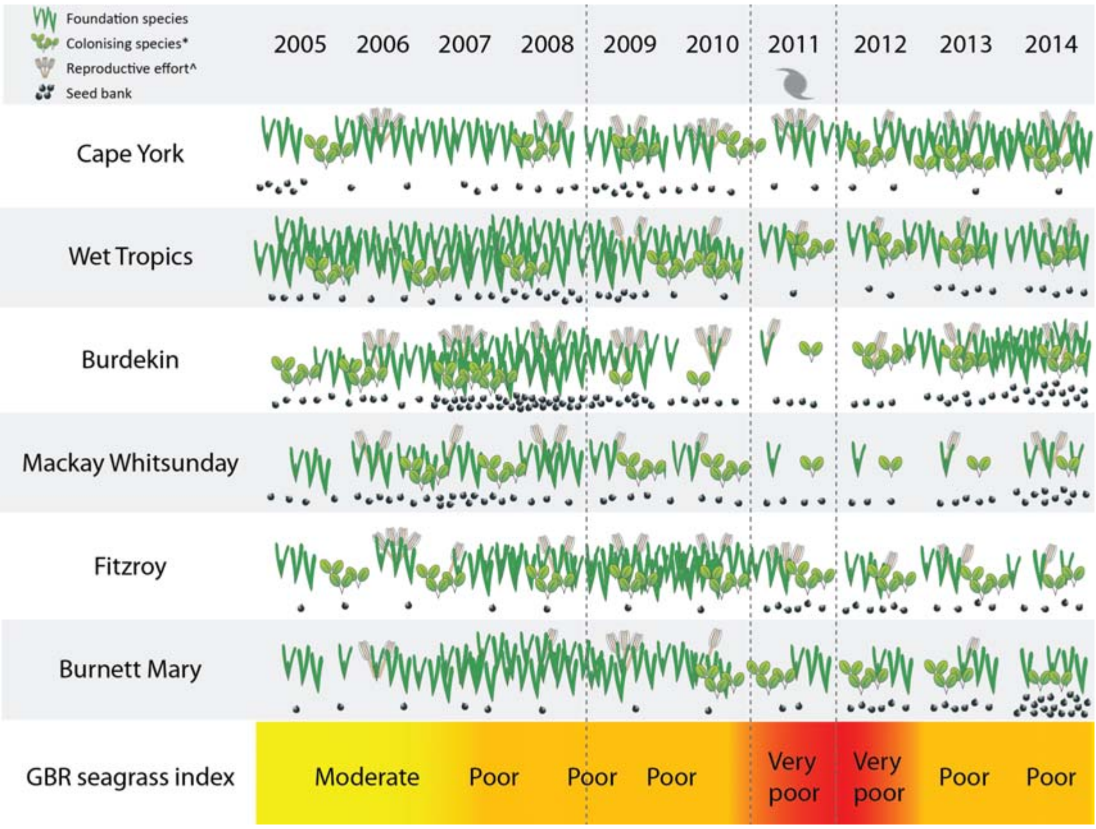

Figure 120. *Summary of GBR MMP inshore seagrass state illustrating abundance of foundation / colonising species, seed banks and reproductive effort from 2005 to 2014. * colonising species are represented by the genus Halophila, however, Zostera and Halodule can be both colonising and foundational species depending on meadow state. ^ not conducted in 2005.*

Following the extreme weather events of early 2011, seagrass habitats across the GBR further declined, with severe losses reported from the Wet Tropics, Burdekin, Mackay Whitsunday and Burnett Mary regions. By 2011-12, the onset of seagrass recovery was observed across some regions, however a state change had occurred and colonising species dominated many habitats. The majority of meadows appeared to allocate resources to vegetative growth rather than reproduction, indicated by the lower reproductive effort and seed banks. In 2013-14, recovery continued to progress across most of the regions.

There was increasing evidence that water quality degradation within the seagrass meadows of the inshore GBR prior to the episodic disturbances of 2011 may have reduced their resilience. Light availability is one of the primary driving factors in seagrass growth and persistence. From 2009, reduced canopy light to low and limiting light levels was reported in seagrass meadows across the GBR, and, coincident with this, nutrients (N and P) increasing relative to plant requirements. The strong correlation between seagrass abundance and light availability has been demonstrated for subtidal meadows (Collier *et al.* 2012b). At shallow sites, daily measurements of light can be "swamped" by high availability during low tide, giving the appearance of light levels in excess of light requirements (above MLR and thresholds), and yet seagrass declines occurred throughout the GBR at intertidal and subtidal monitoring sites in the years leading up to and including 2011. There are a number of possible explanations for this:

1. High light during low tide "light window" does not directly translate into increased photosynthetic C incorporation due to reduced photosynthetic efficiency at very high light and C-limitation during periods of exposure to air. There is a strong need to quantify the effect of widely fluctuating light levels and spectral quality on photosynthetic efficiency;

2. Synergistic environmental impacts of the low tide environment increase their vulnerability to more moderate levels of light stress.

Water quality variables (e.g. turbidity, chlorophyll-*a* and CDOM) are the primary light attenuating factors and knowing the cause of low light conditions enables targeted management to reduce impacts on seagrass meadows. However, seagrasses can survive in highly turbidity sites if restricted to shallow areas where light reaches the canopy during low tide, but plants remain submerged. Therefore, direct water quality measures and light are complimentary indicators, each with their own benefits to the interpretation of monitoring data, and management of water quality impacts. Direct measurement of water quality variables is not currently and routinely incorporated into the program for seagrass sites.

The current monitoring program includes indicators that represent various stages of impact/stress, including early warning indicators (tissue nutrients) through to advanced levels of impact (changes in meadow area, or localised loss) (Figure 121). Findings from the MMP have demonstrated a cascade of seagrass population responses, particularly between 2006 and 2011, to stressors analogous to the stress response model, including:

- leaf tissue N and P increasing above global averages in all habitats from 2006 and 2010 respectively, and in surplus to C, possibly indicating N enrichment;
- variable reproductive effort and seed banks indicating low capacity to recover from loss;
- decreased abundance and extent from 2009 to 2011, when they reached minima;
- change in population state from foundation species to colonising species, possibly reducing ecosystem resistance.

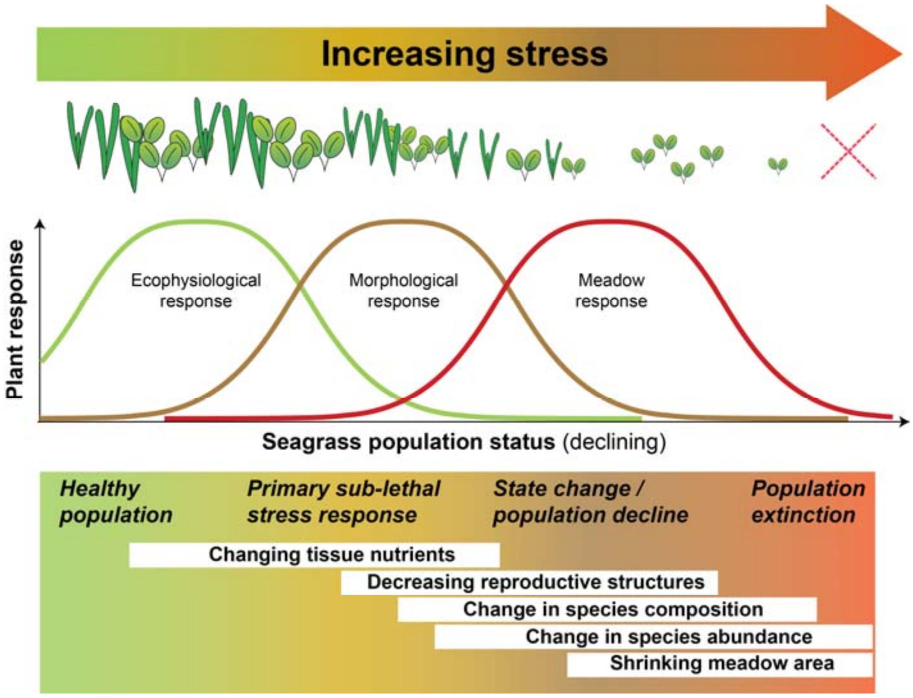

Figure 121. *Seagrass stress response model outlining the sequence of changes that occur in response to increasing stress. Adapted from Waycott and McKenzie (2010).*

Recovery of seagrass populations from the declines experienced in 2011 may take many years and there are a number of factors that will facilitate recovery, including seed banks, connectivity and improvement in environmental conditions such as light available for photosynthesis. It was estimated that recovery of meadows may be slow (>5 years) in the southern Wet Tropics, moderate (2-5 years) in the Burdekin and fair (1-3 years) in the Fitzroy regions (McKenzie*, et al.* 2013). Current rates of recovery, as well as examples taken from previous localised impacts (Birch and Birch, 1984; Campbell and McKenzie 2004b) indicate that a return to a moderate or good condition could take slightly longer than initially predicted at some locations and could occur within 2 more years (i.e. > 5years from impact), providing conditions remain favourable.

The capacity of seagrass meadows to naturally recover community structure following disturbance will involve the interaction between light availability, nutrient loads and the availability of seeds to form the foundation of new populations. At present, the improving light availability across the northern GBR habitats and region appears advantageous to the recovery potential of GBR seagrass meadows. However, increased epiphyte and macroalgae abundance as a consequence of high or elevated N in coastal environments, could compromise the light available for photosynthesis and in turn reduce plant survival and capacity to produce a viable seed bank (van Katwijk *et al.* 2010). This may in turn leave the meadows vulnerable to further environmental perturbations from which some may then fail to recover after loss.

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Appendix 1: Material and Methods

A1.1. Methods

The following section includes excerpts from McKenzie *et al.* (2014a).

A1.1.1. Sampling design

The sampling design was selected to detect change in inshore seagrass community status to compare with seagrass environmental status (water quality) in relation to specific catchments or groups of catchments (NRM region). Within each region, a relatively homogenous section of a representative seagrass meadow is selected to represent each of the seagrass habitats present (estuarine, coastal, reef) (Habitat(Region)). To account for spatial heterogeneity, two sites were selected within each location (Site[Habitat(Region)]). Subtidal sites were not replicated within locations. Within each site, finer scale variability is accounted for by using three 50 m transects nested in each site. An intertidal site is defined as a 50mx50m area. The sampling strategy for subtidal sites was modified to sample along 50m transects 2-3 m apart (aligned along the depth contour) due to logistical purposes of SCUBA diving in often poor visibility. At each site, monitoring is conducted during the late-monsoon (April) and late-dry (October) periods each year; additional sampling is conducted at more accessible locations in the dry (July) and monsoon (January).

A1.1.2. Field survey methods - Inshore seagrass meadow abundance, community structure and reproductive health

Site marking

Each selected inshore seagrass site is permanently marked with plastic star pickets at the 0 m and 50 m points of the centre transect. Labels identifying the sites and contact details for the program are attached to these pickets. Positions of 0 m and 50 m points for all three transects at a site are also noted using GPS (accuracy ±3 m). This ensures that the same site is monitored each event.

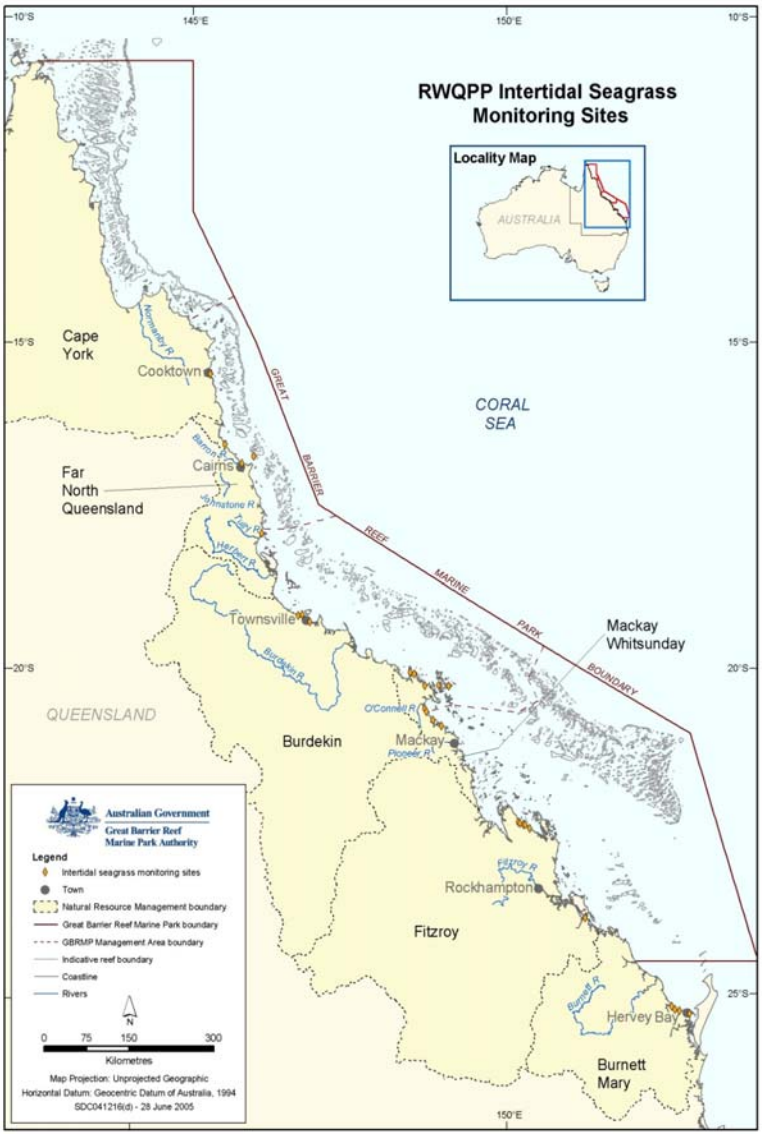

Figure 122. *Inshore seagrass monitoring sites for the Reef Rescue Marine Monitoring Program.*

Seagrass cover and species composition

Survey methodology follows globally standard methodologies, originally developed for the Seagrass-Watch program (McKenzie*, et al.* 2003). A site is defined as an area within a relatively homogenous section of a representative seagrass community/meadow (McKenzie *et al.* 2000b).

Monitoring at the 45 sites identified for the MMP long-term inshore monitoring in late-monsoon (April) and late dry season (October) of each year is conducted by qualified and trained scientists who have demonstrated competency in the methods (see Appendix 1.1.3). Monitoring conducted outside these periods is conducted by a trained scientist assisted by volunteers.

At each site, during each survey, observers record the percent seagrass cover within a 50 cm × 50 cm quadrat every 5 m along three 50m transects, placed 25m apart. A total of 33 quadrats are sampled per site A total of 33 quadrats were sampled per site. Seagrass abundance (% cover) was visually estimated as the fraction of the seabed (substrate) obscured by the seagrass species when submerged and viewed from above. This method was used because the technique has wider application and is very quick, requiring only minutes at each quadrat; yet it is robust and highly repeatable, thereby minimising among-observer differences. Quadrat percent cover measurements have also been found to be far more efficient in detecting differences in seagrass abundance than seagrass blade counts or measures of above- or below-ground biomass (Heidelbaugh and Nelson 1996). To improve resolution and allow greater differentiation at very low percentage covers (e.g. <3%), shoot counts based on global species density maxima were used. For example: 1 pair of *Halophila ovalis* leaves in a quadrat = 0.1%; 1 shoot/ramet of *Zostera* in a quadrat = 0.2%. Additional information was collected at the quadrat level, although only included as narrative in this report, including: seagrass canopy height of the dominant strap leaved species; macrofaunal abundance; abundance of burrows, as an measure of bioturbation; presence of herbivory (e.g. dugong and sea turtle); a visual/tactile assessment of sediment composition (see McKenzie 2007); and observations on the presence of superficial sediment structures such as ripples and sand waves to provide evidence of physical processes in the area (see Koch 2001b).

Seagrass reproductive health

An assessment of seagrass reproductive health at locations identified in Table 4 via flower and fruit production is conducted in late-dry season (October) of each year at each site. Additional collections are also conducted in late-monsoon (April) where possible.

In the field, 15 haphazardly placed cores (100mm diameter x 100mm depth) of seagrass are collected from an area adjacent, of similar cover and species composition, to each monitoring site. All samples collected are given a unique sample code/identifier providing a custodial trail from the field sample to the analytical outcome.

Seeds banks and abundance of germinated seeds were sampled according to standard methods (McKenzie*, et al.* 2003) by sieving (2mm mesh) 30 cores (50mm diameter, 100mm depth) of sediment collected across each site and counting the seeds retained in each. For *Zostera muelleri* subsp. *capricorni*, where the seeds are <1mm diameter, intact cores (18) were collected and returned to the laboratory where they were washed through a 710µm sieve and seeds identified using a hand lens/microscope.

Seagrass tissue nutrients

Collection of seagrass leaf tissue (targeted foundation genus include *Halodule*, *Zostera* and *Cymodocea*) for analysis of tissue nutrients (C, N, P, $\delta^{15}N$, $\delta^{13}C$) is conducted in the late-dry season (October) sampling period at regions identified in Table 4. Approximately 5 to 10 grams wet weight of seagrass leaves is harvested from three to six haphazardly chosen plots (2 to 3 m apart) in an area adjacent, of similar cover and species composition, to each monitoring site. All samples collected are given a unique sample code/identifier providing a custodial trail from the field sample to the analytical outcome.

Rhizosphere sediment herbicide (haphazard)

Sediment samples (approximately 250ml) for analysis of herbicide concentrations are collected in late-monsoon (April) at selected monitoring sites when funding is available. Rhizosphere herbicide samples are obtained using a stainless steel spoon and bowl rinsed with acetone between each sample collection. Approximately 20ml of sediment is collected every 5 metres along each transect to a depth approximately equal to the depth of the rhizome layer. Three homogenised samples (one per each transect) were collected per site. The samples are stored in acetone rinsed Teflon lidded jars provided by the QHFSS. Sediments are kept frozen until analyses by the NATA accredited commercial laboratory at the QHFSS.

A1.1.3. Observer training

The JCU personnel collecting data in association with this project are without exception highly experienced in the collection of seagrass monitoring data. The majority of observers have been involved in seagrass monitoring for at least a decade and were employed specifically for their skills associated with the tasks required.

All observers have successfully completed at Level 1 Seagrass-Watch training course (seagrasswatch.org/training.html) and have demonstrated competency across 7 core units: achieved 80% of formal assessment (classroom and laboratory) (5 units); and demonstrated competency in the field both during the workshop (1 unit) and post workshop (1 unit = successful completion of 3 monitoring events/periods within 12 months). Volunteers who assist JCU scientists have also successfully completed a Level 1 training course.

Technical issues concerning quality control of data are important and are resolved by: using standard methods which ensure completeness in the field (the comparison between the amounts of valid or useable data originally planned to collect, versus how much was collected); using standard seagrass cover calibration sheets 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 through routine comparisons during sampling events. Any discrepancy 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, 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. Evidence of competency is securely filed on a secure server in Cairns at James Cook University

Howley Consulting is responsible for surveys in the Cooktown region. The Howley Consulting observer, Christina Howley, has been assessing seagrass resources in the Cape York region for over a decade and has successfully completed a Level 1 training course .

A1.1.4. Laboratory analysis - Inshore seagrass meadow abundance, community structure and reproductive health

Seagrass reproductive health

In the laboratory, reproductive structures (spathes, fruit, female flower or male flowers; Figure 123) of plants from each core are identified and counted for each sample and species. If *Halodule uninervis* seeds (brown green colour) are still attached to the rhizome, they are 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 muelleri* subsp. *capricorni*, the number of spathes is recorded, male and female flowers and seeds counted during dissection, if there is time after the initial pass of the samples. Apical meristems are counted if possible, however, most are not recorded as they were too damaged by the collection process to be able to be identified correctly. The number of nodes for each species is counted, and for each species present in the sample, 10 random internode lengths and 10 random leaf widths are measured. Approximately 5% of samples are cross-calibrated between technicians (preferable from another centre). All samples, including flowers and spathes and fruits/fruiting bodies are kept and re-frozen in the site bags for approximately 2 years for revalidation if required. Reproductive effort is calculated as the number of reproductive structures per core.

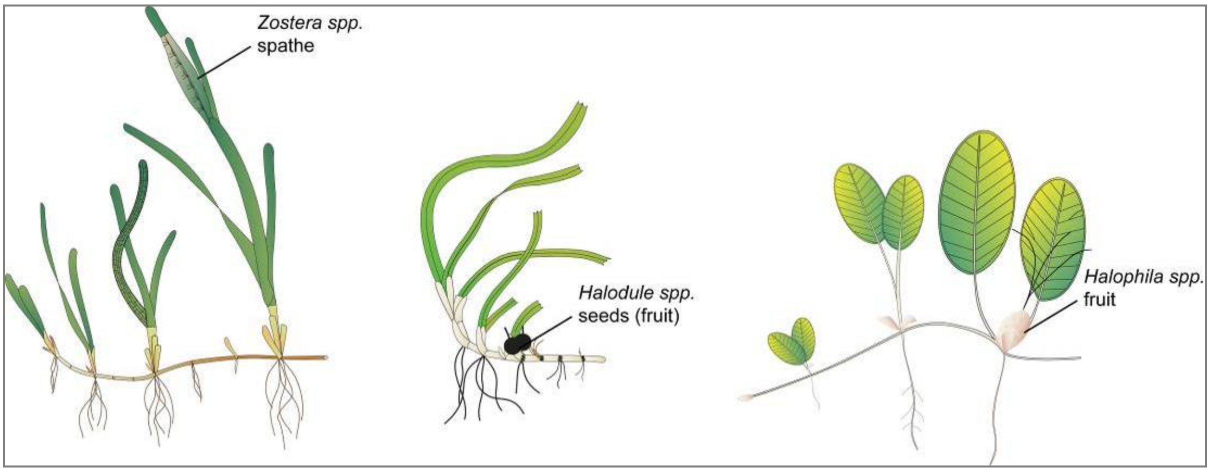

Figure 123. Form and size of reproductive structure of the seagrasses collected: *Halophila ovalis*, *Halodule uninervis* and *Zostera muelleri* subsp. *capricorni*

Seagrass tissue nutrients

Leaves are separated in the laboratory into seagrass species and epiphytic algae removed by gently scraping the leaf surface. Samples are oven dried at 60°C to weight constancy. Dried biomass samples of leaves are then homogenised by milling to fine powders prior to nutrient analyses and stored in sealed vials.

The ground tissue samples are sent to Chemcentre (Western Australia) for analysis. The Chemcentre holds NATA accreditation for constituents of the environment including soil, sediments, waters and wastewaters. (Note that details of Chemcentre accreditation can be found at the NATA website: http://www.nata.asn.au/). The NATA accreditation held by the ChemCentre includes a wide variety of QA/QC procedures covering the registration and identification of samples with unique codes and the regular calibration of all quantitative laboratory equipment required for the analysis. The ChemCentre 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. In 2010, QA/QC also included an inter-lab comparison (using Queensland Health and Scientific Services – an additional NATA accredited laboratory) and an additional blind internal comparison.

Nitrogen and phosphorus are extracted using a standardized selenium Kjeldahl digest and the concentrations determined with an automatic analyser using standard techniques at Chemcentre in Western Australia (a NATA certified laboratory). Percent C was determined using atomic absorption, also at Chemcentre. Elemental ratios (C:N:P) are then calculated on a mole:mole basis using atomic weights (i.e., C=12, N=14, P=31). Analysis of all seagrass tissue nutrient data is based upon the calculation of the atomic ratios of C:N:P.

To determine percent carbon, dried and milled seagrass leaf tissue material is combusted at 1400°C in a controlled atmosphere (e.g. Leco). This converts all carbon containing compounds to carbon dioxide. Water and oxygen is then removed from the system and the gaseous product is determined spectrophotometrically.

Total nitrogen and phosphorus content of dried and milled homogenous seagrass tissue material is determined by Chemcentre using a standardized selenium Kjeldahl digest. Samples are digested in a mixture of sulphuric acid, potassium sulphate and a copper sulphate catalyst (cf. Kjeldahl). This converts all forms of nitrogen to the ammonium form and all forms of phosphorus to the orthophosphate form. The digest is diluted and any potentially interfering metals present are complexed with citrate and tartrate. For the nitrogen determination an aliquot is taken and the ammonium ions are determined colorimetrically following reduction with hydrazine to the nitrate ion, followed by diazotisation of 1-naphthylenediamine and subsequent coupling with sulphanilamide. For total phosphorus an aliquot of the digest solution is diluted and the P determined as the phosphomolybdenum blue complex (modified Murphy and Riley[117] procedure).

Seagrass leaf isotopes

A subset of each ground tissue sample was sent to Natural Isotopes (Western Australia) for $\delta^{15}N$ and $\delta^{13}C$ analysis. The samples were weighed into tin capsules and combusted by elemental analyser (ANCA-SL, SerCon Limited, Crewe, United Kingdom) to N_2 and CO_2. The N_2 and CO_2 was purified by gas chromatography and the nitrogen and carbon elemental composition and isotope ratios were determined by continuous flow isotope ratio mass spectrometry (20-22 IRMS, SerCon Limited, Crewe, United Kingdom). Reference materials of know elemental composition and isotopic ratios were interspaced with the samples for calibration.

Raw nitrogen and carbon elemental composition and isotope ratio data were corrected for instrument drift and blank contribution using Callisto software SerCon Limited, Crewe, United Kingdom). A standard analysed at variable weights corrects for instrument linearity, IAEA-N-2 and IAEA-N-1 used to normalise the nitrogen isotope ratio, IAEA-CH-6 and IAEA-CH-7 to normalise the carbon isotope ratio, such that IAEA-N-2 ($\delta^{15}N$ = 20.32‰), IAEA-N-1 ($\delta^{15}N$ = 0.43‰), IAEA-CH-6 ($\delta^{13}C$ = -10.45‰) and IAEA-CH-7 $\delta^{13}C$ = -32.15‰).

Nitrogen isotope ratios were reported in parts per thousand (per mil) relative to N_2 in air. The nitrogen bearing internationally distributed isotope reference material N_2 in air had a given value of 0‰ (exactly). Carbon isotope ratios were reported in parts per thousand (per millilitre) relative to V-PDB. The carbon bearing internationally distributed isotope reference materials NBS19 and L-SVEC, had a given value of +1.95‰ (exactly) and -46.6‰ (exactly). Compositional values were reported as percent nitrogen and percent carbon present in the sample analysed.

Rhizosphere sediment herbicide (haphazard)

Extraction, clean-up and analysis of the sediments for herbicides is conducted according to NATA approved methods developed by the QHFSS. Approximately 50 grams of sediment is extracted overnight on an orbital shaker using a mixture of acetone and hexane (50:50). The organic layer is filtered through sodium sulphate and then concentrated using a rotary evaporator to a low volume. The extract is solvent exchanged into Methanol/water (50:50) (1 ml) and quantisation is performed using high performance liquid chromatography attached to a triple stage mass spectrometer (LCMSMS). A separate ten grams of sediment is taken for dry weight calculations.

Limits of Reporting on a dry weight basis are:

- Atrazine and metabolites 0.1 µg/kg
- Diuron 0.1 µg/kg
- Irgarol 0.5 µg/kg

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 of diuron 5 µg/kg , atrazine 5 µg/kg and irgarol 2 µg/kg. An internal standard, deuterated atrazine, is added to all samples, fortified sample, reagent blank and standards before LCMSMS quantification. Certified reference standards are used for instrument calibration with a standard being run every 10 samples. Where possible, a duplicate sample, is analysed every 10 samples.

A1.1.5. Sampling design - Inshore seagrass meadow boundary mapping

Mapping the edge of the seagrass meadow within 100 metres of each monitoring site is conducted in both the late dry (October) and late monsoon (April) monitoring periods at all sites identified in Table 4. Training and equipment (GPS) are provided to personnel involved in the edge mapping.

Mapping methodology follows standard methodology (McKenzie *et al.* 2001). Edges are recorded as tracks (1 second polling) or a series of waypoints in the field using a portable Global Positioning System receiver (i.e. Garmin GPSmap® 60CSx or 62s). Accuracy in the field is dependent on the portable GPS receiver (Garmin GPSmap® 60CSx is <15m RMS95% (DGPS (USCG) accuracy: 3-5m, 95% typical) and how well the edge of the meadow is defined. Generally accuracy is within that of the GPS (i.e. 3 to 5 metres) and datum used is WGS84. Tracks and waypoints are downloaded from the GPS to portable computer using MapSource or BaseCamp software as soon as practicable (preferably on returning from the day's activity) and exported as *.dxf files to ESRI® ArcGIS™. Subtidal edge mapping data has yet to be plotted.

Mapping is conducted by trained and experienced scientists using ESRI® ArcMap™ 9.3 (Environmental Systems Research Institute, ArcGIS™ Desktop 9.3). Boundaries of meadows are determined based on the positions of survey Tracks and/or Waypoints and the presence of seagrass. Edges are mapped using the polyline feature to create a polyline (i.e. 'join the dots') which is then smoothed using the B-spline algorithm. The smoothed polyline is then converted to a polygon and saved as a shapefile. Coordinate system (map datum) used for projecting shapefile is AGD94.

In certain cases seagrass meadows form very distinct edges that remain consistent over many growing seasons. However, in other cases the seagrass landscape tends to grade from dense continuous cover to no cover over a continuum that includes small patches and shoots of decreasing density. Boundary edges in patchy meadows are vulnerable to interpreter variation, but the general rule is that a boundary edge is determined where there is a gap with the distance of more than 3 metres (i.e. accuracy of the GPS). Final shapefiles are then overlayed with aerial photographs and base maps (AusLig™) to assist with illustration/presentation.

The expected accuracy of the map product gives some level of confidence in using the data. Using the GIS, meadow boundaries are assigned a quality value based on the type and range of mapping information available for each site and determined by the distance between waypoints and GPS position fixing error. These meadow boundary errors are used to estimate the likely range of area for each meadow mapped (see McKenzie *et al.* 1996; Lee Long *et al.* 1997b; McKenzie*, et al.* 1998).

Mapping at subtidal sites has been altered to suit the low visibility conditions and the requirement to map by SCUBA. From the central picket (deployment location of light and turbidity loggers) straight lines of 50m length are swum at an angle of 45 degrees from each other. The locations where the edges of the seagrass meadows/patches intercept the line are recorded. A GPS is attached to a flotation device at the surface of the water and fastened to the SCUBA diver to record travelling distance and transect orientation. Eight lines at 45 degrees are performed, with the first following the orientation of the monitoring transects; the others are undertaken at 45 degree angles from the first.

A1.1.6. Sampling design - Within seagrass canopy temperature loggers

Autonomous iBTag™ submersible temperature loggers are deployed at all sites identified in Table 26. The loggers record temperature (degrees Celsius) within the seagrass canopy every 30 to 90 minutes (depending on duration of deployment and logger storage capacity) and store data in an inbuilt memory which is downloaded every three to six months, depending on the site.

iBCod 22L model of iBTag™ loggers are used as they can withstand prolonged immersion in salt water to a depth of 600 metres. It is reinforced with solid titanium plates and over molded in a tough polyurethane casing that can take a lot of rough handling.

Main features of the iBCod 22L include:

- Operating temperature range: -40 to +85°C
- Resolution of readings: 0.5°C or 0.0625°C
- Accuracy: ±0.5°C from -10°C to +65°C
- Sampling Rate: 1 second to 273 hours
- Number of readings: 4,096 or 8,192 depending on configuration
- Password protection, with separate passwords for read only and full access.

The large capacity of this logger allows the collection of 171 days of readings at 30 minute intervals.

iBCod 22L submersible temperature loggers are placed at the permanent marker at each site for three to six months (depending on monitoring frequency). Loggers are attached to the permanent station marker using cable ties, above the sediment-water interface. This location ensures that the sensors are not exposed to air unless the seagrass meadow is completely drained and places them out of sight of curious people.

Each logger has a unique serial number which is recorded within a central secure database. The logger number is recorded on the monitoring site datasheet with the time of deployment and collection. At each monitoring event (every three to six months) the iBTag™ temperature loggers are removed and replaced with a fresh logger (these are dispatched close to the monitoring visit). After collection, details of the logger number, field datasheet (with date and time) and logger are returned for downloading.

Logger deployment and data retrieval is carried out by JCU professional and technical personnel who have been trained in the applied methods. Methods and procedures documents are available to relevant staff and are collectively kept up-to-date. Changes to procedures are developed and discussed and recorded in metadata records.

A1.1.7. Sampling design and logistics - Seagrass meadow canopy light loggers

Autonomous light loggers are deployed at selected nearshore and offshore seagrass sites in all regions monitored (Table 26).

Submersible Odyssey™ photosynthetic irradiance loggers are placed at the permanent marker at each of the sites for three to six month periods (depending on monitoring frequency).

Odyssey™ data loggers (Odyssey, Christchurch, New Zealand) record Photosynthetically Active Radiation (400-1100nm) and store data in an inbuilt memory which is retrieved every three to six months, depending on the site. Each logger has the following technical specifications:

- Cosine corrected photosynthetic irradiance sensor 400-700 nm
- Cosine corrected solar irradiance sensor 400-1100 nm
- Integrated count output recorded by Odyssey data recorder
- User defined integration period
- Submersible to 20m water depth
- 64k memory.

The logger is self-contained in a pressure-housing with batteries providing sufficient power for deployments of longer than six months. For field deployment, loggers are attached to a permanent station marker using cable ties; this is above the sediment-water interface at the bottom of the seagrass canopy. This location ensures that the sensors are not exposed to air unless the seagrass meadow is almost completely drained and places them out of sight of curious people. At subtidal sites, the loggers are deployed on the sediment surface (attached to a permanent marker) with the sensor at seagrass canopy height. Two loggers are deployed at subtidal sites as there is an increased chance of logger fouling, and the dual logger set-up offers a redundant data set in the instance that one logger fouls completely. Where possible, additional light loggers are deployed at subtidal sites 80 cm from the sediment surface. Data from this logger, together with data from the logger at canopy height, is used for calculation of the light attenuation co-efficient. Furthermore, another logger is deployed above the water surface at each of the subtidal monitoring stations. These additional loggers (surface and subtidal higher in the water column) allow comparison of water quality indices for some of the time.

Measurements are recorded by the logger every 30 minutes (this is a cumulative 30 minute reading). Experiments utilizing loggers with and without wipers were conducted to determine the benefits of wiper use and it was confirmed that the wipers improved the quality of the data by keeping the sensor free from fouling. Automatic wiper brushes are attached to each logger to clean the optical surface of the sensor every 30 minutes to prevent marine organisms fowling the sensor, or sediment settling on the sensor, both of which would diminish the light reading.

Each light logger has a unique serial number which is recorded within a central secure database. The logger number is recorded on the monitoring site datasheet with the time of deployment and collection. At each monitoring event (every three to six months) the light loggers are removed and replaced with a ‘fresh’ logger. At subtidal monitoring sites, the loggers are checked by SCUBA (and replaced if fouled) every six weeks due to the increased fouling rates at permanently submerged sites. After collection, details of the logger number, field datasheet (with date and time) and logger are returned to JCU for downloading.

Photographs of the light sensor and/or notes on the condition of the sensor are recorded at logger collection. If fouling is major (e.g. wiper failure), the data are truncated to included only that data before fouling began – usually one to two weeks. If fouling was minor (up to ~25% of the senor covered), back corrections to the data are made to allow for a linear rate of fouling (linear because with minor fouling it is assumed that the wiper was retarding algal growth rates, but not fully inhibiting them).

A1.1.8. Sampling design and logistics - Turbidity loggers

ECO FLNTU loggers (Wetlabs), which measure chlorophyll, fluorescence and turbidity, are deployed at Green Island and Magnetic Island (Picnic Bay) subtidal sites. They are attached to star pickets 80cm from the sediment surface. Up to February 2011 a FLNTU logger was also deployed at Dunk Island, however this logger was lost during TC Yasi and cannot be replaced. Logger calibration and attachment procedures used by the inshore water quality monitoring sub-program (AIMS) are employed. Loggers are replaced and re-calibrated every three months during routine subtidal monitoring. Instrumental data are validated by comparison to chlorophyll *a* samples and TSS samples collected at logger deployment and retrieval. See section 2.2.3 'Autonomous environmental water quality loggers' for further details on QA/QC procedures for FLNTU loggers.

A1.2. Report card approach

A1.2.1. Seagrass abundance guidelines

The seagrass abundance measure in the MMP is the average % cover of seagrass per monitoring site. Individual site and subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on % cover data collected from individual sites and/or reference sites (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference site conditions.

A reference site is a site whose condition is considered to be a suitable baseline or benchmark for assessment and management of sites in similar habitats. Ideally, seagrass meadows in near pristine condition with a long-term abundance database would have priority as reference sites. However, as near-pristine meadows are not available, sites which have received less intense impacts can justifiably be used. In such situations, reference sites are those where the condition of the site has been subject to minimal/limited disturbance for 3-5 years. The duration of 3-5 years is based on recovery from impact times (Campbell and McKenzie 2004b).

No rigorous protocol is possible for the selection of reference sites and the process is ultimately iterative. The criteria for defining a minimally/least disturbed seagrass reference site is based on Monitoring River Health Initiative 1994) and includes some or all of the following:

- beyond 10km of a major river: as most suspended solids and particulate nutrients are deposited within a few kilometres of river mouths (McCulloch *et al.* 2003; Webster and Ford 2010; Bainbridge *et al.* 2012; Brodie *et al.* 2012).
- no major urban area/development (>5000 population) within 10km upstream (prevailing current)
- no significant point source wastewater discharge within the estuary
- has not been impacted by an event (anthropogenic or extreme climate) in the last 3-5 years
- where the species composition is dominated by the foundation species expected for the habitats (Carruthers*, et al.* 2002), and
- does not suggest the meadow is in recovery (i.e. dominated by early colonising).

The 80th, 50th and 20th percentiles were used to define the guideline values as these are recommended for water quality guidelines (Department of Environment and Resource Management 2009), and there is no evidence that this approach would not be appropriate for seagrass meadows in the GBR. At the request of the Paddock to Reef Integration Team, the 80th percentile was changed to 75th to align with other Paddock to Reef report card components. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (e.g. Figure 124).

Across the majority of reference sites, variance for the 50th and 20th percentiles was found to level off at around 15–20 samples (i.e. sampling events), suggesting this number of samples was sufficient to provide a reasonable estimate of the true percentile value. This sample size is reasonably close to the ANZECC 2000 Guidelines recommendation of 24 data values.

Nonlinear regressions (exponential rise to maximum, two parameter) were then fitted to percent cover percentile values at each number of sampling events using the following model:

$$y = a\left(1 - e^{-bx}\right)$$

where y is the seagrass cover percentile at each number of sampling events (x), a is the asymptotic average of the seagrass cover percentile, and b is the rate coefficient that determines how quickly (or slowly) the maximum is attained (i.e., the slope). The asymptotic average was then used as the guideline value for each percentile (Table 7).

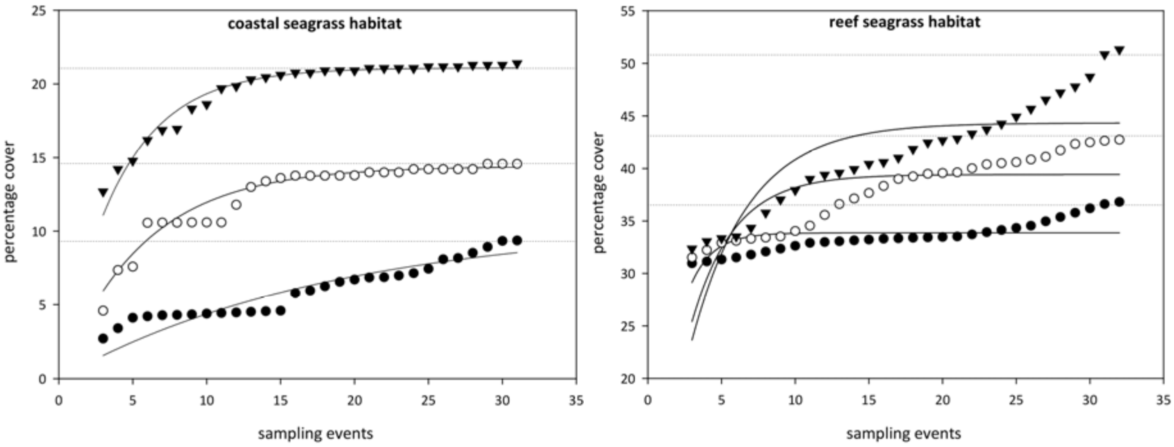

Figure 124. *Relationship between sample size and the error in estimation of percentile values for seagrass abundance (% cover) in coastal and reef seagrass habitats in the Wet Tropics NRM. ▼= 75th percentile, ○ = 50th percentile,● = 20th percentile. Dashed lines are asymptotic averages for each percentile plot.*

As sampling events occur every 3-6 months depending on the site, this is equivalent to 3-10 years of monitoring to establish percentile values. Based on the analyses, it was recommended that estimates of the 20th percentile at a reference site should be based on a minimum of 18 samples collected over at least three years. For the 50th percentile a smaller minimum number of samples (approximately 10–12) would be adequate but in most situations it would be necessary to collect sufficient data for the 20th percentile anyway. For seagrass habitats with low variability, a more appropriate guideline was the 10th percentile primarily the result of seasonal fluctuations (as nearly every seasonal low would fall below the 20th percentile). Percentile variability was further reduced within a habitat type of each region by pooling at least two (preferably more) reference sites to derive guidelines. The subregional guideline is calculated from the mean of all reference sites within a habitat type within a region.

Using the seagrass guidelines, seagrass state can be determined for each monitoring event at each site and allocated as good (median abundance at or above 50th percentile), moderate (median abundance below 50th percentile and at or above 20th percentile), poor (median abundance below 20th or 10th percentile). For example, when the median seagrass abundance for Yule Point is plotted against the 20th and 50th percentiles for coastal habitats in the Wet Tropics (Figure 125), it indicates that the meadows were in a poor condition in mid 2000, mid 2001 and mid 2006 (based on abundance).

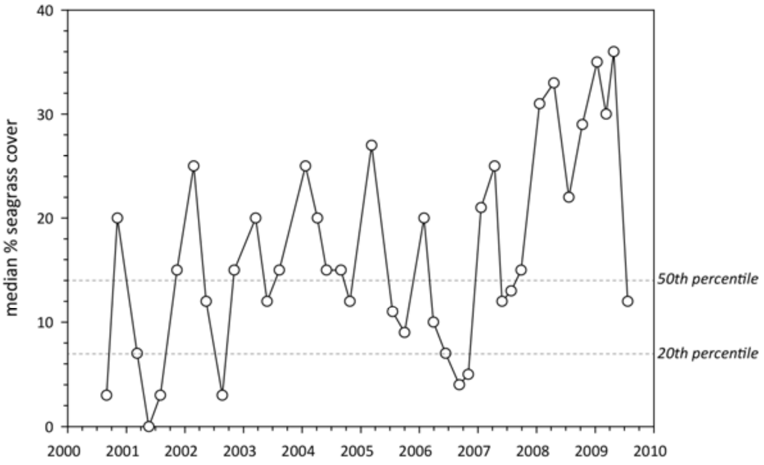

Figure 125. *Median seagrass abundance (% cover) at Yule Point plotted against the 50th and 20th percentiles for coastal seagrass habitat in the Wet Tropics.*

Similarly, when the median seagrass abundance for Green Island is plotted against the 20th and 50th percentiles for intertidal reef habitats in the Wet Tropics, it indicates that the meadows were in a poor condition in the middle of most years (based on abundance). However, the poor rating is most likely a consequence of seasonal lows in abundance. Therefore, in this instance, it was more appropriate to set the guideline at the 10th rather than the 20th percentile.

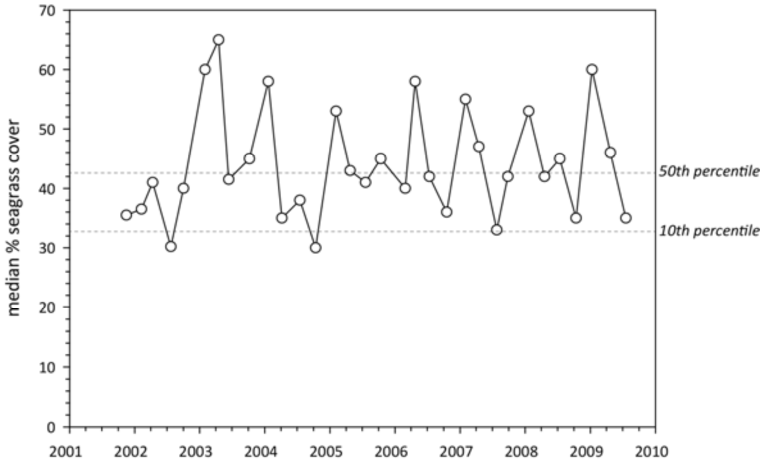

Figure 126. *Median seagrass abundance (% cover) at Green Island plotted against the 50th and 10th percentiles for intertidal reef seagrass habitat in the Wet Tropics.*

Using this approach, subregional seagrass abundance guidelines (hereafter known as “the seagrass guidelines”) were developed for each seagrass habitat types where possible (Table 7). If an individual site had 18 or more sampling events and no identified impacts (e.g., major loss from cyclone), an abundance guideline was determined at the site or location level rather than using the subregional guideline from the reference sites (i.e. as more guidelines are developed at the site level, they contribute to the subregional guideline).

Appendix 2: Additional Information

Table 26. *Samples collected at each inshore monitoring site per parameter for each season. Activities include: SG = seagrass cover & composition, SM=seed monitoring, TN=tissue nutrients, EM=edge mapping, RH=reproductive health, TL=temperature loggers, LL=light loggers, SH=sediment herbicides. ^=subtidal.*

Sector	Region	Catchment	Monitoring location		late dry Season (2013)							late monsoon Season (2014)						
					SG	SM	TN	EM	RH	TL	LL	SG	SM	EM	RH	SH	TL	LL
Far Northern	Cape York		Shelburne Bay	SR1	33	30	3	✓	15	✓		33	30	✓	15	✓	✓	
				SR2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓	✓
			Piper Reef	FR1	33	30	3	✓	15	✓		33	30	✓	15	✓	✓	
				FR2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓	✓
		Normanby	Stanley Island	ST1	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓	✓
				ST2	33	30	3	✓	15	✓		33	30	✓	15	✓	✓	
			Bathurst Bay	BY1	33	30	3	✓	15	✓		33	30	✓	15	✓	✓	
				BY2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓	✓
		Annan	Cooktown	AP1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				AP2	33	30	3	✓	15	✓		33	30	✓	15		✓	
Northern	Wet Tropics	Daintree	Low Isles	LI1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				LI2^	33	30	3	✓		✓	✓	33	30	✓	15		✓	✓
		Barron	Cairns	YP1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				YP2	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
		Russell - Mulgrave, Johnstone	Green Island	GI1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				GI2	33	30	3	✓	15	✓		33	30	✓	15		✓	
				GI3^	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
		Tully	Mission Beach	LB1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				LB2	33	30		✓	15	✓		33	30	✓	15		✓	
			Dunk Island	DI1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				DI2	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				DI3^	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
Central	Burdekin	Burdekin	Magnetic Island	MI1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				MI2	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				MI3^	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
			Townsville	SB1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				BB1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
			Bowling Green Bay	JR1	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓	✓
				JR2	33	30	3	✓	15	✓		33	30	✓	15	✓	✓	
	Mackay Whitsunday	Proserpine	Whitsundays	PI2	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				PI3	33	30	3	✓	15	✓		33	30	✓	15		✓	
			Hamilton Is.	HM1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				HM2	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
		Pioneer	Mackay	SI1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				SI2	33	30	3	✓	15	✓		33	30	✓	15		✓	
Southern	Fitzroy	Fitzroy	Shoalwater Bay	RC1	33	30	3	✓	15	✓							✓	
				WH1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
			Great Keppel .	GK1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				GK2	33	30		✓	15	✓		33	30	✓	15		✓	
		Boyne	Gladstone	GH1	33	30	3	✓	15	✓		33*	30*	✓	15		✓	
				GH2	33	30	3	✓	15	✓		33*	30*	✓	15			
	Burnett Mary	Burnett	Rodds Bay	RD1	33	30		✓	15	✓		33	30	✓	15		✓	
				RD2	33	30		✓	15	✓		33	30	✓	15		✓	
		Mary	Hervey Bay	UG1	33	30	3	✓	15	✓		33	30	✓	15		✓	
				UG2	33	30	3	✓	15	✓		33	30	✓	15		✓	✓

A2.1. Seagrass report card calculations

Three indicators (presented as unitless scores) were selected by the GBRMPA, using advice from expert working groups and the Paddock to Reef Integration Team, for the seagrass report card:

1. seagrass abundance (% cover)
2. reproductive effort
3. nutrient status (seagrass tissue C:N ratio)

All report card scores are transformed to a five point scale from 0 to 100 to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014).The method for calculation of the regional scores was chosen by the Paddock to Reef Integration Team (i.e. template was provided) and has been followed as directed. *Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.*

Table 27. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Cape York NRM region habitat over the 2013-14 period.Scores calculated as per Table 8. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	mean % cover	median % cover	Low percentile	50th percentile	75th percentile	score
coastal intertidal	Bathurst Bay	BY1	01-Oct-13	15.73	14	6.6	12.9	14.8	75
		BY1	01-Apr-14	30.12	32	6.6	12.9	14.8	100
		BY2	01-Oct-13	14.30	14	6.6	12.9	14.8	75
		BY2	01-Apr-14	25.91	28	6.6	12.9	14.8	100
	Shelburne Bay	SR1	01-Oct-13	13.79	12	6.6	12.9	14.8	50
		SR1	01-Apr-14	7.21	5	6.6	12.9	14.8	0
		SR2	01-Oct-13	12.15	10	6.6	12.9	14.8	50
		SR2	01-Apr-14	10.58	10	6.6	12.9	14.8	50
reef intertidal	Archer Point	AP1	01-Oct-13	1.54	0.5	11	18.9	23.7	0
		AP1	01-Apr-14	16.02	12	11	18.9	23.7	50
		AP2	01-Oct-13	9.35	7	11	18.9	23.7	0
		AP2	01-Apr-14	19.79	15	11	18.9	23.7	50
	Piper Reef	FR1	01-Oct-13	9.61	10	16.8	18.9	23.7	25
		FR1	01-Apr-14	12.64	11	16.8	18.9	23.7	25
		FR2	01-Oct-13	21.82	20	16.8	18.9	23.7	75
		FR2	01-Apr-14	21.91	18	16.8	18.9	23.7	50
	Stanley Island	ST1	01-Oct-13	12.42	10	16.8	18.9	23.7	25
		ST1	01-Apr-14	8.36	8	16.8	18.9	23.7	0
		ST2	01-Oct-13	6.24	6	16.8	18.9	23.7	25
		ST2	01-Apr-14	5.18	5	16.8	18.9	23.7	25
NRM region									**43**

Table 28. *Late dry season average seagrass reproductive effort (RE ±Standard Error) and report scores for each monitoring site (species pooled) within each NRM region habitat. Scores calculated as per Table 9. NB: scores do not have units.*

NRM region	habitat	site	RE ±SE	GBR RE (2005-10)	ratio	score
Cape York	coastal intertidal	BY1	0.73 ±0.38	8.22	0.09	0
		BY2	0	8.22	0	0
		SR1	0.33 ±0.21	8.22	0.04	0
		SR2	0	8.22	0	0
						0
	reef intertidal	AP1	0	1.32	0	0
		AP2	0.54 ±0.33	1.32	0.41	0
		FR1	0	1.32	0	0
		FR2	0	1.32	0	0
		ST1	2.20 ±0.86	1.32	1.67	50
		ST2	1.73 ±0.96	1.32	1.31	50
						17
	region					**8**
Wet Tropics	coastal intertidal	LB1	0	8.22	0	0
		LB2	0	8.22	0	0
		YP1	0	8.22	0	0
		YP2	0	8.22	0	0
						0
	reef intertidal	DI1	0	1.32	0	0
		DI2	2.33 ±1.25	1.32	1.77	50
		GI1	0.53 ±0.31	1.32	0.40	0
		GI2	0	1.32	0	0
		LI1	0	1.32	0	0
						10
	reef subtidal	DI3	0	0.24	0	0
		GI3	0.47 ±0.32	0.24	1.94	50
		LI2	*			
						25
	region					**12**
Burdekin	coastal intertidal	BB1	3.60 ±1.64	8.22	0.44	0
		SB1	18.73 ±3.27	8.22	2.28	75
		JR1	1.13 ±0.79	8.22	0.14	0
		JR2	2.13 ±0.65	8.22	0.26	0
						19
	reef intertidal	MI1	4.69 ±1.37	1.32	3.55	75
		MI2	2.40 ±1.05	1.32	1.82	50
						63
	reef subtidal	MI3	3.36 ±0.86	0.24	13.99	100
						100
	region					**60**
Mackay Whitsunday	estuarine intertidal	SI1	7.07 ±2.01	5.07	1.39	50
		SI2	0	5.07	0	0
						25
	coastal intertidal	PI2	0.53 ±0.53	8.22	0.06	0
		PI3	3.67 ±1.00	8.22	0.45	0
						0
	reef intertidal	HM1	13.20 ±2.13	1.32	10.00	100
		HM2	0	1.32	0	0
						50
	region					**25**
Fitzroy	estuarine intertidal	GH1	3.40 ±1.23	5.07	0.67	25
		GH2	3.33 ±1.10	5.07	0.66	25
						25
	coastal intertidal	RC1	1.38 ±0.64	8.22	0.17	0
		WH1	0.86 ±0.58	8.22	0.10	0
						0
	reef intertidal	GK1	0	1.32	0	0
		GK2	0	1.32	0	0
						0
	region					**8**
Burnett Mary	estuarine intertidal	RD1	0	5.07	0	0
		RD2	0	5.07	0	0
		UG1	0	5.07	0	0
		UG2	1.67 ±0.78	5.07	0.33	0
						0
	region					**0**

Table 29. *Average seagrass leaf tissue C:N ratios and report scores for each monitoring site (species pooled) within each NRM region habitat. C:N ratios transformed to a 0 to 100 score using Equation 1. NB: scores do not have units.*

NRM region	habitat	site	C:N ±SE	score
Cape York	coastal intertidal	BY1	15.70 ±0.78	28.48
		BY2	19.57 ±0.26	47.85
		SR1	16.97 ±1.03	34.86
		SR2	16.24 ±1.30	31.22
				36
	reef intertidal	AP1	14.44 ±0.59	22.18
		AP2	16.14 ±1.19	30.69
		FR1	17.25 ±0.17	36.24
		FR2	15.75 ±0.21	28.74
		ST1	19.84	49.21
		ST2	19.17 ±1.69	45.85
				35
	region			**35**
Wet Tropics	coastal intertidal	LB1	12.88	14.41
		LB2	11.03	5.13
		YP1	12.85 ±0.22	14.25
		YP2	16.34 ±0.76	31.70
				16
	reef intertidal	DI1	18.60 ±0.55	43.02
		DI2	17.73 ±0.37	38.64
		GI1	18.11 ±1.38	40.53
		GI2	17.01 ±0.22	35.04
		LI1	18.09 ±1.16	40.47
				40
	reef subtidal	DI3	19.07 ±1.68	45.35
		GI3	19.19 ±0.57	45.94
		LI2	*	
				46
	region			**34**
Burdekin	coastal intertidal	BB1	15.95 ±0.44	29.77
		SB1	16.90 ±0.26	34.50
		JR1	18.91 ±0.57	44.54
		JR2	19.36 ±1.12	46.79
				39
	reef intertidal	MI1	26.41 ±1.08	82.05
		MI2	21.14 ±0.75	55.69
				69
	reef subtidal	MI3	31.29 ±3.03	100
				100
	region			**69**
Mackay Whitsunday	estuarine intertidal	SI1	16.19 ±0.75	30.94
		SI2	19.49 ±1.62	47.43
				39
	coastal intertidal	PI2	13.26 ±0.31	16.29
		PI3	15.89 ±0.94	29.46
				23
	reef intertidal	HM1	11.28 ±0.59	6.42
		HM2	21.01 ±0.20	55.03
				31
	region			**31**
Fitzroy	estuarine intertidal	GH1	16.73 ±0.52	33.63
		GH2	16.47 ±0.06	32.33
				33
	coastal intertidal	RC1	21.52 ±0.83	57.62
		WH1	25.23 ±0.36	76.17
				67
	reef intertidal	GK1	18.11 ±0.55	40.53
		GK2	*	
				41
	region			**47**
Burnett Mary	estuarine intertidal	RD1	*	
		RD2	*	
		UG1	24.80 ±2.33	74.00
		UG2	25.97 ±0.80	79.83
				77
	region			**77**

Table 30. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Wet Tropics NRM region habitat over the 2013-14 period. Scores calculated as per Table 8. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean % cover	Median % cover	Low percentile	50th percentile	75th percentile	score
coastal intertidal	Lugger Bay	LB1	01-Jul-13	0.03	0	6.6	12.9	14.8	0
		LB1	01-Oct-13	0.01	0	6.6	12.9	14.8	0
		LB1	01-Apr-14	0.00	0	6.6	12.9	14.8	0
		LB2	01-Jul-13	0.02	0	6.6	12.9	14.8	0
		LB2	01-Oct-13	0.00	0	6.6	12.9	14.8	0
		LB2	01-Apr-14	0.00	0	6.6	12.9	14.8	0
	Yule Point	YP1	01-Jul-13	3.85	0.7	7	14	15.4	0
		YP1	01-Oct-13	7.07	6	7	14	15.4	25
		YP1	01-Jan-14	18.53	18	7	14	15.4	100
		YP1	01-Apr-14	13.97	12	7	14	15.4	50
		YP2	01-Jul-13	3.25	2.7	6.2	11.8	14.2	0
		YP2	01-Oct-13	5.52	6	6.2	11.8	14.2	25
		YP2	01-Jan-14	12.53	9	6.2	11.8	14.2	50
		YP2	01-Apr-14	7.27	8	6.2	11.8	14.2	50
reef intertidal	Dunk Island	DI1	01-Jul-13	0.27	0	27.5	37.7	41	0
		DI1	01-Oct-13	0.39	0	27.5	37.7	41	0
		DI1	01-Apr-14	0.28	0	27.5	37.7	41	0
		DI2	01-Jul-13	0.52	0	27.5	37.7	41	0
		DI2	01-Oct-13	0.16	0	27.5	37.7	41	0
		DI2	01-Apr-14	0.95	0	27.5	37.7	41	0
	Green Island	GI1	01-Jul-13	32.67	36	32.5	42.7	45.5	50
		GI1	01-Oct-13	40.27	39	32.5	42.7	45.5	50
		GI1	01-Jan-14	51.27	52	32.5	42.7	45.5	100
		GI1	01-Apr-14	36.27	38	32.5	42.7	45.5	50
		GI2	01-Jul-13	19.58	18	22.5	32.7	36.7	0
		GI2	01-Oct-13	29.94	30	22.5	32.7	36.7	50
		GI2	01-Jan-14	34.27	35	22.5	32.7	36.7	75
		GI2	01-Apr-14	26.82	28	22.5	32.7	36.7	50
	Low Isles	LI1	01-Jul-13	6.32	5	22.5	32.7	36.7	25
		LI1	01-Oct-13	5.79	5	22.5	32.7	36.7	25
		LI1	01-Apr-14	1.09	0	22.5	32.7	36.7	0
reef subtidal	Dunk Island	DI3	01-Jul-13	0.64	0	26	33	39.2	0
		DI3	01-Oct-13	0.55	0	26	33	39.2	0
		DI3	01-Apr-14	0.32	0	26	33	39.2	0
	Green Island	GI3	01-Jul-13	29.61	30	26	33	39.2	50
		GI3	01-Oct-13	41.76	40	26	33	39.2	100
		GI3	01-Apr-14	13.50	10	26	33	39.2	0
	Low Isles	LI2	01-Apr-14	0.00	0	22.5	32.7	36.7	0
NRM region									**24**

Table 31. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Burdekin NRM region habitat over the 2013-14 period. Scores calculated as per Table 8. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean % cover	Median % cover	Low percentile	50th percentile	75th percentile	score
coastal intertidal	Townsville	BB1	01-Jul-13	21.48	20	21.4	25.4	35.2	25
		BB1	01-Oct-13	23.88	25	21.4	25.4	35.2	50
		BB1	01-Jan-14	22.91	25	21.4	25.4	35.2	50
		BB1	01-Apr-14	14.43	10	21.4	25.4	35.2	0
		SB1	01-Jul-13	14.39	15	10	16.8	22	50
		SB1	01-Oct-13	12.70	13	10	16.8	22	50
		SB1	01-Jan-14	19.14	20	10	16.8	22	75
		SB1	01-Apr-14	7.98	7	10	16.8	22	0
	Bowling Green Bay	JR1	01-Oct-13	22.18	22	15.7	21.1	28.6	75
		JR1	01-Apr-14	18.36	18	15.7	21.1	28.6	50
		JR2	01-Oct-13	19.28	20	15.7	21.1	28.6	50
		JR2	01-Apr-14	18.73	18	15.7	21.1	28.6	50
reef intertidal	Magnetic Island	MI1	01-Jul-13	16.88	20	26	33.4	37	0
		MI1	01-Oct-13	15.02	20	26	33.4	37	25
		MI1	01-Apr-14	21.56	30	26	33.4	37	50
		MI2	01-Jul-13	42.00	40	21.3	35.6	41	75
		MI2	01-Oct-13	26.88	25	21.3	35.6	41	50
		MI2	01-Apr-14	49.76	50	21.3	35.6	41	100
reef subtidal	Magnetic Island	MI3	01-Jul-13	25.76	25	22.5	32.7	36.7	50
		MI3	01-Oct-13	27.42	30	22.5	32.7	36.7	50
		MI3	01-Jan-14	37.08	40	22.5	32.7	36.7	100
		MI3	01-Apr-14	57.61	75	22.5	32.7	36.7	100
NRM region									**51**

Table 32. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Mackay Whitsunday NRM region habitat over the 2013-14 period. Scores calculated as per Table 8. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean % cover	Median % cover	Low percentile	50th percentile	75th percentile	score
estuarine intertidal	Sarina Inlet	SI1	01-Oct-13	14.33	14	18	34.1	54	25
		SI1	01-Apr-14	4.02	2.5	18	34.1	54	0
		SI2	01-Oct-13	20.85	17	18	34.1	54	25
		SI2	01-Apr-14	2.23	0.7	18	34.1	54	0
coastal intertidal	Pioneer Bay	PI2	01-Jul-13	6.13	5	18.7	25.1	27.6	0
		PI2	01-Oct-13	15.68	13	18.7	25.1	27.6	25
		PI2	01-Apr-14	15.38	16	18.7	25.1	27.6	25
		PI3	01-Jul-13	9.70	5	7.6	13.1	16.8	25
		PI3	01-Oct-13	14.47	12	7.6	13.1	16.8	50
		PI3	01-Apr-14	17.92	15	7.6	13.1	16.8	75
reef intertidal	Hamilton Island	HM1	01-Oct-13	2.42	0.3	22.15	34.5	39	0
		HM1	01-Apr-14	1.77	0	22.15	34.5	39	0
		HM2	01-Oct-13	4.62	0	22.15	34.5	39	0
		HM2	01-Apr-14	1.97	0	22.15	34.5	39	0
NRM region									**18**

Table 33. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Fitzroy NRM region habitat over the 2013-14 period. Scores calculated as per Table 8. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean % cover	Median % cover	Low percentile	50th percentile	75th percentile	score
estuarine intertidal	Gladstone Harbour	GH1	01-Jul-13	25.00	25	18	34.1	54	50
		GH1	01-Oct-13	33.67	32	18	34.1	54	50
		GH1	01-Jan-14	12.70	12	18	34.1	54	0
		GH1	01-Apr-14	10.42	12	18	34.1	54	25
		GH2	01-Jul-13	19.12	20	18	34.1	54	50
		GH2	01-Oct-13	25.97	26	18	34.1	54	50
		GH2	01-Jan-14	17.91	20	18	34.1	54	50
		GH2	01-Apr-14	14.76	15	18	34.1	54	0
coastal intertidal	Shoalwater Bay	RC1	01-Oct-13	6.55	6	17.3	21.8	34.5	0
		WH1	01-Oct-13	10.88	12	14.4	18.8	22.3	25
		WH1	01-Apr-14	7.24	7	14.4	18.8	22.3	0
reef intertidal	Great Keppel Island	GK1	01-Oct-13	1.94	1	22.15	34.5	39	25
		GK1	01-Apr-14	2.40	0	22.15	34.5	39	0
		GK2	01-Oct-13	0.44	0	22.15	34.5	39	0
		GK2	01-Apr-14	0.02	0	22.15	34.5	39	0
NRM region									**22**

Table 34. *Mean and median seagrass % cover and report score for each long-term monitoring site within each Burnett Mary NRM region habitat over the 2013-14 period. Scores calculated as per Table 8. NB: scores do not have units.*

Location	Site	Seasonal date	Mean % cover	Median % cover	Low percentile	50th percentile	75th percentile	score
Rodds Bay	RD1	01-Jul-13	0.28	0.1	18	34.1	54	25
	RD1	01-Oct-13	0.02	0	18	34.1	54	0
	RD1	01-Apr-14	0.02	0	18	34.1	54	0
	RD2	01-Jul-13	0.58	0.2	18	34.1	54	25
	RD2	01-Oct-13	0.01	0	18	34.1	54	0
	RD2	01-Apr-14	0.00	0	18	34.1	54	0
Urangan	UG1	01-Oct-13	2.85	0	18	34.1	54	0
	UG1	01-Apr-14	5.10	0	18	34.1	54	0
	UG2	01-Oct-13	3.48	0.4	18	34.1	54	0
	UG2	01-Apr-14	25.19	27	18	34.1	54	50
NRM region								**10**

Table 35. *Summary of GAMM statistical outputs.*

Analysis & NRM region	***n***	**edf**	**Ref df**	***F***	***p*-value**	**R-sq (adj)**
average % cover vs time						
Cape York	92	4.03	4.03	10.51	<0.0001	0.132
Wet Tropics	399	7.92	7.92	14.5	<0.0001	0.036
Burdekin	204	9.3	9.3	13.72	<0.0001	0.419
Mackay Whitsunday	164	8.96	8.96	7.92	<0.0001	0.281
Fitzroy	148	2.81	2.81	4.05	0.01	0.005
Burnett Mary	144	8.3	8.3	12.72	<0.0001	0.487
Reproductive effort vs time						
Cape York	92	4.03	4.03	10.51	<0.0001	0.132
Wet Tropics	126	2.76	2.76	5.78	0.0015	0.114
Burdekin	204	7.0	7.0	13.07	<0.0001	0.317
Mackay Whitsunday	50	3.32	3.32	3.09	0.0321	0.159
Fitzroy	96	1	1	17.08	<0.0001	0.149
Burnett Mary	55	1	1	6.65	0.013	-0.033
seed banks vs time						
Cape York	52	1	1	0.79	0.378	-0.071
Wet Tropics	209	8.47	8.47	17.01	<0.0001	-0.007
Burdekin	190	5.22	5.22	11.03	<0.0001	0.18
Mackay Whitsunday	164	9.04	9.04	7.89	<0.0001	0.282
Fitzroy	123	4.08	4.08	3.16	0.016	0.097
Burnett Mary	76	9.52	9.52	10.6	<0.0001	0.293
Epiphyte % cover vs time						
Cape York	93	3.71	3.71	3.63	<0.0107	-0.081
Wet Tropics	374	6.89	6.89	6.06	<0.0001	0.018
Burdekin	200	4.61	4.61	4.97	0.00041	0.102
Mackay Whitsunday	160	1.8	1.8	0,65	<0.51	0.012
Fitzroy	123	1	1	6.77	0.01	0.028
Burnett Mary	142	6.02	6.02	4.3	0.0005	0.102
Macroalgae % cover vs time						
Cape York	93	2.47	2.47	9.95	<0.0001	-0.154
Wet Tropics	374	3.48	3.48	6.4	0.0002	-0.042
Burdekin	202	1	1	4.27	0.04	0.017
Mackay Whitsunday	161	3.28	3.28	6.38	0.0003	0.12
Fitzroy	123	2.68	2.68	18.54	<0.0001	0.147
Burnett Mary	142	1.74	1.74	0.48	0.593	-0.002
light vs time						
Cape York	1306	3.942	3.942	49.86	<0.0001	0.110
Wet Tropics	11589	13.96	13.96	196.4	<0.0001	0.123
Burdekin	7782	13.76	13.76	73.72	<0.0001	0.080
Mackay Whitsunday	3378	13.71	13.71	66.58	<0.0001	0.207
Fitzroy	4003	13.59	13.59	36.56	<0.0001	0.114
Burnett Mary	1651	12.76	12.76	36.28	<0.0001	0.145
seagrass extent vs time						
GBR	590	5.729	5.729	6.011	<0.0001	0.0201

A2.2. Conceptual diagrams

BIOLOGICAL ENVIRONMENT

Cymodocea serrulata
Halophila ovalis
Zostera muelleri
mangrove
macro-invertebrates
Cymodocea rotundata
Syringodium isoetifolium
seagrass seedbank
Macro-algae
boulder corals
Halodule uninervis
Thalassia hemprichii
epiphytes
Commercial prawns
branching corals
Halophila decipiens
Thalassodendron ciliatum
encrusting epiphytes
forest & grassland
reef fish

BIOLOGICAL PROCESS

seagrass germination & growth

seagrass loss & recovery

high and low seagrass production

parrotfish and urchin herbivory regulates distribution of seagrass species near patch reefs (38, 39, 40)

grazing epifauna reduce epiphyte biomass and promote seagrass growth, productivity and depth distribution (41)

Bioturbation can excavate or bury seagrass plants and seeds (36, 37, 42)

Grazing by dugongs and green sea turtles can impact seagrass community structure by favoring rapidly growing, opportunistic seagrass species (43,44,45)

PHYSICAL ENVIRONMENT & PROCESS

sediment resuspension & deposition

Nutrient input

nitrogen limitation

Phosphorus limitation

flushing

bank erosion

Suspended sediments

wind

Wave energy creates an unstable sediment environment where it is difficult for seagrass seedlings to establish or persist (51)

Dessiccation results in photosynthesis inhibition & tissue death in some seagrass species (59)

Pulsed turbidity events from river discharges of summer rainfall restrict light availability, limiting seagrass growth (49, 48, 50)

Reduced light quality & quantity with depth results in reduction of maximum depth distribution of seagrass (54)

High light reduces effective photochemical efficiency in seagrass (58)

No light. Seagrass require ~11% of surface irradiance for growth, but ranges from 5-25% depending on species (58)

Herbicides in water column inhibit photosynthesis in seagrass (1, 2, 3, 4)

Elevated seawater temperatures >40°C inhibit photosynthesis causing seagrass leaf death (53)

Anoxia from fine sediments & high organic loading stresses seagrasses (57)

Floods, cyclones and long term weather patterns modify seagrass abundance (47, 48)

Low & high salinities decrease chlorophyll content in seagrass leaves, uptake of nutrients and soluble sugar content in rhizomes (55, 56)

Ground water & submarine springs can be a source of phosphorus and/or iron to seagrasses (60, 63, 64)

Low salinity, turbidity and siltation associated with rainfall events depresses seagrass abundance and neatively impacts macro-invertebrates (57)

High tidal velocities scour and resuspend sediments inhibiting seagrass colonisation (34)

Particulate organic matter from sewage promotes excessive algae/epiphyte growth which reduces light available to seagrass (61, 62)

ANTHROPOGENIC IMPACTS

water quality related

Herbicides in runoff from intensive coastal agriculture (sugarcane, banana and dairying) can reduce or inhibit local seagrass (1, 2, 3, 4)

Land clearing/deforestation cause sediment plumes which reduce subsurface light intensity, resulting in plant loss (21)

Treated effluent, nutrient enrichment & heavy metals can degrade seagrasses (1, 22, 23, 35)

Groundwater nutrients from housing developments can cause eutrophication and seagrass loss (24, 26)

Non-nutrient chemicals from industry can poison seagrass (18, 20, 26)

Port dredging and sand mining physically remove and/or bury seagrass and increase turbidity & sedimentation (15, 16, 17)

Oil spills cause intertidal seagrass leaf death (28), decrease invertebrate abundances (28, 29, 30, 31) and associated algae blooms reduce available light (28, 30, 32). Dispersants use in oil spill cleanup are toxic to many tropical seagrass species (33)

Shipping antifouling chemicals reduce seagrass photosynthetic efficiency and growth (13, 14)

Deep-draft vessel movements in shallow waters resuspend sediments inhibiting light to seagrass & induce erosion (51, 52)

other

Marinas decrease penetration of light resulting in lower chlorophyll and seagrass density (10, 11, 12, 25)

Recreational boat wash depresses abundances of macroinvertebrates due to displacement by flapping seagrass blades (5). Propeller scars, anchoring and mooring of boats can physically damage seagrass (6, 7, 8, 9)

Artificial beach nourishment can bury or physically remove seagrass (19)

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31. Baca et al. 1996
32. Ralph & Burchett, 1998
33. Thorhaug & Marcus 1987
34. Coles et al 2009
35. Costanzo et al. 2005
36. Meysman et al. 2008
37. Inglis 2000
38. Unsworth et al. 2007
39. Armitage & Fourqurean 2006
40. Eklöf et al. 2008
41. Howard & Short 1986
42. Ogden and Ogden, 1982
43. Preen, 1995
44. Aragones and Marsh, 2000
45. Lanyon et al., 1989
47. Birch and Birch, 1984
48. Preen et al. 1995
49. McKenzie 1994
50. Hamilton, 1994
51. Garel et al. 2008
52. Schoellhamer 1996
53. Campbell et al. 2006
54. Abal and Dennison 1996
55. Touchette 2007
56. Thorhaug et al. 2006
57. Connolly et al. 1999
58. Ralph et al. 2007
59. Shafer et al. 2007
60. Carruthers et al. 2005
61. Dennison & Abal 1999
62. Costanzo et al. 2003
63. Stieglitz 2005
64. Gagan et al 2002

Figure 127. *Key to symbols used for conceptual diagrams detailing impacts to seagrasses.*

A2.2.1.Cape York

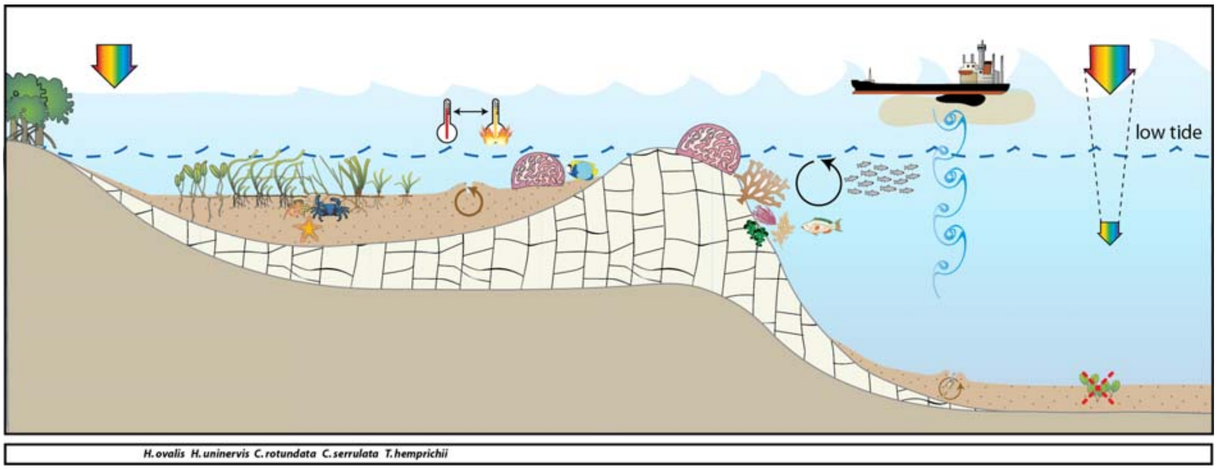

Figure 128. *Conceptual diagram of reef habitat in the Cape York region – major control is pulsed physical disturbance, salinity and temperature extremes: general habitat and seagrass meadow processes (see Figure 127 for icon explanation).*

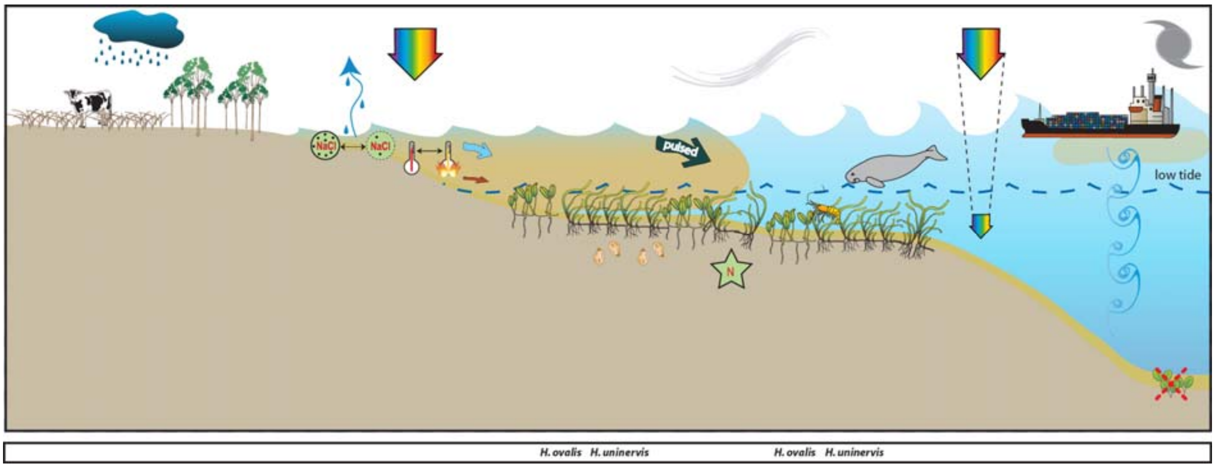

Figure 129. *Conceptual diagram of coastal habitat in the Cape York region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

A2.2.2. Wet Tropics

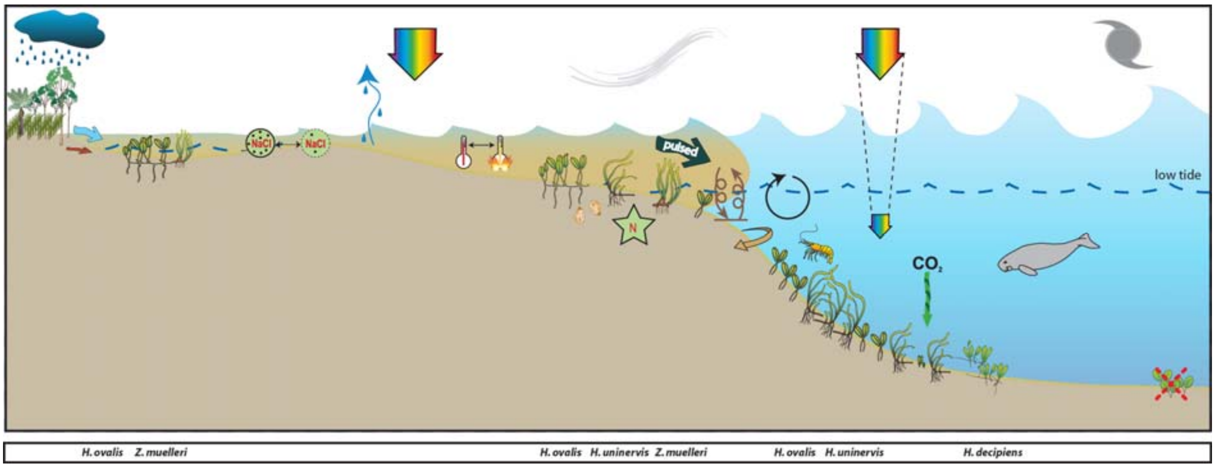

Figure 130. *Conceptual diagram of coastal habitat (<15m) in the Wet Tropics region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

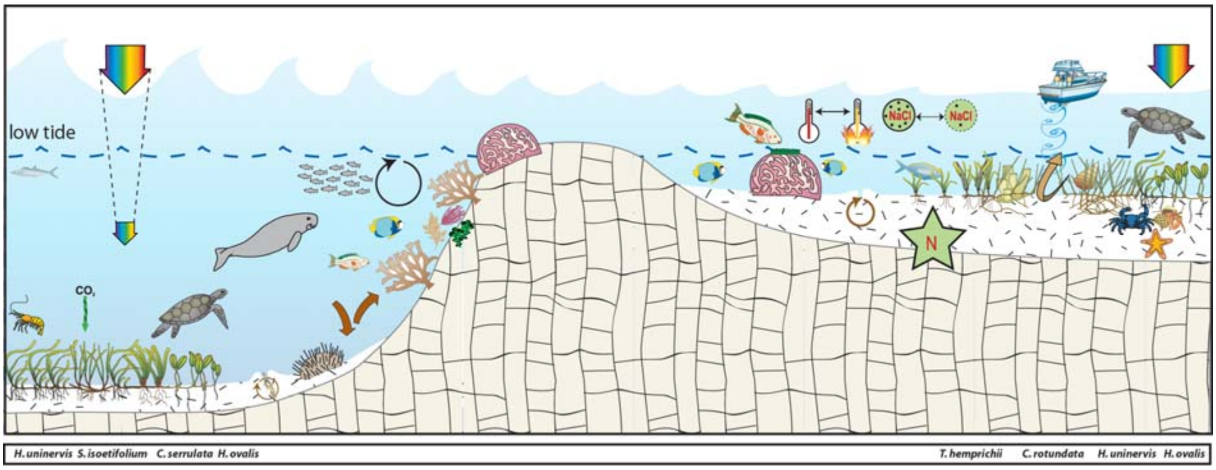

Figure 131. *Conceptual diagram of reef habitat (<15m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

A2.2.3.Burdekin

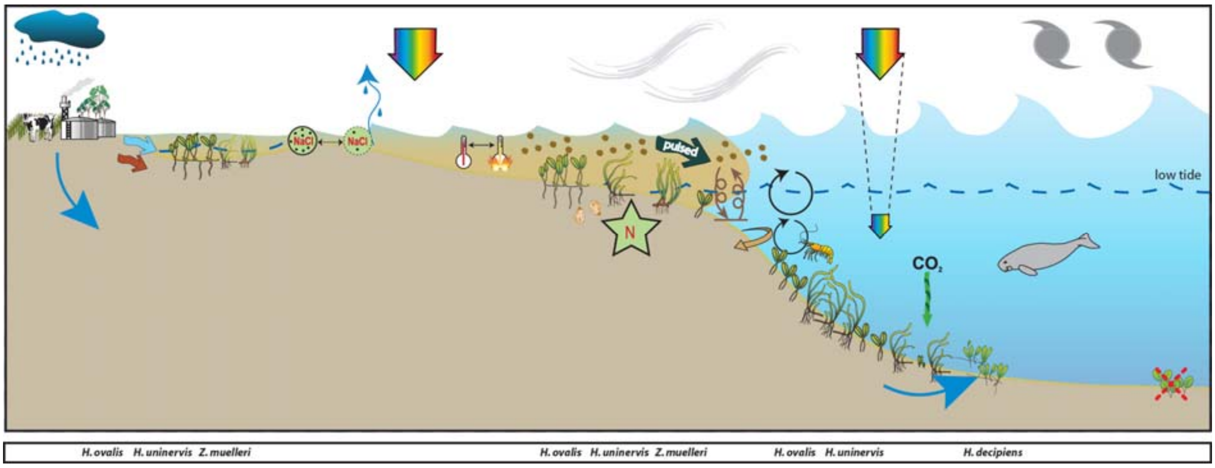

Figure 132. *Conceptual diagram of coastal habitat in the Burdekin region - major control is wind and temperature extremes, general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

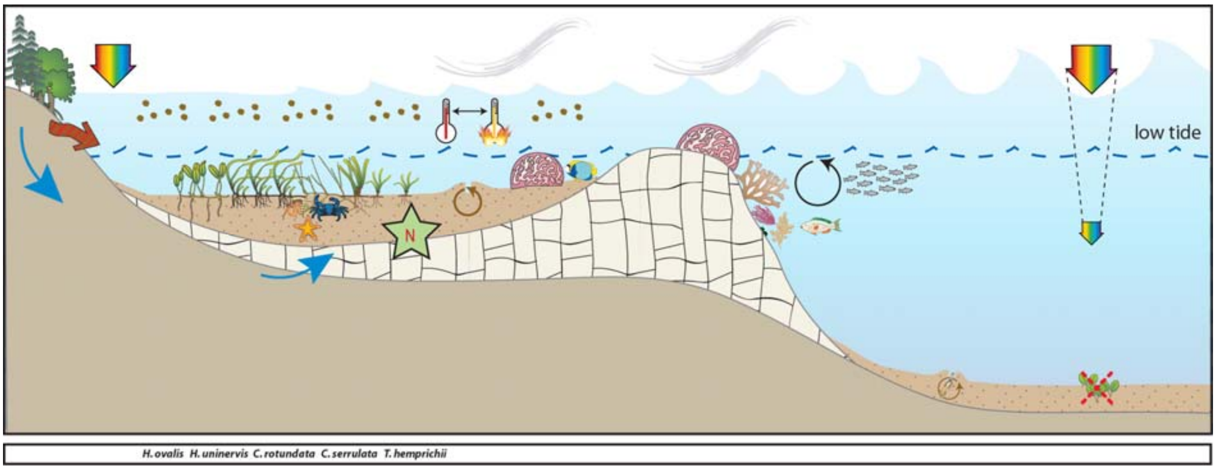

Figure 133. *Conceptual diagram of fringing reef habitat in the Burdekin region - major control is nutrient supply (groundwater), light and shelter: general habitat and seagrass meadow processes (see Figure 127 for icon explanation).*

A2.2.4.Mackay Whitsunday

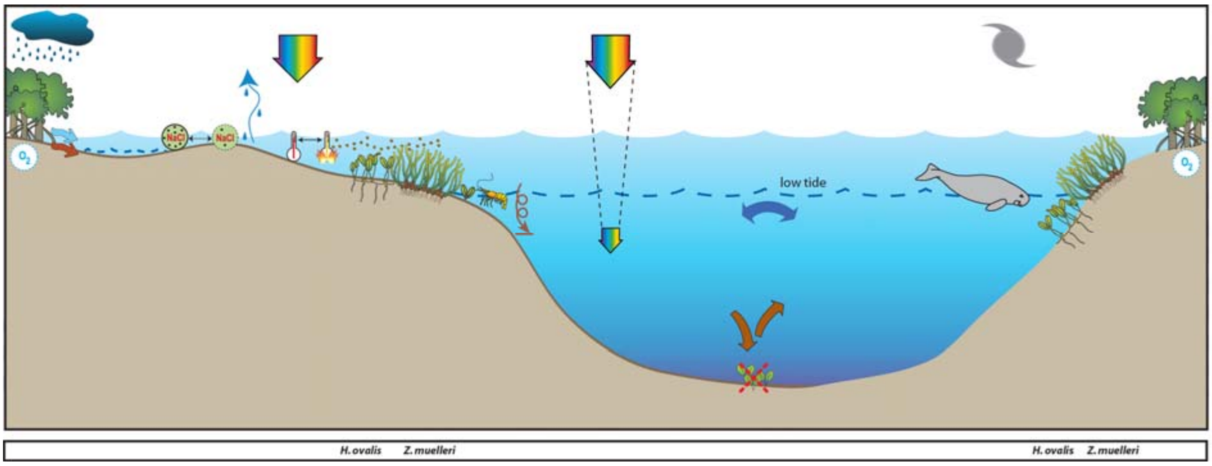

Figure 134. *Conceptual diagram of estuary habitat in the Mackay Whitsunday region: general habitat and seagrass meadow processes (see Figure 127 for icon explanation).*

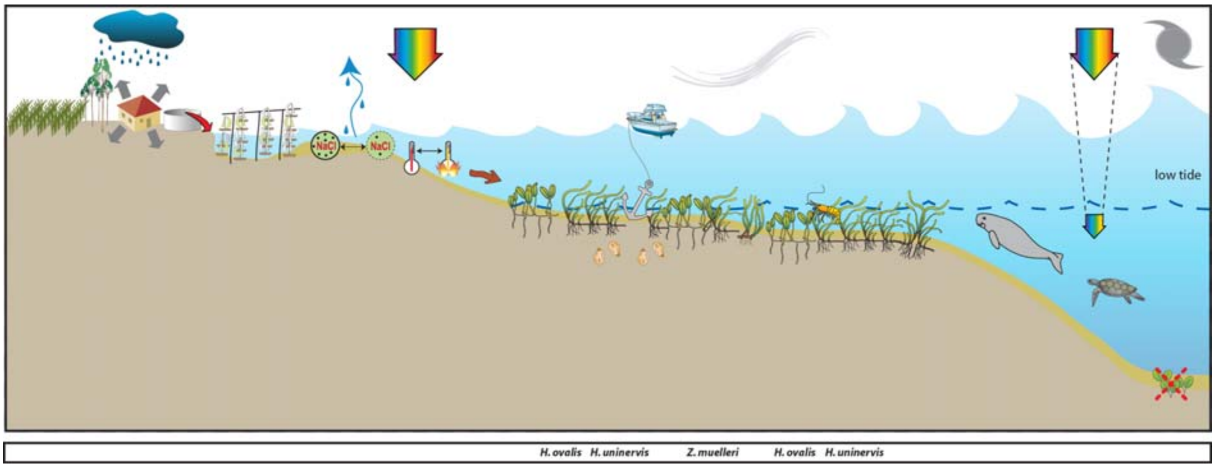

Figure 135. *Conceptual diagram of coastal habitat in the Mackay Whitsunday region – major control is shelter and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

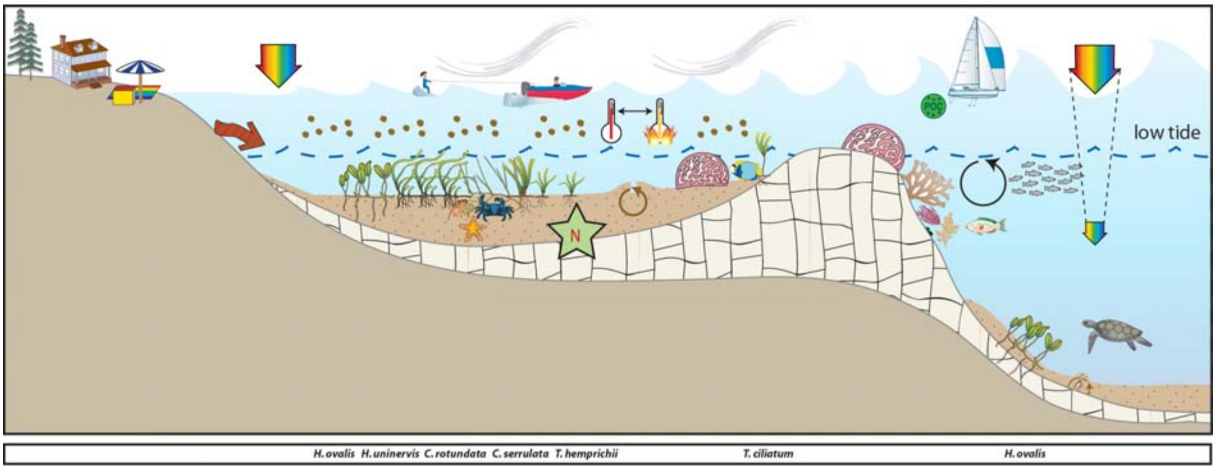

Figure 136. *Conceptual diagram of reef habitat in the Mackay Whitsunday region - major control is light and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

A2.2.5.Fitzroy

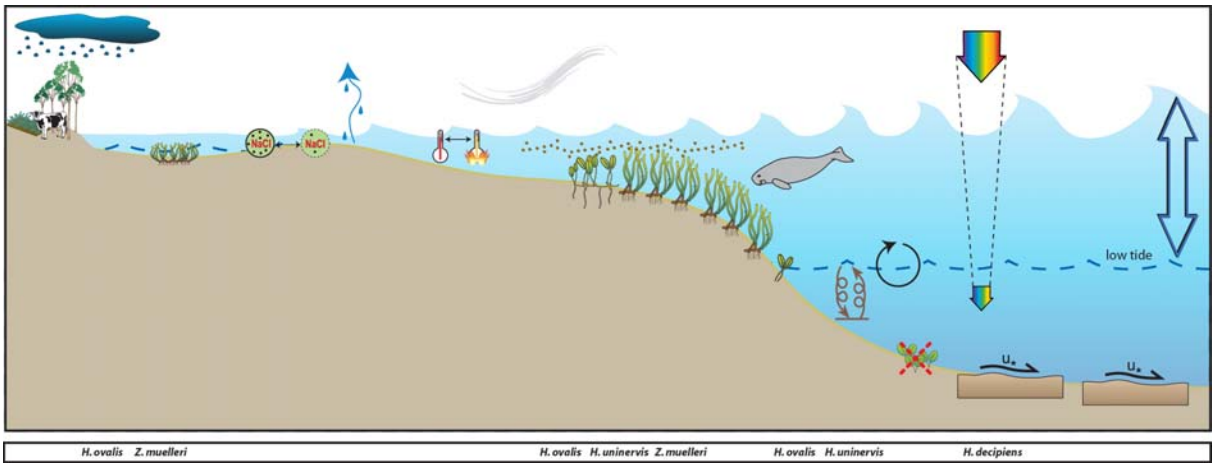

Figure 137. *Conceptual diagram of coastal habitat in the Fitzroy region – major control is pulsed light, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

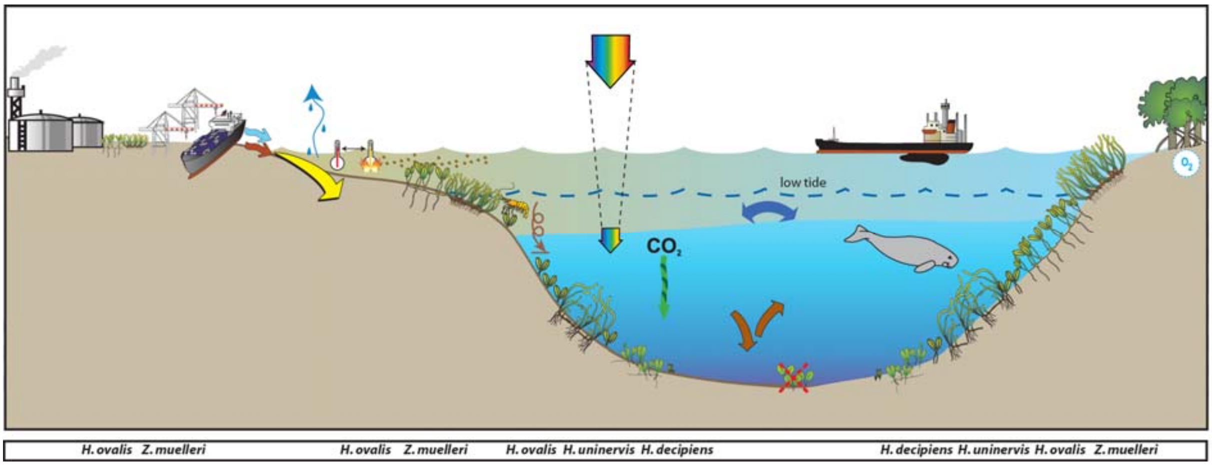

Figure 138. *Conceptual diagram of estuary habitat in the Fitzroy region – major control variable rainfall and tidal regime: general habitat, seagrass meadow processes and threats/impacts (see Figure 2 for icon explanation).*

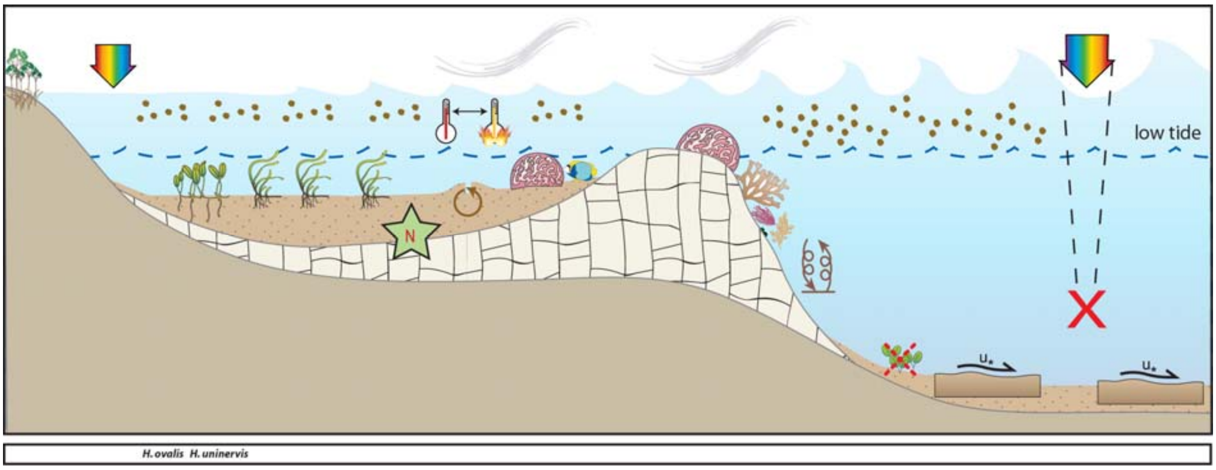

Figure 139. *Conceptual diagram of reef habitat in the Fitzroy region - major control is light and temperature extremes and benthic shear from tidal currents: general habitat, seagrass meadow processes and threats/impacts (see Figure 127 for icon explanation).*

A2.2.6.Burnett Mary

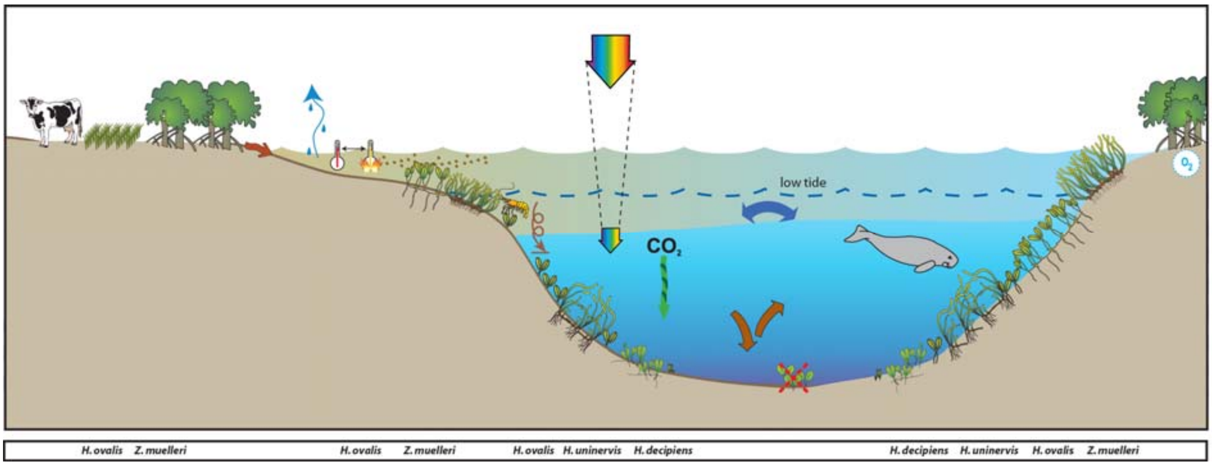

Figure 140. *Conceptual diagram of Estuary habitat in the GBR section of the Burnett Mary region – major control is shelter from winds and physical disturbance: general habitat and seagrass meadow processes (see Figure 127 for icon explanation).*

A2.3. Seagrass extent

Table 36. *Proportion of area (within 100m radius of each monitoring site) which is covered by seagrass. For sites codes, see Table 5. Shading indicates area of seagrass below baseline (first measure).*

Date	Oct 2005	Apr 2006	Oct 2006	Apr 2007	Oct 2007	Apr 2008	Oct 2008	Apr 2009	Oct 2009	Apr 2010	Oct 2010	Apr 2011	Oct 2011	Apr 2012	Oct 2012	Apr 2013	Oct 2013	Apr 2014
SR1														1	1	1	1	1
SR2														0.94	0.93	0.94	0.92	0.92
FR1														0.72	0.70	0.70	0.70	0.75
FR2														0.91	0.91	0.89	0.91	0.93
ST1														0.69	0.63	0.71	0.72	0.72
ST2														0.94	0.96	0.95	0.96	0.96
BY1														0.75	0.77	0.85	0.83	0.88
BY2														0.90	0.90	1	0.96	0.96
AP1	0.68	0.61	0.71	0.78	0.77	0.72	0.72	0.62	0.68		0.73	0.72	0.71	0.69	0.58	0.63	0.64	0.67
AP2	0.68	0.58	0.66	0.75	0.75	0.64	0.66	0.60	0.66		0.71	0.65	0.67	0.65	0.58	0.64	0.63	0.64
LI1														0.78	0.88	0.97	1	1
LI2													0.48	0	0.01	0.001	0.002	0.002
YP1	0.25	0.33	0.33	0.45	0.57	0.53	0.54	0.46	0.42	0.30	0.31	0.33	0.08	0.23	0.11	0.46	0.41	0.46
YP2	0.67	0.76	0.69	0.69	0.82	0.88	0.82	0.87	0.86	0.83	0.79	0.81	0.38	0.67	0.31	0.72	0.65	0.61
GI1	0.98	0.99	0.98	0.98	0.98	0.99	0.98	0.99	0.98	0.99	0.98	0.98	0.99	0.99	0.98	0.99	0.98	0.97
GI2	0.86	0.86	0.878	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.86	0.87	0.88	0.87	0.87	0.86	0.85
GI3													0.26	0.70	0.94	0.38	0.77	0
LB1	0.31	0.20	0.08	0.18	0.22	0.20	0.30	0.23	0.23	0.09	0.03	0	0	0	0	0	0.01	0
LB2	0.34	0.27	0.10	0.22	0.30	0.27	0.36	0.31	0.29	0.09	0.03	0	0	0	0.01	0.01	0.015	0.001
DI1				0.59	0.63	0.61	0.61	0.603	0.62	0.61	0.619	0	0.01	0.003	0.01	0.04	0.24	0.28
DI2				0.72	0.76	0.80	0.78	0.80	0.79	0.75	0.77	0.002	0.05	0.03	0.05	0.12	0.21	0.24
DI3													0	0	0	0	0	0
BB1	1.00	1.00	1	0.96	0.98	0.96	0.99	0.43	0.87	0.47	0.21	0.48	0.40	0.21	1	0.98	1	1
SB1	0.81	0.66	0.54	0.74	0.85	0.39	0.31	0.22	0.51	0.39	0.67	0.05	0.16	0.16	0.94	0.87	0.72	0.96
MI1	0.55	0.64	0.32	0.49	0.59	0.514	0.52	0.50	0.73	0.48	0.43	0.21	0.42	0.46	0.48	0.49	0.48	0.53
MI2	0.77	0.82	0.77	0.78	0.78	0.79	0.81	0.98	0.66	0.39	0.75	0.22	0.75	0.77	0.97	0.99	0.90	0.99
MI3													0.63	0.34	0.39	0.60	0.59	0.34
JR1														1	1	1	1	1
JR2														0.83	0.83	0.83	1	1
PI2	0.65	0.67	0.72	0.79	0.80	0.77	0.78	0.85	0.99	0.87	0.96	0.29	0.22	0.46	0.33	0.70	0.83	0.97
PI3	0.46	0.38	0.74	0.84	0.80	0.79	0.81	0.84	0.91	0.67	0.96	0.19	0.16	0.49	0.40	0.72	0.95	0.97
HM1					0.30	0.34	0.28	0.25	0.18	0.13	0.26	0.15	0.32	0.54	0.64	0.62	0.67	0.53
HM2					0.12	0.04	0.07	0.04	0.02	0.01	0.04	0.01	0.03	0.03	0.05	0.04	0.06	0.04
SI1	0.64	0.33	0.84	0.78	0.90	0.32	0.68	0.33	0.47	0.13	0.27	0.12	0.73	0.50	0.80	0.65	0.76	0.67
SI2	0.71	0.47	0.70	0.67	0.90	0.35	0.71	0.27	0.46	0.17	0.23	0.05	0.69	0.50	0.70	0.70	0.76	0.69
RC1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WH1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GH1	1	0	1	1	0.77	0.83	0.94	0.93	0.88	0.96	0.96	0.92	0.88	0.89	0.88	0.88	0.89	0.85
GH2	0.96	0	1	0.96	0.88	0.94	0.90	0.98	0.93	0.98	0.95	0.91	0.90	0.91	0.87	0.94	0.86	0.83
GK1					0.81	0.17	0.30	0.58	0.78	0.76	0.30	0.12	0.09	0.09	0.38	0.20	0.40	0.28
GK2					0.78	0.46	0.62	0.43	0.72	0.74	0.73	0.54	0.25	0.25	0.18	0.22	0.15	0.04
RD1					0.18	0.24	0.22	0	0.01	0	0.10	0.04	0.05	0	0.22	0.17	0	0.02
RD2					0.66	0.65	0.67	0.66	0.51	0	0	0.02	0.01	0	0.03	0	0	0.02
UG1	0.99	0	0	0	0.001	0.07	0.06	0.01	0.06	0.34	0.27	0.06	0.07	0.09	0.20	0.21	0.20	0.27
UG2	1	0	0	0	0	0.29	0.52	0.09	0.19	0.70	0.70	0.38	0.43	0.54	0.67	0.61	0.53	0.64

A2.4. Seagrass leaf tissue

The following graphs display the elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each habitat or location in the NRM regions of the Great Barrier Reef. The horizontal shaded band on the C:N ratio panels represent the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment. The horizontal shaded band on the N:P ratio panels represent the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).

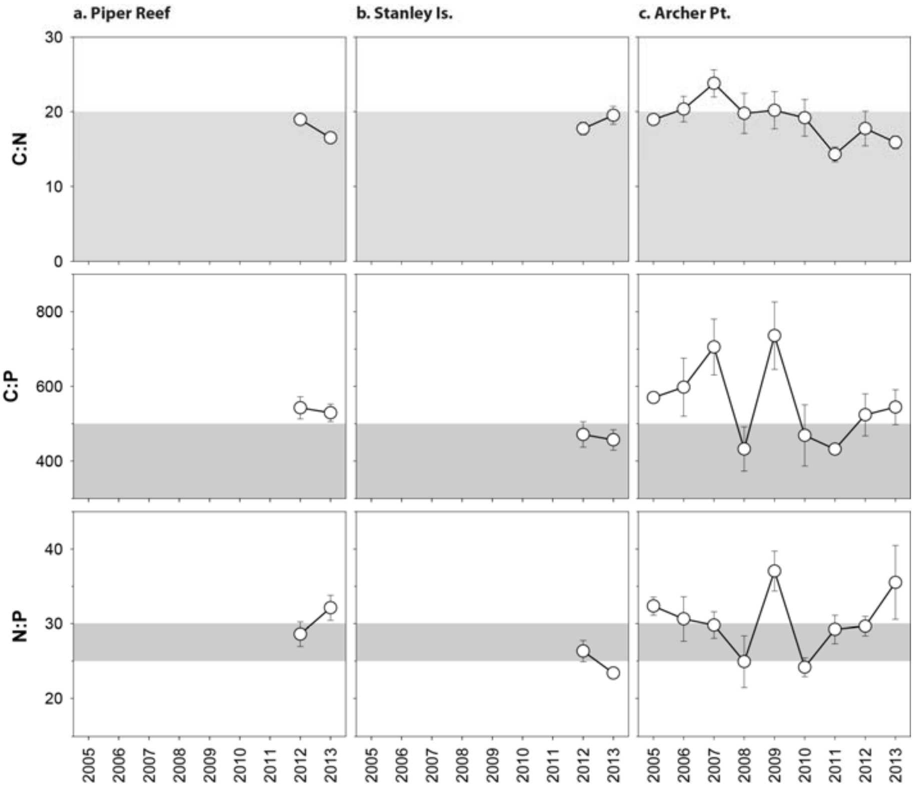

Figure 141. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each reef location in the Cape York region each year (species pooled) (mean ± Standard Error).*

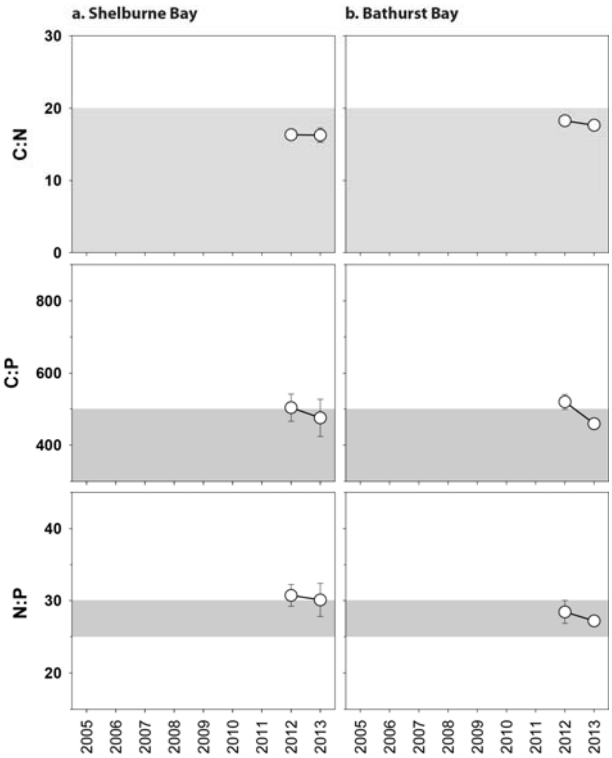

Figure 142. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each coastal location in the Cape York region each year (species pooled) (mean ± Standard Error).*

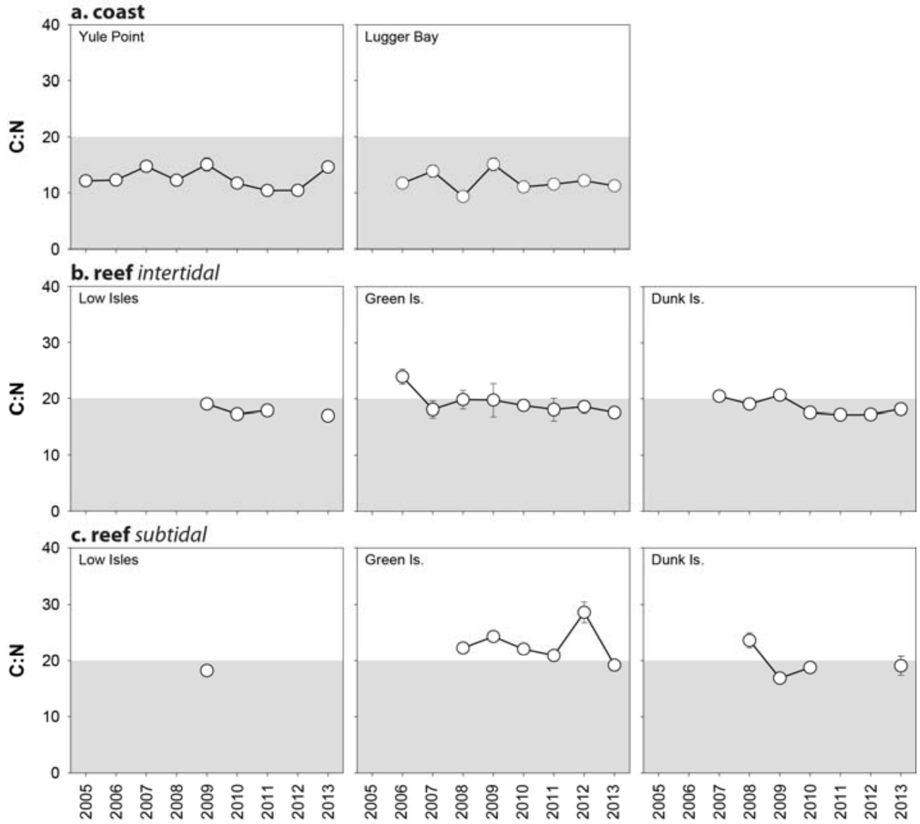

Figure 143. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat and location in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

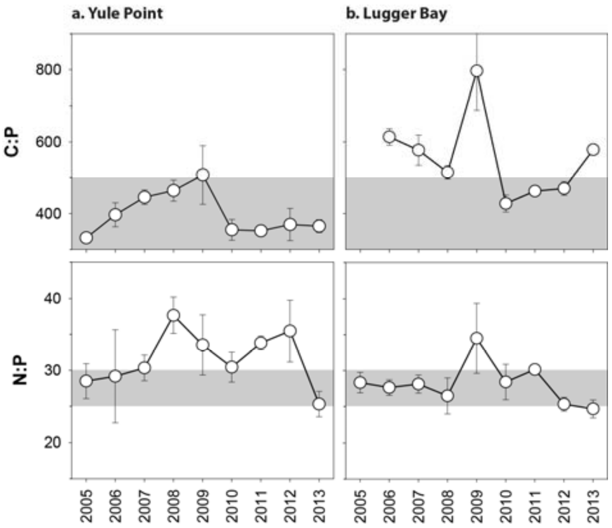

Figure 144. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at intertidal coastal habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

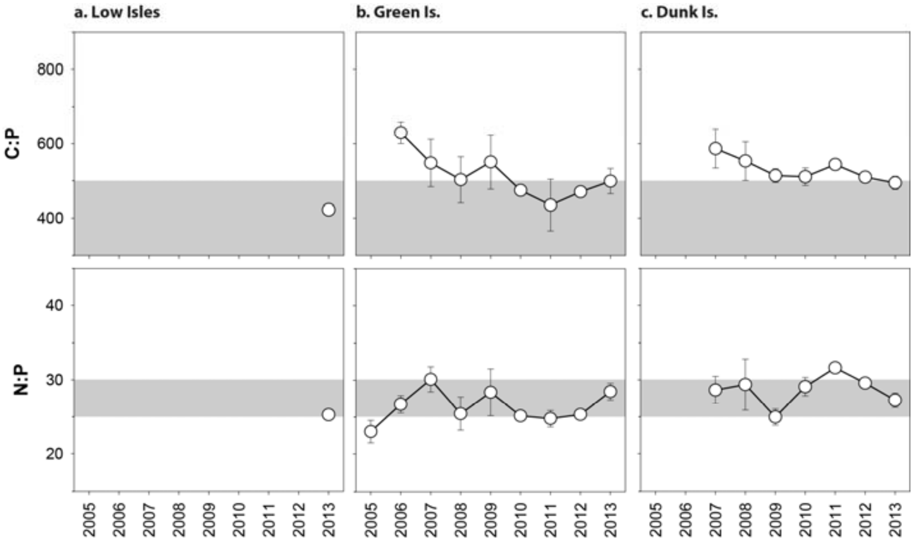

Figure 145. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at intertidal reef habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

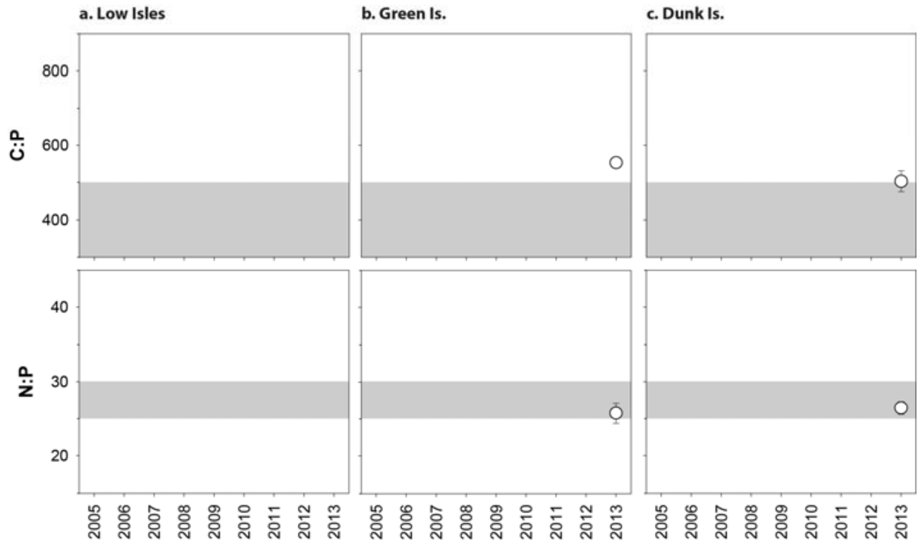

Figure 146. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at subtidal reef habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

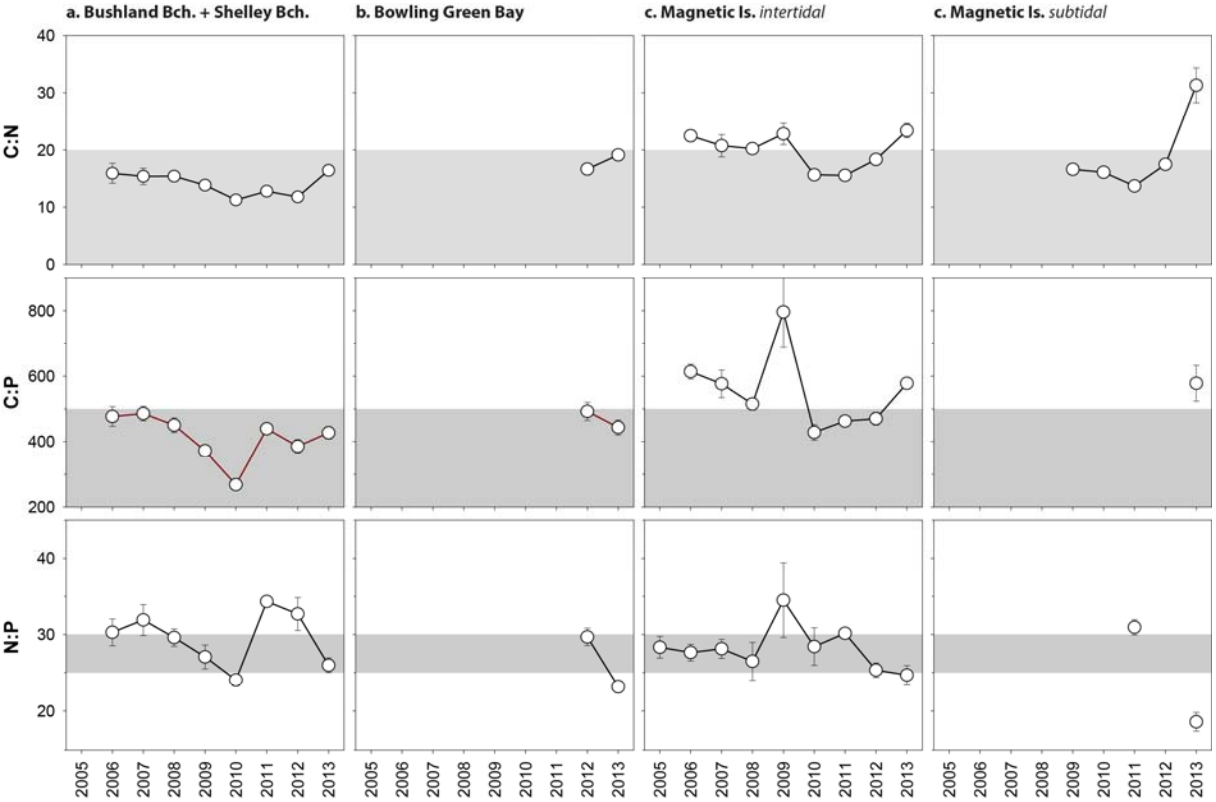

Figure 147. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each habitat and location in the Burdekin region each year (species pooled) (mean ± Standard Error).*

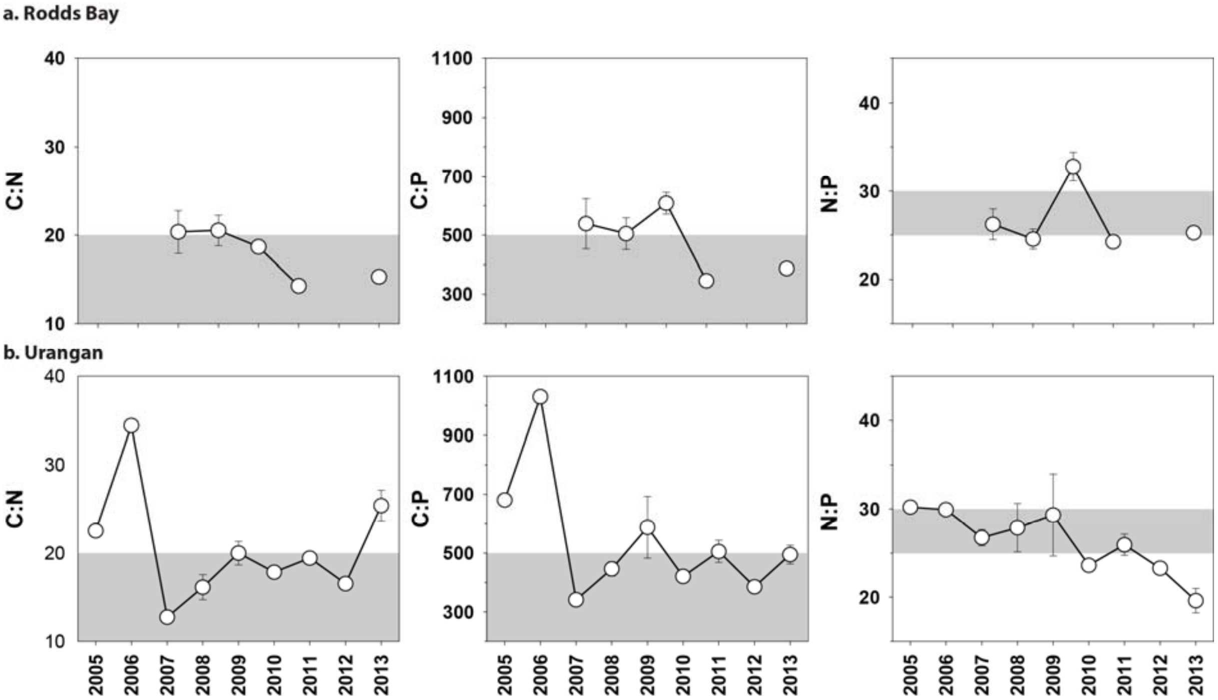

Figure 148. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Burnett Mary region each year (species pooled) (mean ± Standard Error).*

Table 37. *Seagrass leaf tissue nutrient, δ^{13}C and δ^{15}N concentrations from each NRM region in the late dry 2011 to 2013. Leaf tissues with low %C (see Table 38), low C:N (<20:1), and isotopically depleted δ^{13}C may indicate that growth is light limited (Grice et al. 1996; Fourqurean et al. 2005). Global δ^{13}C averages from Hemminga and Mateo 1996). Shading indicates values lower than literature. CR=Cymodocea rotundata, EA=Enhalus acoroides, HO=Halophila ovalis, HS=Halophila spinulosa, HU=Halodule uninervis, TH=Thalassia hemprichii, ZM=Zostera muelleri.*

NRM	Habitat	Species	Year	%C	C:N	δ^{13}C ‰	δ^{15}N ‰	%C lit median	δ^{13}C ‰ global average
Cape York	coastal	EA	2012	36.68	14.72	-13.07	-9.41	*38.3*	*-5.8 (-6.7 to -4.9)*
		HU	2012	40.61	15.92	-11.00 ±0.46	0.06 ±0.26	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	39.86	15.74	-11.71 ±0.25	-1.77 ±0.93		
		SI	2012	36.74	16.52	-4.78	0.35	*28*	*-6.0 (-8.3 to -3.6)*
			2013	36.34	18.07	-6.10 ±0.09	-0.58 ±0.34		
		TH	2012	35.74	15.37	-9.97 ±0.22	-1.28 ±0.60	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	36.15	17.97	-10.50 ±0.15	-1.33 ±0.47		
		ZM	2012	38.94	17.28	-10.23	1.84	*32*	*-10.8 (-12.4 to -9.2)*
	reef	CR	2012	39.65	18.03	-7.96 ±0.25	-2.44 ±0.61	*39*	*-8.1 (-8.9 to -7.4)*
			2013	36.89	24.16	-8.32	-0.83		
		CS	2012	40.34	19.12	-8.57	0.37	*40.4*	*-10.7 (-12.4 to -8.0)*
		HU	2011	42.48	15.50	-8.78 ±0.30	0.72 ±0.44	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	41.22	16.13	-8.74 ±0.22	0.15 ±1.34		
			2013	41.93	16.86	-8.97 ±0.04	-1.58 ±0.51		
		SI	2012	22.27	19.83	-4.01 ±0.24	1.11 ±0.94	*28*	*-6.0 (-8.3 to -3.6)*
			2013	37.52	19.46	-5.27	0.24		
		TH	2012	37.42	15.91	-6.26 ±0.27	0.65 ±0.84	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	37.61	16.79	-6.99 ±0.12	0.42 ±0.59		
		ZM	2011	39.70	22.27	-9.27	1.57	*32*	*-10.8 (-12.4 to -9.2)*
			2013	36.86	20.08	-9.03 ±0.08	-0.66 ±0.38		
Wet Tropics	coastal	HU	2011	44.90	10.65	-10.35	0.64	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	42.08	11.13	-9.59 ±0.16	0.85 ±0.27		
			2013	41.29	11.82	-10.12 ±0.25	0.42 ±0.19		
	reef intertidal	CR	2011	42.38	18.17	-7.88 ±0.27	-0.71 ±0.31	*39*	*-8.1 (-8.9 to -7.4)*
			2012	40.83	17.64	-6.71 ±0.11	-0.27 ±0.36		
			2013	39.96	18.35	-7.67 ±0.34	0.76 ±0.89		
		CS	2013	41.81	22.61	-10.63 ±0.07	3.64 ±0.22	*40.4*	*-10.7 (-12.4 to -8.0)*
		HU	2009	34.29	19.45	-11.05 ±0.14	0.23 ±1.08	*38.5*	*-11.2 (-13.0 to -7.8)*
			2010	34.34	17.22	-12.86 ±1.14	1.75 ±0.17		
			2011	39.84	19.02	-9.32 ±0.43	1.66 ±0.35		
			2012	41.74	17.08	-7.83 ±0.23	1.76 ±0.66		
			2013	41.41	19.38	-9.01 ±0.22	1.78 ±0.54		
		TH	2009	30.41	18.55	-8.66 ±0.24	1.22 ±0.17	*35.6*	*-6.9 (-8.1 to -5.2)*
			2011	40.43	17.29	-7.02 ±0.11	1.80 ±0.24		
			2012	38.71	15.97	-7.40 ±0.21	1.24 ±0.15		
			2013	37.95	17.12	-6.34 ±0.18	2.88 ±0.47		
	reef subtidal	CR	2013	40.91	16.77	-9.50 ±0.20	-0.37 ±0.37	*39*	*-8.1 (-8.9 to -7.4)*
		CS	2008	33.35	22.74	-9.65 ±0.26	1.91 ±0.33	*40.4*	*-10.7 (-12.4 to -8.0)*
			2009	33.69	24.27	-9.87 ±0.03	2.19 ±0.15		
			2010	32.70	22.87	-9.78 ±0.24	1.34 ±0.36		
			2011	37.88	22.89	-9.91 ±0.13	2.79 ±0.29		
			2012	40.60	28.58	-9.73 ±0.13	2.11 ±0.35		
			2013	38.59	22.56	-10.11 ±0.43	3.04 ±0.44		
		HU	2008	35.25	22.63	-10.62 ±0.17	2.19 ±0.23	*38.5*	*-11.2 (-13.0 to -7.8)*
			2009	34.46	17.24	-11.25 ±0.36	0.95 ±0.15		
			2010	33.50	19.96	-11.69 ±1.11	2.23 ±0.48		
			2011	38.94	18.88	-9.64 ±0.04	1.82 ±0.23		
			2013	39.19	19.58	-9.85 ±0.17	2.71 ±0.29		
		SI	2013	37.10	20.92	-4.71 ±0.14	0.86 ±0.34	*28*	*-6.0 (-8.3 to -3.6)*
Burdekin	coastal	HU	2012	40.30	12.82	-11.23 ±0.13	1.22v0.19	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	38.81	15.75	-11.49 ±0.03	2.34 ±0.17		

NRM	**Habitat**	**Species**	**Year**	**%C**	**C:N**	***δ*^{13}C ‰**	***δ*^{15}N ‰**	**%C lit median**	***δ*^{13}C ‰ global average**
		ZM	2012	36.33	17.76	-10.44 ±0.23	2.18 ±0.39	*32*	*-10.8 (-12.4 to -9.2)*
			2013	35.75	18.56	-10.75 ±0.06	2.59 ±0.15		
	reef intertidal	CS	2012	40.47	21.91	-9.07 ±0.02	1.54 ±0.60	*40.4*	-10.7 (-12.4 to -8.0)
			2013	40.71	19.46	-10.00 ±0.09	2.06 ±0.04		
		HO	2011	39.50	13.44	-10.79	1.88	*30.5*	*-10 (-15.5 to -6.4)*
		HU	2011	44.57	12.62	-9.84 ±0.18	0.96 ±0.04	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	41.63	16.53	-9.11 ±0.07	1.32 ±0.50		
			2013	39.50	20.04	-10.03 ±0.17	2.23 ±0.13		
		TH	2012	39.61	15.14	-8.31	0.09 ±0.45	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	36.48	15.65	-8.85 ±0.05	1.58 ±0.09		
	reef subtidal	CS	2009	35.10	18.83	-10.96 ±0.18	1.03 ±0.38	*40.4*	-10.7 (-12.4 to -8.0)
			2013	40.28	24.21	-11.59 ±0.24	3.39 ±0.22		
		HS	2013	37.35	31.12	-12.32	3.11		
		HU	2009	38.29	16.60	-10.69 ±1.00	1.05 ±0.48	*38.5*	*-11.2 (-13.0 to -7.8)*
			2010	30.12	16.10	-12.35 ±0.40	-0.16 ±0.13		
			2011	40.31	13.70	-10.88 ±0.03	0.20 ±0.24		
			2012	42.78	17.47	-11.16 ±0.06	1.82 ±0.10		
			2013	40.41	22.55	-11.62 ±0.15	3.02 ±0.04		
Mackay Whitsunday	estuarine	ZM	2011	43.22	12.13	-10.02 ±0.12	0.53 ±0.47	*32*	*-10.8 (-12.4 to -9.2)*
			2012	40.47	12.92	-10.45 ±0.19	2.08 ±0.22		
			2013	38.77	15.66	-10.16 ±0.24	2.06 ±0.22		
	coastal	HU	2012	43.02	10.84	-11.42 ±0.06	-0.98 ±0.15	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	42.31	12.84	-10.93 ±0.19	3.25 ±0.10		
		ZM	2012	40.00	12.85	-11.10 ±0.13	4.13 ±0.33	*32*	*-10.8 (-12.4 to -9.2)*
			2013	41.05	13.56	-11.47 ±0.14	4.15 ±0.55		
	reef	HU	2011	45.40	9.81	-10.23	1.44	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	42.80	10.04	-9.22 ±0.03	-0.20 ±0.19		
			2013	42.19	10.67	-8.91 ±0.08	0.80 ±0.72		
		ZM	2011	42.50	13.77	-9.3	0.74	*32*	*-10.8 (-12.4 to -9.2)*
			2012	39.80	14.35	-9.15 ±0.05	2.47 ±0.34		
			2013	36.06	19.49	-9.94 ±0.08	2.34 ±0.19		
Fitzroy	estuarine	ZM	2012	39.56	22.70	-9.51 ±0.23	2.27 ±0.13	*32*	*-10.8 (-12.4 to -9.2)*
			2013	36.53	18.45	-9.19 ±0.25	2.27 ±0.28		
	coastal	HU	2013	40.34	20.40	-11.17	1.07	*38.5*	*-11.2 (-13.0 to -7.8)*
		ZM	2011	40.08	18.36	-9.28 ±0.07	0.72 ±0.10	*32*	*-10.8 (-12.4 to -9.2)*
			2012	37.64	16.57	-8.24 ±0.17	0.94 ±0.35		
			2013	36.59	18.26	-9.58 ±0.16	0.90 ±0.12		
	reef	HU	2013	41.22	17.15	-9.40	-0.72	*38.5*	*-11.2 (-13.0 to -7.8)*
		ZM	2012	39.88	13.38	-6.39 ±0.19	-0.47 ±0.29	*32*	*-10.8 (-12.4 to -9.2)*
			2013	39.79	16.05	-7.36 ±0.15	0.92 ±0.37		
Burnett Mary	estuarine	HO	2011	36.90	15.89	-10.46 ±	4.55	*30.5*	*-10 (-15.5 to -6.4)*
		ZM	2011	41.03	17.80	-8.94 ±0.21	3.11 ±0.42	*32*	*-10.8 (-12.4 to -9.2)*
			2012	39.48	15.75	-10.78 ±0.05	1.72 ±0.33		
			2013	35.02	18.92	-10.540.08	3.79 ±0.30		

Table 38. *Percent carbon in seagrass leaf tissue from published literature.*

Species	%C	Citation	Location
Cymodocea rotundata	38.9	Yamamuro & Chirapart 2005	Trang, Thailand
Cymodocea serrulata	42.7	Grice et al. (1996)	Green Island
	38	Atkinson & Smith (1984)	Cockle Bay
	40.4	median	
Enhalus acoroides	38.3	Duarte (1990)	Palau
Halophila ovalis	32 ± 0.5	McMahon (2005)	Moreton Bay - Aug
	29 ± 0.4	McMahon (2005)	Moreton Bay - Jan
	30.5	median	
Halophila spinulosa			
Halodule uninervis	40.9	Grice et al. 1996	Green Island
	36	Atkinson & Smith (1984)	N Queensland
	38.5	median	
Syringodium isoetifolium	28	Grice et al. 1996	Green Island
Thalassia hemprichii	32..61	Erftemeijer and Herman 1994	Kudingareng, Indonesia
	35.58	Erftemeijer and Herman 1994	Barang Lompo, South Sulawesi, Indonesia
	37.4	Koike et al (1987)	Port Moresby, PNG
	40.4	Koike et al (1987)	Port Moresby, PNG
	33	Atkinson & Smith (1984)	Cockle Bay
	33.5	Yamamuro & Chirapart 2005	
	35.6	median	
Zostera muelleri (capricorni)	32	Atkinson & Smith (1984)	Pallerenda
	32 ±04	McMahon (2005)	Urangan - April
	25 ±1.8	McMahon (2005)	Urangan -Dec
	32	*median*	
Global	33.6 ±0.31	Duarte 1990	

A2.5. Epiphytes and macroalgae

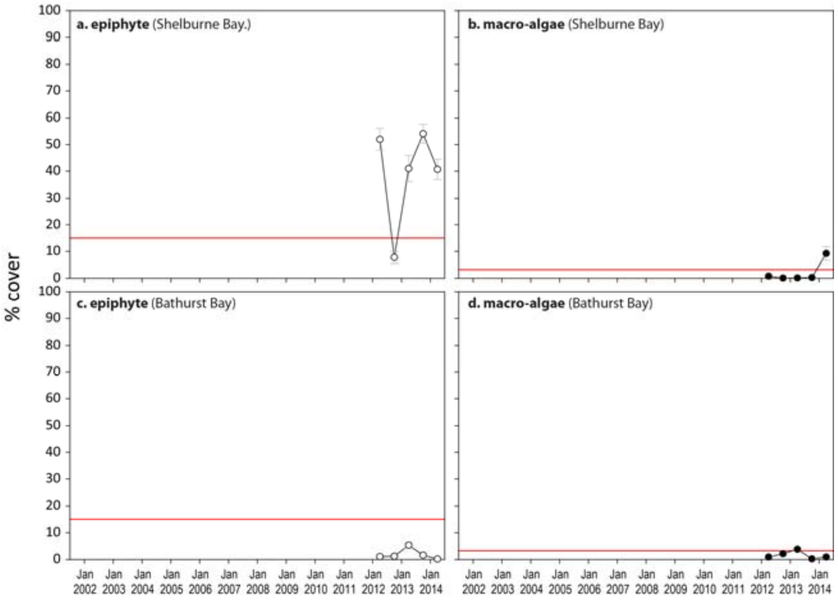

Figure 149. *Long-term trend in mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal coastal habitats (sites pooled), Cape York NRM region. Red line = GBR long-term average; epiphytes=15.0%, macroalgae=3.2%.*

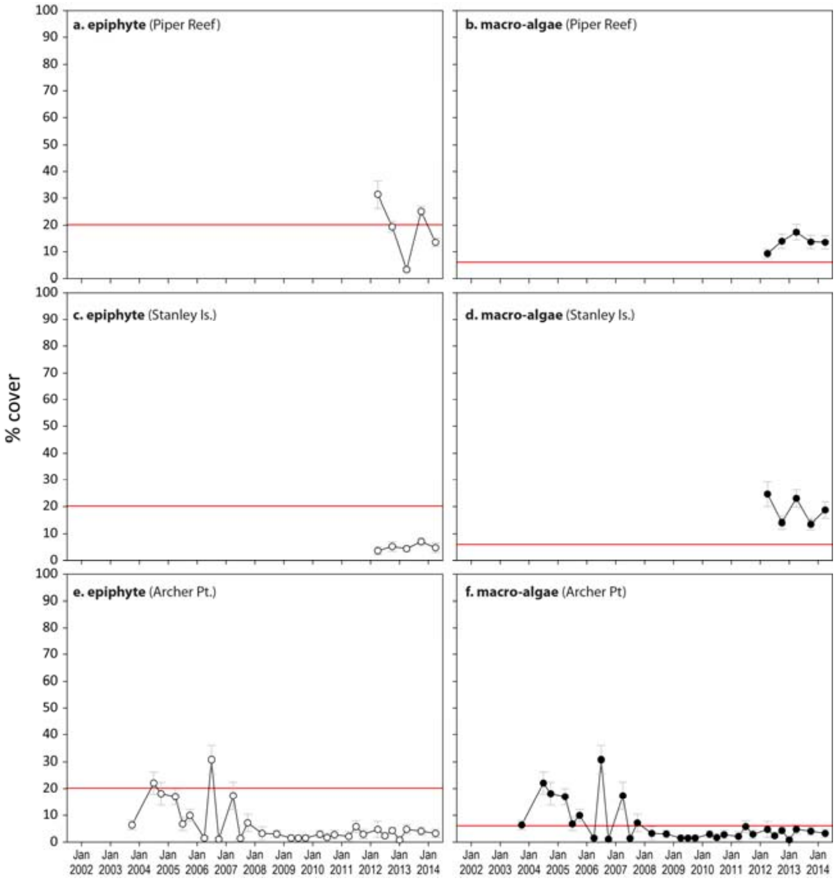

Figure 150. *Long-term trend in mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef habitats (sites pooled), Cape York NRM region. Red line = GBR long-term average; epiphytes=20.2%, macroalgae=6.1%.*

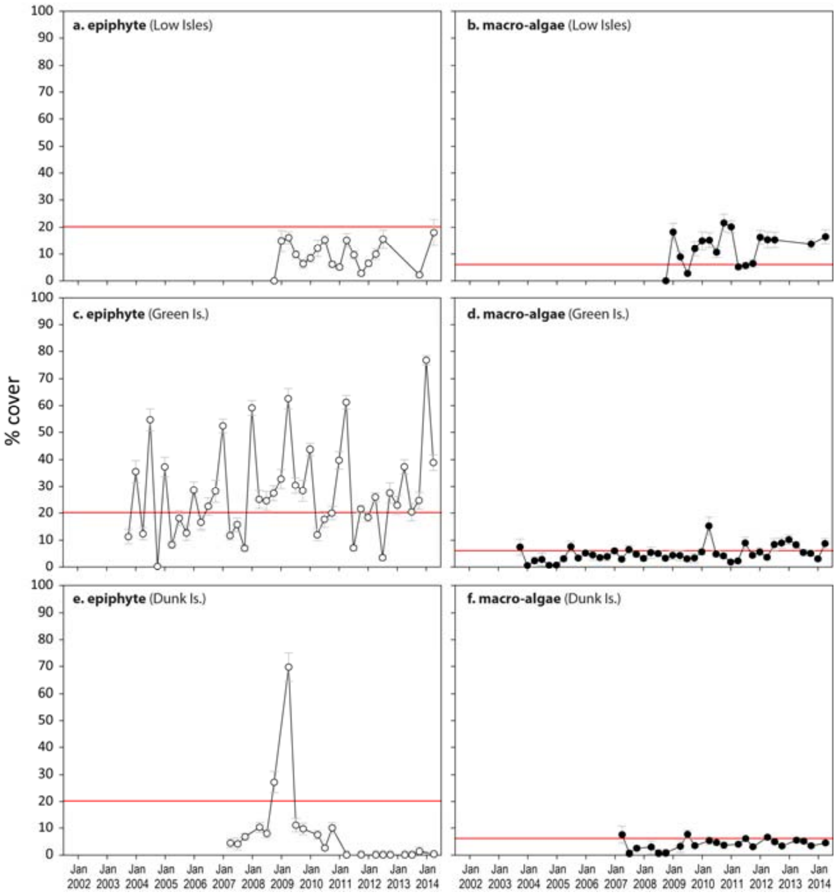

Figure 151. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=20.2%, macroalgae=6.1%.*

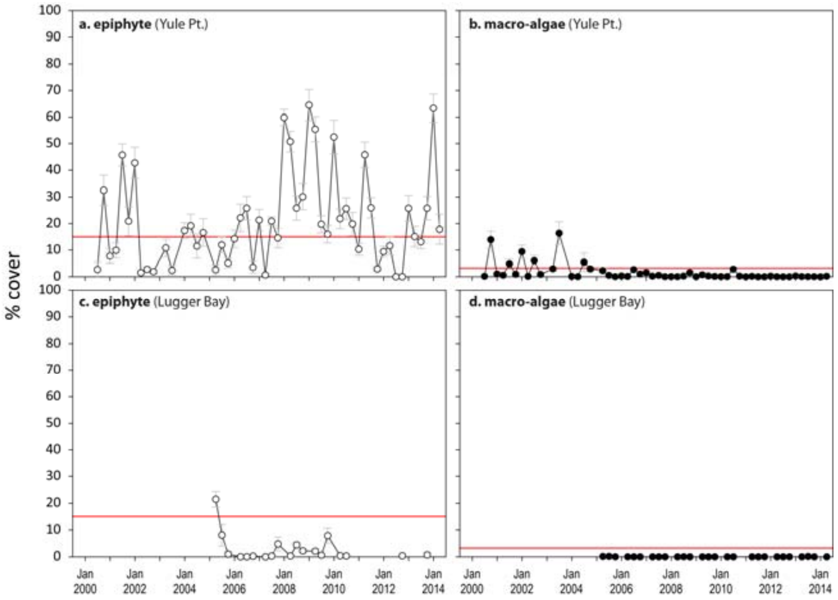

Figure 152. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=15%, macroalgae=3.2%.*

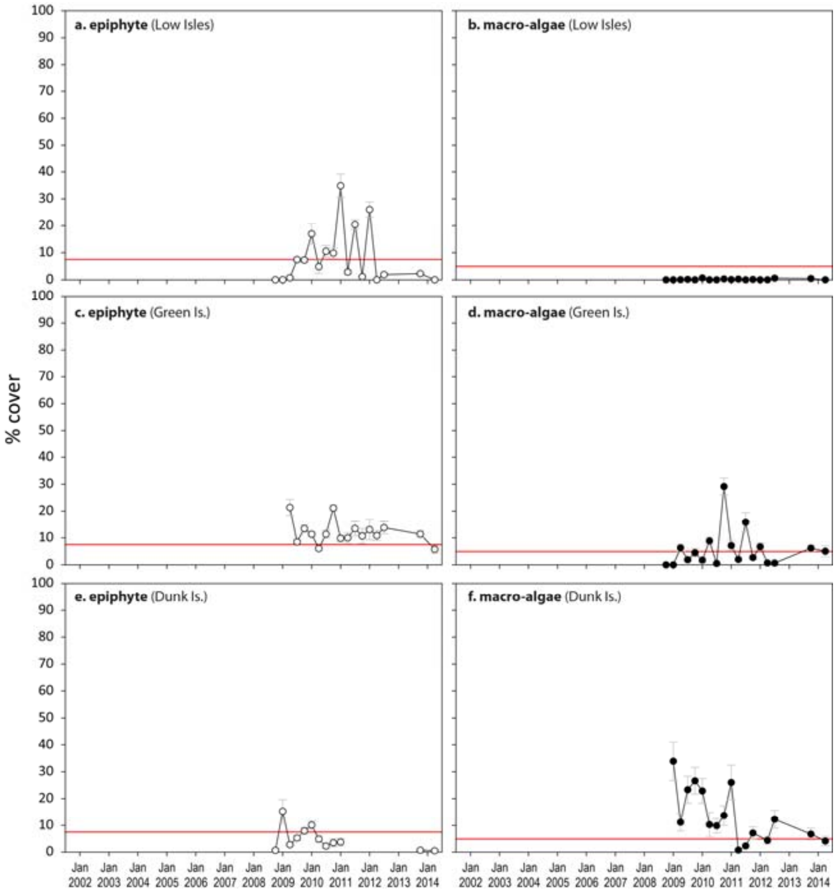

Figure 153. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef seagrass monitoring sites in the Wet Tropics NRM region. Red line = GBR long-term average for subtidal sites; epiphytes=7.5%, macroalgae=4.9%.*

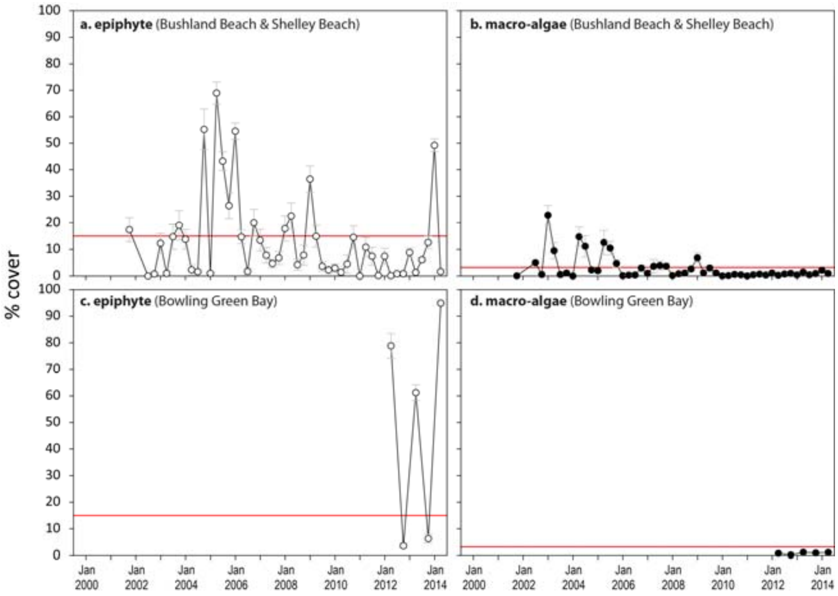

Figure 154. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=15%, macroalgae=3.2%.*

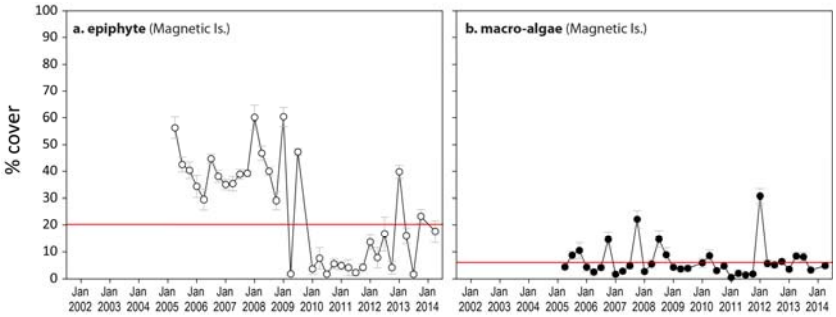

Figure 155. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass monitoring locations (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=20.2%, macroalgae=6.1%.*

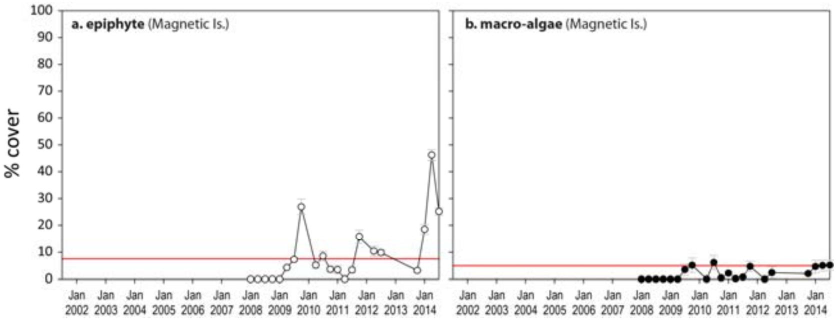

Figure 156. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef monitoring sites in Picnic Bay, Burdekin NRM region. Red line = GBR long-term average; epiphytes=7.5%, macroalgae=4.9%.*

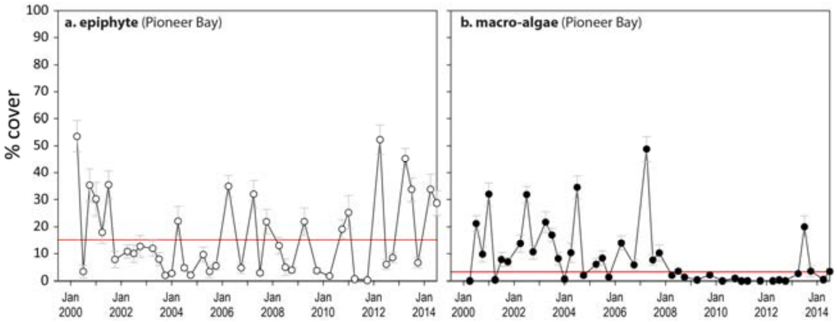

Figure 157. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=15%, macroalgae=3.2%.*

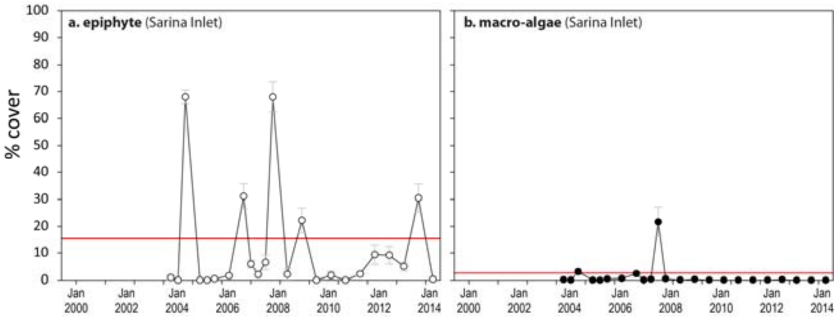

Figure 158. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=15.4%, macroalgae=2.6%.*

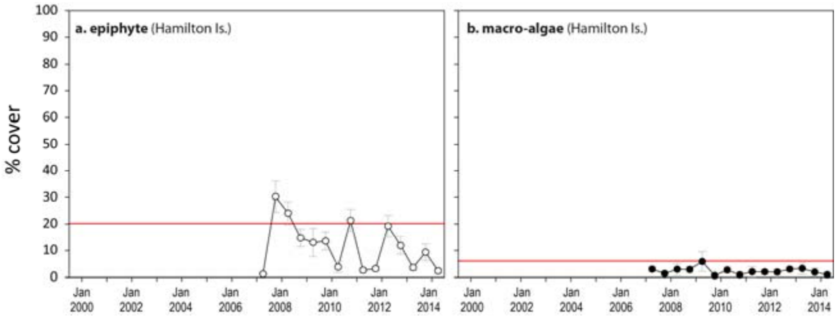

Figure 159. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=20.2%, macroalgae=6.1%.*

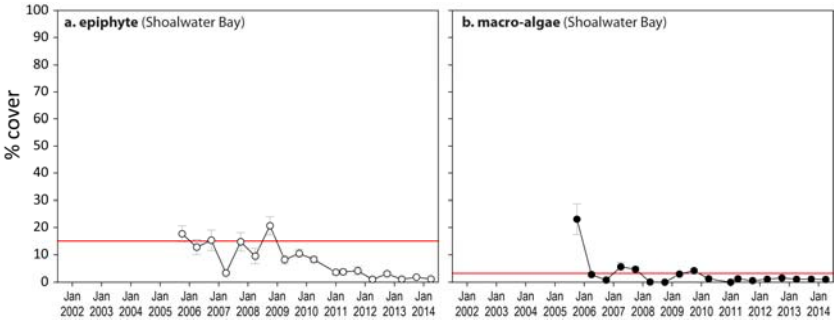

Figure 160. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=15%, macroalgae=3.2%.*

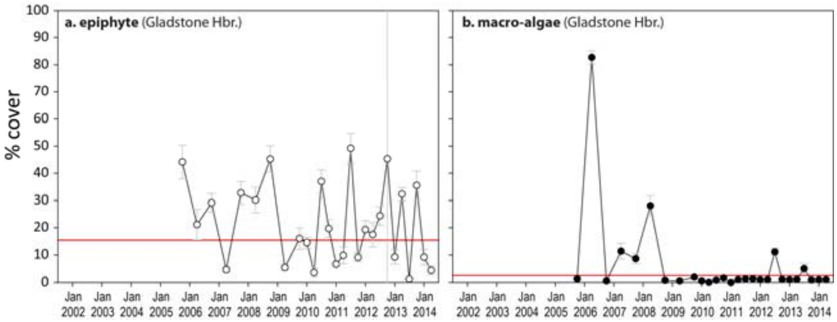

Figure 161. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=15.4%, macroalgae=2.6%.*

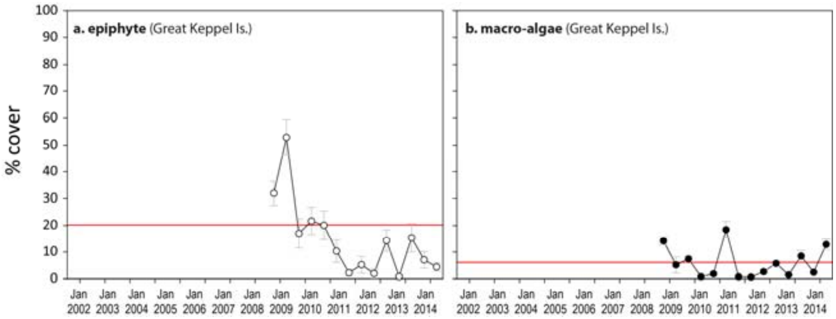

Figure 162. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=20.2%, macroalgae=6.1%.*

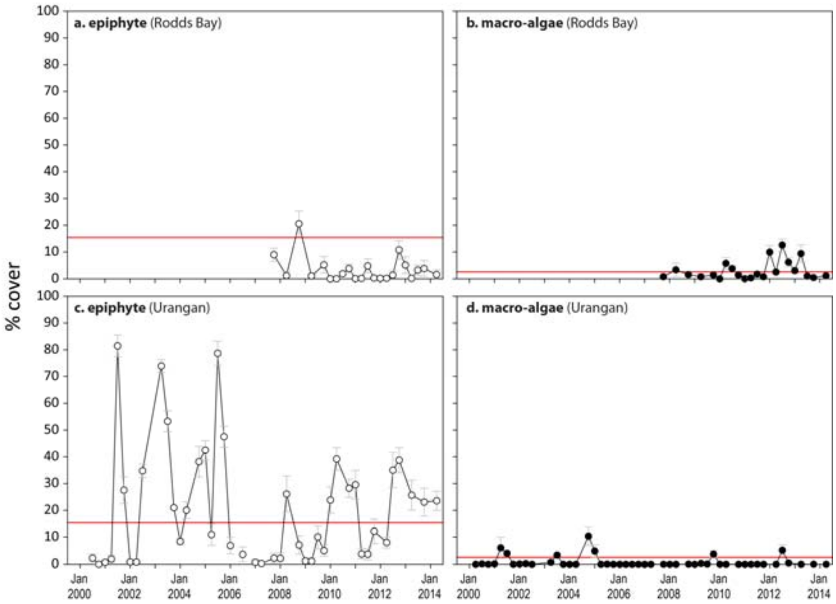

Figure 163. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Burnett Mary NRM region. Red line = GBR long-term average; epiphytes=15.4%, macroalgae=2.6%.*

A2.6. Tidal exposure

Table 39. *Height of intertidal monitoring meadows/sites above Lowest Astronomical Tide (LAT) and annual daytime tidal exposure (total hours) when meadows become exposed at a low tide. Year is June - May. Observed tidal heights courtesy Maritime Safety Queensland, 2014. NB: Meadow heights have not yet been determined in the far northern Cape York.*

NRM	Site	Meadow height (above LAT)	Site depth (bMSL)	Meadow height (above LAT) relative to Standard Port	Annual median hours exposed during daylight (long-term)	% of annual daylight hours meadow is exposed (long-term)	Annual daytime exposure 2013-14 (hrs)
Cape York	AP1	0.46	1.02	0.46	69.50	1.59%	64.17
	AP2	0.46	1.02	0.46	69.50	1.59%	64.17
Wet Tropics	LI1	0.65	0.90	0.65	178.50	4.08%	167.34
	YP1	0.64	0.94	0.64	169.83	3.88%	163.84
	YP2	0.52	1.06	0.52	97.33	2.22%	97.01
	GI1	0.51	1.03	0.61	113.83	2.60%	105.17
	GI2	0.57	0.97	0.67	151.83	3.47%	135.66
	DI1	0.65	1.14	0.54	75.08	1.71%	73.17
	DI2	0.55	1.24	0.44	44.00	1.00%	45.00
	LB1	0.42	1.37	0.31	20.33	0.46%	24.00
	LB2	0.46	1.33	0.35	24.58	0.56%	28.17
Burdekin	BB1	0.58	1.30	0.58	89.83	2.05%	70.67
	SB1	0.57	1.31	0.57	68.92	1.57%	60.50
	MI1	0.65	1.19	0.67	197.17	4.50%	130.67
	MI2	0.54	1.30	0.56	181.25	4.14%	113.33
	JR1	0.47	1.32	0.47	65.17*	1.49%	66.67
	JR2	0.47	1.32	0.47	65.17*	1.49%	66.67
Mackay Whitsunday	PI2	0.28	1.47	0.44	80.67	1.84%	80.67
	PI3	0.17	1.58	0.33	41.50	0.95%	45.00
	HM1	0.68	1.52	0.38	56.67	1.29%	60.50
	HM2	0.68	1.52	0.38	56.67	1.29%	60.50
	SI1	0.60	2.80	0.54	21.08	0.48%	22.33
	SI2	0.60	2.80	0.54	21.08	0.48%	22.33
Fitzroy	RC1	2.03	1.30	1.06	162.67	3.71%	159.00
	WH1	2.16	1.17	1.19	231.75	5.29%	226.83
	GK1	0.52	1.93	0.43	33.25	0.76%	32.17
	GK2	0.58	1.87	0.49	51.00	1.16%	46.83
	GH1	0.80	1.57	0.69	97.33	2.22%	103.67
	GH2	0.80	1.57	0.69	97.33	2.22%	103.67
Burnett Mary	RD1	0.56	1.48	0.56	66.58	1.52%	76.17
	RD2	0.63	1.41	0.63	91.42	2.09%	109.00
	UG1	0.70	1.41	0.70	149.67	3.42%	121.67
	UG2	0.64	1.47	0.64	104.25	2.38%	121.67

**limited dataset*

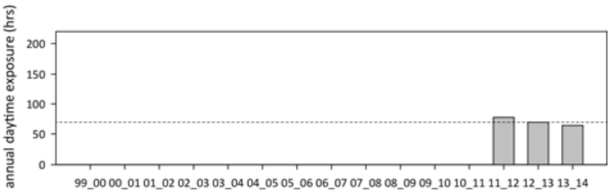

Figure 164. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows at Archer Point, Cape York NRM region; 2011 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014. NB: Meadow heights have not yet been determined in the far northern Cape York sites.*

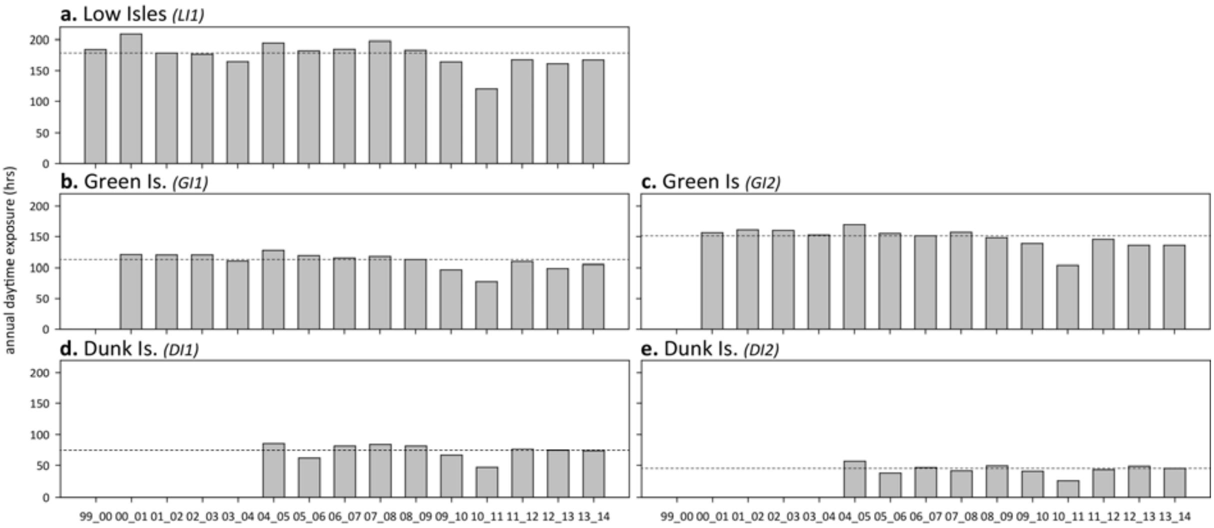

Figure 165. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows in the Wet Tropics NRM region; 1999 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

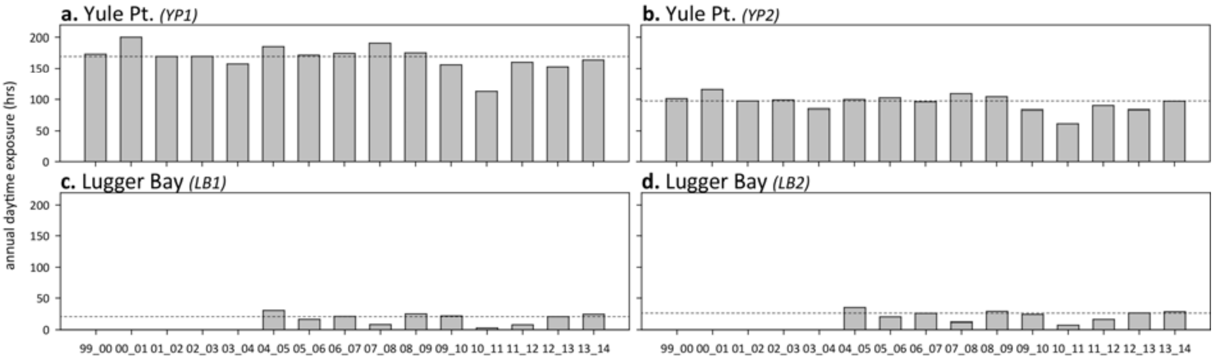

Figure 166. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal coastal seagrass meadows in Wet Tropics NRM region; 1999 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

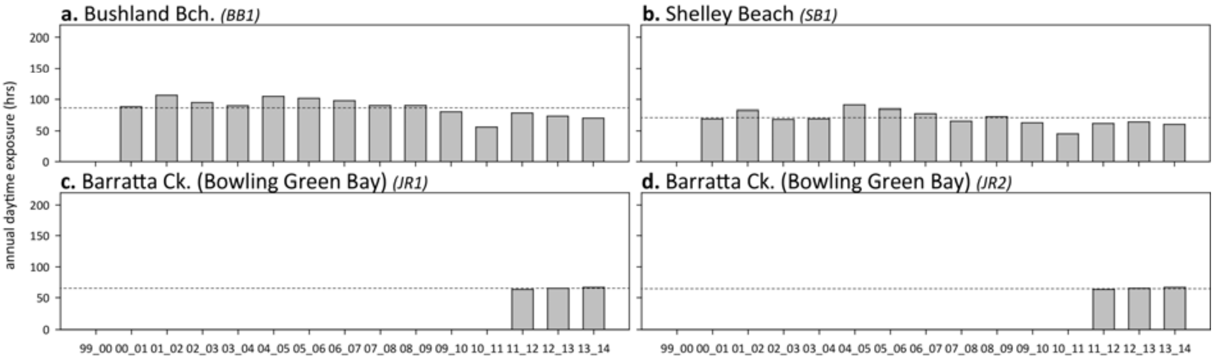

Figure 167. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal coastal seagrass meadows in Burdekin NRM region; 2000 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

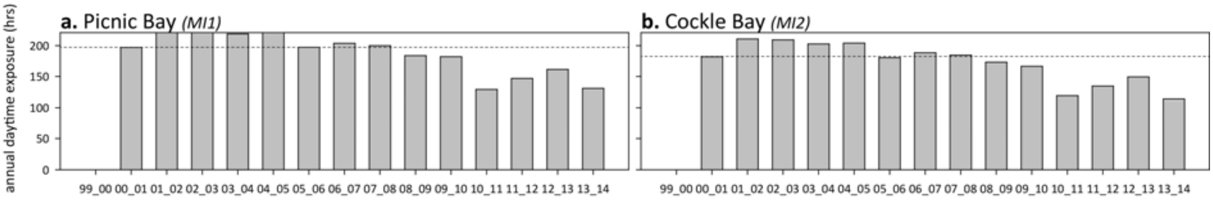

Figure 168. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows in Burdekin NRM region; 2000 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

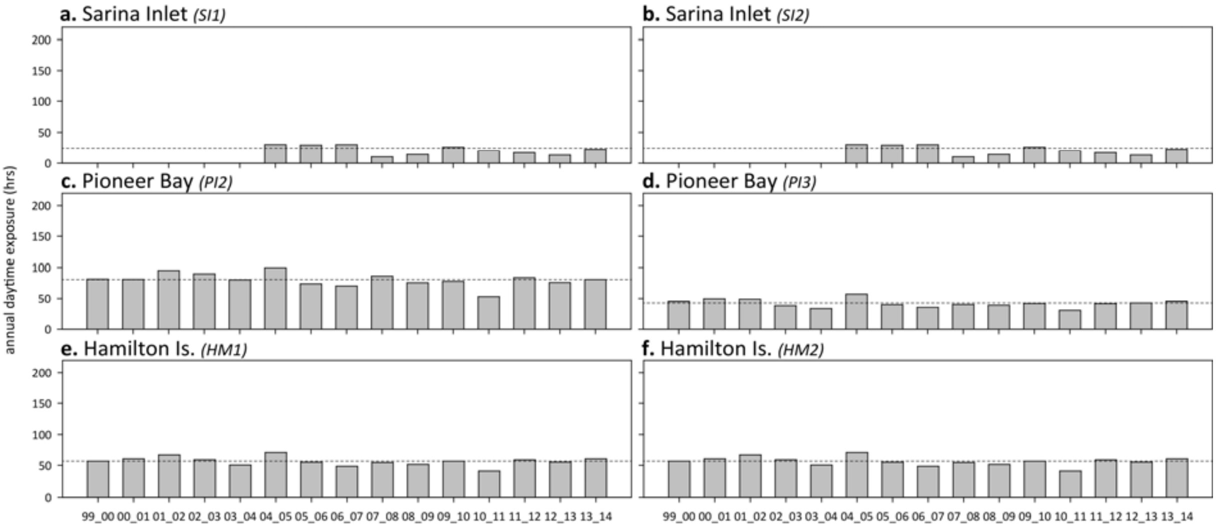

Figure 169. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine (a, b) coastal (c, d) and reef (e, f) seagrass meadows in Mackay Whitsunday NRM region; 1999 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

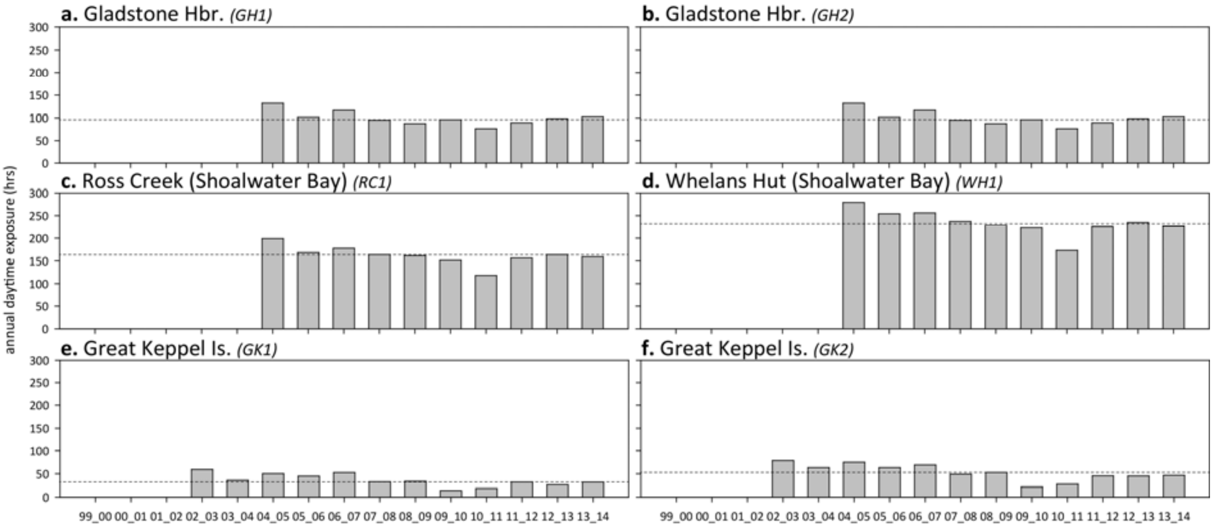

Figure 170. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine (a, b) coastal (c, d) and reef (e, f) seagrass meadows in the Fitzroy NRM region; 1999 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

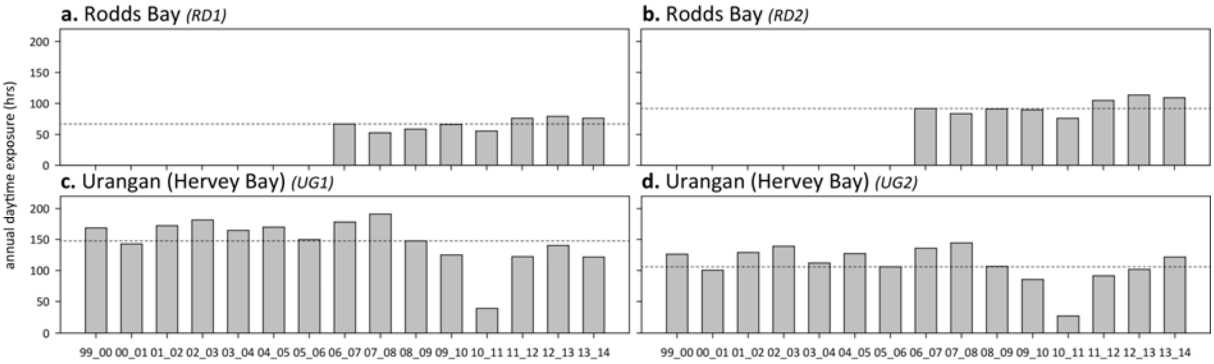

Figure 171. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine seagrass meadows in the Burnett Mary NRM region; 1999 - 2014. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 39. Observed tidal heights courtesy Maritime Safety Queensland, 2014.*

A2.7. Rhizosphere sediment herbicides

Table 40. *Concentration of herbicides (mg kg^{-1}) in sediments of sites from Cape York and Burdekin in late monsoon 2013. ND=not detectable above limit of 0.001 mg kg^{-1}, * = confirmed traces of Diuron at levels below the stated limit of reporting. For site codes, refer Table 4.*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
SR1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
SR2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
FR1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
FR2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
BY1	*ND*	*ND**	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
BY2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
ST1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
ST2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
JR1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
JR2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

A2.8. Within canopy sea temperature

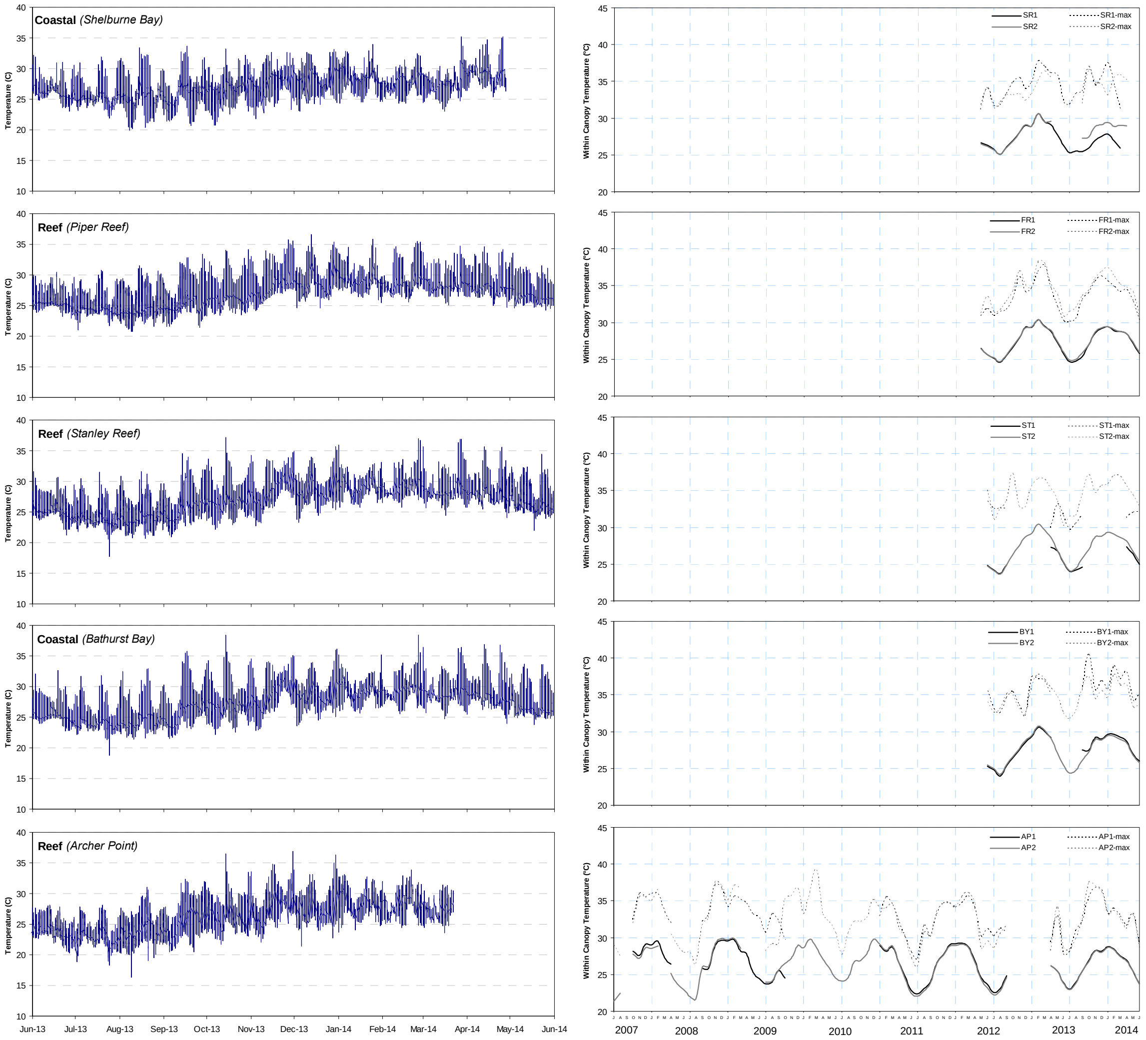

Figure 172. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in the Cape York NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

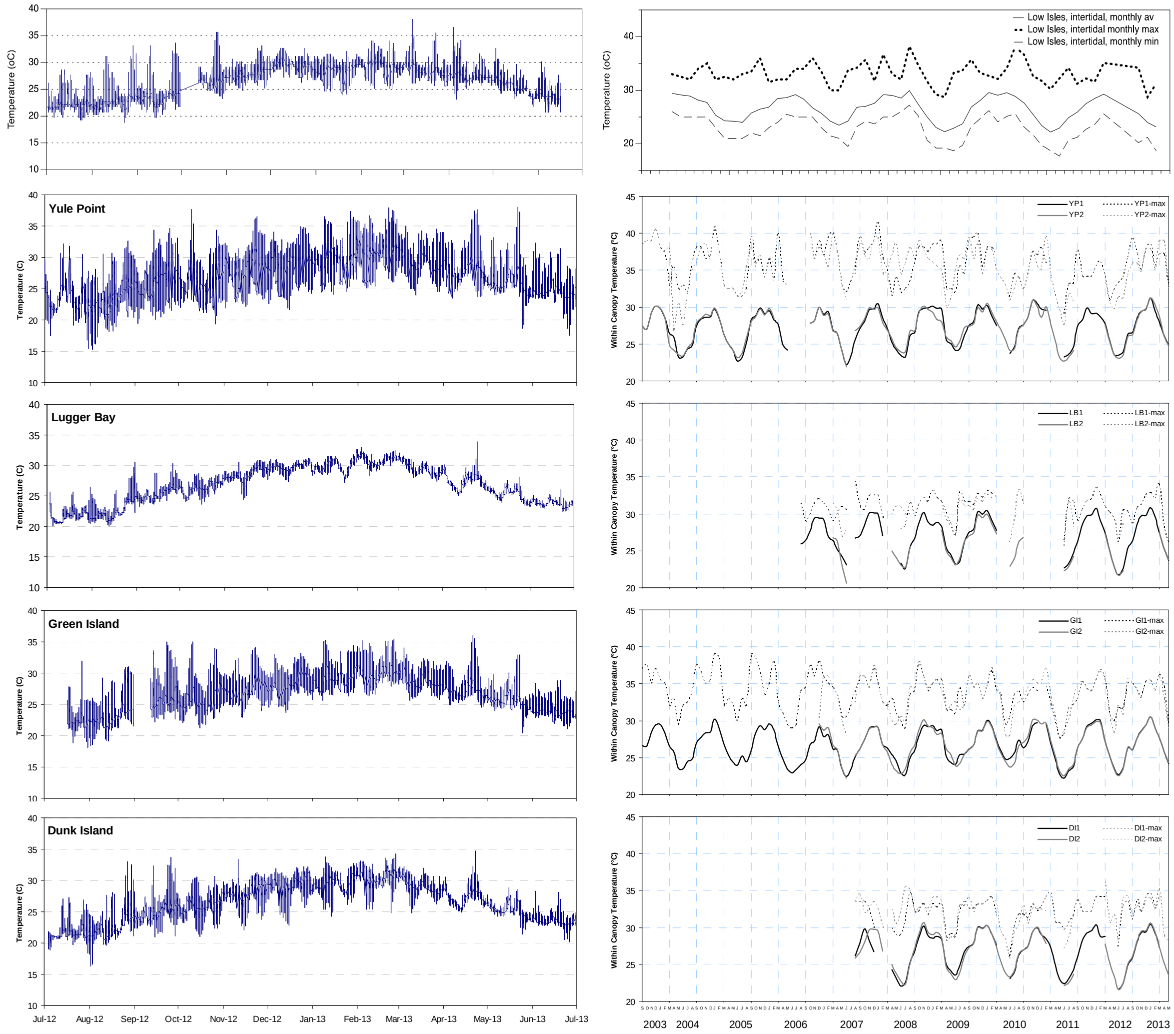

Figure 173. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in Wet Tropics NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

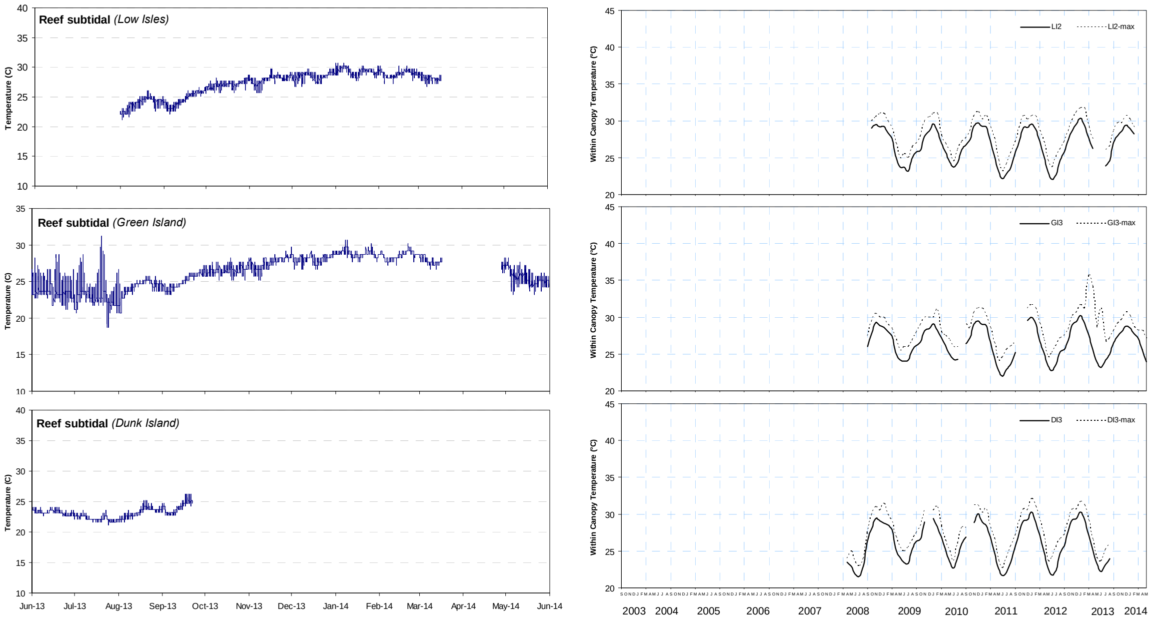

Figure 174. *Daily within seagrass canopy temperature (°C) over the 2013-14 monitoring period (left) and long-term monthly mean and maximum (right) at Low Isles (top), Green Island (middle) and Dunk Island (bottom) subtidal meadows within the Wet Tropics region.*

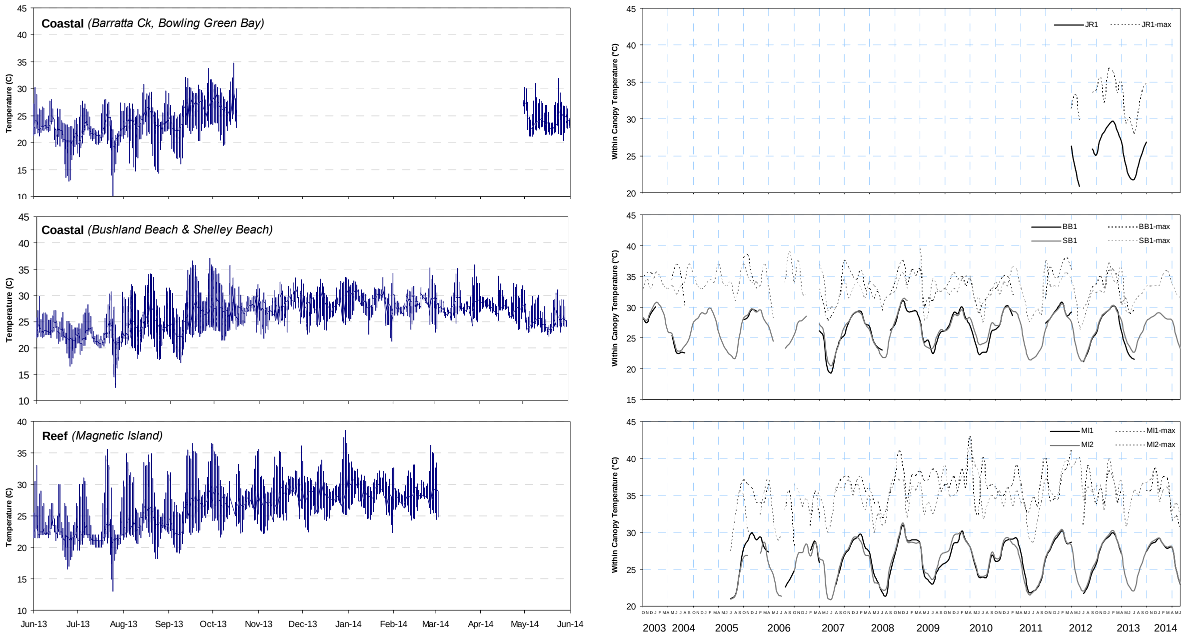

Figure 175. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in Burdekin NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

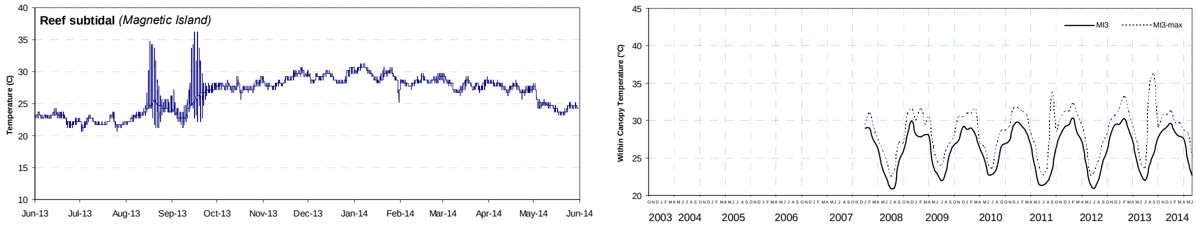

Figure 176. *Within seagrass canopy temperatures (°C) at subtidal monitoring locations in Burdekin NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

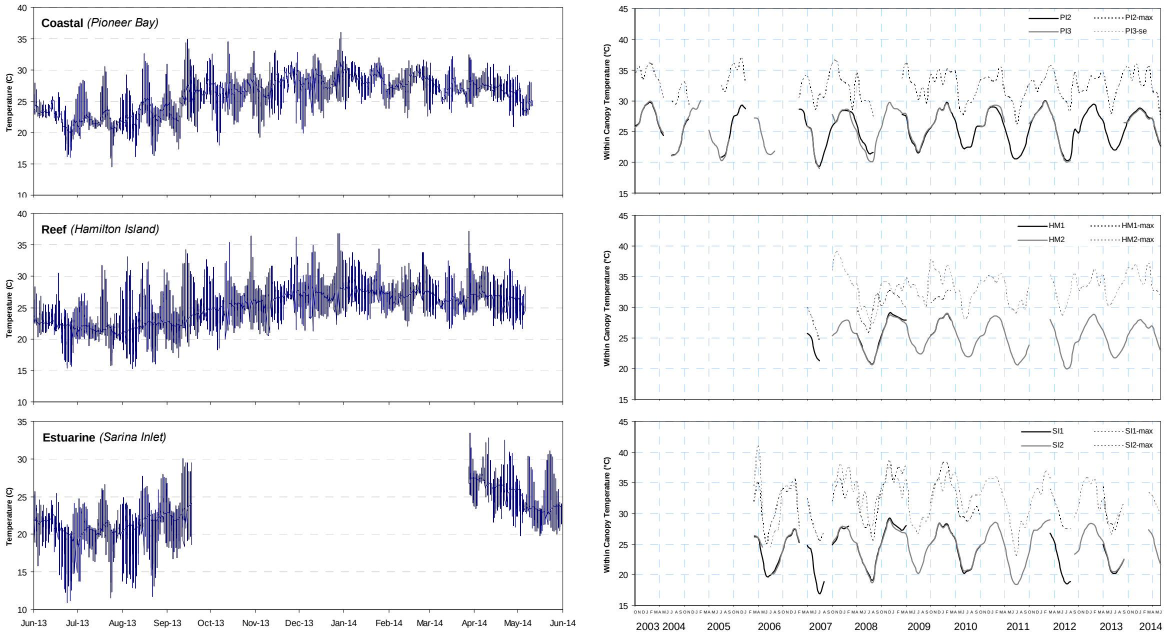

Figure 177. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in Mackay Whitsunday NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

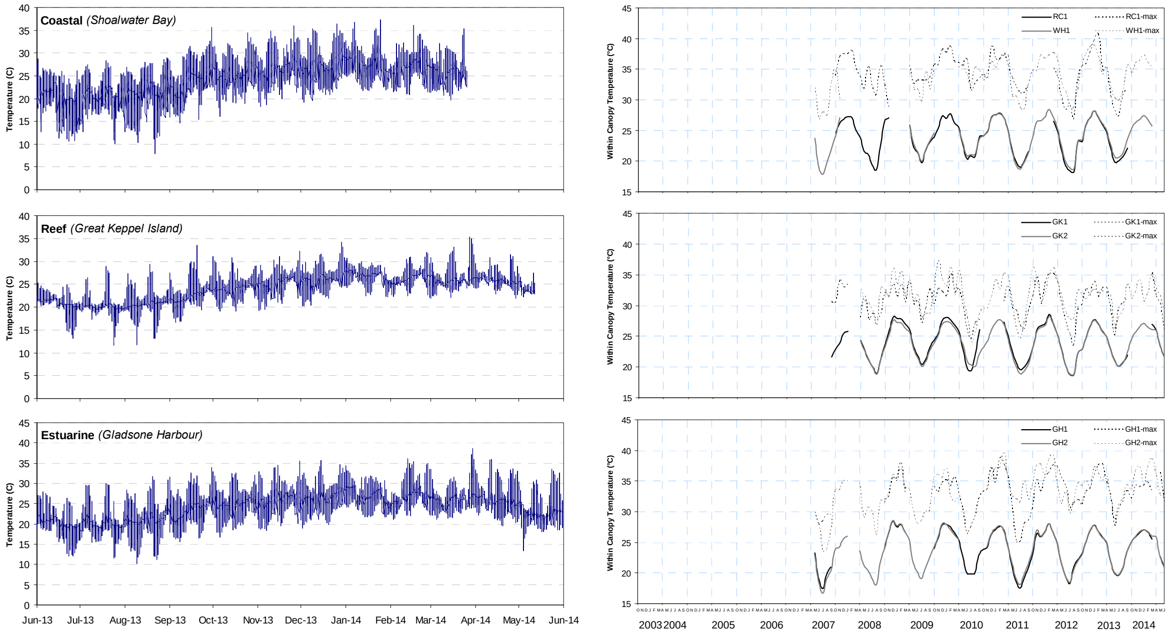

Figure 178. *Within seagrass canopy temperatures (°C) at monitoring locations in Fitzroy NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

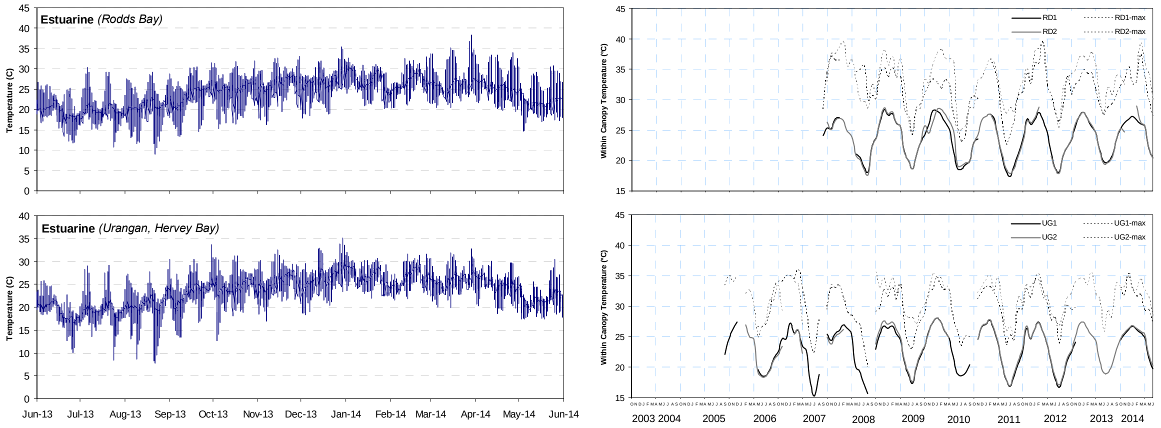

Figure 179. *Within seagrass canopy temperatures (°C) at monitoring locations in Burnett Mary NRM region: daily mean (sites pooled) over 2013-14 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

A2.9. Light at seagrass canopy

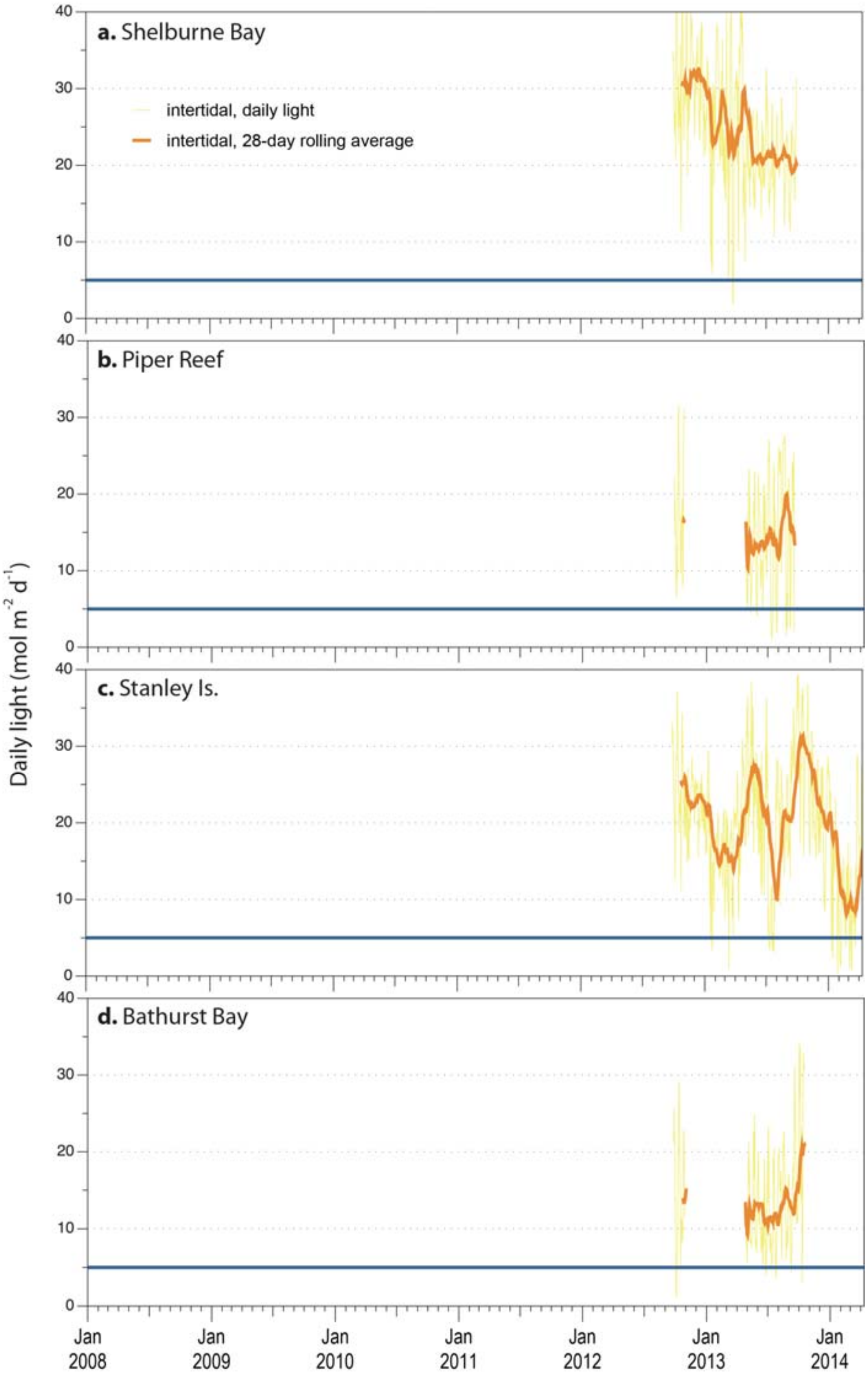

Figure 180. *Daily light (28-day rolling average) at Cape York locations, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}) Collier, et al. 2012b NB threshold is based on 90-day average.*

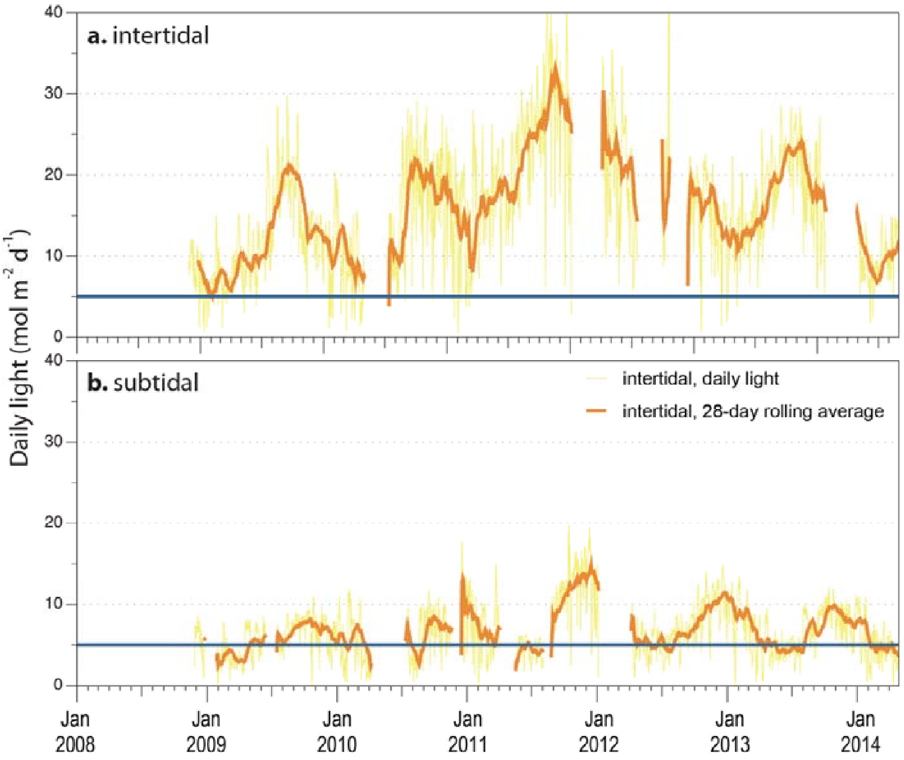

Figure 181. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Low Isles habitats in the Wet Tropics, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold based on 90-day average.*

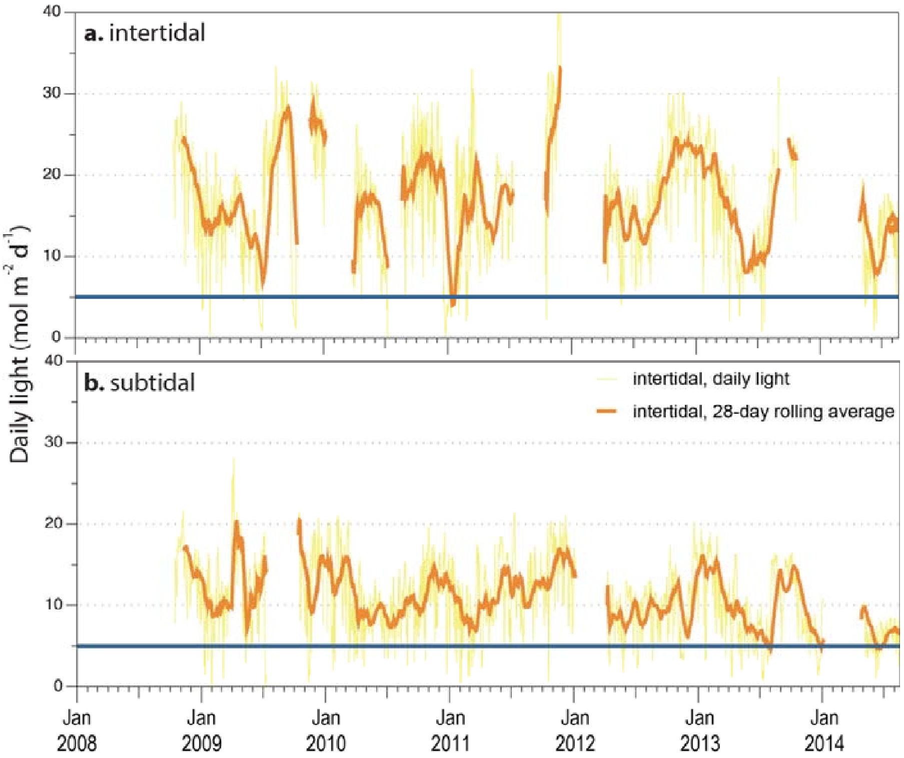

Figure 182. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Green Island habitats in the Wet Tropics, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold based on 90-day average.*

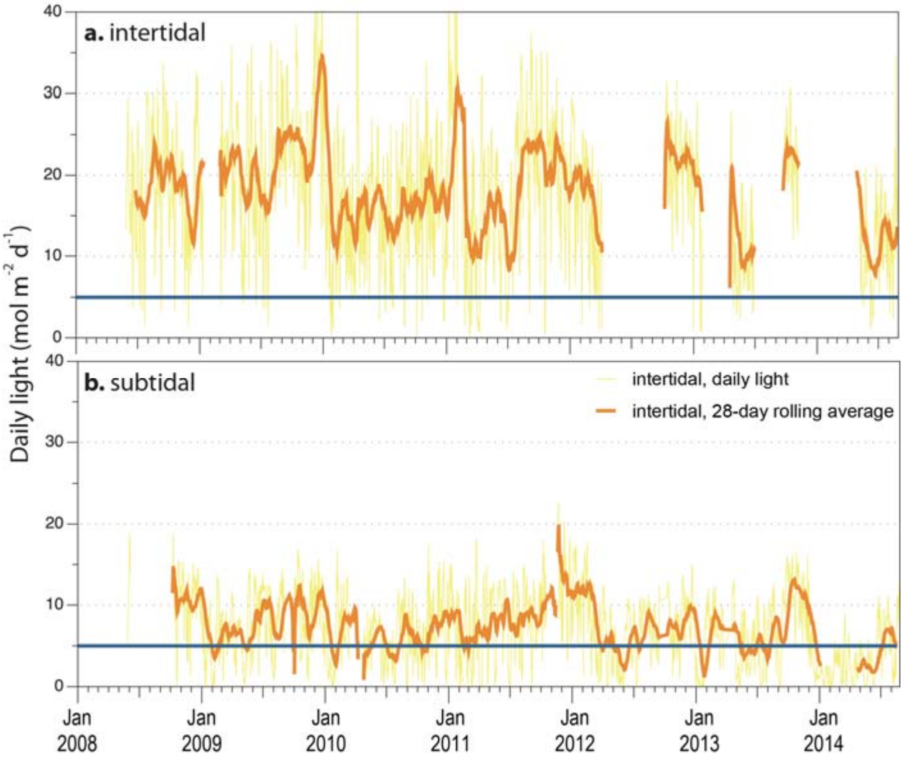

Figure 183. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Dunk Island habitats in the Wet Tropics, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold based on 90-day average.*

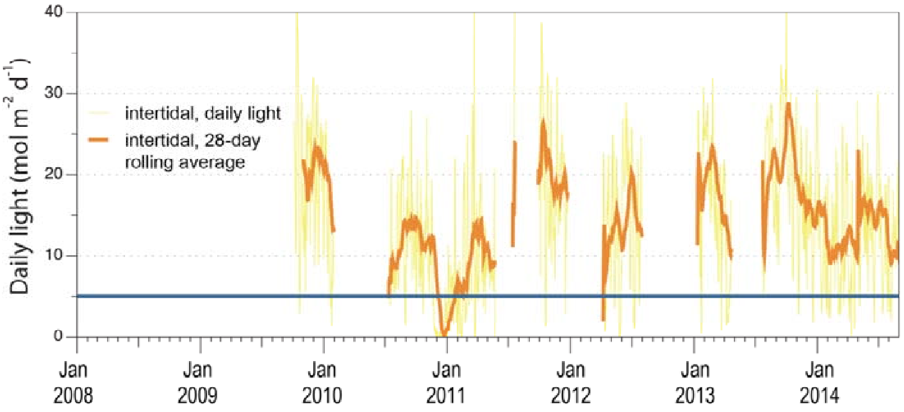

Figure 184. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Yule Point in the Wet Tropics, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold based on 90-day average.*

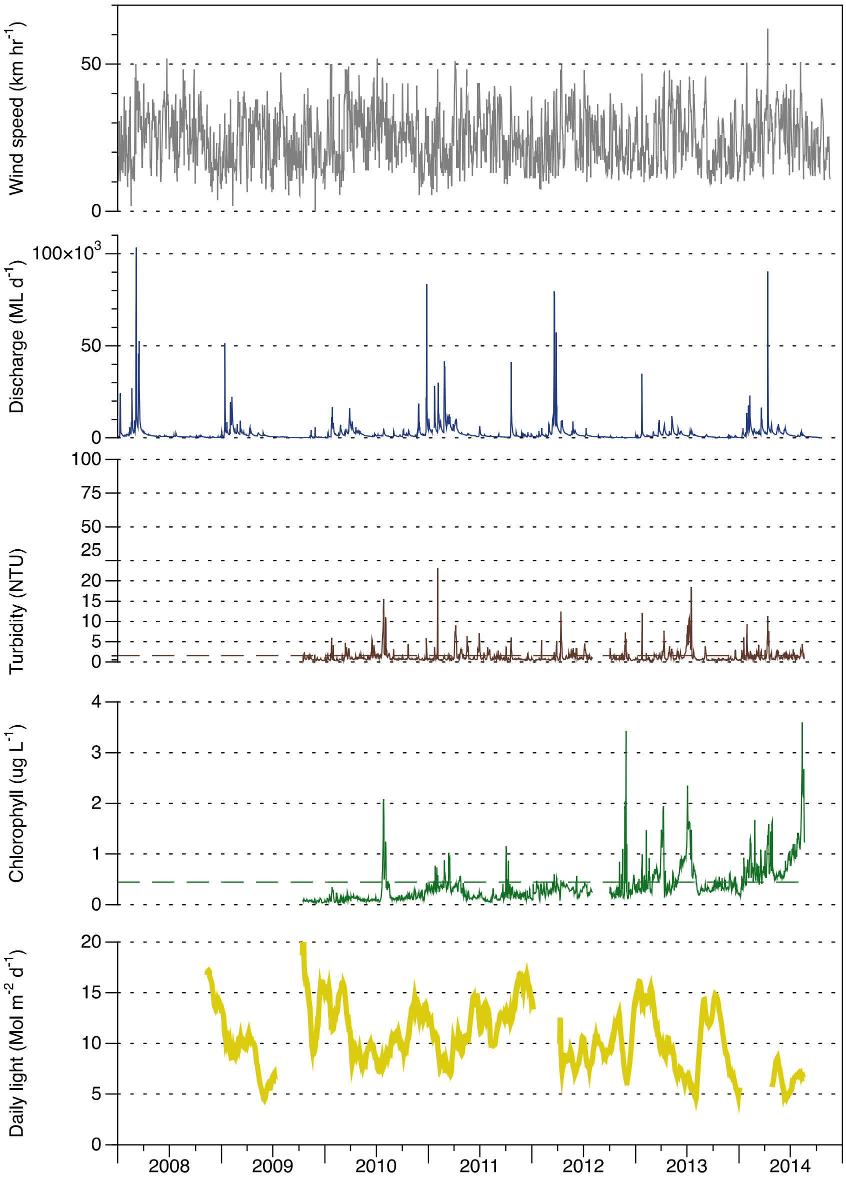

Figure 185. *Daily mean chlorophyll concentration (green line, µg L^{-1}), turbidity (brown line, NTU) at Green Island in the Wet Tropics NRM Region. Additional panels are daily discharge (Mulgrave, ML d^{-1} x10^{-5}), daily wind speed (Low Isles), and daily light at seagrass canopy height. Horizontal green and red lines are the GBR Water Quality Guidelines values (GBRMPA 2009). Turbidity trigger value (1.54 NTU red line) was derived by transforming the suspended solids trigger value (see Schaffelke et al. 2009).*

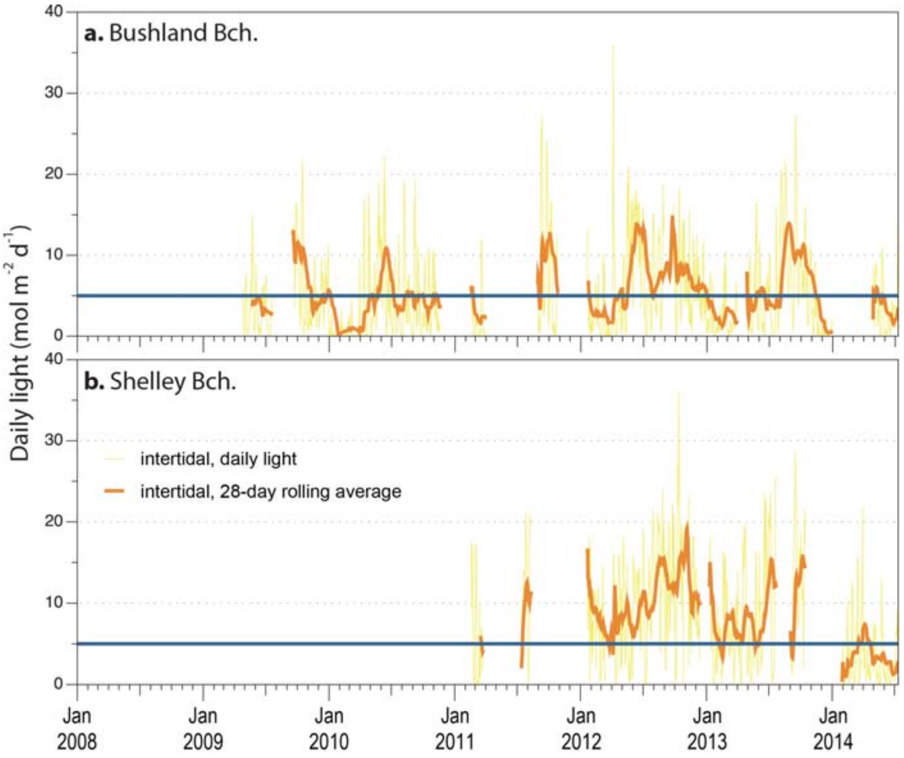

Figure 186. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at coastal sites in the Burdekin region, also showing approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

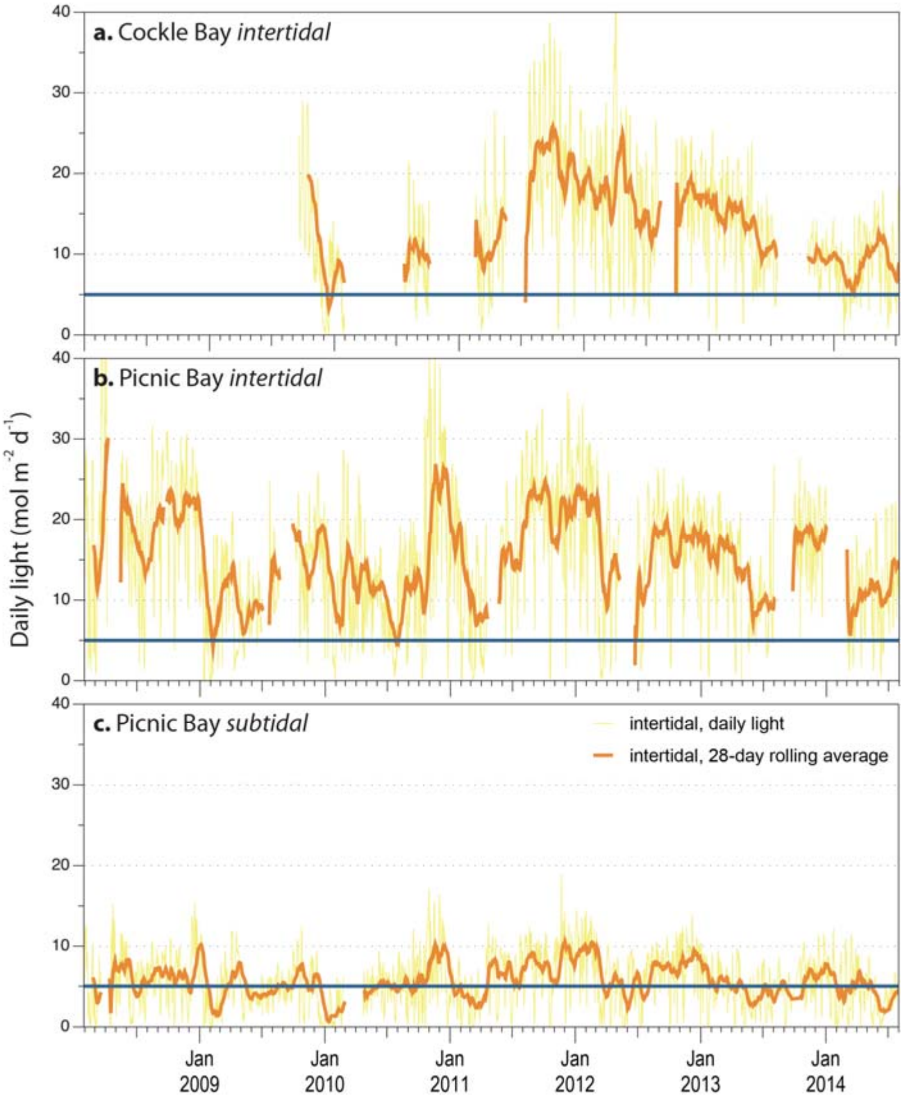

Figure 187. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Magnetic Island habitats in the Burdekin, also showing approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

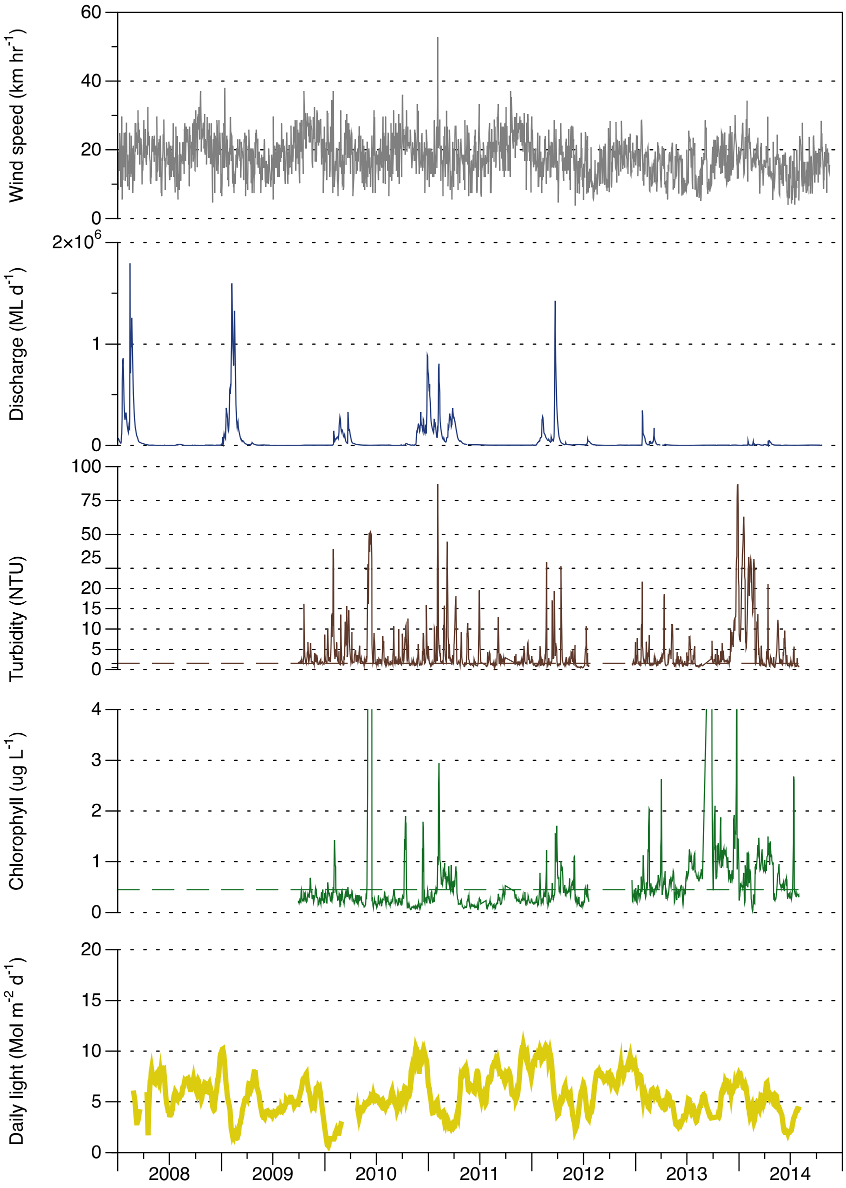

Figure 188. *Daily mean chlorophyll concentration (green line, µg L^{-1}), turbidity (brown line, NTU) at Picnic Bay on Magnetic Island in the Burdekin NRM Region over duration of monitoring. Additional panels are daily discharge (Burdekin River, ML d^{-1} x10^{-5}), daily wind speed (Townsville airport), and daily light at seagrass canopy. Horizontal green and red lines are the GBR Water Quality Guidelines values (GBRMPA 2009). Turbidity trigger value (1.54 NTU red line) was derived by transforming the suspended solids trigger value (see Schaffelke et al. 2009).*

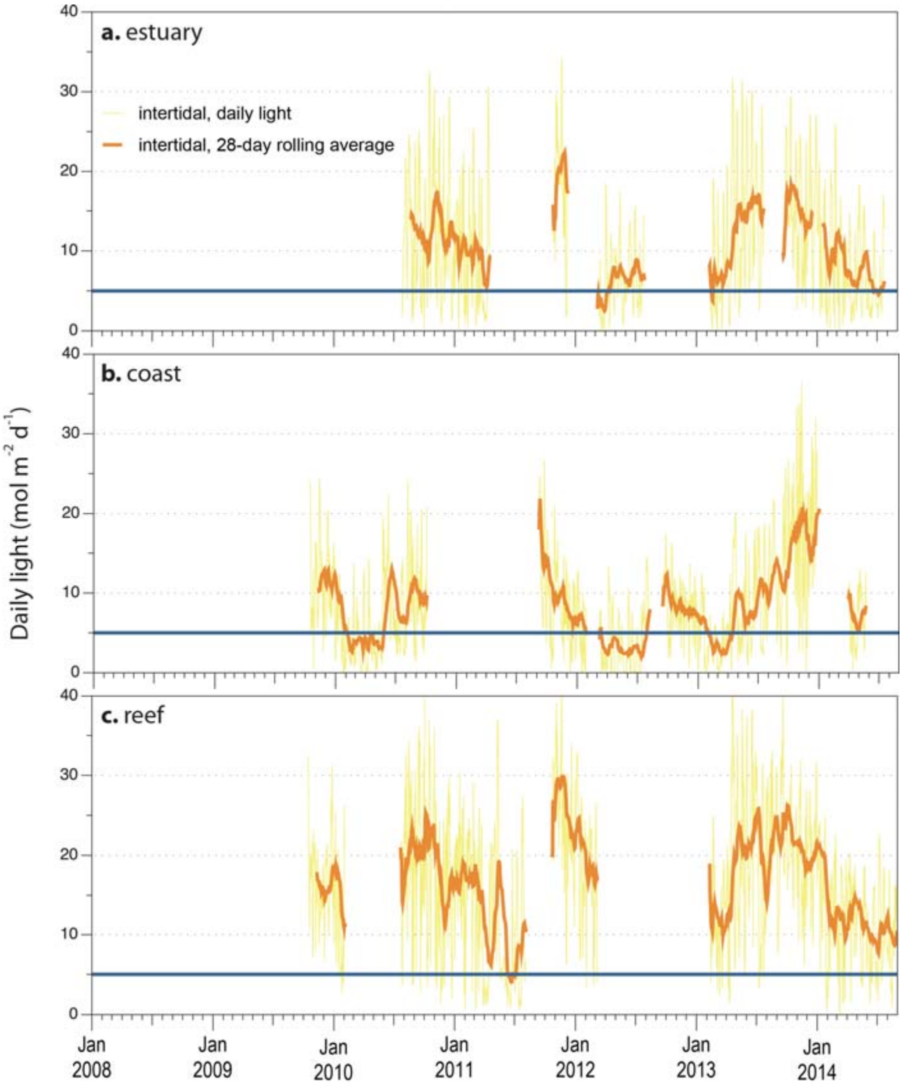

Figure 189. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Mackay Whitsunday habitats: a. estuary = Sarina Inlet; b. coast = Pioneer Bay; c. reef = Hamilton Island. Also displayed is approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

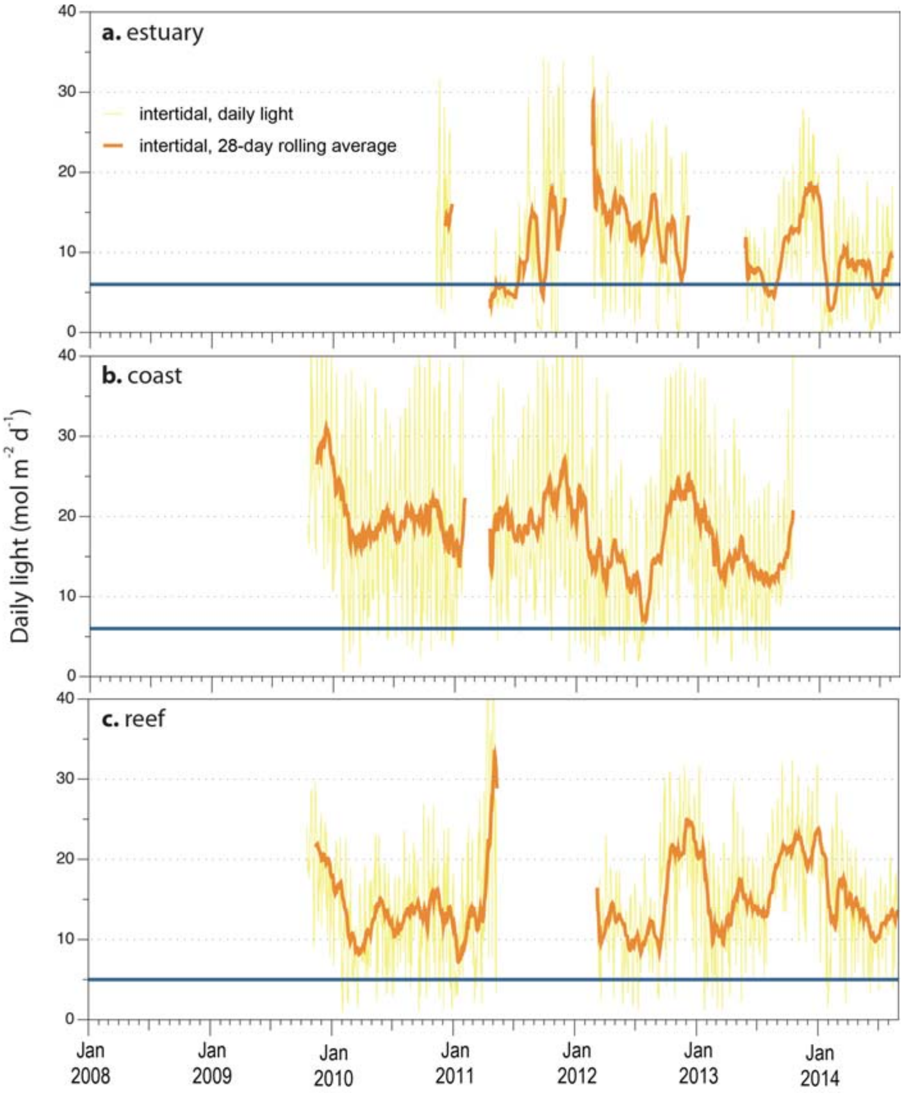

Figure 190. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Fitzroy habitats: a. estuary = Pelican Banks, Gladstone Hbr.; b. coast = Shoalwater Bay; c. Great Keppel Is. Also displayed is approximate light threshold required for positive growth in Zostera muelleri dominated communities (6 mol m^{-2} d^{-1}) and* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

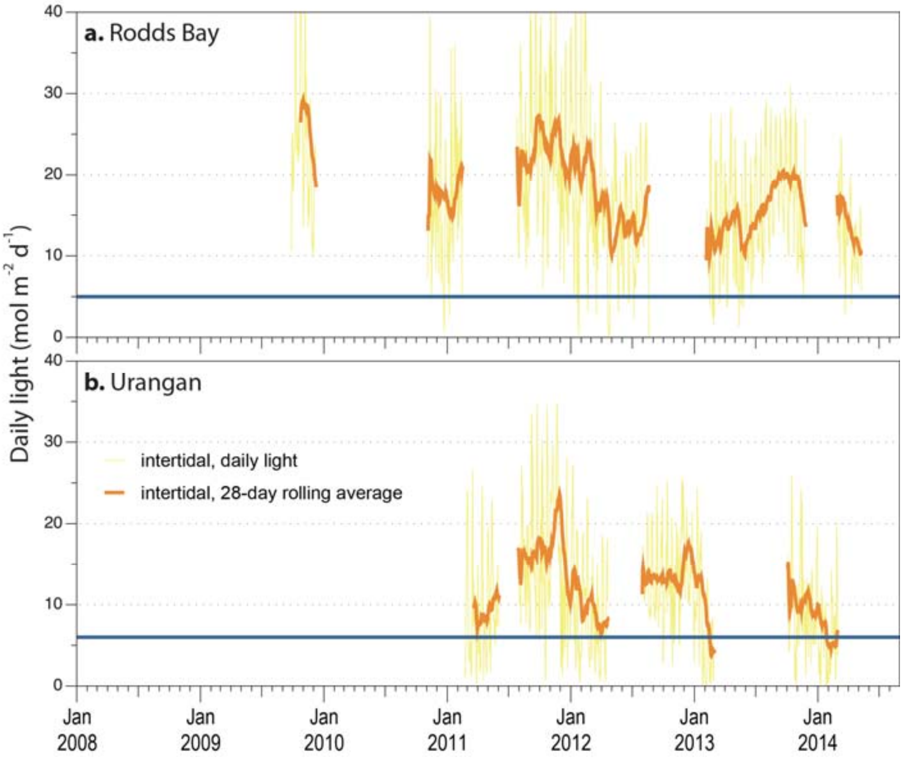

Figure 191. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Burnett Mary NRM locations, also showing approximate light threshold required for positive growth in Zostera muelleri dominated communities in the southern GBR (6 mol m^{-2} d^{-1}).*

A2.10. Climate

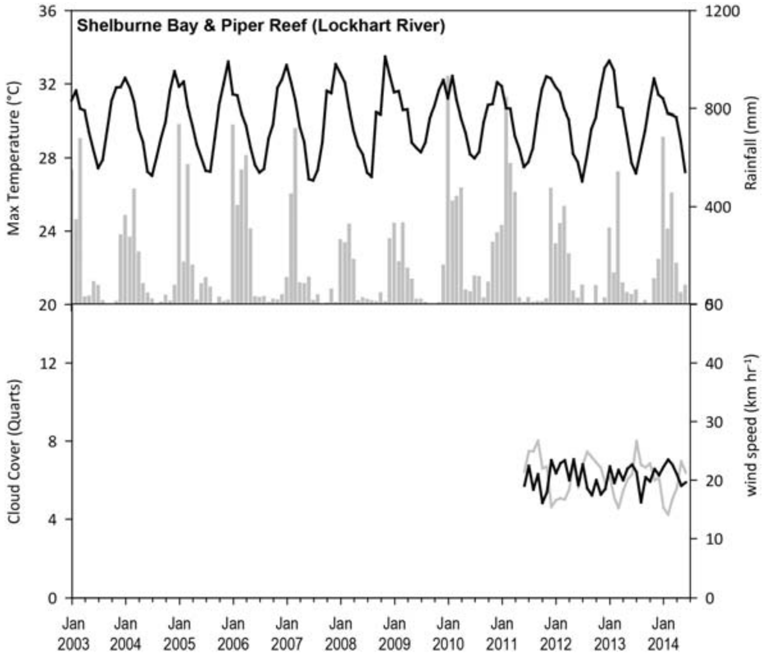

Figure 192. *Mean monthly daily maximum air temperature (°C), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km.hr^{-1}, lighter line) recorded at Lockhart River Airport (BOM station 028008, source www.bom.gov.au), located 108km from Shelburne Bay and 61km from Piper Reef monitoring sites.*

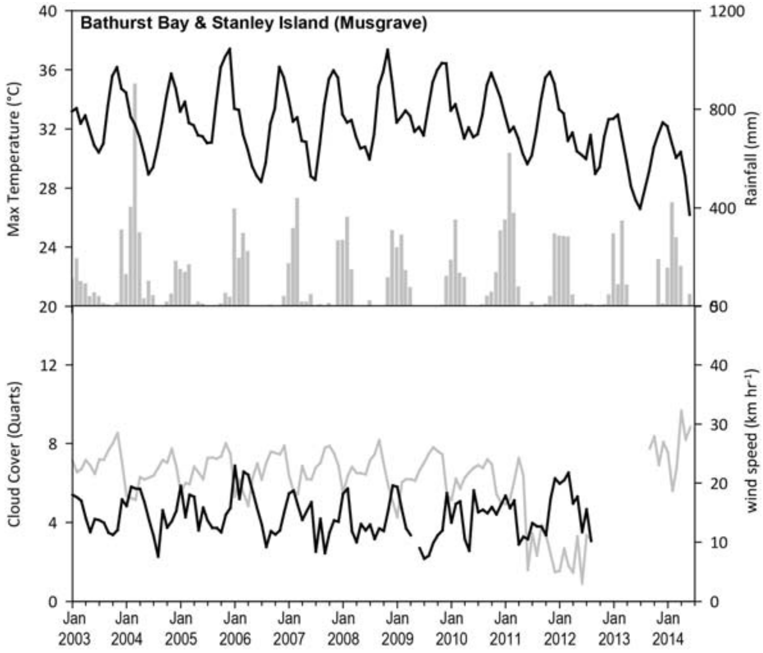

Figure 193. *Total monthly rainfall (mm, bar graph) recorded at Lotus Bird Lodge (BOM station 028035, source www.bom.gov.au), located approximately 73km and 84km from Bathurst Bay and Stanley Island monitoring sites, respectively. Mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) pre-August 2012 from Musgrave (BOM station 028007) located approximately 97km and 107km from Bathurst Bay and Stanley Island monitoring sites, respectively, and post-August 2012, from Cape Flattery (BOM station 031213), located approximately 139km and 144km from Bathurst Bay and Stanley Island monitoring sites, respectively (source www.bom.gov.au).*

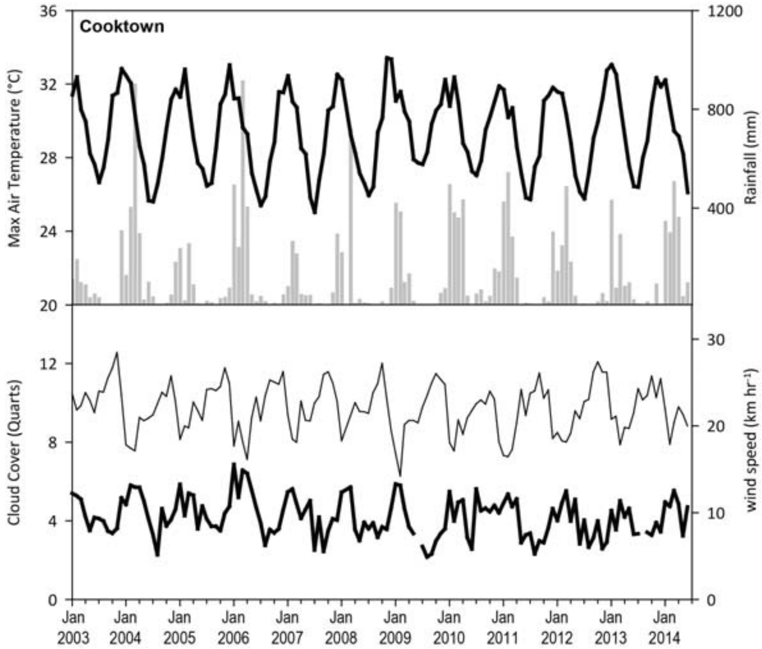

Figure 194. *Mean monthly daily maximum air temperature (°C), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km. hr^{-1}, lighter line) recorded at Cooktown airport (BOM station 031209, source www.bom.gov.au), located 16km from Archer Point monitoring sites.*

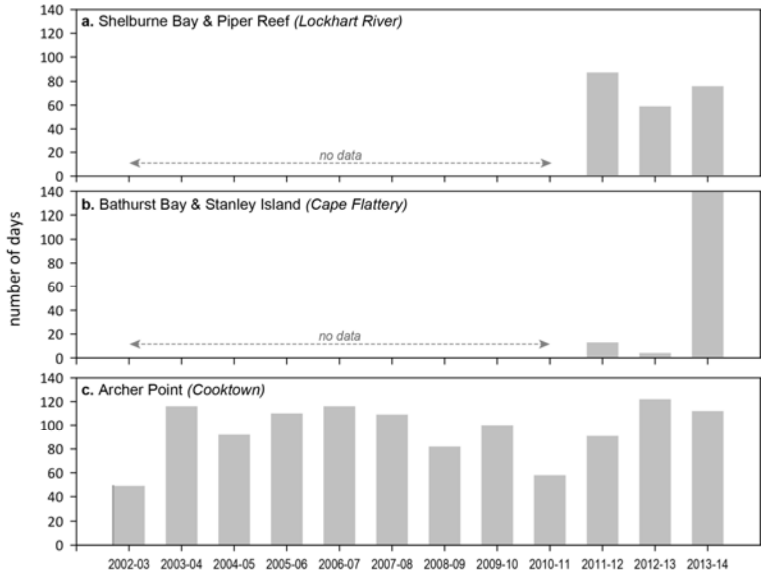

Figure 195. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Cape York NRM region. Daily 3pm wind speed from: a) from Lockhart River Airport (BOM station 028008, source www.bom.gov.au), located 108km from Shelburne Bay and 61km from Piper Reef monitoring sites; b) Cape Flattery (BOM station 031213), located approximately 139km and 144km from Bathurst Bay and Stanley Island monitoring sites, respectively and; c) Cooktown airport (BOM station 031209), located 16km from Archer Point monitoring sites.*

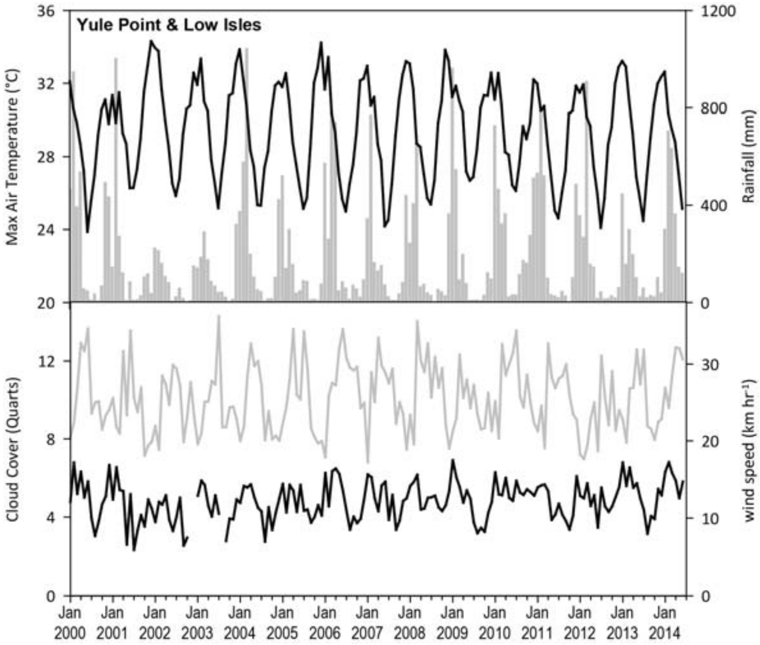

Figure 196. *Total monthly rainfall (mm, bar graph) recorded at Port Douglas - Warner St (BOM station 31052, source www.bom.gov.au), located approximately 11km from Yule Point and 15 from Low Isles monitoring sites. Mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) from Low Isles (BOM station 31037, source www.bom.gov.au), located approximately 21km from Yule Point monitoring sites.*

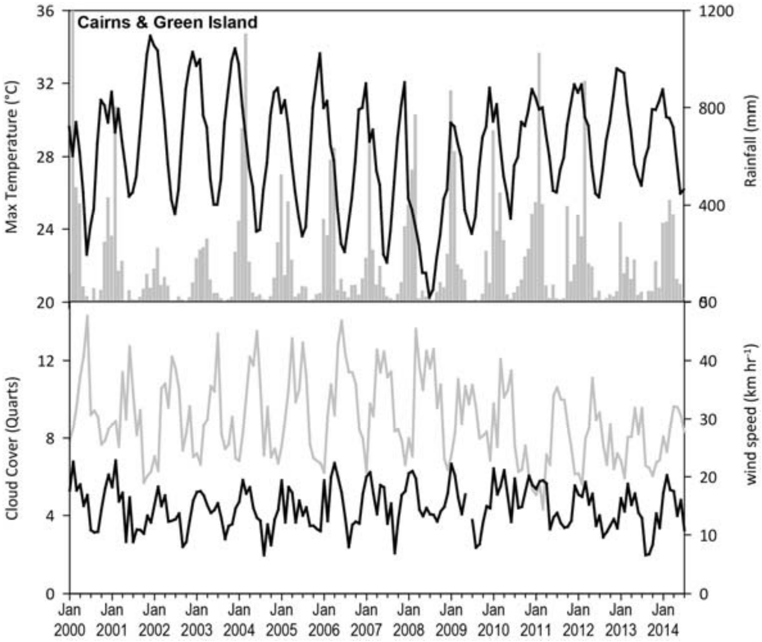

Figure 197. *Mean monthly daily maximum air temperature (°C, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) pre-July 2010 from Green Island (BOM station 31192). Mean monthly daily maximum air temperature (°C), total monthly rainfall post-Jun 2010 (mm, bar graph), and mean monthly cloud cover (quarts, black line), recorded at Cairns airport (BOM station 031011), located approximately 26km from Green Island monitoring sites. Mean monthly 3pm wind speed (km. hr^{-1}, grey line) post-July 2010 from Low Isles (BOM station 31037) (source www.bom.gov.au).*

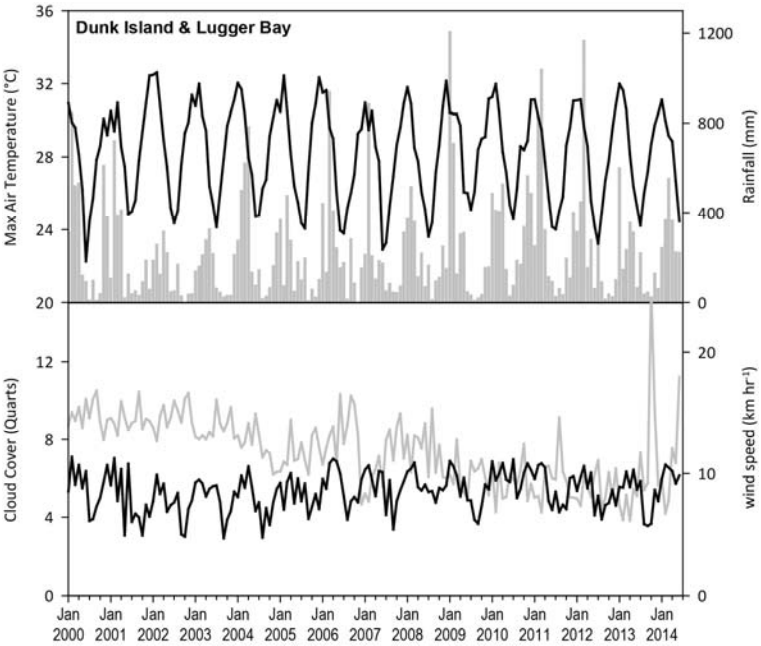

Figure 198. *Total monthly rainfall (mm, bar graph), recorded at Dunk Island Resort (BOM station 32118, source www.bom.gov.au). Mean monthly daily maximum air temperature (°C), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km.hr^{-1}, lighter line) recorded at Innisfail (BOM station 032025, source www.bom.gov.au), located approximately 48km from monitoring sites at Lugger Bay and Dunk Island.*

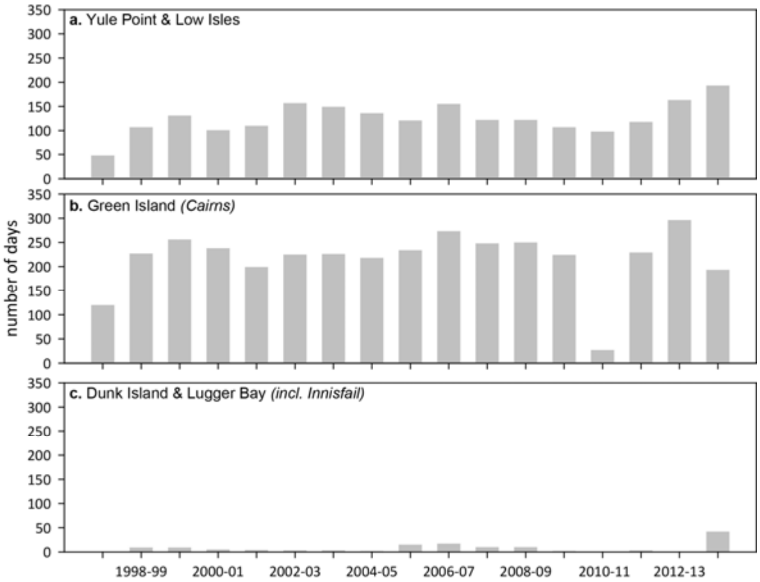

Figure 199. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Wet Tropics NRM region. Daily 3pm wind speed from: a) Low Isles (BOM station 31037), located approximately 21km from Yule Point monitoring sites; b) Green Island (BOM station 31192); and C) Innisfail (BOM station 032025), located approximately 48km from monitoring sites at Lugger Bay and Dunk Island.*

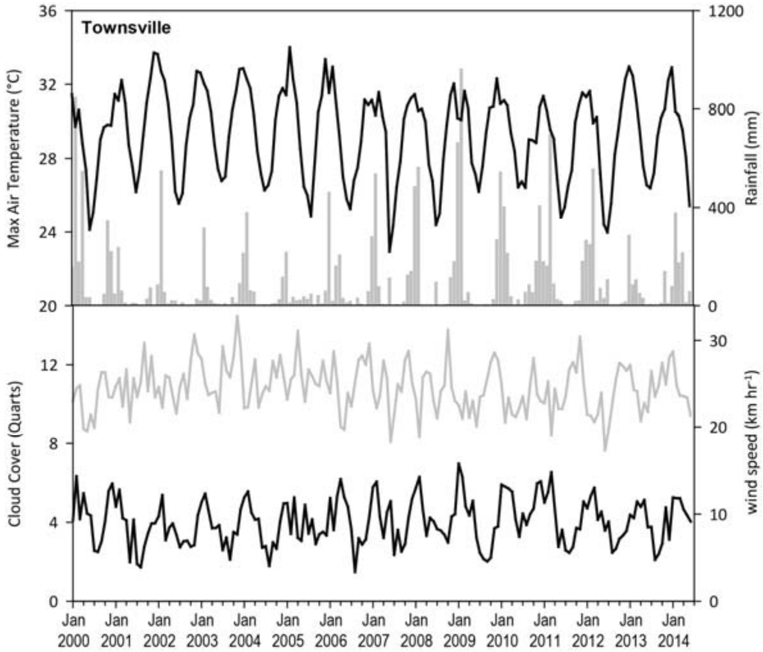

Figure 200. *Mean monthly daily maximum temperature (°C, line), total monthly rainfall (grey bars), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) recorded at Townsville Airport (BOM station 032040, source www.bom.gov.au). Townsville Airport is located approximately 11km from coastal (Townsville) and reef (Magnetic Island) monitoring site.*

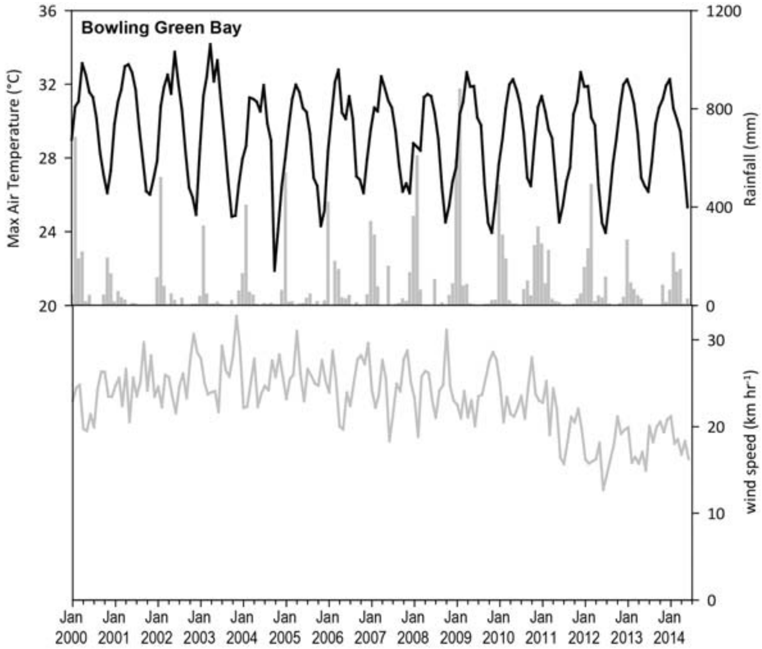

Figure 201. *Mean monthly daily maximum temperature (°C, line), total monthly rainfall (grey bars), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) recorded at Ayr (BOM station 033002, source www.bom.gov.au), located approximately 26km from Jerona (Bowling Green Bay) monitoring sites.*

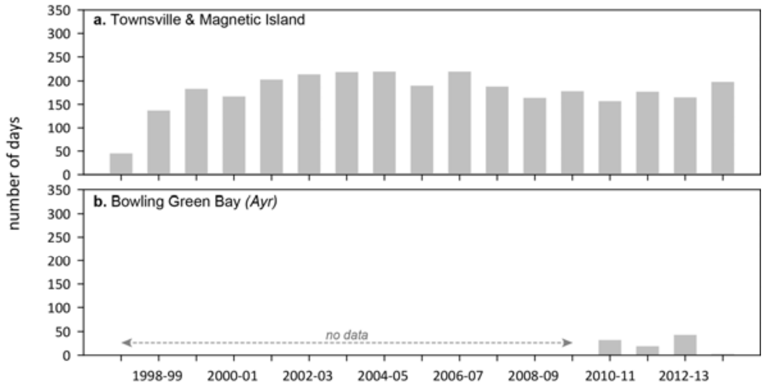

Figure 202. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Wet Tropics NRM region. Daily 3pm wind speed from: a) Townsville Airport (BOM station 032040) located approximately 11km from coastal (Townsville) and reef (Magnetic Island) monitoring sites, and 53km from Jerona (Bowling Green Bay) monitoring sites; and b) Ayr (BOM station 033002), located approximately 26km from from Jerona (Bowling Green Bay) monitoring sites.*

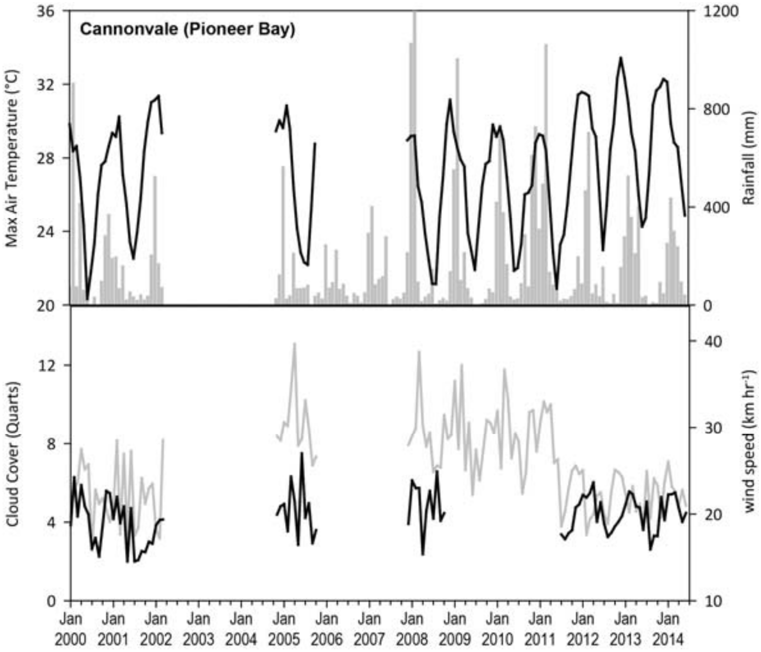

Figure 203. *Total monthly rainfall (grey bars) (post December 2004), mean monthly daily maximum temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) recorded at Proserpine Post Office (BOM station 33316, source www.bom.gov.au) (post June 2011), located 18km from Pioneer Bay monitoring sites. All other recordings from Hamilton Island (BOM station 033106, source www.bom.gov.au), approximately 28km from Pioneer Bay monitoring sites.*

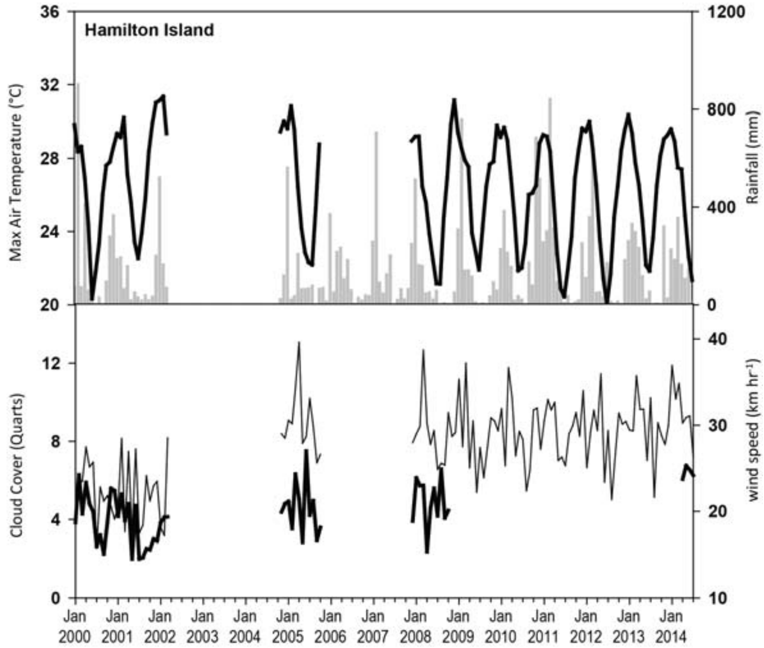

Figure 204. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km. hr^{-1}) recorded at Hamilton Island (BOM station 033106, source www.bom.gov.au), located 1.5km from Hamilton Island monitoring sites.*

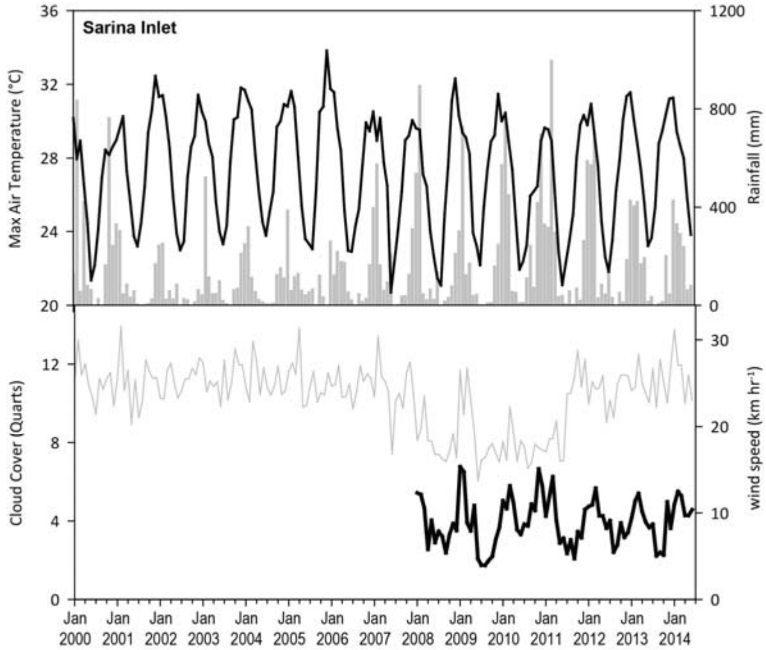

Figure 205. *Total monthly rainfall (grey bars) recorded at Plane Creek Sugar Mill (BOM station 033059, source www.bom.gov.au), located 10km from Sarina Inlet monitoring sites. Mean monthly daily maximum temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) recorded at Mackay Airport (BOM station 033045, source www.bom.gov.au), approximately 28km from Sarina Inlet monitoring sites.*

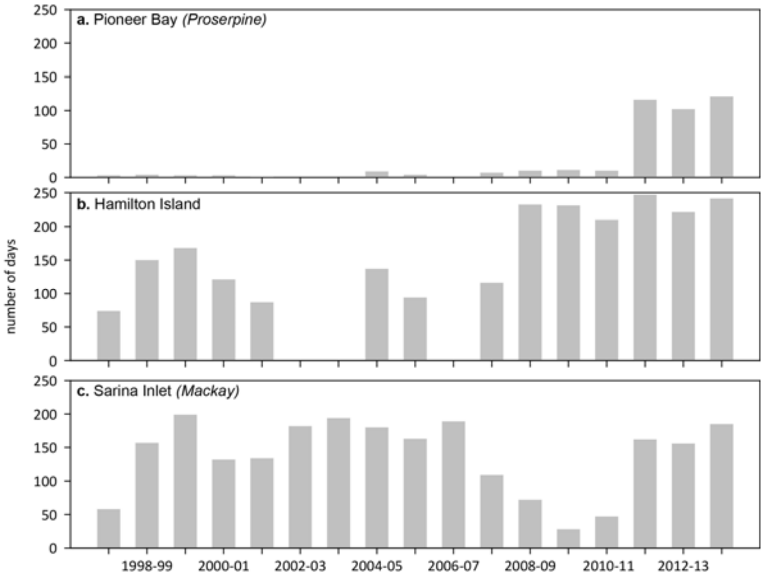

Figure 206. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Mackay Whitsunday NRM region. Daily 3pm wind speed from: a) Proserpine Post Office (BOM station 33316) (post June 2011), located 18km from Pioneer Bay monitoring sites; b) Hamilton Island (BOM station 033106), located 1.5km from Hamilton Island monitoring sites; and c) Mackay Airport (BOM station 033045, source www.bom.gov.au), approximately 28km from Sarina Inlet monitoring sites*.

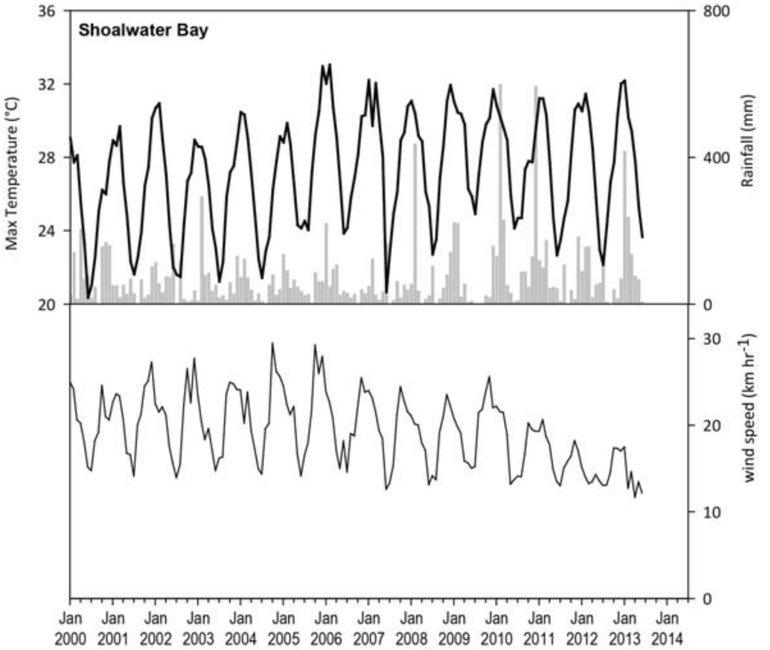

Figure 207. *Total monthly rainfall (grey bar), mean monthly daily maximum temperature (°C) and mean monthly 3pm wind speed (km. hr^{-1}) post May 2005 recorded at Williamson, Shoalwater Bay (BOM station 033260, source www.bom.gov.au), located 10km from the monitoring sites. Prior to May 2005, observations recorded at Yeppoon (BOM station 033106, source www.bom.gov.au), approximately 96km from monitoring sites.*

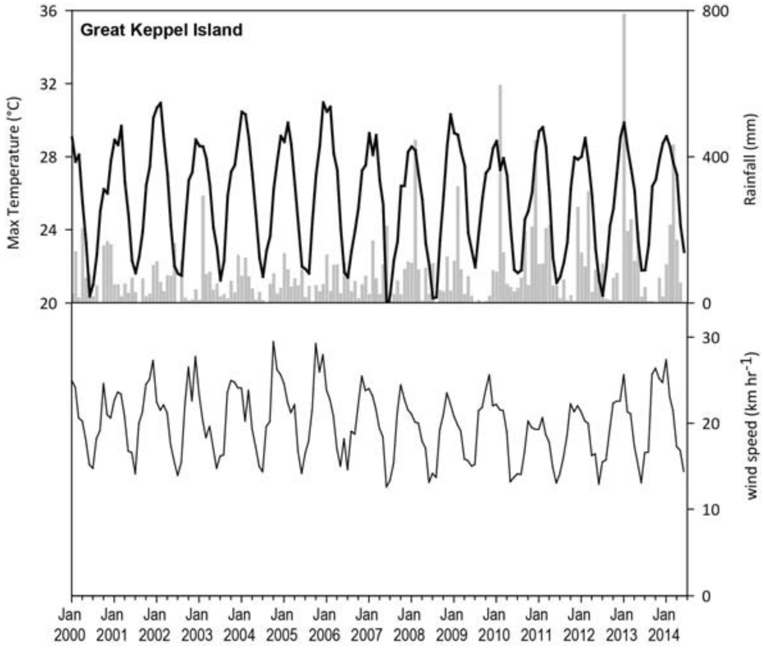

Figure 208. *Total monthly rainfall (grey bar) recorded at Svendsen Beach, Great Keppel Island (BOM station 033260, source www.bom.gov.au), located 4.5km from the monitoring sites. Mean monthly daily maximum temperature (°C) and mean monthly 3pm wind speed (km. hr^{-1}) recorded at Yeppoon (BOM station 033106, source www.bom.gov.au), approximately 22km from monitoring sites.*

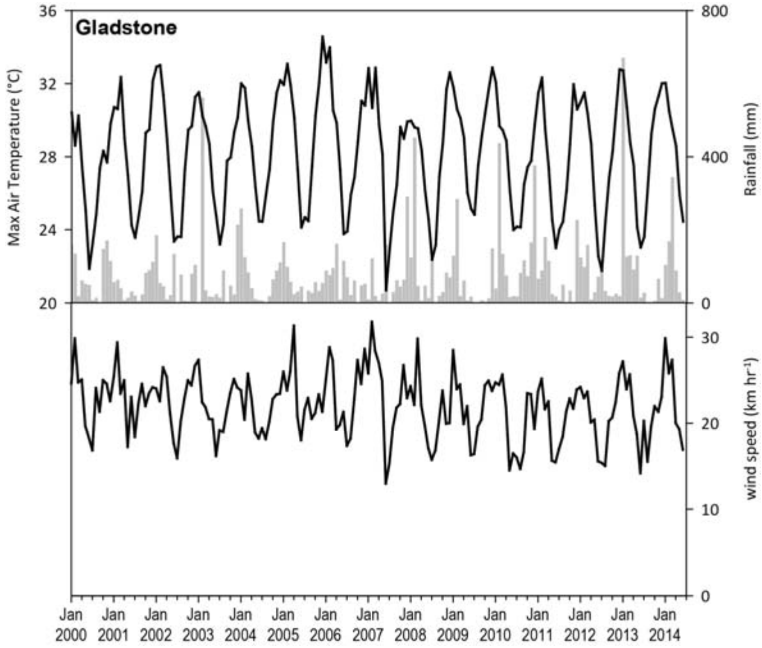

Figure 209. *Total monthly rainfall (grey bars) recorded at Southend Curtis Island (BOM station 039241, source www.bom.gov.au), located 1km from monitoring sites. Mean monthly daily maximum temperature (°C), and mean monthly 3pm wind speed (km. hr^{-1}) recorded at Gladstone Airport (BOM station 039123, source www.bom.gov.au), located approximately 13km from monitoring sites.*

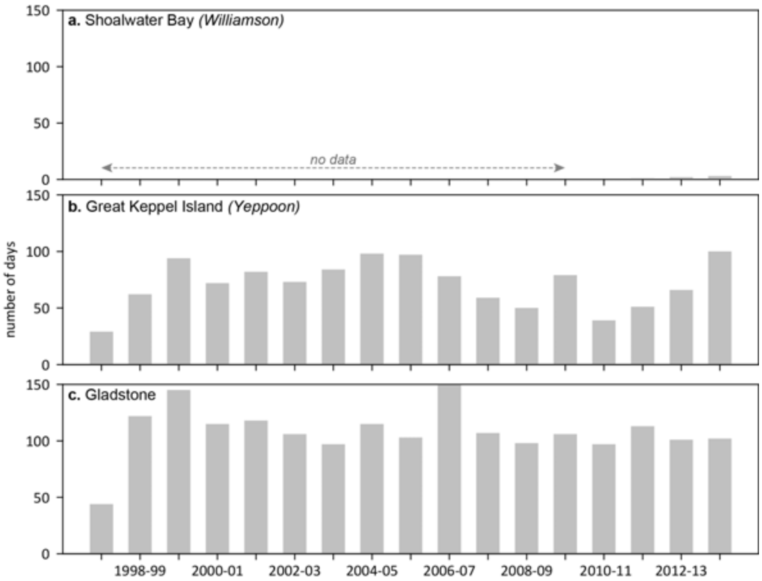

Figure 210. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Fitzroy NRM region. Daily 3pm wind speed from: a) Williamson, Shoalwater Bay (BOM station 033260), located 10km from the monitoring sites; b) Yeppoon (BOM station 033106), approximately 22km from monitoring sites; and c) Gladstone Airport (BOM station 039123), located approximately 13km from monitoring sites.*

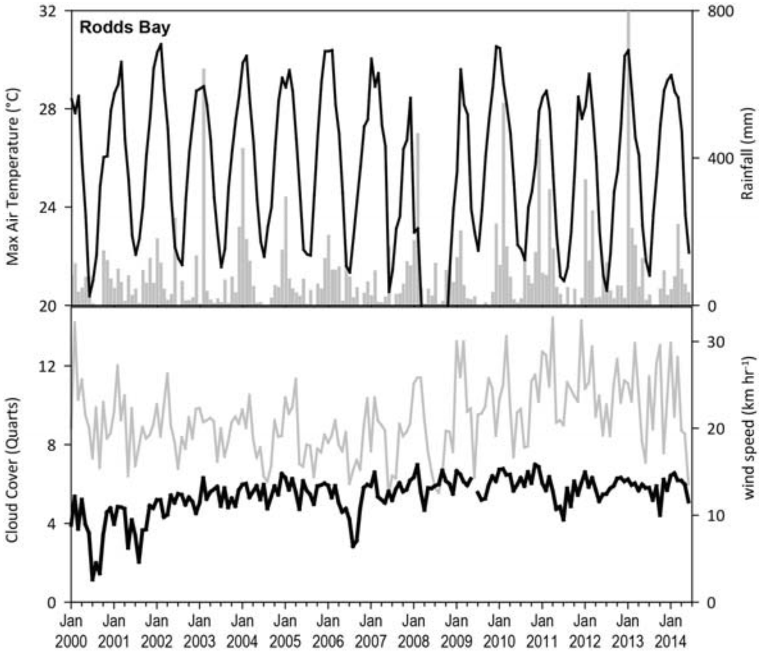

Figure 211. *Mean monthly daily maximum temperature (°C) (black line), mean monthly cloud cover (quarts) (black line), and mean monthly 3pm wind speed (km. hr^{-1}) (grey line) recorded at Seventeen Seventy (BOM station 039314, source www.bom.gov.au), approximately 27km from Rodds Bay monitoring sites. Total monthly rainfall (grey bar), recorded at Turkey station (BOM station 039261) pre-2014 and Bustard Head Lighthouse (BOM station 039018), approximately 12km from Rodds Bay monitoring sites. (source www.bom.gov.au).*

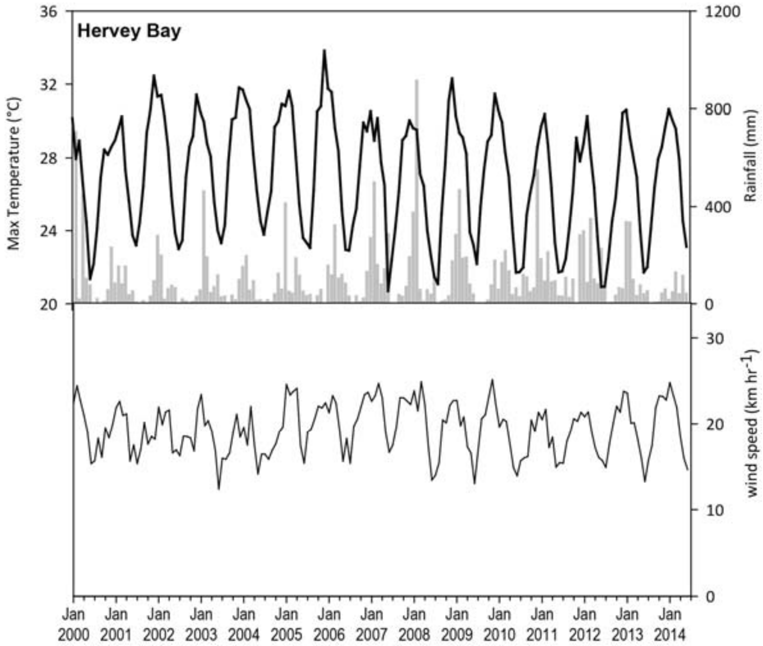

Figure 212. *Mean monthly daily maximum temperature (°C), total monthly rainfall, and mean monthly 3pm wind speed (km. hr^{-1}) recorded at Hervey Bay Airport (BOM station 040405, source www.bom.gov.au), approximately 3km from Urangan monitoring sites.*

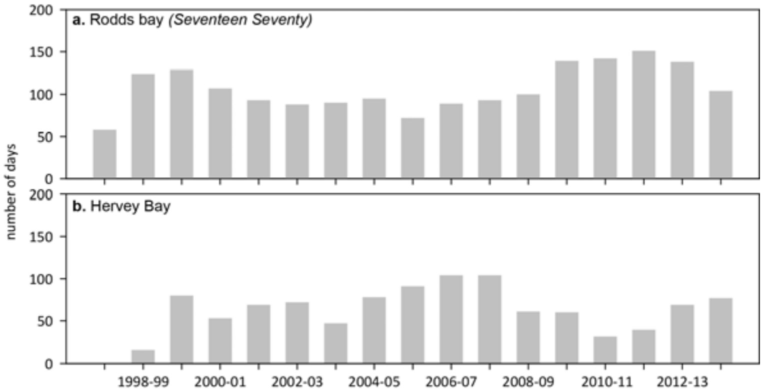

Figure 213. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Burnett Mary NRM region. Daily 3pm wind speed from: a) Seventeen Seventy (BOM station 039314), approximately 27km from Rodds Bay monitoring sites; and b) Hervey Bay Airport (BOM station 040405), approximately 3km from Urangan monitoring sites.*

A2.11. River discharge

Table 41: *Long term river discharge (in megalitres) for the major GBR Catchment rivers in proximity to the inshore seagrass sampling sites (where data available) for the 2013-2014 wet season (c.a., from Nov 1st to Apr 30th), compared against the previous four wet seasons and long-term (LT) median. Colours indicate levels above LT median: yellow for 1.5 to 2 times; orange for 2 to 3 times, and red for greater than 3 times. Long term statistics were calculated based on the wet seasons from Nov 1st, 1949 to Apr 30th, 2000. (Data source: Queensland Department of Natural Resources and Mines on dnrm.qld.gov.au/water/water-monitoring-and-data/portal accessed 31 October 2014.*

Region	River	LT median	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014
CapeYork	Pascoe	1,142,458	1,406,502	1,877,760	691,628	770,637	1,301,037
	Stewart	210,621	181,398	368,703	101,761	87,708	155,664
	Normanby	-	2,866,267	5,862,830	1,090,140	1,776,332	2,480,188
	Annan	219,963	321,352	485,961	266,446	129,570	153,064
WetTropics	Daintree	544,611	983,652	1,429,899	744,055	501,552	1,398,947
	Barron	436,847	430,065	1,753,305	551,025	226,406	435,082
	Mulgrave	440,347	541,997	1,315,073	751,882	277,064	638,717
	Russell	632,309	878,223	1,293,058	815,652	413,715	844,227
	Nth Johnstone	1,099,439	1,237,422	2,881,043	1,327,523	697,401	1,415,212
	Sth Johnstone	558,969	491,994	1,305,473	627,572	321,335	530,425
	Tully	1,894,102	1,860,031	4,642,874	1,445,101	1,576,555	2,370,649
	Herbert	2,642,191	2,557,679	10,563,954	3,331,307	2,255,089	3,148,938
Burdekin	Burdekin	4,669,849	7,661,648	33,885,815	14,333,639	3,110,624	1,098,661
	Don	51,062	127,202	785,986	197,426	151,384	80,783
MackayWhitsunday	Proserpine	14,770	44,487	336,045	47,309	31,284	19,113
	O'Connell	137,245	312,483	568,859	261,755	102,193	87,713
	Pioneer	214,496	1,094,115	3,111,545	1,045,129	797,991	426,441
	Sandy	111,143	360,756	608,377	342,215	244,717	88,010
	Carmila	29,863	95,345	84,405	53,424	42,330	24,941
Fitzroy	Fitzroy	1,880,471	10,906,736	35,886,042	6,479,801	8,307,530	1,494,599
Burnett-Mary	Burnett	171,904	849,348	8,175,217	468,541	6,750,996	170,302
	Mary	496,172	1,772,714	5,671,760	2,627,321	5,243,992	361,863

** The Normanby River gauge station started in 2005, so there is no long-term data for the statistics computation.*

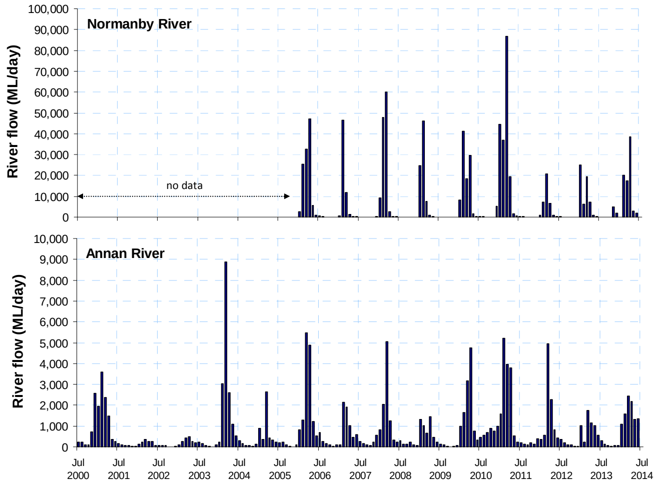

Figure 214. *Average daily flow (ML day^{-1}) per month from the Normanby River at Kalpowar Crossing and Annan River at Beesbike (stations 105107A - Normanby River at Kalpowar Crossing 14.91683°S 144.211279°E, Elev:21.3m and 107003A, 15.68773°S, 145.2085°E, Elev: 115m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

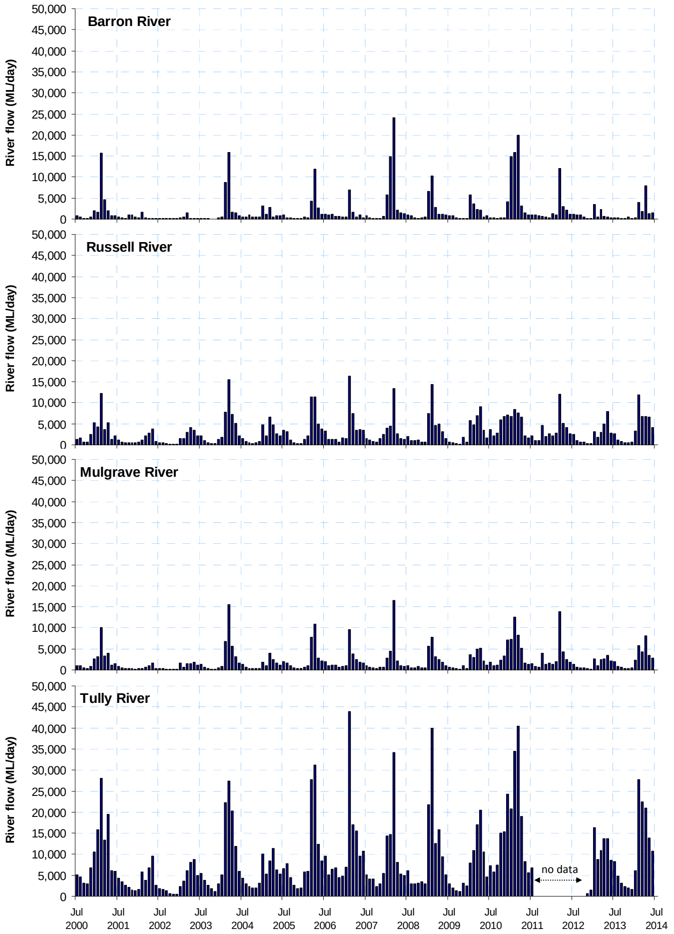

Figure 215. *Average daily flow (ML day^{-1}) per month from the main rivers impacting the seagrass monitoring sites in the Wet Tropics (stations 110001D - Barron River at Myola, 16.79983333°S 145.61211111°E, Elev 345m; 111007A - Mulgrave River at Peets Bridge, 17.13336111°S 145.76455556°E, Elev 27.1m; 111101D - Russell River at Bucklands 17.38595°S 145.96726667°E, Elev10m; 113006A - Tully River at Euramo, 17.99213889°S 145.94247222°E, Elev 8.76m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

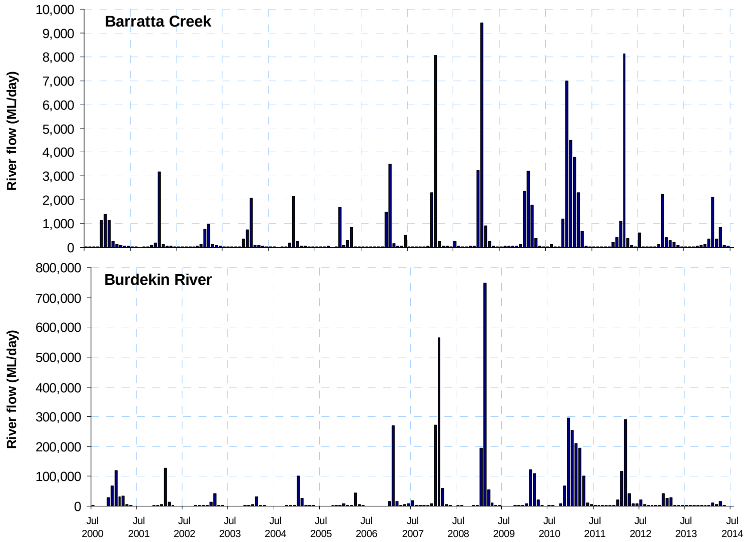

Figure 216. *Average daily flow (ML day^{-1}) per month from the Burdekin River impacting the seagrass monitoring sites in the Burdekin region (stations 120006B - Burdekin River at Clare, 19.75856°S 147.24362°E, Elev 29m; 119101A - Barratta Creek at Northcote Lat:-19.69072778 Long:147.169825 Elev: 17.3m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

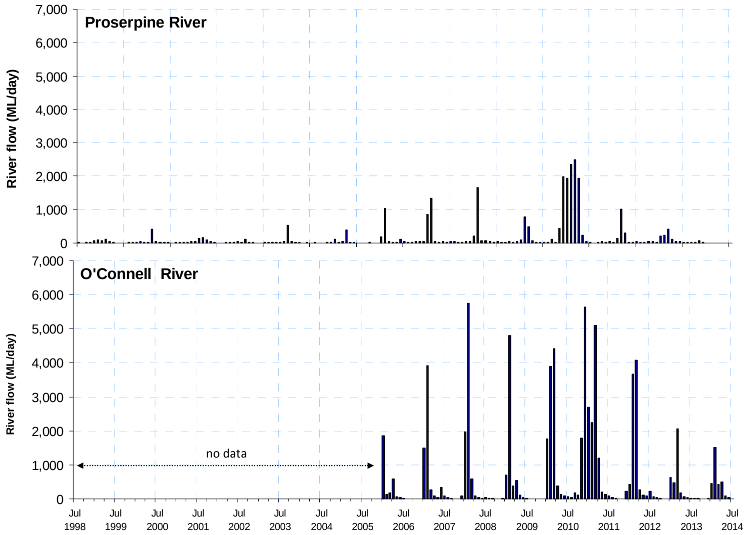

Figure 217. *Average daily flow (ML day^{-1}) per month from the main rivers impacting coastal and reef seagrass monitoring sites in the Mackay Whitsunday region (stations 122005A - Proserpine River at Proserpine, 20.39166667°S 148.59833333°E, Elev 7m; 124001B - O'Connell River at Stafford's Crossing 20.65255556°S 148.573°E, Elev:0m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

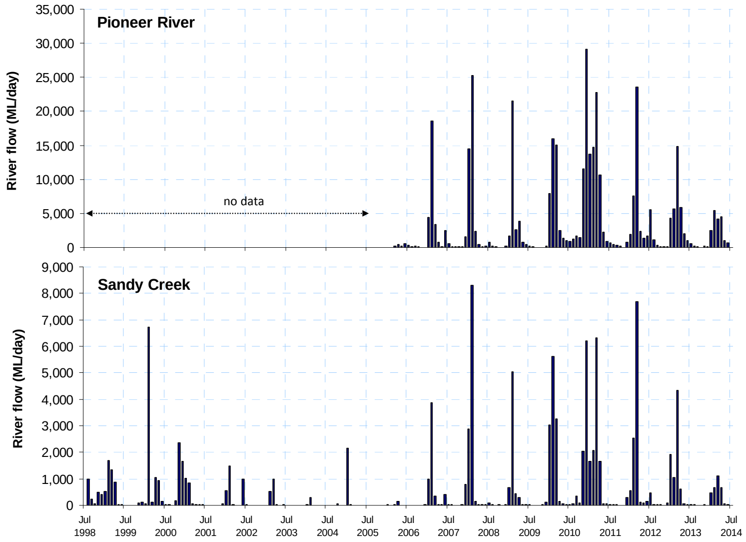

Figure 218. *Average daily flow (ML day^{-1}) per month from the main river impacting estuarine seagrass monitoring sites in the Mackay Whitsunday region (stations 125016A - Pioneer River at Dumbleton Weir T/W 21.14236111°S 149.07625°E, Elev 10m; 126001A - Sandy Creek at Homebush Lat:-21.2832888 Long:149.0225055, Elev 62m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

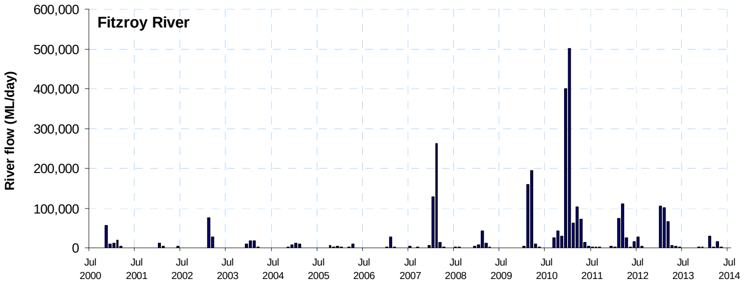

Figure 219. *Average daily flow (ML day^{-1}) per month from the Fitzroy River which impacts coastal and reef seagrass monitoring sites in the Fitzroy region (station 130005A - Fitzroy River at The Gap, 23.08897222°S 150.10713889°E, Elev 0m)(source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

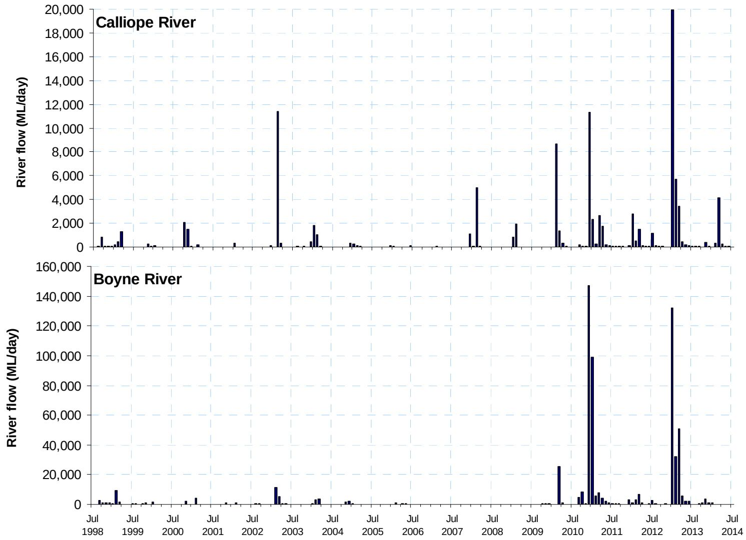

Figure 220. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact estuarine seagrass monitoring sites in the Fitzroy region (stations 132001A - Calliope River at Castlehope 23.98498333°S 151.09756389°E, Elev:21m; 136319A - Boyne River at Cooranga 25.78592226°S 151.33283673°E, Elev:0)(source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

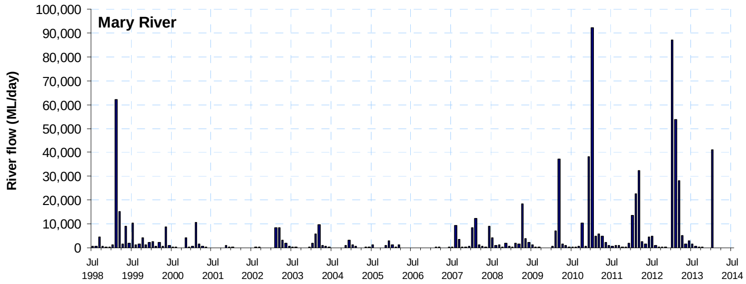

Figure 221. *Average daily flow (ML day^{-1}) per month from the Mary River which would impact estuarine seagrass monitoring sites at Urangan, southern Burnett Mary region (station 138001A - Mary River at Miva Lat:25.95332924°S:152.4956601 °E, Elev 0m) (source ©The State of Queensland (DNRM) 2014, dnrm.qld.gov.au/water/water-monitoring-and-data/portal).*

Appendix 3. Scientific publications and presentations associated with the Program 2013-14

List of scientific publications, scientific presentations and community seminars arising from the monitoring program.

Publications

Coles, R.G., Rasheed, M.A., McKenzie, L.J., Grech, A., York, P.H., Sheaves, M., McKenna, S., Bryant, C. (2015) The Great Barrier Reef World Heritage Area seagrasses: Managing this iconic Australian ecosystem resource for the future. *Estuarine, Coastal and Shelf Science* 153: A1-A12.

Presentations

McKenzie, L., Collier, C., Unsworth, R., Yoshida, R., Smith, N., Langlois, L. and Waycott, M. 2014. The resilience of inshore seagrasses of the Great Barrier Reef and their response to water quality and extreme weather events. *In* The 11th International Seagrass Biology Workshop Abstracts, Declining seagrasses in a changing world. 06-10 November 2014, Sanya, China. Session 1: Vulnerability and Resilience. p. 55.