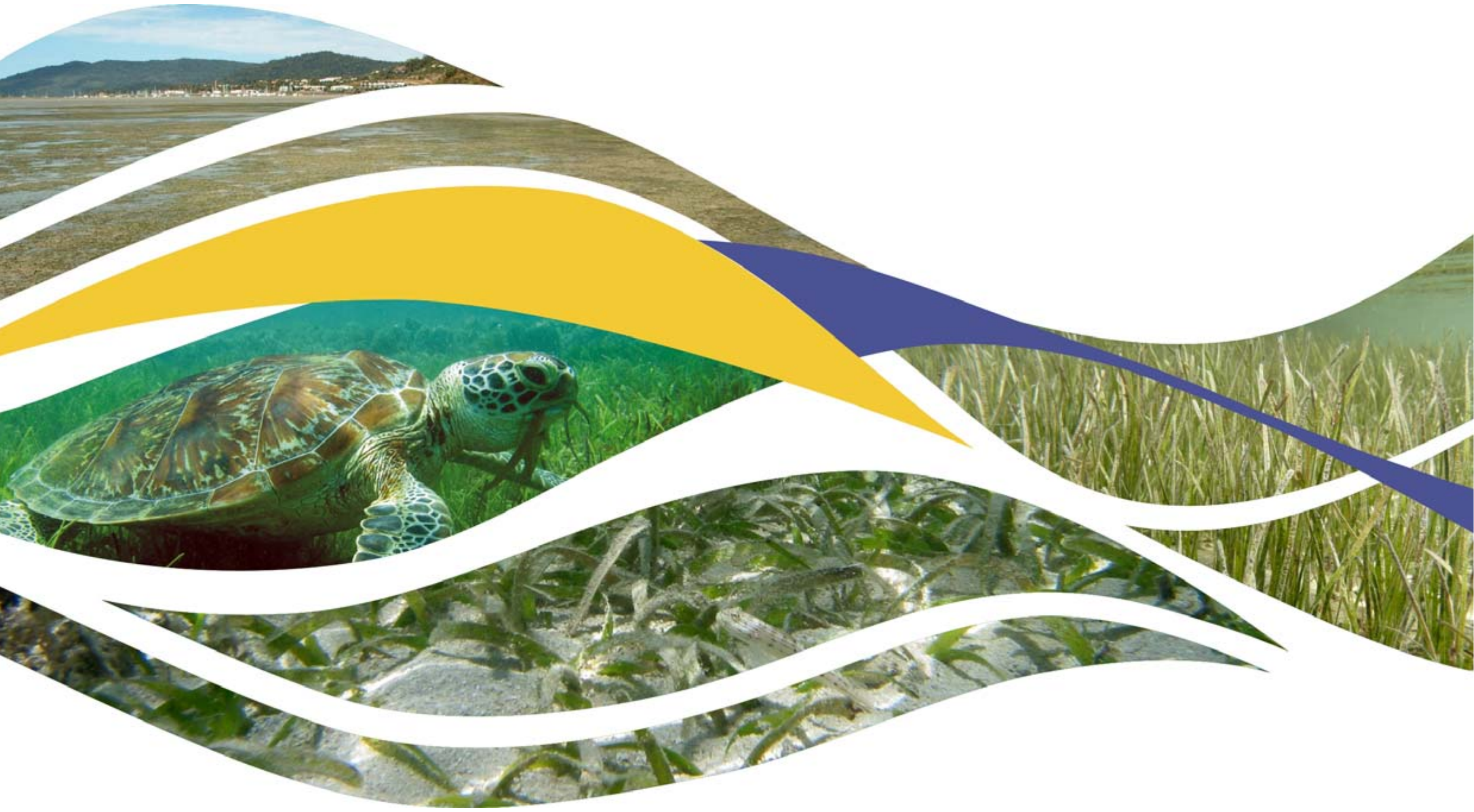

Reef Rescue

Marine Monitoring Program

Inshore Seagrass

ANNUAL REPORT

For the sampling period 1st June 2012 – 31st May 2013

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Michelle Waycott

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Contents

List of Figures

List of Tables

Acronyms Used In This Report

SEWPaC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
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
MMP	Marine Monitoring Program
NRM	Natural Resource Management
Paddock to Reef	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

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We thank Regional Services, Queensland Department of Agriculture, Fisheries and Forestry (DAFF) for the financial support to establish and monitor additional sites in the Cape York region north of Cooktown and within Bowling Green Bay (Burdekin region).

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.

Executive summary

The Reef Rescue 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 Reef Rescue initiative. Established in 2005 to help assess the long-term status and health of GBR ecosystems the MMP is a critical component in the assessment of 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 and Reef Rescue. 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, community structure, distribution, reproductive health, and nutrient status from representative 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. 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 sites.

Prior to 2011, inshore seagrass meadows along the developed (agricultural/urban) coast of the GBR were in a vulnerable condition with declining trajectories. The extreme weather events of early 2011 resulted in substantial decline of inshore seagrass meadows throughout much of the GBR. As a critical component of the GBR inshore ecosystems, the losses had significant flow-on effects to dugong and green turtle populations, which are highly dependent on seagrass as their primary food supply, and the productivity of adjacent ecosystems including coral reefs and mangroves.

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 function in the face of disturbance (Folke *et al.* 2004; Bernhardt and Leslie 2013). These attributes are also important in GBR seagrass meadows faced with multiple cumulative stressors, including water quality, and it is therefore helpful to consider monitoring results in the context of resistance and recovery attributes. The attributes of seagrasses that provide resistance include: abundance, species composition, genetic diversity, and storage reserves. Whereas, recovery is facilitated by reproductive output, seed banks and species composition. In 2012-13, the majority of seagrass meadows across the GBR remained in a vulnerable state, with weak resistance (low abundance and low diversity, or dominated by colonising species) and a low capacity to recover (both low seed bank and low reproductive effort).

In 2012-13, there were indications that seagrass meadows along the GBR developed coast were continuing to improve over the last 12 months, although still remaining in a vulnerable and poor state (particularly in the southern NRMs). The indicators of this improvement were: increasing abundance at 73% of sites (predominately coastal habitats); 78% of meadows expanding in area or remaining at their maximum extent; and declining epiphyte loads with below average cover at 64% sites. Of concern, however, is the low resistance of meadows to major stressors and their reduced capacity to recover, rendering the seagrass of the GBR vulnerable to major disturbances. The indicators of this vulnerability were: 58% of sites with lower than average composition of foundational species; the absence of seed banks at 60% of sites and declining seed banks at another 13% of sites; 69% of sites with lower than average daily light, particularly across the southern NRM regions; nutrient enrichment at 45% sites and of these, 56% with either high or elevated nitrogen.

Elemental ratios of tissue nutrients indicate some sites in the Mackay Whitsundays have degraded water quality with an excess of nutrients compared to light availability.

Many meadows had a higher than average proportion of colonising species that were expanding in meadow area, but investing little in seed production or sexual reproduction. Seagrass meadows in the Burdekin, Mackay Whitsunday, and parts of the Fitzroy regions were in a less vulnerable state, with greater resistance (conferred by abundance increases of half to ten-fold compared to the previous year) and an improved capacity to recover (increasing seeds banks and improved reproductive effort). Despite these improvements, seed banks remain low indicating a reduced capacity to recover from disturbance in the near future.

Leaf tissue analysis in 2012-13 indicated elevated or high N in the Wet Tropics to Mackay Whitsunday region, particularly in coastal habitats, where $\delta^{15}N$ suggested the source of N was derived from human activities (e.g. fertiliser and sewage). Seagrass environmental stressors appeared greater in southern GBR regions than in the north: lower light availability, higher and increasing epiphyte loads, increasing macroalgae, higher seawater temperatures, more days of inshore wind driven sediment resuspension, higher rainfall, and above median river flows discharging runoff over inshore meadows. Overall, the status of inshore seagrass meadows of the GBR improved in 2012-13 compared to the previous 2 years, but remained in a **poor state** (Table 1, Table 2).

Table 1. *Report card for seagrass status for the GBR and each NRM region: June 2012 – May 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). NB: new additional locations in Cape York and Burdekin regions included.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	42	8	39	30
Wet Tropics	17	0	23	13
Burdekin	34	33	34	34
Mackay Whitsunday	14	17	16	16
Fitzroy	31	0	41	24
Burnett Mary	6	0	30	12
GBR	36	12	36	**28**

Table 2. *Paddock to Reef report card for seagrass status for the GBR and each NRM region: June 2012 – May 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). NB: only the 30 long-term intertidal sites included.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	21	50	36	36
Wet Tropics	17	0	23	13
Burdekin	34	50	27	37
Mackay Whitsunday	14	17	16	16
Fitzroy	31	0	41	24
Burnett Mary	6	0	30	12
GBR	27	25	28	**26**

1. Introduction

A key component of Reef Rescue is the implementation of a long-term water quality and ecosystem monitoring program in the Great Barrier Reef lagoon (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:

a. Understand the status and trend of GBR inshore seagrass *(detect long-term trends in seagrass abundance, community structure, distribution, reproductive health, and nutrient status from representative inshore seagrass meadows)*,

b. Identify response of seagrass to environmental drivers of change,

c. Integrate reporting on GBR seagrass status including production of seagrass report card metrics for use in an annual Paddock to Reef report card.

Background

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). Seagrass are the primary food for sea turtles and dugongs, which are seagrass specialists (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.* 2012).

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, e.g., reef fish. The incorporation of carbon within their tissues can affect local *p*H and increase calcification of coral reefs, thereby mitigating the effects of ocean acidification (Fourqurean*, et al.* 2012; Unsworth*, et al.* 2012). Therefore, monitoring changes in seagrasses meadows can provide an indication of coastal ecosystem health and be used to improve our capacity to predict expected changes to reefs, mangroves and associated resources upon which coastal communities depend (Heck *et al.* 2008).

Chronic declines in inshore water quality in the Great Barrier Reef (GBR) since European settlement have led to dramatic ecological shifts in GBR marine ecosystems (De'ath and Fabricius 2010; Roff *et al.* 2013). Multiple stressors are the cause of this decline, including intensive use of the Reef 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) 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 has some seagrass present (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.

There are 15 species of seagrass in the GBR (Waycott *et al.* 2007). A high diversity of seagrass habitats 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 tropical seagrass ecosystems of the GBR are a complex mosaic of different habitat types comprised of multiple seagrass species (Carruthers *et al.* 2002) in which timing and mechanisms that capture their dynamism are relatively poorly understood. The seagrass ecosystems of the GBR, on a global scale, would be for the most part categorised as being dominated by disturbance opportunist species (e.g. *Halophila*, *Halodule* and *Zostera*) typically having 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 persistent species are found, although they are still relatively capable of being responsive to disturbance (Carruthers *et al.* 2002, Waycott *et al.* 2007, Collier and Waycott 2009).

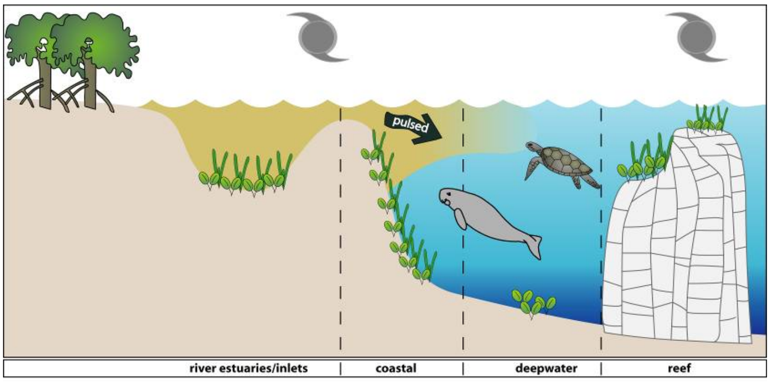

Figure 1. *General conceptual model of seagrass habitats in north east Australia (from Carruthers et al., 2002)*

The requirements for 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 *p*H (Waycott and McKenzie, 2010). As seagrasses are well recognised as integrators of environmental stressors, monitoring their status and trend can provide insight into the status of the surrounding environment (e.g. Dennison *et al.* 1997). In low nutrient, oligotrophic systems there is typically high light availability to the plants, while high nutrient, eutrophic ecosystems have 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 3) 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 3. *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	-
Chlorophyll concentrations	Rapid short term changes observed	Limited by species variable upper threshold	-
Production of reproductive structures	-	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.

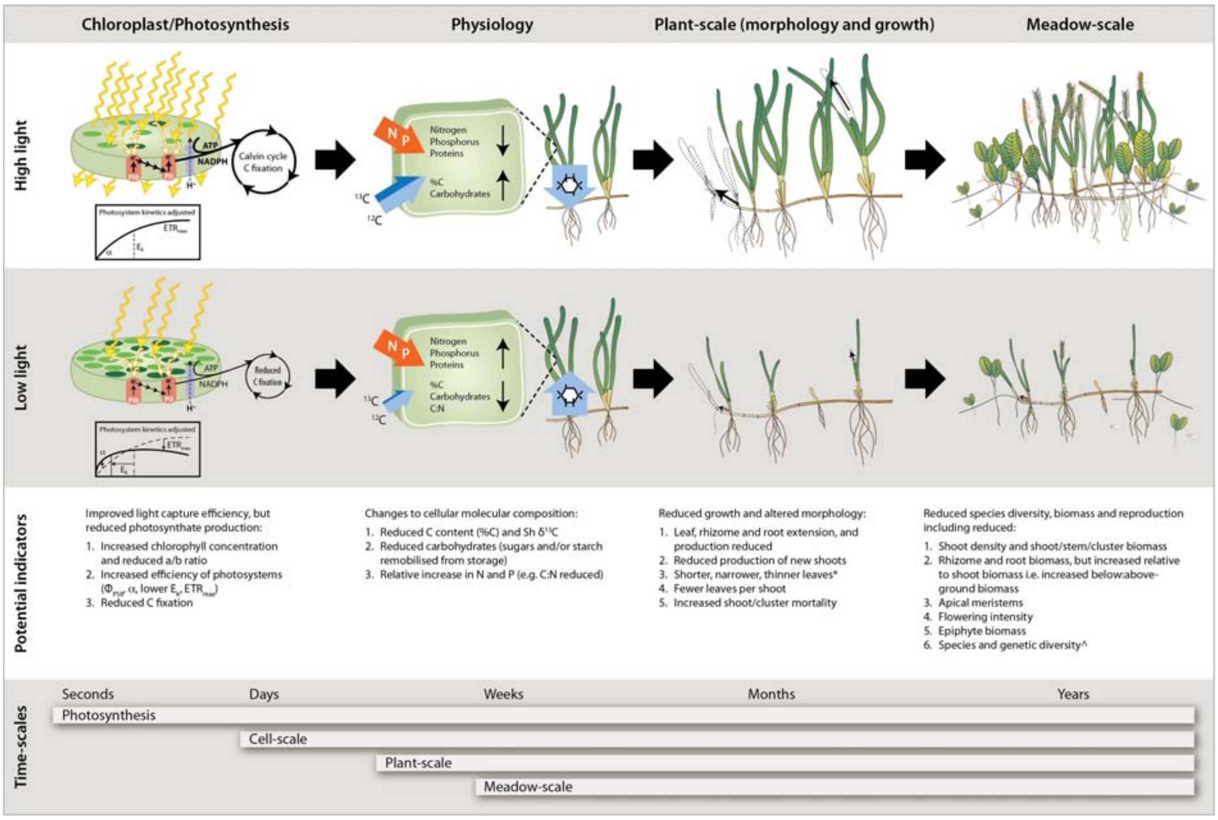

Figure 2. *Conceptual diagram of the current understanding of the of seagrass response pathway under low light conditions separated by photosynthetic, other physiological, plant-scale (growth and morphology) and meadow-scale variables. The timescales at which the responses to light reduction generally 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 ninth period of monitoring inshore seagrass ecosystems of the Great Barrier Reef under the MMP (undertaken from June 2012 to May 2013; hereafter called “2012-13”).

2. Methodolgy

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 a separate report, updated in May 2014 (McKenzie *et al.* 2014).

Sampling design & site selection

The sampling design was selected for the detection of change in inshore seagrass meadows in response to improvements in water quality parameters associated to 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 (previously know as the Reef Plan), that existing long-term monitoring programs (e.g. Seagrass-Watch) and legacy sites provided an excellent opportunity on which the inshore seagrass monitoring component could be based. In late 2004 all data collected within the GBR region as part of existing monitoring programs were supplied to Glenn De'ath (Senior Statistician, AIMS) for independent review. De'ath (2005) examined the available datasets to estimate expected performance of the monitoring program. Seagrass data included from 2000–2004 was collected from 63 sites in 29 locations from Cooktown to Hervey Bay. Results concluded that the existing 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.* 1997, Lee Long *et al.* 1998; McKenzie *et al.* 2000; Rasheed *et al.* 2003; Campbell *et al.* 2002; Goldsworthy 1994)
2. sampling locations where possible include 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).

To account for spatial heterogeneity of meadows within habitats, two sites were selected at each location. Meadows were selected using mapping surveys across the regions prior to site establishment. 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). Ideally mapping was conducted immediately prior to site positioning, however in most 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).

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 Rescue 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) and sub littoral (permanently covered with water). This limited monitoring to the very low spring tides within small tidal windows (mostly 2-4hrs per day for 3-4 days per month for 6-8 months of the year). Traditional approaches using seagrass monitoring to assess water quality have been 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 ranges spanning 3.42m (Cairns) to 7.14m (Hay Point) (www.msq.qld.gov.au);
- a variety of 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 meadows 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). The foundation species were all di-meristematic leaf-replacing forms.

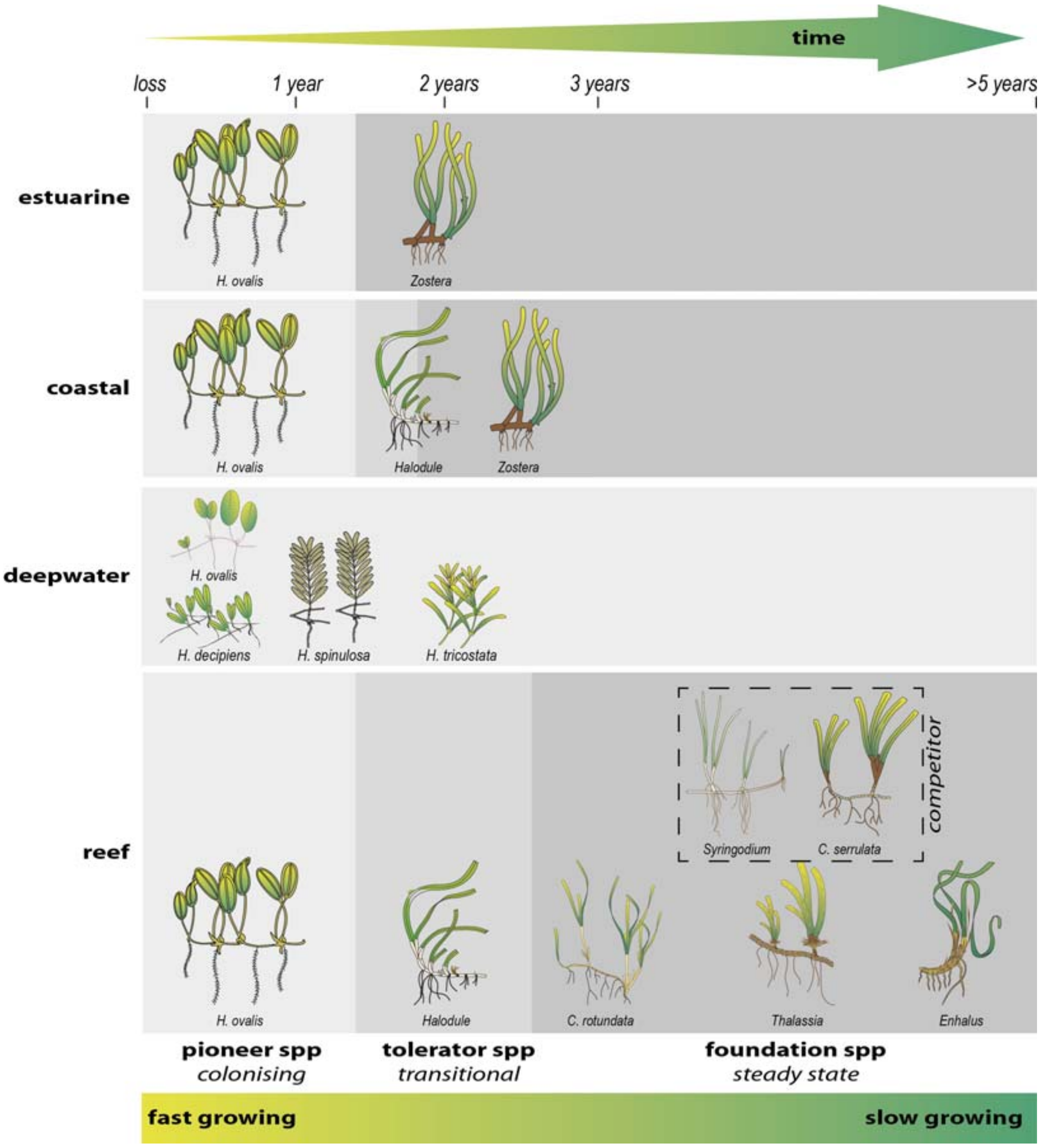

Figure 3. *Illustration of seagrass recovery after loss and the categories of successional species over time.*

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 2012-13 monitoring period (Table 5). This included seven coastal, five 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 5). 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 6. The seagrass species present at each monitoring site (including foundation seagrass species) is listed in Table 6.

Seagrass abundance, composition and distribution

Field survey methodology followed standardised protocols (McKenzie *et al.*, 2003). At each location, with the exception of subtidal sites, sampling included two sites nested 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 2012) and late monsoon (March/April 2013) of each year was conducted by a qualified and trained scientist. Monitoring conducted outside these periods was conducted by a trained scientist, 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. A total of 33 quadrats were sampled per site. Seagrass abundance 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 a 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).

Mapping the edge of the seagrass meadow within 100m of each intertidal monitoring site was conducted in the late dry and late monsoon monitoring periods. Edge mapping was used to determine if changes in seagrass abundance were the result of the meadow shrinking/increasing in distribution or the plant increasing/decreasing in density, or both. 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 with the traits that are thought to characterise *r*-selection are the generalist species - ruderal species or weeds - opportunistically colonising highly disturbed sites, common 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. 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 also 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 Figure 3 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 4), 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 4. *Long-term average proportion (±SE) of K-strategist species in each GBR seagrass habitat type. (refer Figure 3)*

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 5. *Reef Rescue 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*
		Endeavour	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*)	Mossman	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	Cairns *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 6. *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 (2012)							late monsoon Season (2013)						
					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	✓	✓	✓
		Endeavour	Cooktown	**AP1**	33	30	3	✓	15	✓		33	30	✓	15		✓	
				AP2	33	30	3	✓	15	✓		33	30	✓	15		✓	
Northern	Wet Tropics	Mossman	Low Isles	**LI1**	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
				LI2^	33	30	3	✓	15	✓	✓	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	3	✓	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	✓		33	30	✓	15		✓	
				WH1	33	30	3	✓	15	✓	✓	33	30	✓	15		✓	✓
			Great Keppel .	**GK1**	33	30	3	✓	15	✓		33	30	✓	15		✓	
				GK2	33	30	3	✓	15	✓		33	30	✓	15		✓	
		Boyne	Gladstone	**GH1**	33	30		✓	15	✓		33*	30*	✓	15		✓	
				GH2	33	30		✓	15	✓		33*	30*	✓	15			
	Burnett Mary	Burnett	Rodds Bay	**RD1**	33	30	3	✓	15	✓		33	30	✓	15		✓	
				RD2	33	30	3	✓	15	✓		33	30	✓	15		✓	
		Mary	Hervey Bay	**UG1**	33	30	3	✓	15	✓		33	30	✓	15		✓	
				UG2	33	30	3	✓	15	✓		33	30	✓	15		✓	✓

Table 7. *Presence of foundation (■) and other (□) seagrass species in monitoring locations sampled in Reef Rescue 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*	*H. decipiens*	*H. ovalis*	*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	■			□	■	□	■	
	Endeavour	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				□*				■

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

Seagrass reproductive health

Seagrass reproductive health was assessed from samples collected in the late dry 2011 and late monsoon 2012 at locations identified in Table 6. Samples were processed according to standard methodologies (McKenzie *et al.* 2010a).

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 sample 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.

Seagrass tissue nutrients

In late dry season (October) 2012, foundational seagrass species leaf tissue nutrient samples were collected from each monitoring site (Table 6, Table 7). 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 mean 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). N:P values in excess of 30 may potentially indicate P-limitation and less than 25 are 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 ($\delta^{15}N$ and $\delta^{13}C$).

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 ($\delta^{15}N$) 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 $\delta^{15}N$ 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 $\delta^{15}N$ 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 $\delta^{15}N$ signatures (i.e. $\delta^{15}N$ ~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 $\delta^{15}N$ 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 ($\delta^{15}N$ ~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. $\delta^{13}C$) 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 (more negative) isotopic enrichment: i.e. low %C, low C:N, less negative $\delta^{13}C$, may indicate that light is limited (Grice*, et al.* 1996; Fourqurean *et al.* 2005).

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 (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 (particularly during the growing season when leaf turnover is high) 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 MMP and MTSRF did not identify threshold levels beyond which loss of abundance occurred (McKenzie 2008) suggesting further research and analysis.

Within seagrass canopy temperature

Autonomous iBTag™ submersible temperature loggers were deployed at all sites identified in Table 6. 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.

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 6). Detailed methodology for the light monitoring (including cosine correction factors) can be found in McKenzie*, et al.* 2010a. Measurements were recorded by the logger every 15 - 30 minutes (this is a cumulative reading over the time period by the sensor). 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 (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 (μmol 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 is I_d 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 8. *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**

Rhizosphere sediment herbicides

Sediment (approximately 250ml) for herbicide analysis was collected at selected monitoring sites in the Cape York and Burdekin regions (identified in Table 6). 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.

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.* 2014). As river discharge volumes are the foundation 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).

Data analyses

In this report results are presented to reveal temporal and spatial differences, however, detailed statistical analyses is restricted.

Due to the seagrass declines experienced over the last 3 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.

We are working with the CSIRO Mathematics, Informatics and Statistics section to more fully interrogate the temporal and covariate components of the data as the time series of observations lengthen. Limited statistical analysis is currently presented. 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.

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.

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 102).

Report card

Three indicators (presented as indexed 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
2. reproductive effort
3. nutrient status (seagrass tissue C:N ratio)

Seagrass abundance 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.

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).

Seagrass abundance

The status of seagrass abundance was determined using the seagrass abundance guidelines developed by McKenzie (2009). Individual site and subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on abundance 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 4).

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 (Figure 4).

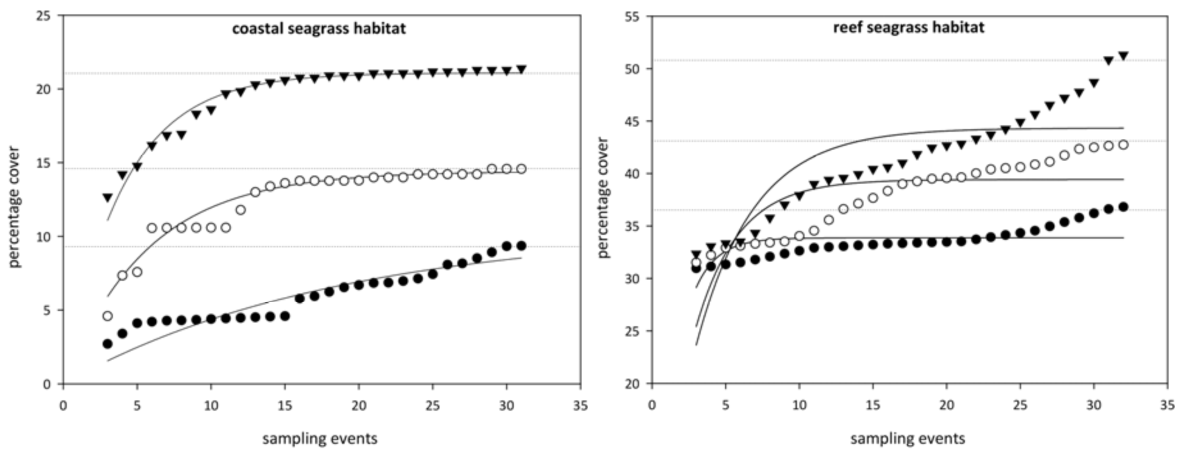

Figure 4. *Relationship between sample size and the error in estimation of percentile values for seagrass abundance (% cover) in coastal and reef seagrass habitats in the Wet Tropics NRM. ▼= 75th percentile, ○ = 50th percentile,● = 20th percentile. Dashed lines are asymptotic averages for each percentile 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, which is 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 5), it indicates that the meadows were in a poor condition in mid 2000, mid 2001 and mid 2006 (based on abundance).

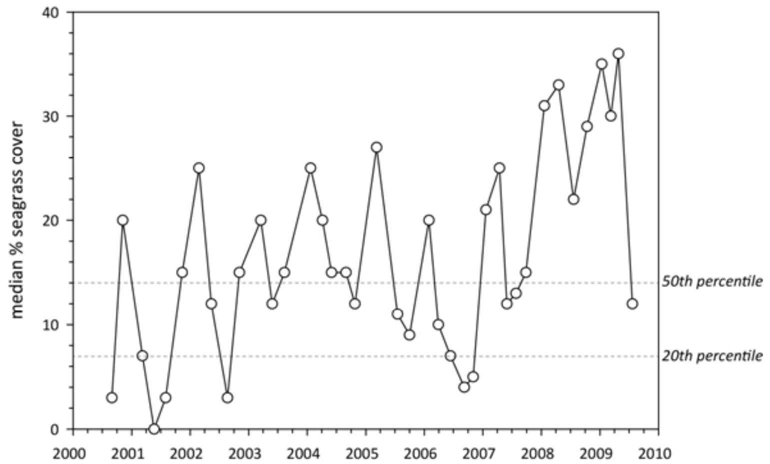

Figure 5. *Median seagrass abundance (% cover) at Yule Point plotted against the 50th and 20th percentiles for coastal seagrass habitat in the Wet Tropics.*

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) (Figure 6). 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.

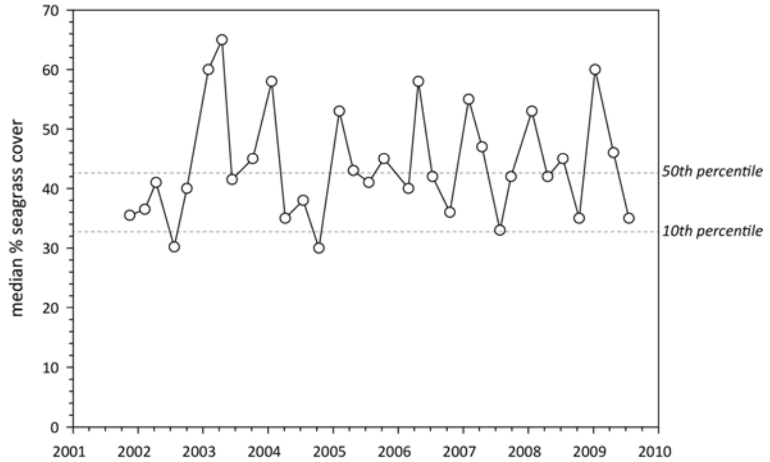

Figure 6. *Median seagrass abundance (% cover) at Green Island plotted against the 50th and 10th percentiles for intertidal reef seagrass habitat in the Wet Tropics.*

Using this approach, subregional seagrass abundance guidelines (hereafter known as "the seagrass guidelines") were developed for each seagrass habitat types where possible (Table 9). 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 then using the subregional guideline from the reference sites (i.e. as more guidelines are developed at the sites level, they contribute to the subregional guideline).

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 (Table 10). Please note that the scale from 0 to 100 has no units.

Table 9. *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	LB1	coastal intertidal		6.6	12.9	14.8
	LB2	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***
	DI1	reef intertidal	27.5		37.7	41
	DI2	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
	NRM	***reef intertidal***	***27.5***	***31.9***	***37.7***	***41.1***
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***
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 10. *Scoring threshold table to determine seagrass abundance status. low = 10th or 20th percentile guideline (Table 9)*

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

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 season 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 reproductive structures), the reproductive effort was scored as the number of reproductive structures per core and the overall status determined (Table 11) as the ratio of the average number observed in the 15 cores per site divided by the long term average for that habitat.

Table 11. *Scores for late dry monitoring period reproductive effort average against long-term (2005-2009) GBR habitat average.*

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

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 (*Zostera muelleri, Syringodium isoetifolium, Halodule uninervis, Halopihla spinulosa, Cymodocea serrulata*) 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:

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 12).

Table 12. *Scores for leaf tissue C:N against guideline to determine light and nutrient availability.*

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

Seagrass index

The seagrass index is the average scores (0-100) of the three seagrass status indicators chosen for the Reef Rescue MMP. Each indicator is equally weighted as we have no preconception that it should be otherwise. To calculate the overall score for all seagrass of the Great Barrier Reef (GBR), the six regional scores were weighted on the percentage of GBRWHA seagrass (shallower than 15m) within that region (Table 13). *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 13. *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

GBR Summary

The greatest extent of seagrass in the GBRWHA are located in the deeper waters (>15m) of the lagoon (Coles *et al.* 2009a), however, these meadows are relatively sparse, structurally smaller, more 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, are of higher fisheries importance, and are 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 ±1.8% for estuarine, 16.5 ±1.9% for coastal, and 22.7 ±2.4% for reef (McKenzie *et al.* 2012c). After the extreme weather events of 2011, the abundances of GBR inshore seagrass were the lowest recorded since monitoring was established. In the 2012-13 monitoring period, although the overall seagrass score increased (Figure 7), 63% of the MMP sites examined remained classified as poor or very poor in abundance (below the guidelines) in late monsoon 2013; with an annual average abundance (all sites and sampling events) of 6.8 ±2.5% for estuarine, 11.7 ±1.6% for coastal, and 14.1 ±3.7% for reef. The only region where seagrass abundance did not change in 2012-13 from the previous monitoring period was the Fitzroy NRM. Otherwise, abundances improved in both coastal and estuarine habitats across the GBR; with greatest increases at coastal sites. There was also an overall increase of 19% in meadow extent summed over all the monitoring sites in 2012-13.

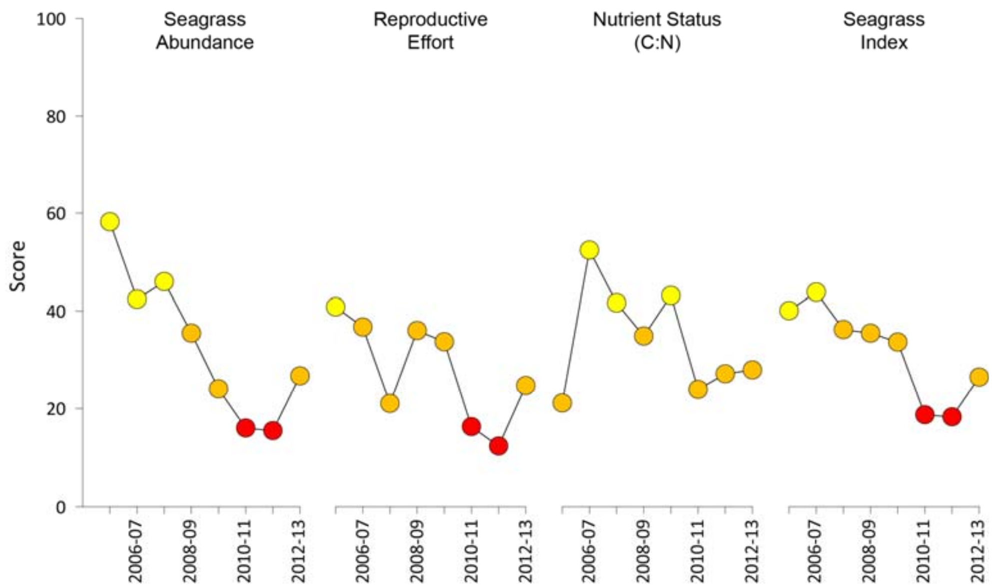

Figure 7. *GBR report card scores (regions pooled) for each indicator and total seagrass index over the life of the MMP. Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

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, over the last two monitoring periods, meadows monitored in the GBR have undergone a state change being dominated by a greater than average proportion of colonising or *r*-strategist seagrass species. The smaller seeds banks and low reproductive effort in reef habitats suggests a low capacity to recover following disturbance and they may be vulnerable to repeated impacts.

Variable and overall poorer light conditions in 2012-13 (i.e. below the long-term average) may have created stress to the plants, possibly slowing recovery. Although light availability was higher at reef than coastal habitats, light availability generally improved in the northern GBR and was more variable in the southern GBR.

Seagrass leaf tissue nutrients for foundation species across the majority of GBR habitats and locations in late 2012 suggested P and N surplus to C requirements. There was a marginal improvement in leaf tissue C:N:P ratios in 2012 compared to 2011 (Figure 7). The high tissue nutrient concentrations measured across most coastal locations were likely a consequence of the elevated N, where the primary source of N was either from sewage or fertiliser.

Epiphyte cover on seagrass leaves was variable across GBR habitats in 2012-13, either increasing above or remaining at long-term averages in estuary and coast meadows. Epiphyte cover at reef habitats was lower in 2012-13. Macroalgae abundance was low and changed little during 2012-13.

Seawater temperatures within the meadows were slightly cooler than the long-term average in 2012-13, and the only location to experience extreme seawater temperatures was Shoalwater Bay (40.7°C). The number of days when seawater temperatures exceed 35°C in 2012-13 was higher in the Wet Tropics, than Fitzroy, Burdekin, Cape York, Burnett Mary and Mackay Whitsunday regions respectively.

Rainfall across the GBR was variable, however, discharges from rivers were all above median for the southern regions (Mackay Whitsunday, Fitzroy and Burnett Mary). Also, in the southern regions, the number of days with winds >25 km.hr^{-1} was high enough to have created periods of both physical disturbance and light limitation for large portions of the year.

Across the GBR NRM regions, the seagrass report card scores improved during 2012-13 in Cape York, Burdekin and Mackay Whitsunday, remained relatively unchanged in Wet Tropics, and declined in Fitzroy and Burnett Mary (Figure 8).

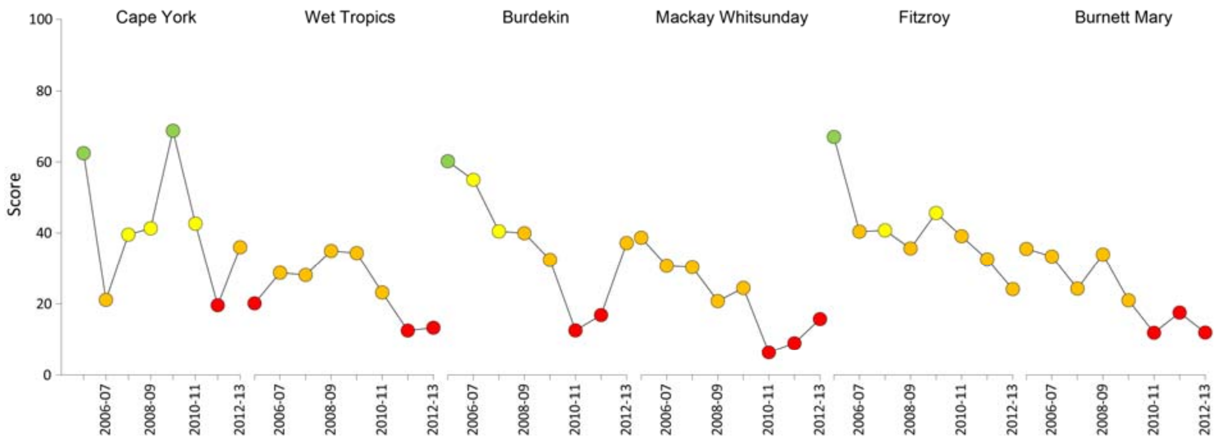

Figure 8. *Report card of seagrass index/status for each NRM region (averaged across indicators). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Table 14. *Report card for seagrass status for the GBR and each NRM region: June 2012 – May 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). NB: scores are unitless.*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	21	50	37	36
Wet Tropics	17	0	23	13
Burdekin	34	50	27	37
Mackay Whitsunday	14	17	16	16
Fitzroy	31	0	41	24
Burnett Mary	6	0	30	12
GBR	27	25	28	**26**

Status of the seagrass community

Of the 30 long-term intertidal monitoring sites examined across the GBR in 2012-13, seagrass abundance at 70% of sites were classified as poor or very poor (below the seagrass guidelines) in late monsoon 2013. Based on the average score against the seagrass guidelines (determined at the site level), the abundance of seagrass in the GBR over the 2012-13 period was classified as **poor** (all sites and seasons pooled) (Figure 9). Seagrass abundance at the MMP monitoring sites had been declining since 2005-06 until 2012-13, when abundances increased (Figure 9).

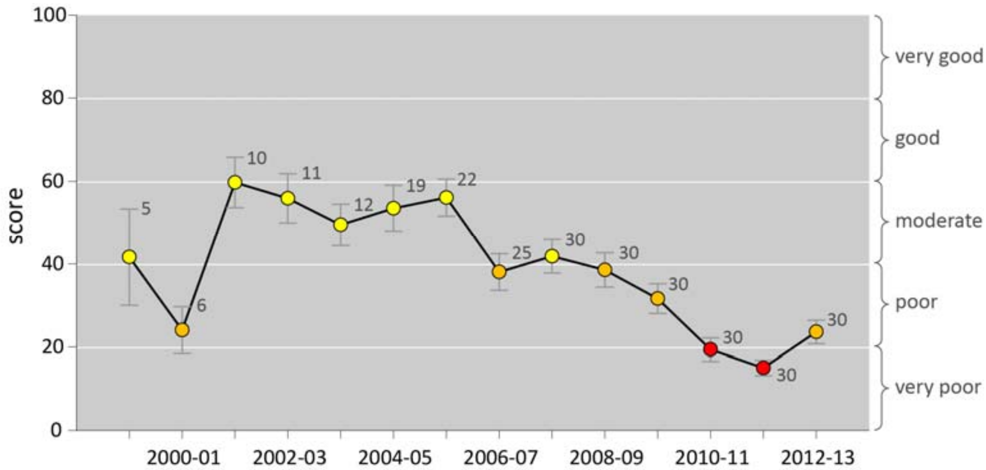

Figure 9. *Average seagrass abundance score (all sites and seasons pooled) for the GBR (±Standard Error) for each monitoring period from 1999 to 2013. Median percentage cover at a site for each monitoring event was scored relative to each site's guideline value, taking into account species and habitat. NB: only includes long-term sites; sites established in 2012 excluded. Numbers indicate total sites contributing to the score. Score is unitless.*

With the inclusion of the additional recently established intertidal sites in Cape York and Burdekin, seagrass abundance across the GBR was slightly improved with 63% of sites being classified as poor or very poor (below the seagrass guidelines) in late monsoon 2013. GBR seagrass abundance status increased above very poor in 2012-13 for the first time in three years (Table 15). The only region where seagrass abundance did not change in 2012-13 from the previous monitoring period was the Fitzroy NRM (Figure 10). Otherwise, abundances improved in both coastal and estuarine habitats across the GBR; with greatest increases in coastal habitats. With the exception of the Burdekin NRM, abundances at reef habitats decreased in 2012-13 from the previous monitoring period.

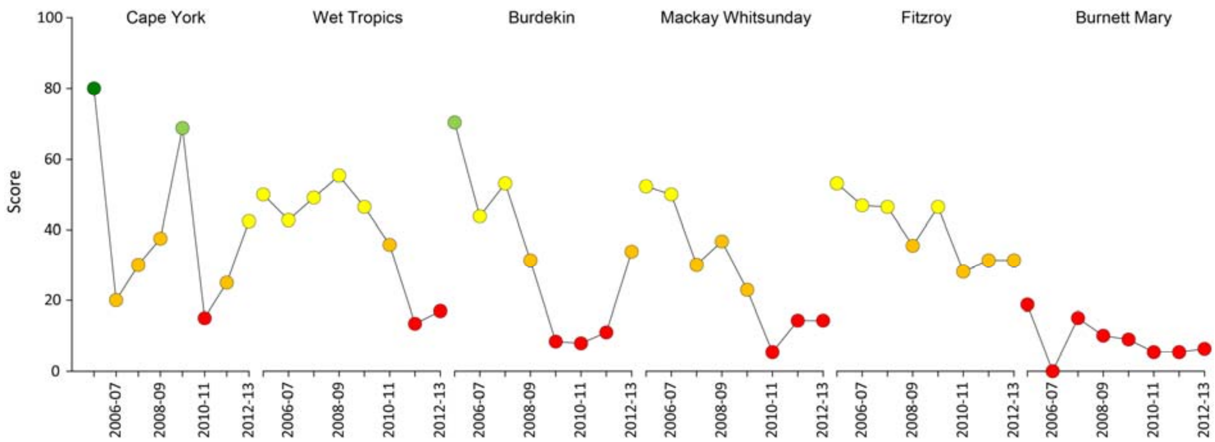

Figure 10. *Regional report card scores for seagrass abundance over the life of the MMP (includes new sites established in 2012 in the Cape York and Burdekin regions). For Paddock to Reef reporting scores are categorised in to a five point scale; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Table 15. *Long-term report card for seagrass abundance status for each habitat in each NRM region: July 2005 – May 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 13).*

NRM region	Habitat	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012-13
Cape York	reef intertidal	80	20	30	38	69	15	25	22
	coastal intertidal								81
Wet Tropics	reef intertidal	72	58	43	41	39	25	20	21
	coastal intertidal	38	32	55	70	54	46	7	13
Burdekin	reef intertidal	59	59	75	38	6	9	19	41
	coastal intertidal	81	28	31	25	11	6	3	29
Mackay Whitsunday	reef intertidal	0	25	6	13	6	6	13	0
	coastal intertidal	63	88	54	63	56	8	17	17
	estuarine intertidal	40	25	20	25	6	0	13	25
Fitzroy	reef intertidal	0	0	13	6	6	13	6	6
	coastal intertidal	81	81	100	75	81	31	25	25
	estuarine intertidal	25	13	44	25	50	34	47	47
Burnett Mary	estuarine intertidal	19	0	15	10	9	5	5	6
Great Barrier Reef		**58**	**42**	**46**	**35**	**24**	**16**	**15**	**27**

Long-term total seagrass abundance (percent cover) across the inshore GBR was generally higher in reef than coastal and estuarine habitats (Figure 11). Over the past decade, the patterns of seagrass abundance in each GBR habitat have differed (Figure 12), however both reef and coastal habitats show declining trajectories from 2009 to 2011. Seagrass abundance has fluctuated in estuarine habitats; most often as a response to climate (e.g. rainfall, temperature and desiccation) and at smaller localised scales there have been some acute event related changes (McKenzie*, et al.* 2012c).

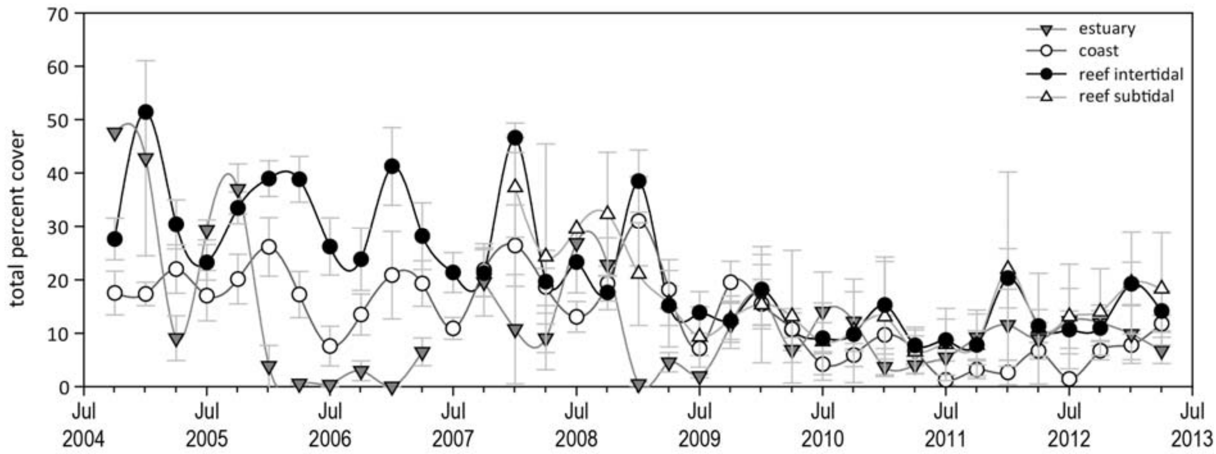

Figure 11. *Seagrass percent cover for each GBR habitat (locations pooled) across all sampling events from late dry 2004 to late monsoon 2013.*

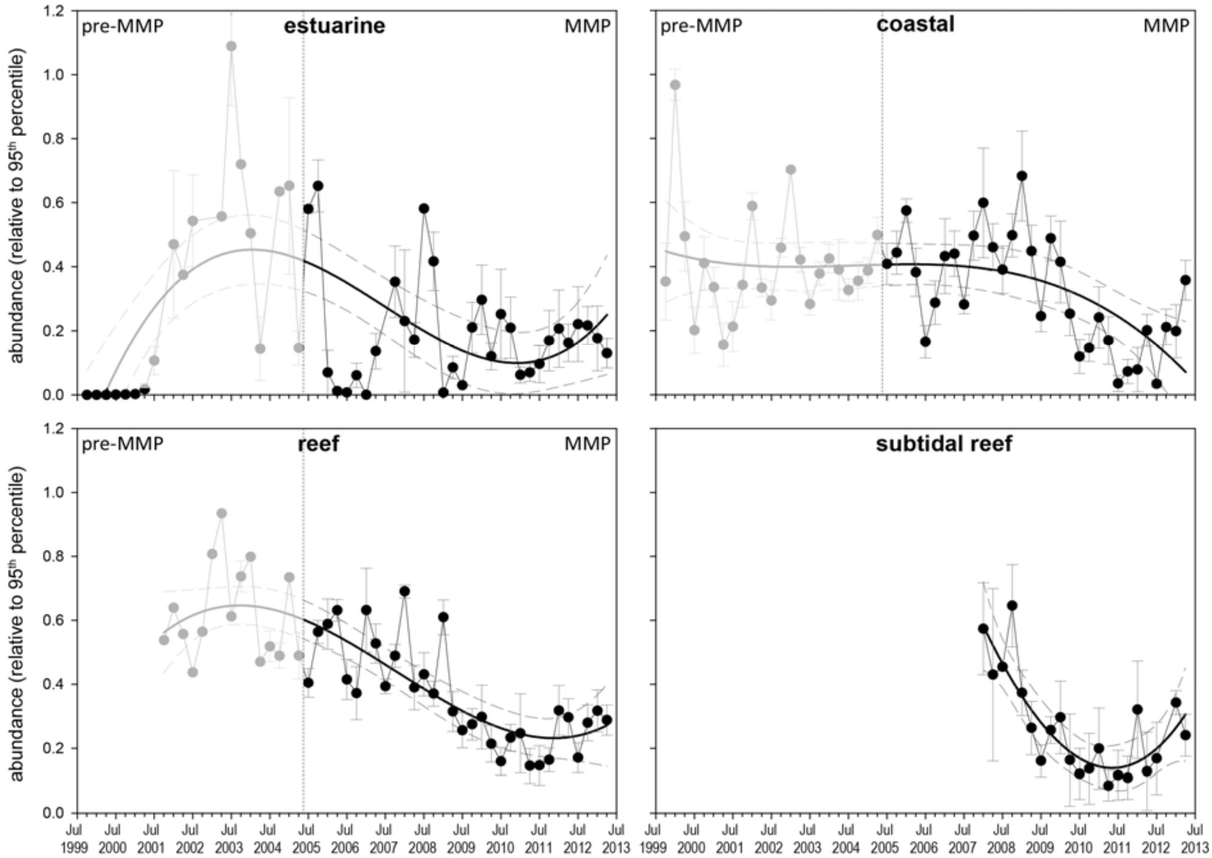

Figure 12. *Generalised trends in seagrass abundance for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data. Data prior and post implementation of the RRMMP displayed. Trendline is 3rd order polynomial, 95% confidence intervals displayed, estuarine (8 sites) r^2 = 0.35, coastal (16 sites) r^2 = 0.26, reef (17 sites) r^2 =0.67, subtidal reef (4 sites) r^2 =0.72.*

Over the last two monitoring periods, increases in seagrass meadow extent appears primarily a consequence of the proliferation of *r*-strategist (colonising) seagrass species such as *Halophila ovalis*, rather than recovery of K-strategist (foundation) species (Figure 13).

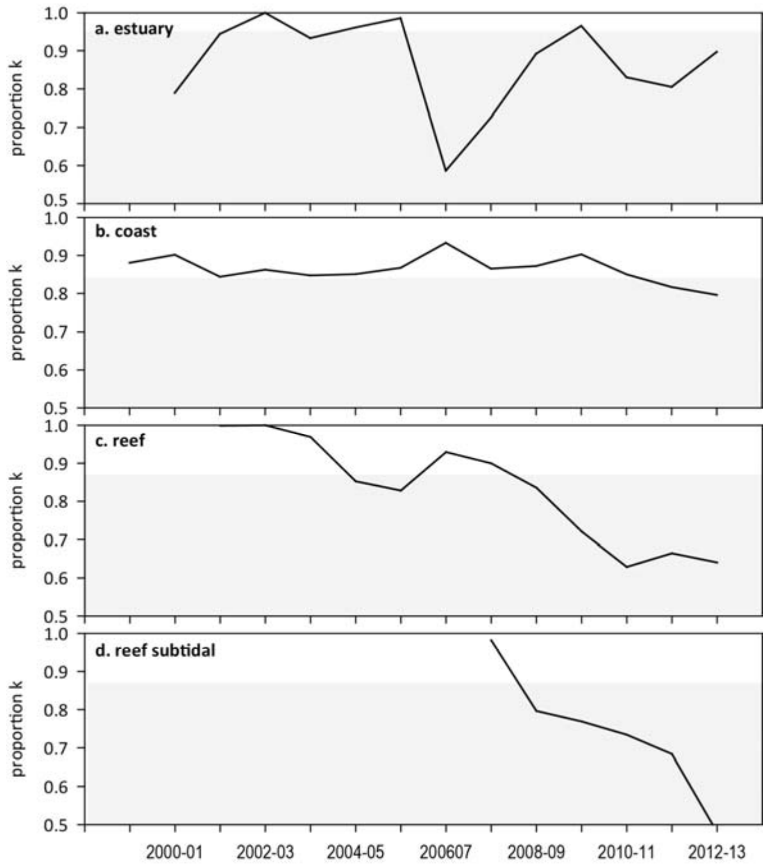

Figure 13. *Proportion of total seagrass abundance composed of K-strategist (foundation) species in a) estuary intertidal, b) coastal intertidal, c) reef intertidal and d) reef subtidal habitats (sites pooled) for the GBR (regions pooled) each monitoring period.*

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 the long-term in estuary than coastal and reef habitats (Figure 14). Reproductive effort increased in 2012-13 relative to the previous year and was higher in reef and coastal habitats (respectively) than estuary (Figure 14).

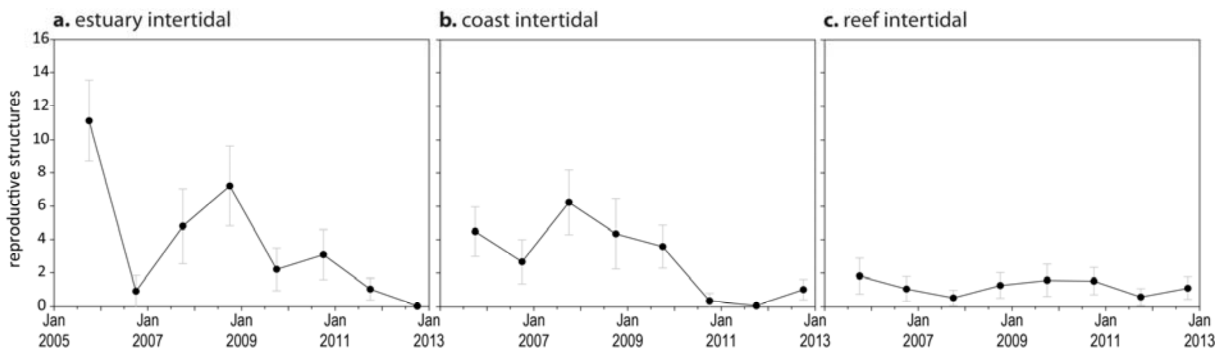

Figure 14. *Seagrass reproductive effort (number of reproductive structures produced by any seagrass species) during the late dry of each monitoring period, for a) estuary; b) coast; and c) reef.*

The only increases in reproductive effort observed across the GBR NRM regions was in the Burdekin and Mackay Whitsunday (Figure 15). With the exception of the Burdekin, reproductive efforts in all other regions was classified as very poor in 2012-13 (Figure 15).

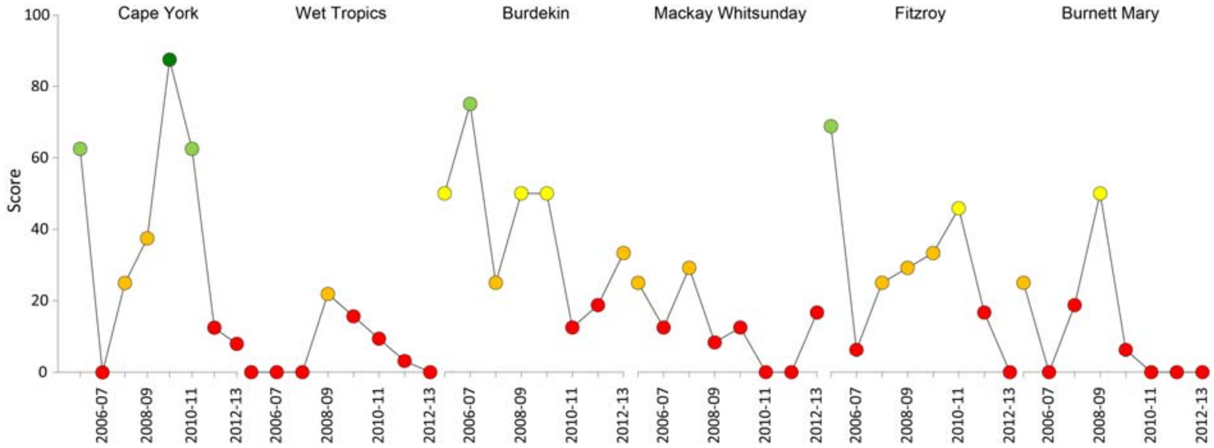

Figure 15. *Regional report card scores for seagrass reproductive effort over the life of the MMP (includes new sites established in 2012 in the Cape York and Burdekin regions). For Paddock to Reef reporting scores are categorised in to a five point scale; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Seed banks across the inshore GBR meadows were higher in late dry season and greater in coastal than reef or estuarine habitats over the long-term (8 years) (Figure 16). Coastal seed banks declined between 2008 and 2011, but have marginally increased since (Figure 16). This suggests that coupled with the increased reproductive effort, GBR coastal meadows in 2012-13 have a slightly improved capacity to recover from disturbances. Although a persistent *Zostera muelleri* seed bank in estuary habitats during 2012-13 suggests an improved capacity to recover from disturbances, the banks may become limited as a result of low reproductive effort and lack of replenishment.

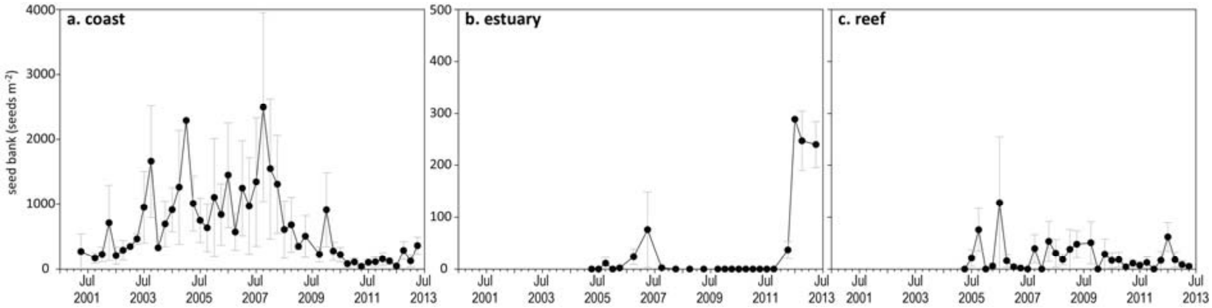

Figure 16. *Average seeds banks (seeds per square metre of sediment surface, all species pooled) in GBR seagrass habitats: a) coast; b) estuary and c) reef. Note: y-axis scale is same for panels b and c, which are both lower than panel a.*

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 7) to pool across foundation species as the presence of individual species was not 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 become apparent.

Tissue nutrient concentrations (%N and %P) have increased since 2006 across all habitats (species pooled) (Figure 17). The 2005 values may be unreliable due to contamination of the samples during the grinding phase (see McKenzie and Unsworth 2009) and should be interpreted with caution.

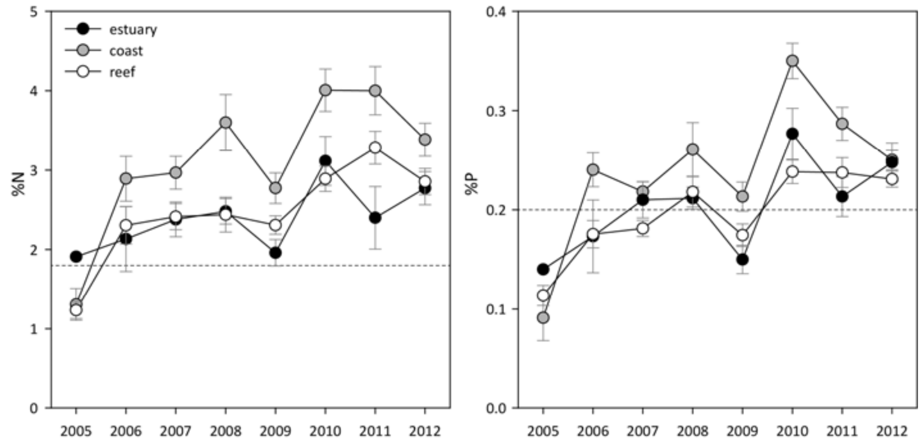

Figure 17. *Median tissue nutrient concentrations (±Standard Error) in seagrass leaves for each habitat type (species pooled) over the entire monitoring program. Dashed lines indicate global median values of 1.8% and 0.2% for tissue nitrogen and phosphorus, respectively (Duarte 1990).*

Since 2005, median tissue nitrogen concentrations for all habitats have exceeded the global value of 1.8% (Duarte 1990; Schaffelke *et al.* 2005) (Figure 17). Median tissue phosphorus concentrations for all habitats remained above the global value of 0.2% (Duarte 1990; Schaffelke*, et al.* 2005) in 2012, but continued to decrease in coastal habitats from the peak reported in 2010 (Figure 17). Duarte (1990) suggested tissue nutrient concentrations less that the global average implied nutrient limitation to seagrass growth. Although some concerns have been raised as to accuracy of the global tissue nutrient values (Schaffelke*, et al.* 2005), nitrogen and phosphorus concentrations for reef habitats reached their highest level in 2011 since monitoring commenced.

Experiments on seagrasses (*Zostera muelleri, Syringodium isoetifolium, Halodule uninervis, Halopihla spinulosa, Cymodocea serrulata*) in Queensland have suggested that at an atomic C:N ratio <20, may suggest reduced light availability (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 habitat types (coast, reef and estuary) had C:N ratios <20. These low C:N levels in 2012 potentially indicate either reduced light availability, but due to the increase in tissue %N, most likely indicate elevated N in the environment (Figure 18).

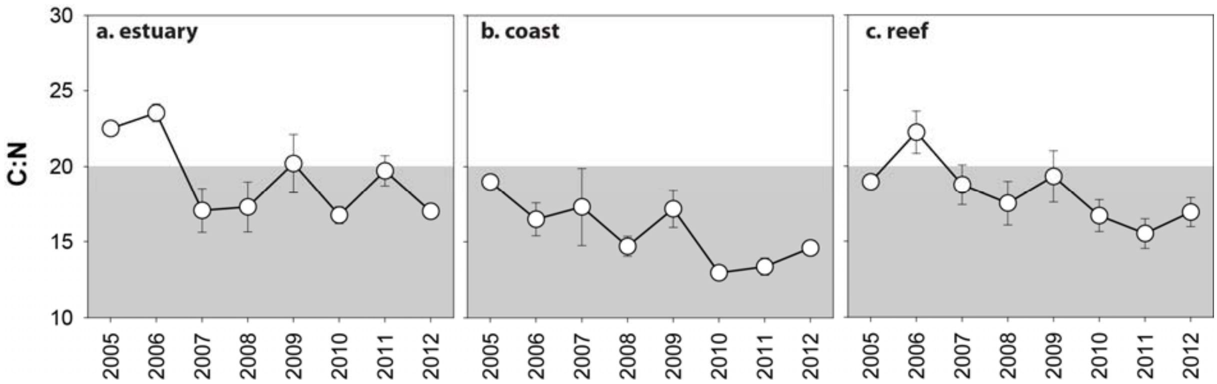

Figure 18. *Elemental ratios (atomic) of seagrass leaf tissue C:N for each habitat each year (foundation species pooled). Horizontal dashed line on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

Seagrass nutrient status scores (using only C:N) across the GBR NRM regions, improved in Cape York and Burdekin, but declined in Fitzroy and Burnett Mary from 2011 to 2012 (Figure 19). At the remaining NRM regions (Wet Tropics and Mackay Whitsunday), nutrient status scores remained relatively unchanged, while Mackay Whitsunday was the only region where nutrient status was very poor (Figure 19).

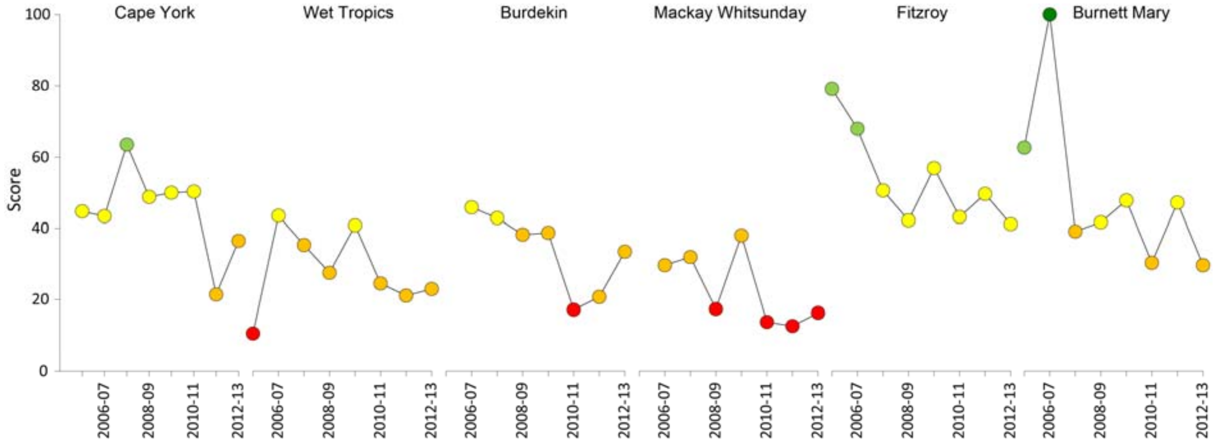

Figure 19. *Regional report card scores for seagrass leaf tissue nutrient status (C:N) over the life of the MMP (includes new sites established in 2012 in the Cape York and Burdekin regions). For Paddock to Reef reporting scores are categorised in to a five point scale; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Seagrass habitats across the GBR were consistently rich in nutrients relative to carbon with C:P ratios below 500, indicating a relatively large P pool (Figure 20). In 2012, N:P ratios in the leaf tissue changed little from the previous year across all habitats (Figure 20). 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. Leaf tissue molar N:P ratios remained above 30 in coastal habitats, which coupled with the low C:P ratios suggests elevated N in the environment. Conversely, the leaf tissue molar N:P ratios remaining below 25 in estuary habitats, suggests the enrichment in P remained greater than the N enrichment (Figure 20).

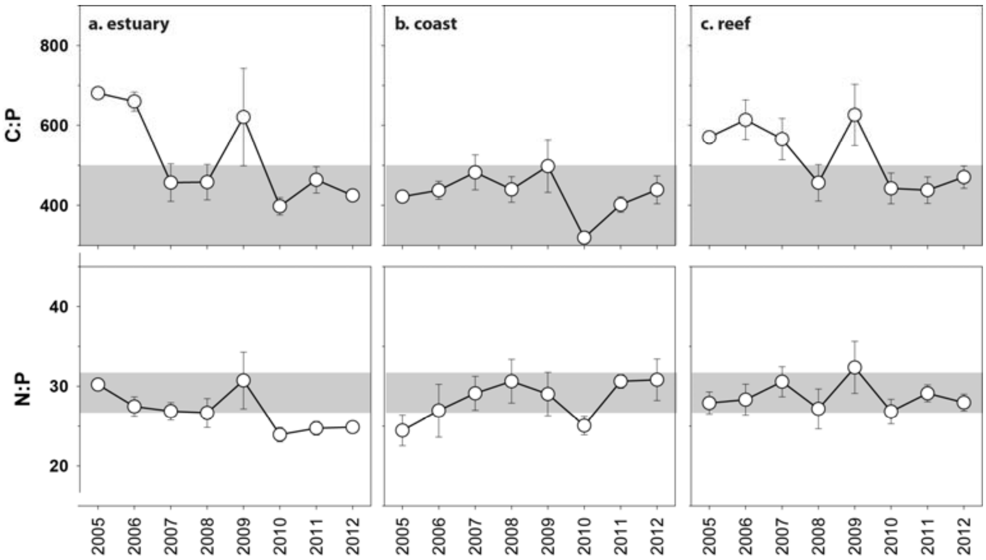

Figure 20. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for each habitat each year (foundation species pooled) (± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" 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).*

Across the majority of GBR habitats and locations, seagrass tissue nutrient concentrations for foundation species in late 2012 suggested P and N surplus to C requirements. The low C:N ratios measured across most locations was likely a consequence of the elevated N, where the low δ^{15}N value in the leaf tissue suggested that their primary source of N was either from fertiliser or sewage. At three locations (Magnetic Island, Hamilton Island and Urangan) the higher δ^{15}N values in the leaf tissue indicated some sewage influence. The δ^{13}C values were higher in reef habitats (both intertidal and subtidal), suggesting lower light availability in coastal and estuarine habitats (Figure 21).

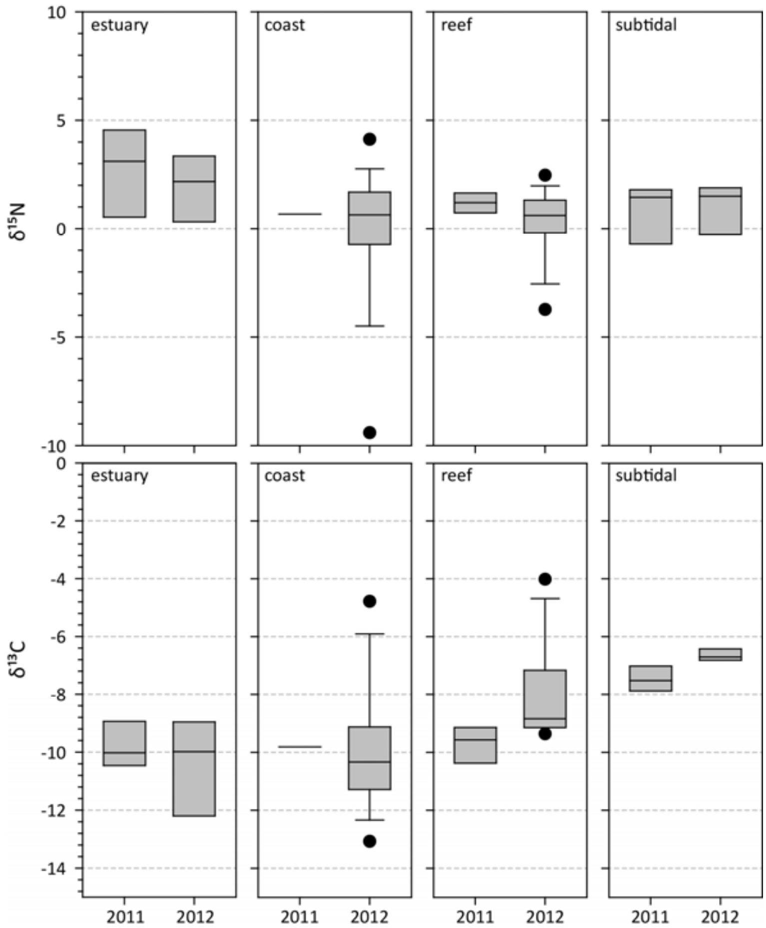

Figure 21. *Seagrass leaf tissue δ^{13}C and δ^{15}N concentrations from each GBR seagrass habitat (locations pooled) in the late dry 2011 and 2012. The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box 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 in estuary habitats was higher in the dry season than the wet and increased above the GBR long-term average in 2012-13 (Figure 22). Conversely, epiphyte cover was higher in the wet season in coastal habitats and although it decreased slightly in 2012-13, it remained above the GBR long-term average (Figure 22). Epiphyte cover at intertidal reef habitats remained below the GBR long-term average in 2012-13, and at subtidal habitats declined below the GBR long-term average for the first time in 4 years (Figure 22).

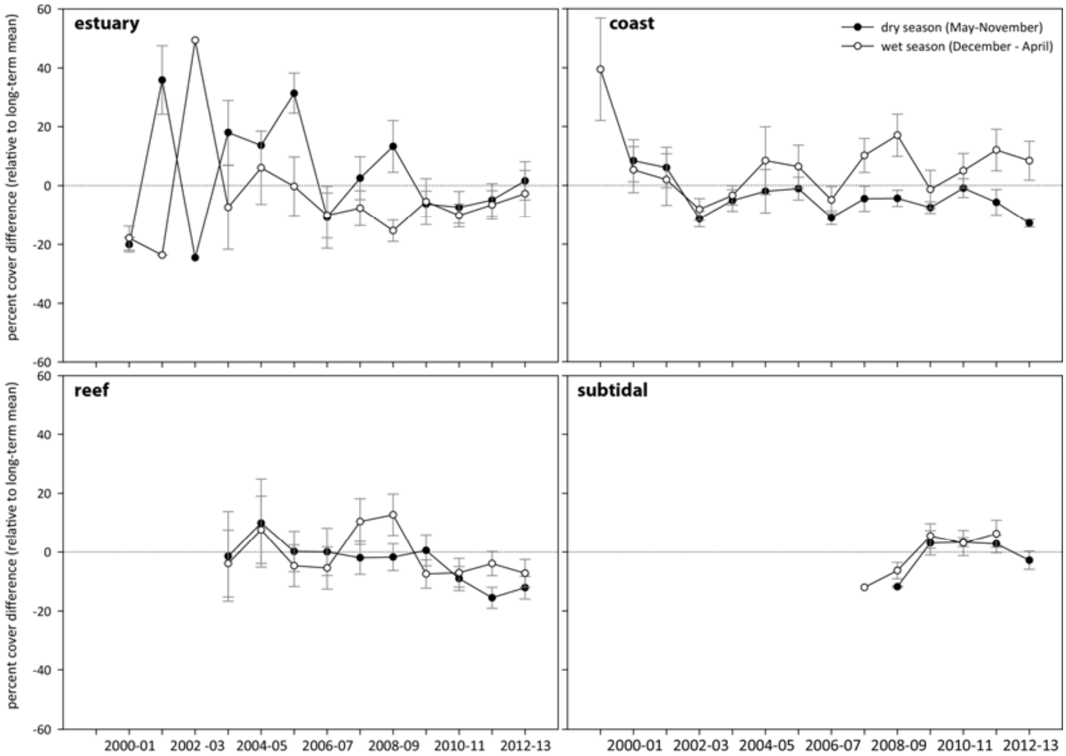

Figure 22. *Epiphyte abundance (% cover) relative to the long-term average for each GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 24.6% coastal=17%, reef = 28%, subtidal= 7.2%.*

Macroalgae abundance changed little and remained low either at or below the GBR long-term average during the 2012-13 monitoring period (Figure 23).

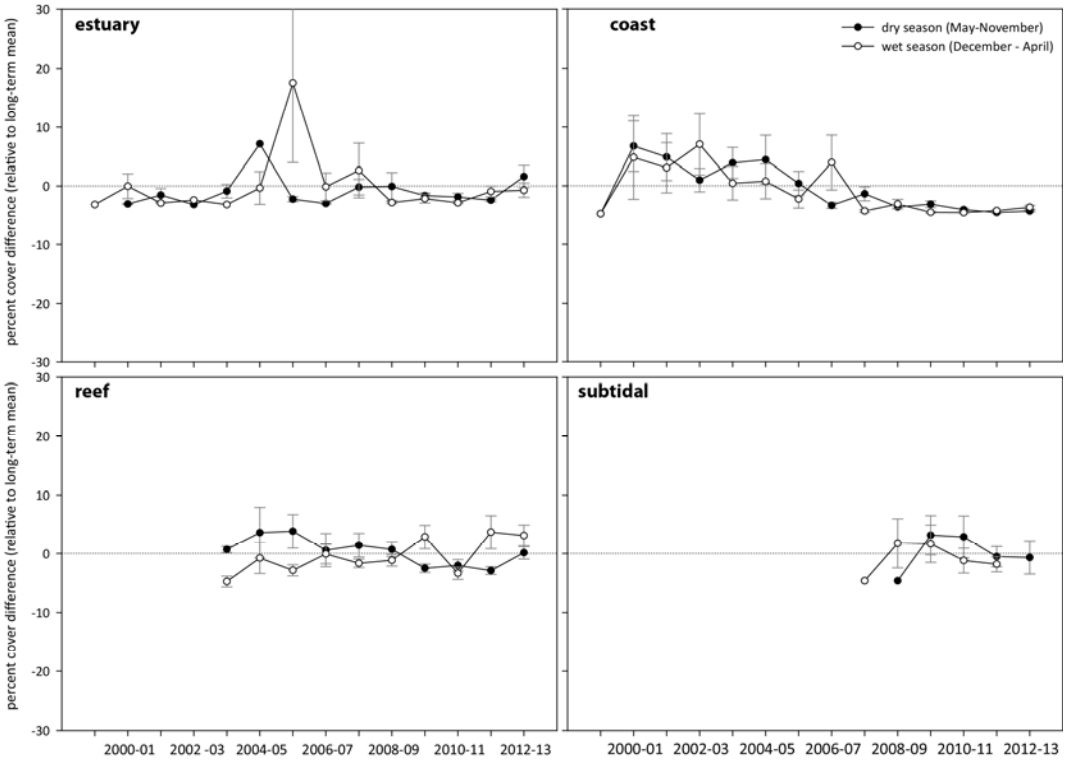

Figure 23. *Macroalgae abundance (% cover) relative to the long-term average for each inshore GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 3.2%, coastal=4.7%, reef = 6.2%, subtidal = 4.7%.*

Within canopy seawater temperature

Within seagrass canopy seawater temperature data were reported for the period of September 2003 to June 2013. Over the 2012-13 monitoring period, seagrasses in the Wet Tropics NRM region (all locations pooled) experienced a total of 54 days when sea temperatures exceeded 35°C. The GBR region with next highest days of exceedance was Fitzroy with 52 days. Only 6 days of seawater temperatures above 35°C were experienced in Mackay Whitsunday. The only region to experience extreme (>40°C) seawater temperatures in 2012-13 was the Fitzroy NRM region (40.7°C at Shoalwater Bay on 20 February 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 24).

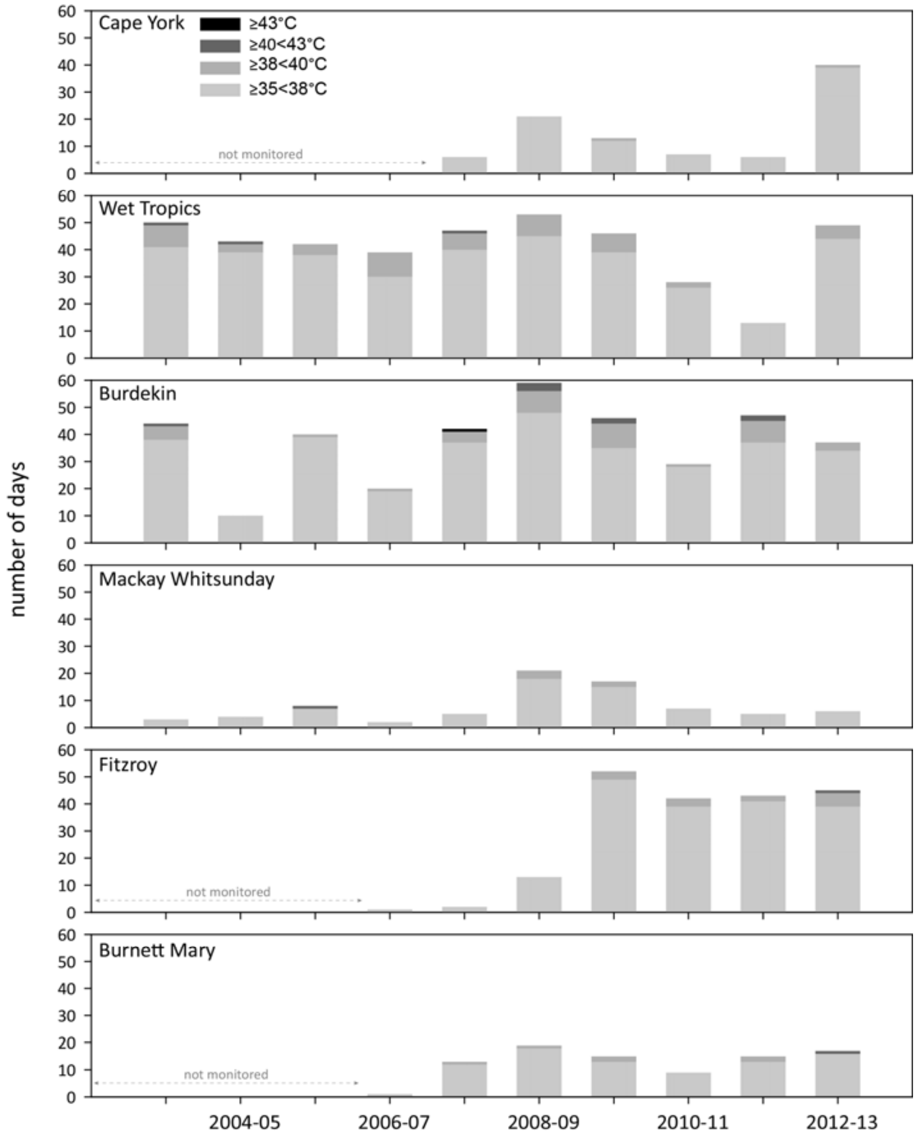

Figure 24. *Number of days when inshore sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region. Thresholds adapted from Campbell et al. 2006; Collier, et al. 2012b.*

Within canopy seawater temperatures have been slightly cooler than the long-term (10 year) average over the last 2 years (Figure 25). The warmest period since monitoring commenced was 2009-10 and the coolest was 2006-07 (Figure 25)

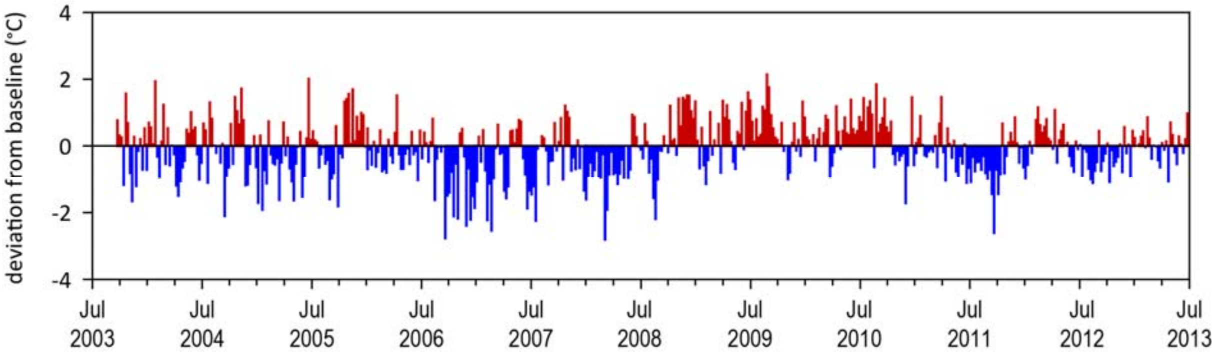

Figure 25. *Inshore sea temperature deviations from baseline for GBR seagrass habitats 2003 to 2013. Data presented are deviations from 10-year mean weekly temperature records (based on records from September 2003 to June 2013). Weeks above the long-term average are represented as red bars and the magnitude 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.*

Light and turbidity

Daily incident light (I_d, mol m^{-2} d^{-1}) reaching the top of the seagrass canopy in the GBR at lower littoral (intertidal) locations in 2012-13 (13.3 mol m^{-2} d^{-1}) was slightly lower than the long-term average (14.3 mol m^{-2} d^{-1}) (Figure 26). There was, however, some variability with northern locations in the Wet Tropics and Burdekin having higher than average light levels in 2012-13 compared to the long-term mean. The situation was uncertain at Dunk Island, as there was very poor data retrieval in 2012-13 (only 35% of days had data). At locations in the Mackay Whitsunday, Fitzroy and Burnett Mary NRM regions the trends were more variable, and I_d was generally lower in 2012-13 compared to the long-term mean (these locations all had shorter data records, being initiated in late 2009 or early 2010). Highest I_d occurred at the Green Island (18.4 mol m^{-2} d^{-1}) and Low Isles (17.9 mol m^{-2} d^{-1}) intertidal locations in the Wet Tropics, which is a change from previous years when Shoalwater Bay in the Fitzroy NRM region had recorded the highest I_d. The lowest I_d occurred at Pioneer Bay (5.4 mol m^{-2} d^{-1}) in the Mackay Whitsunday NRM region and at Bushland Beach (6.3 mol m^{-2} d^{-1}) in the Burdekin region, which is consistent with results from previous years. At subtidal locations (northern GBR only) in 2012-13 mean I_d was slightly higher (8.2 mol m^{-2} d^{-1}) compared to the long-term average (7.9 mol m^{-2} d^{-1}).

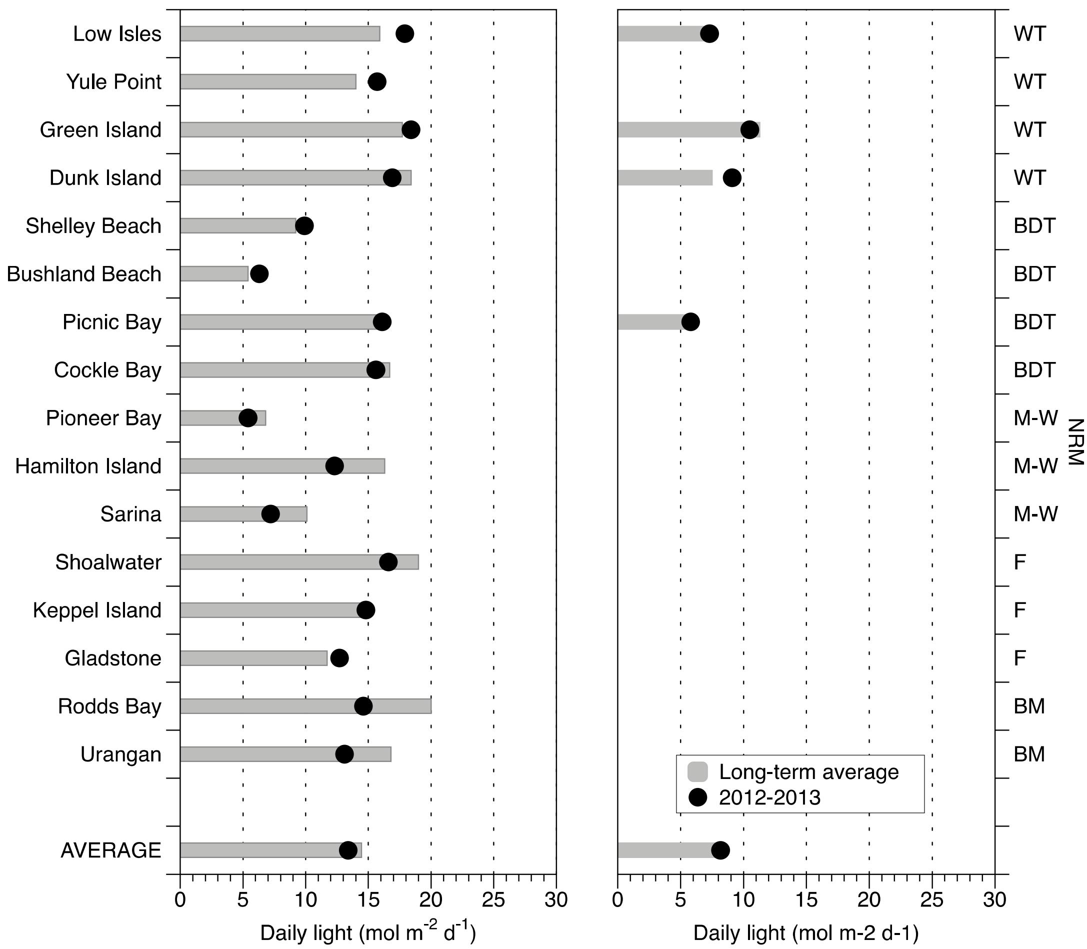

Figure 26. *Average daily light for all intertidal (left) and subtidal (right) sites including the long-term average and the value for the 2012-13 reporting period. NRM regions: WT= Wet Tropics, BDT = Burdekin; M-W = Mackay Whitsunday; F = Fitzroy; BM = Burnett Mary.*

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 locations is largely a reflection of location-specific differences in water quality. For example, turbidity at Green Island (1.24 NTU) was lower than at Picnic Bay (2.52 NTU) (Appendix 1, Figure 139), and these correspond to mean I_d in 2012-13 of 10.4 mol m^{-2} d^{-1} and 5.8 mol m^{-2} d^{-1} at the same locations, respectively (i.e. light is the inverse of turbidity). Turbidity data are not available for other seagrass monitoring locations. The spatial variability in I_d 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 locations (Schaffelke et al 2013) confirming the role of water quality in the observed patterns of canopy incident light.

Threshold exceedance (number of days <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 (Figure 27). At intertidal locations, thresholds were exceeded on fewer days (14% of days) compared to the long-term mean (18% of days) and for subtidal locations in 2012-13 threshold exceedance was also lower in 2012-13 (24% days) compared to the long-term mean (31% of days). This indicates that there were fewer days of very low light levels, and these very low light levels were the conditions associated with seagrass loss in the years 2008-2011 (Collier et al 2012). Regional trends were similar to those for I_d (see above) with comparisons to long-term trends indicating that exceedance was relatively more improved for northern locations, and more variable at southern locations.

Long-term trends for all GBR locations combined demonstrate that the peak in canopy light occurs in September to December as incident solar irradiation reaches its maximum. Light levels during this period were lower than in 2012-13 than the 2011-12 year during September to December (Figure 28). The lowest light levels often occur in the wet season, in particular during January to April and in 2012-13, these light levels were not as low as those seen in previous years. A break-down of long-term trends by habitat (Figure 29) demonstrates that the GBR-wide trends were most pronounced for the reef habitats (intertidal and subtidal). Light levels in estuarine habitats, in particular, and also coastal habitats are more variable, and these inter-annual differences in daily light were more pronounced.

Daily light levels in the dry season (May-October, as per water quality definition, Shaffaelke et al 2013) and the wet season (November to April) were not vastly different (Figure 30). This is likely due to the very high light levels occurring in November and December, which falls within the "wet season" according to this classification. When grouped this way, these high light levels mask the lower levels occurring in January-April, which also fall within the wet season.

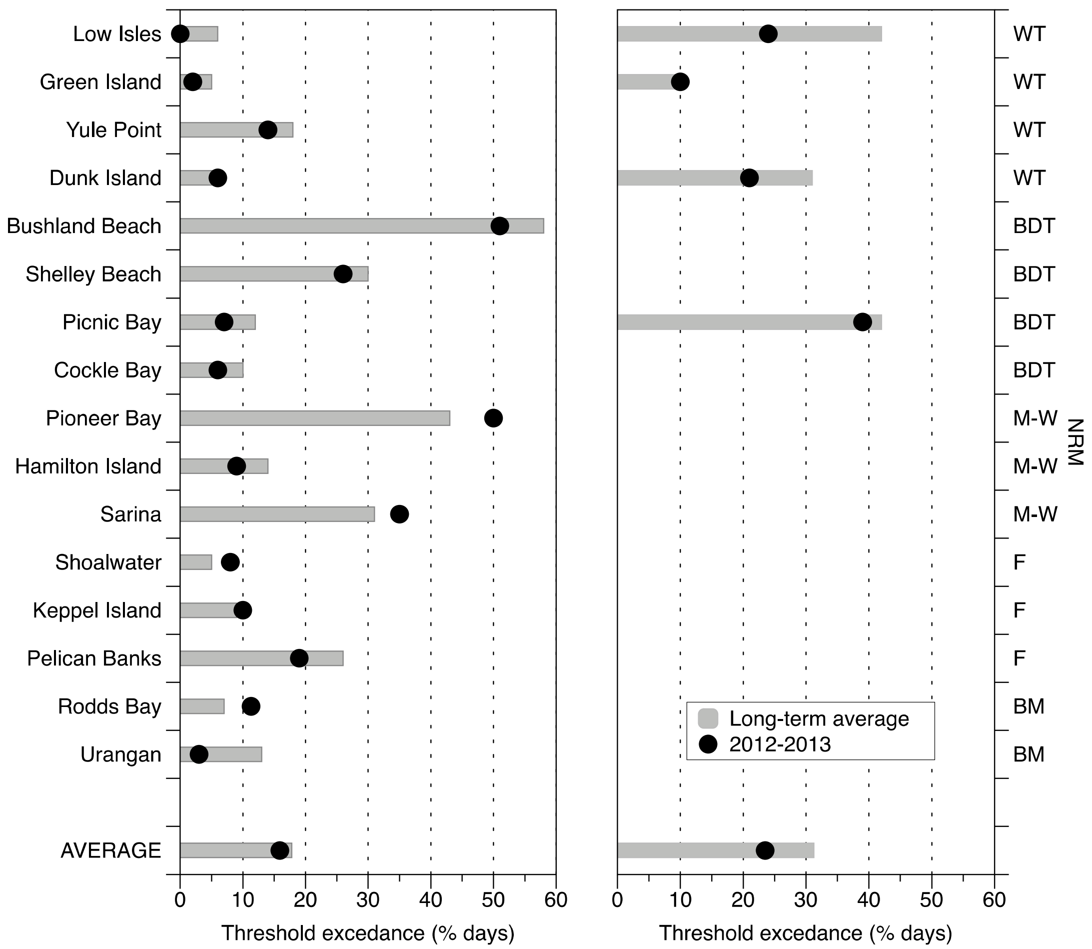

Figure 27. *Threshold exceedance for all intertidal (left) and subtidal (right) locations including the long-term average and the value for the 2012-13 reporting period. Thresholds adapted from Collier, et al. 2012b for northern GBR* Halodule uninervis *dominated meadows and Chartrand, et al. 2012 for southern GBR* Zostera muelleri *dominated meadows.*

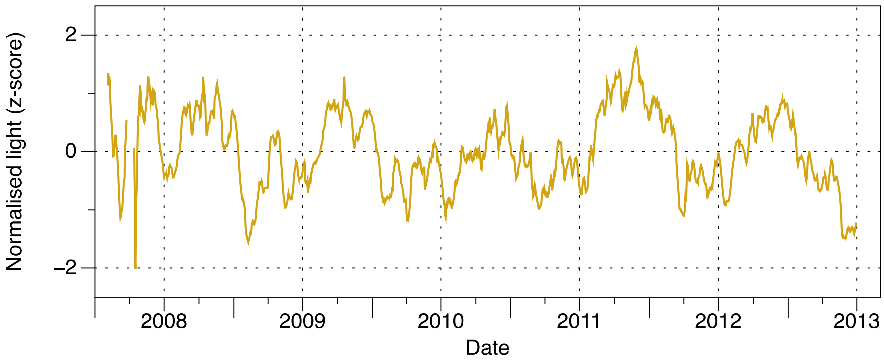

Figure 28. *GBR-wide (locations pooled) normalised daily light data (28-day rolling average). Daily light data were z-score transformed for each site and then averaged (mean) across all sites in the GBR. X-axis marks 1st January for each year.*

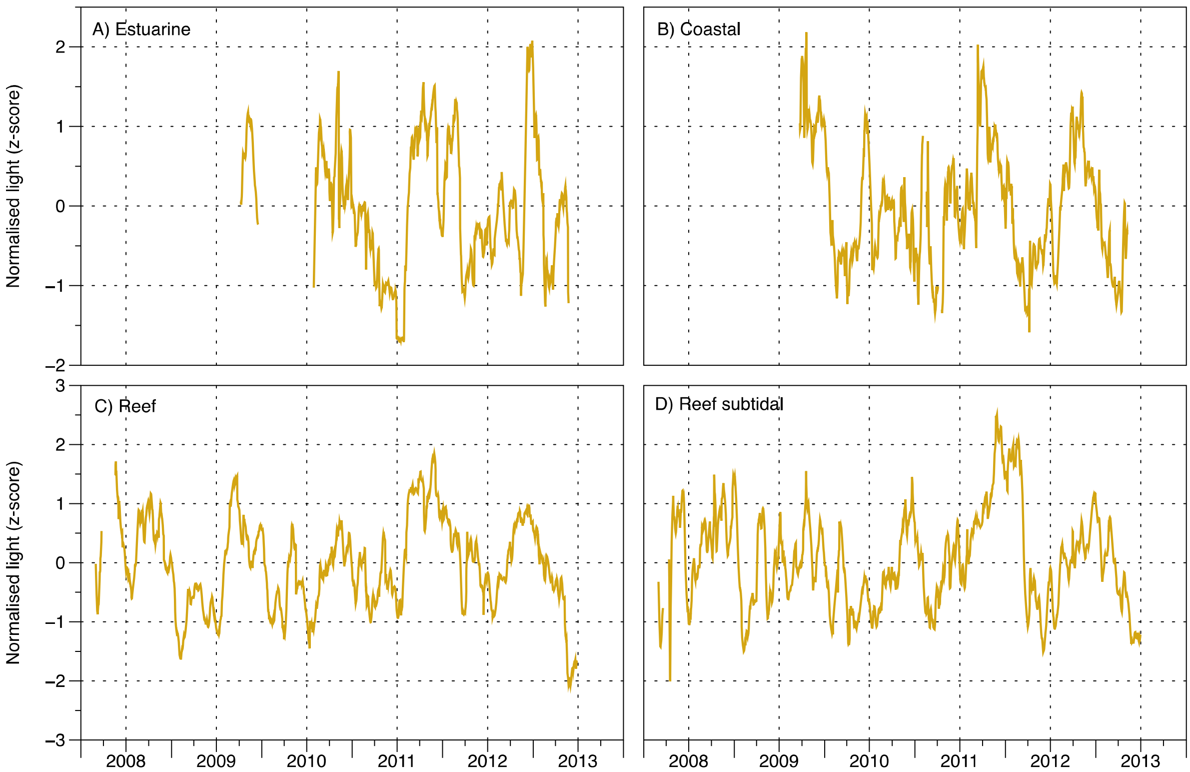

Figure 29. *Normalised (z-score) daily light data (28-day rolling average) for inshore GBR searass habitats: (A) intertidal estuarine, (B) intertidal coastal, (C) intertidal reef; and (D) subtidal reef. Daily light data were z-score transformed for each site and then averaged (mean) across all sites within each habitat type. X-axis marks 1st January for each year.*

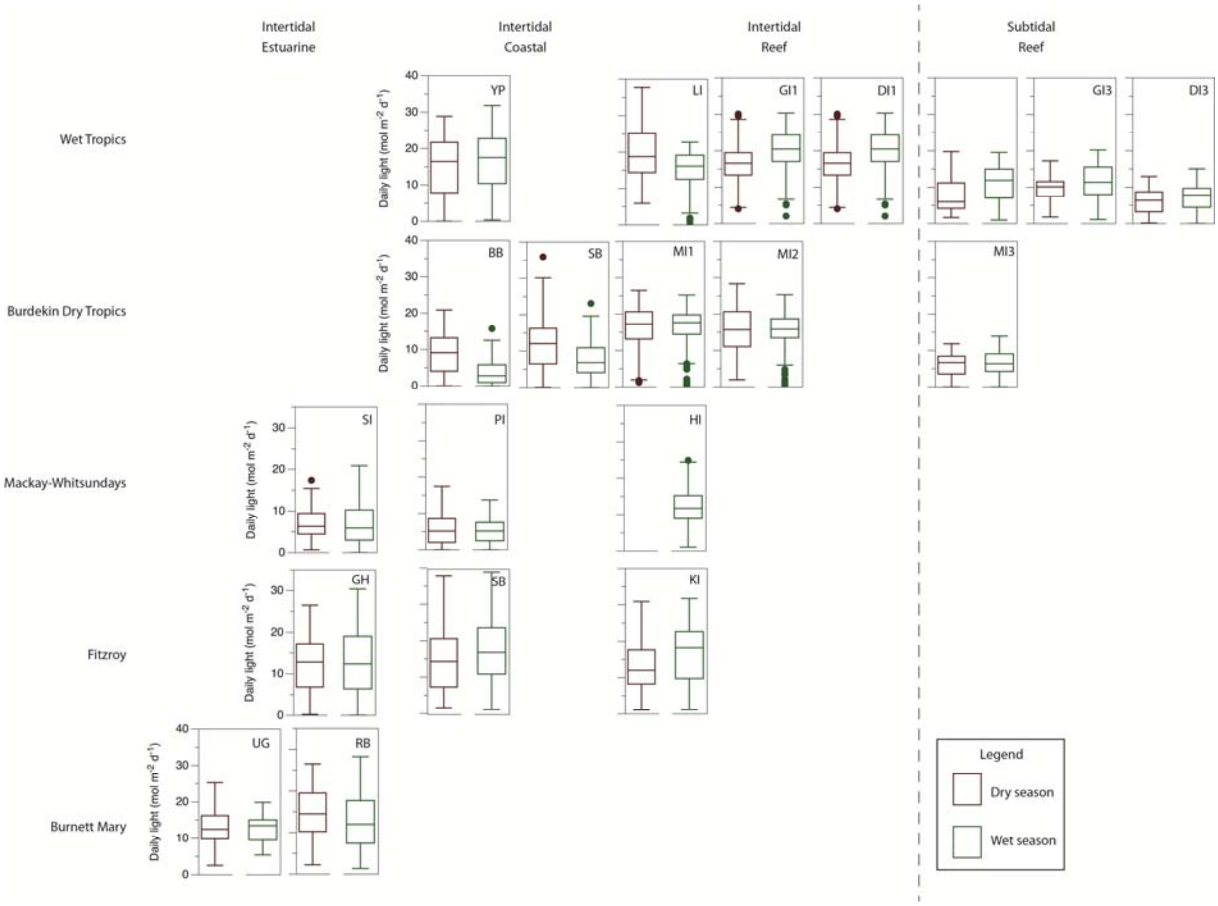

Figure 30. *Daily light for the 2012-13 reporting period separated into dry season (May-October; brown box plots) and wet season (November to April; green box plots) for each location. Data for November 2012-June 2013 from Pelican Banks, Gladstone Harbour, was provided by Gladstone Ports Corporation Ltd and Vision Environment Pty Ltd.*

Light vs abundance

There was no relationship between mean seagrass abundance at each monitoring site and mean I_d at the same site (Figure 31a), indicating that daily light (I_d) does not emerge as a strong driver in the spatial variability in seagrass abundance. Furthermore, there was no relationship between the change in seagrass abundance from one measurement period to the next (typically 3 months) and I_d over the same period (Figure 31b). This is likely due to the unit in which the light environment is described (i.e. I_d), as daily light may not adequately describe photosynthetically usable light, particularly in intertidal environments (Petrou *et al.* 2013), however, alternative and suitable metrics have not yet been developed. In contrast, responses between abundance and I_d at the individual site level can be much stronger (Figure 32). The relationship between change in seagrass abundance and light have previously been reported in Collier *et al*. (2012b) and an update is shown in Figure 32. There was a strong relationship between seagrass abundance and the light metrics including hours of light saturating irradiance (H_{Sat}) and I_d; however, this was only during event driven (run-off) loss in the years leading up to and including TC Yasi. Furthermore this was not as strong at Green Island where event-driven loss did not occur (Figure 32). During meadow recovery, the relationship between abundance and the light metrics is considerably weaker, as factors other than light are likely to limit recruitment during this early phase of meadow recovery.

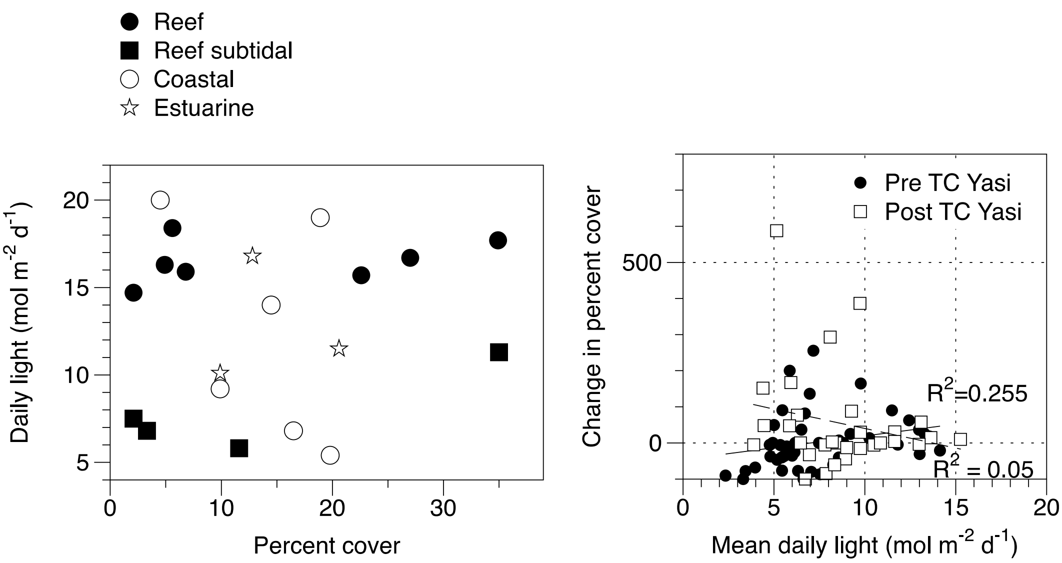

Figure 31. *Mean percent cover and mean I_d for each location (left panel) and change in seagrass abundance and daily light for each monitoring period (~3months) for all locations in the GBR pooled (right panel) (Collier, et al. 2012b).*

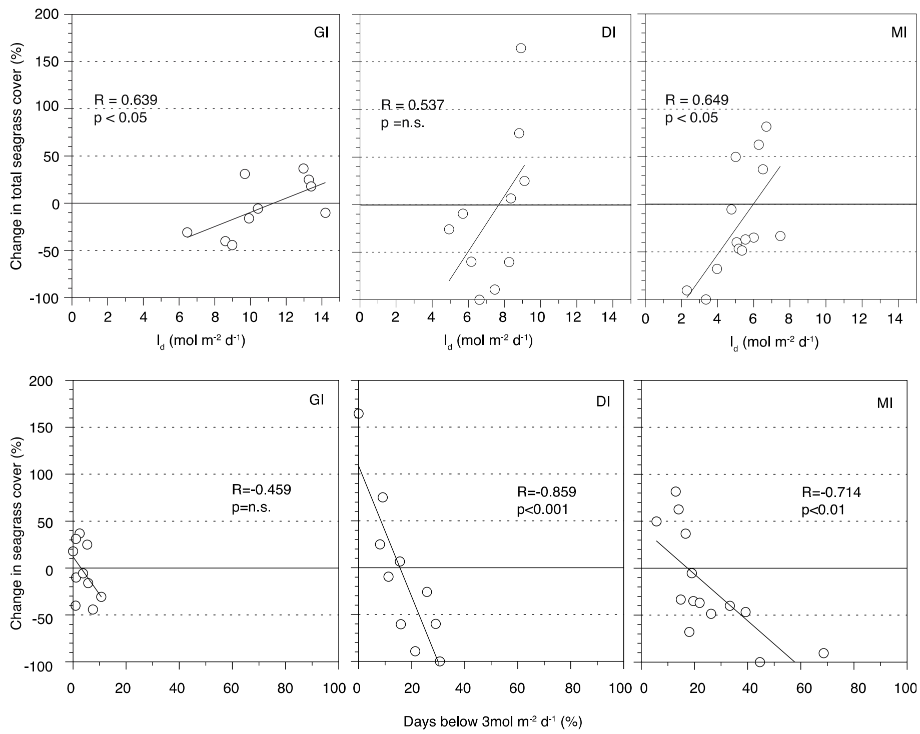

Figure 32. *Change in seagrass abundance (percent cover) and hours of light saturating irradiance (H_{Sat}) (upper row) and change in seagrass percent cover and median I_d for the same sites over the same monitoring period (bottom row) at Green Island, Dunk Island and Magnetic Island (Picnic Bay). Each data point represents change in abundance over a single sample period, which are space approximately 3 months apart. Upper panel represents post-Yasi and lower panel is post-Yasi, to highlight trends during event-driven loss caused by higher than average run-off in 2009-2011, and which led to complete loss at 2 of the sites) and post-Yasi, when meadows were in a recovery mode.*

Cape York

2012-13 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. Seagrass abundance differed across the region in 2012-13, however extent remained stable. Seagrass abundance at reef habitats remained poor, which coupled with a greater than average proportion of colonising species may suggest weaker ecosystem resistance to perturbations. The low seed bank and poor reproductive effort at reef sites further indicates a low capacity to recover following disturbance. Although similarly composed of greater than average proportion of colonising/pioneering species, coastal seagrass meadows may have greater resistance on account of their very good abundance. The greater seed banks in coastal meadows 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 tissue nutrients in late 2012, there was no indication of elevated N or light limitation across the region in any of the seagrass habitats. Epiphyte abundance decreased in 2012-13 and macroalgae remained below GBR long-term average. No extreme within canopy seawater temperatures were experienced over the monitoring period and meteorological conditions, in general, were favourable for seagrass growth apart from rougher seas which may have mobilised inshore sediments resulting in some physical disturbance of the seabed. The drier than average conditions in 2012-13 resulted in annual freshwater discharges from all Cape York rivers below the long-term median and no herbicides were found above detectable limits in the sediments of the meadows in the central and northern sections of the region (southern section not measured). On account of these favourable conditions, the regional seagrass state has improved over the last 12 months, but remains **poor** (Table 16).

Table 16. *Report card for seagrass status (community & environment) for the Cape York region: June 2012 – May 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). NB: report card differs from Paddock to Reef as new locations included.*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
reef intertidal	22	17	40	26
coastal intertidal	81	0	38	40
estuarine intertidal	*not monitored*			
Cape York	42	8	39	**30**

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 33).

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 (i.e. potential area that seagrass could colonise) 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 (Figure 103). 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.

Seagrass meadows on inshore reef habitats were monitored at 3 locations (Piper Reef, Stanley Island, and Archer Point), from the north of the region (12.25°S), to the south (15.6°S) (Figure 33). 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 33). 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).

In early 2012, two additional reef habitat locations were included for monitoring: Stanley Island and Piper Reef. Stanley Island is within the Flinders Island group north of Bathurst Bay (Figure 33). 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 33). 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.

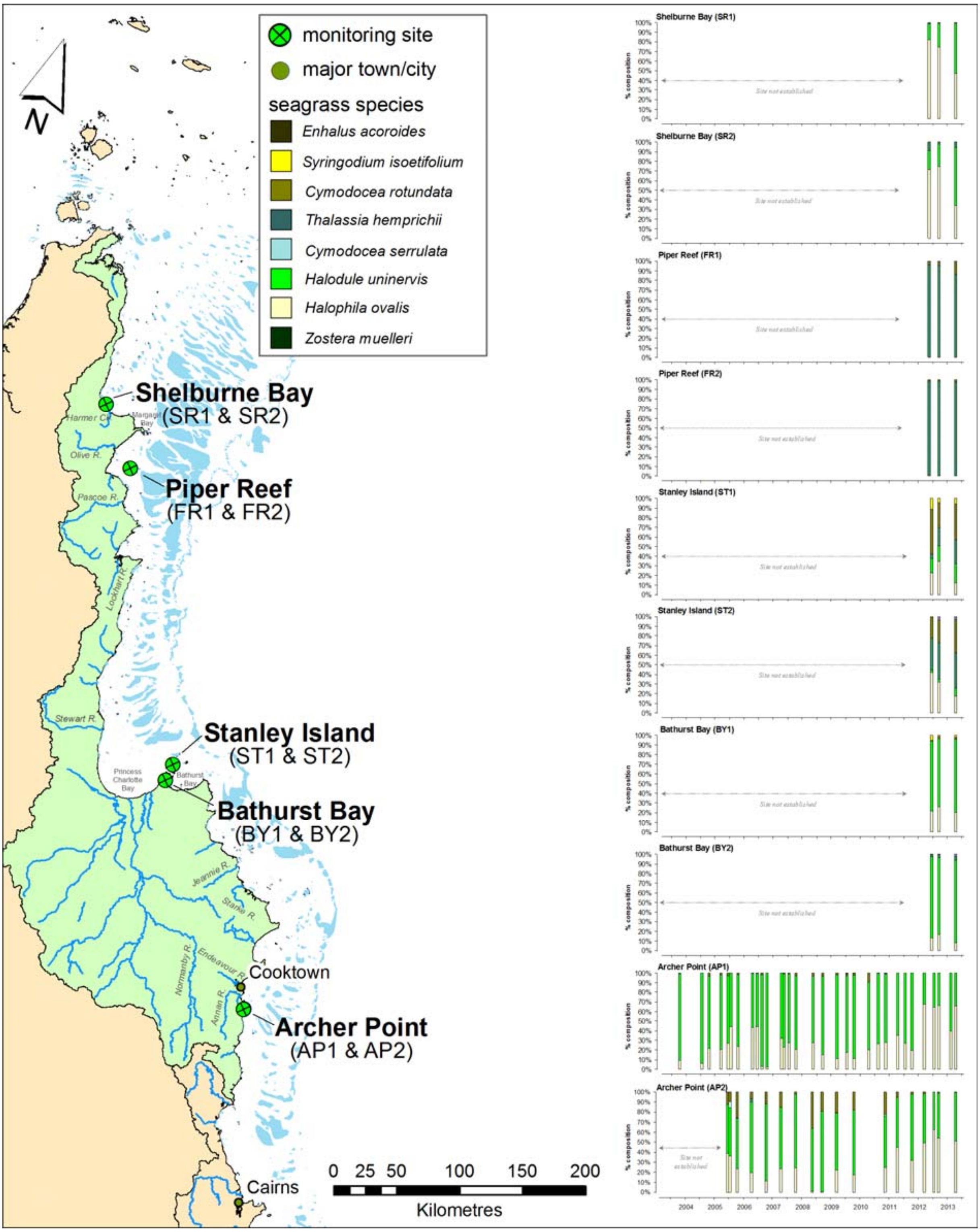

Figure 33. *Location of the Cape York region monitoring sites and seagrass species percent composition at each site since 2003. Please note: replicate sites within 500m of each other.*

In early 2012, two coastal seagrass habitat locations were paired with the new reef habitat locations, they included: Bathurst Bay (paired with Stanley Island) and Shelburne Bay (paired with Piper Reef). The coastal seagrass meadows at Bathurst Bay 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 1, Figure 105).

Bathurst Bay is located just east of Combe Point in the Bathurst Bay area to the east of Princess Charlotte Bay (Figure 33). 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.

Results and discussion

Status of the seagrass community

Seagrass abundance and composition

The seagrass abundance score across the region was rated as moderate in 2012-13 (Figure 34). Seagrass abundance at reef habitats declined from 2003 to 2011, and although they have improved in cover since, remains in a poor state. Seagrass abundance at coastal habitats was in a very good state in 2012-13. 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.

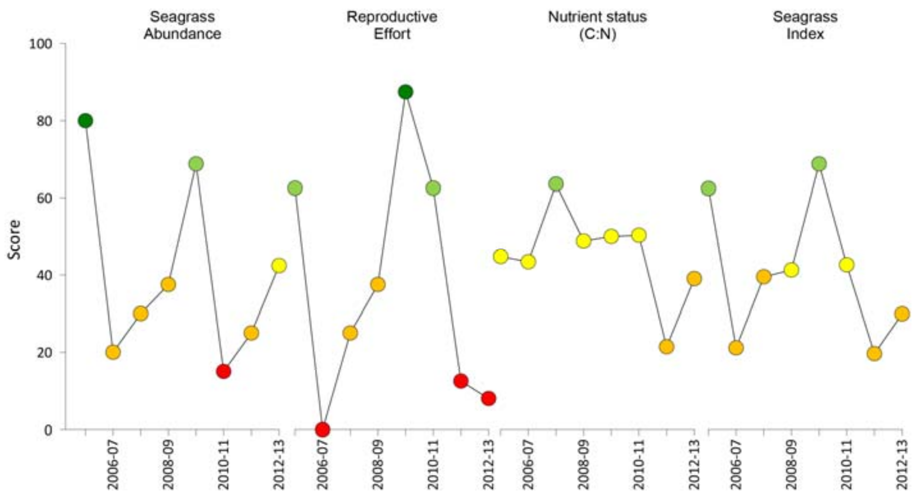

Figure 34. *Report card of seagrass status indicators and index for the Cape York NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

The long-term average seagrass cover at reef habitats in the Cape York NRM region varied little between seasons: 8.9 ±1.5% in the late dry and 10.7 ±1.2% in late monsoon season. Seagrass abundance in 2012-13 remained similar at far northern sites (Piper and Stanley Reefs), but was approximately 20% lower at Archer Point than the previous monitoring period (Figure 35): a consequence of very low abundances in July 2012.

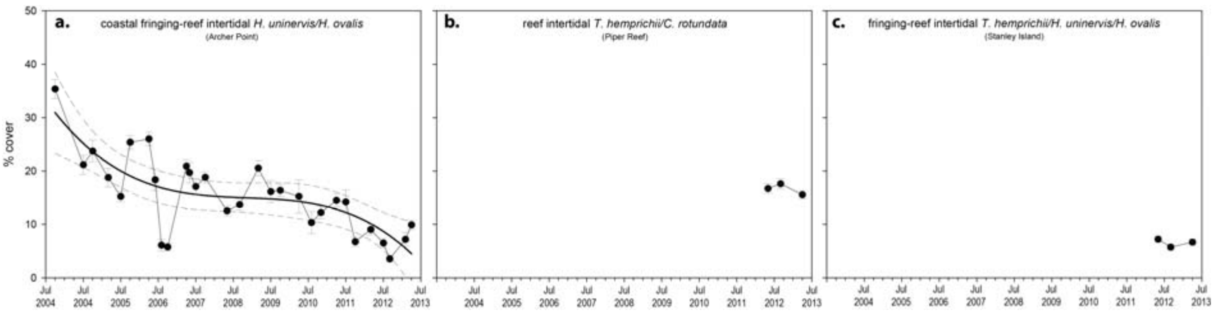

Figure 35. *Seagrass abundance (% cover ± Standard Error) at inshore intertidal reef habitats (replicate sites pooled) in the Cape York NRM. Trendline for Archer Point is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.60.*

In the late monsoon 2013, the Cape York reef habitat with the highest seagrass abundance was Piper Reef (20.6 ±1.7% at site FR2), followed by Archer Point (13.4 ±2% at site AP2) and Stanley Island (7.0 ±0.7% at ST1). In 2012-13 seagrass abundance increased across reef habitat sites, from declines observed in 2011-12. Since monitoring was established at Archer Point site 1 (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 sites was less apparent.

Seagrass abundance at coastal habitats in the northern and central sections of eastern Cape York NRM region slightly increased in 2012-13 (Figure 36), although no long-term patterns are apparent due to the limited dataset. In 2012-13, seagrass abundances at Shelburne Bay remained mostly below the 50th percentile guideline, however, at Bathurst Bay they were above the 75th percentile guideline (Figure 36, see Table 10 for guideline values).

Cape York reef sites were dominated by *Thalassia hemprichii*, *Cymodocea rotundata, Halodule uninervis* and *Halophila ovalis* with varying amounts of *Syringodium isoetifolium* and *Enhalus acoroides* (Figure 33). 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, sites were dominated by *Halodule uninervis* (Figure 33). Five seagrass species were present in the Bathurst Bay meadows, whereas only three species were present at Shelburne Bay (Figure 33). As the dataset is limited, no temporal trends are apparent.

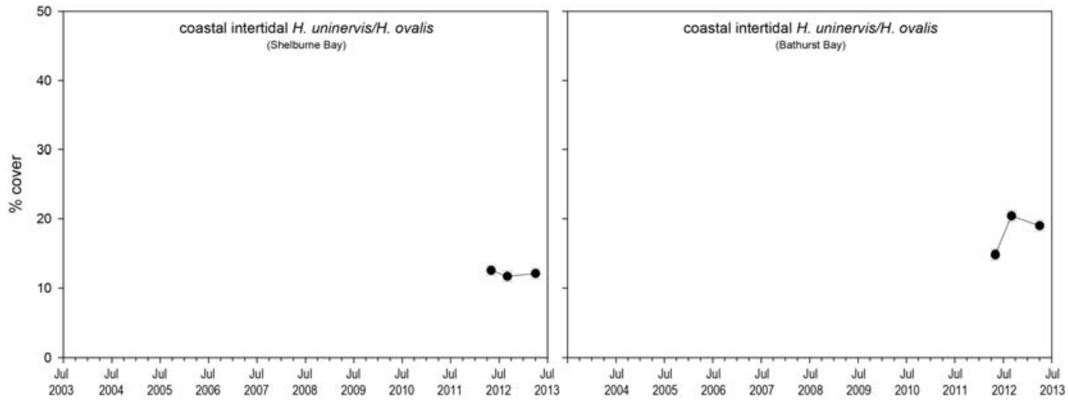

Figure 36. *Seagrass abundance (% cover ± Standard Error) at inshore intertidal coastal habitats (sites pooled) in the Cape York NRM region.*

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 37). This suggests the meadows are dynamic in nature and have experienced perturbations in recent years. The greater proportion of *r*- strategist species also suggests weaker ecosystem resistance, particularly for meadows with poor abundance.

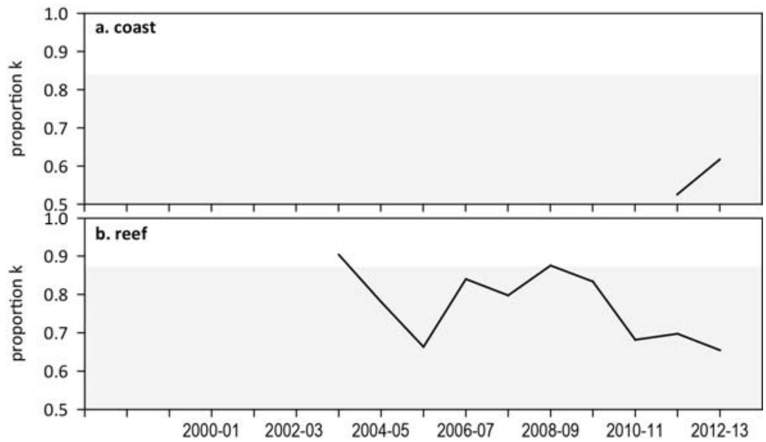

Figure 37. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Cape York region. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in October 2012 and April 2013 to determine if changes in abundance were a consequence of the meadow edges changing (Appendix 1, Table 22). The meadows within 100m of the monitoring sites on the reef flat at Archer Point have fluctuated within and between years (Figure 38), primarily due to changes in the landward edge and appearance of a drainage channel from an adjacent creek (data not presented). Meadows at Piper Reef and Stanley Island have changed little in extent over the past 18 months (Figure 38; Appendix 1, Table 22).

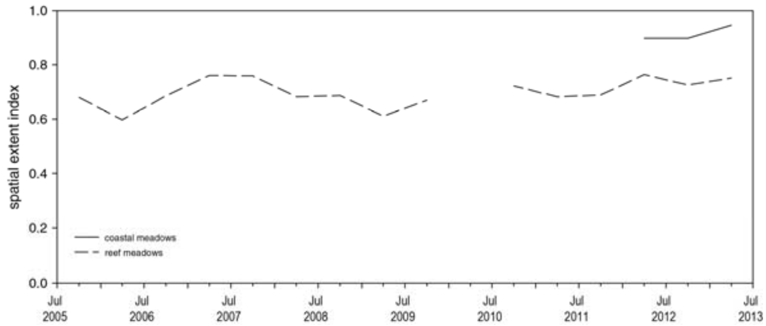

Figure 38. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each habitat and monitoring period across the eastern Cape York NRM region.*

Seagrass reproductive status

Reproductive effort increased in 2012-13 at reef habitats (0.83 reproductive structures per core) compared to the previous monitoring period, but remained below the GBR long-term average for reef habitats (1.32 reproductive structures per core) (Figure 39).

Seagrass seed banks in Cape York meadows were often larger in the late dry than late monsoon (Figure 39). Seed banks were also higher at coastal than reef habitats (Figure 39). A seed bank of predominately *Halodule uninervis* persists at reef habitat sites (Figure 39), however late dry season abundances in 2012-13 were the lowest since monitoring was established. Although *Cymodocea* plants were present across reef sites, no seeds have been found since monitoring commenced. Total reproductive effort was similar between habitat types, and increased in 2012, but remains lower than the peak in 2009 (Figure 39).

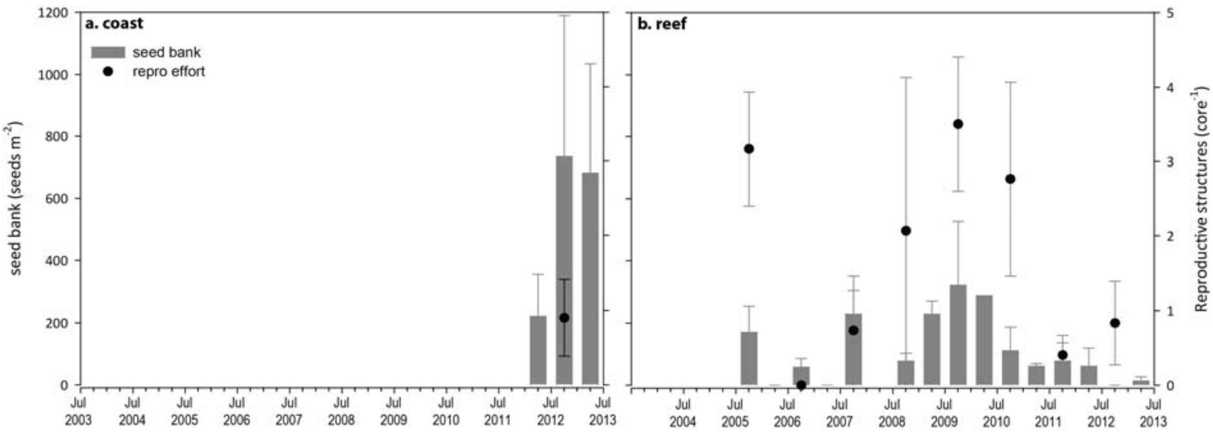

Figure 39. *Seed banks and reproductive effort at inshore intertidal coastal (a) and reef (b) habitats in the Cape York region (species and sites pooled). Seed banks presented as the total number of seeds per m^2 sediment surface. Reproductive effort for late dry season presented as the average number of reproductive structures per core.*

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

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 2012 (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 (Figure 40). $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were above (isotopically heavier) the global average and within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth. The only species which may indicate light limitation was *Enhalus acoroides* in the coastal habitat of Shelburne Bay, as $\delta^{13}C$ concentrations were isotopically lighter: below the global average (Appendix 1, Table 23). This, however, may be a consequence of *E. acoroides* growing adjacent to mangroves and experiencing either shading or higher epiphytic cover (data not available).

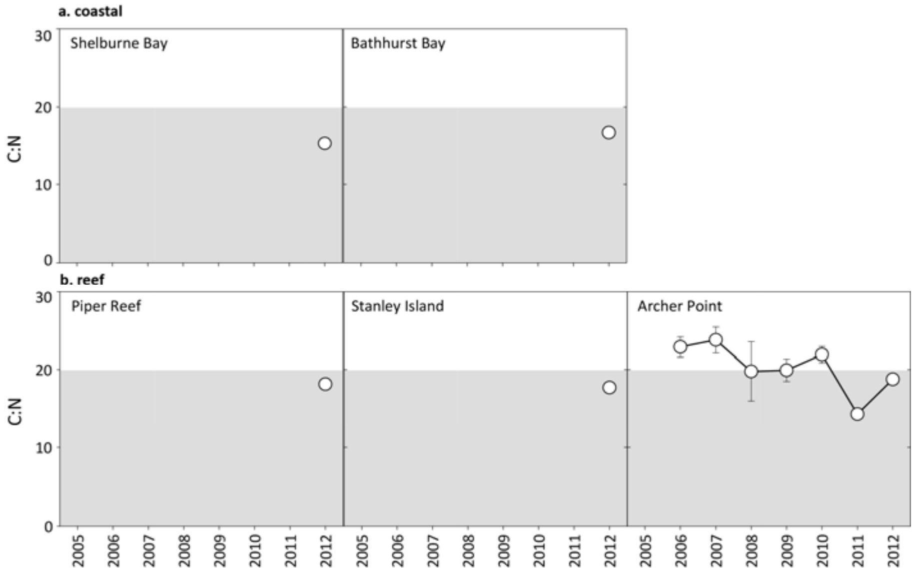

Figure 40. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation species in inshore intertidal coastal (a) and reef (b) habitats in the Cape York region from 2005 to 2012 (species pooled) (mean and SE displayed). Horizontal shaded band on the C:N ratio panel represents the accepted 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.*

With the exception of Archer Point, seagrass leaf molar C:P ratios in 2012 were <500 for reef and coastal habitats, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 41). N:P ratios for the foundation species increased slightly since the previous monitoring period, however ratios were mostly between 25 and 30, indicating the plants remained replete (well supplied and balanced macronutrients for growth)(Figure 41).

There was no indication of elevated N at Cape York coastal habitats or the reef habitats in the central and northern Cape York region as N:P ratios were between 24 - 26 (Figure 41), and $\delta^{15}N$ values in the leaf tissues were all below 0‰ (Appendix 1, Table 23), suggesting the primary source of N was from N_2 fixation. At Archer Point, however, the higher N:P ratio (29.9) may indicate higher available N, with $\delta^{15}N$ values in the leaf tissues suggesting that the primary source of N was either from N_2 fixation or fertiliser (Appendix 1, Table 23). This was a slight improvement from 2011 where leaf tissue nutrients indicated elevated N.

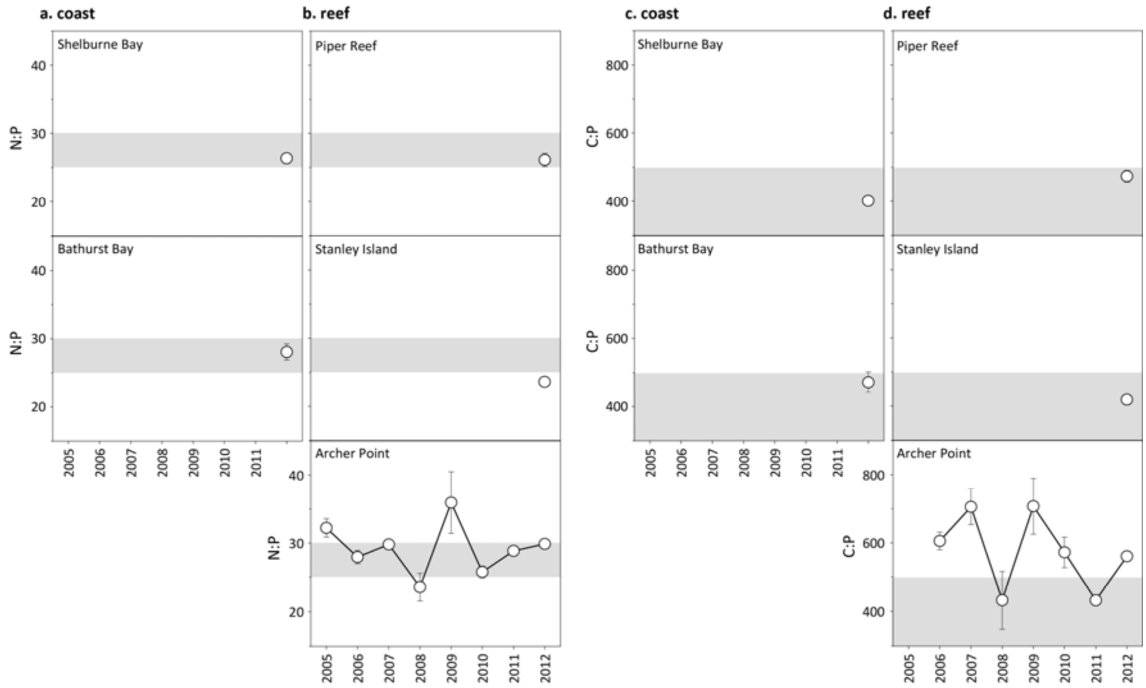

Figure 41. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation species in inshore coastal (a, c) and reef (b, d) habitats in the Cape York region from 2005 to 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, 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 and in the dry season at reef habitats (Figure 42). Epiphyte abundances at reef habitats (i.e. Archer Point) were lower in 2012-13 than the GBR long-term average and the previous monitoring period (Figure 42; Appendix 1, Figure 97).

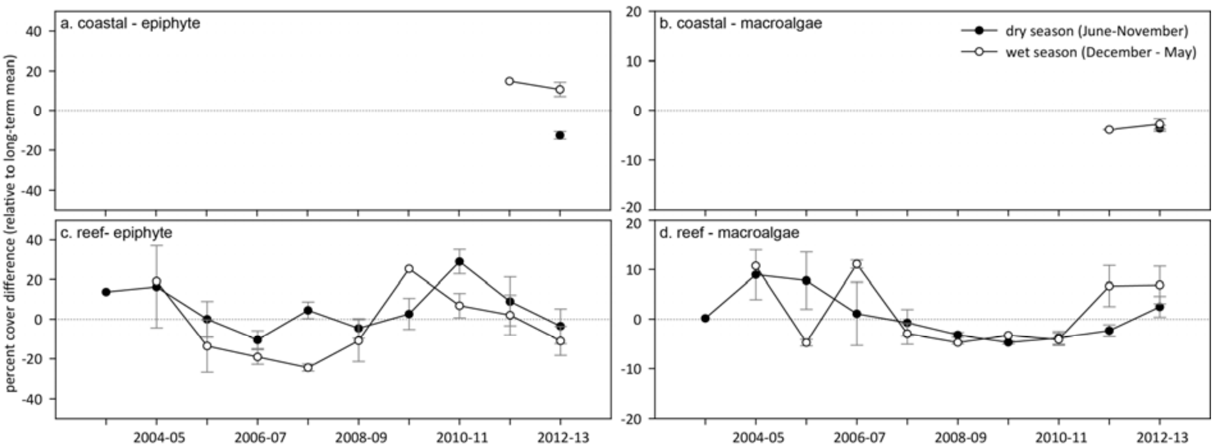

Figure 42. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore GBR intertidal seagrass habitat (sites pooled, ±SE). GBR long-term average; coastal epiphytes = 17%, coastal macroalgae = 4.7%, reef epiphytes= 25%, reef macroalgae = 6.2%.*

Percentage cover of macroalgae was variable between years, but appears to have increased on the last two monitoring periods and was above the GBR long-term average for reef habitats throughout 2012-13 (Figure 42; Appendix 1, Figure 116). Macroalgae cover remained below the GBR long-term average for coastal habitats (Figure 42).

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows at sites in the north and central Cape York region in the late monsoon 2013 (Appendix 1, Table 25). Archer Point sediments were not examined for the presence of herbicides.

Within canopy sea temperature

Autonomous temperature loggers were deployed at all sites over the monitoring period. The longest dataset was from Archer Point, as other sites were established in May 2012. Failure or loss of replicate loggers from Archer Point during the 2012-13 monitoring period resulted in no data available over the 2012-13 summer/monsoon (Appendix 1, Figure 130). High temperatures (>35°C) were recorded from September 2012 to May 2013, with the highest temperature (38.3°C) recorded at 1:00pm on the 4 February 2013 at Piper Reef (Figure 43a). A greater number of days where the sea water temperatures exceeded 35°C was experienced in 2012-13, however this is likely a result of additional monitoring sites being established further north of the existing sites at Archer Point. At Archer Point, temperatures appeared closer to the long-term average over the 2012-13 monitoring period, however due to missing data, no comparisons were possible with the previous 12 months.

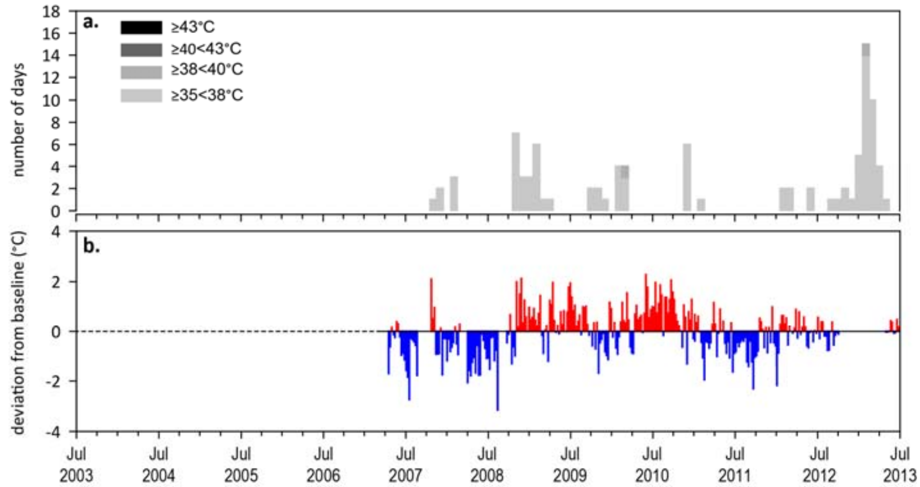

Figure 43. *Inshore sea temperature for intertidal seagrass habitats in the Cape York NRM region from April 2007 to June 2013: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations at Archer Point from 6-year 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). Dashed line represents period when monitoring not established.*

Regional climate and river discharge

In general, climate over the monitoring period was warmer, drier, with clearer skies and stronger winds than the long-term average meteorological conditions. The mean maximum daily air temperatures recorded in during 2012-13 was either similar (Lockhart R.) or 0.4°C warmer (Cooktown) than 2011/12 and between 0.2 -0.5°C warmer than the decade average (Appendix 1, Figure 145, Figure 146, Figure 147). The highest recorded daily maximum air temperature in 2012-13 was 38.6°C at Cooktown, cooler than the long-term highest annual maximum of 41.7°C in 1958, but the highest annual maximum since 2009.

Mean annual monthly cloud cover in 2012-13 was lower than the previous period, and 5-15% lower than the decadal average. Mean monthly wind speeds in 2012-13 were 20.6 km.hr^{-1} in the north and 22.7 km.hr^{-1} in the south, which was 2 - 3% higher than the long-term average. However, there were 122 days in 2012-13 where winds were greater than 25 km.hr^{-1}, the highest since 2005/06, which would have mobilised and resuspended sediments in shallow inshore waters for a third of the year, reducing available light and destabilised the seabed.

The 2012-13 monitoring period was drier than average with a total rainfall of 1139 - 1347mm (south and north, respectively). This was 25% lower than the previous years rainfall, and 23% lower than both the decadal and 69 year mean annual rainfall. As a consequence, the discharge from all rivers throughout the Cape York region in 2012-13 was below the long-term median (Appendix 1, Table 26, Figure 167), which would have reduced exposure of inshore meadows to plumes of turbid, sediment laden waters.

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Wet Tropics

2012-13 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 increased over the last 12 months in coastal habitats, it remained in a very poor state. Seagrass abundance at reef habitats remained unchanged in a poor state. There was little or no expansion of the meadows as the plants appeared in an establishment phase (onset of recovery) or hadn't recovered enough to allocate resources to vegetative expansion. 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. Seed banks across the region remained unchanged or declined and reproductive effort remained very poor. This indicates that meadows in the region will take longer to recover following disturbance and may be at risk from chronic impacts.

Analysis of seagrass leaf tissue suggests sufficient light for growth, but elevated N in the coastal environment and high N in reef habitats. Low $\delta^{15}N$ values in the leaf tissue indicate the primary source of N was either N_2 fixation or fertiliser. Epiphyte abundances remained unchanged at reef habitats relative to the previous monitoring period, but increased during the monsoon at coastal habitats. Macroalgae abundances also remained low. Seagrasses across the region experienced slightly warmer sea temperatures in 2012-13 than the previous 12 months, particularly during February 2013 when there were 19 days above 35°C, including one which was above 38°C. No extreme temperatures (>40°C) which would result in high stress to plants were measured in 2012-13, but the hottest seawater temperature in 2 years occurred at Yule Point in October 2012 (39.3°C). Although average air temperatures were experienced across the region, the climate in the north was wetter, cloudier and windier on average than the south. 2012-13 was a drier than average year and discharges from rivers which would impact the seagrass monitoring locations were below median. Overall the status of seagrass condition in the Wet Tropics has remained **very poor** in 2012-13 (Table 17).

Table 17. *Report card for seagrass status (community & environment) for the Wet Tropics region: June 2012 – May 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).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
reef intertidal	21	0	39	**20**
coastal intertidal	13	0	7	**6**
estuarine intertidal	*not monitored*			
Wet Tropics	17	0	23	**13**

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 1, Figure 105). 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 44). 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 250m 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 44). 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).

Dunk Island is an inshore continental island located in the southern section of the region (Figure 44). 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.

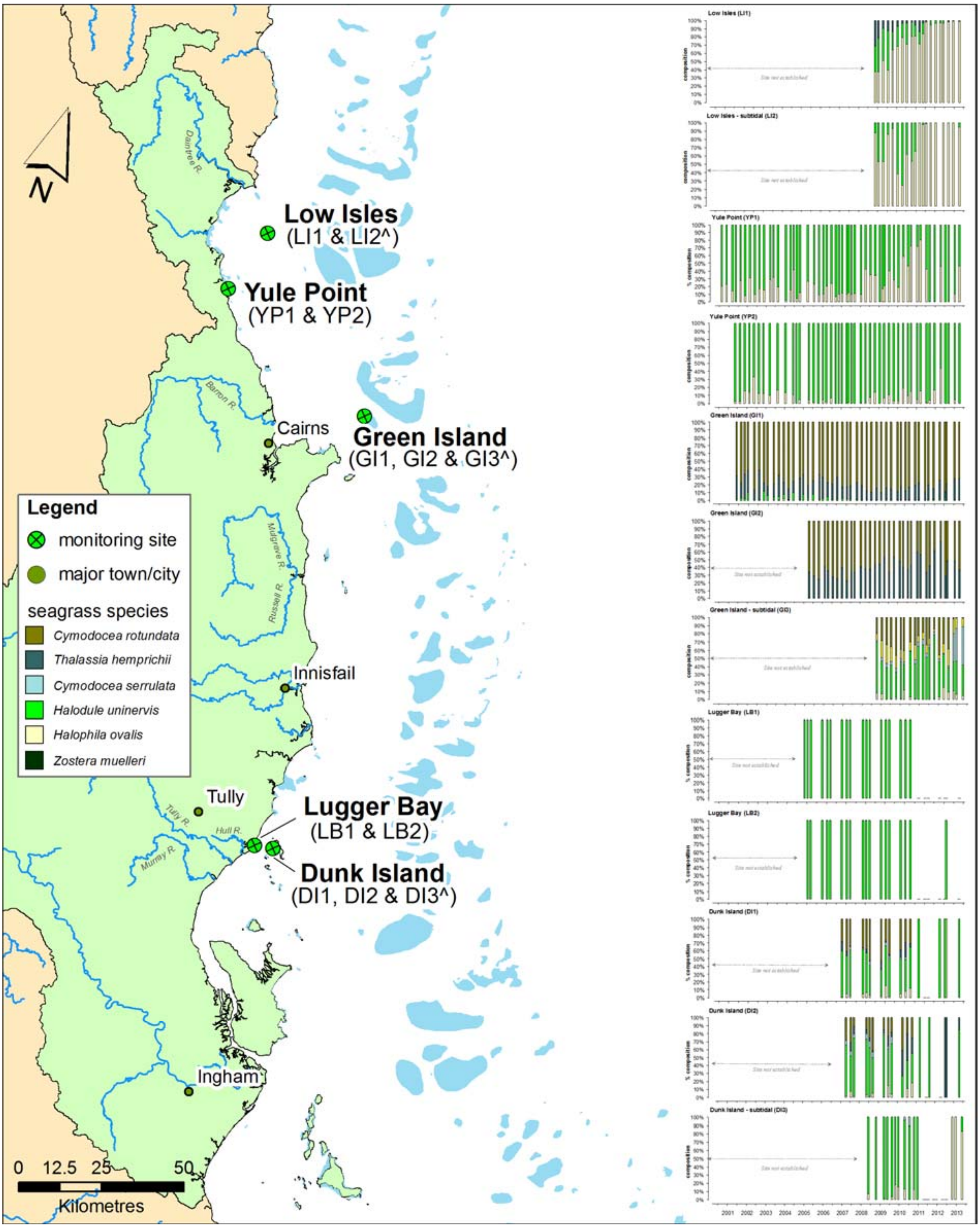

Figure 44. *Location of Wet Tropics region long-term monitoring sites and seagrass species composition at each site. Please note: replicate sites within 500m of each other; ^ denotes subtidal site.*

Shallow unstable sediment, fluctuating temperature, and variable salinity in shallow regions characterise reef habitats. Physical disturbance from waves and swell and associated sediment movement are the primary forcing factors which control seagrass growing in these habitats (Appendix 1, Figure 106). 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. However, the converse was reported at Green Island, where in the 1990's seagrasses were reported to be nitrogen limited (Udy, *et al.* 1999). In the Wet Tropics region, seagrass meadows inhabiting the near shore inner reefs and fringing reefs of coastal islands inhabit a mixture of terrigenous and carbonate sediments.

Results and discussion

Status of the seagrass community

Seagrass abundance and composition

The seagrass abundance score across the region was rated as very poor in 2012-13 (Figure 45). Seagrass abundance at coastal habitats increased over the last 12 months, but remained in a very 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.

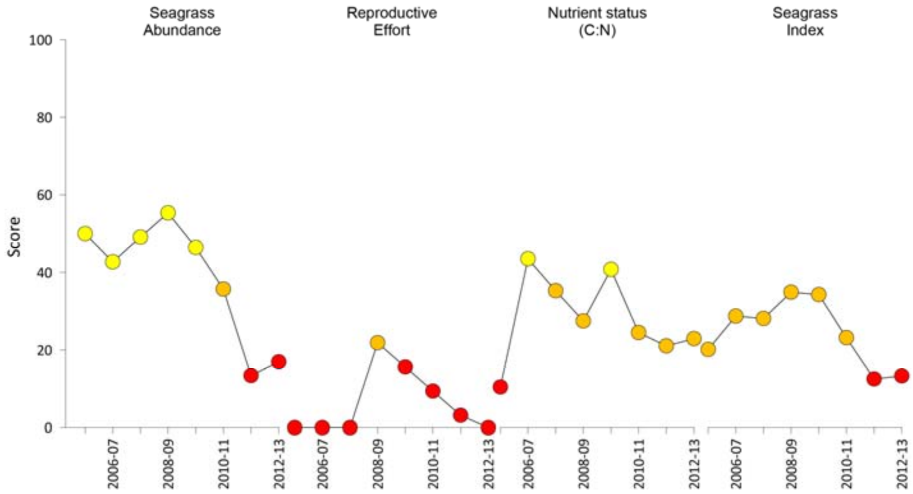

Figure 45. Report card of seagrass status indicators and index for the Wet Tropics NRM region *(averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

The long-term average seagrass cover at coastal habitats in the Wet Tropics NRM region varied greatly between seasons: 6.8 ±1.1 % in the dry and 13.2 ±1.6 % in the monsoon season. Seagrass abundance over the 2012-13 monitoring period increased at Yule Point, nearly doubling the 2011-12 abundances, but remained very poor at Lugger Bay where the few isolated plants which appeared in late dry were lost over the monsoon (Figure 46). 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. Although seagrass cover remained low, it continued to follow a seasonal trend over the past 12 months with higher abundances over the period from late dry to monsoon season (Figure 46).

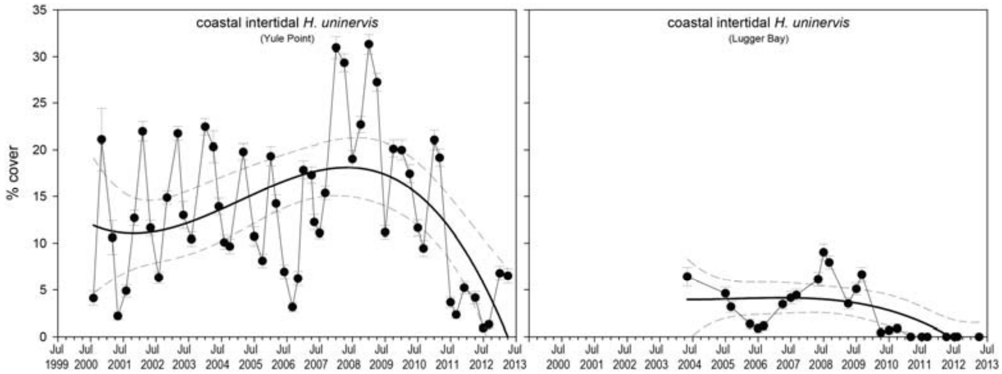

Figure 46. *Changes in seagrass abundance (% cover ±Standard Error) at inshore intertidal coastal habitats in the Wet Tropics region, 2000 - 2013. Trendline is 3rd order polynomial (95% confidence intervals displayed) where Yule Pt r^2 = 0.27 and Lugger Bay r^2 = 0.39).*

Reef intertidal seagrass abundances were higher at Green Island than the other locations, but have remained low across the Wet Tropics, changing little over 2012-13 (Figure 47). The greatest increase was the intertidal seagrass at Low Isles in the early monsoon, but it declined in late monsoon as rapidly as it had increased.

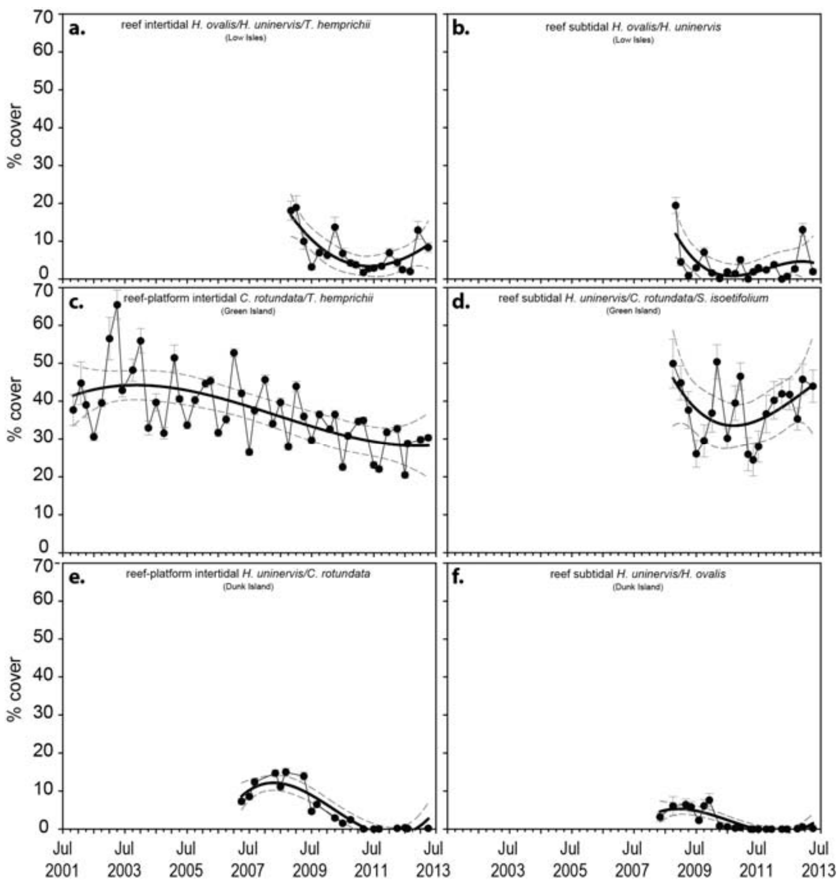

Figure 47. *Changes in seagrass abundance (% cover ±Standard Error) for inshore intertidal and subtidal reef habitats (left and right respectively) in the Wet Tropics region, 2001 - 2013: trendline is 3rd order polynomial (95% confidence intervals displayed), a-b) Low Isles from 2008 to 2012, where intertidal r^2 = 0.58 and subtidal r^2 = 0.38; c-d) Green Island from 2001 to 2013, where intertidal r^2 = 0.40 and subtidal r^2 = 0.20; and e-f) Dunk Island from 2007 to 2011, where intertidal r^2 = 0.86 and subtidal r^2 = 0.69. 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

44). The proportion of foundation (K-strategist) species in the Yule Point meadows was above average for GBR coastal habitats during 2012-13 (Figure 48), which suggests the meadows were recovering with improved ecosystem resistance, particularly with increasing abundance.

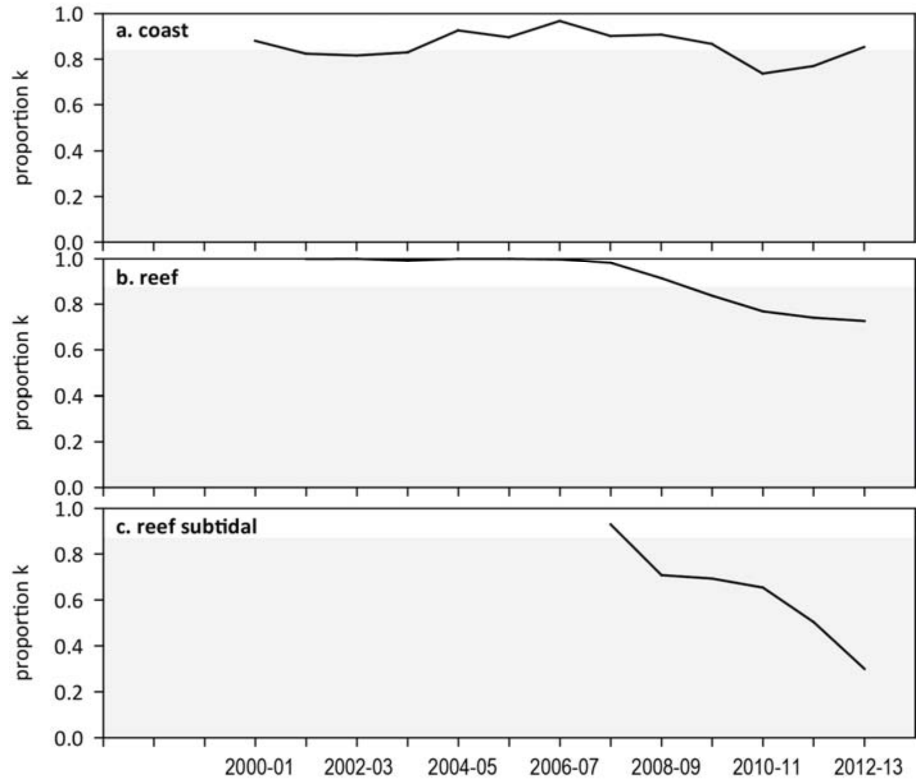

Figure 48. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Wet Tropics region, 2001 - 2013. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

The seagrass meadows at Low Isles, Green Island and Dunk Island are typical of reef platform seagrass communities in the region and were dominated by *Cymodocea rotundata*, *C. serrulata Thalassia hemprichii* and *Halodule uninervis* (Figure 44). However, for the past 2-3 monitoring periods, with the exception of Green Island, both intertidal and subtidal meadows were composed of a greater than average proportion of *r*-strategist species (Figure 48). This suggests the meadows had experienced perturbations in recent years. The greater proportion of *r*-strategist species also suggests weaker ecosystem resistance, particularly for meadows with poor abundance.

With the exception of Low Isles, 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 1, Table 22). The meadows within 100m of coastal monitoring sites have fluctuated within and between years (Figure 49), primarily due to losses and subsequent recolonisation. Meadows on reef sites changed little over the past 18 months (Figure 49; Appendix 1, Table 22)

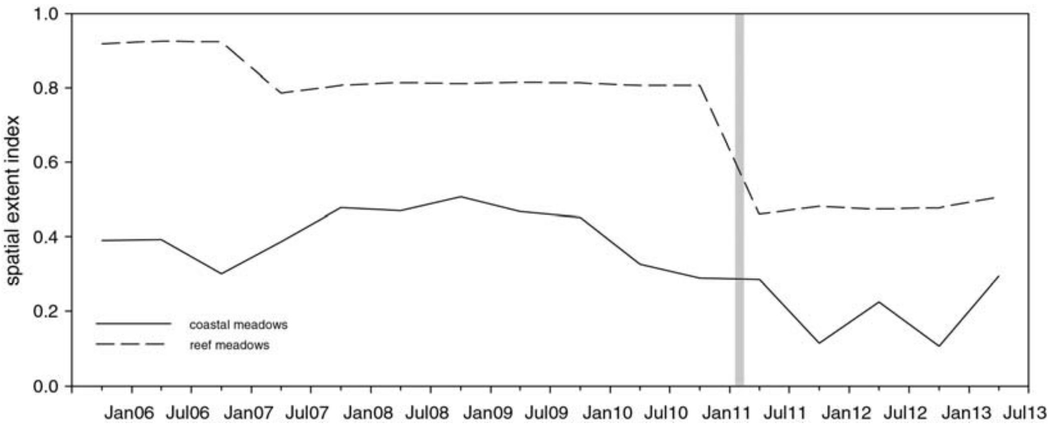

Figure 49. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Wet Tropics region. Vertical grey bar indicates TC Yasi.*

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 (McKenna and Rasheed 2013a; Rasheed *et al.* 2013). While, recovery of these estuarine meadows has been slower than that observed in coastal and reef habitats monitored across the region as part of the MMP. In October 2012, there was no improvement in the abundance or extent of the meadows in Cairns Harbour, with poor abundance and only remnant patches of seagrass remaining. At the same time, meadows in Mourilyan Harbour increased in extent although remained dominated by low density pioneering *Halophila* species. Although climate conditions improved in 2012, with no monitoring of stressors (e.g. light, temperature) apart from climate records, the authors suggest recovery may be a limited due to the absence of seed banks or propagules (data not collected) (McKenna and Rasheed 2013a; Rasheed*, et al.* 2013).

Seagrass reproductive status

Seed banks and reproductive effort across the region either remained unchanged or declined over the monitoring period (Figure 50). A *Halodule uninervis* seed bank persisted at Yule Point, however it has been small since October 2010. A *Halodule uninervis* seed bank, albeit very small, was found at both Dunk Island and Lugger Bay in October 12, the first seeds observed in 2 years. 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.

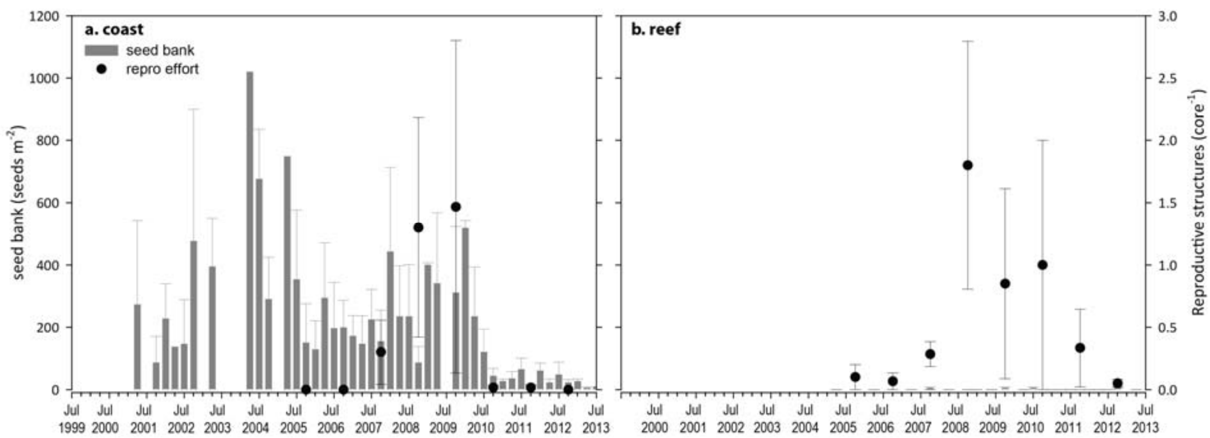

Figure 50. *Seed bank and late dry season reproductive effort for inshore intertidal coast and reef habitats in the Wet Tropics region, 2001 - 2013. Seed banks presented as the total number of seeds per m^2 sediment surface, and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

Status of the seagrass environment

Seagrass tissue nutrients

Seagrasses in reef habitats of the Wet Tropics region had higher leaf molar C:N ratios than those in coastal habitats (Figure 51). This pattern has been consistent across all years of monitoring. In 2012, C:N ratios were relatively unchanged across all seagrass habitats from the 2011 value. $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were above (isotopically heavier) the global average and within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth. The only species which may indicate light limitation was possibly *Thalassia hemprichii* in the reef habitat of Green Island, as $\delta^{13}C$ concentrations were isotopically lighter: below the global average (Appendix 1, Table 23). This, however, may be a consequence of slightly higher epiphyte cover and lower leaf turnover of *T. hemprichii* (McKenzie, unpublished data).

Seagrass leaf molar C:P ratios in 2012 were <500 for reef and coastal habitats, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 52). N:P ratios for the foundation species increased greatly above 30 in coastal habitats, which coupled with the C:P ratio indicates elevated N in the coastal environment (Figure 52). N:P ratios for the foundation species in reef habitats remained between 25-30, indicating the plants were replete(well supplied and balanced macronutrients for growth) with high N (Figure 52). The low C:N ratios in the foundation species is therefore likely a consequence of the elevated N, where the low $\delta^{15}N$ value in the leaf tissue (Appendix 1, Table 23) suggests that their primary source of N was influenced by anthropogenic N sources such as fertiliser.

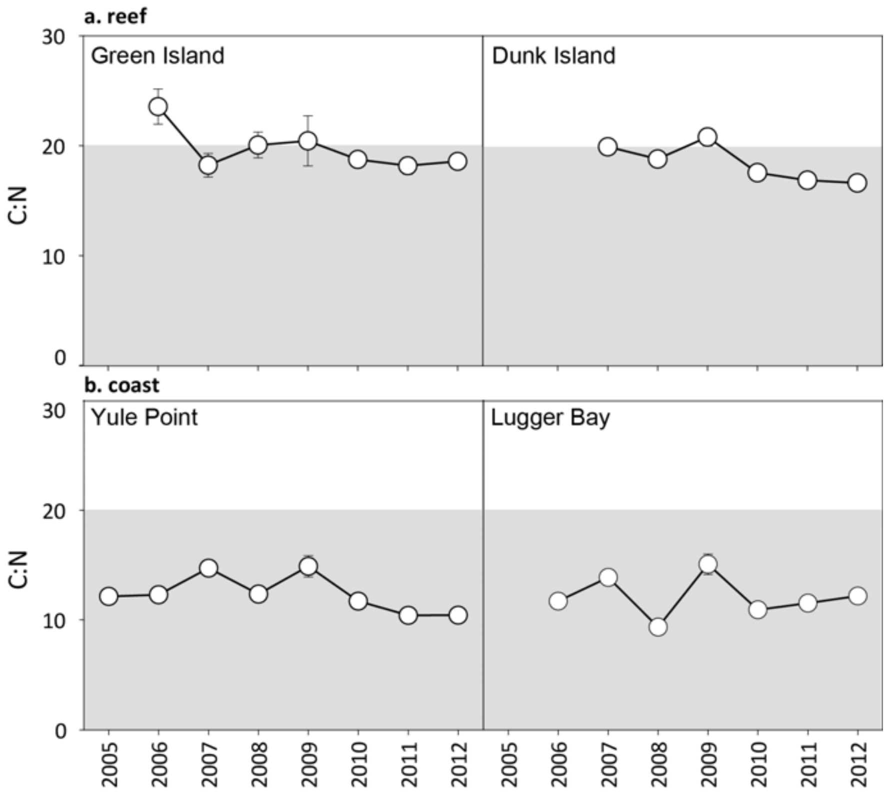

Figure 51. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore intertidal habitat in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline 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.*

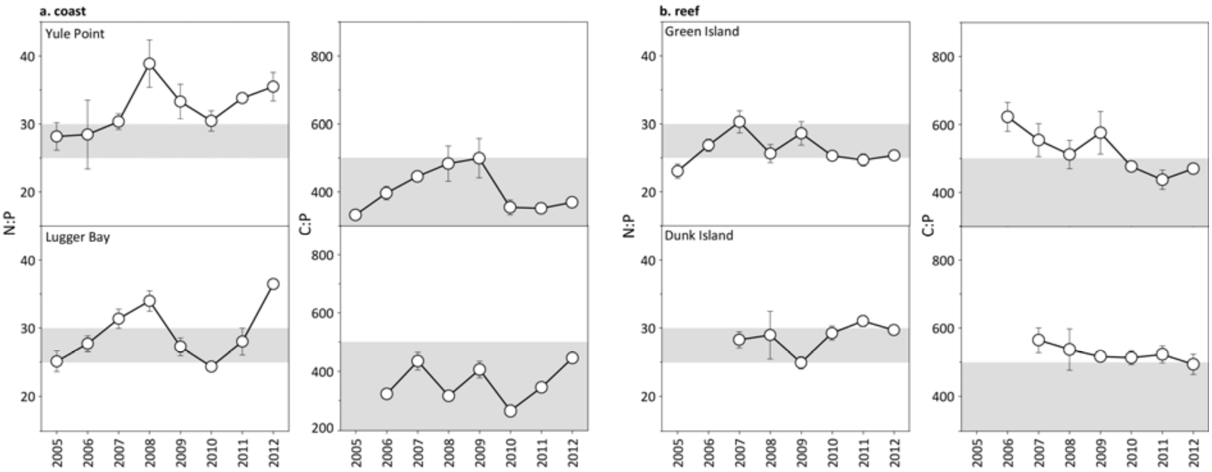

Figure 52. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore intertidal habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of 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).*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades was generally higher in the wet season across all habitats in the Wet Tropics NRM region (Figure 53). Epiphyte abundances remained relatively unchanged at reef habitats from the previous monitoring period, but increased during the wet season at coastal habitats (Figure 53; Appendix 1, Figure 117,Figure 118, Figure 119). Percentage cover of macroalgae has remained stable between years across both coastal and reef intertidal habitats, either below or at the GBR average (Figure 53; Appendix 1, Figure 117,Figure 118, Figure 119).

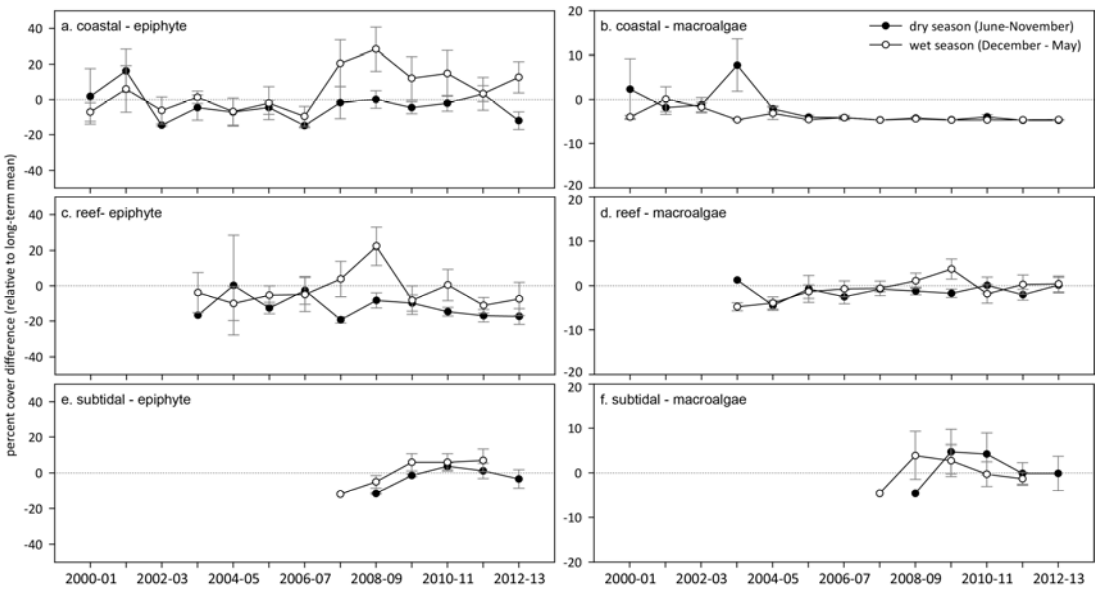

Figure 53. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore seagrass habitat in the Wet Tropics region, 2001 - 2013 (sites pooled, ±SE). GBR long-term average; coastal epiphytes = 17%, coastal macroalgae = 4.7%, reef epiphytes= 28%, reef macroalgae = 6.2%, reef subtidal epiphytes = 7.2%, reef subtidal macroalgae = 4.7%.*

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 1, Figure 131, Figure 132). Annual average within canopy sea temperatures were slightly warmer across the region over 2012-13 than the previous 2011-12 monitoring period. Seagrass meadows in the region experienced up to 54 days of seawater temperatures above 35°C, which was the most per annum since 2008-09 (cf. 53 days in 2008-09) (Figure 54). 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 1, Figure 132), 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 2012-13, but the hottest sea temperature in 2 years occurred at Yule Point in October 2012 (39.3°C). The month with the greatest temperature stress to seagrasses would have been in February 2013 when there were 19 days above 35°C, including one of which was above 38°C (Figure 54). Overall, 2012-13 was a slightly above average year for seawater temperatures, relative to the long-term (10year).

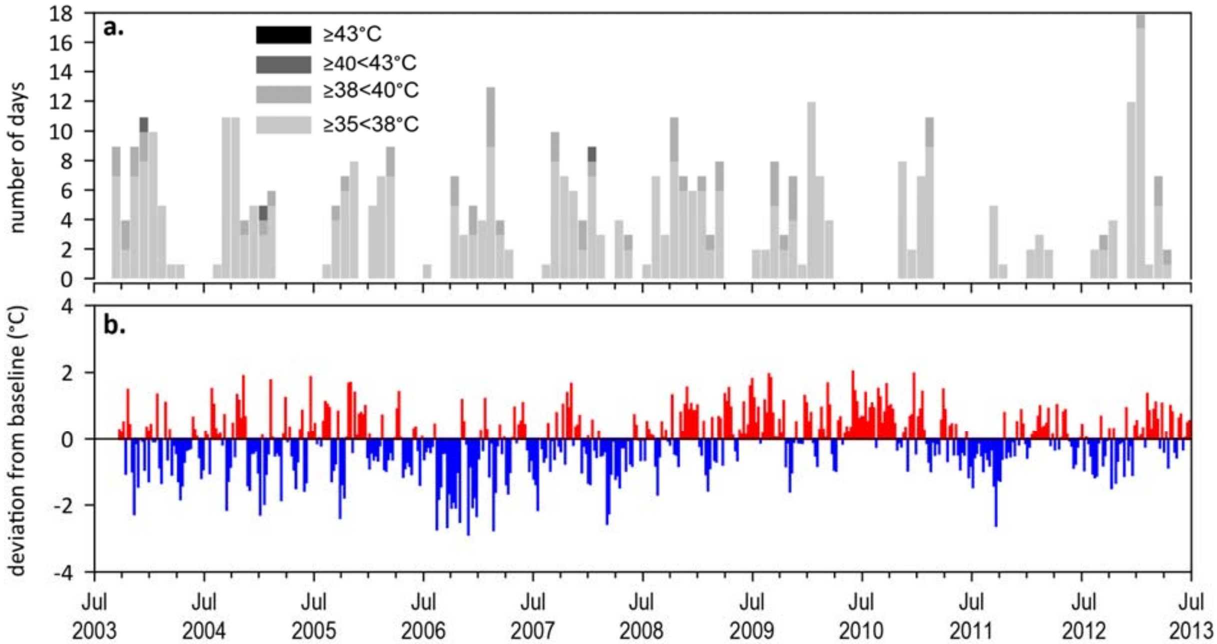

Figure 54. *Inshore sea temperature monitoring for intertidal habitats in the Wet Tropics region, September 2003 to June 2013: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 10-year mean weekly 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 (I_d) for the wet tropics sites was generally at or above the long-term average (Appendix 1, Figure 138) during the 2012-13 reporting period. The exception was at Dunk Island intertidal site where there was very poor data retrieval for this year (35% of days with data). There was site variability in I_d, with intertidal reef sites having the highest I_d (15.9-18.4 mol m^{-2} d^{-1}) and subtidal the lowest (6.8-11.3 mol m^{-2} d^{-1}). Thresholds were typically exceeded more frequently at subtidal (10-42% of days) than intertidal sites (5-18% of days, Appendix 1, Figure 138). Threshold exceedance was lower in 2012-13, compared to the long-term average (Appendix 1, Figure 138). Daily light reached a peak in November and remained high through to February (Figure 55).

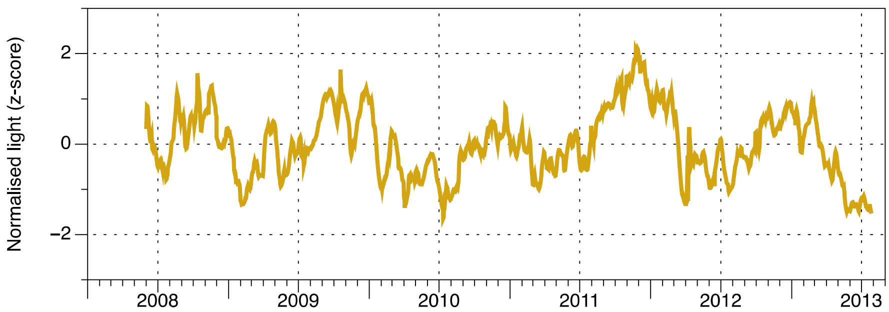

Figure 55. *Standardised daily light (28 day rolling average) for seagrass habitats in the Wet Tropics region, 2008 - 2013 (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

Regional climate and river discharge

Although average air temperatures were experienced across the region during the 2012-13 monitoring period, the climate in the north of the region was on average wetter, cloudier and windier than the south (Appendix 1, Figure 149, Figure 150, Figure 151). Overall, 2012-13 was a drier than average year.

The mean maximum daily air temperatures recorded across the region (from the north to the south) during the monitoring period were similar to both the long-term and decadal averages. The highest recorded daily maximum air temperature in 2012-13 was 38.6°C at Cairns. Cloud cover was higher in the north than the south for much of the year, with 20% higher than both the long-term and decadal averages in the north. Winds were also stronger on average in the north (25.8 $k.hr^{-1}$) than the south (8.2$km.hr^{-1}$) which was slightly higher and lower, respectively, than the annual long-term average respectively. This resulted in 175 days in the north with winds >25 $km.hr^{-1}$; the highest in over a decade (Appendix 1, Figure 152). 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.

2012-13 was also a dry year relative to both the decadal average with 45% to 17% less rainfall in the north and south respectively (Appendix 1, Figure 149, Figure 150, Figure 151). It was also between 7% and 15% less than the long-term (70 year) average in the north and south, respectively.

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: a consequence of the Coriolis effect and prevailing trade winds (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). However, the lower than average rainfall in 2012-13 resulted in below median discharges from the major rivers in the Wet Tropics (Appendix 1, Table 26, Figure 168, Figure 169), which would have reduced stressors, making conditions more favourable for seagrass growth .

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Burdekin

2012-13 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: they are primarily nitrogen limited with secondary phosphate limitation. Rainfall in the region is lower than other regions within tropical Queensland.

Seagrass in the region over 2012-13 appeared within a less vulnerable state relative to the previous 12 months, with improved resistance and capacity to recover from major disturbances. Seagrass meadows in the Burdekin NRM region experienced half- to ten-fold increases in abundance over the 2012-13 period, at coastal and reef habitats, respectively. These were the highest abundances recorded in the last four years. Reef meadows in 2012-13 were composed of a greater than average proportion of colonising species, suggesting weaker ecosystem resistance to higher levels of disturbance. In comparison, ecosystem resistance is stronger in coastal meadows due to the dominance of foundational species, however, this may weaken if the increasing proportion of colonising species continues.

Reproductive effort improved in 2012-13 at reef habitats and a small seed bank has established, indicating an improved capacity to recover following disturbance. A small seed bank persists at coastal habitats and reproductive effort has increased, suggesting an improved capacity to recover, although meadows may be at risk if there is another sizeable impact in the near future. Meadows have continued to expand across the region to their pre-2009 extents, and this may slow in the near future as plants allocate resources to sexual reproduction (i.e. seed production) rather than vegetative expansion.

Analysis of seagrass leaf tissue suggests sufficient available C, but elevated N in the coastal environment and high N in reef habitats. Stable isotope ($\delta^{15}N$) values in the leaf tissue indicate the primary source of N was anthropogenically influenced, possibly fertiliser and/or sewage. Epiphyte cover increased at reef habitats, but remained below the GBR long-term average. Conversely, epiphyte abundances have continued to decline in coastal meadows over the last three monitoring periods, but remained above the GBR long-term average, further supporting the indication of high available N in the inshore areas of the region. Macroalgae abundances continued to remained low.

Seagrass across the region faced fewer climatic pressures in 2012-13 than the previous 12 months as seawater temperatures were lower, overall ranking 7th over the last 9 years of data, and air temperatures and cloud cover were below average. Winds were similarly below average, although the number of days with winds strong enough to resuspend benthic sediments was higher than the previous few years. This would have created periods of both physical disturbance and light limitation for the inshore seagrasses. Although the lower than average rainfall resulted in below median discharges from the major rivers impacted the seagrass meadows monitored in the Burdekin region in 2012-13, traces (below limit of reporting) of Diuron were confirmed in the sediments of the meadow adjacent to the mouth of Barratta Creek (Bowling Green Bay). Overall the Burdekin regional seagrass state has continued to improve since 2010/11, from very poor in 2011/12 to **poor** in 2012-13 (Table 18).

Table 18. *Report card for seagrass status (community & environment) in the Burdekin region: June 2012 – May 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). NB: report card differs from P2R as new locations included.*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
reef intertidal	41	75	45	**54**
coastal intertidal	29	25	22	**25**
estuarine intertidal		*not monitored*		
Burdekin	34	33	34	**34**

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 13, 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 1, Figure 107). 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 availabile for photosynthesis during the growing 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 .

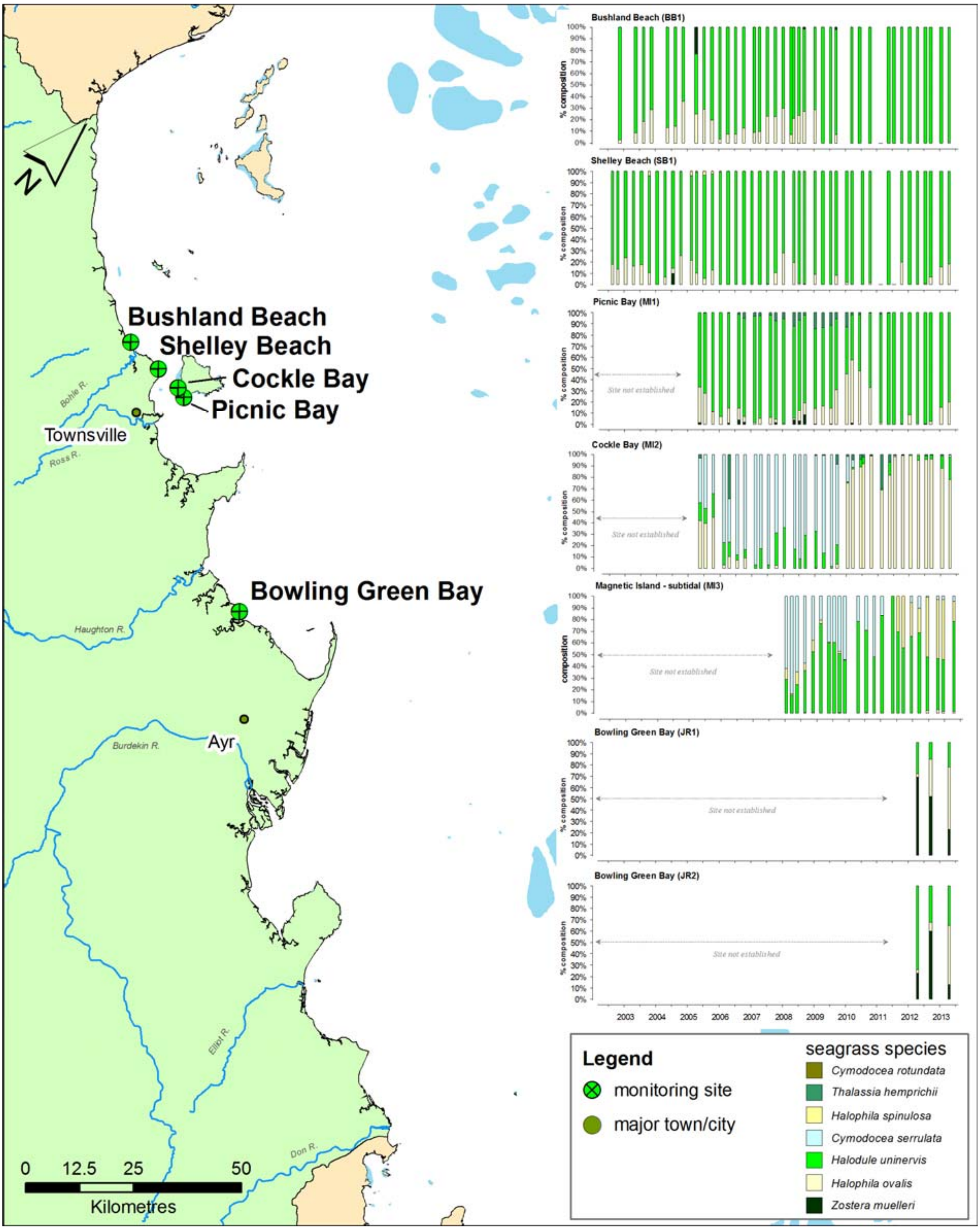

Figure 56. *Location of Burdekin region long-term monitoring sites in coastal (Bushland Beach, Shelley Beach and Bowling Green Bay) and reef (Picnic Bay and Cockle Bay, Magnetic Island) habitats, and the seagrass species composition at each site each monitoring event. Please note: replicate sites within 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 1, Figure 108). The meadows are typically composed of zones of seagrasses: *Cymodocea serrulata, Thalassia hemprichii* and *Halodule uninervis* (wide leaved) 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 primarily nitrogen limited, 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.

Results and discussion

Status of the seagrass community

Seagrass abundance and composition

Seagrass abundance (% cover) improved over the past 12 months, but remains in a poor state (Figure 57).

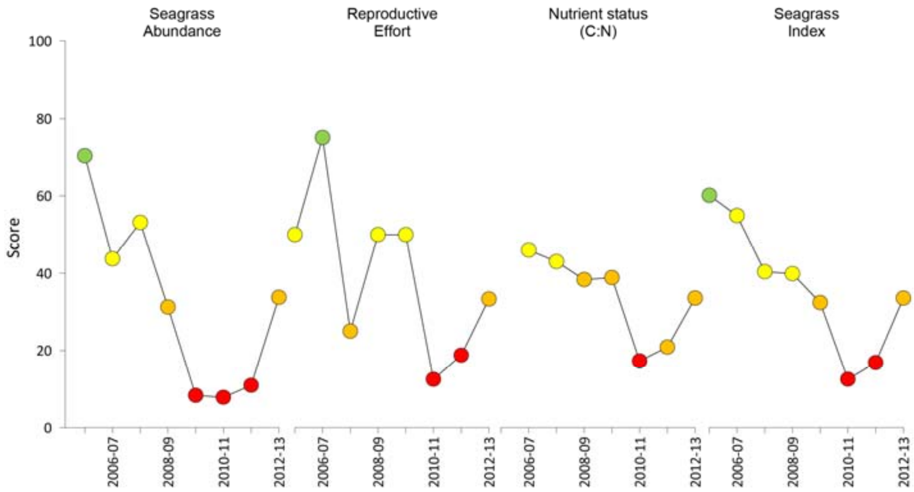

Figure 57. *Report card of seagrass status indicators and index for the Burdekin NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Seagrass meadows in the Burdekin NRM region experienced half- to ten-fold increases in abundance over the 2012-13 period, compared to the previous monitoring period, at coastal and reef habitats, respectively (Figure 58). These were the highest abundances in the last four years. Although the change in abundance was not as great in 2012-13 as the previous monitoring period, this was a consequence of plants in 2011/12 recolonising either bare substrate or areas with remnant shoots.

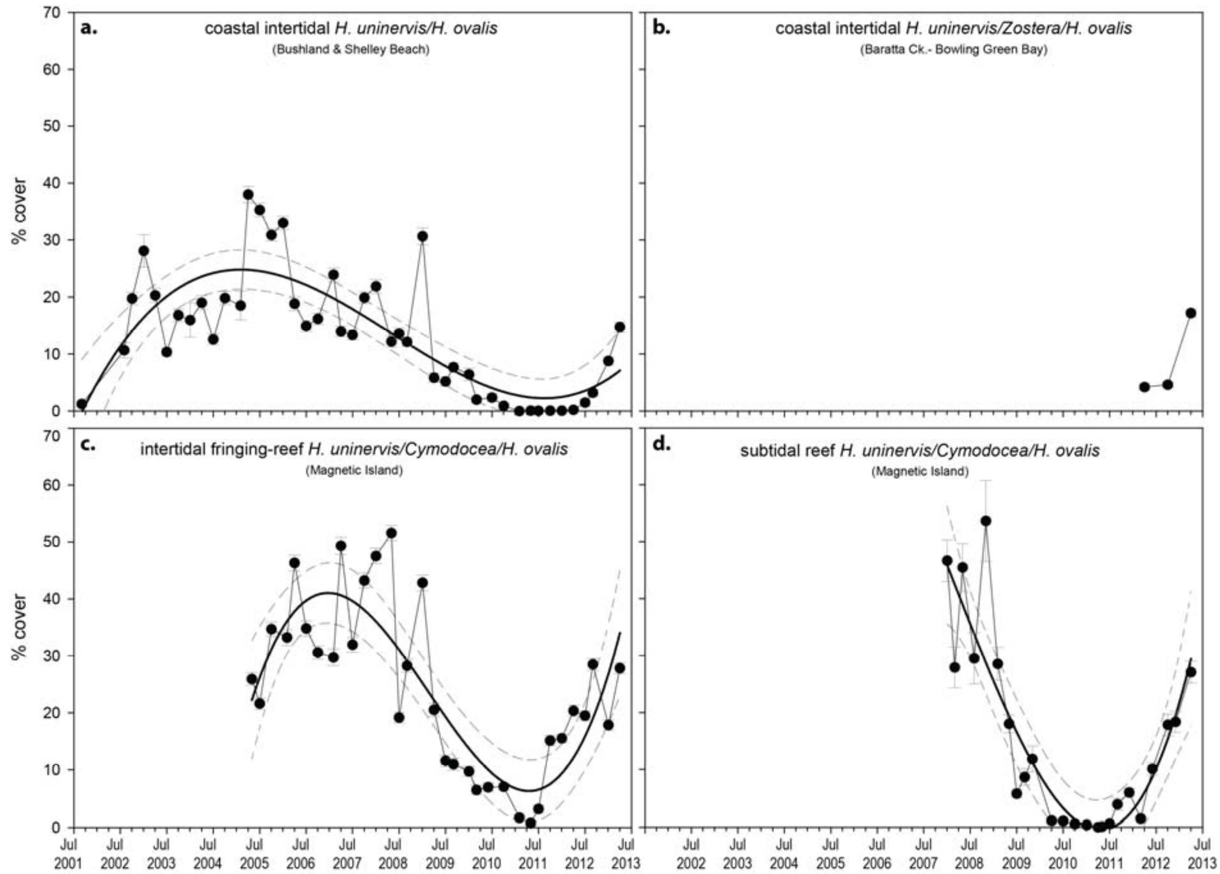

Figure 58. *Changes in mean seagrass abundance (% cover ±Standard Error) at inshore coastal intertidal (a, b), reef intertidal (c) and reef subtidal (d) meadows in the Burdekin region, 2001-2012. Trendline is 3rd order polynomial, 95% confidence intervals displayed, coastal intertidal r^2 = 0.64, reef intertidal r^2 = 0.72 and reef subtidal r^2 = 0.83.*

Since monitoring was established, coastal meadows in the region have displayed a seasonal pattern in abundance; high in the monsoon and low in the dry season (McKenzie *et al.* 2012a). This, however, was not apparent over the last 2 years, as seagrass has been recovering from losses experienced in early 2011 as a consequence of TC Yasi. Long-term seagrass abundances were generally higher in reef than coastal habitats, however, the seasonal difference (approximately two thirds) in percent cover for each was similar: coastal = 12.2 ±1.7% in the dry and 14.9 ±2.2% in monsoon season; reef = 22.4 ±2.4% in dry and 26.8 ±3.0% in monsoon.

Coastal meadows remained dominated by either *Halodule uninervis* or *Zostera muelleri* with small amounts of *Halophila ovalis* over the 2012-13 period (Figure 56). The dominance of the foundational/K-strategist species, particularly over the last 5 monitoring periods indicates meadow recovery. The increase in K-strategist species during the greatest period of disturbance (2011) is unexpected (Figure 59), however 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 colonising/*r*-strategist species (*Halophila ovalis*) in 2012-13 suggests some level of increasing disturbance, which if continued may weaken ecosystem resistance.

Intertidal reef habitats on the fringing reef platforms of Magnetic Island, were dominated by either *Halodule uninervis* (Picnic Bay) or *Halophila ovalis* (Cockle Bay). Prior to 2009-10, the meadow at Cockle Bay was dominated by the foundational species *Cymodocea serrulata* and *Thalassia hemprichii* (Figure 56). 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. Intertidal meadows at reef habitats in the Burdekin NRM region during 2012-13 were composed of a greater than average proportion of *r*-strategist species, particularly over the last 4 monitoring periods (Figure 59). This suggests the meadows have been severely disturbed and are recovering from perturbations in recent years. The greater proportion of colonising/*r*-strategist species also suggests weaker ecosystem resistance. Conversely, the meadows in the subtidal reef habitat were dominated by K-strategist species (Figure 59), suggesting a stronger ecosystem resistance.

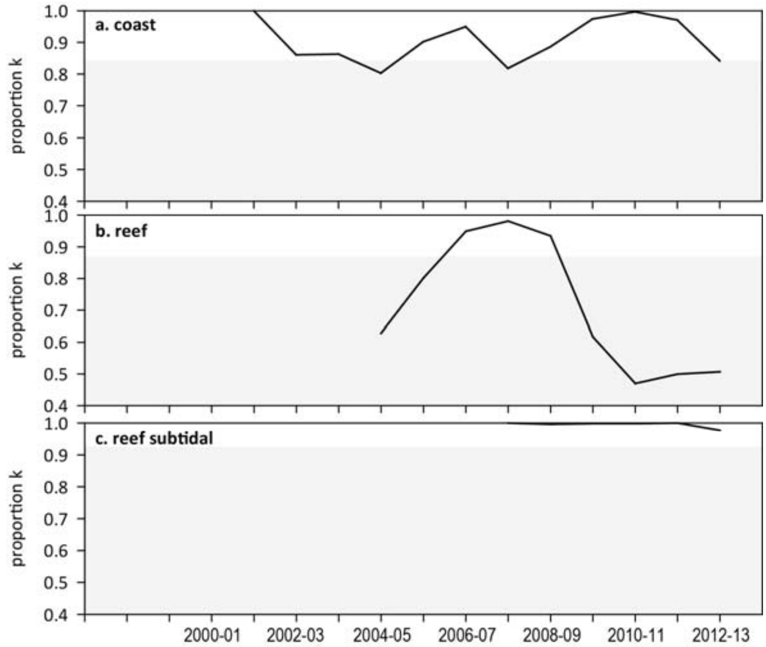

Figure 59. *Proportion of seagrass abundance composed of K-strategist species at inshore habitats in the Burdekin region, 2001 - 2013. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

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 1, Table 22). 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 60). Since 2011, meadow extents have increased in both coastal and reef habitats to pre-2009 levels (Figure 60).

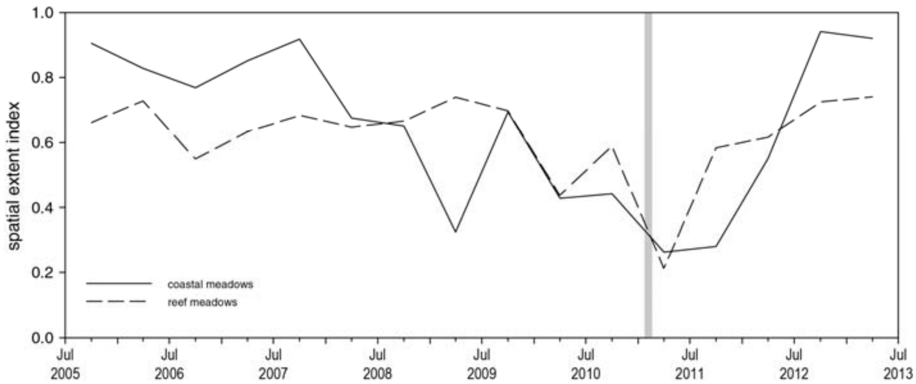

Figure 60. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Burdekin region, 2005 - 2013. Vertical grey bar indicates TC Yasi.*

Seagrass at other locations not monitored by the MMP, either reported recovery or no improvement in 2012. Annual monitoring for the Port of Townsville reported the onset of recovery in October 2011 after unprecedented declines in biomass and distribution in 2010 (McKenna and Rasheed 2012), and recovery continued throughout 2012 (data and report not available). Quarterly monitoring for the North Queensland Bulk Ports Corporation in the Port of Abbot Point reported protracted seagrass recovery in early 2012 (after losses experienced in September 2011). Only one of the five inshore meadows monitored showed the onset of recovery in 2012, but all seagrass was lost by September 2012 (McKenna and Rasheed 2013b). Discerning seagrass state at coastal and subtidal locations such as Abbott Point 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. The authors suggest recovery may be limited due to the absence of seed banks or propagules (data not presented) (McKenna and Rasheed 2013b).

Seagrass reproductive status

A persistent *Halodule uninervis* seed bank has remained, albeit a very low amount, at coastal habitats across the region (Figure 61). A seed bank was absent at reef habitats in 2011/12, but recovered in 2012-13 after increasing in the late dry season 2012 (Figure 61). Reproductive effort improved across the region to good in 2012-13 for reef habitats, but remained poor at coastal habitats (Table 18). The greater seed bank and higher reproductive effort at reef sites indicates a high capacity to recover following disturbance. 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.

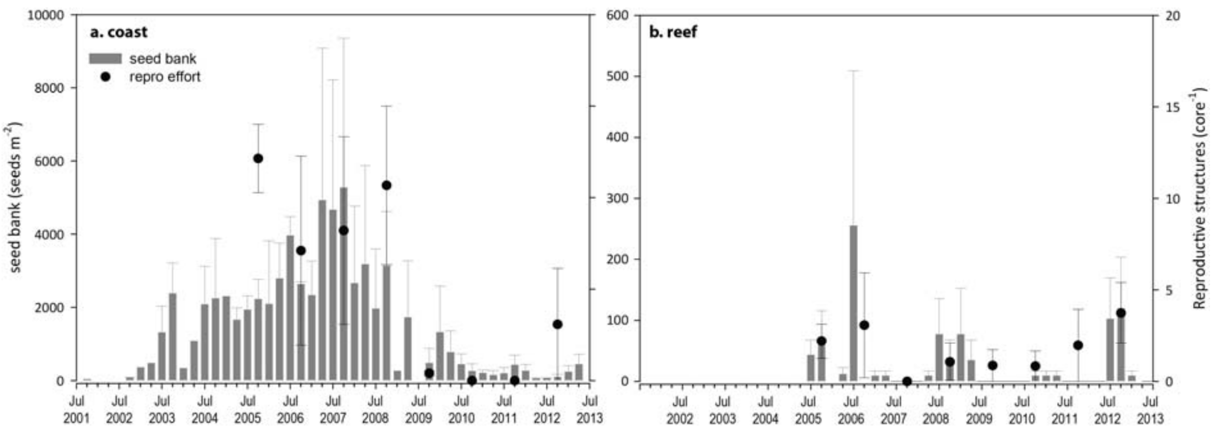

Figure 61. *Seed bank and late dry season reproductive effort at inshore intertidal coast and reef habitats in the Burdekin region. Seed bank presented as the total number of seeds per m² sediment surface, and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled). NB: Y-axis scale for seed banks differs between habitats.*

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf tissue molar C:N ratios across the region remained below 20 in 2012 (Figure 62). The lowest values were at coastal sites (Townsville and Bowling Green Bay), and values increased in 2012 at intertidal reef sites (Magnetic Island). Low and decreasing C:N ratios across the region since 2006 may indicate decreasing light availability and/or elevated N loading. $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were above (isotopically heavier) the global average and within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth.

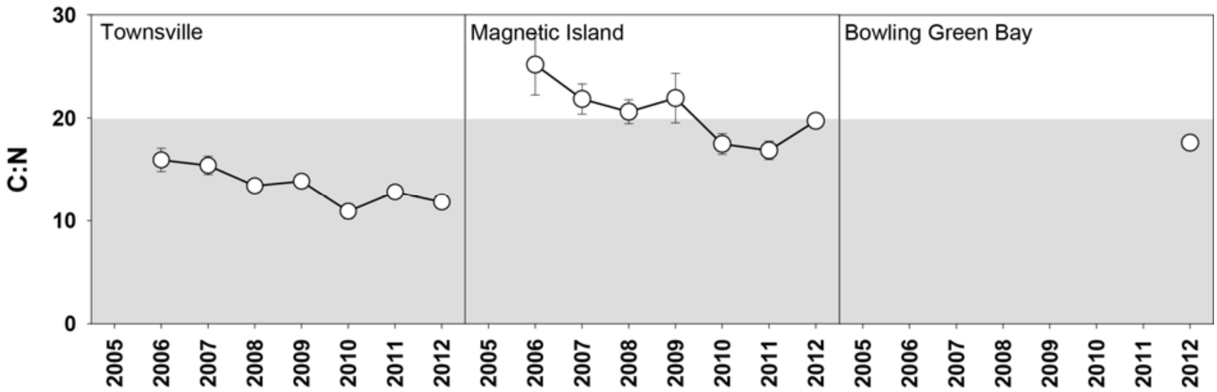

Figure 62. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore intertidal location in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline 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.*

With the exception of Townsville (Bushland Beach and Shelley Beach), seagrass leaf molar C:P ratios in 2012 were >500, indicating that the plants were growing in an environment with a relatively small P pool (Figure 63). Since monitoring was established in the coastal meadows at Townsville, C:P ratios have remained below 500, indicating the habitat remains nutrient rich, containing a large P pool (Figure 63). N:P ratios for the foundation species decreased slightly since the previous monitoring period, however reef habitat ratios remained between 25 and 30, indicating the plants remained replete (well supplied and balanced macronutrients for growth) (Figure 63). In the coastal meadows at Townsville, the N:P ratios remained above 30 (Figure 63), which coupled with a large P pool, indicated elevated N and P in the coastal environment. Leaf tissue ratios for the foundation species in Bowling Green Bay may also indicate elevated N, as the C:P and N:P ratios are only just above 500 and 30, respectively (Figure 63). In both coastal locations, the $\delta^{15}N$ values were between 1‰ and 5‰ for *Zostera muelleri* and *Halodule uninervis* in coastal habitats, suggesting the primary source of the elevated N was fertiliser and/or sewage (Appendix 1, Table 23).

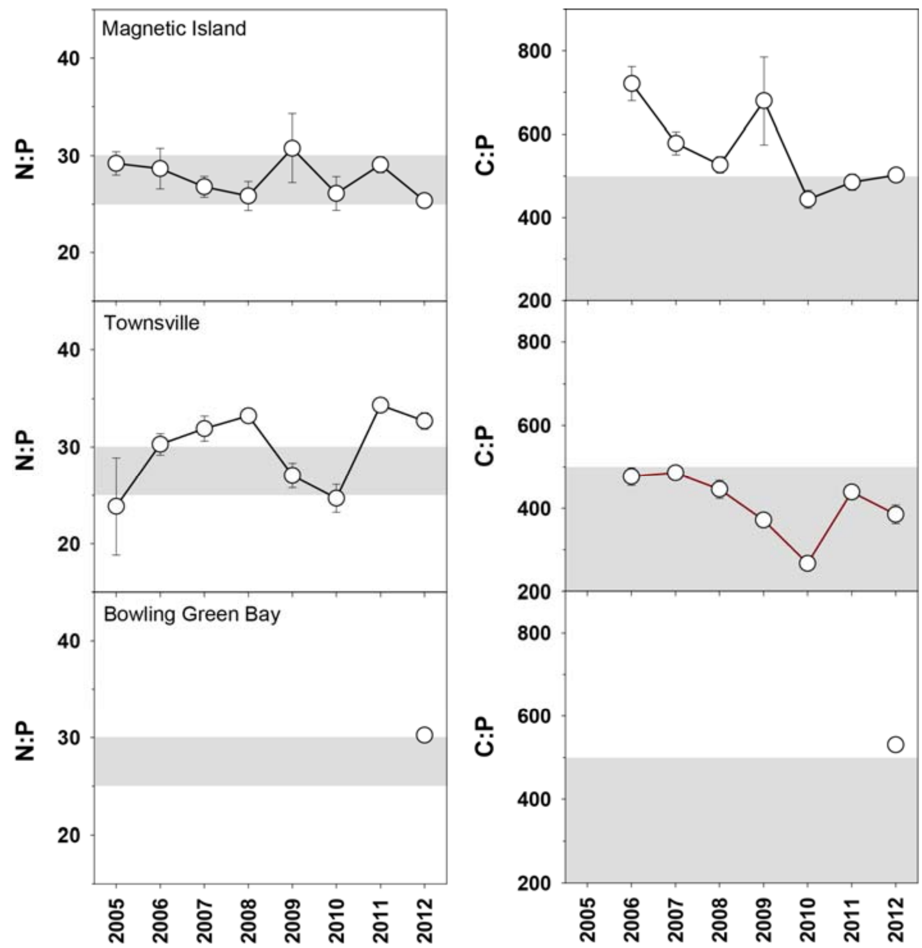

Figure 63. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore intertidal locations in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of 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 64; Appendix 1, Figure 120). Epiphyte cover appeared to have declined over the last three monitoring periods, but remained above the GBR long-term average over the 2012-13 wet season. Percentage cover of macroalgae at coastal sites has remained low over the past couple of years below the GBR long-term average (Figure 64; Appendix 1, Figure 120).

Epiphyte cover at reef habitats has increased over the last two monitoring periods, but in 2012-13 remained below the GBR long-term average. Prior to 2009, macroalgae was higher during the dry season at reef habitats, but over the last 24 months has been higher and above the GBR long-term average in the wet (Figure 64). Whether this difference is a result of macroalgae species changes is unknown as species identification is not collected. Epiphyte and macroalgae cover have remained low at subtidal habitats (Figure 64; Appendix 1, Figure 121).

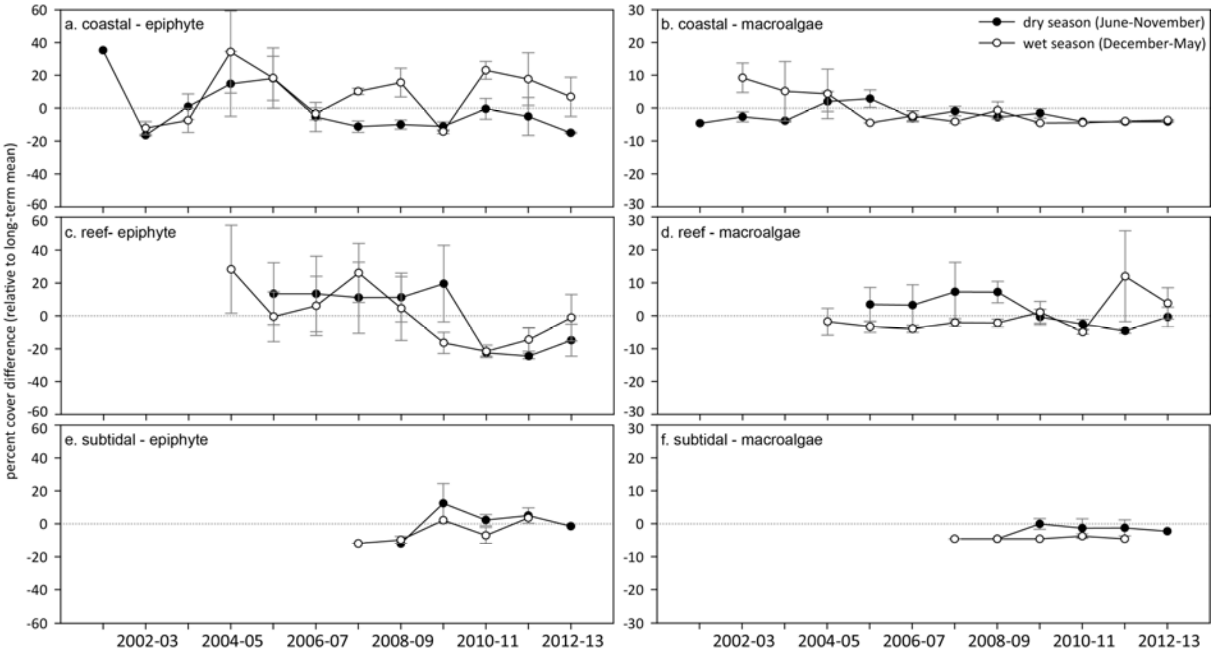

Figure 64. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore seagrass habitat in the Burdekin region (sites pooled, ±SE). GBR long-term average; coastal epiphytes = 17%,, coastal macroalgae = 4.7%, reef epiphytes= 285%, reef macroalgae = 6.2%.*

Rhizosphere sediment herbicides

Confirmed traces of Diuron at levels below the stated limit of reporting (0.001mg kg^{-1}) were found in the sediments of the seagrass meadows at sites adjacent to the mouth of Barratta Creek (Bowling Green Bay) on the 25th April 2013 (Appendix 1, Table 25). 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 (Appendix 1, Figure 133, Figure 134). Mean seawater temperatures within the seagrass meadows were similar to or slightly below the long-term (9 years) average, for reef and coastal habitats, respectively (Appendix 1, Figure 133, Figure 134). Coastal seawater temperatures were less than half a degree higher at Bowling Green Bay than Townsville. Higher temperatures (>35°C) were recorded from January to February 2013, however no extreme temperatures (>40°C) were recorded across the region (Figure 65). The highest temperature recorded was at Cockle Bay on 10 January 2013 when the seawater temperatures remained at 39.8°C for at least 30min between 1-3 pm (Figure 65a, Appendix 1, Figure 133). Overall, seagrass meadows in the region were exposed to 40 days of seawater temperatures above 35°C and 3 days above 38°C, which was less days than the previous 12 months (Figure 65). This suggests that 2012-13 was a less stressful year for seagrass in regards to seawater temperatures, ranking 7th over the last 9 years of data.

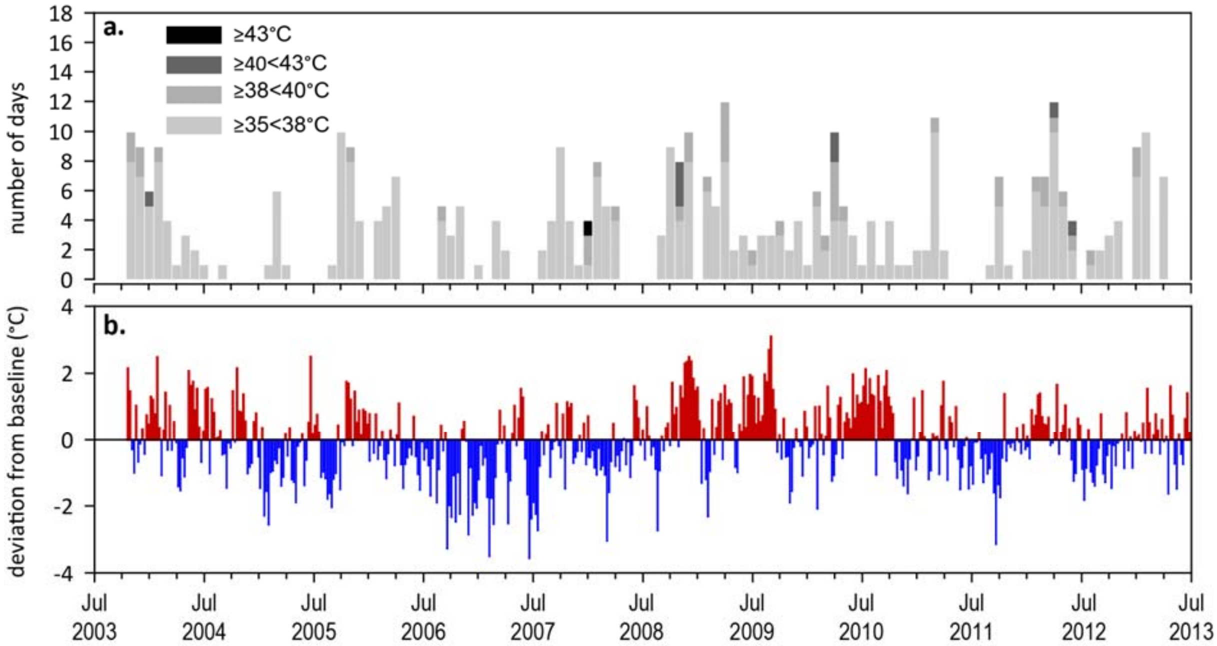

Figure 65. *Inshore sea temperature at inshore seagrass habitats in the Burdekin region, September 2003 - June 2013: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 10-year mean weekly temperature 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

Daily light (I_d) at monitoring sites in the Burdekin region were similar to, or above the long-term average during the 2012-13 reporting period, except at Cockle Bay where I_d was slightly lower than the long-term average (Figure 66; Appendix 1, Figure 140). There was site variability in I_d, with intertidal reef sites having the highest Id (15.6-16.1 mol m^{-2} d^{-1}) and the subtidal site at Picnic Bay having the lowest (5.8 mol m^{-2} d^{-1}). Thresholds were typically exceeded more frequently at the reef subtidal site (39% of days) than intertidal sites (6-26% days); except for the coastal intertidal site at Bushland Beach, which exceeded the light threshold 51% of days (Figure 27). Frequency of threshold exceedance was lower in 2012-13 than the long-term average at all sites. Similarly, turbidity, which is measured at only one site (MI3) in the Burdekin region was lower in 2012-13 (mean 2.5 NTU), compared to the long-term average (3.9 NTU) (Appendix 1, Figure 141). Daily light increased early in the dry season (during August) but peaked at a lower level than average (Figure 66).

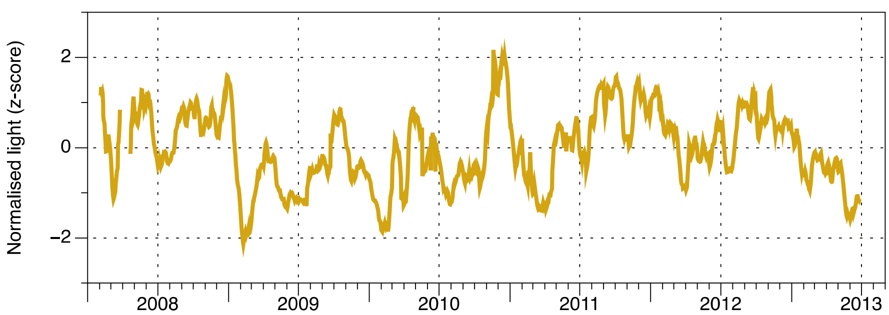

Figure 66. *Standardised daily light (28 day rolling average) for inshore seagrass habitats in the Burdekin region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

Regional climate and river discharge

Seagrass meadows across the Burdekin region (Cleveland Bay and Bowling Green Bay) in 2012-13 experienced 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 was higher than the previous few years.

The mean maximum daily air temperatures recorded across the region during 2012-13 (Townsville = 29.2°C; Ayr = 28.8°C) were similar to decadal and long-term (72 year) averages. The highest recorded daily maximum temperature in 2012-13 was 38.3°C in Townsville, the hottest in over a decade (Appendix 1, Figure 153). Skies were relatively clear in the region for much of the year, with 8% less cloud than the decade average, but 15% higher than the long-term (70 year) (Appendix 1, Figure 153, Figure 154). Although annual mean wind speed (24.1 $km.hr^{-1}$) was similar to both the last decade and long-term averages, the year had more days (174) with >25 $km.hr^{-1}$ winds than the last 2 years (Appendix 1, Figure 155). Annual rainfall over the current monitoring period (Townsville = 683mm, Ayr = 648mm) was 36% to 40% below average (for both the decade and long-term) (Appendix 1, Figure 153, Figure 154).

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 $4.6x10^6$ 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 2012-13, however, the lower than average rainfall resulted in below median discharges from the major rivers which benefitted the seagrass meadows monitored in the Burdekin region (Appendix 1, Table 26, Figure 170). The only river in the region with above median freshwater discharge was the Don in the very south (data not shown). Monitoring sites are approximately 135km north and outside the primary and secondary plumes (Michelle Devlin, JCU, Pers Comm).

Mackay Whitsunday

2012-13 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.

Seagrass abundance marginally increased at reef habitats in 2012-13, however at coastal and estuary habitats there was a near 2- to 3-fold increase. Despite this increase and the fact that 2012-13 abundances were the highest since 2009, seagrass abundance remains poor across all habitats. Reef and estuary meadows in 2012-13 were composed of a greater than average proportion of colonising species, suggesting weaker ecosystem resistance to major impacts, particularly for meadows with poor abundance. The increasing dominance of the foundational species in the coastal seagrass habitats over the last 4 monitoring periods suggests an improved ability to tolerate major disturbances. Meadows continued to increase in spatial extent across the region and their resource allocation appears towards vegetative expansion rather than seed production or sexual reproduction which may however make them vulnerable with a low capacity to recover following disturbance.

Analysis of seagrass leaf tissue suggests sufficient light for growth, but with elevated N in the coastal and reef habitats. Stable isotope ($\delta^{15}N$) values in the leaf tissue indicates the primary source of N was possibly sewage and/or fertiliser. Epiphyte cover increased at the coast habitats above the GBR long-term average further supporting the indication of increased available N in the inshore areas of the region.

Although seawater temperatures were cooler than the long-term average for the second consecutive year, seagrass across the region continued to face a number of climatic pressures in 2012-13, including above average air temperatures and some of the highest daily maximum air temperatures in over a decade. Rainfall across the region was variable, however, discharges from rivers which would impact nearby meadows were all above median for the 5th to 7th consecutive year. Also, the number of days with winds strong enough to resuspend benthic sediments was high enough to have created periods of both physical disturbance and light limitation for a nearly half of the year. Overall, the Mackay Whitsunday regional seagrass state has continued to improve since 2010/11, but in 2012-13 remains **very poor** (Table 19).

Table 19. *Report card for seagrass status (community & environment) for the Mackay Whitsunday region: June 2012 – May 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).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index^**
reef intertidal	0	50	11	**21**
coastal intertidal	17	0	16	**11**
estuarine intertidal	25	0	19	**15**
Mackay Whitsunday	14	17	16	**16**

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). 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, 55.5 ±11.8 km^2 of seagrass was mapped in the central section of the region, 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 catchments (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 1, Figure 109). Monitoring sites of estuary habitat were located on the intertidal mud banks within Sarina Inlet in the south of the Mackay Whitsunday region.

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 1, Figure 110). Monitoring sites of coastal seagrass habitat were located on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay.

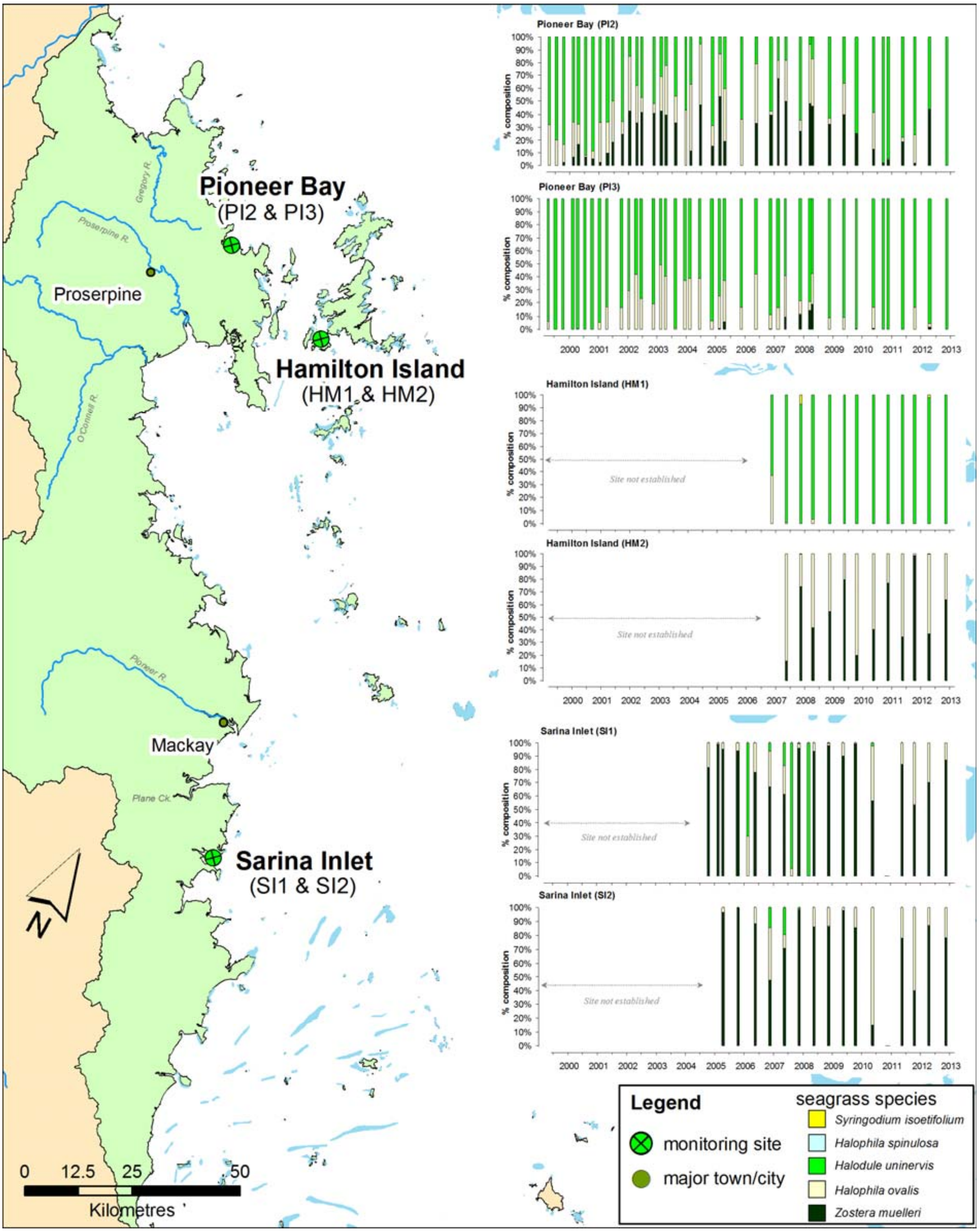

Figure 67. *Location and species composition of each long-term seagrass monitoring site in the Mackay Whitsunday region. Please note: replicate sites within 500m of each other.*

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 1, Figure 111). Major threats would be increased tourism activities including marina and coastal developments. Monitoring sites of reef habitat were located at Hamilton Island, within Catseye Bay.

Results and discussion

Status of the seagrass community

Seagrass abundance, composition and extent

Seagrass abundance marginally increased at reef habitats in 2012-13, however at coastal and estuary habitats there was a near 2- to 3-fold increase. Despite the increase and that 2012-13 abundances were the highest since 2009, seagrass abundance remains poor across all habitats (Table 19, Figure 68).

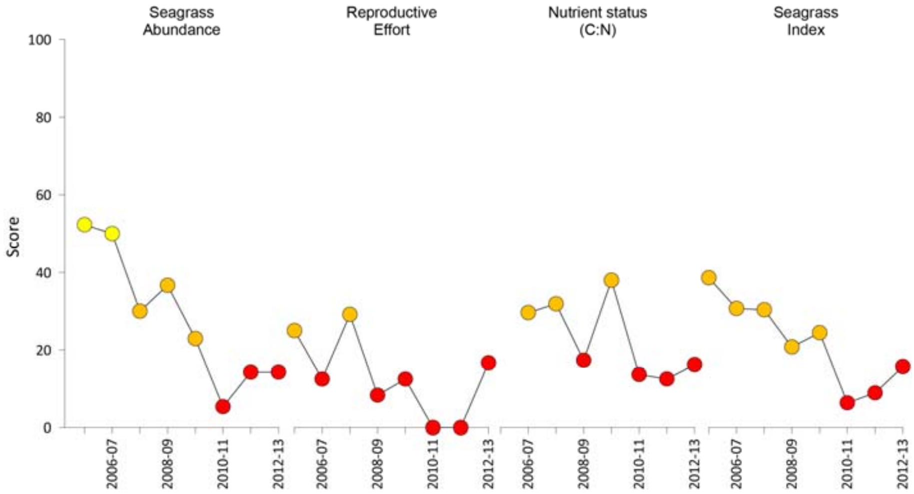

Figure 68. *Report card of seagrass status indicators and index for the Mackay Whitsunday NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Seagrass species and abundance has fluctuated at the coastal habitats between and within years, indicating disturbance regimes at longer time periods than annually (Figure 69). Seagrass abundance remained low at coastal habitats in 2012-13, although in the late monsoon abundances increased to just below the long-term (14 years) average. 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 due to consecutive monsoon seasons of above average rainfall (Figure 69).

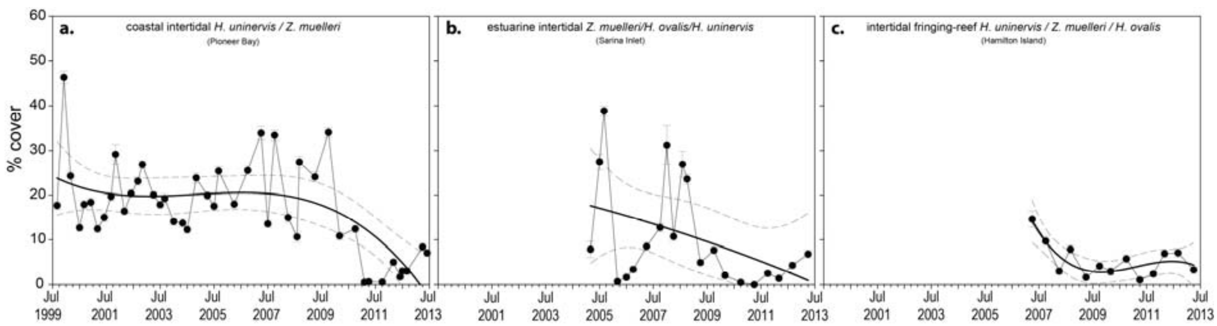

Figure 69. *Changes in seagrass abundance (% cover ±Standard Error) at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2013: a). coastal, b). estuarine, and c). reef. Trendline is 3rd order polynomial, 95% confidence intervals displayed: coastal r^2 = 0.37, estuarine r^2 = 0.19, reef r^2 = 0.67.*

The estuarine monitoring meadows improved in abundance throughout 2012-13 and although still rated as poor, were at the same state as the 2009 baseline (Figure 69). Seagrass cover has fluctuated greatly since monitoring was established in early 2005, with seagrass severely declining in the late wet season of 2006, recovering within 18 months, and subsequently declining again in 2008 (Figure 69). 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 season (Figure 69).

Seagrass abundance at reef habitats slightly improved over the 2012, however this improvement was protracted as the meadows subsequently declined in late monsoon 2013 (Figure 69).

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 67). Since the late monsoon 2011, the seagrass meadows were predominately *H. uninervis* (Figure 67). 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 2012-13 they were dominated by *Zostera muelleri* with some *Halophila ovalis* (Figure 67). 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 67).

Seagrass meadows on reef and estuary habitats in the Mackay Whitsunday NRM region were composed of a greater than average proportion of *r*-strategist species (Figure 70). This suggests the meadows in these two habitats are dynamic in nature and have experienced perturbations in recent years. The greater proportion of *r*-strategist species also suggests a weaker ability to tolerate major disturbances, particularly for meadows with poor abundance. The dominance of the foundational/K-strategist species in the coastal seagrass habitats in the Mackay Whitsunday NRM region, particularly over the last 4 monitoring periods suggests these meadows may have a greater ecosystem resistance to tolerate disturbances (Figure 70).

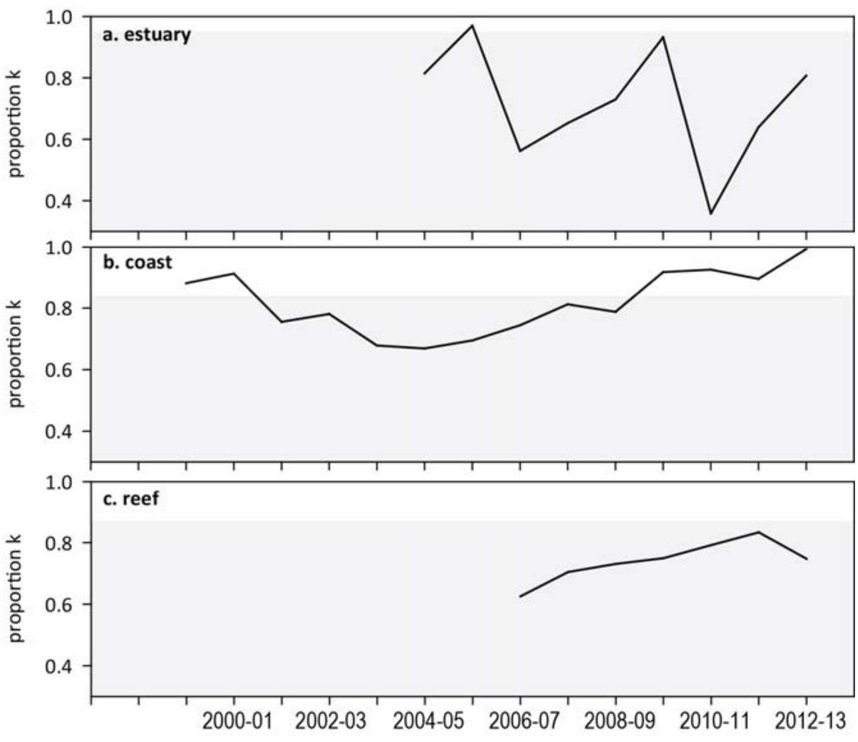

Figure 70. *Proportion of seagrass abundance composed of K-strategist species at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2013. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type*.

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 1, Table 22) to determine if changes in abundance were a consequence of the meadow edges changing. Over the past 12 months, reef meadows expanded and coastal meadows reached their greatest extent since the losses in 2011 (Figure 71). The estuarine meadows increased slightly in extent, although they appear to expand and contract seasonally (Figure 71).

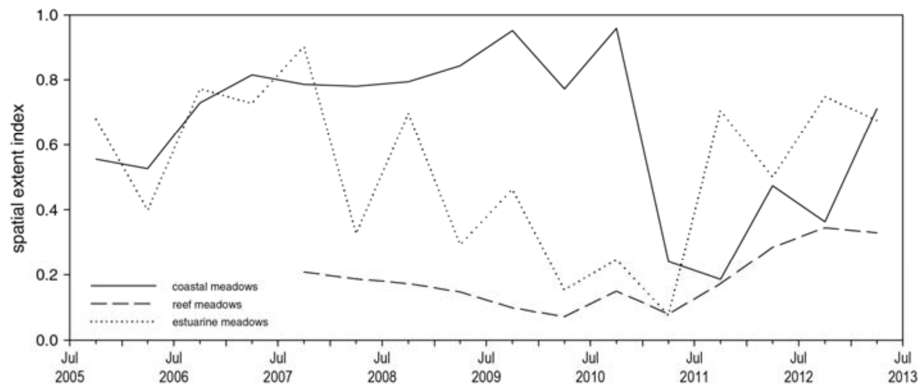

Figure 71. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat and monitoring period across the Mackay Whitsunday NRM region.*

Seagrass reproductive status

Banks of predominately *Halodule uninervis* and some *Zostera muelleri* seeds have varied greatly over the past decade, however, no seeds have been found in reef habitat meadows. Seeds were generally higher at coastal than estuary habitats (Figure 39), although, over the last 12 months, banks have increased within estuary meadows. As reproductive effort was very low (estuary) or absent (coast) in 2012-13, the meadows will have limited capacity to continue to recover without production of seeds. Overall, this may reduce the capacity of the meadows to recover from disturbances in the near future. The higher reproductive effort in reef habitats may suggest an improvement in seed banks in future, which would improve the capacity of the meadows to recover from larger disturbances.

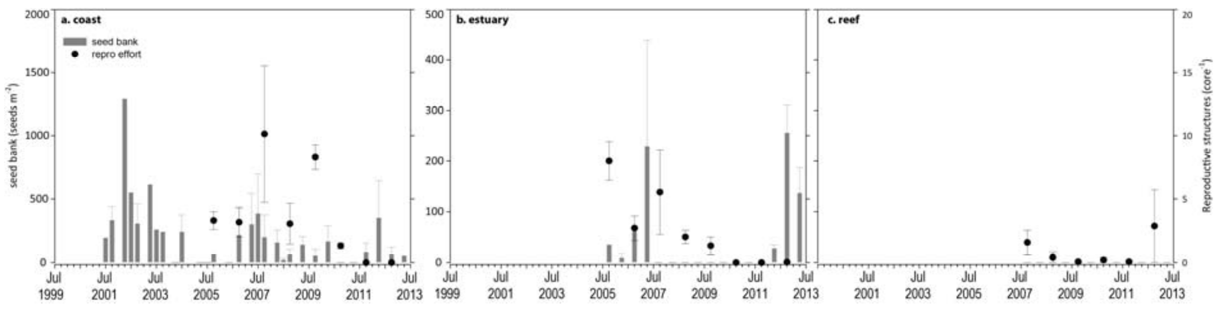

Figure 72. *Seed bank and late dry season reproductive effort at inshore intertidal coast, estuary, and reef habitats in the Mackay Whitsunday region, 2001 - 2013. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled). NB: Y-axis scale for seed banks differs between habitats.*

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf molar C:N ratios in the Mackay Whitsunday region have all remained below 20 since 2007 (Figure 73). $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were above (isotopically heavier) the global average and within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth.

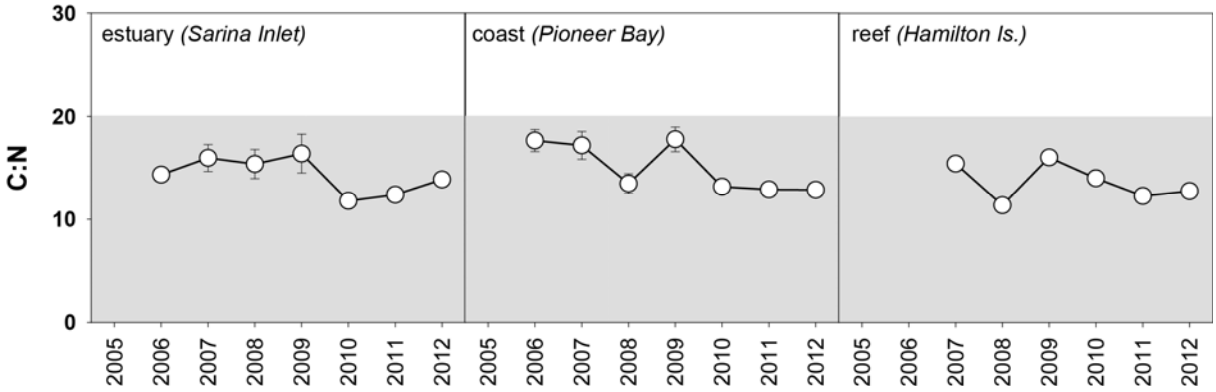

Figure 73. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline 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.*

Seagrass leaf molar C:P ratios have remained below 500 for all seagrass habitats over the last 3 years, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 74). N:P ratios for the foundation species also increased at reef and coastal habitats to >30 in 2012-13, which coupled with the large P pool, indicates elevated N and P in the reef and coastal environments. Estuary N:P ratios decreased slightly since the previous monitoring period, but remained replete, indicating well supplied and balanced macronutrients for growth (high N and P) (Figure 63). In both estuarine and reef locations the $\delta^{15}N$ values for the dominant species (*Zostera muelleri*) were above 2‰, and at reef habitats it was above 4‰ (both among the highest values observed in this species), suggesting the primary source of the elevated N was fertiliser or sewage (Appendix 1, Table 23).

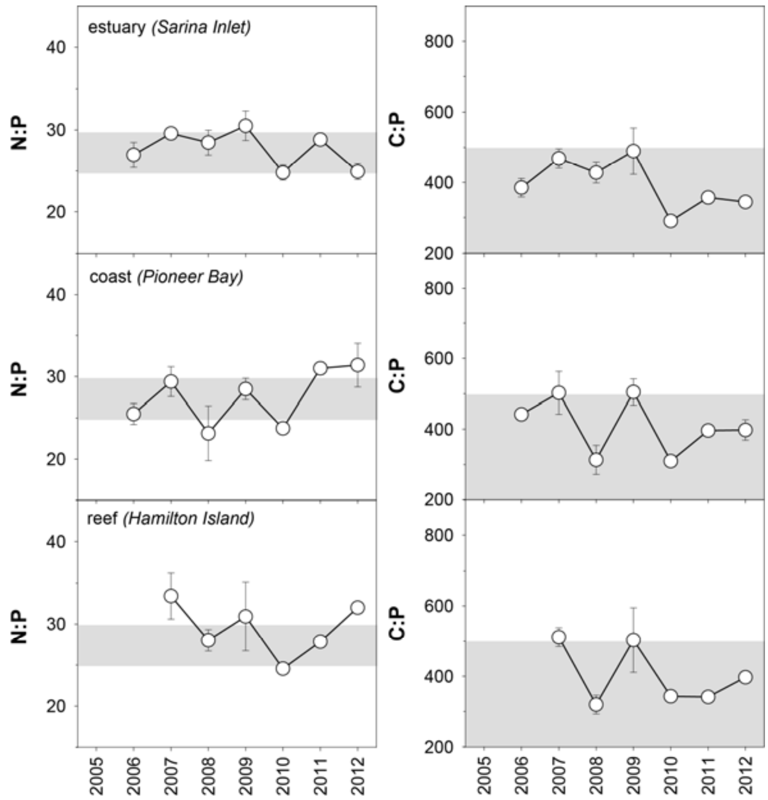

Figure 74. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, 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, however no patterns were apparent for estuary or reef habitats (Figure 75; Appendix 1, Figure 123). Epiphyte cover at reef and estuary habitats in 2012-13 were lower than the GBR long-term average (Appendix 1, Figure 124, Figure 125). Epiphyte cover at coastal habitats during the 2012-13 wet season were not only similar to the previous wet season, but remain some of the higher recorded over the past decade (Figure 75; Appendix 1, Figure 123). Percentage cover of macroalgae remained unchanged and below the GBR long-term average for all seagrass habitats throughout 2012-13 (Appendix 1, Figure 123, Figure 124, Figure 125).

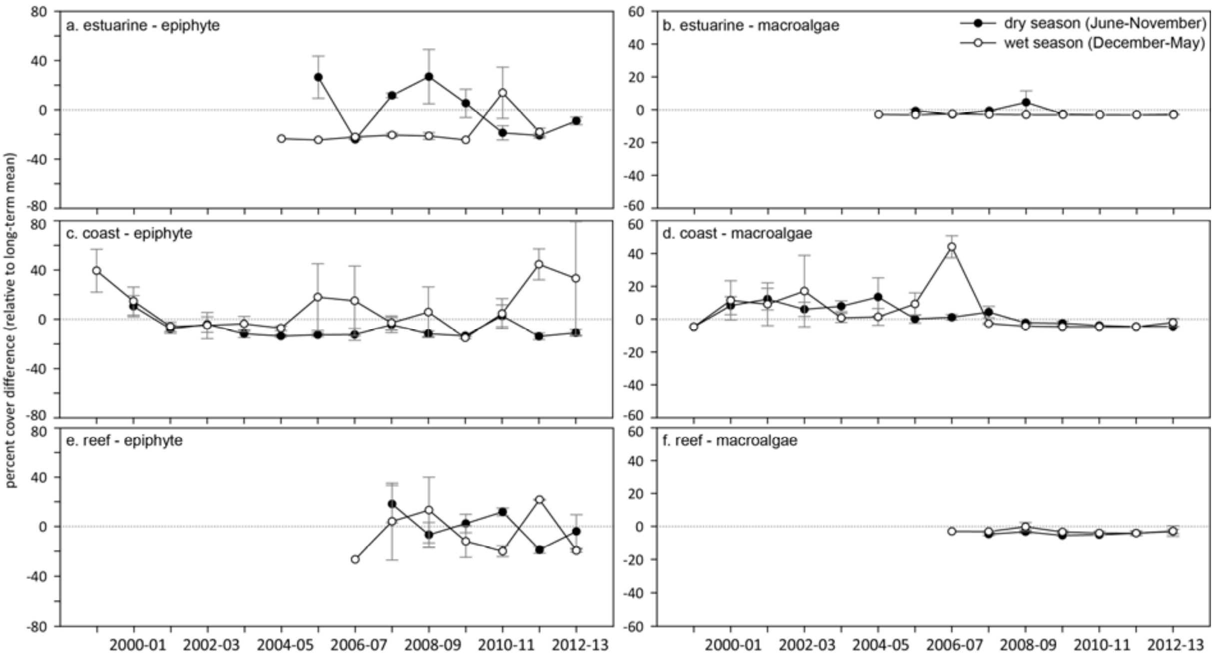

Figure 75. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore intertidal habitat in the Mackay Whitsunday region, 1999 - 2013 (sites pooled, ±SE). GBR long-term average; estuary epiphytes = 24.6%, estuary macroalgae = 3.2%, coastal epiphytes = 17%, coastal macroalgae = 4.7%, reef epiphytes= 25%, reef macroalgae = 6.2%.*

Within canopy seawater temperature

Autonomous temperature loggers were deployed at all locations monitored in the region (Appendix 1, Figure 135). Within canopy seawater temperatures followed a similar pattern at all habitats over the monitoring period (Appendix 1, Figure 135). Six days with high temperatures (>35°C) were recorded spread from September 2012 to April 2013, with the highest temperature (36.2°C) recorded at 2:30pm on the 26 October 2012 at Hamilton Island (Figure 76a). No extreme temperatures (>40°C) were recorded over the last 12 months. Within canopy temperatures across the region were cooler than the long-term average for the second consecutive year (Figure 76b), suggesting 2012-13 was a less stressful year for seagrass in regards to seawater temperature pressures.

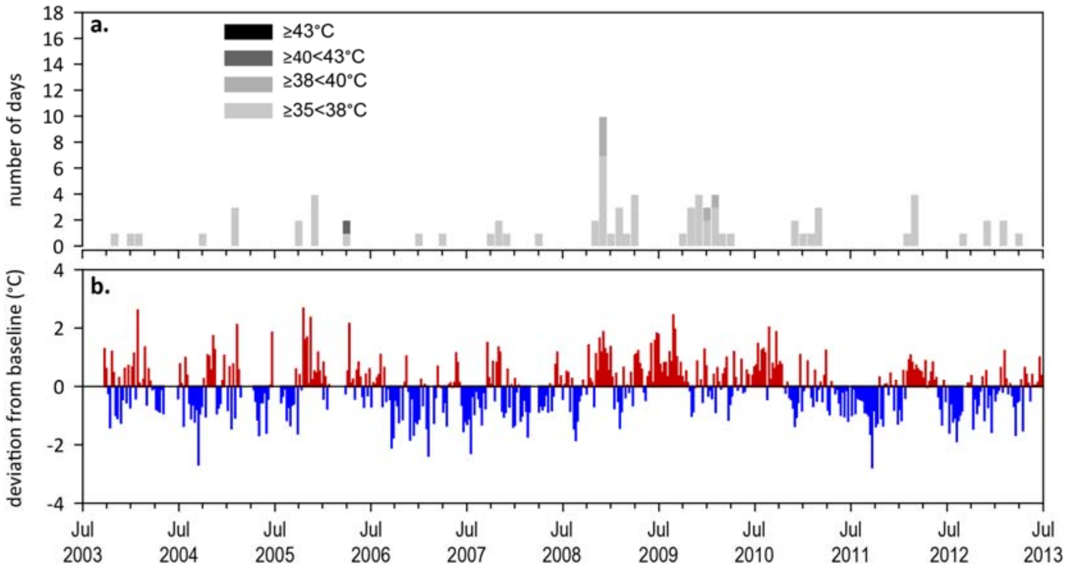

Figure 76. *Inshore sea temperatures within each intertidal seagrass habitat in the Mackay Whitsunday region, September 2003 - June 2013: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 10-year 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

Unlike the northern regions, daily light (I_d) at Mackay Whitsunday habitats was lower than the long-term average during the 2012-13 reporting period (Figure 77; Appendix 1, Figure 152). There was variability in I_d between habitats, with the intertidal reef having the highest I_d (12.3 mol m^{-2} d^{-1}) and the coastal having the lowest (5.4 mol m^{-2} d^{-1}). Thresholds were exceeded more frequently at the estuarine (Sarina Inlet) and coastal (Pioneer Bay) (35% and 50% of days) than the reef habitats (9% of days) (Figure 27). Furthermore, frequency of threshold exceedance was higher in 2012-13 than the long-term average at the estuarine and coastal habitats. Across the region (habitats pooled), daily light peaked in late September 2012 and was the lowest in February to March 2013 (Figure 77).

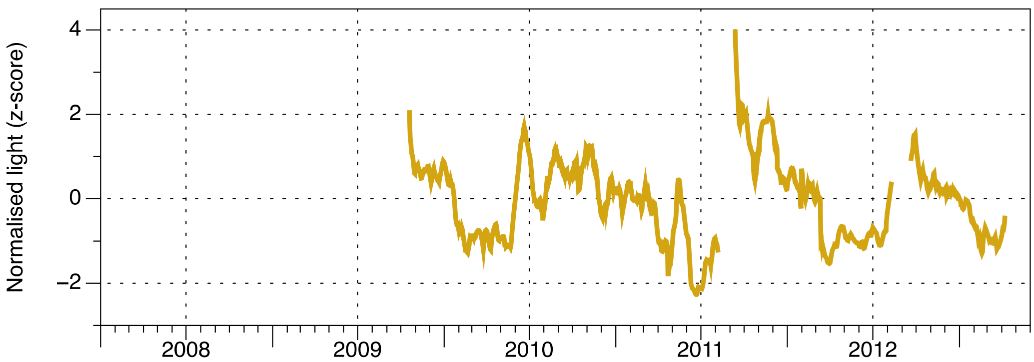

Figure 77. *Standardised daily light (28 day rolling average) for inshore intertidal seagrass habitats in the Mackay Whitsunday region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

Regional climate and river discharge

Seagrass meadows across the Mackay Whitsunday region in 2012-13 experienced above average air temperatures in the north and below average in the south, with some of the highest daily maximum air temperatures in over a decade. Rainfall across the region was variable however cloud cover was close to average values. Discharges from rivers which would impact nearby meadows were all above median for the 5th - 7th consecutive year, and although wind speeds varied across the region (close to average in the north and above average in the south), they were strong enough to have resulted in resuspension of inshore sediments, reducing water clarity, for 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 2012-13 was 28.6°C, which was 2°C higher than decade average but similar to the long-term (25 year) average (Appendix 1, Figure 156). The highest recorded daily maximum temperature in 2012-13 was 39.5°C, which was the highest in over a decade. Average temperatures were also experienced at Hamilton Island and Mackay (Sarina Inlet), and these locations similarly experienced the hottest days in 4 to 7 years (Hamilton Island = 33.2°C; Mackay = 36.9°C) respectively (Appendix 1, Figure 157, Figure 158). Average cloud cover was experienced throughout the year. Annual wind speeds in the north of the region (Proserpine = 21.8 $km.hr^{-1}$) were similar to the previous monitoring period and the long-term (23 year) average, but 23% lower than the decadal average. Wind speeds at Hamilton Island (29.5 $km.hr^{-1}$) were similar to the decadal average but 23% above long term (18 year) average and wind speeds at Mackay were also 8-10% higher than both the decadal and long-term (100 year) averages (Appendix 1, Figure 159). Overall this resulted in between 106 - 225 days in the north (Proserpine and Hamilton Island) and 165 days in the south (the highest in 6 years) where wind speeds would have resulted in resuspension of inshore sediments from the seabed into the water column, reducing water clarity for close to half of the year.

2012-13 was also a variable year in rainfall across the region. In the north annual rainfall (Proserpine = 1527mm) was 20% less than the decade annual average, but 3% higher than the long-term average. The islands experienced annual rainfall above the decade average (Hamilton = 1677mm), but 8% below the long-term annual average. The south, however, experienced 10 - 20% above annual rainfall (Plane Creek = 2057mm) compared to decadal and long-term (100yr) annual averages. Important to note that the cumulative rainfall totals are high because of consistent rains throughout the year, rather than large peak rainfall events like in previous years

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.* 2014). 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 2012-13 was the 5th - 7th consecutive year where above median volumes of freshwater were discharged from the major rivers in the region (Appendix 1, Table 26). Proserpine River experienced above median discharge for the 9th consecutive year. Similarly the discharges from the Pioneer River and Sandy Creek in 2012-13 were above median, but the O'Connell remained below median. Of the estimated volume discharged from the Proserpine River over the monitoring period (37,411 ML), 68% of the volume discharged occurred between January and March 2013, with the greatest average flows in March (Appendix 1, Figure 171). Similarly, 60-85% of discharge from the Pioneer River and Sandy Creek (respectively) also occurred between January and March 2013 (Appendix 1, Figure 172).

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Fitzroy

2012-13 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 state of seagrass abundance across the Fitzroy NRM region in 2012-13 remained unchanged from 2011-12. Seagrass abundance state at each of the habitats in the region remained very poor in reef habitats, poor in coastal habitats and moderate in estuarine habitats. The greater than average composition of colonising species in meadows indicates coastal and reef meadows had experienced perturbations in recent years and suggests weaker ability to tolerate major disturbances, particularly for meadows with poorer abundance. Coastal meadows remained relatively stable in extent, allocating resources to production of a greater seed bank, suggesting a higher capacity to recover, however, poor reproductive effort in 2012-13 may indicate seed bank limitation in the near future. The estuarine meadows have similarly remained relatively stable over the past 6 monitoring periods, however the small seed bank and poor reproductive effort indicates a low capacity to recover should they be experience any sizeable disturbances. Reef meadow extent increased in 2012-13, but the absence of reproductive effort and a seed bank may indicate that these meadows are allocating resources toward vegetative expansion rather than seed production or sexual reproduction. This also suggests a very low capacity to recover should they experience major disturbance.

There was no indication of elevated N in the estuary habitat, although *Zostera muelleri* $\delta^{15}N$ values suggested some influence of sewage. Similarly, there was no indication of elevated N at coastal habitats and $\delta^{15}N$ 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, possibly a consequence of increased epiphyte cover. The months with the most environmental stress to seagrass meadows over the monitoring period from climate related pressures was January to March 2013 when highest (incl. extreme) air and sea temperatures were experienced, rainfall and resulting river discharge was highest and when a greater number of days (particularly in the north) with wind-wave generated turbidity reducing light availability in the water column occurred.

Overall, the Fitzroy regional seagrass state has continued to decline since 2009/10, and remained **poor** in 2012-13 (Table 20).

Table 20. *Report card for seagrass status (community & environment) for the Fitzroy NRM region: June 2012 – May 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).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
reef intertidal	6	0	21	**9**
coastal intertidal	25	0	41	**22**
estuarine intertidal	47	0	62	**36**
Fitzroy	31	0	41	**24**

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 the concern about 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. 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 which frequently mobilise benthic sediments and reduce light availability, providing unsuitable environments for seagrass to establish (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 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) results in a near pristine environment, removed form anthropogenic influence. In contrast, the estuarine sites are located within Gladstone Harbour: a heavily industrialized port.

The Shoalwater Bay monitoring sites are located in a bay which is a continuation of an estuarine meadow that is protected by headlands. A feature of the region is the large tidal amplitudes and consequent strong tidal currents (Figure 112). As part of this tidal regime, large intertidal banks are formed which are left exposed for many hours at low tide. Pooling of water in the high intertidal, results in small isolated seagrass patches 1-2m above Mean Sea Level (MSL).

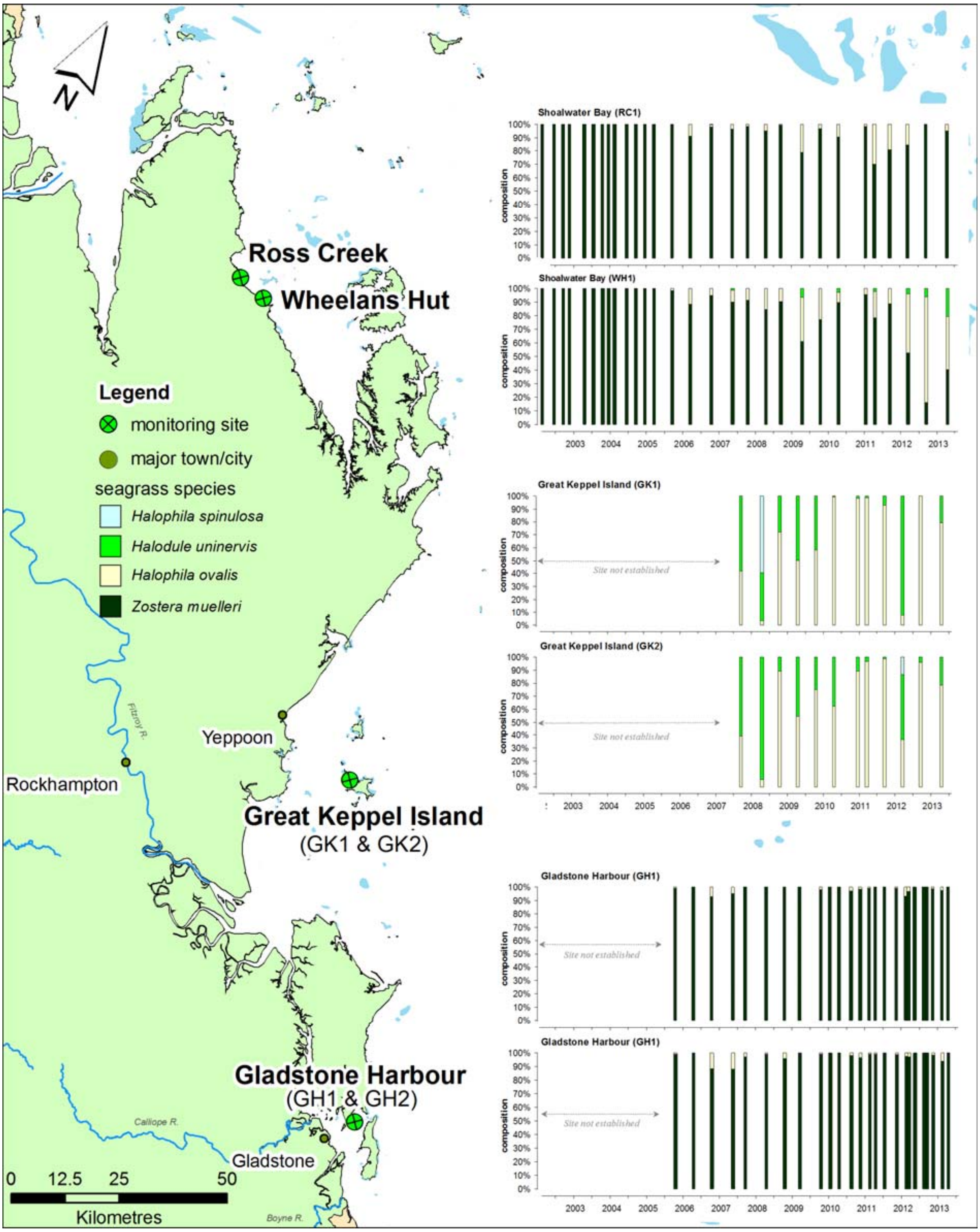

Figure 78. *Location and seagrass species composition of long-term monitoring sites in the Fitzroy region. Please note: some replicate sites within 500m of each other.*

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 113). 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.

Inshore reef habitat seagrass meadows are uncommon throughout the region, and are restricted to fringing reefs associated with islands in this region. Inshore turbidity in high due to the large tides, which also restrict seagrass to shallow banks. The drivers of these habitats are light and temperatures extremes and benthic sheer from the large tides (Figure 114). The monitoring sites are located on the shallow fringing reef in Monkey Beach, on the south-western shores of Great Keppel Island (Figure 78).

Results and discussion

Status of the seagrass community

Seagrass abundance, composition and extent

The state of seagrass abundance across the Fitzroy NRM region in 2012-13 remained unchanged from 2011-12. Seagrass abundance state at each of the habitats in the region remained very poor in reef habitats, poor in coastal habitats and moderate in estuarine habitats. Coastal and reef meadows across the region were also composed of a greater than average proportion of *r*-strategist species, which coupled with poor abundance may suggest weaker ability to tolerate/resist major disturbances.

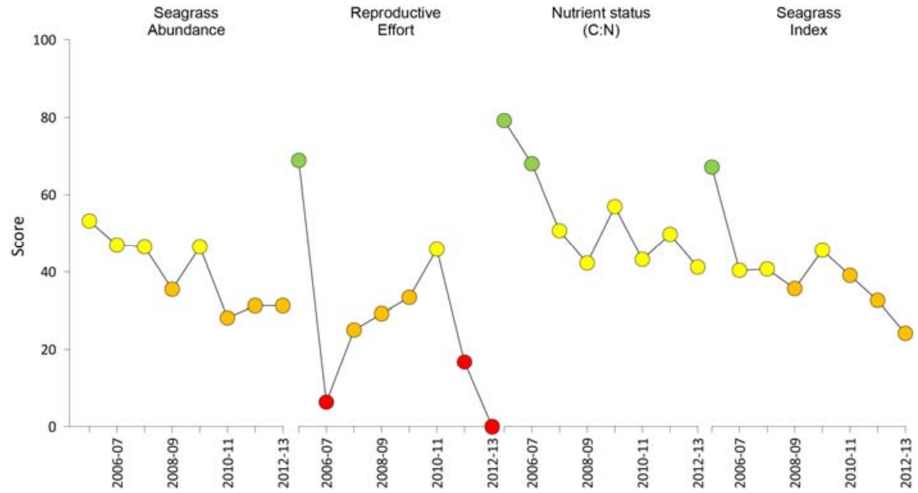

Figure 79. *Report card of seagrass status indicators and index for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

Over the 2012-13 monitoring period there was little change (excluding seasonal) in seagrass abundances at any of the habitats relative to the previous 12 months and no evidence that the declines experienced at the coastal sites since 2009 have continued (Figure 80). The long-term average seagrass abundances at coastal habitats in the Fitzroy NRM region differed seasonally, with late monsoon covers (17.4 ±1.7%) approximately three quarters those of the late dry season (23.7 ±1.7%). In 2012-13, coastal average abundances were a third lower in the late monsoon, but less than half the long-term (9 year) late dry seasonal average. Estuarine abundances in 2012-13 were close to or higher than average (incl. 95% confidence intervals): late dry season abundance was near 20% lower than the long term average, while late monsoon was 28% higher. Seagrass abundances at reef habitats did not change seasonally in 2012-13 (late dry=0.8 ±0.3%, late monsoon=0.8 ±0.2%) and remained below the long-term average (1.9 ±0.6%).

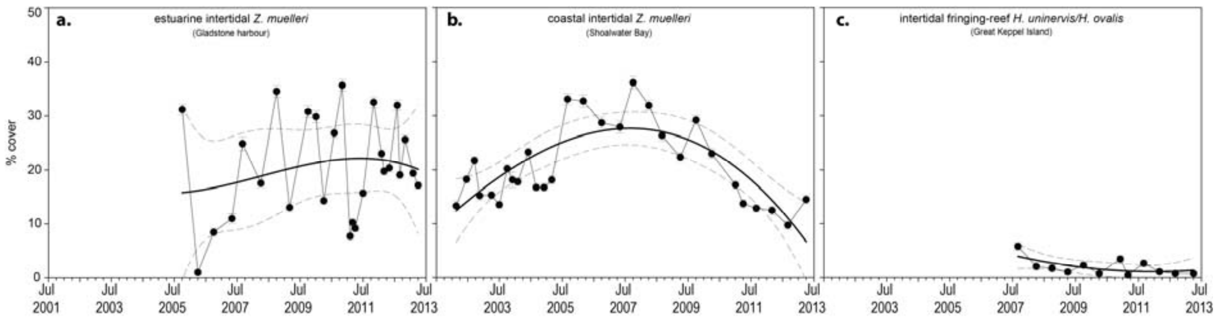

Figure 80. *Changes in seagrass abundance (% cover ±Standard Error) in inshore intertidal habitats of the Fitzroy region, 2001 - 2013: a) estuarine (Gladstone Harbour, b) coastal (Shoalwater Bay) and c) reef (Great Keppel Island). Trendline is 3rd order polynomial, 95% confidence intervals displayed, estuarine r^2 = 0.08, coastal r^2 = 0.61, and reef r^2 = 0.37.*

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 the colonising species *Halophila ovalis* at one of the replicates (WH1) may indicate a level of disturbance across the meadow (Figure 78). The monitoring sites at Great Keppel Island differ greatly from the inshore sites, being generally composed predominately of *H. uninervis* and *Halophila ovalis* on sand substrate (Figure 78). Over the 2012-13 monitoring period, meadows were dominated by *Halophila ovalis*. The estuarine meadows in Gladstone Harbour, located on the extensive intertidal Pelican Banks at the southern end of Curtis Island, remain dominated by *Zostera muelleri* and species composition has remained stable (Figure 78).

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 81). 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.

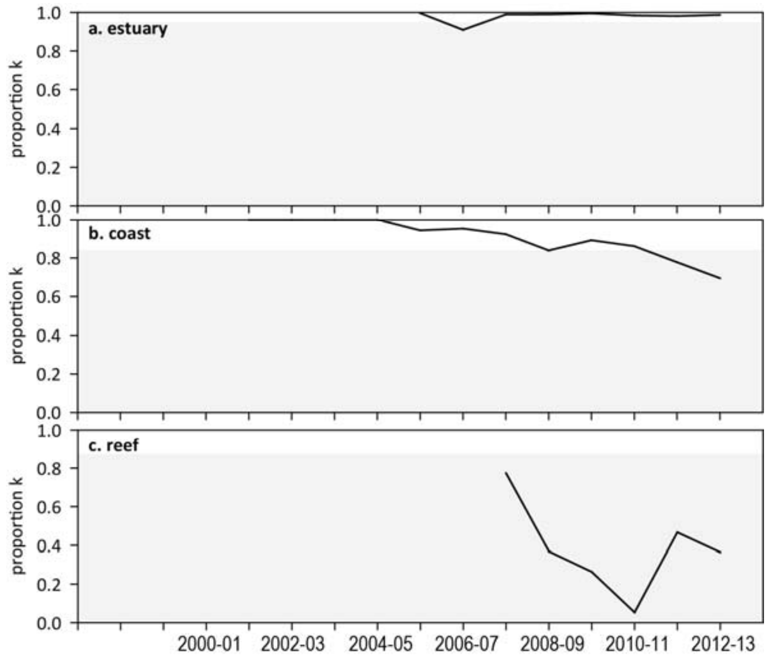

Figure 81. *Proportion of seagrass abundance composed of K-strategist species in inshore intertidal habitats of the Fitzroy region, 2001 - 2013. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 1, Table 22) to determine if changes in abundance were a consequence of the meadow edges changing. The coastal meadows in Shoalwater Bay have remained stable in extent since monitoring began. The estuarine meadows have remained relatively stable over the past 6 monitoring periods, however the meadows at the reef (Great Keppel Island) habitat have varied greatly (Figure 82). At Great Keppel Island, although the meadow increased overall in 2012-13, they in fact increased by over 3-fold in late 2012, only to halve in early 2013 (Figure 82).

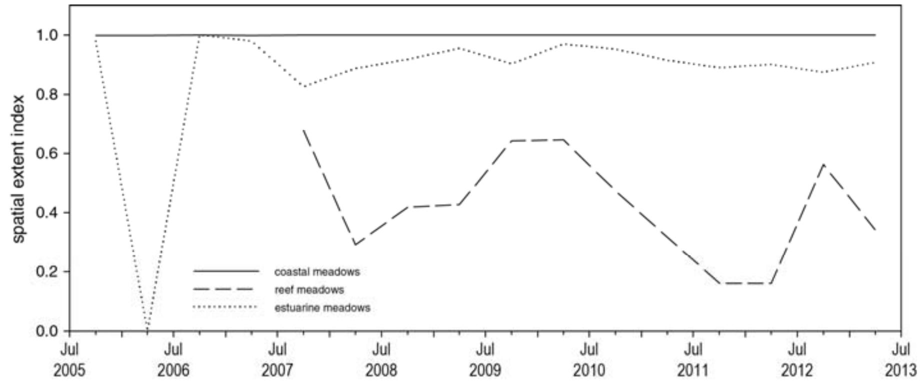

Figure 82. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each inshore intertidal habitat across the Fitzroy NRM region, 2005 - 2013.*

Seagrass reproductive status

Seed banks were higher at coastal than estuary or reef habitats in 2012-13 (Figure 83). A seed bank has persisted at estuarine meadows since early 2011 and increased in coastal meadows from 2011 to 2012. In the coastal habitats of Shoalwater Bay the largest seed banks since MMP commenced were measured in 2012-13.

The low seed bank and poor reproductive effort at estuary sites indicates a low capacity to recover following disturbance (Figure 83). Alternatively, at coastal sites, 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 83), 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.

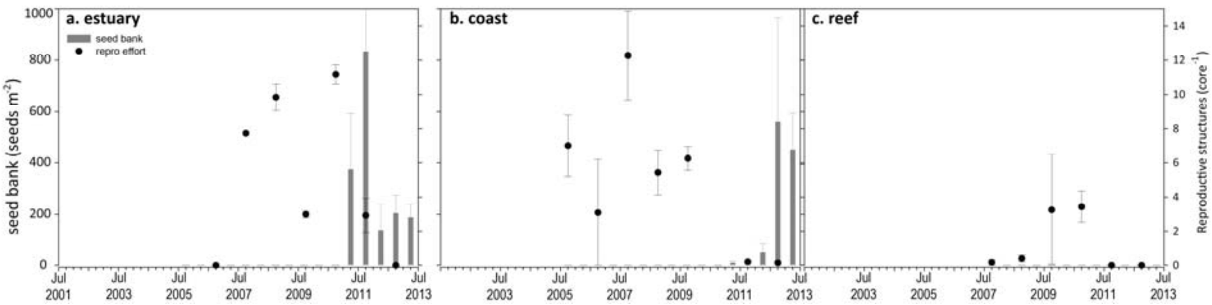

Figure 83. *Seed bank and late dry season reproductive effort for inshore intertidal coastal, estuary and reef habitats in the Fitzroy region, 2005 - 2013. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

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 84). Plants in reef and coastal habitats have remained low in carbon relative to nitrogen in 2012 (seagrass leaf molar C:N ratios <20) which may indicate either reduced light availability or elevated N. At estuary habitats, however, the ratio has remained above 20 for the last four years (Figure 84). $\delta^{13}C$ values for foundation species at all habitats during the late dry (growing) season were above (isotopically heavier) the global average and within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth.

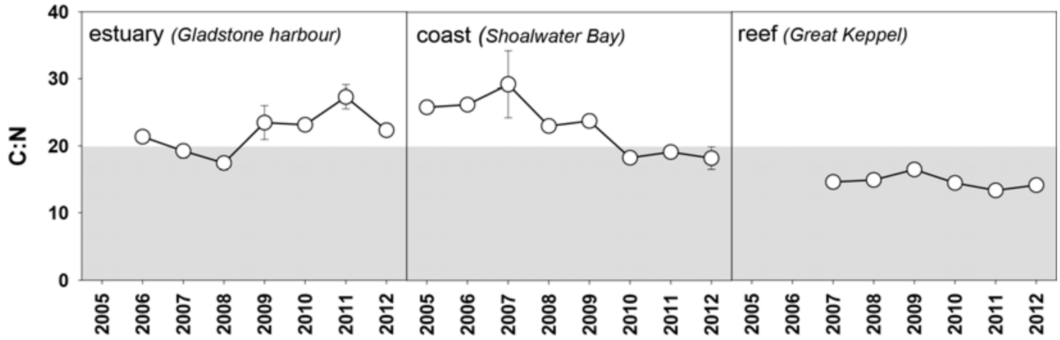

Figure 84. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "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.*

At coastal and reef habitats in the Fitzroy region, seagrass leaf molar C:P ratios remained below 500 in 2012, indicating nutrient rich habitats (large P pool) (Figure 85). At estuary habitats in Gladstone Harbour in late dry 2012, C:P ratios remained above 500, indicating a nutrient poor environment (small P pool) (Figure 85), which was also reflected in the increasing N:P ratios for foundation species (Figure 85). N:P ratios at coastal sites decreased below 25 in late dry 2012 (Figure 85); indicating the plants were low (possibly limited) in N relative to P. 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 1, Table 23).

At reef habitats in the Fitzroy region, N:P ratios decreased below 30 in late dry 2012 (Figure 85); indicating decreasing N in the environment but that the plants were replete (well supplied and balanced macronutrients for growth). 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 2012.

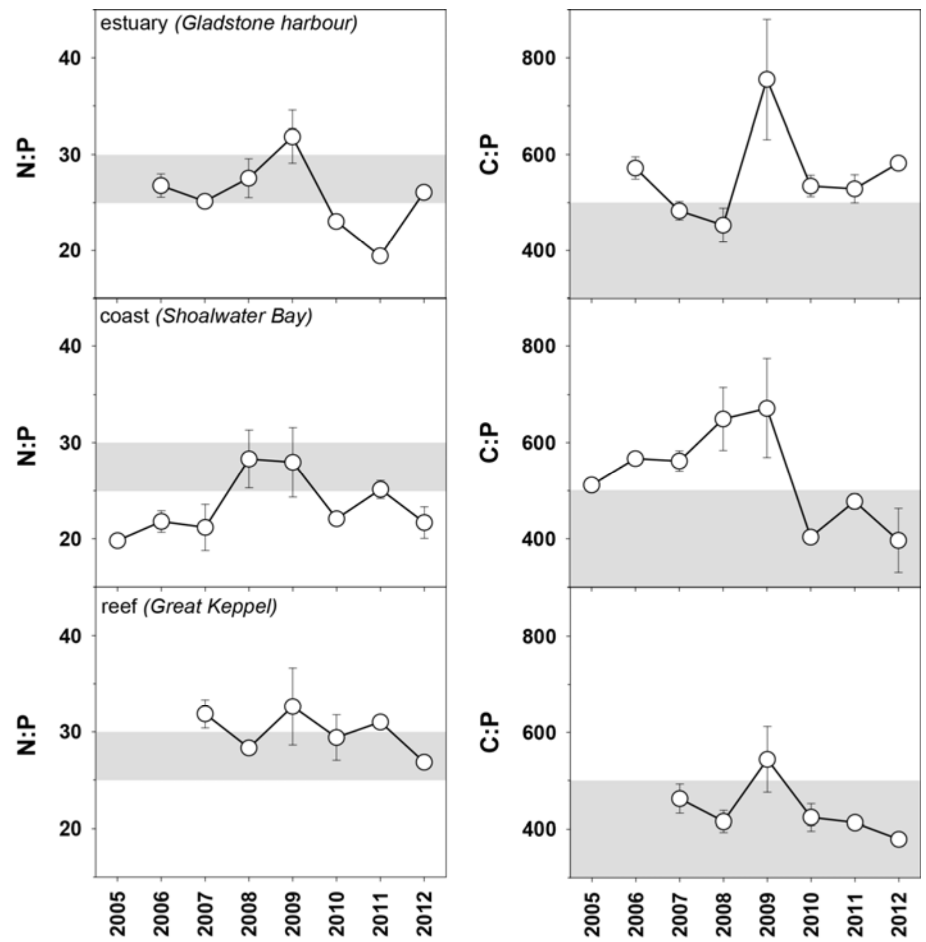

Figure 85. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2012 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value 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 estuarine and coast habitats either decreased or remained below the GBR long-term average over the 2012-13 monitoring period, respectively (Figure 86; Appendix 1, Figure 127, Figure 128). At reef habitats, however, epiphyte cover increased above GBR long-term average for the first time in 3 years, but only during the monsoon season (Figure 86; Appendix 1, Figure 126). Macroalgae cover remained unchanged at coastal and estuarine meadows in 2012-13 relative to the GBR long-term average, but marginally increased during the late monsoon at Great Keppel Island (reef habitat) (Figure 86).

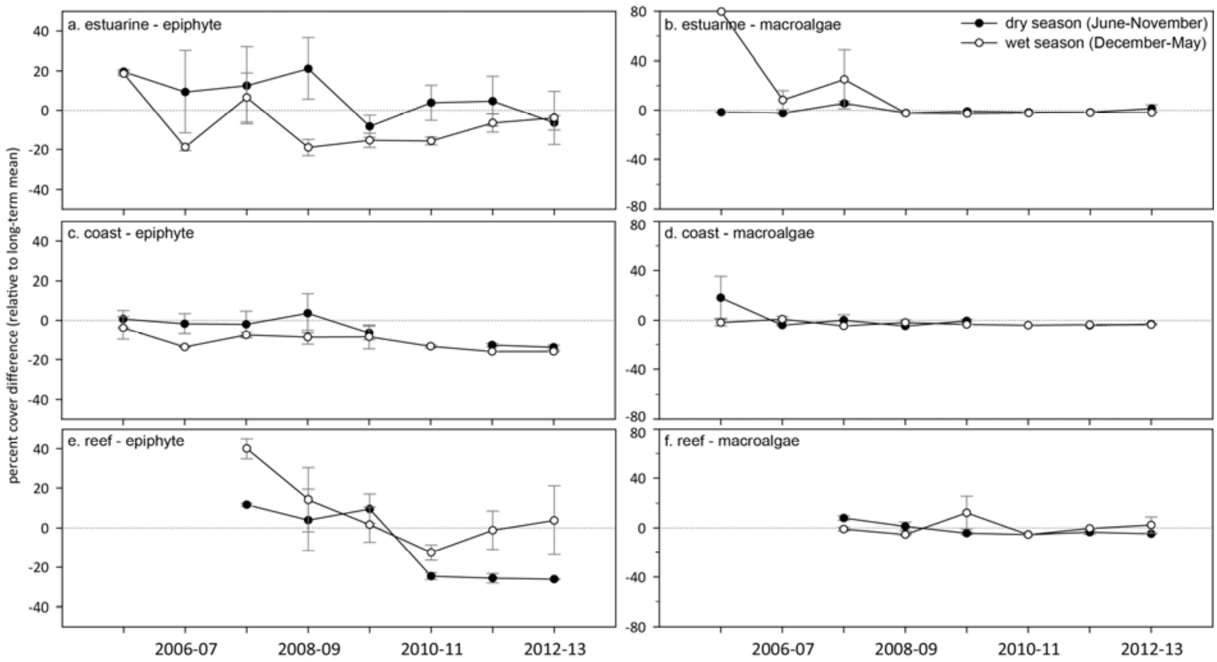

Figure 86. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Fitzroy region, 2005 - 2013 (sites pooled, ±SE). GBR long-term average; estuary epiphytes = 24.6%, estuary macroalgae = 3.2%, coastal epiphytes = 17%, coastal macroalgae = 4.7%, reef epiphytes= 28%, reef macroalgae = 6.2%.*

Within meadow canopy temperature

Autonomous temperature loggers were successfully deployed at all monitoring locations over the monitoring period (Appendix 1, Figure 136). The lowest mean temperatures across the region occurred in July/August and highest in January. Average annual temperature at the reef habitats in 2012-13 was <0.5°C below the long-term (6 year) annual average, while both coast and estuary were <0.5°C above in 2012-13.

High sea water temperatures (>35°C) within the seagrass canopy were recorded from October 2012 to April 2013, with the highest (40.7°C) at Shoalwater Bay on 20 February 2013 (at 3pm) (Appendix 1, Figure 136). This was just below the maximum ever recorded in the region (40.9°C, November 2003 to February 2004, Limpus*, et al.* 2005). A greater number of days (52 days) where the sea water temperatures exceeded 35°C was experienced in 2012-13 than the previous year and the highest since 2009 (when it reached 55 days) (Figure 87).

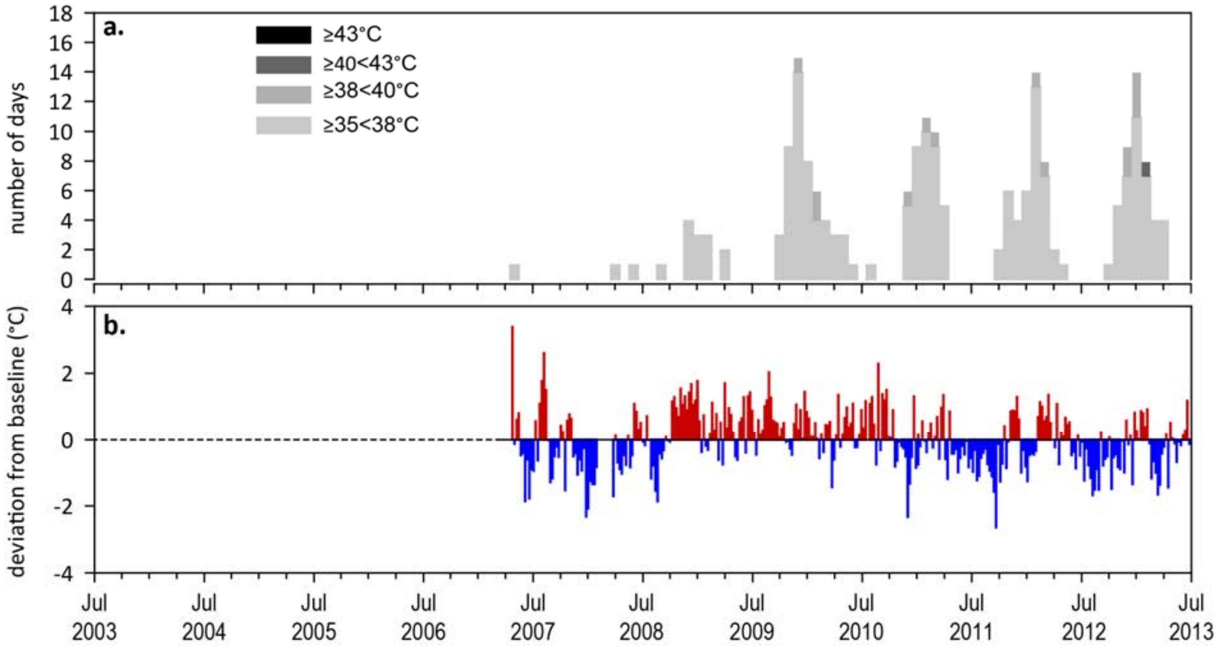

Figure 87. *Inshore sea temperatures for intertidal habitats in the Fitzroy region, September 2003 - June 2013: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006); b) deviations from 10-year mean weekly temperature 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 (I_d) at habitats in the Fitzroy region were similar to the long-term average during the 2012-13 reporting period (Figure 88; Appendix 1, Figure 143); with the exception of the coastal habitat in Shoalwater Bay where there was an anomalously low period of I_d early in the dry season (July 2012, Appendix 1, Figure 143). Variability was low between habitats in the Fitzroy region, with mean I_d during 2012-13 ranging from 12.3 to 16.6. Thresholds were exceeded on 8 to 19% of days, with the highest frequency occurring at the estuarine habitat in Gladstone Harbour (Figure 27). Across the region (habitats pooled), daily light peaked much later in the dry season (November-December), than in other regions (August-September) and reached lowest values in February to March 2013 (Figure 88).

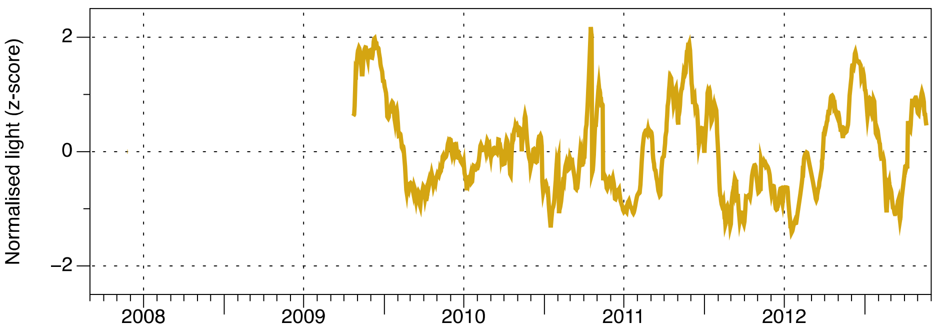

Figure 88. *Standardised daily light (28 day rolling average) for inshore intertidal habitats in the Fitzroy region (locations pooled). Daily light data were z-score transformed for each site and then averaged (mean) across all sites. Pelican Banks data for November 2012-June2013 courtesy of Gladstone Ports Corporation Ltd and Vision Environment Pty Ltd.*

Regional climate and river discharge

Seagrass meadows across the region experienced close to or slightly below (0.4 - 0.7°C) average annual maximum daily air temperatures (Shoalwater Bay = 27.5°C, Great Keppel Island = 25.4°C, Gladstone Harbour = 27.6°C) over the current monitoring period. Maximum temperatures, however, were hotter than the last 2-4 years in the north-central (Shoalwater Bay = 35.7°C, Great Keppel Island = 34.6°C), but cooler than the last 5 years in the south (Gladstone Harbour= 36.1°C) (Appendix 1, Figure 160, Figure 161, Figure 162).

Wind speeds across the region were close to or slightly below (~5%) long-term annual averages, however, meadows in the central and south experienced between 66 and 102 days of winds strong enough (>25 $km.hr^{-1}$) to re-suspend sediments and reduce water clarity (Appendix 1, Figure 163). The number of windier days was higher than or similar to the last 2--3 years for the central and southern locations, respectively.

Above average annual rainfall was experienced across the region, including the highest record at Great Keppel Island (1807mm), nearly twice the decade and long term (25yr) averages. Rainfall in Gladstone (1366mm), was the highest in over a decade, 55% above decade and long term averages.

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 kilometres 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.* 2014).

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 monitoring sites, and the exposure of the seagrass to elevated Total Suspended Solids and PSII herbicides has been documented (Michelle Devlin, JCU, pers. comm.).

2012-13 was the 4th consecutive period where the total discharge from all rivers in the region were above median (Appendix 1, Table 26). Approximately 85% of the volume discharged from the Fitzroy River was between January and March 2013, with the highest volume in January (Figure 173). Similarly, approximately 58% and 64% of the volume discharged from the Boyne and Calliope Rivers, respectively, occurred in January (Figure 174).

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Burnett Mary

2012-13 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 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. 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 one of the Rodds Bay monitoring sites in late monsoon 2013. Although a *Zostera muelleri* seed bank persisted throughout the year, indicating a high capacity to recover following disturbance, the very low reproductive effort suggests seed bank limitation in the near future. *Zostera muelleri* leaf tissue analysis in late 2012, suggested sufficient carbon available for growth and that the plants remained replete (well supplied and balanced macronutrients for growth) or possibly limited in N, which across the region indicated some low level of either fertiliser and/or sewage influence. Epiphyte and macroalgae abundance increased above the GBR long-term average in 2012-13. No extreme within canopy seawater temperatures were experienced over the monitoring period and although canopy seawater temperatures were lower than the long-term average, more days where sea water temperatures exceeded 35°C was experienced in 2012-13 than the previous 3 years. Meteorological conditions varied between the northern and southern locations over the 2012-13 monitoring period. In the north the climate was warmer, wetter and the seas calmer, whereas in the south it was cooler, drier and the seas rougher than the previous 5-10 years. It was also the 4th and 6th consecutive years that river discharges in the north and south remained above median. Overall the state of seagrass in the Burnett Mary region declined slightly in 2012-13, and remains **very poor** (Table 21).

Table 21. *Report card for seagrass status (community & environment) for the Burnett Mary NRM region: June 2012 – May 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).*

Habitat	Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
coastal intertidal	*not monitored*			
estuarine intertidal	6	0	30	**12**
Burnett Mary	6	0	30	**12**

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 89). 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).

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 with 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 is 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 meadows in the region were first broadly surveyed in 1988 (Lee Long *et al.* 1992) with the section north of Rodds Peninsula resurveyed at a fine scale 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 and marine park boundaries, the majority of seagrass meadows are within coastal and estuary habitats, however, south of the GBRWHA boundary is one of the largest single areas of seagrass resources on the eastern Australian seaboard within Hervey Bay and the Great Sandy Strait (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).

MMP monitoring sites are located in the north and south of the Burnett Mary region. In the north, they are located within Rodd's Bay, a location which generally faces low levels of anthropogenic threats, and in the south they are located at Urangan (Hervey Bay), adjacent to the Urangan marina and in close proximity to the mouth of the Mary River.

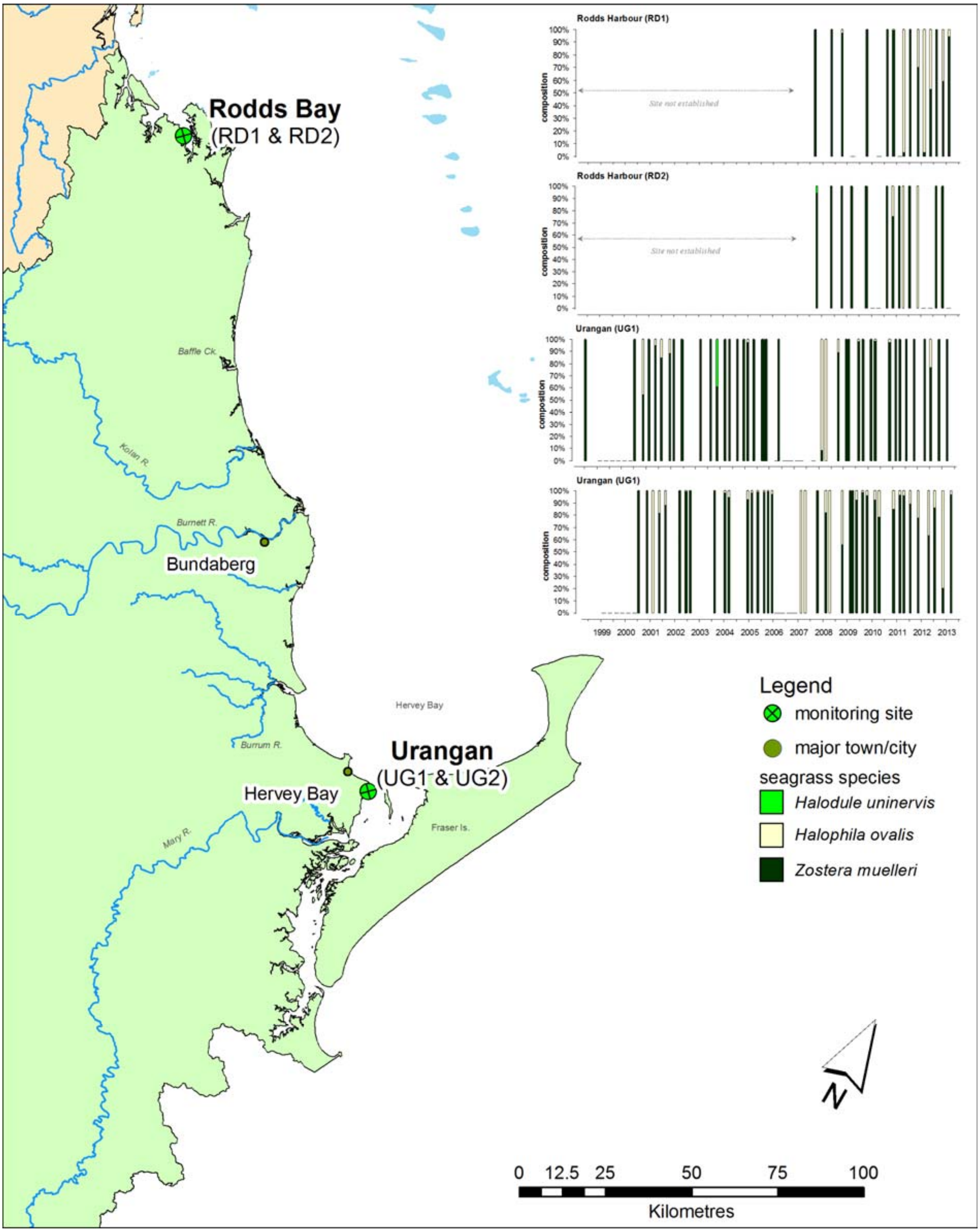

Figure 89. *Location and species composition of long-term monitoring sites in the Burnett Mary region. Please note: replicate sites are within 500m of each other.*

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 115).

Results and discussion

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, and as a consequence, the seagrass abundance state in the region has remained in a very poor state (Figure 90).

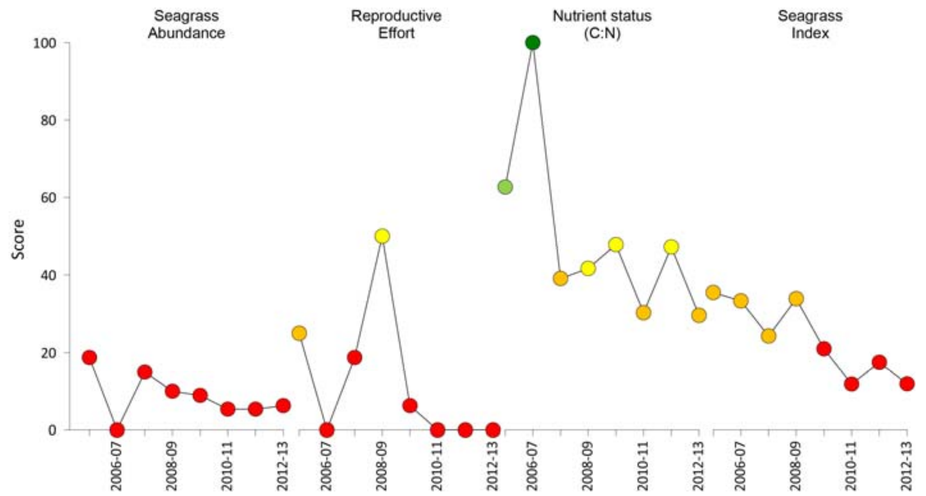

Figure 90. *Report card of seagrass status indicators and index for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100; ■ = very good (80-100), ■ = good (60 - <80), ■ = moderate (40 - <60), ■ = poor (20 - <40), ■ = very poor (0 - <20).*

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 locations with greater abundance in the late dry season (McKenzie *et al.* 2013).

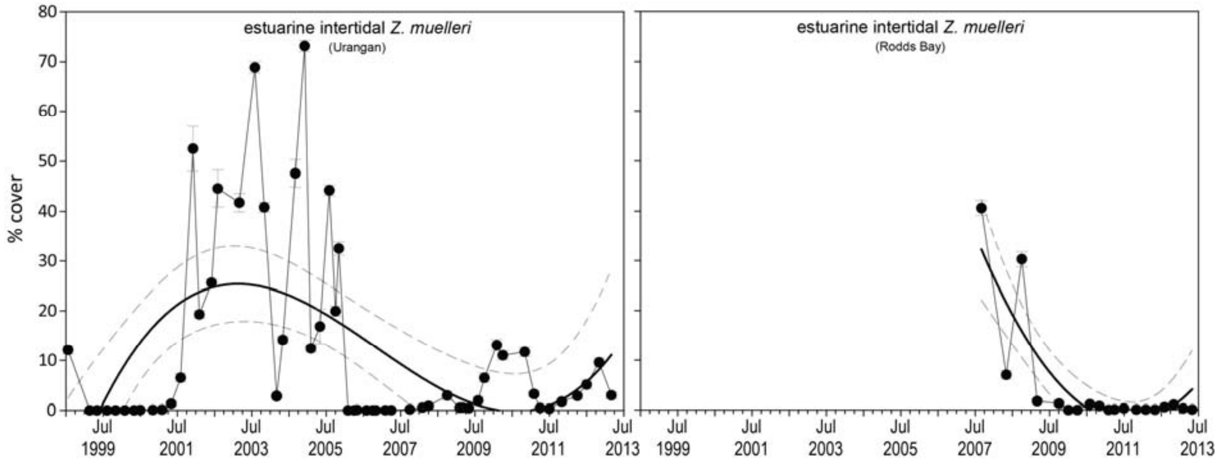

Figure 91. *Changes in seagrass abundance (% cover ±Standard Error) at estuarine meadows in Burnett Mary region from 1999 to 2011. Urangan trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.34. Rodds Bay trendline is 2nd order polynomial, 95% confidence intervals displayed, r^2 = 0.69.*

The estuarine seagrass habitats were dominated by *Zostera muelleri* with varying components of *Halophila ovalis* over the monitoring period (Figure 89). 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.

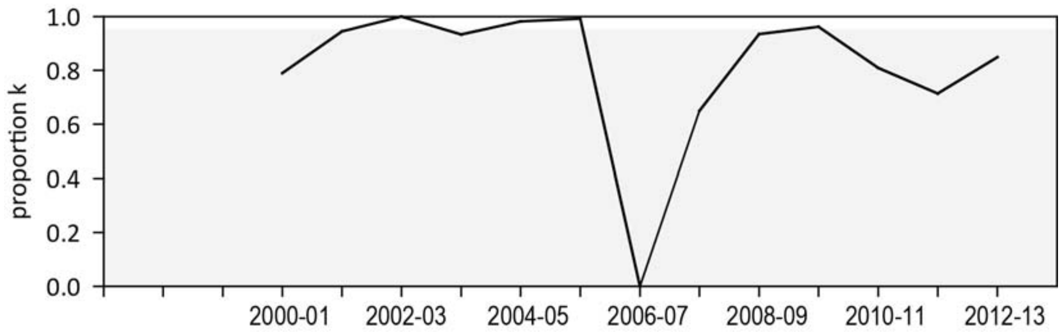

Figure 92. *Proportion of seagrass abundance composed of K-strategist species. Grey area represents GBR long-term average proportion of K-strategist species for each habitat type.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Appendix 1, Table 22) 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 increased after significant losses occurred in early 2010 and 2011 (Figure 93). In 2012, the isolated patches of seagrass that had appeared at Urangan sites the previous year, continued to expand, however, seagrass was lost from one of the Rodds Bay monitoring sites in late monsoon 2013. Overall, meadows in 2013/13 were of greater extent than the previous monitoring period, but still remained less than 40 of their original extent.

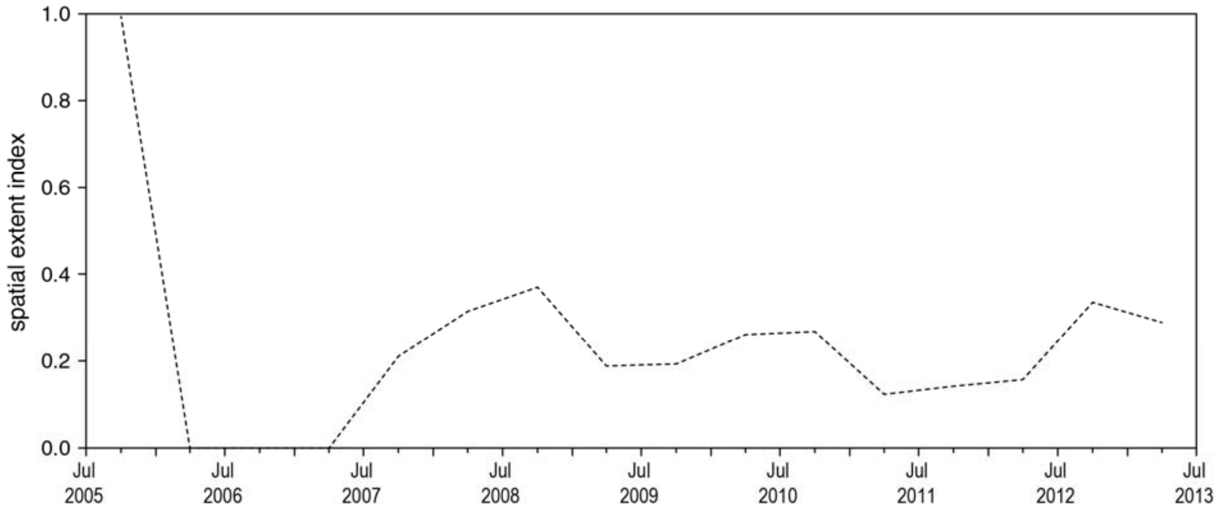

Figure 93. *Change in spatial extent of seagrass meadows within a 100m radius of monitoring sites for each habitat and monitoring period across the Burnett Mary NRM region.*

Seagrass reproductive status

Seagrass seed banks in Burnett Mary NRM region meadows did not differ between seasons (Figure 94). A *Zostera muelleri* seed bank persisted throughout the year at the estuary habitats (Figure 94), 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.

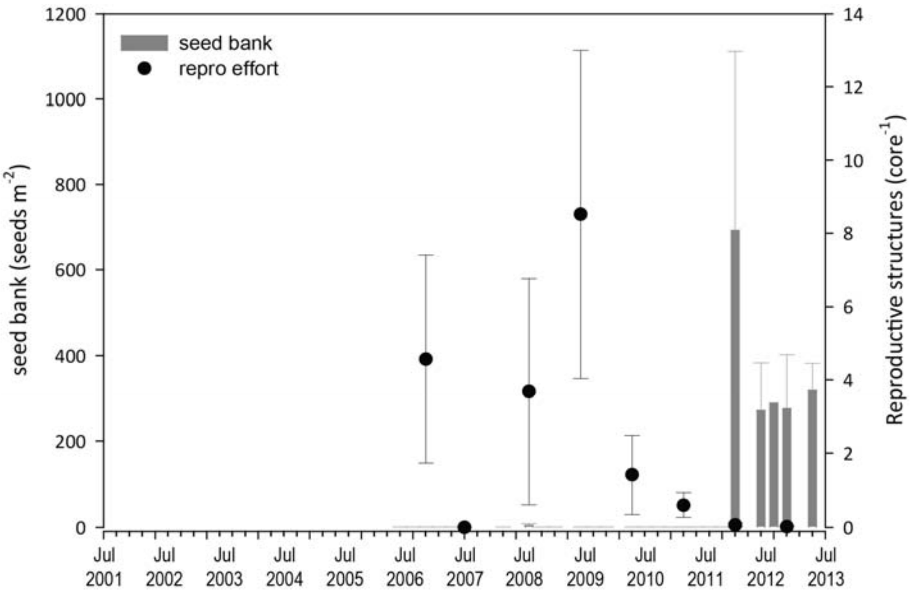

Figure 94. *Burnett Mary estuary seed bank and late dry season reproductive effort. Seed bank presented as the total number of seeds per m^2 sediment surface and reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

Status of the seagrass environment

Seagrass tissue nutrients

In 2012, *Zostera muelleri* leaf molar C:N ratios remained below 20 (Figure 95) and $\delta^{13}C$ values were within global ranges (Appendix 1, Table 23), suggesting sufficient carbon available for growth and a possible increasing N pool.

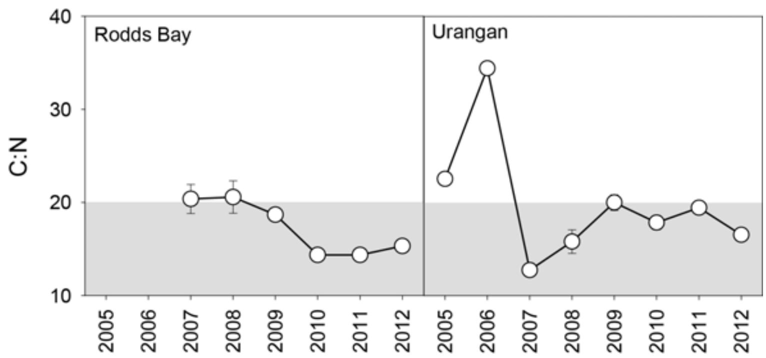

Figure 95. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Burnett Mary region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" 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.*

Zostera muelleri leaf molar C:P ratios in 2012 were <500 for at both locations, indicating that the plants were growing in a nutrient rich environment with a relatively large P pool (Figure 96). N:P ratios for *Zostera muelleri* increased slightly since the previous monitoring period at Rodds Bay, but decreased at Urangan (Hervey Bay), indicating the plants remained replete (well supplied and balanced macronutrients for growth) or possibly N limited, respectively (Figure 96). Leaf tissue $\delta^{15}N$ values were lower in 2012 than 2011 (Appendix 1, Table 23) and suggest some low level of either fertiliser and/or sewage influence as the primary source of N.

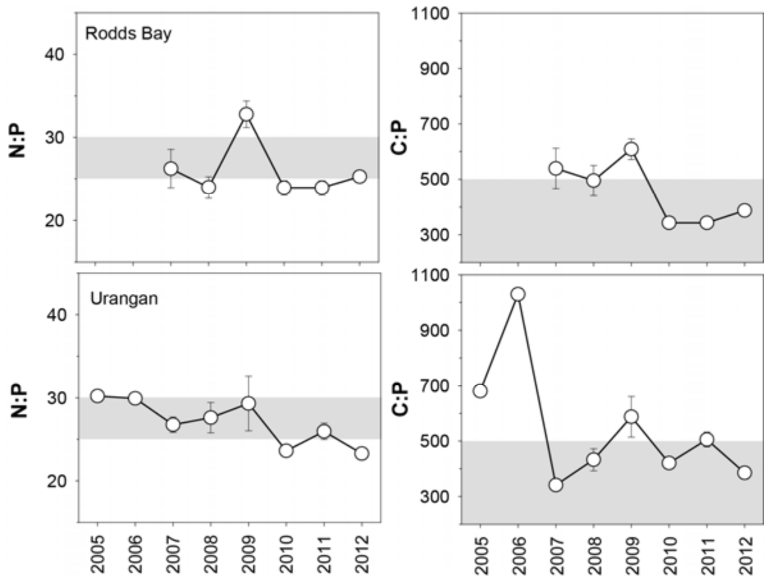

Figure 96. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in the Burnett Mary region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated 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).*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades was higher in the dry season and increased above the GBR long-term average in 2012-13 (Figure 97; Appendix 1, Figure 129). Percentage cover of macroalgae similarly increased above the GBR long-term average and was also higher in the dry season (Figure 97; Appendix 1, Figure 129).

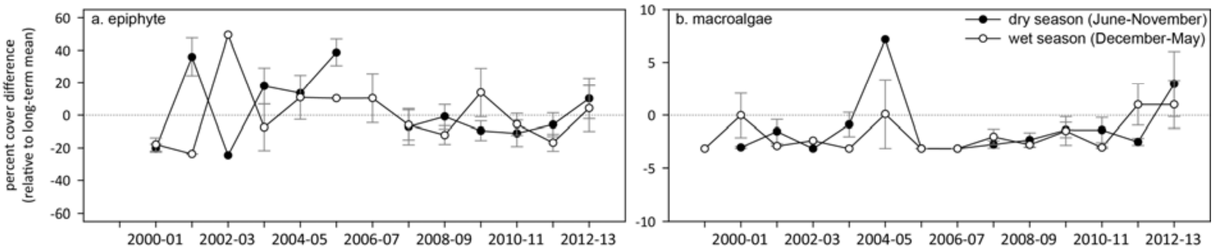

Figure 97. *Long-term trend in mean epiphyte and macroalgae abundance (% cover) relative to the long-term average for each seagrass habitat in the Burnett Mary NRM region (sites pooled, ±SE). GBR long-term average; estuary epiphytes = 24.6%, estuary macroalgae = 3.2%.*

Within canopy temperature

Autonomous temperature loggers were deployed at both locations over the monitoring period (Appendix 1, Figure 137). High temperatures (>35°C) were recorded from December 2012 to April 2013, with the highest temperature (37.7°C) recorded at 2:00pm on the 24 March 2013 at Rodds Bay (Figure 98a). Within canopy seawater temperatures were lower than the long-term (8 year) average in 2012-13 (Figure 98b), however, more days where sea water temperatures exceeded 35°C were experienced in 2012-13 than the previous 3 years (Figure 98a).

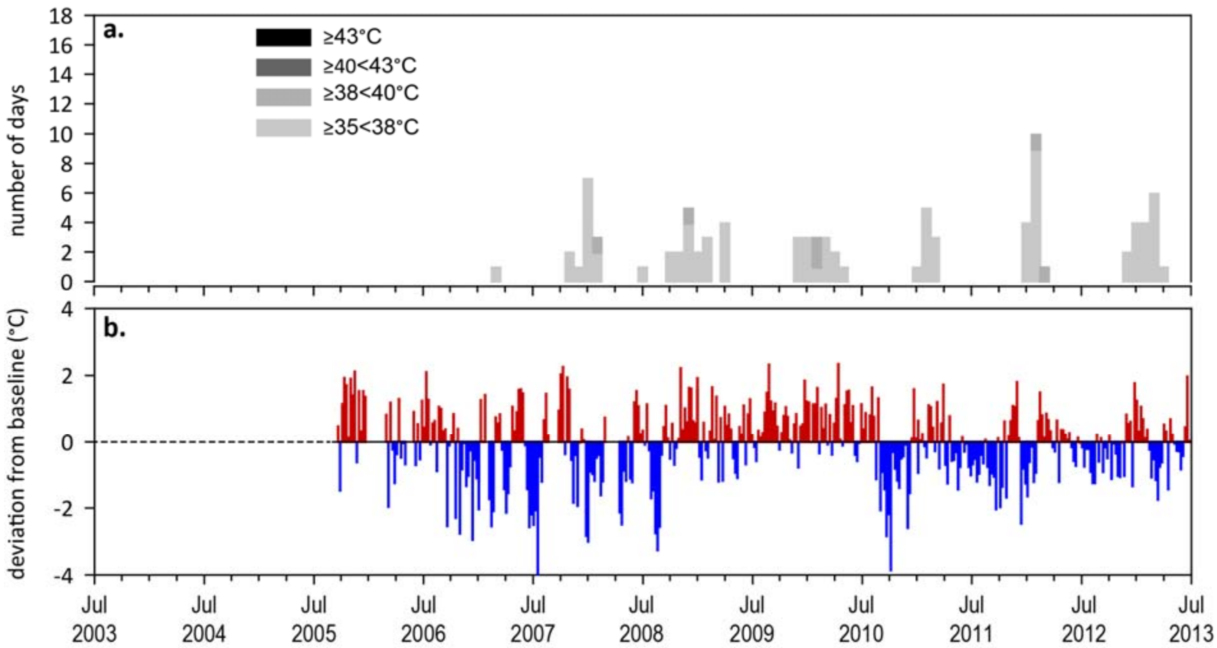

Figure 98. *Inshore sea temperature monitoring September 2005 to June 2013 for seagrass meadows in Burnett Mary NRM region: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from SJ Campbell et al., 2006); b) deviations from 8-year mean weekly 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 (I_d) at Burnett Mary locations was lower than the long-term average (16.8 to 20 mol m^{-2} d^{-1}) during the 2012-13 (31.1 to 14.6 mol m^{-2} d^{-1}) reporting period (Figure 99; Appendix 1, Figure 144). However, long-term trends should be interpreted with caution, as data availability is low in this region due to poor data retrieval and a shorter duration over which light has been monitored. Thresholds were exceeded on 3 to 13% of days, which is similar to the long-term average in this region (Figure 27). It is difficult to asses intra-annual trends over the 2012-13 year as there is no data available for late in the dry season (September-December), which coincides with the peak I_d in the adjacent region (Fitzroy).

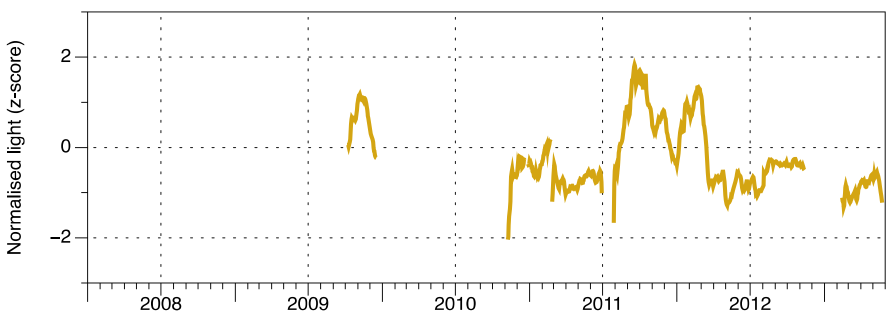

Figure 99. *Standardised (z-score) daily light (28-day rolling average) for all locations (pooled) in the Burnett Mary NRM region. Daily light data were z-score transformed for each site and then averaged (mean) across all sites.*

Regional climate and river discharge

Climate across the Mary Burnett region varied between the northern and southern locations over the 2012-13 monitoring period. In the north the climate was warmer, wetter and the seas calmer, whereas in the south it was cooler, drier and the seas rougher than the previous 5-10 years. It was also the 6th and 4th consecutive years that river discharges in the south and north, respectively, were above median.

Temperatures in the north of the region were slightly warmer (Seventeen Seventy = 25.6°C) and in the south slightly cooler (Hervey Bay = 26°C) than the average annual maximum for the last decade and long-term (14 years) (Appendix 1, Figure 164, Figure 165). However, both the north and south experienced the hottest daily maximum air temperatures (Seventeen Seventy = 33.1°C, Hervey Bay = 36.8°C) in the last 6 and 14 years, respectively.

Wind speeds across the region were either above (Seventeen Seventy = 23.3 km.hr^{-1}) or below (Hervey Bay = 19.3 km.hr^{-1}) the average for the last decade and long-term (14 years) (Appendix 1, Figure 164, Figure 165). Although wind speeds were above average in the north, they resulted in the lowest number of days (132 days) in the last 4 years with winds above 25 km.hr^{-1}(Appendix 1, Figure 166). However, meadows in the south experienced the highest number of days (68 days) in 5 years with winds above 25 km.hr^{-1} (Appendix 1, Figure 166), which would have resulted in rougher seas resuspending sediments and reducing water clarity.

Rainfall during 2012-13 also varied across the region, with the north (Seventeen Seventy = 1533mm) experiencing a wetter than average year (56% higher than last decade, 36% higher than long-term), and the south (Hervey Bay = 1157mm) a drier than average year (for the last decade, but similar to long-term) (Appendix 1, Figure 164, Figure 165). 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, flood waters from the Calliope and Boyne Rivers have been reported to travel southward exposing Rodds Bay (41 km to the south) to plumes (Petus and Devlin 2012). 2012-13 was the 4th consecutive period where the total discharge from the Calliope River was above the long-term median (Appendix 1, Table 26, Figure 174).

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). 2012-13 was the 6th consecutive year with above median discharges from the Mary River (Appendix 1, Table 26). The volume discharged over the period (5,464,353 ML) was approximately 76% higher than for the previous monitoring period (Appendix 1, Table 26, Figure 174, Figure 175).

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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 (Figure 100).

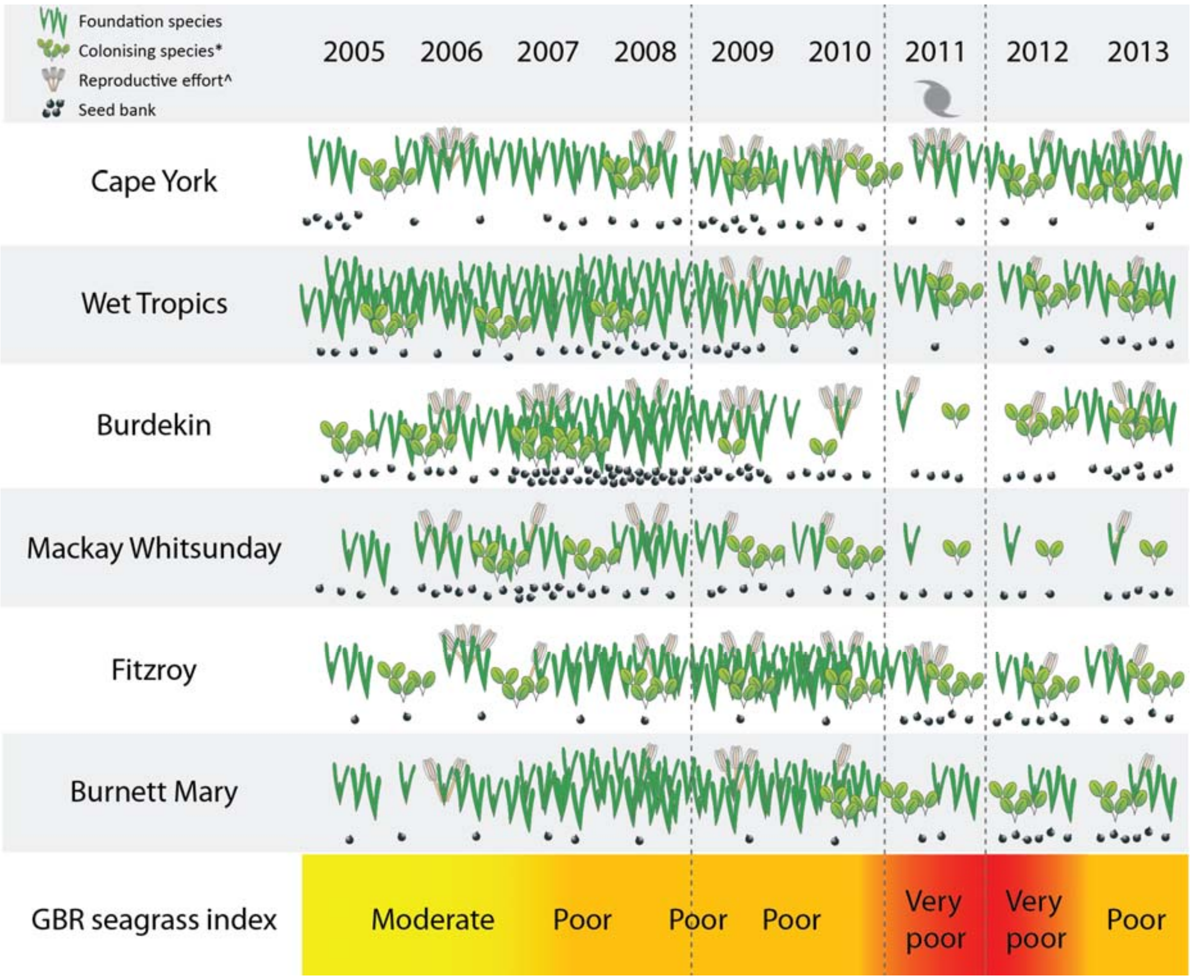

Figure 100. *Summary of GBR MMP inshore seagrass state illustrating abundance of foundation / colonising species, seed banks and reproductive effort from 2005 to 2013. Dashed lines delineate periods of major seagrass loss. * colonising species are represented by the genus* Halophila*, however,* Zostera *and* Halodule *can be both colonising and foundational species depending on meadow state. ^ not conducted in 2005.*

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 above average rainfall resulted in floodwater discharges from large rivers and associated catchments. 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 symptoms 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.

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 2012-13, recovery was progressing 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 forcing factors in seagrass growth and persistence. From 2009 onwards, canopy irradiance reduced to low and limiting light levels was reported in seagrass meadows across the GBR, and, coincident with this, nutrients (N and P) increased relative to plant requirements. A strong correlation between seagrass abundance and light availability has been demonstrated for subtidal meadows (Collier*, et al.* 2012b). Conversely, at shallow sites daily light measurements of light can be “swamped” by light 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 both intertidal and subtidal monitoring sites. 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. There is a strong need to quantify the usable light range and the effect of widely fluctuating light levels on photosynthetic efficiency; 2. Synergistic environmental impacts (e.g. desiccation) 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 high turbidity sites, by being restricted to shallow areas where light reaches the canopy during low tide. 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.

In the current reporting year, light availability improved in the northern GBR relative to previous years at a number of locations, but was more variable and overall lower in southern regions (Mackay Whitsunday, Fitzroy and Burnett Mary). Above median runoff continued in the southern region, however runoff reduced in northern regions over this period, and this has likely reduced sediment loads and suspended sediment concentrations in the north. There is now a growing body of evidence that exposure to primary and secondary water types in flood plumes may be a significant forcing factor in structuring inshore seagrasses communities of the GBR (Collier*, et al.* 2014). Flood plume water types (identified by Devlin and Schaffelke 2009; Devlin *et al.* 2012), include: Primary, the poorest water quality (e.g. very high turbidity limits light penetration, inhibiting primary production); Secondary, intermediate water quality (e.g. reduced light availability from elevated CDOM concentrations promoting phytoplankton growth and elevated sedimentation); and Tertiary occupies the external region of the river plume (the transition between Secondary water and marine ambient water). The relationship between flood plume exposure (frequency) and seagrass health (including abundance), however, is not linear, as both very high and very low flood plume exposure frequency can be associated with low seagrass abundance at sites throughout the GBR (Collier*, et al.* 2014). Preliminary analysis suggests the most sensitive meadows (showing significant declines in abundance) are those receiving moderate exposure to both primary and secondary water types. Large-scale water quality mapping could help define seagrass communities types and identify the main water types, which shape and drive seagrass response. Thus long-term water quality data, both *in situ* and through remote sensing would be a valuable addition to the current monitoring to provide measures of risk relative to the seagrass communities.

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 101).

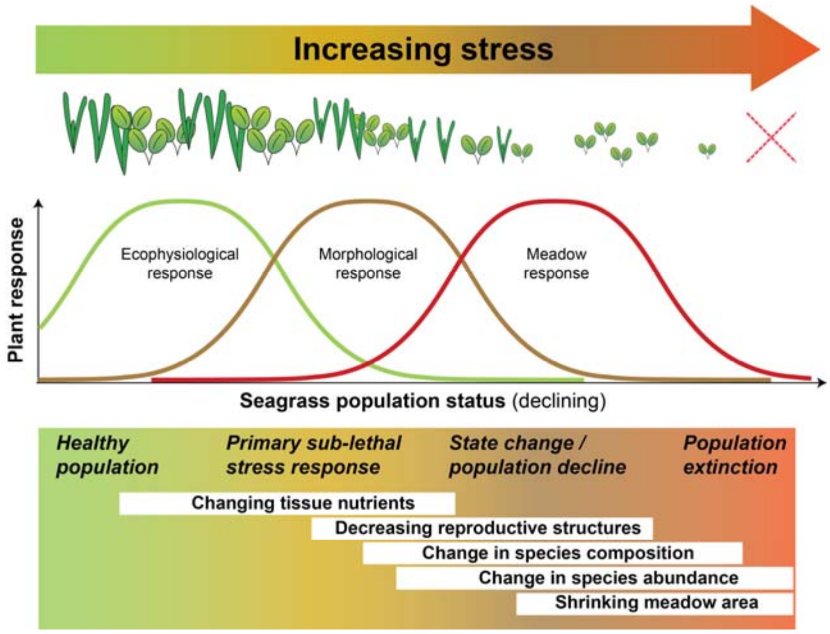

Figure 101. *Seagrass stress response model outlining the sequence of changes that occur in response to increasing stress. Adapted from Waycott and McKenzie (2010).*

Results to date from the MMP have demonstrated a cascade of seagrass population responses to stressors analogous to the stress response model, including: leaf tissue N and P increasing above global average in all habitats since 2006 and 2010 respectively, and because they are in surplus to C indicate N enrichment; variable but declining reproductive effort and seed banks indicating low capacity to recover from loss; decreasing abundance and extent since 2009, reaching minimum in early 2011; changing population state with foundation species being replaced by colonising species, possibly reducing ecosystem resistance.

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 among seagrass populations 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 2012).

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 regions 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.

Conceptual diagrams

Figure 102. *Key to symbols used for conceptual diagrams detailing impacts to seagrasses.*

Cape York

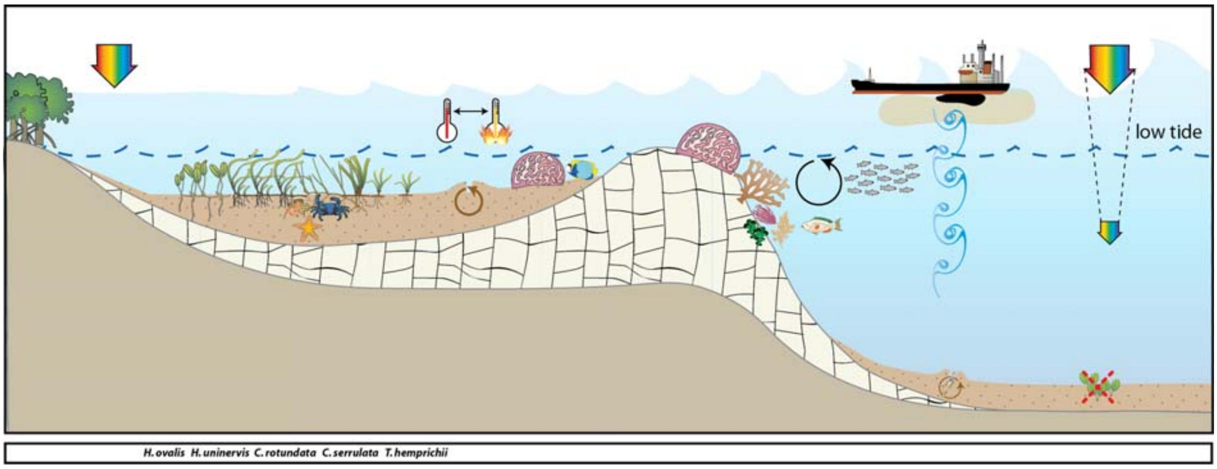

Figure 103. *Conceptual diagram of reef habitat in the Cape York region – major control is pulsed physical disturbance, salinity and temperature extremes: general habitat and seagrass meadow processes (see Figure 102 for icon explanation).*

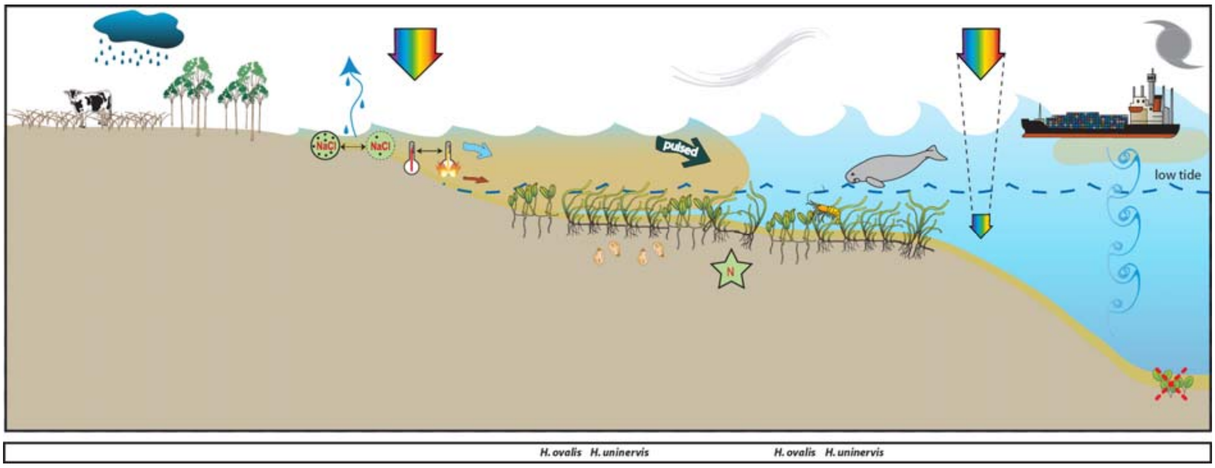

Figure 104. *Conceptual diagram of coastal habitat in the Cape York region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

Wet Tropics

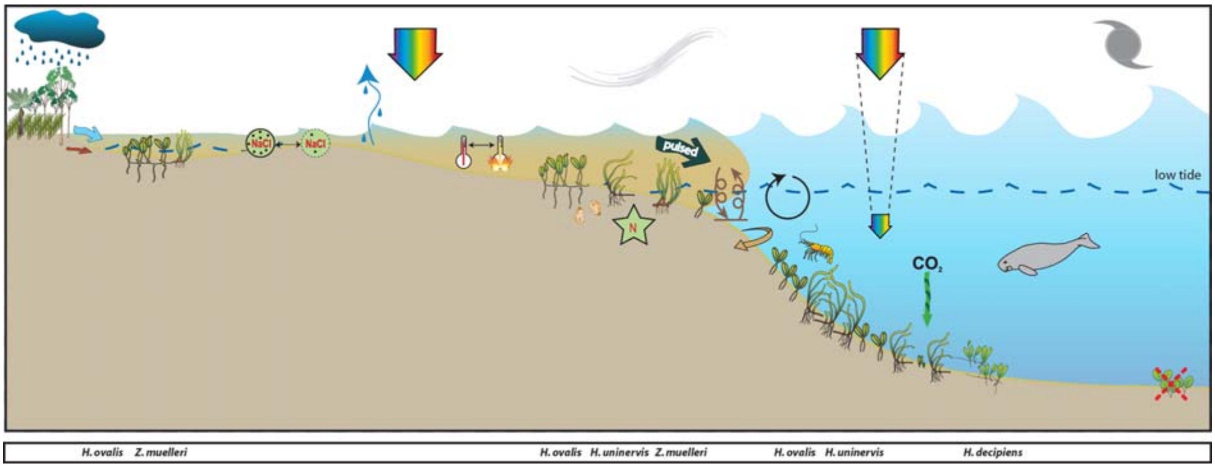

Figure 105. *Conceptual diagram of coastal habitat (<15m) in the Wet Tropics region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

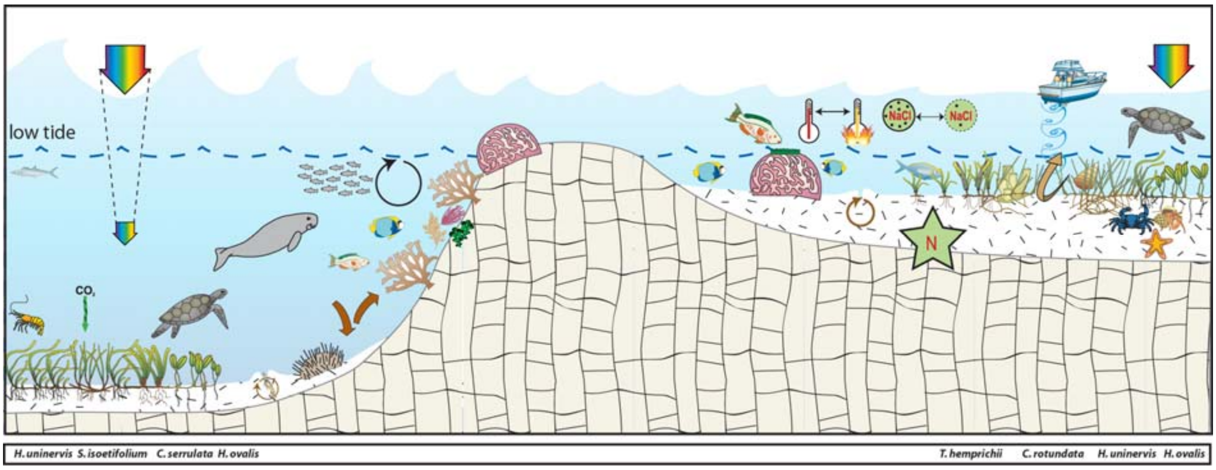

Figure 106. *Conceptual diagram of reef habitat (<15m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

Burdekin

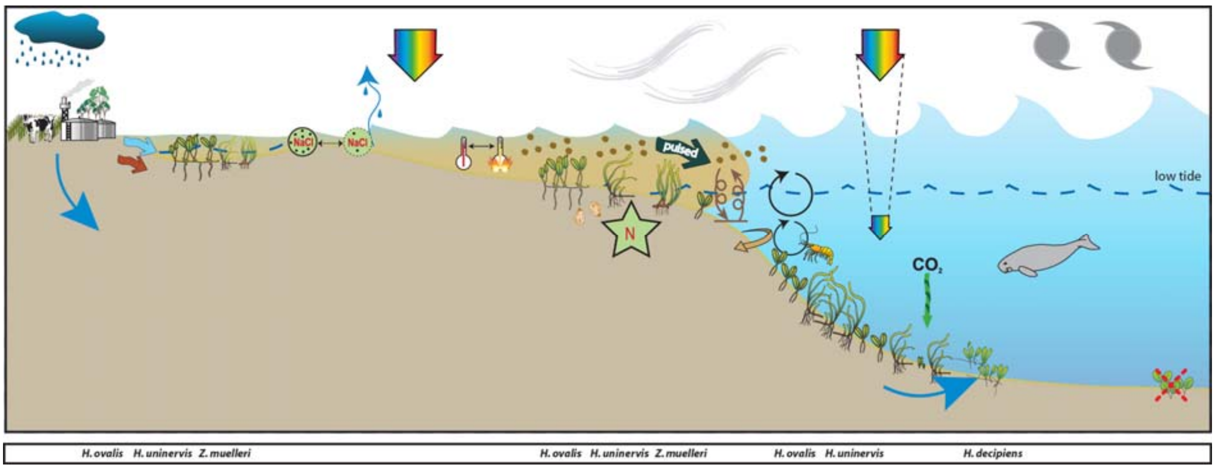

Figure 107. *Conceptual diagram of coastal habitat in the Burdekin region - major control is wind and temperature extremes, general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

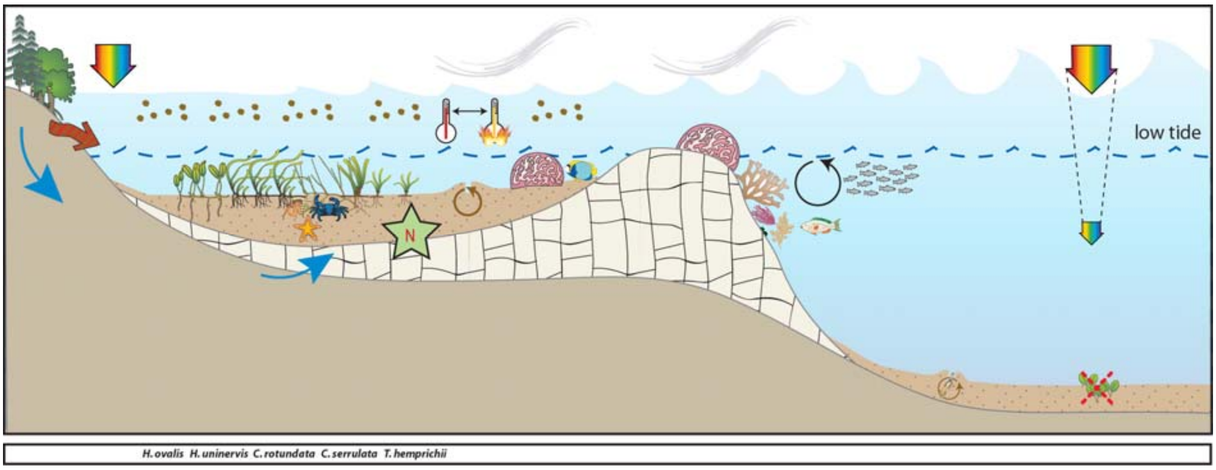

Figure 108. *Conceptual diagram of fringing reef habitat in the Burdekin region - major control is nutrient supply (groundwater), light and shelter: general habitat and seagrass meadow processes (see Figure 102 for icon explanation).*

Mackay Whitsunday

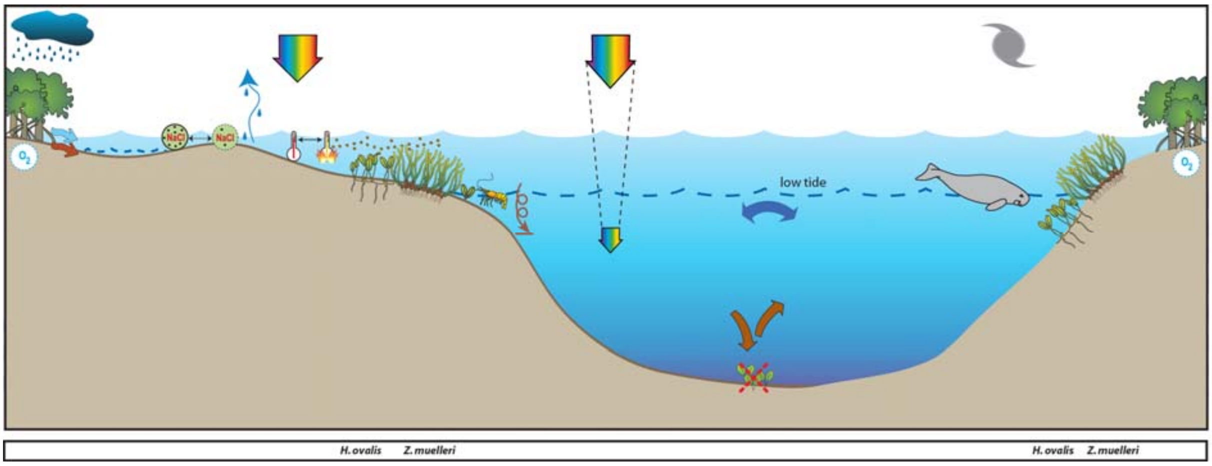

Figure 109. *Conceptual diagram of estuary habitat in the Mackay Whitsunday region: general habitat and seagrass meadow processes (see Figure 102 for icon explanation).*

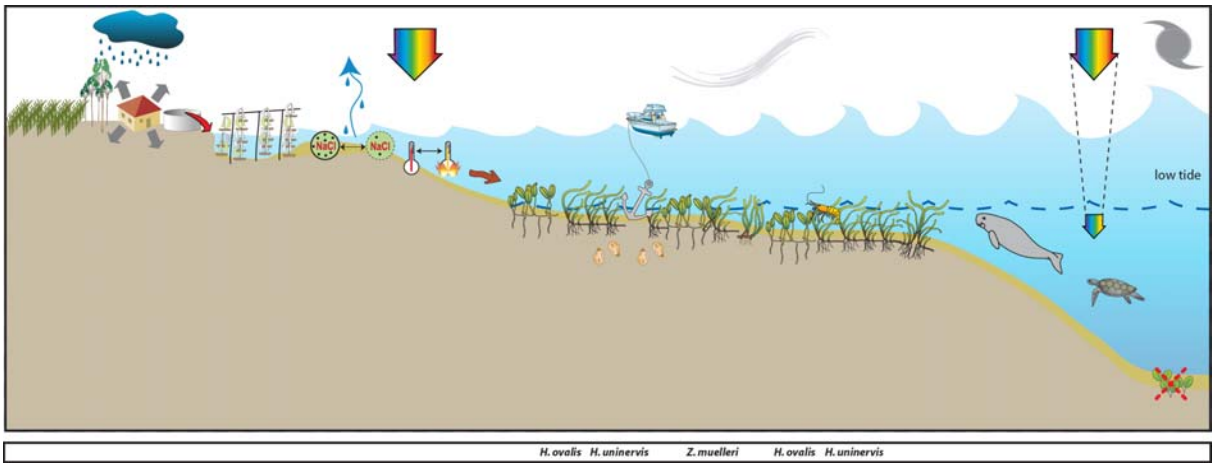

Figure 110. *Conceptual diagram of coastal habitat in the Mackay Whitsunday region – major control is shelter and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

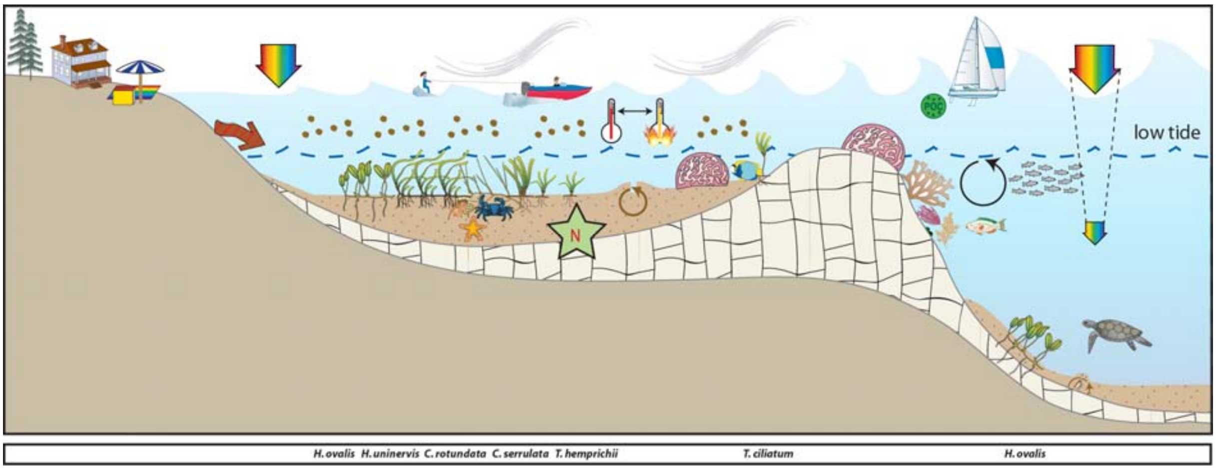

Figure 111. *Conceptual diagram of reef habitat in the Mackay Whitsunday region - major control is light and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

Fitzroy

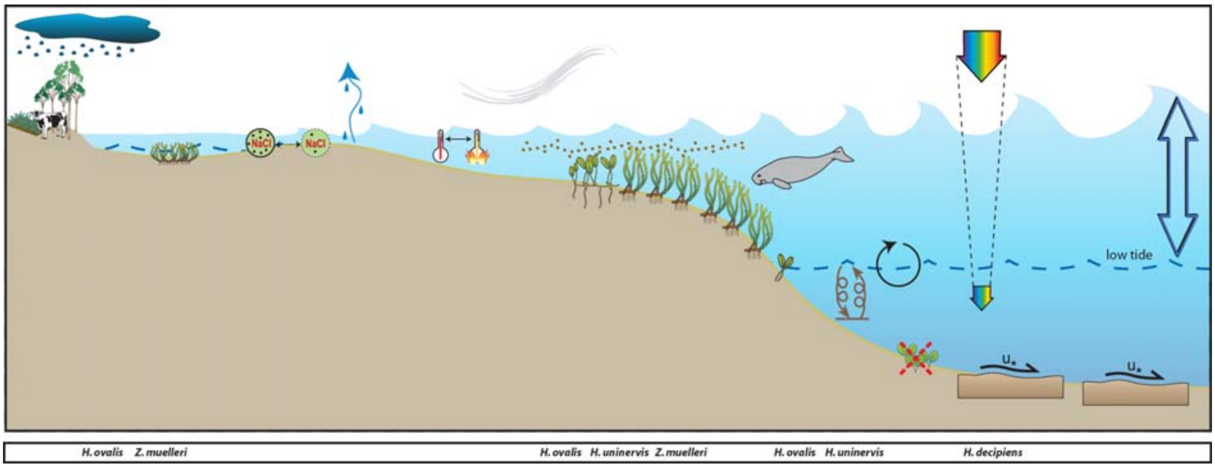

Figure 112. *Conceptual diagram of coastal habitat in the Fitzroy region – major control is pulsed light, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

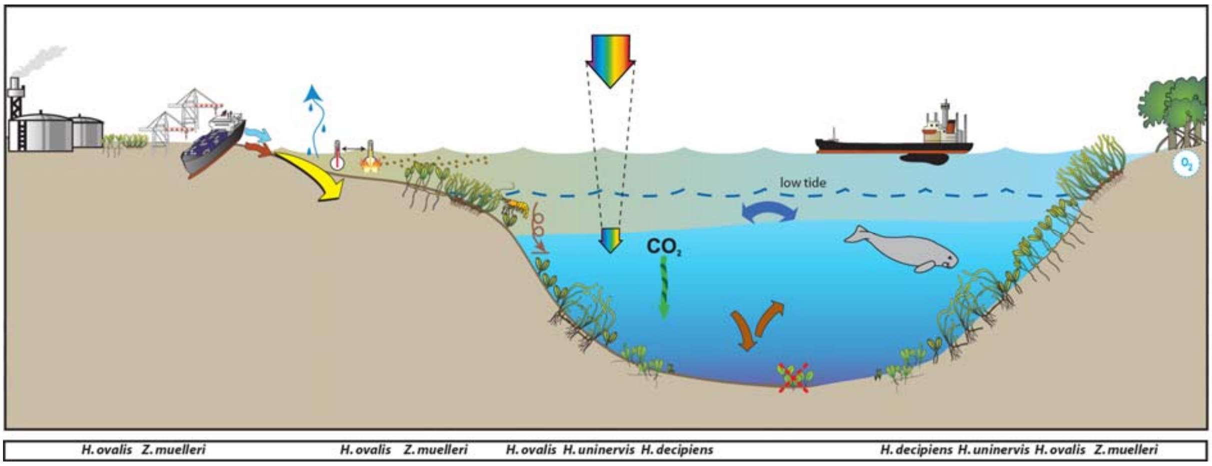

Figure 113. *Conceptual diagram of estuary habitat in the Fitzroy region – major control variable rainfall and tidal regime: general habitat, seagrass meadow processes and threats/impacts (see Figure 2 for icon explanation).*

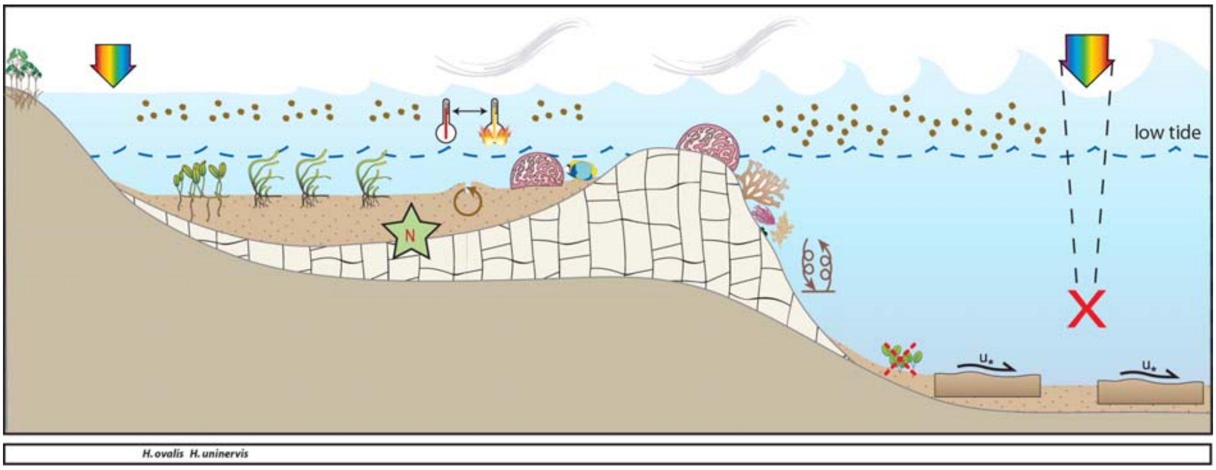

Figure 114. *Conceptual diagram of reef habitat in the Fitzroy region - major control is light and temperature extremes and benthic shear from tidal currents: general habitat, seagrass meadow processes and threats/impacts (see Figure 102 for icon explanation).*

Burnett Mary

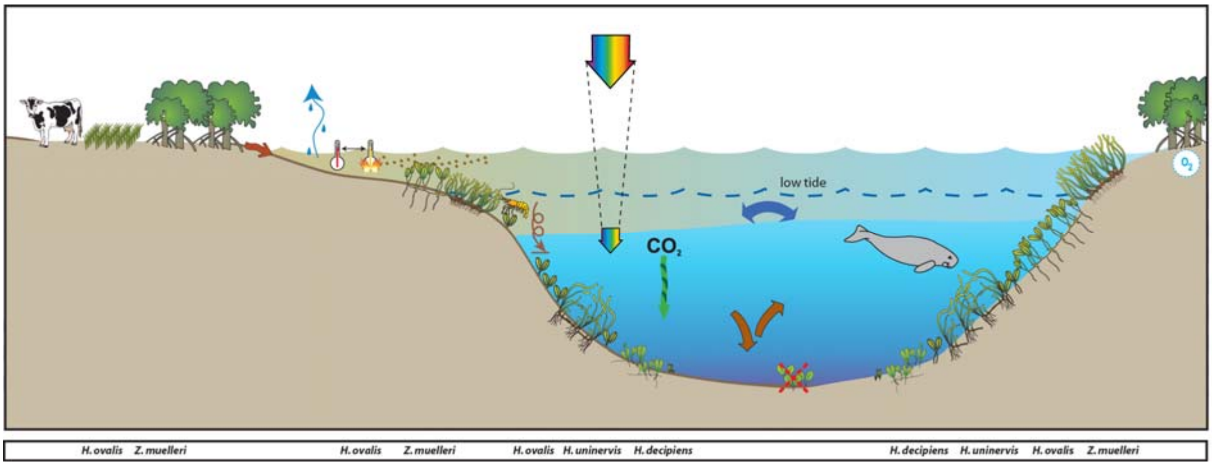

Figure 115. *Conceptual diagram of Estuary habitat in the GBR section of the Burnett Mary region – major control is shelter from winds and physical disturbance: general habitat and seagrass meadow processes (see Figure 102 for icon explanation).*

Seagrass extent

Table 22. *Proportion of area (within 100m radius of each monitoring site) which is covered by seagrass each late dry and late monsoon, 2005 to 2013. For sites codes, see Table 5. Shading indicates area of seagrass below baseline (first measure).*

Site	Oct 05	Apr 06	Oct 06	Apr 07	Oct 07	Apr 08	Oct 08	Apr 09	Oct 09	Apr 10	Oct 10	Apr 11	Oct 11	Apr 12	Oct 12	Apr 13
SR1														1	1	1
SR2														0.94	0.93	0.94
BY1														0.75	0.77	0.85
BY2														0.9	0.9	1
FR1														0.72	0.7	0.69
FR2														0.91	0.91	0.89
ST1														0.69	0.63	0.71
ST2														0.94	0.96	0.95
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
AP2	0.68	0.58	0.66	0.75	0.75	0.64	0.66	0.6	0.66		0.71	0.65	0.67	0.65	0.58	0.64
YP1	0.25	0.33	0.33	0.45	0.57	0.53	0.54	0.46	0.42	0.3	0.31	0.33	0.08	0.23	0.11	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
LB1	0.31	0.2	0.08	0.18	0.22	0.2	0.3	0.23	0.23	0.09	0.03	0	0	0	0	0
LB2	0.34	0.27	0.1	0.22	0.3	0.27	0.36	0.31	0.29	0.09	0.03	0	0	0	0	0
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
GI2	0.86	0.86	0.87	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
DI1				0.59	0.63	0.61	0.61	0.6	0.62	0.61	0.62	0	0.01	0	0.01	0.04
DI2				0.72	0.76	0.8	0.78	0.8	0.79	0.75	0.77	0	0.05	0.03	0.05	0.12
BB1	1	1	1	0.96	0.98	0.96	0.99	0.43	0.87	0.47	0.21	0.48	0.4	0.21	1	0.98
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
JR1														1	1	1
JR2														0.83	0.83	0.83
MI1	0.55	0.64	0.32	0.49	0.59	0.51	0.52	0.5	0.73	0.48	0.43	0.21	0.42	0.46	0.48	0.49
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
PI2	0.65	0.67	0.72	0.79	0.79	0.77	0.78	0.85	0.99	0.87	0.96	0.29	0.22	0.46	0.33	0.7
PI3	0.46	0.38	0.74	0.84	0.79	0.79	0.81	0.84	0.91	0.67	0.96	0.19	0.16	0.49	0.4	0.72
HM1					0.3	0.34	0.28	0.25	0.18	0.13	0.26	0.15	0.32	0.54	0.64	0.62
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
SI1	0.64	0.33	0.84	0.78	0.9	0.31	0.68	0.32	0.47	0.13	0.27	0.11	0.73	0.5	0.8	0.65
SI2	0.71	0.47	0.7	0.67	0.9	0.35	0.71	0.27	0.46	0.17	0.23	0.05	0.69	0.5	0.7	0.7
RC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WH	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
GH2	0.96	0	1	0.96	0.88	0.94	0.9	0.98	0.93	0.98	0.95	0.91	0.9	0.91	0.87	0.94
GK1					0.58	0.12	0.22	0.42	0.56	0.55	0.22	0.09	0.07	0.07	0.82	0.44
GK2					0.78	0.46	0.62	0.43	0.72	0.74	0.73	0.54	0.25	0.25	0.31	0.24
RD1					0.18	0.24	0.22	0	0.01	0	0.1	0.04	0.05	0	0.43	0.34
RD2					0.66	0.65	0.67	0.66	0.51	0	0	0.02	0.01	0	0.03	0
UG1	0.99	0	0	0	0	0.07	0.06	0.01	0.06	0.34	0.27	0.06	0.07	0.09	0.2	0.21
UG2	1	0	0	0	0	0.29	0.52	0.09	0.19	0.7	0.7	0.38	0.43	0.54	0.67	0.61

Seagrass leaf tissue

Table 23. *Seagrass leaf tissue nutrient, $\delta^{13}C$ and $\delta^{15}N$ concentrations from each NRM region in the late dry season of 2011 and 2012. Leaf tissues with low %C (see Table 24), low C:N (<20:1), and isotopically depleted $\delta^{13}C$ may indicate that growth is light limited (Grice et al. 1996; Fourqurean et al. 2005). Global $\delta^{13}C$ averages from Hemminga and Mateo 1996). Shading indicates values lower than literature. CR=*Cymodocea rotundata*, CS=*Cymodocea serrulata*, EA=*Enhalus acoroides*, HO=*Halophila ovalis*, HU=*Halodule uninervis*, SI=*Syringodium isoetifolium*, TH=*Thalassia hemprichii*, ZM=*Zostera muelleri.

NRM	Habitat	Species	Year	%C	C:N	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C lit median	$\delta^{13}C$ ‰ global average
Cape York	coastal	EA	2012			-9.41	-13.07	*38.3*	*-5.8 (-6.7 to -4.9)*
		HU	2012	40.27	16.5	0.06 ±0.87	-10.74 ±1.29	*38.5*	*-11.2 (-13.0 to -7.8)*
		SI	2012			0.35	-4.78	*28*	*-6.0 (-8.3 to -3.6)*
		TH	2012	38.60	15.4	-1.32 ±1.07	-9.91 ±0.84	*35.6*	*-6.9 (-8.1 to -5.2)*
		ZM	2012			1.84	-10.23	*32*	*-10.8 (-12.4 to -9.2)*
	reef	CR	2012			-7.84 ±1.41	-2.75 ±0.99	*39*	*-8.1 (-8.9 to -7.4)*
		CS	2012	40.00		-8.57	0.37	*40.4*	*-10.7 (-12.4 to -8.0)*
		HU	2011	42.48	17.9	-8.78	0.72	*38.5*	*-11.2 (-13.0 to -7.8)*
		HU	2012	40.73	16.4	-8.74 ±0.20	0.15 ±0.47	*38.5*	*-11.2 (-13.0 to -7.8)*
		SI	2012	37.30	19.5	-4.01	1.11	*28*	*-6.0 (-8.3 to -3.6)*
		TH	2012	37.78	17.0	-6.15 ±1.01	0.70 ±0.22	*35.6*	*-6.9 (-8.1 to -5.2)*
		ZM	2011	39.70		-9.27	1.57	*32*	*-10.8 (-12.4 to -9.2)*
Wet Tropics	coastal	HU	2011	44.90	11	-10.35	0.64	*38.5*	*-11.2 (-13.0 to -7.8)*
		HU	2012	41.66	11.3	-9.59 ±0.31	0.85 ±1.17	*38.5*	*-11.2 (-13.0 to -7.8)*
	reef intertidal	HU	2012	41.80	18.2	-8.85	1.64	*38.5*	*-11.2 (-13.0 to -7.8)*
		TH	2012	40.00	16.9	-9.36	0.71	*35.6*	*-6.9 (-8.1 to -5.2)*
		CR	2011	42.48	18.9	-7.88	-0.71	*39*	*-8.1 (-8.9 to -7.4)*
	reef subtidal	CR	2012	41.02		-6.71	-0.27	*39*	*-8.1 (-8.9 to -7.4)*
		HU	2011	41.60		-7.52	1.45	*38.5*	*-11.2 (-13.0 to -7.8)*
		HU	2012	40.90		-6.82	1.89	*38.5*	*-11.2 (-13.0 to -7.8)*
		TH	2011	40.36		-7.02	1.80	*35.6*	*-6.9 (-8.1 to -5.2)*
		TH	2012	38.38		-6.42	1.50	*35.6*	*-6.9 (-8.1 to -5.2)*
Burdekin	coastal	HU	2012	39.79	13.9	-11.23 ±0.11	1.22 ±0.02	*38.5*	*-11.2 (-13.0 to -7.8)*
		ZM	2012	36.63	19.1	-10.44	2.18	*32*	*-10.8 (-12.4 to -9.2)*
	reef intertidal	CS	2012	40.30	23.8	-9.07	1.54	*40.4*	-10.7 (-12.4 to -8.0)
		HO	2011	39.50		-10.79	1.88	*30.5*	*-10 (-15.5 to -6.4)*
		HU	2011	44.57	15.4	-9.84	0.96	*38.5*	*-11.2 (-13.0 to -7.8)*
		HU	2012	41.73	18.3	-9.11	1.32	*38.5*	*-11.2 (-13.0 to -7.8)*
		TH	2012	38.20	17.1	-8.31	0.09	*35.6*	*-6.9 (-8.1 to -5.2)*
Mackay Whitsunday	coastal	HU	2012	42.05	11.8	-11.42	-0.98	*38.5*	*-11.2 (-13.0 to -7.8)*
		ZM	2012	40.28	13.9	-11.10	4.13	*32*	*-10.8 (-12.4 to -9.2)*
	estuarine	ZM	2011	43.14	12.4	-10.02	0.53	*32*	*-10.8 (-12.4 to -9.2)*
		ZM	2012	40.55	13.9	-10.45	2.08	*32*	*-10.8 (-12.4 to -9.2)*
	reef	HU	2011	45.40	10.5	-10.23	1.44	*38.5*	*-11.2 (-13.0 to -7.8)*
		HU	2012	43.33	10.4	-9.22	-0.20	*38.5*	*-11.2 (-13.0 to -7.8)*
		ZM	2011	42.50	14	-9.30	0.74	*32*	*-10.8 (-12.4 to -9.2)*
		ZM	2012	40.07	15.1	-9.15	2.47	*32*	*-10.8 (-12.4 to -9.2)*
Fitzroy	coastal	ZM	2011	40.08	19.1	-9.28	0.72	*32*	*-10.8 (-12.4 to -9.2)*
		ZM	2012	39.01	18.2	-7.32 ±0.93	0.24 ±0.71	*32*	*-10.8 (-12.4 to -9.2)*
	estuarine	ZM	2012	37.53	22.4	-9.51	2.27	*32*	*-10.8 (-12.4 to -9.2)*
Burnett Mary	estuarine	HO	2011	36.90		-10.46	4.55	*30.5*	*-10 (-15.5 to -6.4)*
		ZM	2011	41.03	16.9	-8.94	3.11	*32*	*-10.8 (-12.4 to -9.2)*
		ZM	2012	38.69	15.9	-10.78 ±2.01	1.72 ±1.98	*32*	*-10.8 (-12.4 to -9.2)*

Table 24. *Percent carbon in seagrass leaf tissue from published literature.*

Species	%C	Citiation	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
Halodule uninervis	40.9	Grice et al. 1996	Green Island
	36	Atkinson & Smith (1984)	N Queensland
	38.5	median	
Halophila ovalis			
	32 ± 0.5	McMahon (2005)	Moreton Bay - Aug
	29 ± 0.4	McMahon (2005)	Moreton Bay - Jan
	30.5	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	

Epiphytes and macroalgae

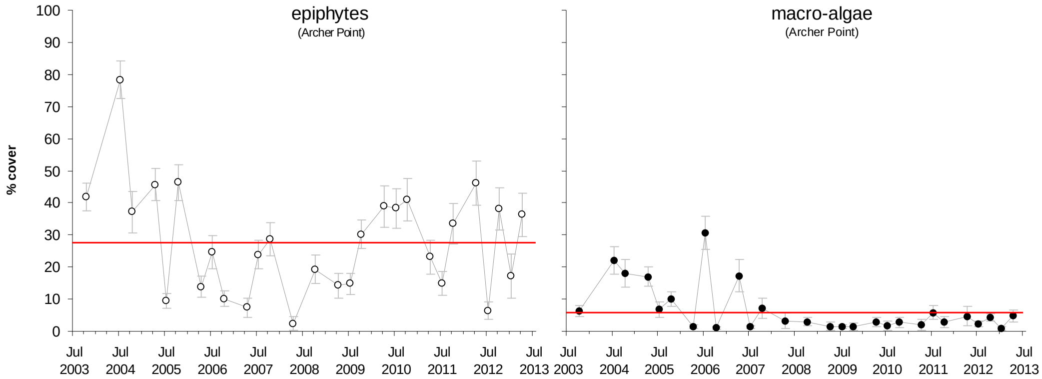

Figure 116. *Long-term trend in mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef habitat (sites pooled), Cape York NRM region. Red line = GBR long-term average; epiphytes=28%, macroalgae=6.2%.*

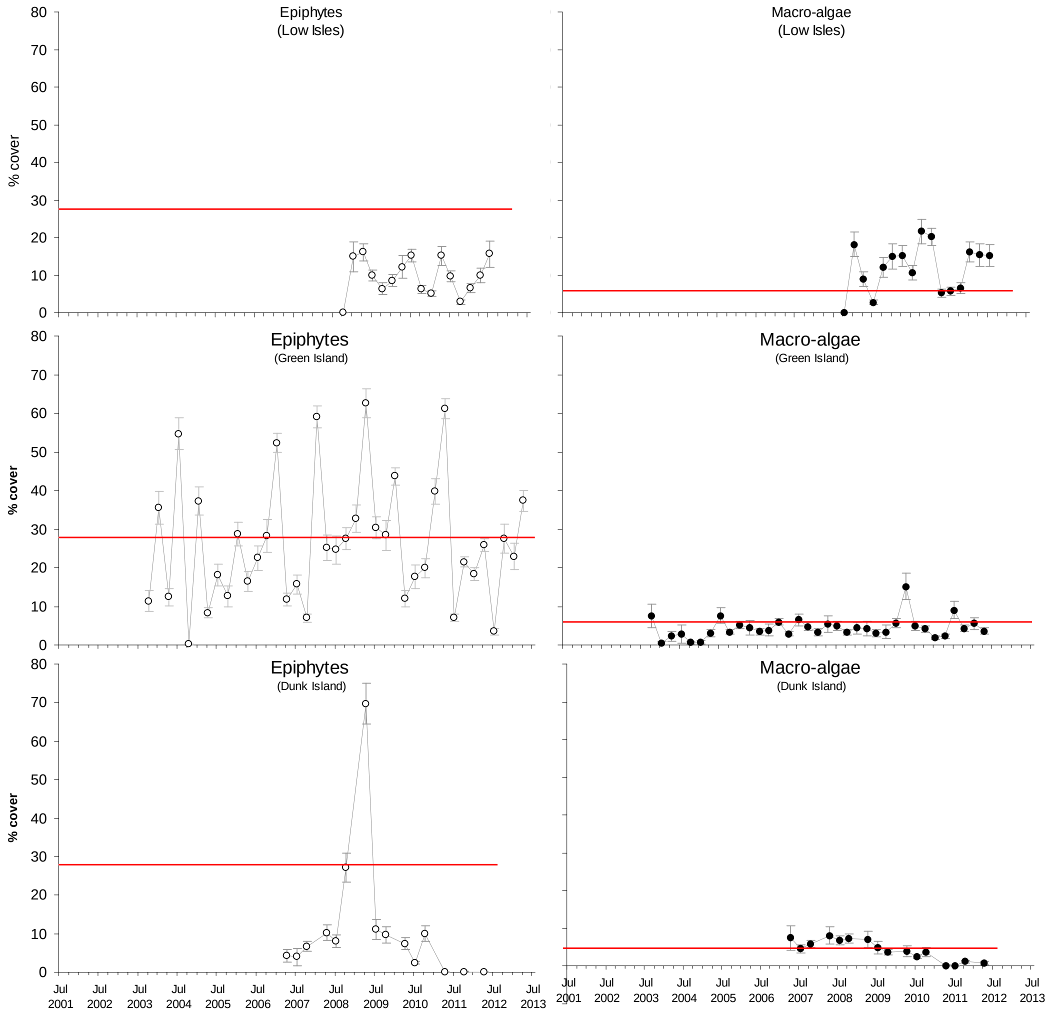

Figure 117. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=28%, macroalgae=6.2%. NB: if seagrass is absent, no value is shown for epiphytes.*

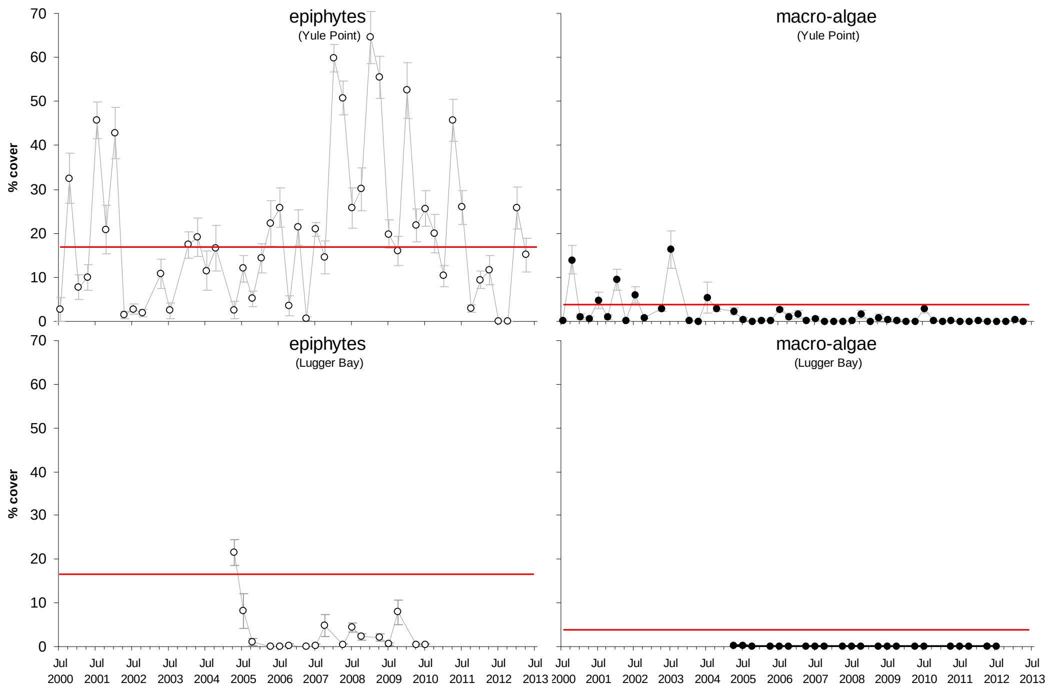

Figure 118. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=17%, macroalgae=4.7%.*

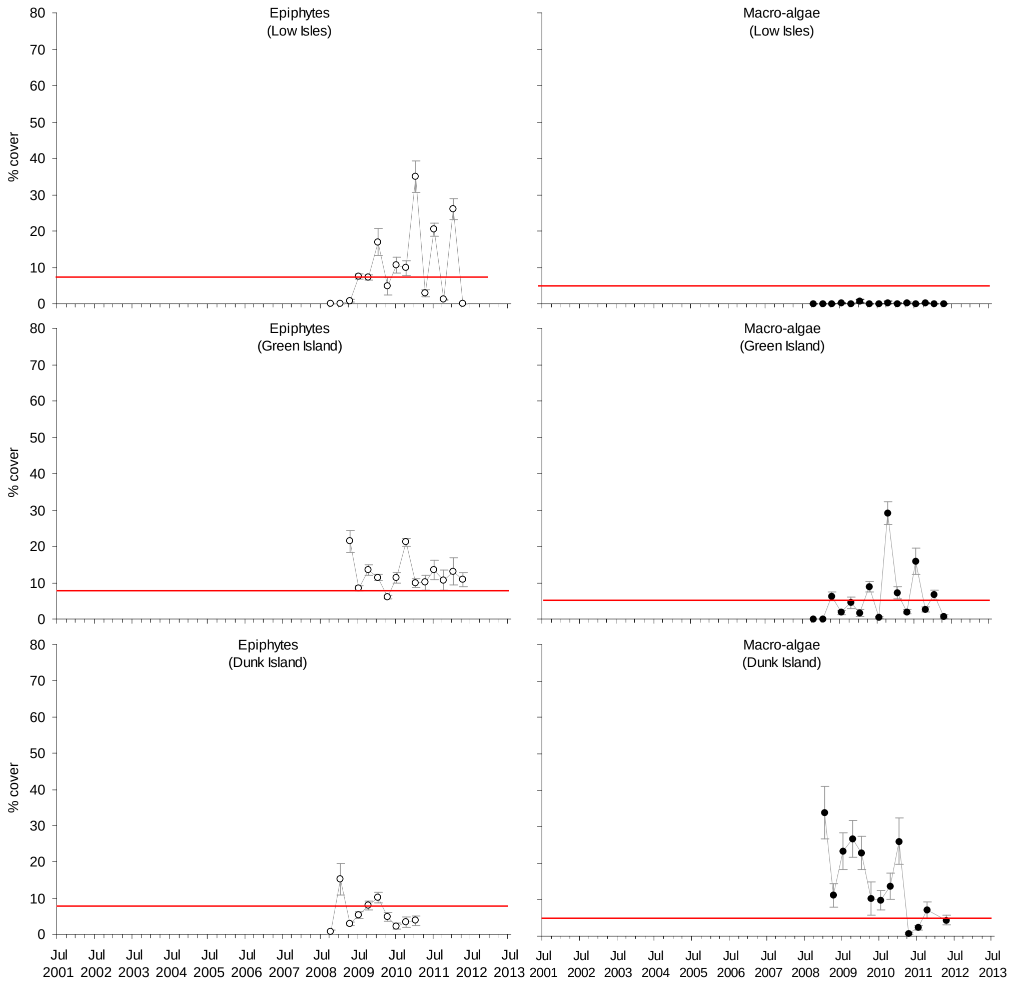

Figure 119. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef seagrass monitoring sites in the Wet Tropics NRM region. Red line = GBR long-term average for subtidal sites; epiphytes=7.2%, macroalgae=4.7%.*

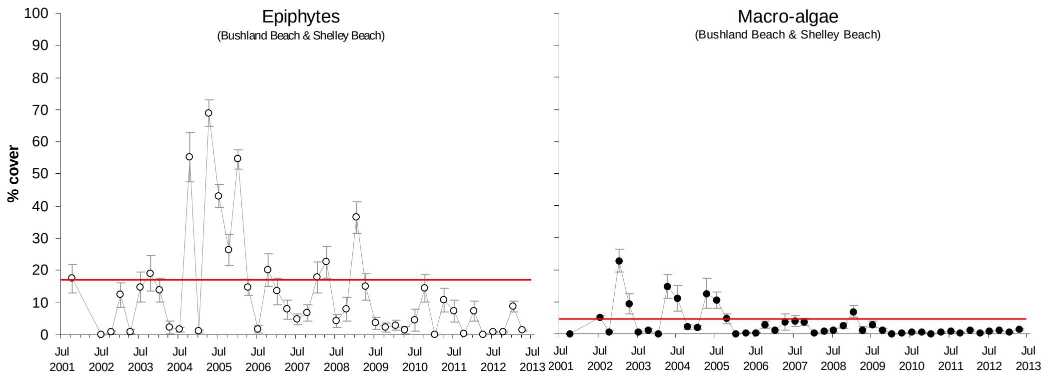

Figure 120. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=17%, macroalgae=4.7%.*

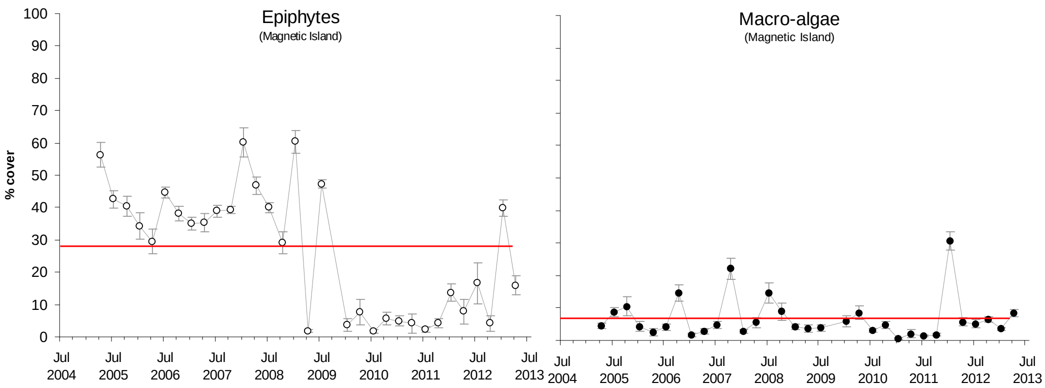

Figure 121. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass habitats (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=28%, macroalgae=6.2%.*

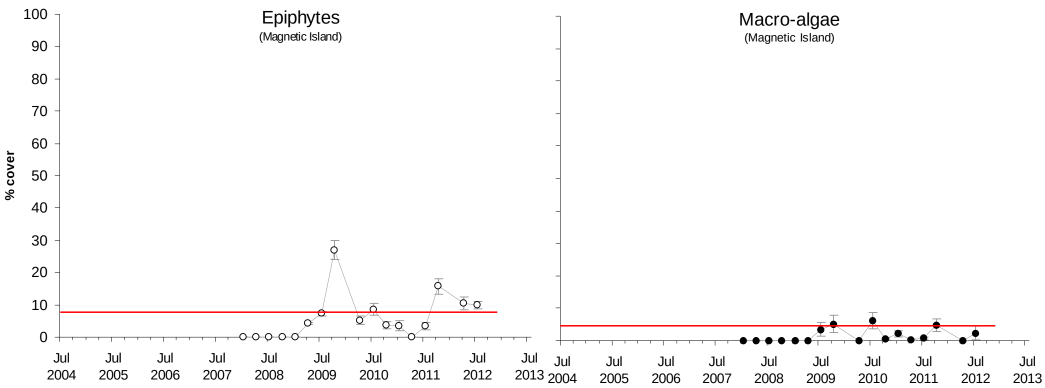

Figure 122. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef monitoring sites in Picnic Bay, Burdekin NRM region. Red line = GBR long-term average for subtidal sites; epiphytes=7.2%, macroalgae=4.7%. NB: if seagrass is absent, no value is shown for epiphytes.*

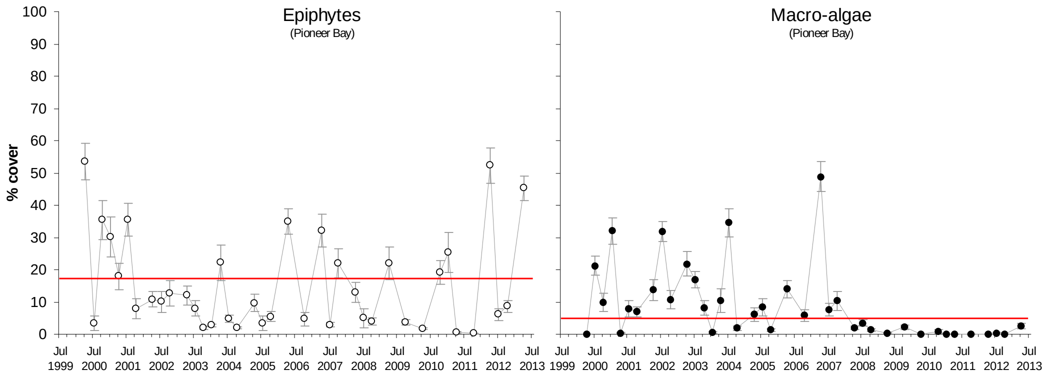

Figure 123. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=17%, macroalgae=4.7%.*

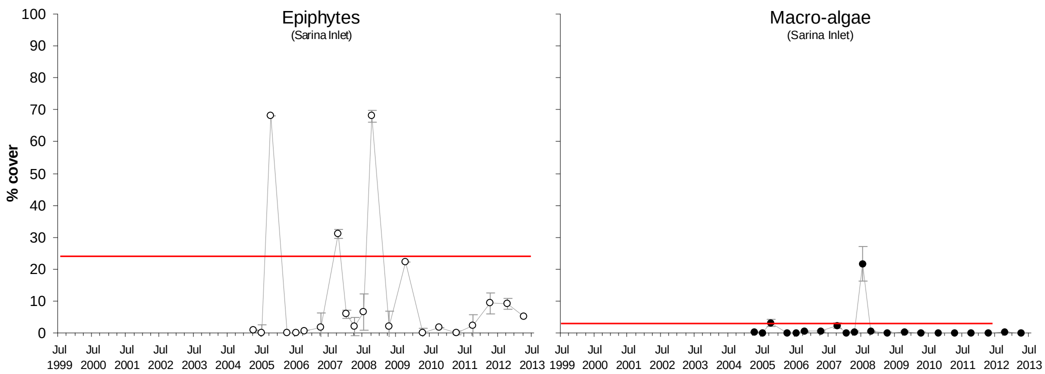

Figure 124. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=24.6%, macroalgae=3.2%.*

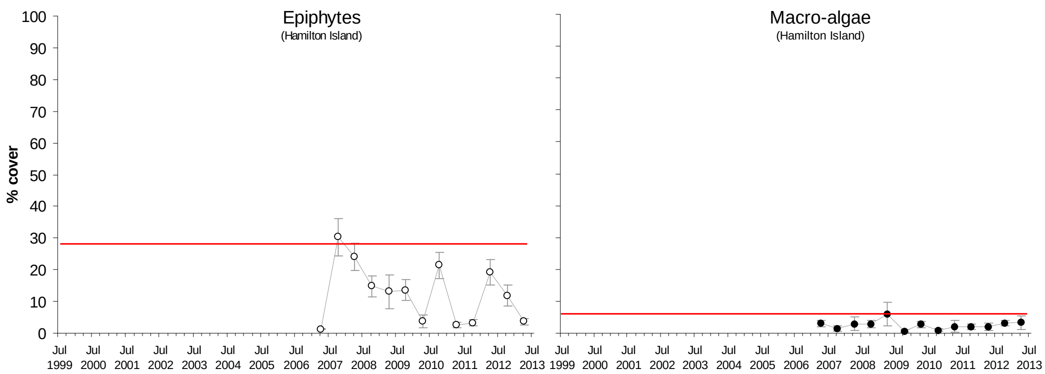

Figure 125. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=28%, macroalgae=6.2%.*

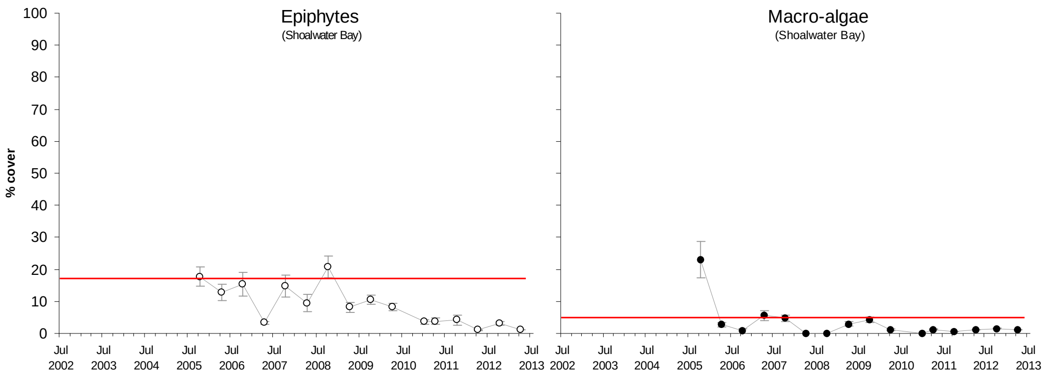

Figure 126. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=17%, macroalgae=4.7%.*

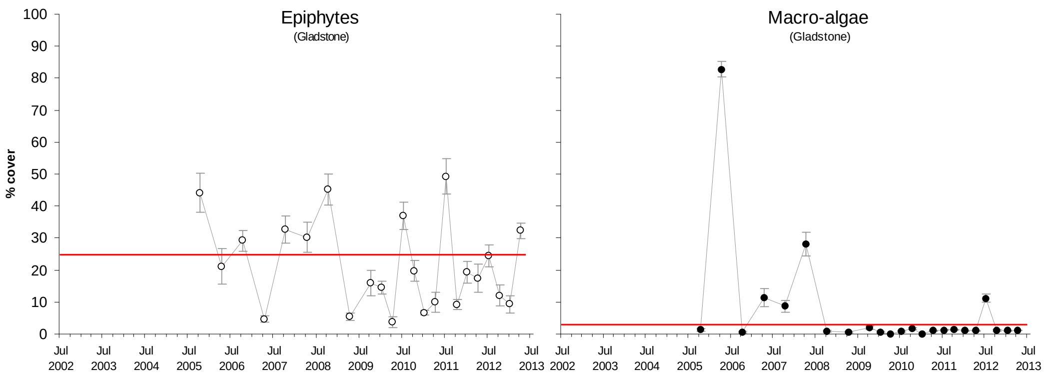

Figure 127. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=24.6%, macroalgae=3.2%.*

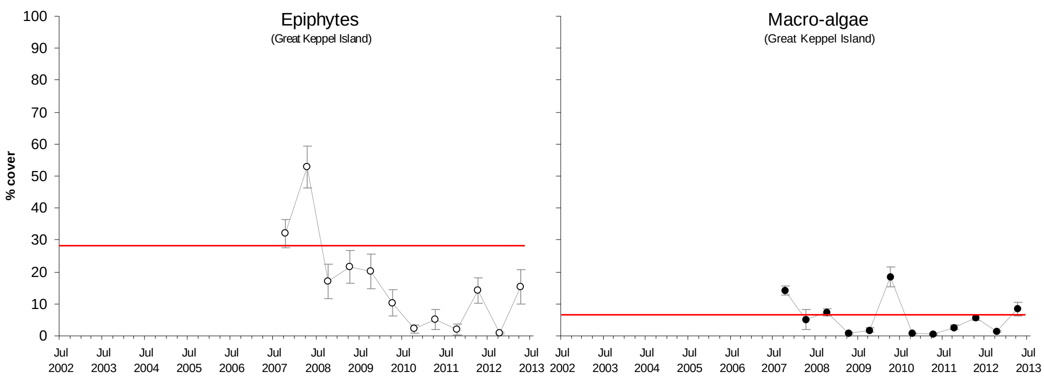

Figure 128. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=28%, macroalgae=6.2%.*

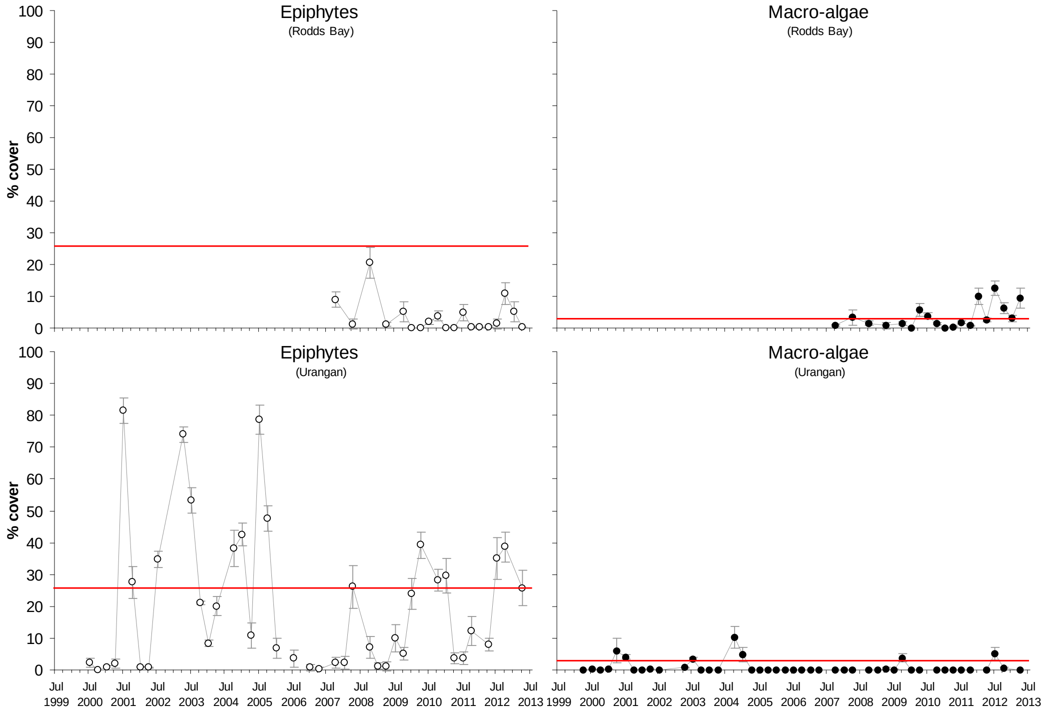

Figure 129. *Mean abundance (% cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Burnett Mary NRM region. Red line = GBR long-term average; epiphytes=24.6%, macroalgae=3.2%.*

Rhizosphere sediment herbicides

Table 25. *Concentration of herbicides (mg kg^{-1}) in sediments of Bowling Green Bay (Burdekin NRM region) seagrass monitoring sites in late monsoon 2012. ND=not detectable above limit of 0.001 mg kg^{-1}, * = confirmed traces of Diuron at levels below the stated limit of reporting.*

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*

Within canopy sea temperature

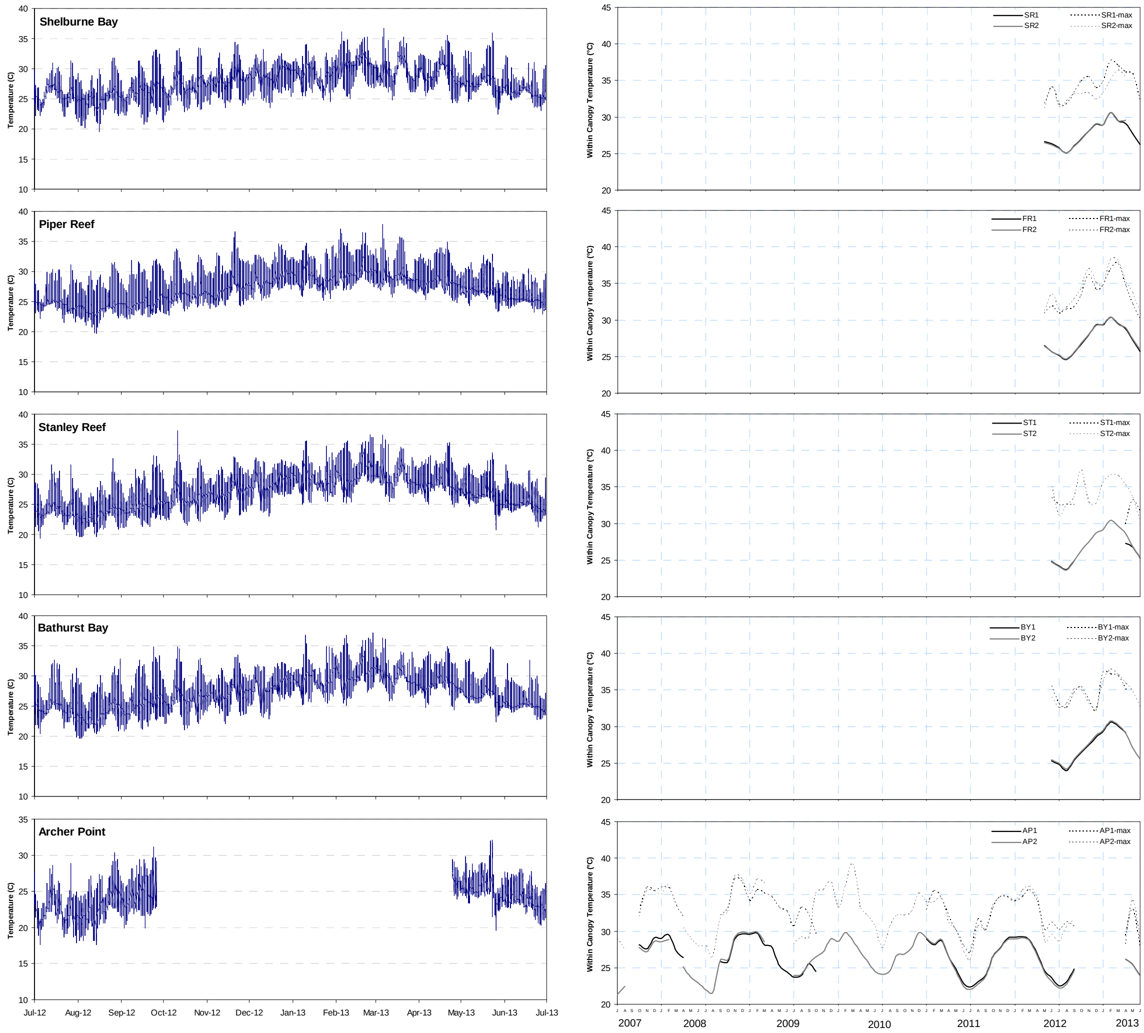

Figure 130. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in the Cape York NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

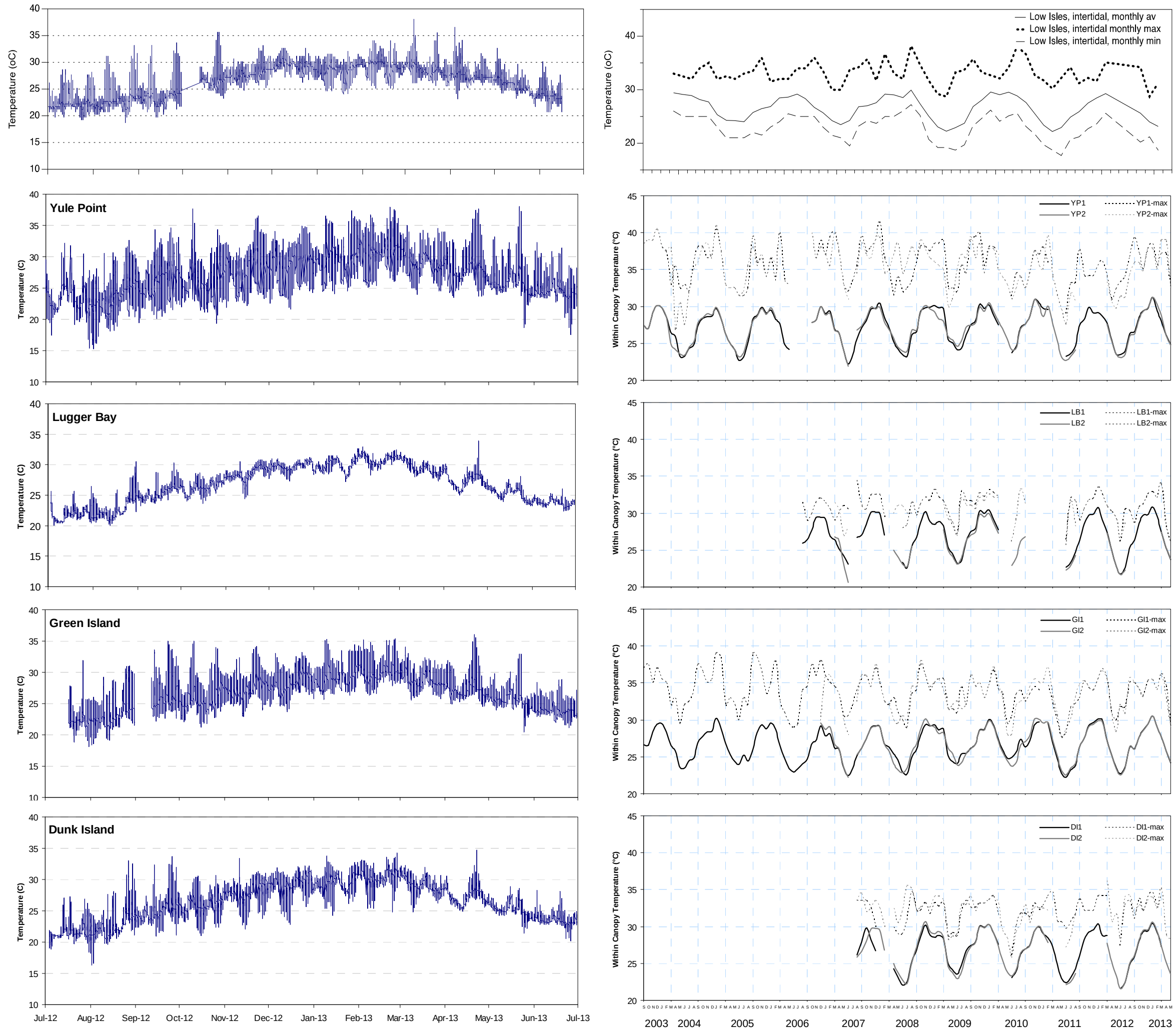

Figure 131. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in the Wet Tropics NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

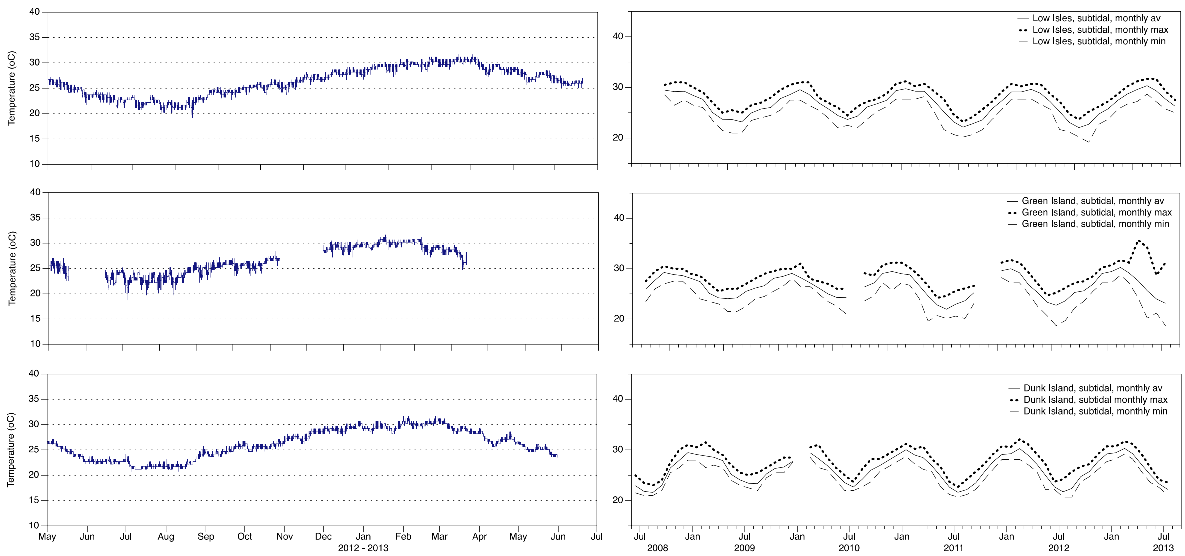

Figure 132. *Within seagrass canopy temperatures (°C) at subtidal monitoring locations in the Wet Tropics NRM region: daily within seagrass canopy temperature (°C) over the 2012-13 monitoring period (left) and long-term monthly mean and maximum (right) at Low Isles (top), Green Island (middle) and Dunk Island (bottom).*

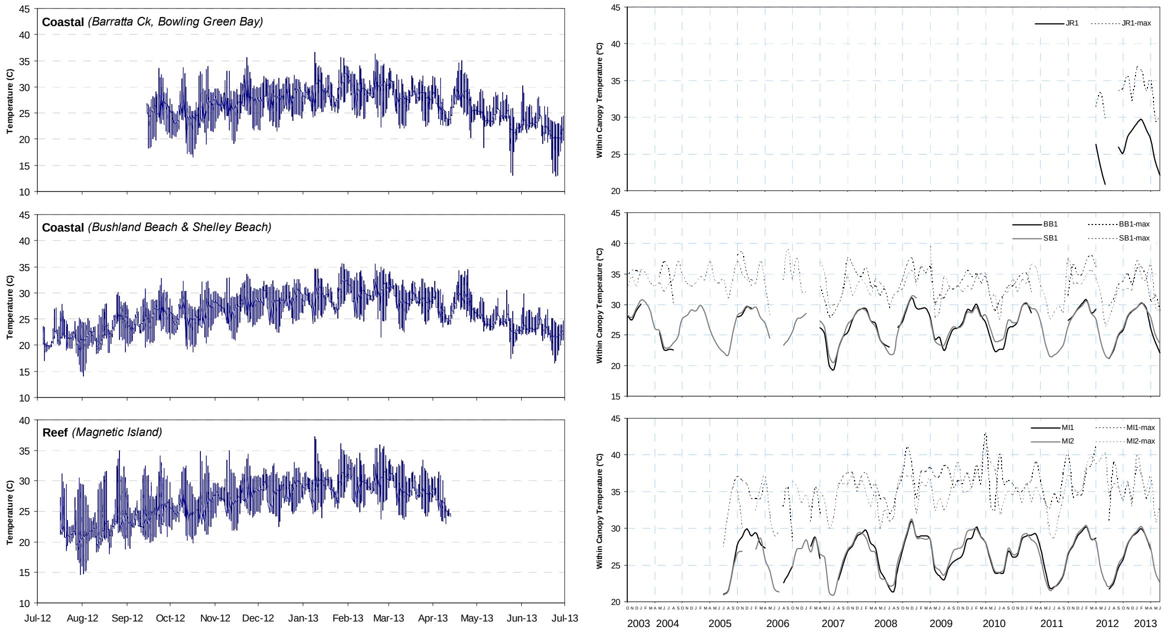

Figure 133. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in the Burdekin NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

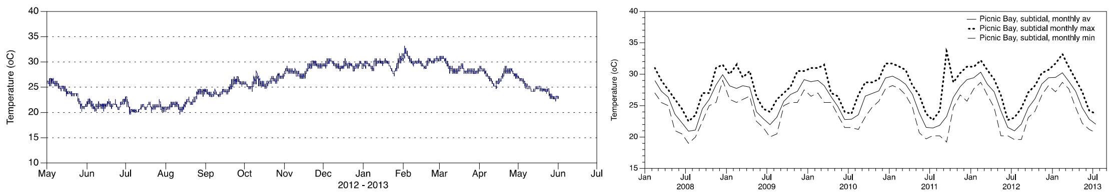

Figure 134. *Within seagrass canopy temperatures (°C) at subtidal monitoring locations in Burdekin NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

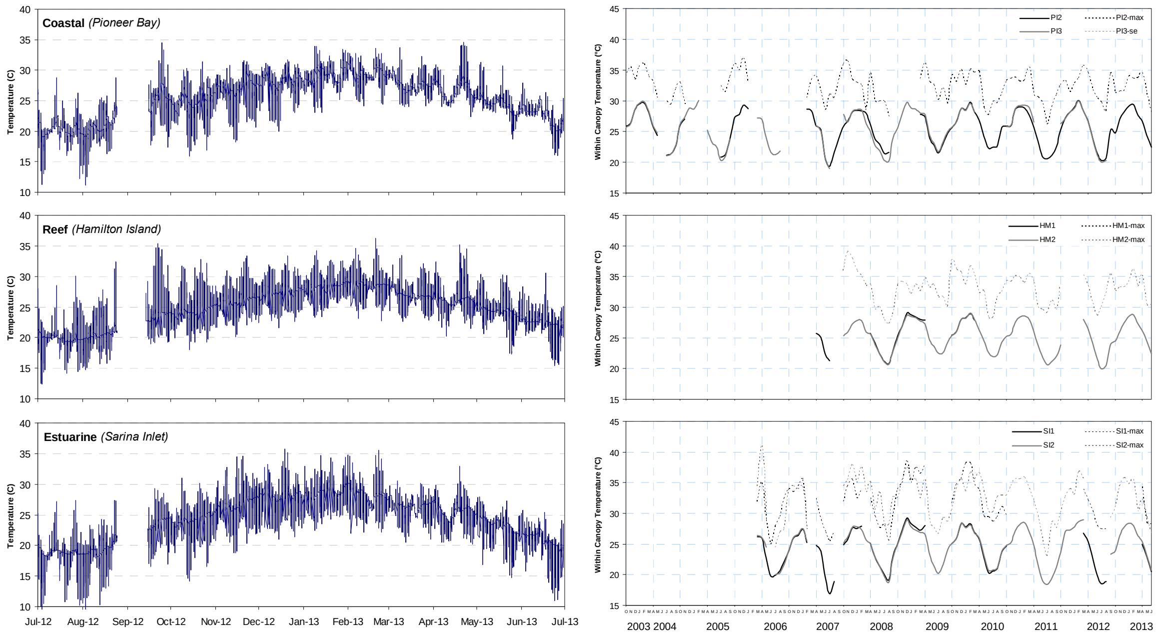

Figure 135. *Within seagrass canopy temperatures (°C) at intertidal monitoring locations in Mackay Whitsunday NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

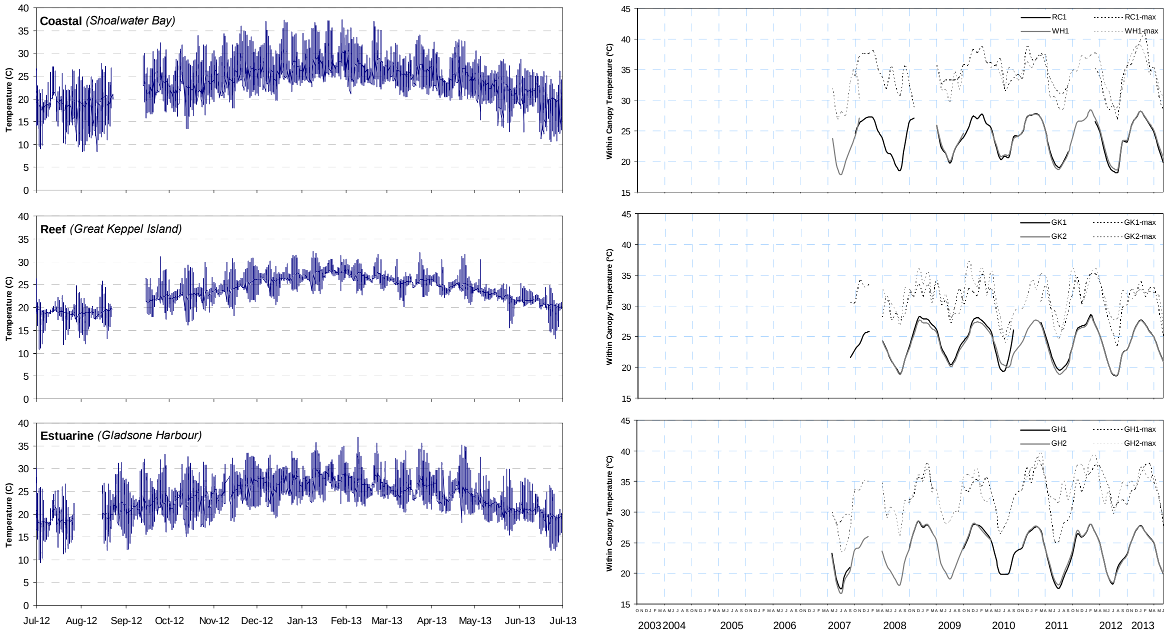

Figure 136. *Within seagrass canopy temperatures (°C) at monitoring locations in the Fitzroy NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

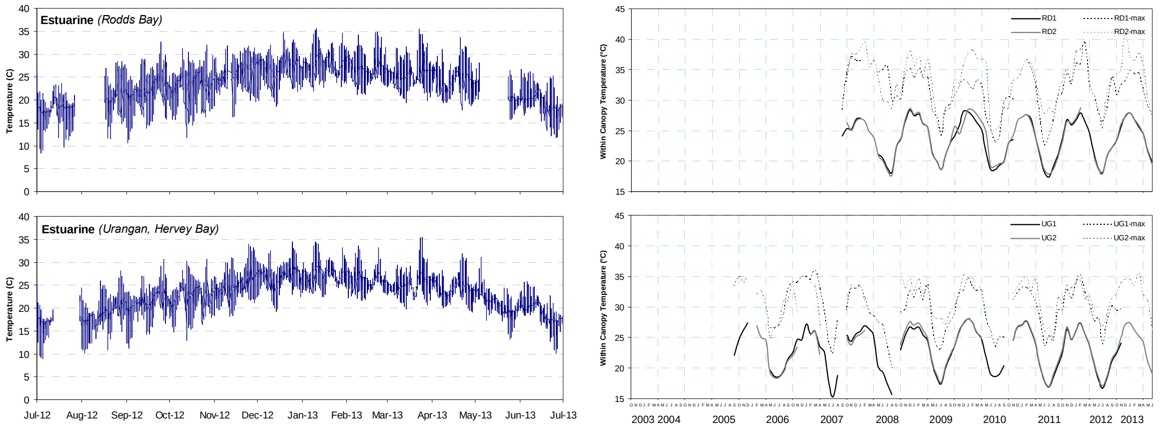

Figure 137. *Within seagrass canopy temperatures (°C) at monitoring locations in the Burnett Mary NRM region: daily mean (sites pooled) over 2012-13 monitoring period (left); and long-term monthly mean and maximum within seagrass canopy temperature at each site (right).*

Light at seagrass canopy

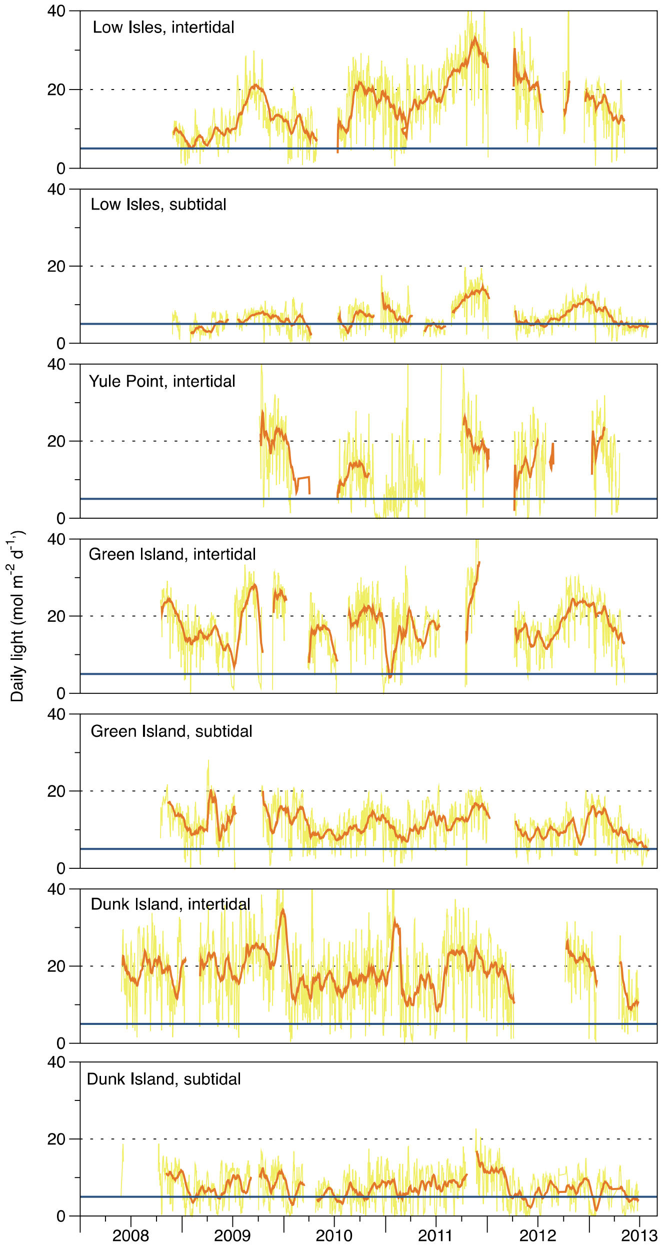

Figure 138. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at locations in the Wet Tropics region, 2008-2013. Also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold based on 90-day average.*

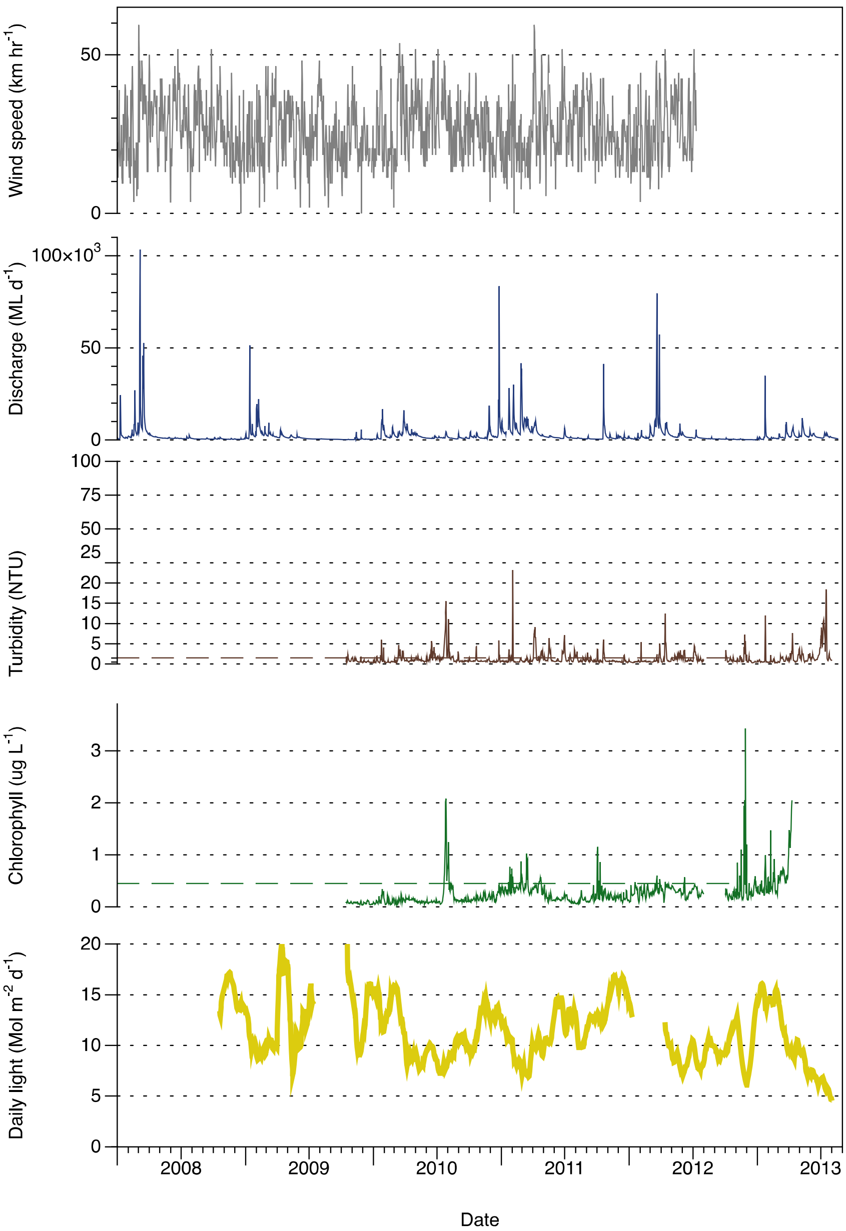

Figure 139. *Daily mean chlorophyll concentration (green line, ųg L-1), turbidity (brown line, NTU) at Green Island in the Wet Tropics NRM Region. Additional panels are daily discharge (Mulgrave, ML d^{-1} $x10^{-5}$), daily wind speed (Low Isles), and daily light at seagrass canopy height. Horizontal 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).*

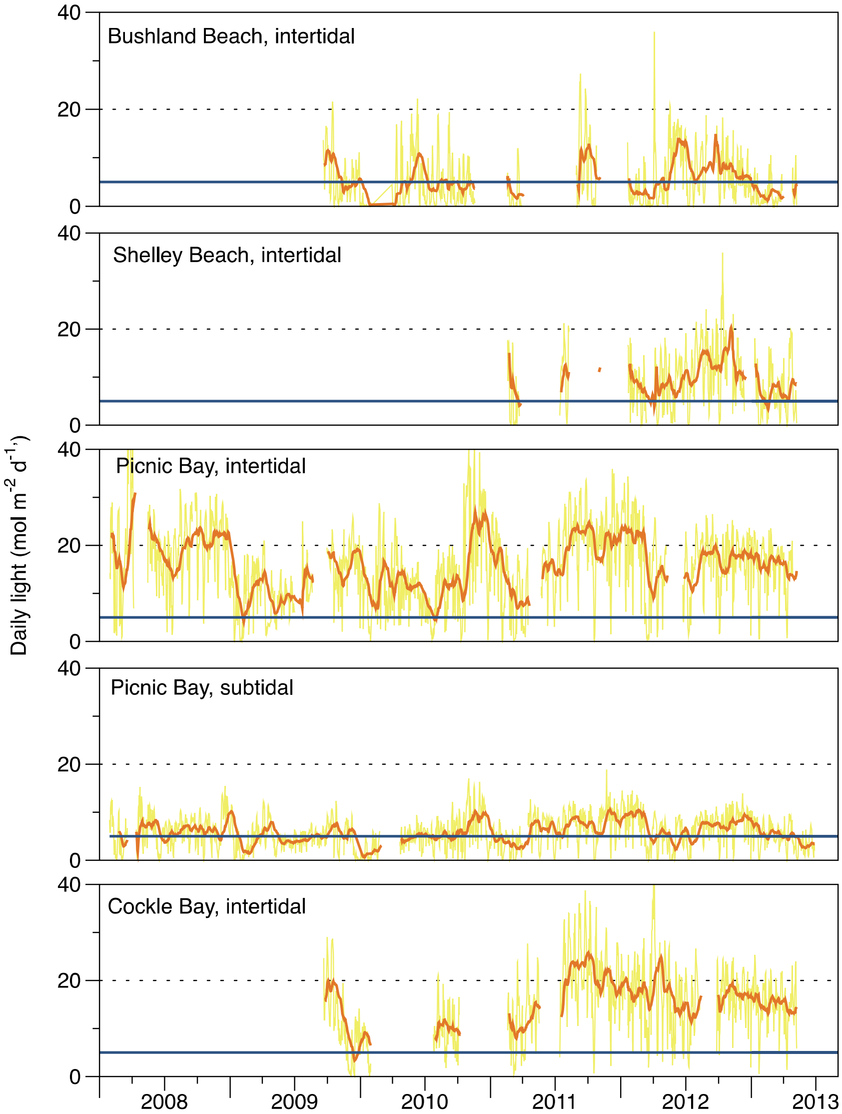

Figure 140. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at locations in the Burdekin region, 2008-2013. Also showing approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

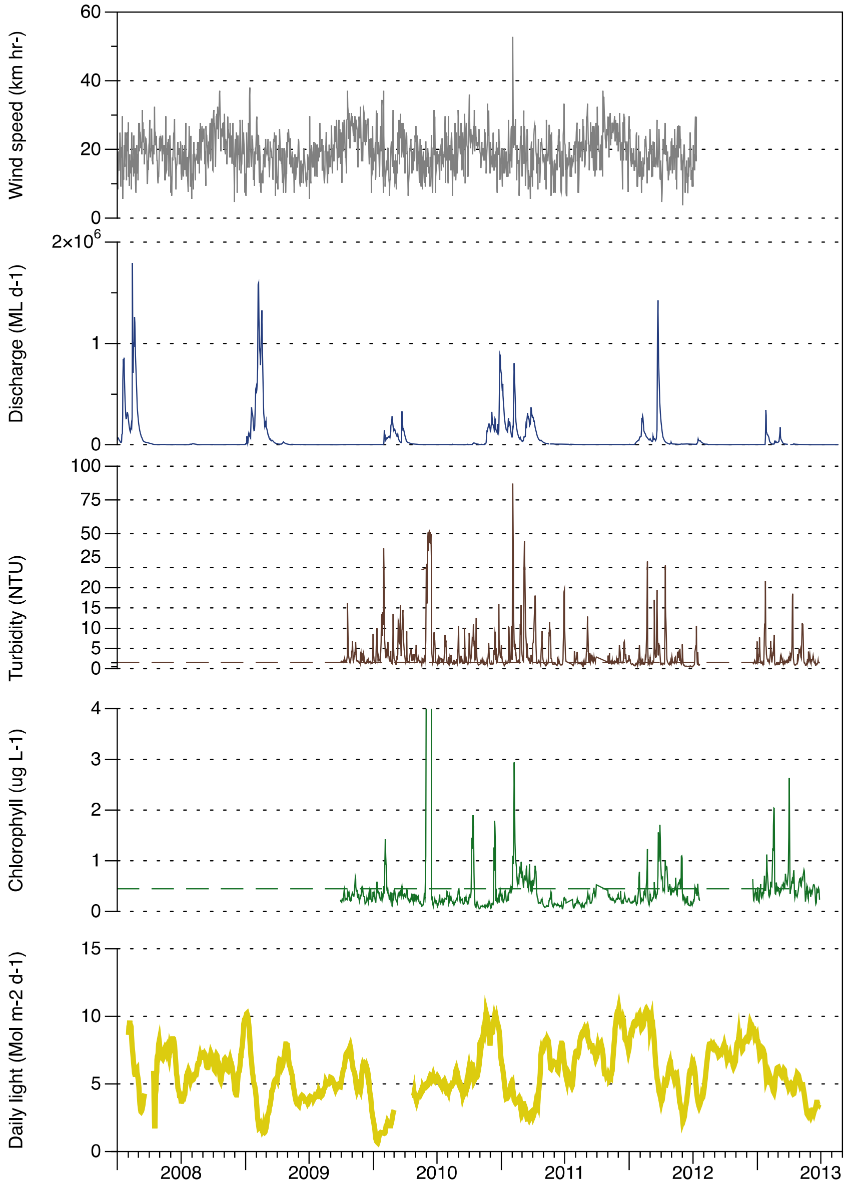

Figure 141. *Daily mean chlorophyll concentration (green line, ɥg L^{-1}), turbidity (brown line, NTU) at the subtidal seagrass habitat on Magnetic Island (Picnic Bay) in the Burdekin NRM Region over duration of monitoring. Additional panels are daily discharge (Burdekin River, ML d^{-1} $x10^{-5}$), 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).*

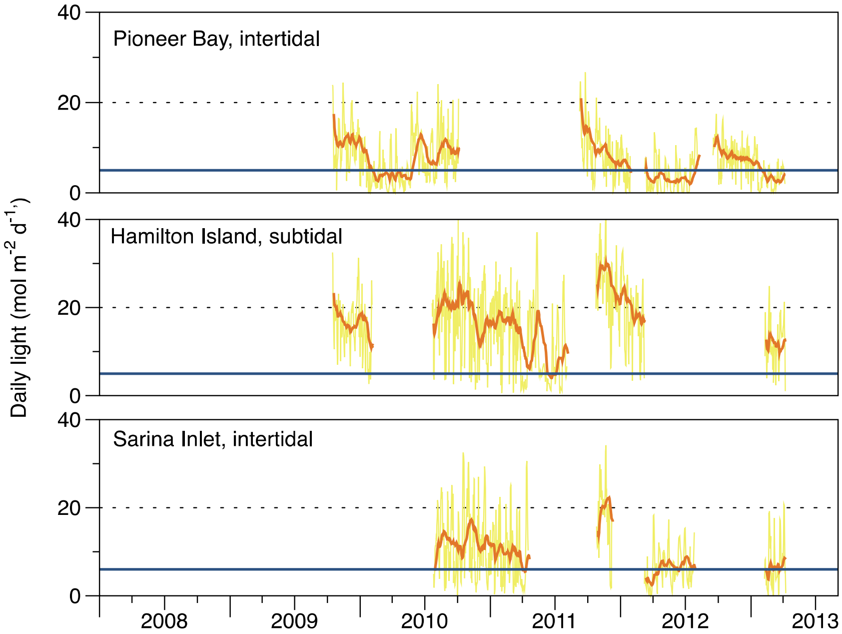

Figure 142. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at intertidal monitoring locations in the Mackay Whitsunday region, 2008-2013. Also showing approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b). NB: threshold is based on 90-day average*.

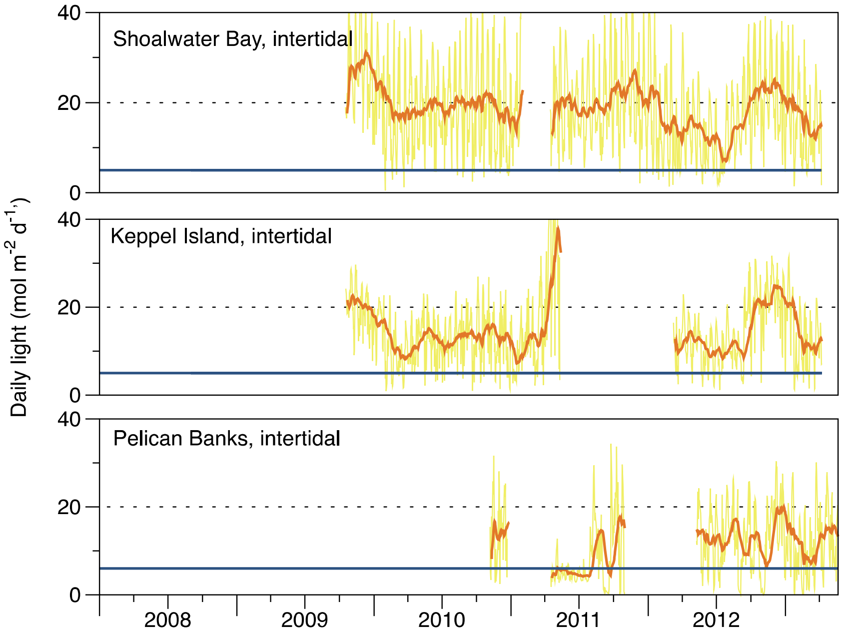

Figure 143. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at intertidal monitoring locations in the Fitzroy region, 2008-2013. Also showing approximate light threshold required for positive growth in* Halodule uninervis *dominated communities (5 mol m^{-2} d^{-1}, Collier, et al. 2012b) and in* Zostera muelleri *dominated communities in the southern GBR (6 mol m^{-2} d^{-1}, Chartrand, et al. 2012). NB: threshold is based on 90-day average for* H. uninervis *and a 2-week average for* Z. muelleri*. Pelican Banks data for November 2012-June2013 courtesy of Gladstone Ports Corporation Ltd and Vision Environment Pty Ltd.*

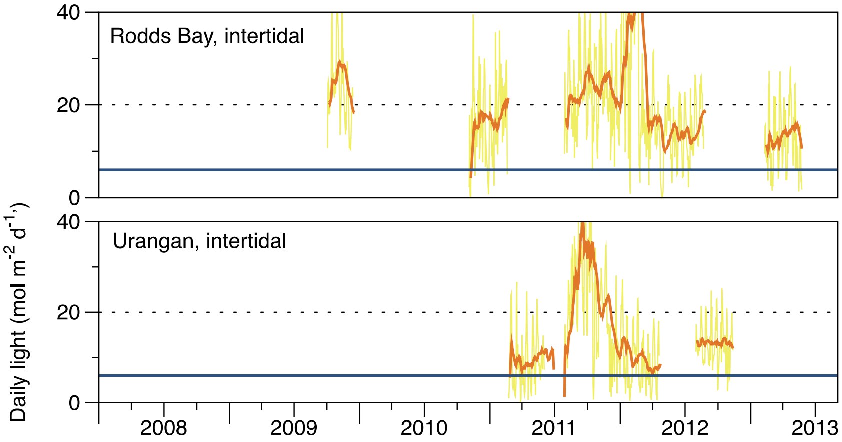

Figure 144. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at intertidal estuary locations in the Burnett Mary region, 2008-2013. Also showing approximate light threshold required for positive growth in* Zostera muelleri *dominated communities in the southern GBR (6 mol m^{-2} d^{-1}, Chartrand, et al. 2012). NB: threshold is based on 2-week average for* Z. muelleri.

Climate

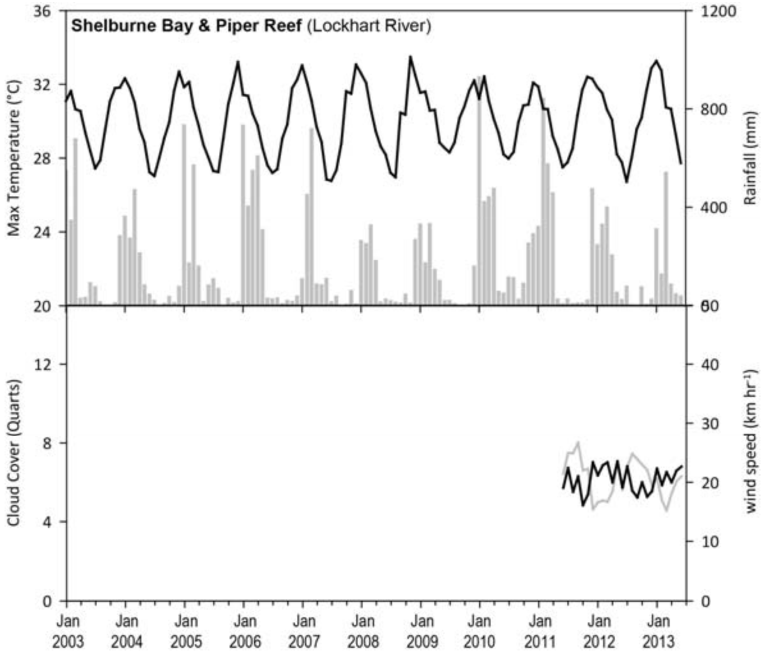

Figure 145. *Mean monthly daily maximum air temperature (°C, black line), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km.hr^{-1}, grey line) at Shelburne Bay and Piper Reef, 2003-2013. Climate data recorded at Lockhart River Airport (BOM station 028008, source www.bom.gov.au), located 108km from Shelburne Bay and 61km from Piper Reef monitoring sites.*

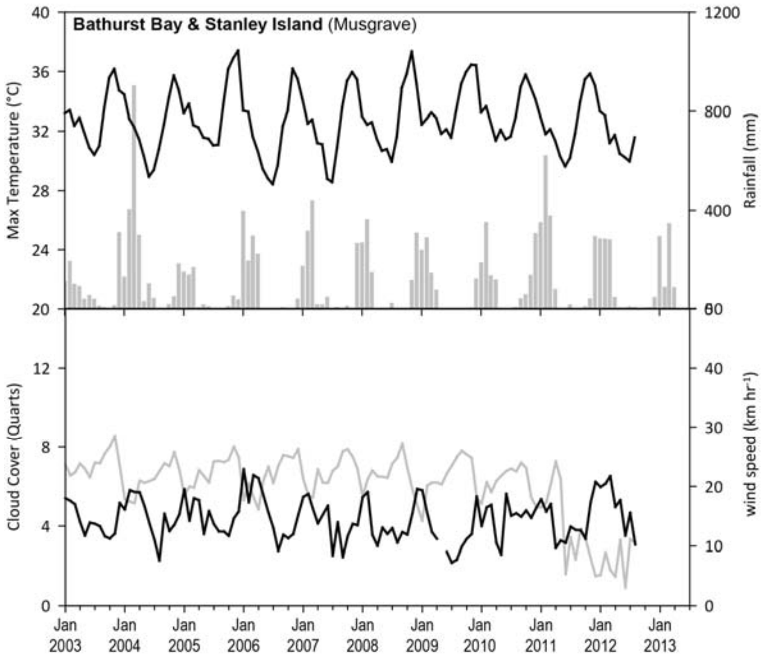

Figure 146. *Total monthly rainfall (mm, bar graph), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Bathurst Bay and Stanley Island, 2003-2013. Rainfall recorded at Lotus Bird Lodge (BOM station 028035, source www.bom.gov.au), located approximately 73km and 84km from Bathurst Bay and Stanley Island monitoring sites, respectively. Air temperature, cloud cover, and wind speed from Musgrave (BOM station 028007, source www.bom.gov.au), located approximately 97km and 107km from Bathurst Bay and Stanley Island monitoring sites, respectively.*

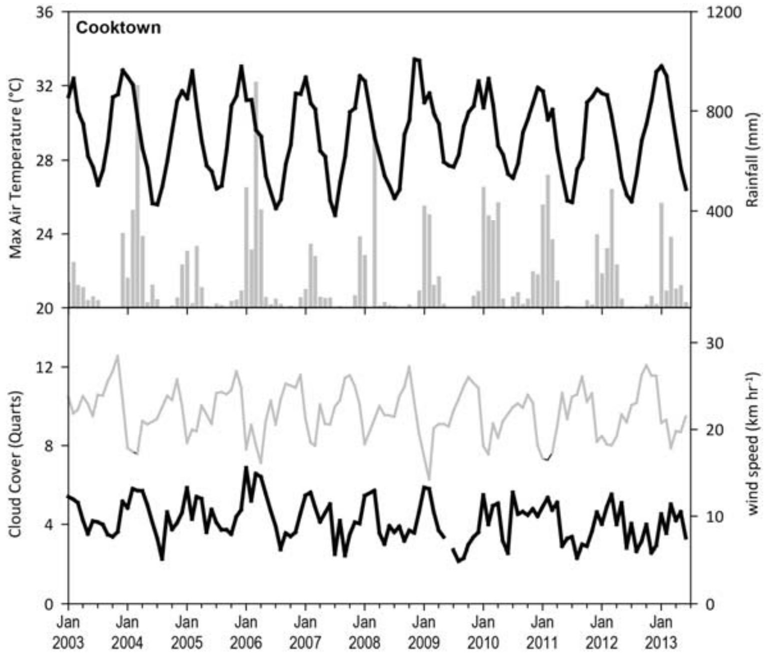

Figure 147. *Mean monthly daily maximum air temperature (°C, black line), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Archer Point, 2003-2013. Data recorded at Cooktown airport (BOM station 031209, source www.bom.gov.au), located 16km from Archer Point monitoring sites.*

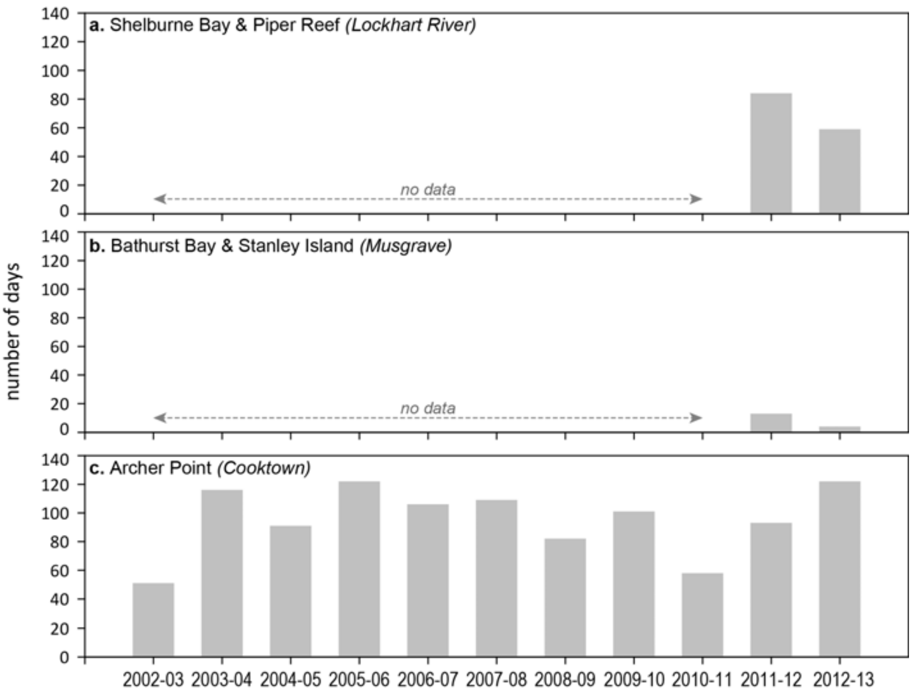

Figure 148. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Cape York NRM region, 2002-2013. Daily 3pm wind speed from: a) Musgrave (BOM station 028007), located approximately 97km and 107km from Bathurst Bay and Stanley Island monitoring sites, respectively; b) Lockhart River Airport (BOM station 028008, source www.bom.gov.au), located 108km from Shelburne Bay and 61km from Piper Reef monitoring sites; and, c) Cooktown airport (BOM station 031209), located 16km from Archer Point monitoring sites.*

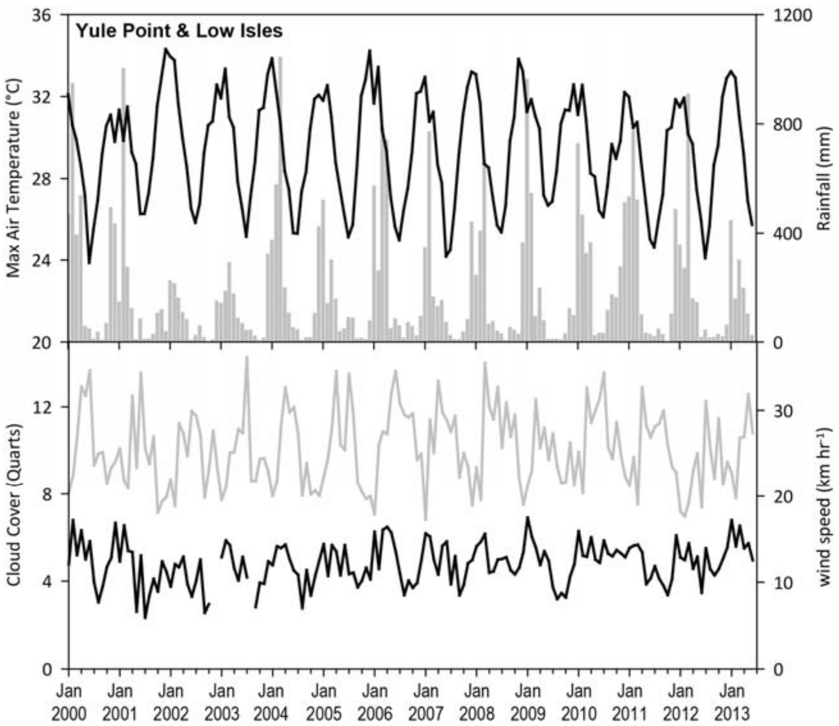

Figure 149. *Total monthly rainfall (mm, bar graph), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Low Isles and Yule Point, 2000-2013. Rainfall recorded at Port Douglas - Warner St (BOM station 31052), located approximately 11km from Yule Point and 15 from Low Isles monitoring sites. Air temperature, cloud cover, and wind speed from Low Isles (BOM station 31037), located approximately 21km from Yule Point monitoring sites. Source www.bom.gov.au*

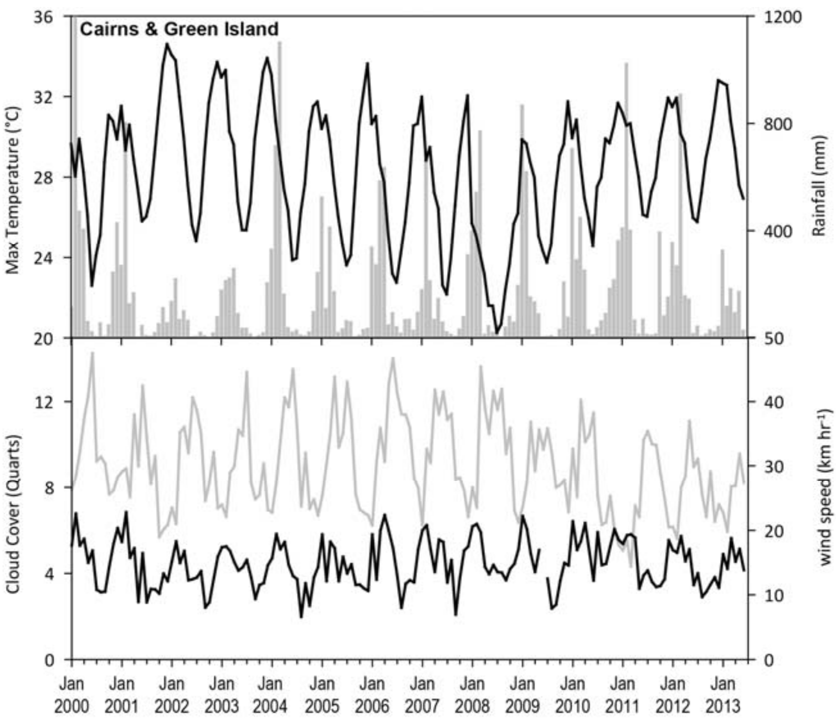

Figure 150. *Mean monthly daily maximum air temperature (°C, black line), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Green Island, 2000-2013. Air temperature (pre-July 2010), rainfall (pre-July 2010), and wind speed recorded at Green Island (BOM station 31192). Air temperature (post-Jun 2010), rainfall (post-Jun 2010), and cloud cover, recorded at Cairns airport (BOM station 031011), located approximately 26km from Green Island monitoring sites. Source www.bom.gov.au*

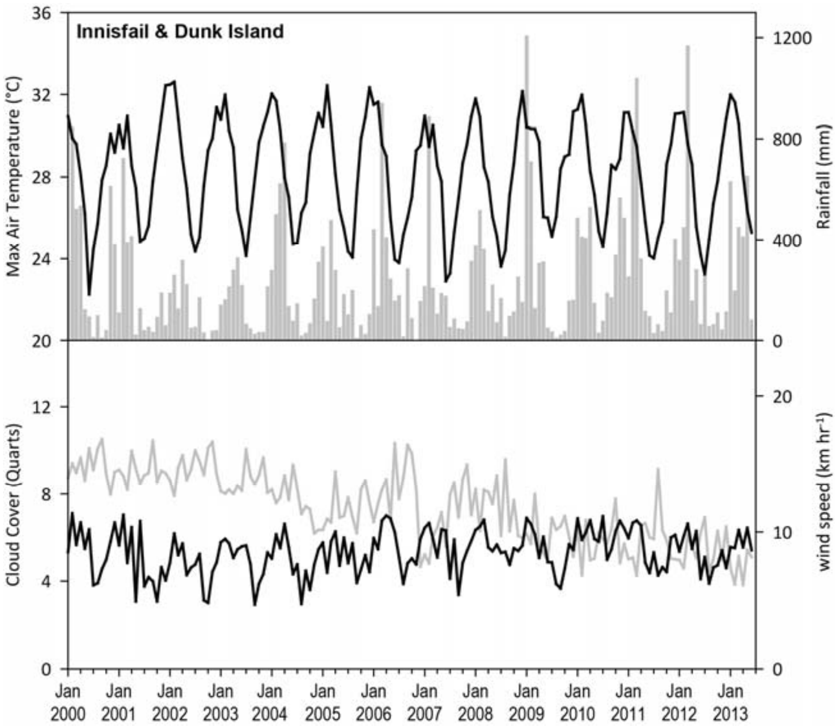

Figure 151. *Mean monthly daily maximum air temperature (°C, black line), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km.hr^{-1}, grey line) at Lugger Bay and Dunk Island, 2000-2013. Rainfall recorded at Dunk Island Resort (BOM station 32118). Air temperature, cloud cover, and wind speed recorded at Innisfail (BOM station 032025), located approximately 48km from monitoring sites at Lugger Bay and Dunk Island. Source www.bom.gov.au*

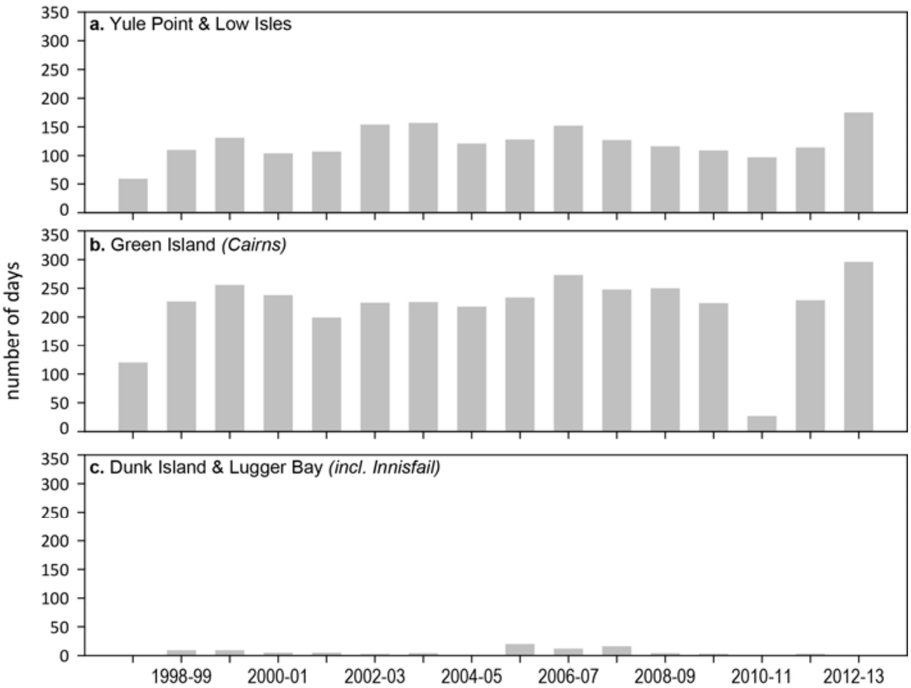

Figure 152. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Wet Tropics NRM region, 1998-2013. Daily 3pm wind speed from: a) Low Isles (BOM station 31037), located approximately 21km from Yule Point monitoring sites; b) Green Island (BOM station 31192); and C) Innisfail (BOM station 032025), located approximately 48km from monitoring sites at Lugger Bay and Dunk Island.*

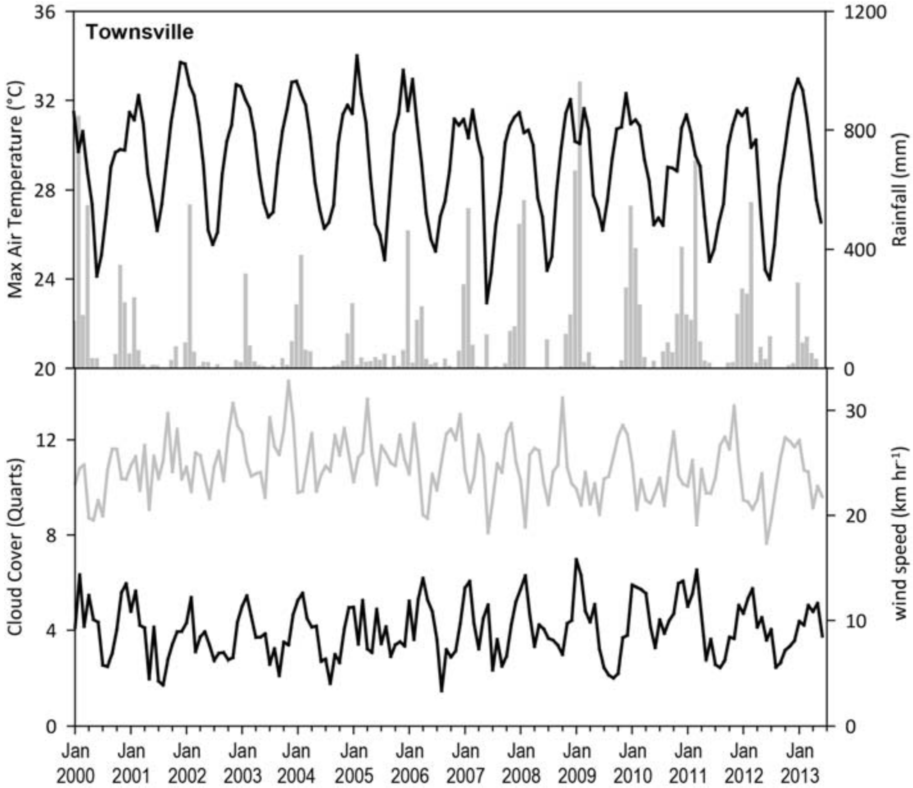

Figure 153. *Mean monthly daily maximum air temperature (°C, black line), total monthly rainfall (grey bars), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Townsville and Magnetic Island, 2000-2013. Air temperature, rainfall, cloud cover, and wind speed recorded at Townsville Airport (BOM station 032040), located approximately 11km from coastal (Townsville) and reef (Magnetic Island) monitoring sites. Source www.bom.gov.au*

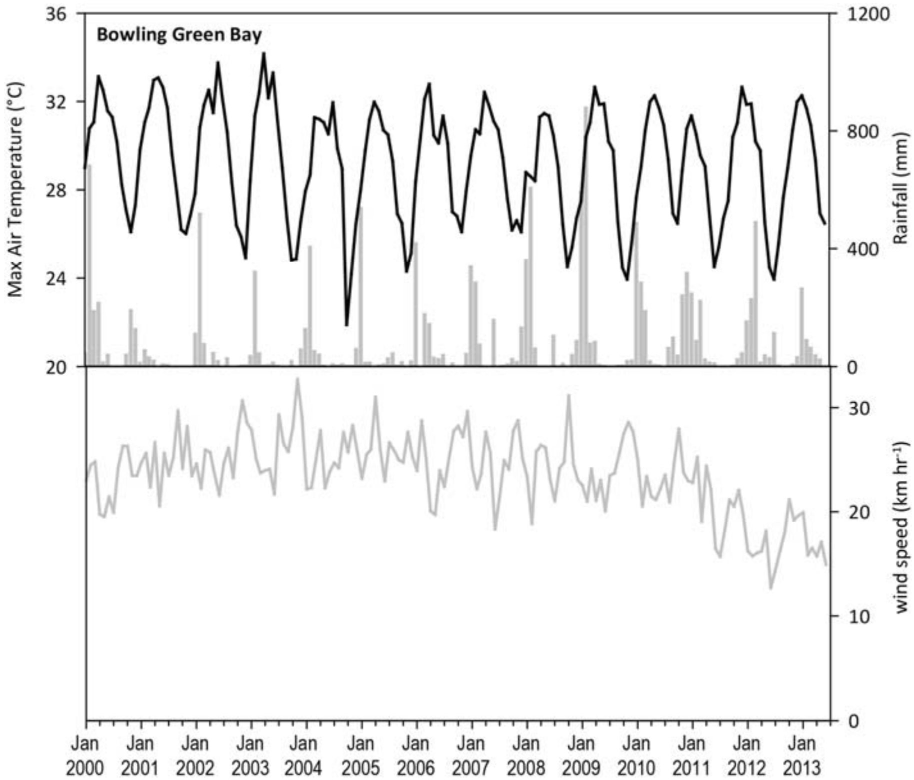

Figure 154. *Mean monthly daily maximum temperature (°C, line), total monthly rainfall (grey bars), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) Bowling Green Bay, 2000-2013. Recorded at Ayr (BOM station 033002, source www.bom.gov.au), located approximately 26km from Jerona (Bowling Green Bay) monitoring sites.*

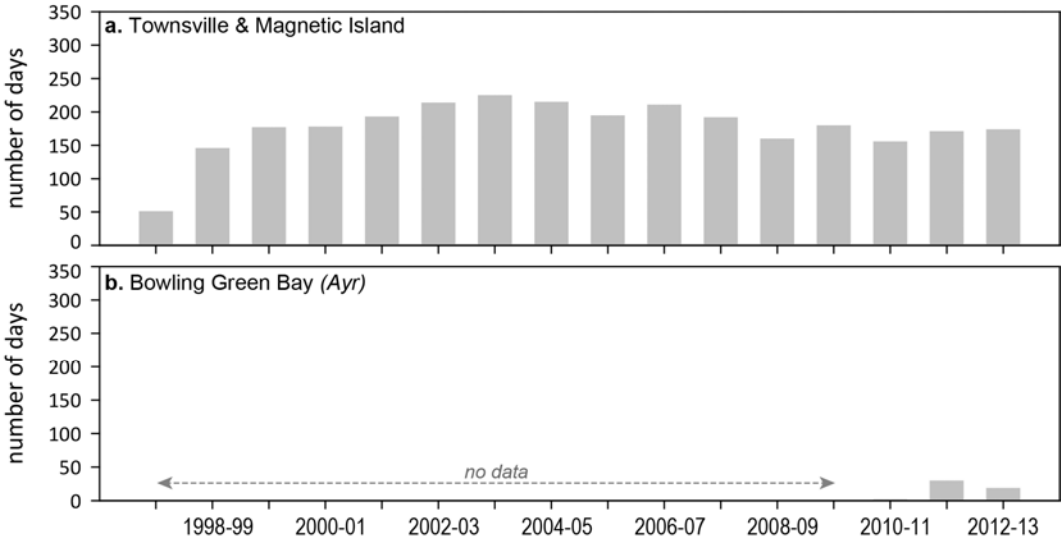

Figure 155. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Burdekin NRM region, 1998-2013. Daily 3pm wind speed from: a) Townsville Airport (BOM station 032040) located approximately 11km from coastal (Townsville) and reef (Magnetic Island) monitoring sites, and 53km from Jerona (Bowling Green Bay) monitoring sites; and b) Ayr (BOM station 033002), located approximately 26km from Jerona (Bowling Green Bay) monitoring sites.*

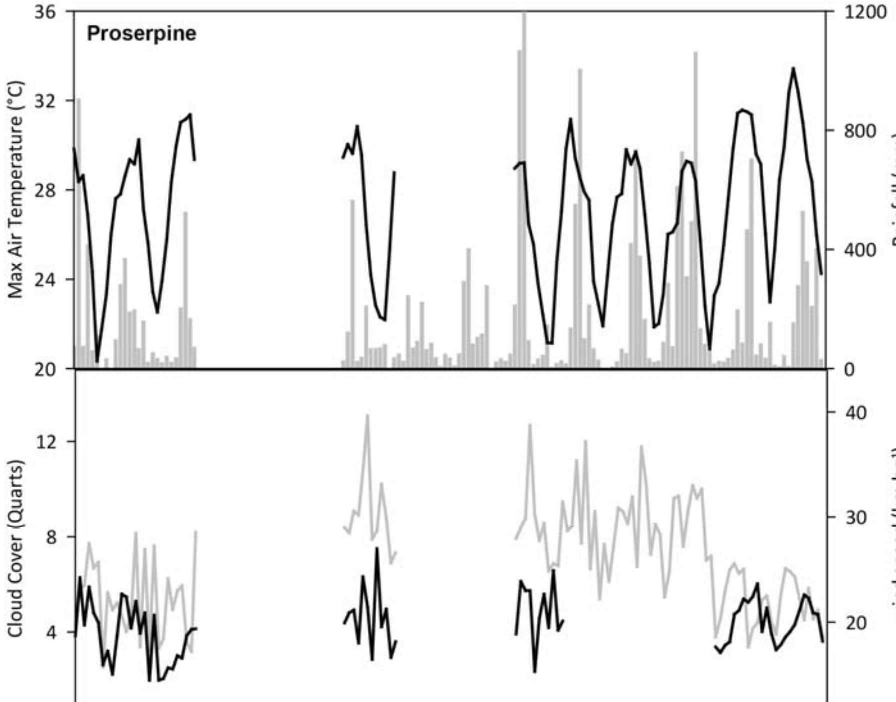

Figure 156. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) Pioneer Bay, 2000-2013. Rainfall (post December 2004), air temperature, cloud cover, and wind speed recorded at Proserpine Post Office (BOM station 33316) (post June 2011), located 18km from Pioneer Bay monitoring sites. All other recordings from Hamilton Island (BOM station 033106), approximately 28km from Pioneer Bay monitoring sites. Source www.bom.gov.au*

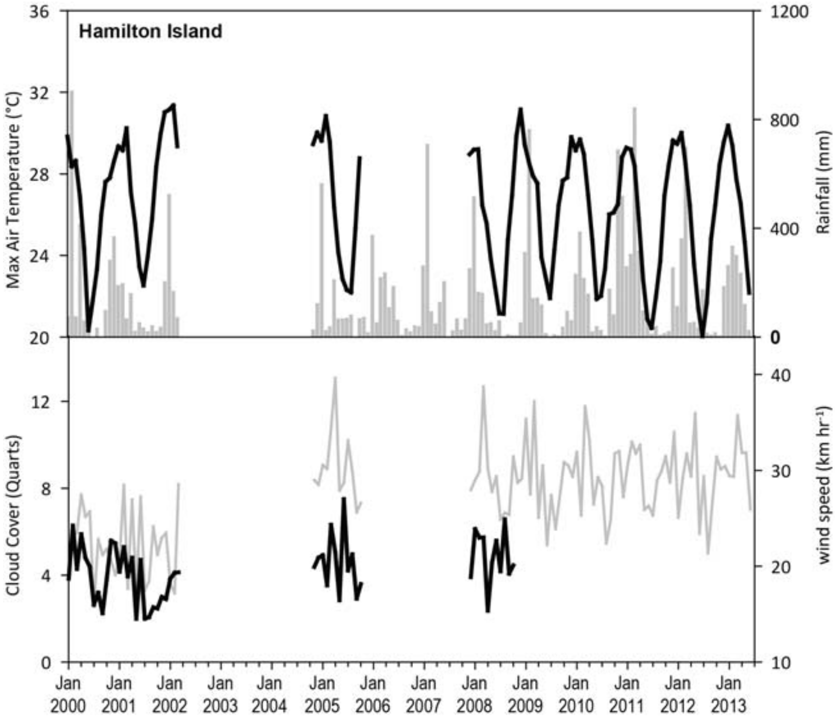

Figure 157. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Hamilton Island (BOM station 033106, source www.bom.gov.au), located 1.5km from Hamilton Island monitoring sites.*

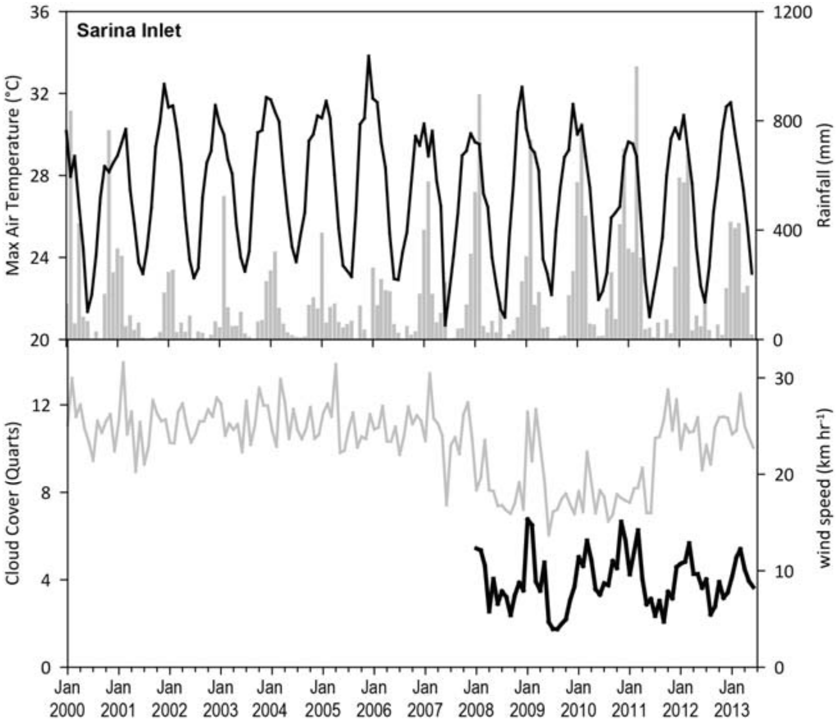

Figure 158. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Sarina Inlet, 2000-2013. Rainfall recorded at Plane Creek Sugar Mill (BOM station 033059), located 10km from Sarina Inlet monitoring sites. Air temperature, cloud cover and wind speed recorded at Mackay Airport (BOM station 033045), approximately 28km from Sarina Inlet monitoring sites*. *Source www.bom.gov.au*

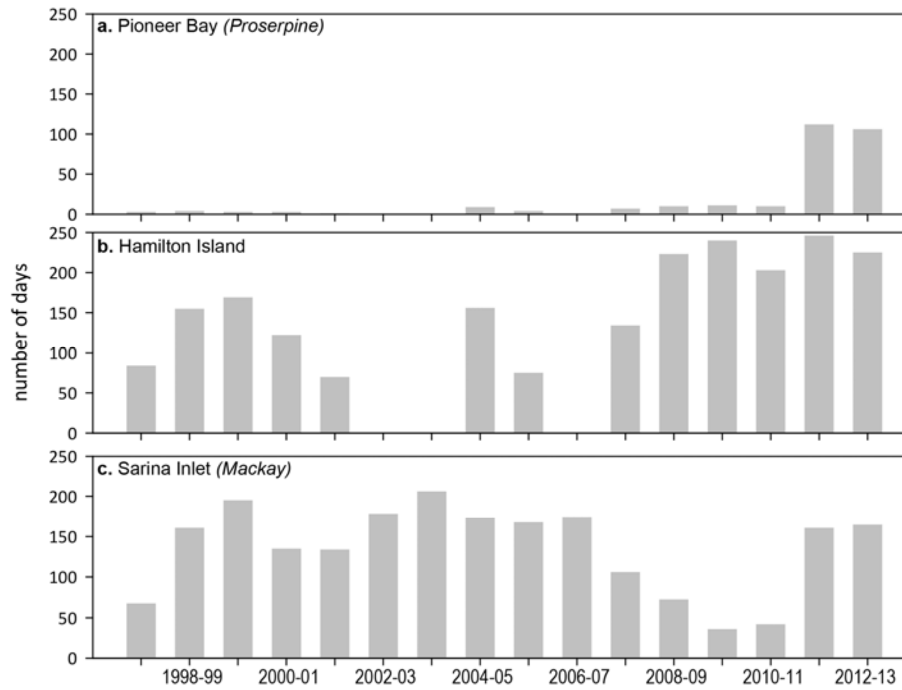

Figure 159. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Mackay Whitsunday NRM region, 1998-2013. Daily 3pm wind speed from: a) Proserpine Post Office (BOM station 33316) (post June 2011), located 18km from Pioneer Bay monitoring sites; b) Hamilton Island (BOM station 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*.

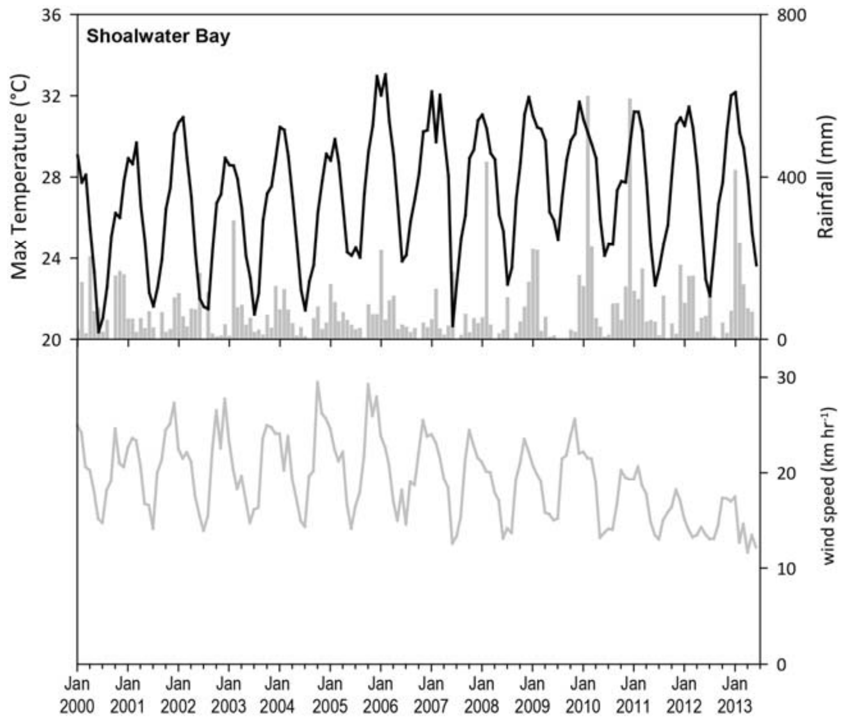

Figure 160. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Shoalwater Bay, 2000-2013. Rainfall, air temperature and wind speed post May 2005 recorded at Williamson, Shoalwater Bay (BOM station 033260), located 10km from the monitoring sites. Prior to May 2005, observations recorded at Yeppoon (BOM station 033106), approximately 96km from monitoring sites. Source www.bom.gov.au*

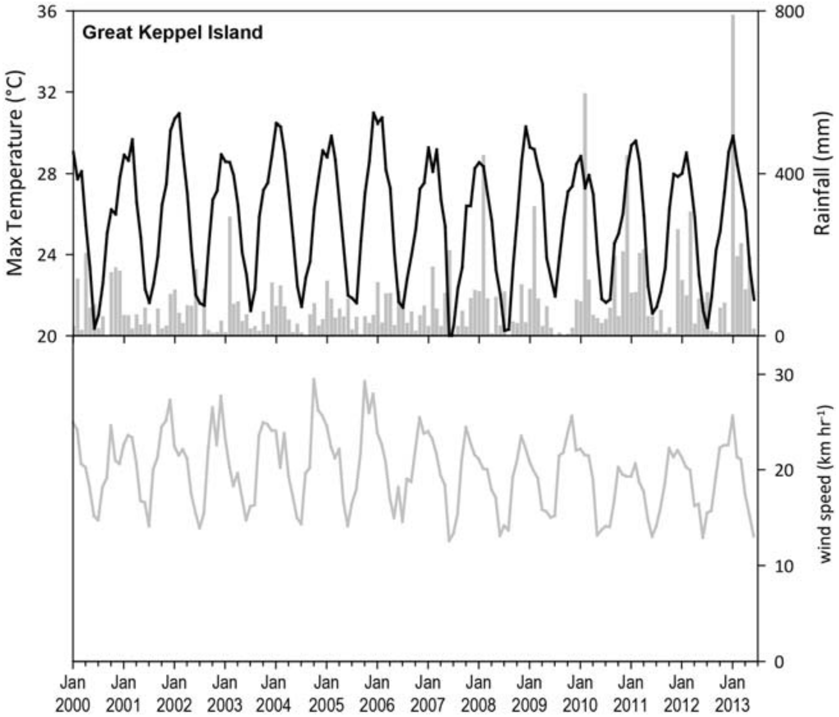

Figure 161. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Great Keppel Island, 2000-2013. Rainfall recorded at Svendsen Beach, Great Keppel Island (BOM station 033260), located 4.5km from the monitoring sites. Air temperature and wind speed recorded at Yeppoon (BOM station 033106), approximately 22km from monitoring sites.* S*ource www.bom.gov.au*

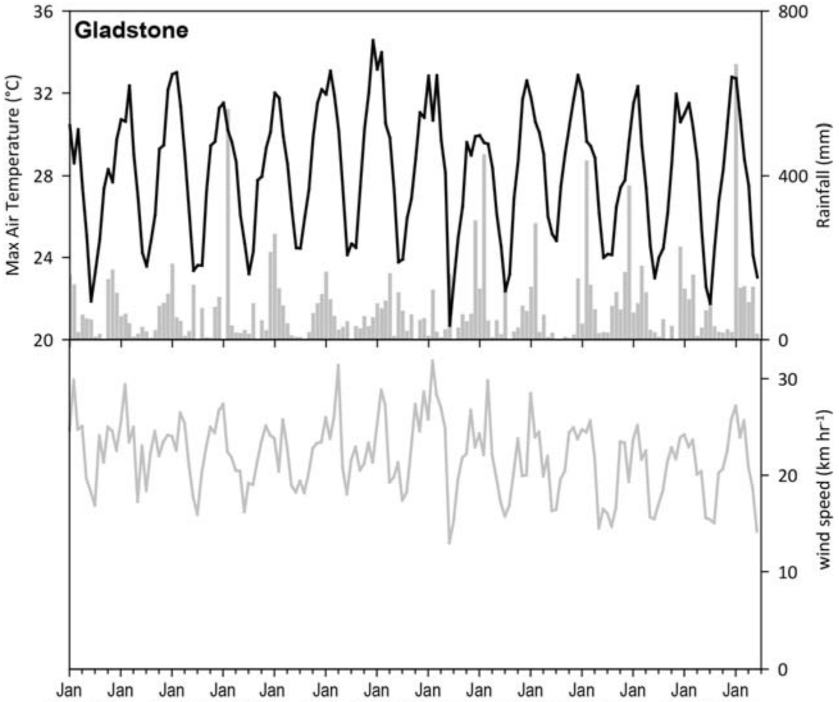

Figure 162. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Gladstone, 2000-2013. Rainfall recorded at Southend Curtis Island (BOM station 039241), located 1km from monitoring sites. Air temperature and wind speed recorded at Gladstone Airport (BOM station 039123), located approximately 13km from monitoring sites. Source www.bom.gov.au*

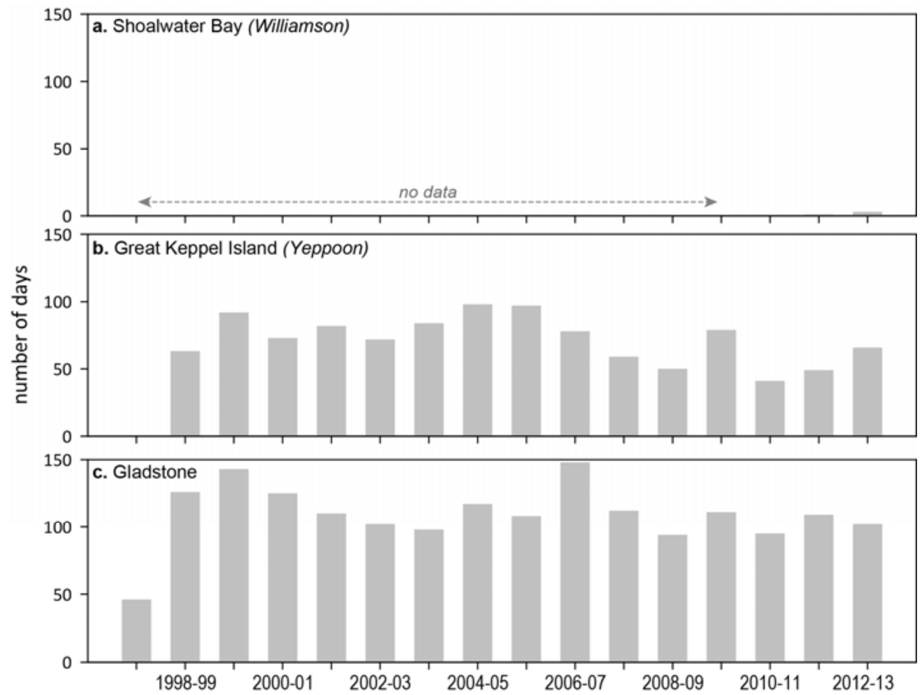

Figure 163. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Fitzroy NRM region, 1998-2013. Daily 3pm wind speed from: a) Williamson, Shoalwater Bay (BOM station 033260), located 10km from the monitoring sites; b) Yeppoon (BOM station 033106), approximately 22km from monitoring sites; and c) Gladstone Airport (BOM station 039123), located approximately 13km from monitoring sites.*

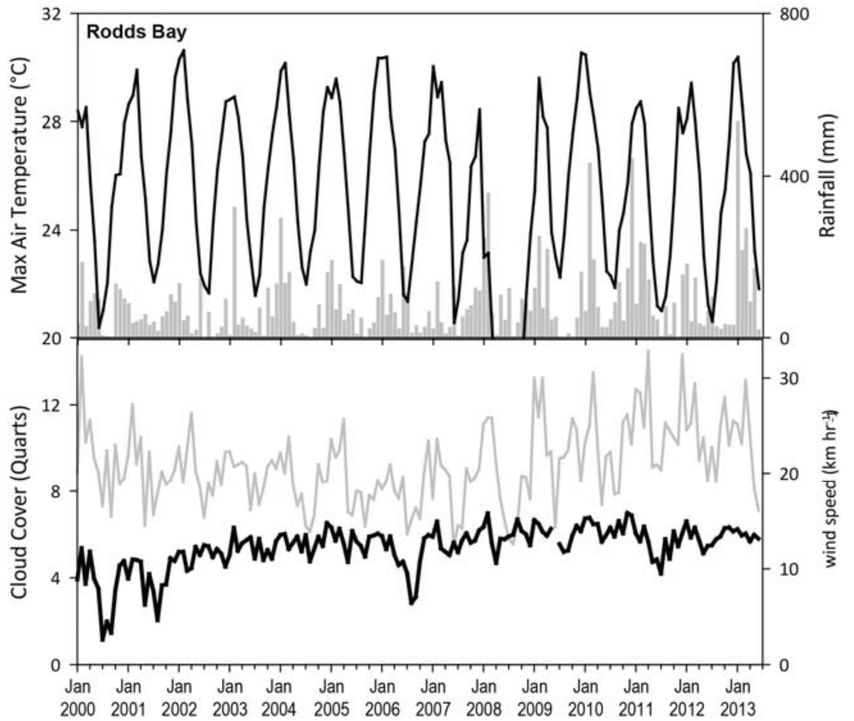

Figure 164. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), mean monthly cloud cover (quarts, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Rodds Bay, 2000-2013. Air temperature, cloud cover, and wind speed recorded at Seventeen Seventy (BOM station 039314), approximately 27km from Rodds Bay monitoring sites. Rainfall recorded at Bustard Head Lighthouse (BOM station 039018), approximately 12km from Rodds Bay monitoring sites. Source www.bom.gov.au*

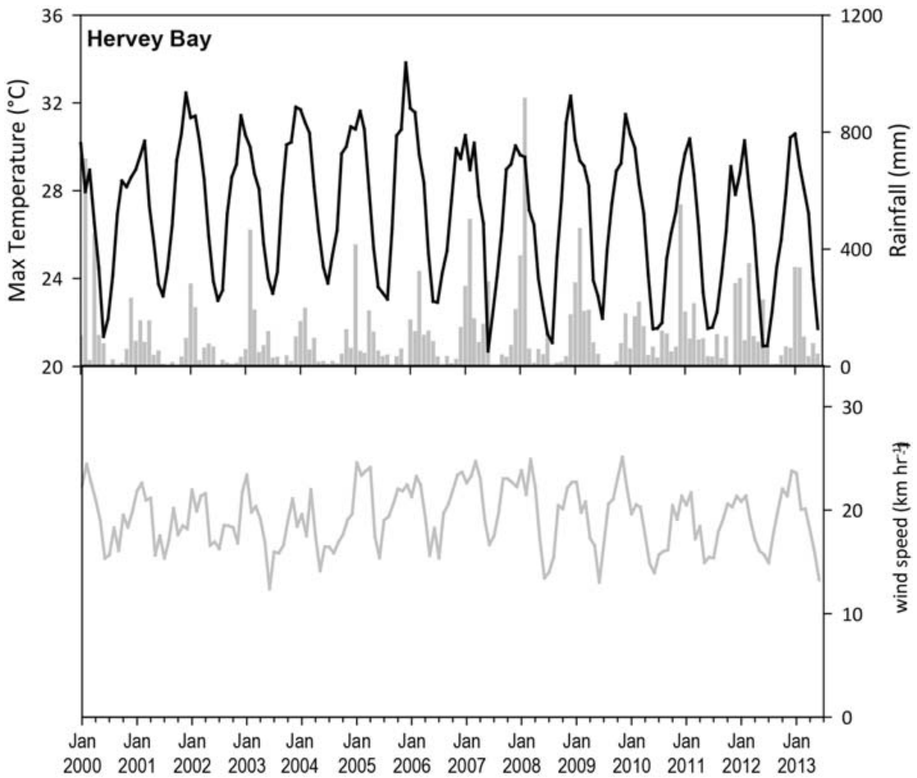

Figure 165. *Total monthly rainfall (mm, grey bars), mean monthly daily maximum air temperature (°C, black line), and mean monthly 3pm wind speed (km. hr^{-1}, grey line) at Urangan, 2000-2013. Recorded at Hervey Bay Airport (BOM station 040405, source www.bom.gov.au), approximately 3km from Urangan monitoring sites.*

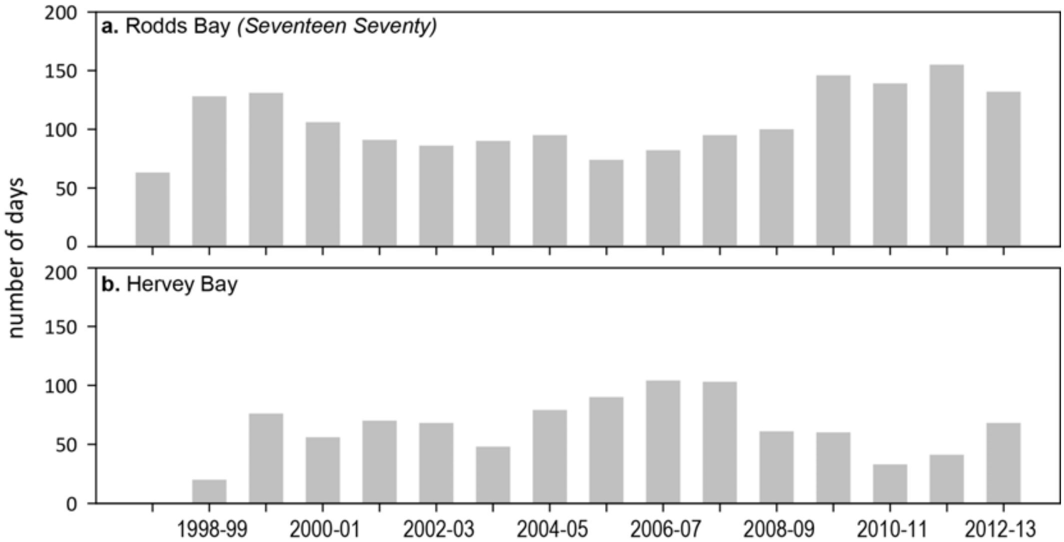

Figure 166. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Burnett Mary NRM region, 1998-2013. Daily 3pm wind speed from: a) Seventeen Seventy (BOM station 039314), approximately 27km from Rodds Bay monitoring sites; and b) Hervey Bay Airport (BOM station 040405), approximately 3km from Urangan monitoring sites.*

River discharge

Table 26. *Annual freshwater discharge (ML form Oct 1 to Sep 30) for the major GBR Catchment rivers in proximity to the inshore seagrass sampling sites. Shaded cells highlight years for which river flow exceeded the median annual flow as estimated from available long-term time series for each river. Discharge data supplied by the Queensland Department of Natural Resources and Mines on watermonitoring.derm.qld.gov.au accessed 31 October 2013*.

Region	River	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012-13
Cape York	Pascoe	577,926	1,058,845	963,010	2,950,709	634,756	661,521	636,350	1,534,694	1,972,999	758,509	827,312
	Stewart	77,521	234,355	101,587	486,366	172,904	99,329	113,018	188,528	376,009	106,219	90,343
	Normanby	NA	NA	NA	3,455,666	1,742,759	3,647,596	2,346,173	2,945,850	5,964,886	1,148,416	1,822,135
	Endeavour	2,126	229,591	46,889	335,101	80,851	177,532	109,221	241,873	282,482	104,827	69,342
	Annan	67,782	518,146	174,494	470,856	211,077	339,978	175,710	407,257	550,403	331,370	196,988
Wet Tropics	Daintree	132,216	1,429,195	489,927	1,252,971	715,190	873,694	641,009	1,216,318	1,640,196	998,710	694,098
	Mossman	176,349	365,105	246,390	411,171	270,866	297,258	236,302	359,242	447,756	339,152	253,804
	Barron	113,639	950,207	383,440	745,781	413,328	1,606,907	772,725	500,233	1,927,091	774,595	297,555
	Mulgrave	333,262	1,132,755	526,496	937,024	738,709	968,794	739,055	773,158	1,568,750	1,083,093	567,079
	Russell	615,927	1,345,241	990,735	1,280,589	1,281,621	1,088,458	1,193,810	1,298,963	1,719,880	1,290,488	888,722
	Nth Johnstone	819,663	2,304,375	1,472,423	2,155,313	2,071,610	1,858,252	1,925,630	1,826,418	3,541,632	2,023,900	1,478,171
	Sth Johnstone	311,763	431,546	542,835	1,014,727	886,683	794,711	1,036,701	728,626	1,612,187	941,983	584,344
	Tully	1,442,044	3,283,940	2,200,706	3,624,289	3,949,123	3,195,148	3,590,160	2,984,477	5,679,966	NA	2,729,119
	Murray	37,184	174,576	59,645	249,385	190,620	179,123	266,683	135,427	601,004	290,437	139,665
	Herbert	NA	NA	NA	NA	NA	NA	NA	3,163,763	11,448,794	4,131,993	2,896,025
Burdekin	Black	10,398	45,388	27,736	53,636	139,241	180,672	299,120	149,320	347,386	182,275	46,488
	Haughton	80,651	172,416	248,110	287,000	584,063	805,802	1,113,845	499,519	1,050,330	763,353	155,789
	Burdekin	2,092,834	1,516,191	4,328,245	2,199,744	9,768,935	27,502,710	29,352,391	7,946,435	34,834,316	15,568,159	3,417,924
	Don	43,688	54,583	97,404	41,176	164,895	461,595	245,354	144,481	847,617	216,956	179,755
Mackay Whitsunday	Proserpine	18,622	10,327	23,770	20,397	44,741	76,477	65,582	52,304	346,248	51,927	37,411
	O'Connell	NA	NA	NA	89,767	184,059	256,582	191,178	327,627	587,525	278,370	109,094
	Pioneer	111,602	44,900	196,115	72,711	716,207	1,300,438	822,653	1,183,875	3,284,668	1,312,054	912,117
	Sandy Ck	47,758	10,110	71,554	6,326	167,432	365,717	189,584	375,904	616,569	365,988	249,778
	Carmila Ck	7,702	2,606	17,988	16,825	67,016	98,120	17,965	96,228	87,644	57,656	44,775
	Rocky Dam Ck	NA	NA	NA	18,694	39,582	98,225	61,176	149,498	162,015	93,126	87,851
Fitzroy	Waterpark Ck	63,159	7,884	27,785	14,603	33,898	160,662	63,234	183,429	312,463	94,903	333,486
	Fitzroy	2,546,763	1,288,103	903,497	667,900	1,038,555	12,410,891	2,002,101	11,755,415	37,942,149	7,993,273	8,532,130
	Calliope	287,570	105,115	21,978	9,703	2,752	185,320	81,062	306,191	588,254	203,355	923,185
Burnett Mary	Baffle Ck	551,805	203,379	33,418	27,560	3,555	447,439	1,12,311	735,505	1,258,653	612,327	700,207
	Kolan	166,221	25,214	217	11	NA	51,099	2,045	144,553	389,584	153,918	405,018
	Burnett	516,892	221,273	136,972	69,506	29,880	16,699	24,556	1,022,820	8,565,016	584,670	6,884,668
	Boyne	13,608	30,855	16,242	32,639	9,280	9,143	22,886	78,438	2,284,321	79,152	757,169
	Gregory	NA	NA	NA	322	1,310	10,565	6,103	11,867	21,602	22,219	17,188
	Burrum	18,880	35,856	3,236	6,201	NA	NA	NA	NA	NA	NA	NA
	Mary	852,583	782,722	309,819	287,175	443,900	1,532,951	1,066,520	1,926,194	6,227,933	3,100,196	5,464,353

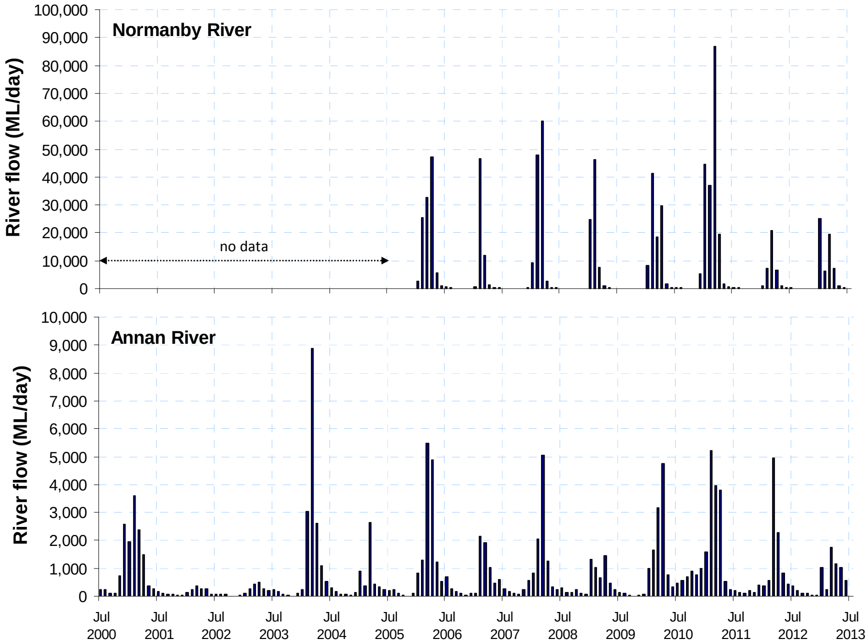

Figure 167. *Average daily flow (ML day^{-1}) per month from the Normanby and Annan Rivers, which could impact monitoring sites at Bathurst Bay/Stanley Islands and Archer Point respectively in the Cape York region (stations: 105107A - Normanby River at Kalpowar Crossing, 14.91683S, 144.211279E, Elev:21.297m; 107003A - Annan River at Beesbike, 15.68773S, 145.2085 E, Elev: 115m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

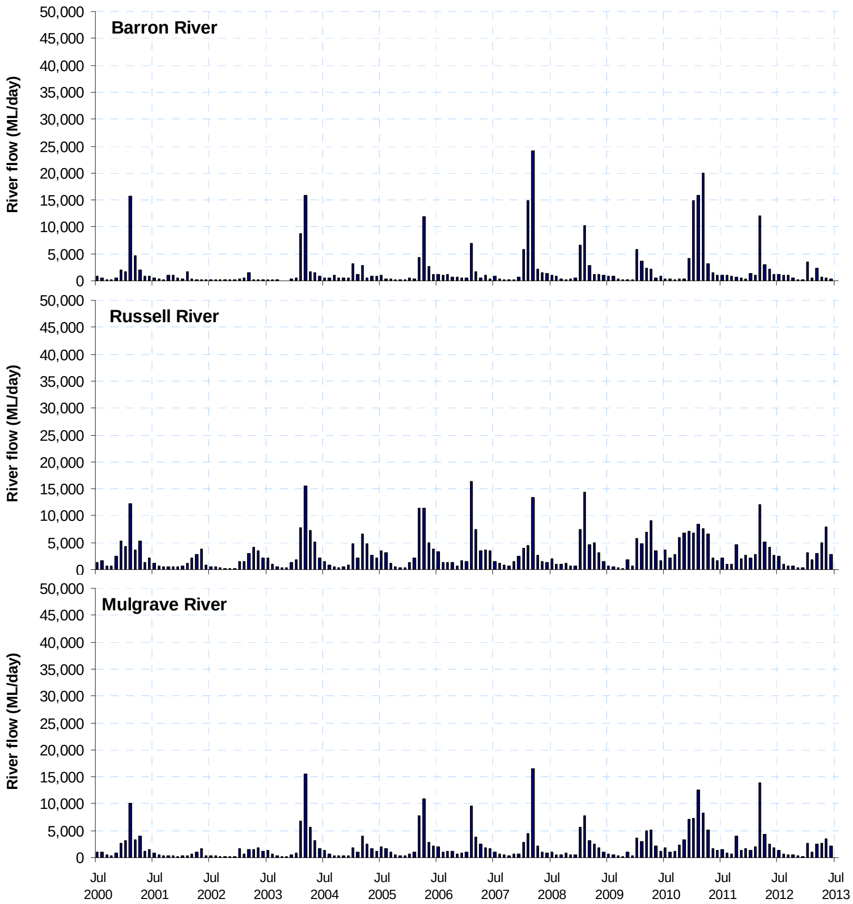

Figure 168. *Average daily flow (ML day^{-1}) per month from the main rivers impacting the seagrass monitoring sites in the Wet Tropics region (stations 110001D - Barron River at Myola, 16.79983333°S 145.61211111°E, Elev 345m; 111007A - Mulgrave River at Peets Bridge, 17.13336111°S 145.76455556°E, Elev 27.1m; 111101D - Russell River at Bucklands 17.38595°S 145.96726667°E, Elev10m; (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

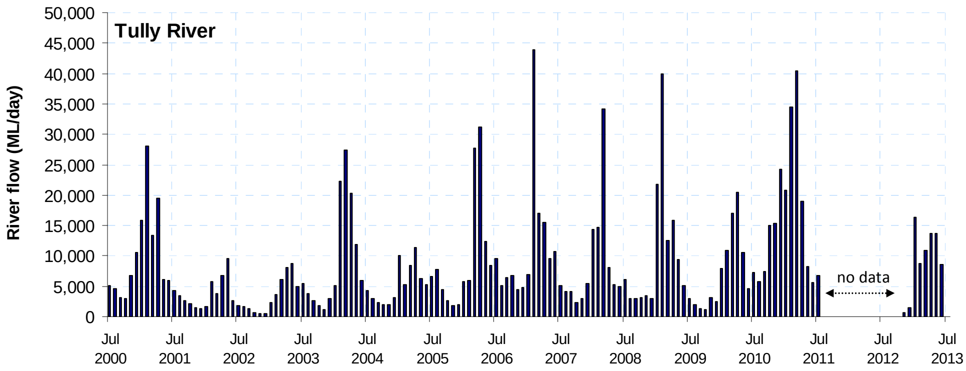

Figure 169. *Average daily flow (ML day^{-1}) per month from the main rivers impacting the seagrass monitoring sites in the southern Wet Tropics region (station 113006A - Tully River at Euramo, 17.99213889°S 145.94247222°E, Elev 8.76m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

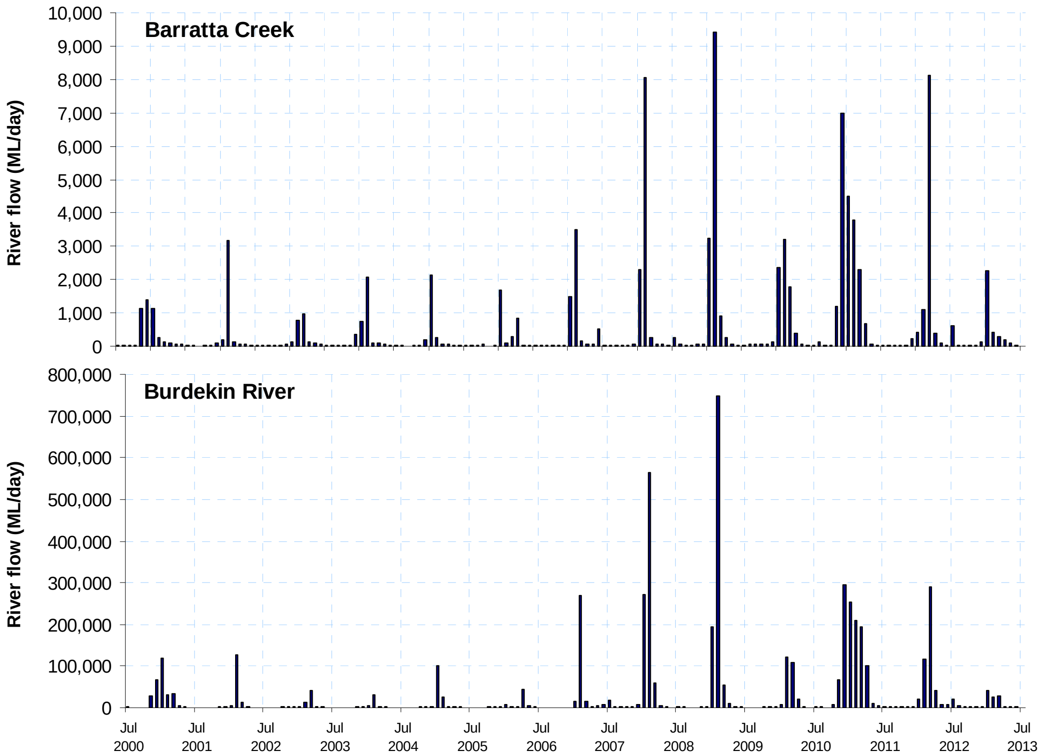

Figure 170. *Average daily flow (ML day^{-1}) per month from the Burdekin River impacting the seagrass monitoring sites in the Burdekin region (stations 120006B - Burdekin River at Clare, 19.75856°S 147.24362°E, Elev 29m; 119101A - Barratta Creek at Northcote Lat:-19.69072778 Long:147.169825 Elev: 17.3m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

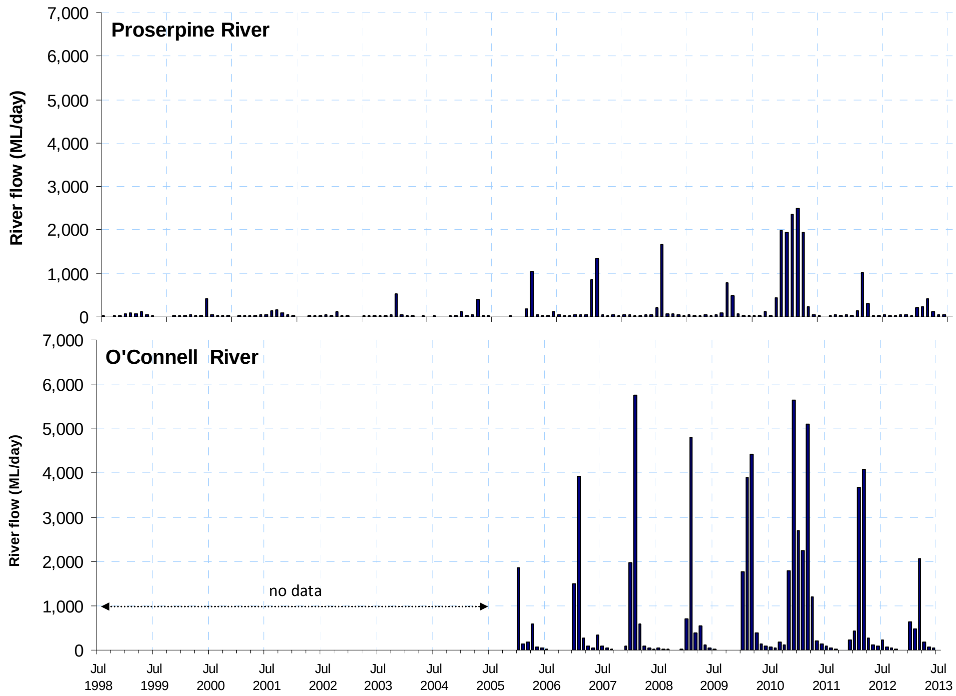

Figure 171. *Average daily flow (ML day^{-1}) per month from the main rivers impacting coastal and reef seagrass monitoring sites in the Mackay Whitsunday region (stations 122005A - Proserpine River at Proserpine, 20.39166667°S 148.59833333°E, Elev 7m; 124001B - O'Connell River at Stafford's Crossing 20.65255556°S 148.573°E, Elev:0m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

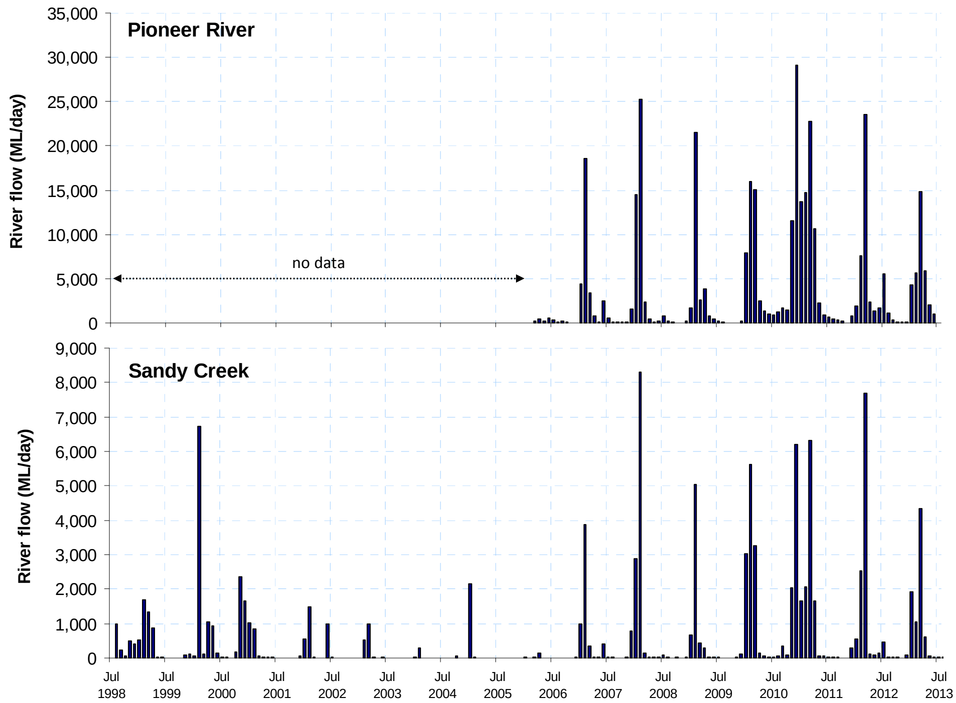

Figure 172. *Average daily flow (ML day^{-1}) per month from the main river impacting estuarine seagrass monitoring sites in the Mackay Whitsunday region (stations 125016A - Pioneer River at Dumbleton Weir T/W 21.14236111°S 149.07625°E, Elev 10m; 126001A - Sandy Creek at Homebush Lat:-21.2832888 Long:149.0225055, Elev 62m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

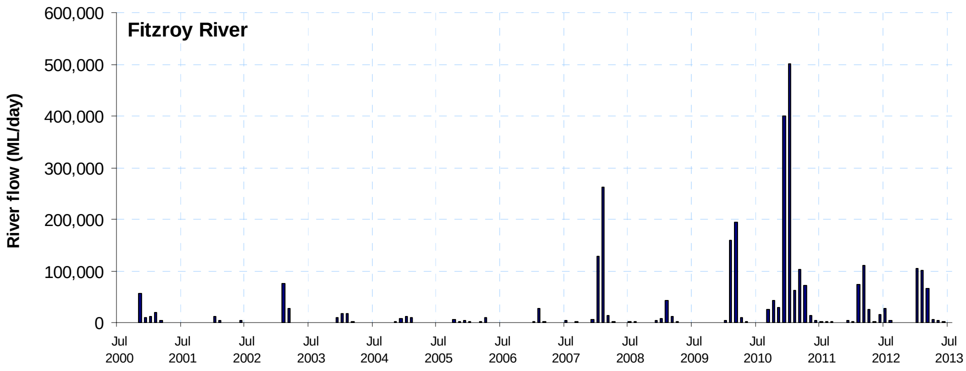

Figure 173. *Average daily flow (ML day^{-1}) per month from the Fitzroy River which impacts coastal and reef seagrass monitoring sites in the Fitzroy region (station 130005A - Fitzroy River at The Gap, 23.08897222°S 150.10713889°E, Elev 0m)(source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

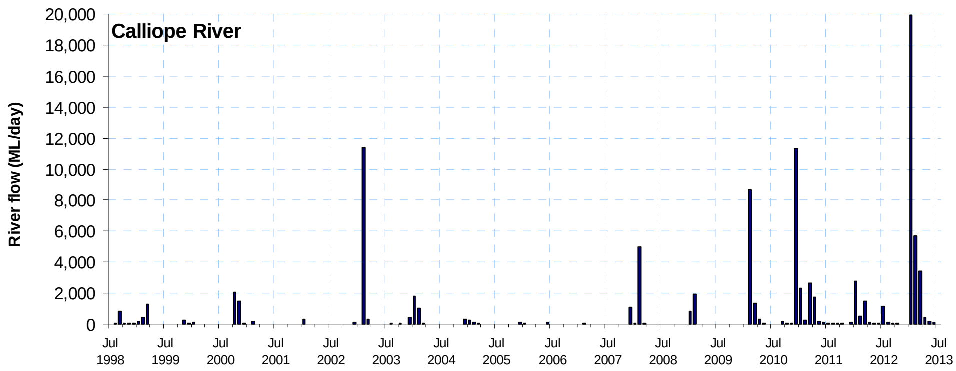

Figure 174. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact estuarine seagrass monitoring sites in the Fitzroy region (station 132001A - Calliope River at Castlehope 23.98498333°S 151.09756389°E, Elev:21m; 133005A (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

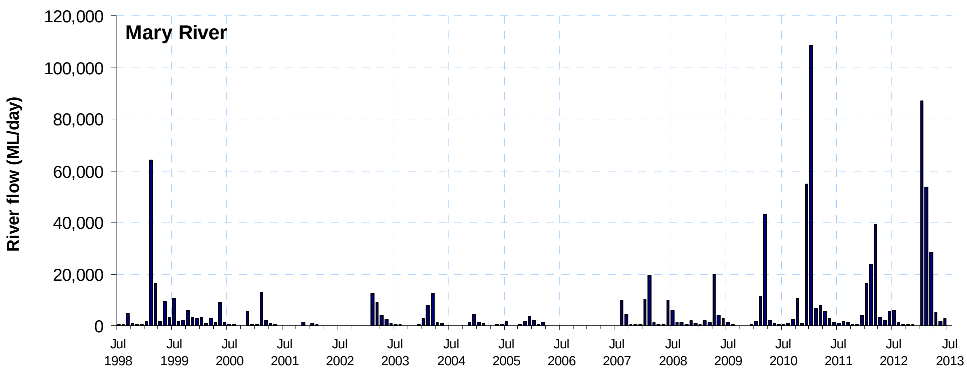

Figure 175. *Average daily flow (ML day^{-1}) per month from the Mary River which would impact estuarine seagrass monitoring sites at Urangan, southern Burnett Mary region (station 138001A - Mary River at Miva Lat:25.95332924°S:152.4956601 °E, Elev 0m) (source ©The State of Queensland (DNRM) 2013, watermonitoring.derm.qld.gov.au).*

Appendix 2.

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

Brodie, J., Waterhouse, J., Schaffelke, B., Johnson, J., Kroon, F., Thorburn, P., Rolfe, J., Lewis, S., Warne, M., Fabricius, K., McKenzie, L., Devlin, M. 2013. Reef Water Quality Scientific Consensus Statement 2013, Department of the Premier and Cabinet, Queensland Government, Brisbane.

Schaffelke, B., Anthony, K., Blake, J., Brodie, J., Collier, C., Devlin, M., Fabricius, K., Martin, K., McKenzie, L., Negri, A., Ronan, M., Thompson, A. and Warne, M. 2013. “Marine and coastal ecosystem impacts” in Synthesis of evidence to support the Reef Water Quality Scientific Consensus Statement 2013, Department of the Premier and Cabinet, Queensland Government, Brisbane.

Brodie, J., Waterhouse, J., Schaffelke, B., Furnas, M., Maynard, J., Collier, C., Lewis, S., Warne, M., Fabricius, K., Devlin, M., McKenzie, L., Yorkston, H., Randall, L., Bennett, J. 2013. “Relative risks to the Great Barrier Reef from degraded water quality” in Synthesis of evidence to support the Reef Water Quality Scientific Consensus Statement 2013, Department of the Premier and Cabinet, Queensland Government, Brisbane.

Collier, C., McKenzie, L., Takahashi, M. and Waycott, M. 2013. Light thresholds derived from segarass loss: an update from the Great Barrier Reef, Australia. *In* CERF 2013, 22nd Biennial Conference of the Coast al and Estuarine Research Federation Abstracts. Toward Resilient Coasts and Estuaries, Science for Sustainable Solutions. 3-7 November 2013, San Diego, California, USA. Session SCI-042A. p.45.

Devlin, M., Collier, C., McKenzie, L., Petus, C. and Waycott. M. 2013. Large scale water quality impacts on seagrass communities in the Great Barrier Reef. *In* CERF 2013, 22nd Biennial Conference of the Coast al and Estuarine Research Federation Abstracts. Toward Resilient Coasts and Estuaries, Science for Sustainable Solutions. 3-7 November 2013, San Diego, California, USA. Session SCI-042A. p.56.

McKenzie, L., Collier, C., Waycott, M., Unsworth, R., Coles, R., Yoshida, R., and Smith, N. 2013. Monitoring inshore seagrasses of the Great Barrier Reef: resistance and recovery in response to water quality and extreme weather events. *In* CERF 2013, 22nd Biennial Conference of the Coast al and Estuarine Research Federation Abstracts. Toward Resilient Coasts and Estuaries, Science for Sustainable Solutions. 3-7 November 2013, San Diego, California, USA. Session SCI-042A. p.150.

O’Brien, K., Waycott, M., Kendrick, G., Ferguson, A., Maxwell, P., Scanes, P., McKenzie, L., Udy, J., Kilminster, K., McMahon, K., Lucieer, V., Radke, L., Lyons, M. and Dennison, B. 2013. Three critical scales to manage for seagrass resilience: physiology morphology and landscape. *In* CERF 2013, 22nd Biennial Conference of the Coast al and Estuarine Research Federation Abstracts. Toward Resilient Coasts and Estuaries, Science for Sustainable Solutions. 3-7 November 2013, San Diego, California, USA. Session SCI-041A. p.170.