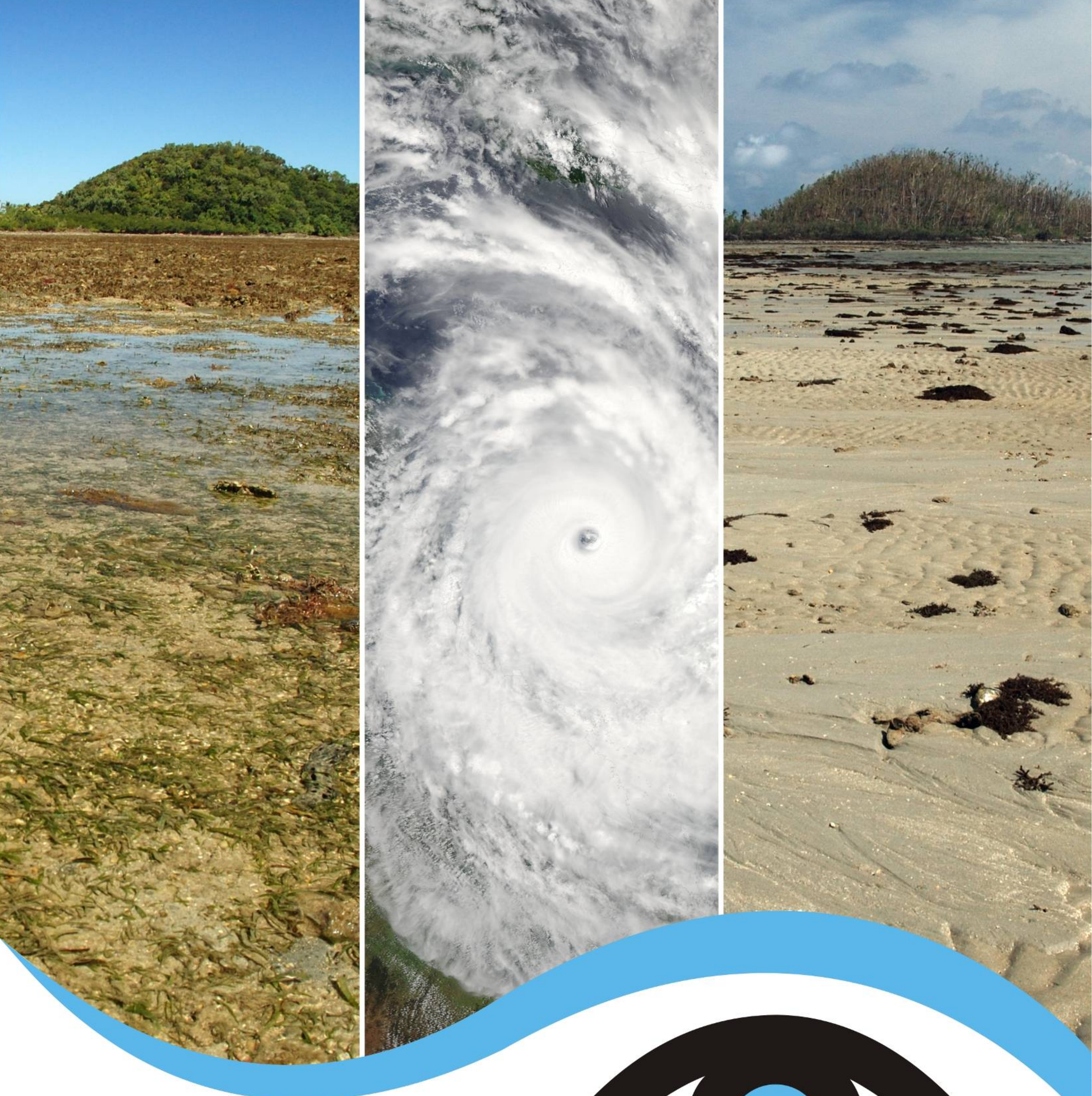

Reef Rescue

Marine Monitoring Program

Inshore Seagrass

ANNUAL REPORT

For the sampling period 1st July 2010 – 31st May 2011

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Michelle Waycott

This report should be cited as:

McKenzie, L.J., Collier, C. and Waycott, M. (2012) Reef Rescue Marine Monitoring Program - Inshore Seagrass, Annual Report for the sampling period 1st July 2010 – 31st May 2011. Fisheries Queensland, Cairns. 230pp.

Published through Fisheries Queensland, a service of the Department of Employment, Economic Development and Innovation (DEEDI) and James Cook University a research provider.

This report has been peer reviewed by three external reviewers.

February 2012

Australian Government

Department of the Environment, Water, Heritage and the Arts
Great Barrier Reef Marine Park Authority

Queensland Government

Seagrass-Watch

JAMES COOK UNIVERSITY AUSTRALIA

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Acronyms Used In This Report

SEWPaC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
DEEDI	Department of Employment, Economic Development and Innovation Queensland
DERM	Department of Environment and Resource Management
Fisheries QLD	Fisheries Queensland (DEEDI)
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

Acknowledgements

We thank our collaborators for their assistance with field collections, laboratory processing and data management: Naomi Smith, Rudi Yoshida, Ana Giraldo Ospina, Ainsley Calladine, Tonia Sankey, Sam Hedge, and Christina Howley.

We also thank the following Seagrass-Watch volunteers (*just to name a few*) who gave up their weekends and free-time to assist with the field monitoring: Nick Atkin, Sheena Barrett, Graham Bradbury, Jason Carroll, Bill Downey, Larrisa Hale, Particia Hamilton, Andrew Hartwig, Jamie Havighurst, Sam Hobbs, Barbara Kinsey, Don Kinsey, Kelly Marlin, John Marlton, Heather Marshall, Catherine McCormack, Jacquie Shiels, Emily Smart, Sue Smith, Jacky Stein, Jenny Terrey, Cecilia Villacorta, Carla Wegscheidl, Helen White, Kim Wilson, Dell Williams, John Williams and Iony Woolaghan.

We also thank Jim Fourqurean, Rob Coles, and Katherine Martin for their guidance and scientific discussions regarding the program. We thank Range Control Officer (Department of Defence) for providing support and access to the Shoalwater Bay Training Area to conduct biannual monitoring.

River discharge data provided by the State of Queensland (Department of Environment and Resource Management) 2011. 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

Prior to the extreme weather events of 2011 the seagrass meadows of the GBR were in a vulnerable condition with declining trajectories reported throughout much of the GBR. These impacts exacerbate the already stressed seagrass ecosystems. Overall there are indications that seagrass meadows along the GBR urban coast are continuing to decline and are now in a very poor state, particularly south of Cairns. The indicators of this decline are: 73% of sites have declined in abundance over the last 12 months (below the seagrass guidelines) and 80% show a declining long-term trend (5-10 years); 55% sites exhibiting shrinking meadow area, majority of sites have limited or are not producing seeds that would enable rapid recovery; indications of light limitation at 90% of sites; nutrient enrichment at 83% sites and 40% of sites with either high or elevated nitrogen. Elemental ratios of tissue nutrients indicate some sites in the Wet Tropics have degraded water quality with an excess of nutrients compared to light availability. Increased epiphyte loads, possibly stimulated by nutrient loading, further exacerbate light limitation on the surfaces of slower-growing seagrass leaves in coastal habitats.

Other interactions will also be important to consider. Under limiting light levels, elevated nutrient levels will saturate the seagrass more rapidly. As seagrass reproduction is positively correlated with nutrient saturation in some circumstances seagrasses experiencing low light but elevated nutrients may be expected to have increased reproductive effort – until light levels result in compromised survival due to respiration demands being greater than photosynthesis. 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, GBR seagrass meadows appear the have variable recovery potential due to changeable light levels and seed availability both spatially and temporally.

Report card for seagrass status for the GBR and each NRM region: July 2010 – May 2011. 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).

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	15	63	50	43
Wet Tropics	36	9	24	23
Burdekin	8	13	17	13
Mackay Whitsunday	5	0	14	6
Fitzroy	28	46	43	39
Burnett Mary	5	0	30	12
GBR	16	16	24	**19**

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 Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) has responsibility for implementation of this program. Fisheries Queensland (DEEDI) and James Cook University (JCU) were contracted to provide the intertidal seagrass monitoring component. The key aims of this component of the programme were to:

a. Understand the status and trend of GBR intertidal 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.

An additional component was incorporated in response to the extreme weather events experienced in early 2011 (attached as Appendix 1).

Background

Seagrass are considered coastal canaries or coastal sentinels that can be monitored to detect human influences to coastal ecosystems (Orth *et al*., 2006). Since 1990, seagrasses globally have been declining at a rate of 7% per year (Waycott *et al*., 2009). Multiple stressors are the cause of this decline, the most significant being degraded water quality. In seagrass ecosystems, nutrients and light are the most common limiting factors that control abundance and these factors are interrelated (see Waycott and McKenzie 2010). Indeed, the various threats to seagrass ecosystems along the coast of the GBR will cause a variety of impacts to seagrass growth (Grech *et al.* 2011, Figure 1). In addition, combinations of stressors will lead to variable conditions impacting growth. In the GBR system, seagrasses are at risk from a wide diversity of impacts, in particular where coastal developments occur (Grech 2010; Grech *et al.* 2010).

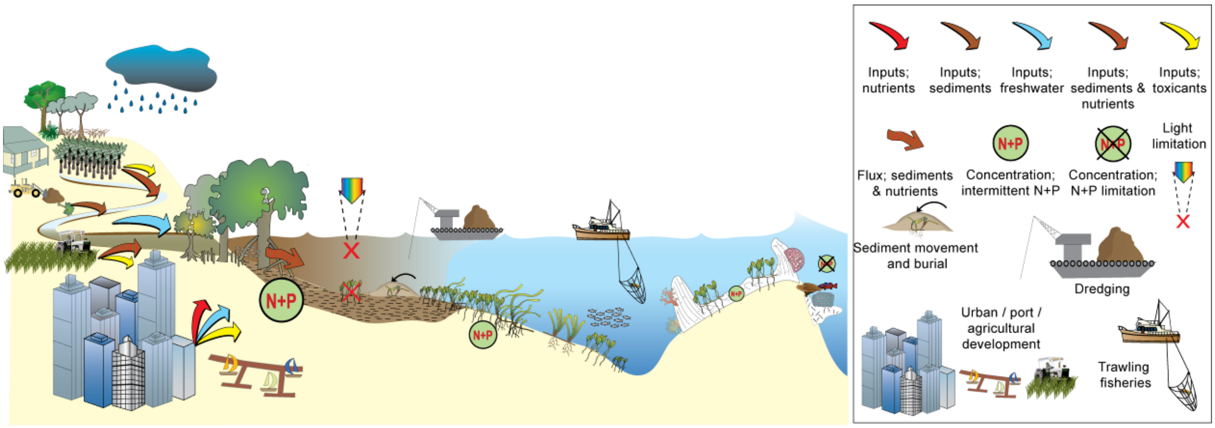


Figure 1. *Conceptual diagram depicting threats to seagrass meadows and potential limitations to seagrass growth in inshore regions of the GBR related to changing water quality (adapted from Waycott and McKenzie 2010).*

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 (**Error! Reference source not found.**) 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 1. *Response stages of seagrass meadows to external stressors and the indicator responses observed in Great Barrier Reef monitored seagrass meadows (adapted from Waycott and McKenzie 2010) * utilised in Paddock to Reef reporting.*

Indicator	***Sub-lethal*** (ecophysiological)	***State change*** (whole plant and population scale)	***Population decline*** (whole meadow scale)
A. 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	-
B. Chlorophyll concentrations	Rapid short term changes observed	Limited by species variable upper threshold	-
C. 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
D. Change in plant morphology	-	Reduction in leaf area	Threshold reached
E. Community structure	-	Change in species composition	Loss of species
F. Change in species abundance (population structure)	-	Change in abundance of species (i.e. % cover)*	Reduction in effective population size
G. Change in meadow area	-	-	Reduction (or increase) in total meadow area
H. Recovery time from loss	Limited or no change	Measurably delayed	Potentially no recovery if threshold reached

In addition to the multiple stressors, 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 are still relatively capable of being responsive to disturbance (Carruthers *et al.* 2002, Waycott *et al.* 2007, Collier and Waycott 2009). As a result, baseline condition of dynamic ecosystems requires a greater level of understanding of causes of dynamism although considerable insight into the causes and responses of ecosystems to perturbations can be inferred when these insights are gained. However, when comparing the species present in the coastal GBR, the area covered by this monitoring program, as well as the ecosystems and drivers themselves, monitoring approaches, thresholds and system drivers being studied in other coastal seagrass ecosystems around the world, which are predominantly in temperate Northern Hemisphere systems (Orth *et al.*, 2006, Waycott *et al*., 2009), few system wide parameters are comparable, as a result, monitoring the unique GBR seagrass system requires baseline understanding to be gained and not rely on models and predictions generated by systems elsewhere.

Healthy seagrass meadows in the GBR act as important resources as the primary food for dugong, green turtles, numerous commercially important fish species and as habitat for large number of invertebrates, fish and algal species (Carruthers *et al.,* 2002). 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. 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).

Approximately 3,063 square kilometres of coastal seagrass meadows has been mapped in Great Barrier Reef World Heritage Area (GBRWHA) waters shallower than 15 metres, relatively close to the coast, and in locations that can potentially be influenced by adjacent land use practices (McKenzie *et al.,* 2010). Surveys and statistical modelling (>50% probability) of seagrass in offshore waters deeper than 15m shows 31,778 square kilometres of the sea floor within the GBRWHA has some seagrass present (McKenzie *et al.,* 2010; Coles *et al.,* 2003; 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 (based on Duarte *et al.* 2005; Nellemann *et al.* 2009; Mcleod *et al.* 2011) making the Great Barrier Reef's seagrass resources globally significant. Monitoring of the major marine ecosystem types most at risk from land based sources of pollutants is being conducted to ensure that any change in their status is identified. Seagrass monitoring sites have been located as close as practically possible (dependent on historical monitoring and location of existing meadows) to river mouth and inshore marine water quality monitoring programs to enable correlation and concurrently collected water quality information.

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 2). All but the outer reef habitats are significantly influenced by seasonal and episodic pulses of sediment laden, nutrient rich river flows, resulting from high volume summer rainfall. Cyclones, severe storms, wind and waves as well as macro grazers (fish, dugongs and turtles) influence all habitats in this region to varying degrees. The result is a series of dynamic, spatially and temporally variable seagrass meadows.

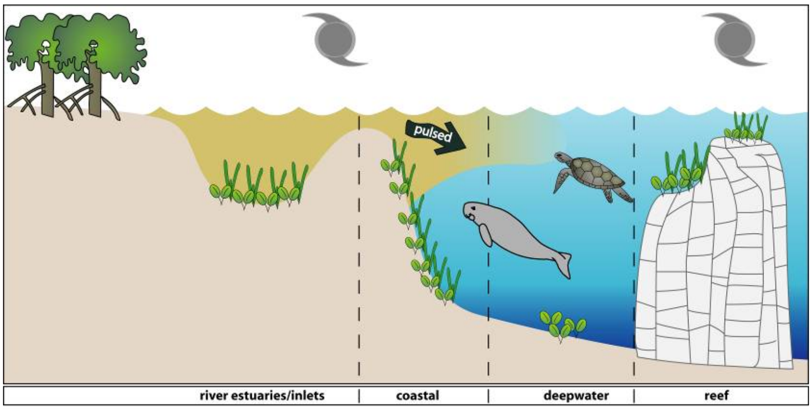


Figure 2. *General conceptual model of seagrass habitats in north east Australia (from Carruthers et al., 2002)*

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). A number of indicators and thresholds of some of these requirements have been established for seagrass communities that are relevant to the GBR, and are monitored as part of the Reef Rescue Marine Monitoring Program.

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 2011 (Reef & Rainforest Research Centre Ltd 2010).

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 beginning of the Reef Rescue 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, that the existing Seagrass-Watch program was 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 the Seagrass-Watch program was supplied to Glenn De'ath (Senior Statistician, AIMS) for independent review. De'ath (2005) examined the available dataset to estimate expected performance of the monitoring program. Data included was from 2000–2004 and collected from 63 sites in 29 locations across 6 regions (Cooktown, Cairns, Townsville, Whitsundays, Hervey Bay, Great Sandy Strait). Results concluded that the Seagrass-Watch 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 to the regions.

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, 1997, 1998; McKenzie *et al.* 2000; Rasheed *et al.* 2003; Campbell *et al.* 2002; Goldsworthy 1994)
2. sampling locations where there was either an existing Seagrass-Watch or MTSRF (subtidal) long-term dataset available.

To account for spatial heterogeneity of meadows within habitats, two sites were selected at each location. Representative meadows were selected using mapping surveys across the regions prior to site establishment. Representative meadows are those which cover a greater extent of the resource, are generally the dominant seagrass community type and are of average abundance. Ideally mapping was conducted immediately prior to site positioning, however in most cases it was based on historic (>5yr) information.

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

- accessibility and cost effectiveness (not requiring 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 through the Seagrass-Watch program, 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 actually lower littoral (rarely not inundated) 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 has been shown to be determined by light. Unfortunately, seagrass meadows within the Great Barrier Reef lagoon do not conform to these models as the system is more complex (Carruthers *et al.* 2002) including:

- a variety of habitat types (estuarine, coastal, reef and deepwater);
- tidal ranges spanning 3.42m (Cairns) to 7.14m (Hay Point) (www.msq.qld.gov.au);
- a variety of substrates vary from terrigenous with high organic content, to oligotrophic calcium carbonate;
- turbid nearshore to clearer offshore waters
- near absence of shallow subtidal meadows south of the Whitsundays due to the large tides which scour the seabed.

Subtidal meadows across the GBR are predominately dominated by *Halophila* species and are highly variable in abundance and distribution (Lee Long *et al.* 2000). Due to this high variability they are generally not recommended for monitoring as the Minimum Detectable Difference (MDD) is very low at the at the 5% level of significance with 80% power (McKenzie *et al.* 1998). Predominately stable intertidal 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, however results have only been presented in Appendix 1. These sites were chosen as they were dominated by species similar to the intertidal 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 typify the habitats both in abundance and structure when the meadow is considered in it's steady state (Figure 3). The foundation species were all di-meristematic leaf-replacing forms.

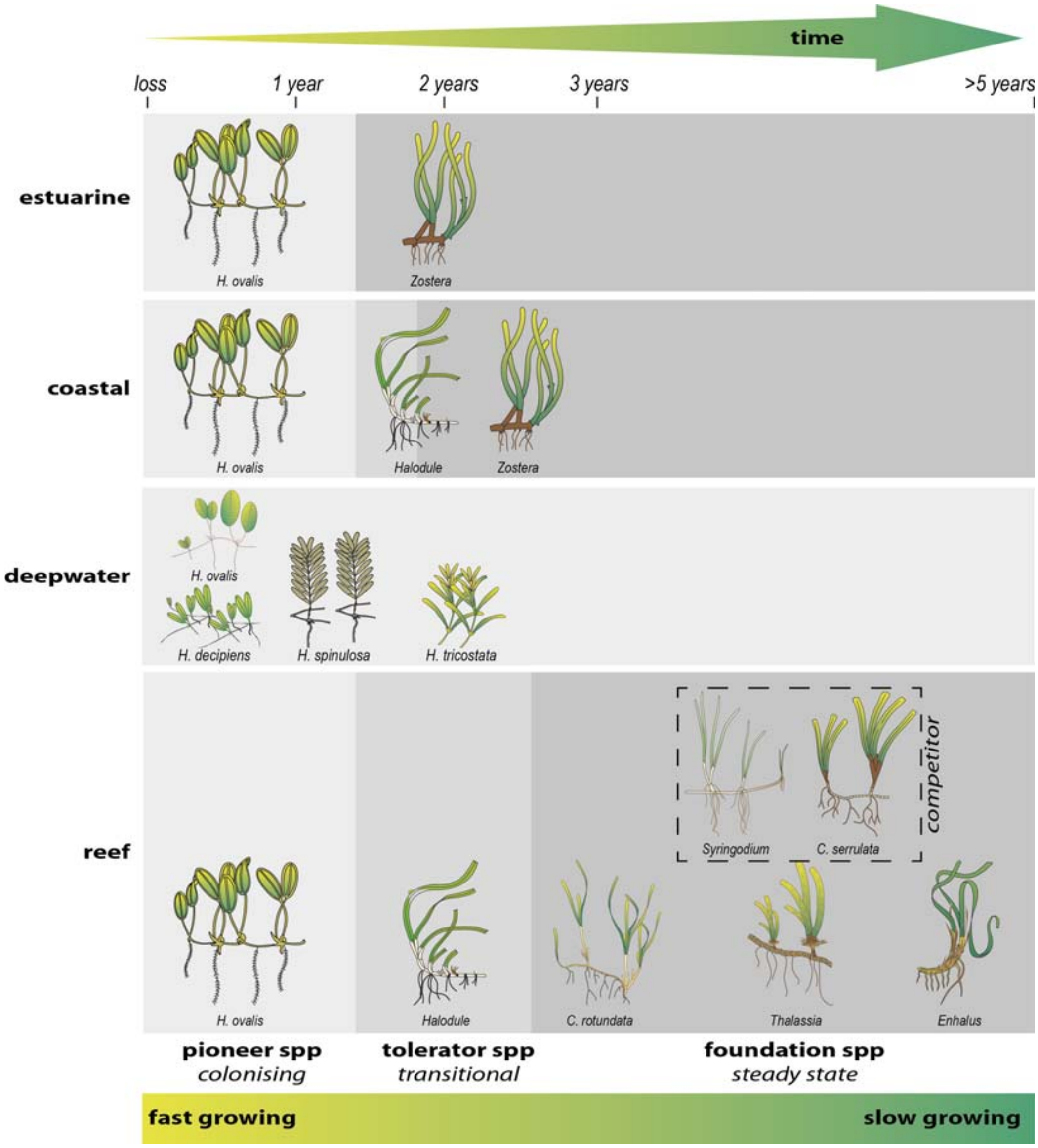


Figure 3. *Illustration of seagrass recovery after loss and the categories of successional species over time.*

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), monitoring was focussed on the late dry season and late wet season to capture the status of seagrass prior and post wet.

Seagrass monitoring methods were conducted as per McKenzie *et al.* (2010). Thirty four sites were monitored during the 2010/11 monitoring period (Table 2). This included nine nearshore (intertidal coastal and estuarine) and seven offshore reef intertidal locations (i.e. two-three sites at each location). At the offshore reef locations in the Burdekin and Wet Tropics, intertidal sites were paired with a subtidal site (Table 2). A description of all the 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 3. The seagrass species present at each monitoring site (including foundation seagrass species) is listed in Table 3.

The different measures and analysis reported in this document were conducted in collaboration between Fisheries Queensland, James Cook University Townsville, and the Seagrass-Watch program with each contributing the following:

- seagrass % cover & species composition (Seagrass-Watch & Fisheries QLD)
- seed banks (Seagrass-Watch & Fisheries QLD)
- epiphytes & macro-algae (Seagrass-Watch & Fisheries QLD)
- meadow edge mapping (late dry Season, late monsoon Season) (Fisheries QLD)
- reproductive health (Fisheries QLD with reporting by JCU)
- seagrass tissue elements (C:N:P) (late dry Season) (Fisheries QLD)
- rhizosphere sediment herbicides (Fisheries QLD)
- *in-situ* within canopy temperature (Fisheries QLD)
- *in-situ* canopy light (JCU with field assistance by Fisheries QLD)

Seagrass abundance, composition and distribution

Field survey methodology followed Seagrass-Watch standard protocols (McKenzie *et al.*, 2007; see also www.seagrasswatch.org). At each location, with the exception of subtidal sites, sampling included two sites nested in a location and three 50m transects nested in each site. 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 logistical purposes of SCUBA diving in often poor visibility. . Monitoring at the sites in the late dry (September/October 2009) and late monsoon (March/April 2010) of each year was conducted by a qualified and trained scientist. Monitoring conducted outside these periods was conducted at some intertidal locations by trained/certified local stakeholders/community volunteers and at subtidal sites by a trained scientist assisted by volunteers (only scientist conducted assessments). Sites were monitored for seagrass cover and species composition. Additional information was collected on canopy height, macro-algae cover, epiphyte cover and macro-faunal abundance.

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 is used to determine if changes in seagrass abundance are 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 is compared against each site's baseline (first measure). As most distributional changes occur at either the shoreward or seaward extents of seagrass meadows, a description of the type of change is provided. The shoreward extent is primarily controlled by exposure at low tide, wave action and associated turbidity and low salinity from fresh water inflow, while the seaward extent is most likely to be controlled by the availability of light for photosynthesis.

Table 2. *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	Endeavour	Cooktown *reef*	AP1*	Archer Point	15°	36.5	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°	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*
	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. capricorni* with *H. ovalis/H. uninervis*
		Pioneer	Mackay *estuarine*	SI1*	Sarina Inlet	21°	23.76	149°	18.2	*Z. capricorni* with *H. ovalis (H. uninervis)*
				SI2*	Sarina Inlet	21°	23.712	149°	18.276	*Z. capricorni* with *H. ovalis (H. uninervis)*
Southern	Fitzroy (*Fitzroy Basin Association*)	Fitzroy	Shoalwater Bay *coastal*	RC1*	Ross Creek	22°	22.953	150°	12.685	*Zostera capricorni* with *H. ovalis*
				WH1*	Wheelans Hut	22°	23.926	150°	16.366	*Zostera capricorni* 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 capricorni* with *H. ovalis*
				GH2*	Gladstone Hbr	23°	45.874	151°	18.224	*Zostera capricorni* with *H. ovalis*
	Burnett Mary (*Burnett Mary Regional Group*)	Burnett	Rodds Bay *estuarine*	RD1*	Rodds Bay	24°	3.4812	151°	39.3288	*Zostera capricorni* with *H. ovalis*
				RD2*	Rodds Bay	24°	4.866	151°	39.7584	*Zostera capricorni* with *H. ovalis*
		Mary	Hervey Bay *estuarine*	UG1*	Urangan	25°	18.053	152°	54.409	*Zostera capricorni* with *H. ovalis*
				UG2*	Urangan	25°	18.197	152°	54.364	*Zostera capricorni* with *H. ovalis*

Table 3. *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. *=additional activity funded by Fisheries QLD.* † *= additional activity funded by Fisheries QLD.*

Sector	Region	Catchment	Monitoring location		late dry Season (2010)							late monsoon Season (2011)						
					SG	SM	TN	EM	RH	TL	LL	SG	SM	EM	RH	TL	LL	SH
Far Northern	Cape York	Endeavour	Cooktown	**AP1**	33	30	3	✓	15	✓		33	30			✓	✓	
				AP2	33	30	3	✓	15	✓								
Northern	Wet Tropics	Mossman	Low Isles	**LI1^**	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*	✓	✓	✓
	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*		✓*		✓*		33*	30*	✓*		✓*		
				GH2*	33*	30*		✓*		✓*		33*	30*	✓*				
	Burnett Mary	Burnett	Rodds Bay	**RD1**	33	30	3	✓		✓		33	30	✓	15*	✓		
				RD2	33	30	3	✓		✓		33	30	✓	15*	✓		
		Mary	Hervey Bay	**UG1**	33	30	3	✓	15	✓		33	30	✓	15*	✓		
				UG2	33	30	3	✓	15	✓		33	30	✓	15*	✓	✓	

Table 4. *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).*

GBR region	NRM Region	Catchment	Seagrass Monitoring location	Habitat type		*C. rotundata^*	*C. serrulata*	*H. decipiens*	*H. ovalis*	*H. uninervis^*	*S. isoetifoilium*	*T. hemprichii^*	*Z. capricorni^*
Far Northern	Cape York	Endeavour	Cooktown	Reef	intertidal	■			□	■			□*
Northern	Wet Tropics	Daintree	Low Isles	Reef	subtidal				□	■			
		Russell - Mulgrave Johnstone	Yule Point	Coast	Intertidal				□	■			□*
			Green Island	Reef	intertidal	■	□		□	■		■	
					subtidal	■	■		□	■	□		
		Tully	Lugger Bay	Coast	intertidal				□*	■			
			Dunk Island	Reef	intertidal	■	□		□*	■		■	
					subtidal		■	□	□	■			
Central	Burdekin	Herbert Burdekin	Magnetic Island	Reef	intertidal	□	■		□	■		□	□*
					subtidal		■	□	□	■			
			Townsville	Coast	intertidal				□	■			
	Mackay Whitsunday	Proserpine	Whitsundays	Coast	intertidal				□	■			■
			Whitsunday Islands	Reef	intertidal				□	■			■
		Pioneer	Mackay	Estuary	intertidal				□	■			■
Southern	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 capricorni = Zostera muelleri subsp. *capricorni, * 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 2010 and late monsoon 2011 at locations identified in Table 3. Samples were processed according to standard methodologies (McKenzie *et al.,* 2010).

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

Seeds banks and abundance of germinated seeds were measured according to standard Seagrass-Watch methods (McKenzie *et al.,* 2010). Seed banks were compared against the GBR long-term average calculated for each habitat.

Seagrass tissue nutrients

In late dry season (October) 2010, foundation seagrass species leaf tissue nutrient samples were collected from each monitoring site (Table 3). 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.* (2010). 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 (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' (Atkinson and Smith 1983; Fouqurean *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. 1992; 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.

Epiphyte and macro-algae abundance

Epiphyte and macro-algae cover were measured according to standard Seagrass-Watch methods (McKenzie *et al.,* 2010), and the percentage of leaf surface area covered by epiphytes and percentage of quadrat area covered by macro-algae, respectively. 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 may prove to be a valuable indicator for assessing both the current status and trends of the GBR seagrass meadows. However, preliminary analysis of the relationship between seagrass abundance and epiphyte cover collected by the RRMMP and Seagrass-Watch were inconclusive (McKenzie 2008) and further research and analysis is recommended before threshold levels for epiphyte abundances can be used as an indicator.

Within seagrass canopy temperature

Autonomous iBTag™ submersible temperature loggers were deployed at all sites identified in Table 2. The loggers recorded temperature (degrees Celsius) within the seagrass canopy every 90 minutes. iBCod 22L submersible temperature loggers were attached to the permanent marker at each site above the sediment-water interface.

Autonomous iBTag™ submersible temperature loggers attached to permanent site marker at Green Island (GI1)

Seagrass canopy light

Submersible Odyssey™ photosynthetic irradiance autonomous loggers were attached to permanent station markers at 15 intertidal and 4 subtidal sites seagrass locations from the Wet Tropics region to the Burnett Mary region (Table 3). Detailed methodology for the light monitoring (including cosine correction factors) can be found in McKenzie *et al.* (2010). Measurements were recorded by the logger every 30 minutes. Automatic wiper brushes cleaned the optical surface of the sensor every 15 minutes to prevent marine organisms fouling.

The deployment durations were variable, with some deployed since 2008 under a different program (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. 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 is every 6 weeks so data gaps were fewer.

Loggers were calibrated against a certified reference Photosynthetically Active Radiation (PAR) sensor (LI-COR™ LI-192SB Underwater Quantum Sensor) in full direct sunlight conditions.

Submersible Odyssey™ photosynthetic irradiance autonomous loggers deployed at Dunk Island (left) and Cockle Bay (right).

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 was then averaged over a 14-day period (half a tidal cycle) to make visual interpretation of the data easier. 14-day averaged I_d are presented graphically with estimates of the minimum light requirements (MLR) for seagrass survival. The values for MLR have not been quantified for most species occurring in the GBR. 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 (**Error! Reference source not found.**). 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 capricorni* is thought to have an MLR grater than 30% (Longstaff 2002).

Table 5. *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**

To examine GBR-wide trends in light, I_d at each site was standardized according to median I_d for that site. Standardized I_d data were then averaged for each site and averaged across the GBR. This focuses on temporal variation across the GBR enabling interpretation of seasonal and inter-annual variability, although interpretation of interannual variability is very limited at this stage, given that monitoring has occurred for only 1.5 years at many sites. For reporting of I_d at each site, unstandardised data are used.

Rhizosphere sediment herbicides

Sediment (approximately 250ml) for herbicide analysis was collected at each monitoring site identified in Table 3. Along each of the three transects monitored per site, approximately 20ml of sediment were collected every 5m to a depth approximately equal to the depth of the rhizome layer. Three homogenised samples (one per each transect) were collected per site. Detailed procedures are outlined in the *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures.* 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.

Data analyses

In this report results are presented to reveal temporal and spatial differences by visual assessment of data plots, however, detailed statistical analyses is restricted. We are working toward the development of appropriate statistical tools to more fully interrogate the temporal and covariate components of the data as the time series of observations lengthen. As yet meaningful trends in tissue nutrients and reproductive effort cannot be statistically evaluated given the relatively short duration of the data set. A detailed analysis is planned in 2013, as much of the analysis of covariates is dependent on feedback from manuscripts currently in review for publication (e.g., determining the ecologically relevant durations of exposure and time lags).

Percent cover data was ArcSin square root transformed prior to ANOVA. 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 Tukey's 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 affect 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 (Figure 4).

Figure 4. *Key to symbols used for conceptual diagrams detailing impacts to seagrasses.*

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, 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). Subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on abundance data collected from reference sites (McKenzie 2009).

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 2004).

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:

- within 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; Brodie *et al.* 2012; Webster and Ford, 2010; Bainbridge *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.* 2001), and
- does not suggest the meadow is in recovery (i.e. dominated by early colonising).

The 50th and 20th percentiles were used to define the guideline values as these are recommended for water quality guidelines (DERM, 2009), and there is no evidence that this approach would not be appropriate for seagrass meadows in the GBR. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (Figure 5). At reference sites, variance for the 50th and 20th percentiles was found to level off at around 15–20 samples (i.e. sample times), 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.

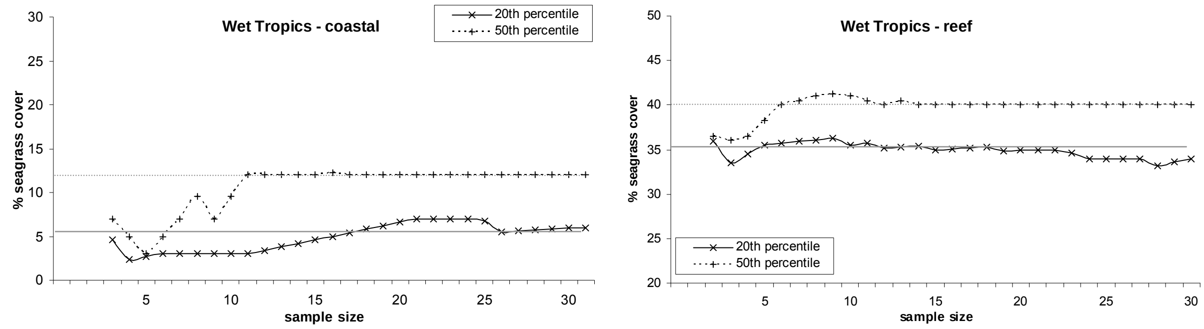


Figure 5. *Relationship between sample size and the error in estimation of percentile values for seagrass abundance (% cover) in coastal and reef seagrass habitats in the Wet Tropics NRM.*

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

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 or 0th 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 6), it indicates that the meadows were in a poor condition in mid 2000, mid 2001 and mid 2006 (based on abundance).

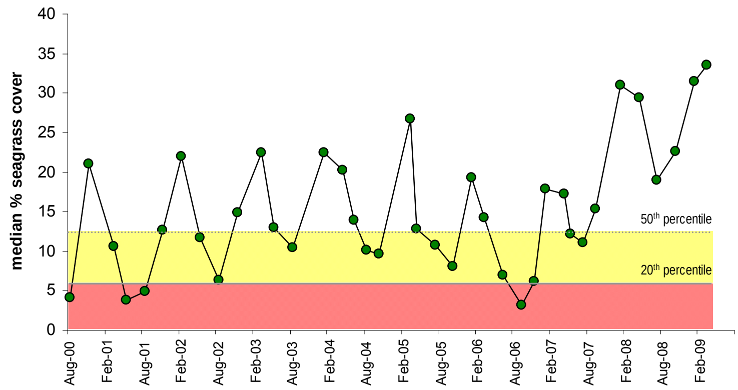


Figure 6. *Median seagrass abundance (% cover) at Yule Point plotted against the 50th and 20th percentiles for coastal seagrass habitat in the Wet Tropics.*

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 (7), it indicates that the meadows were in a poor condition in the middle of most years (based on abundance). However, the poor rating is most likely a consequence of seasonal lows in abundance. Therefore, in this instance, it was more appropriate to set the guideline at the 10th rather than the 20th percentile.

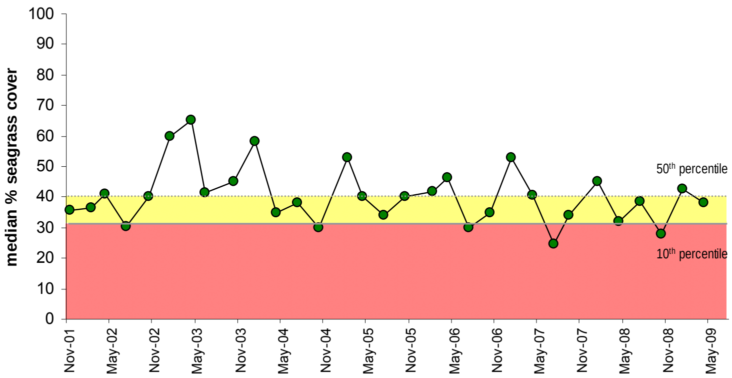


Figure 7. *Median seagrass abundance (% cover) at Green Island plotted against the 50th and 10th percentiles for intertidal reef seagrass habitat in the Wet Tropics.*

Using this approach, subregional seagrass abundance guidelines (hereafter known as "the seagrass guidelines") were developed for each seagrass habitat types where possible (Table 6). 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.

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 7).

Table 6. *Seagrass percentage cover guidelines ("the seagrass guidelines") for each site and the subregional quidelines (bold) for each NRM habitat. Values in light grey not used. ^ denotes regional reference site, * from nearest adjacent region.*

NRM region	Site	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
	NRM	***reef intertidal***	***11***	***16.8***	***18.9***	***23.7***
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
	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	SI1	estuarine intertidal		18	34.1	54
	SI2	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	10.8*	18*	34.1*	
	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	
	HM1	reef intertidal	22.2		34.5	39
	HM2	reef intertidal	22.2		34.5	39
	NRM	***reef intertidal***	***22.2****	***26.2****	***34.5****	***39****
Fitzroy	GH1	estuarine intertidal		18	34.1	54
	GH2	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
	GK1	reef intertidal	22.2		34.5	39
	GK2	reef intertidal	22.2		34.5	39
	NRM	***reef intertidal***	***22.2****	***26.2****	***34.5****	***39****
Burnett Mary	RD1	estuarine intertidal		18	34.1	54
	RD2	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 7. *Scoring threshold table to determine seagrass abundance status.*

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.* 2006b), 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, it is essential that a local seed source is available for recovery. In the GBR, the production of seeds comes in numerous forms (QA/QC doc) and assessments must capture these forms in sampling to establish recovery capacity. Seed banks examined directly by coring excludes *Halophila* species, as the size of the seeds (<1mm diameter) would require more extensive/detailed laboratory proceedures and is beyond the scope of program resources. The measure of seagrass resproductive effort captures both the production of reproductive structures, for all species, while still attached to parent plants, and also the presence of seeds in sediments for species that produce large, longer-lived seeds (*Halodule*, *Zostera*, *Cymodocea*). Data is not available at this time to use measured reproductive effort and recruitment rates which remains a gap for the majority of species in the region. Limited studies that have been conducted on recruitment rates (Inglis 2000).

Using the annual mean of all species pooled in the late dry and comparing with the long-term (2005-2009) average for GBR habitat, the reproductive effort was scored as the number of reproductive structures per core and the overall status determined (Table 8) as the ratio of the average number observed divided by the long term average.

Table 8. *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. With light limitation, seagrass plants are unable to build structure, hence the proportion of carbon in the leaves decreases relative to nitrogen. Experiments on seagrasses in Queensland have reported that at an atomic C:N ratio of less than 20, may suggest reduced light availability relative to nitrogen availability (Abal *et al.,* 1994; 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. This available light can be highly impacted by epiphytic growth or sediment smothering photosynthetic leaf tissue.

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 (excluding *Halophila ovalis*), C:N ratios were categorised on their departure from the guideline and transformed to a 0 to 100 score using equation 1:

equation 1 $$\text{score} = (\text{C:N} \ x\ 5) - 50$$

The score was then used to represent the status to allow integration with other components of the report card (Table 9).

Table 9. *Scores for leaf tissue C:N against guideline to determine light and nutrient availability.*

description	C:N ratio range	value	score	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

**C:N ratios >35 were scored as 100, and C:N ratios <10 were scored as 0*

Seagrass index

The seagrass index is average score (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 seagrass of the Great Barrier Reef (GBR), the regional scores were weighted on the percentage of GBRWHA seagrass (shallower than 15m) within that region (Table 10). *Please note: Cape York was omitted from the GBR score due to insufficient sampling locations to adequately represent the entire region*.

Table 10. *Area of seagrass shallower than 15m in each NRM region (from McKenzie 2010) within the boundaries of the Great Barrier Reef World Heritage Area. n/a denotes seagrass area not included in GBR total.*

NRM	Area of seagrass (km^2)	% of GBRWHA
Cape York	n/a (1,843 km2)	
Wet Tropics	201	0.16
Burdekin	551	0.45
Mackay Whitsunday	154	0.13
Fitzroy	241	0.20
Burnett Mary	73	0.06

GBRWHA	**1,220**	**1.00**

3. Results

GBR Summary

Seagrass meadows are an important component of the GBR nearshore ecosystems. Seagrass species richness differs between locations and habitats in the GBR Region, with inshore reef habitats tending to be more specious than meadows at coastal or estuarine habitats. Intertidal seagrass meadow cover (as a percentage of the substrate covered by plant material) also varies between locations along the length of the GBR. The average seagrass percent cover (over the past 12 years) at each of the intertidal seagrass habitats within the GBR was 13% for estuarine, 16% for coastal, and 22% for reef. Seagrass abundance has declined along the GBR urban coast, particularly south of Cairns. Findings from the 2010/11 monitoring period indicate that the overall status of intertidal seagrass meadows within the GBR were in a **very poor** state (Table 11). The regions of greatest concern for seagrass are the Burdekin, Mackay Whitsunday and Burnett Mary where not only has seagrass abundance declined, but very poor seed banks and reproductive effort have raised concerns about the ability of local seagrass meadows to recover from environmental disturbances. No herbicides were found above detectable limits in the seagrass sediments and above average rainfall/runoff leading to high turbidity and low light is the likely cause of seagrass reduction since 2009. Seagrass leaf tissue nutrients indicate N loading and possibly low light availability across most locations. Furthermore, extremely low light levels (below minimum light requirements) have occurred at a number of sites; however, light has been monitored for only a brief period of time (since 2009) at many sites so long-term trends are not available. Importantly, seagrass monitoring data from the Wet Tropics suggests a coastal location in the north is showing increasing signs of poor water quality conditions, as seagrass tissue indicates light limited, nutrient rich environments with elevated nitrogen. Future declines in abundance may be expected at this location.

Table 11. *Report card for seagrass status for the GBR and each NRM region: July 2010 – May 2011. 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).*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	15	63	50	43
Wet Tropics	36	9	24	23
Burdekin	8	13	17	13
Mackay Whitsunday	5	0	14	6
Fitzroy	28	46	43	39
Burnett Mary	5	0	30	12
GBR	16	16	24	**19**

Status of the seagrass community

Seagrass abundance and composition

Of the 30 sites examined across the GBR in 2010/11, seagrass abundance at 17% of sites were classified as poor and 77% were classified as very poor (below the seagrass guidelines) in late monsoon 2011. Based on the average score against the seagrass guidelines (determined at the site level), the abundance of seagrass in the GBR over the 2010/11 period was classified as **very poor** (all sites and seasons pooled) (Figure 8). The overall trend in seagrass abundance of the same 30 sites monitored as part of the MMP (2005), indicates a decline over the last 5 monitoring periods (Figure 8).

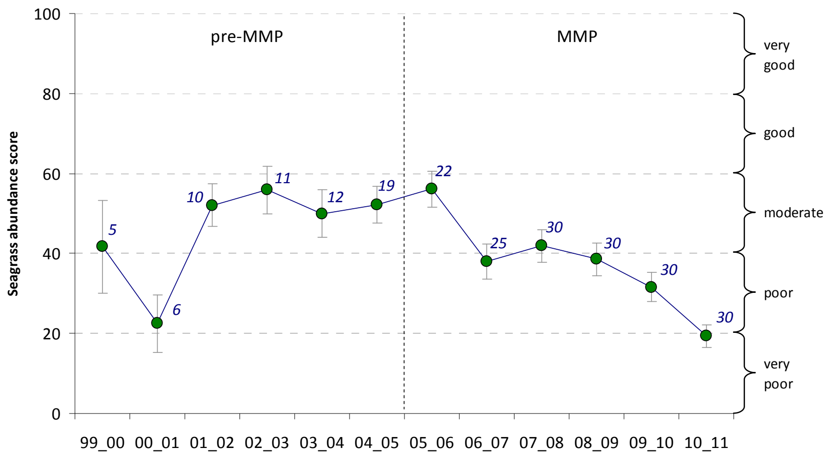


Figure 8. *Average yearly seagrass abundance score (all sites and seasons pooled) for the GBR (± Standard Error). Median percentage cover at a site each monitoring event was scored relative to each site's guideline value, taking into account species and habitat.*

Over the past decade, the patterns of seagrass abundance at each GBR habitat type have differed (Figure 9), however both reef and coastal habitats have been declining since 2009. Seagrass abundance has fluctuated greatly in estuarine habitats; most often as a response to climate (e.g. rainfall, temperature and desiccation) and at smaller localized scales there have been some acute event related changes. Seagrass meadows in coastal habitats have changed over periods of three to five years, however the decadal trend is relatively stable. Inshore reef seagrass meadows appear to have declined in abundance since 2006.

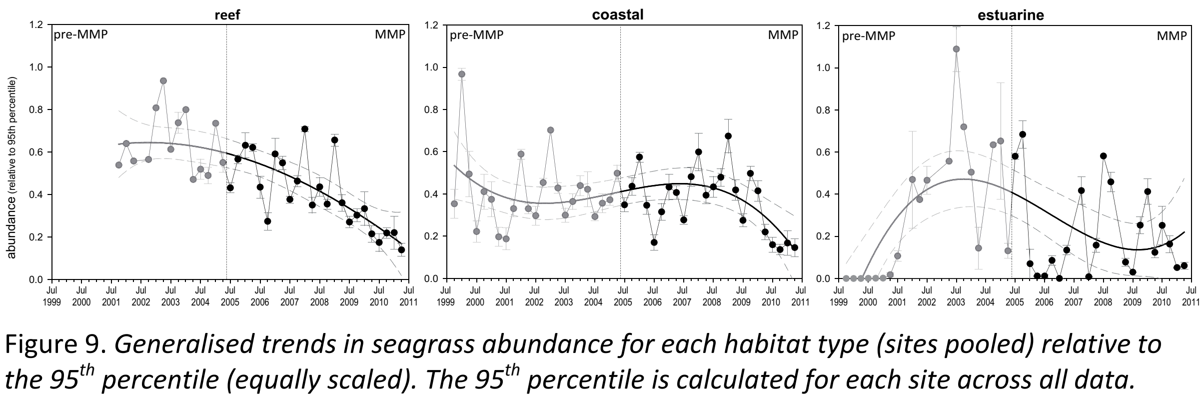


Figure 9. *Generalised trends in seagrass abundance for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data. Data prior and post implementation of the MMP displayed. Trendline is 3rd order polynomial, 95% confidence intervals displayed, reef (12 sites) r^2 =0.606, coastal (10 sites) r^2 = 0.218, estuary (8 sites) r^2 = 0.337.*

Table 12. *Summary of seagrass condition and overall trend at each NRM region habitat, values are Jul10 – May11 with the long term average in parentheses and 5 year trajectory in bold (>20% difference between sampling events). Plant C:N is a surrogate for light where moderate = adequate light availability on average required for growth (C:N>20:1), low = less available light on average than required for growth (C:N<20:1); C:P is a surrogate for nutrient status of the habitat where, rich = relatively large P pool (C:P <500:1), poor = relatively small P pool (C:P >500:1); N:P is the overall nutrient availability to the plant, where N limited = N:P <25, replete N:P = 25 to 30; P limited = N:P >30. Percent cover = mean percent cover for sampling period ± SE. Repro health = repro structures per core.*

Parameter	**Period**	**Unit**	**Region**					
			Cape York	**Wet Tropics**	**Burdekin**	**Mackay Whitsunday**	**Fitzroy**	**Burnett Mary**
Abundance	Late dry & late Wet Seasons	Cover (%)	Reef: 12.7±1.1 *(17)* ***declining***	Coast: 9.0±2.3 *(12)* Reef: 18.1±4.3 *(29)* ***declining***	Coast : 0.9±0.6 *(15)* Reef: 3.0±1.1 *(25)* ***declining***	Estuary: 0.2±0.2 *(10)* Coast: 4.5±2.8 *(19)* Reef: 2.0±0.9 *(5)* ***declining***	Estuary: 23.9±5.2 (21) Coast: 15.5±2.0 *(25)* Reef: 2.0±0.9 *(2)* ***variable***	Estuary: 2.9±1.3 (10) ***declining***
Reproduction		Seed reserve (per m^2)	Reef: 97±35 *(138)* ***increasing***	Coast: 59±24 *(248)* Reef: 1 *(1)* ***declining***	Coast: 192±72 *(1901)* Reef: 7±3 *(28)* ***declining***	Estuary: 0 *(27)* Coast: 0 *(215)* Reef: nil ***declining***	Estuary: nil Coast: 8±8 Reef: nil ***increasing***	Estuary: nil *(0)* ***absent***
		Repro effort (structures per core)	Reef: 2.8±0.7 *(2.0)* ***increasing***	Coast: 0.02±0.02 *(0.5)* Reef: 1±0.4 *(0.8)* ***increasing***	Coast: 0 *(6.4)* Reef: 0.8±0.4 *(1.3)* ***declining***	Estuary: 0 *(3.3)* Coast: 1.3±0.6 *(4.9)* Reef: 0.2±0.1 *(0.6)* ***declining***	Estuary: 11.2±2 *(8.8)* Coast: 0 *(6.8)* Reef: 3.4±1 *(1.8)* ***declining***	Estuary: 0.6±0.3 *(3)* ***declining***
Nutrient status (availability)	Late dry Season	Leaf tissue C:N	Reef: moderate ***moderate & improving***	Coast : low Reef: low ***low & stable***	Coast : Low Reef: low ***low & decreasing***	Estuary: low Coast: low Reef: low ***low & decreasing***	Estuary: moderate Coast: low Reef: low ***moderate & variable***	Estuary: low ***low & variable***
	Late dry Season	Leaf tissue C:P	Reef: poor ***small P pool & variable***	Coast : rich Reef: rich ***high nutrients & variable***	Coast: rich Reef: rich ***high nutrients & increasing***	Estuary: rich Coast: rich Reef: rich ***high nutrients & variable***	Estuary: poor Coast: rich Reef: rich ***high nutrients& variable***	Estuary: rich ***high nutrients & variable***
	Late dry Season	Leaf tissue N:P	Reef: replete ***nitrogen full & variable***	Coast: replete Reef: replete ***nitrogen full & stable***	Coast: N-limited Reef: replete ***nitrogen full & variable***	Estuary: N limited Coast: N limited Reef: N limited ***nitrogen low & variable***	Estuary: N limited Coast: N limited Reef: replete ***nitrogen low & variable***	Estuary: N limited ***nitrogen low & variable***
Epiphytes	Late dry & late Wet Seasons	Epiphytes (%)	Reef: 48.2±6.7 *(28)* ***stable***	Coast : 20.5±5.4 *(18)* Reef: 22±6.1 *(24)* ***increasing***	Coast: 26.9±7.8 *(20)* Reef: 9.4±3 *(34)* ***declining***	Estuary: 5.8±5.8 *(23)* Coast: 20.9±8.1 *(11)* Reef: 23.9±9.4 *(34)* ***declining***	Estuary: 16.7±4.7 *(23)* Coast: 3.7±0.8 *(15)* Reef: 23.9±9.4 *(28)* ***declining***	Estuary: 16.5±5 *(26)* ***declining***

Abundance of intertidal seagrasses at locations in the Fitzroy or northern Wet Tropics regions were stable or increasing; however most locations across the GBR have declined over the past 12 months. Most of these declining locations have poor seed reserves (Table 12). In addition, many of these sites have low or below average reproductive effort and as a result recovery time may take longer, between 18 months and three years as it will be dependent on vegetative growth and/or translocation of vegetative fragments, or arrival of seeds from outside the area that has experienced loss.

Intertidal estuarine locations were only monitored in the Mackay Whitsunday, Fitzroy and Burnett Mary regions. Seagrass abundance at estuarine monitoring sites continues to vary greatly seasonally (Figure 9). Although seagrass was recovering at half the estuarine monitoring sites in 2010, abundances in late monsoon 2011 declined below 2010 abundances; a consequence of the flooding across the regions. The onset of recovery at Rodds Bay in the 2010/11 was primarily from seeds, however seed banks are not well represented at other estuarine intertidal sites (Table 12).

Intertidal coastal sites were monitored in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions over the past 12 months. Seagrass abundance at coastal intertidal seagrass meadows had remained relatively stable until 2009 (Figure 9). As seed banks and reproductive effort continued to decline throughout the 2010/11 monitoring period, the capacity to recover is reduced and time to recovery to pre-2009 abundances and extent may take >5 years (Table 6 in Appendix 1,)

Six reef habitat locations were monitored by the Reef Rescue MMP within the GBR in the Cape York, Wet Tropics, Burdekin and Mackay Whitsunday regions over the past 12 months. Reef habitats are more seagrass specious. The more dominant seagrass species in reef habitats of the GBR include *Cymodocea rotundata*, *Thalassia hemprichii*, and the colonising species *Halophila ovalis* and *Halodule uninervis*. Although one location is on the mainland (Archer Point), most are located on near-shore reef-platforms associated with continental islands or coral cays. Seagrass abundance at intertidal reef-platform meadows has continued to decline over the last 4-5 years (Figure 9). Seed banks are very low at reef habitats compared to both estuarine and coastal intertidal habitats (Table 12), but reproductive effort is increasing in some locations, indicating an improved capacity to recover.

As the long-term goal of the Reef Water Quality Protection Plan (‘Reef Plan’) is to ensure that the quality of water entering the Great Barrier Reef from adjacent catchments has no detrimental impact on its health and resilience, a preliminary/exploratory analysis was conducted to investigate the relationship between seagrass abundance and river flow. Seagrass abundance was standardised relative to the 95th percentile (at site level) and correlated against the average flow for 60 days prior to the seagrass data collection. All sites influenced by the primary-secondary flood waters of the major rivers examined were included. Only abundance data within the wet season (December to March, 1999 to 2011) were included.

There were correlations between seagrass abundance in the monsoon-late monsoon period (relative to the 95th percentile) and average flow (ML/day) for rivers which expose seagrass to freshwater-primary flood plumes (Figure 10). Seagrass abundance declined with increasing river flow and the relationship explained between 15% and 33% of the variance across regions (Figure 10). This supports the understanding that terrigenous runoff from seasonal rains is a dominant influence on coastal and nearshore reef seagrass habitats. This is particularly apparent in the Wet Tropics, where large flows occur annually. However, the influence of the recent extreme climate observations (very high flow accompanied by seagrass loss, see Appendix 1) on the regressions cannot be disregarded for the Burdekin and to a lesser extent the *Calliope* and warrants closer examination. Nevertheless, the relationship is not apparent in all situations, as the impact of flood plumes is dependent on meadow state; e.g. there was no significant relationship between seagrass abundance at Urangan and the flows of the Mary River, as the meadow was constantly undergoing a state change in the population (state of recovery). Further and more detailed analysis is planned in the near future to further elucidate the relationship.

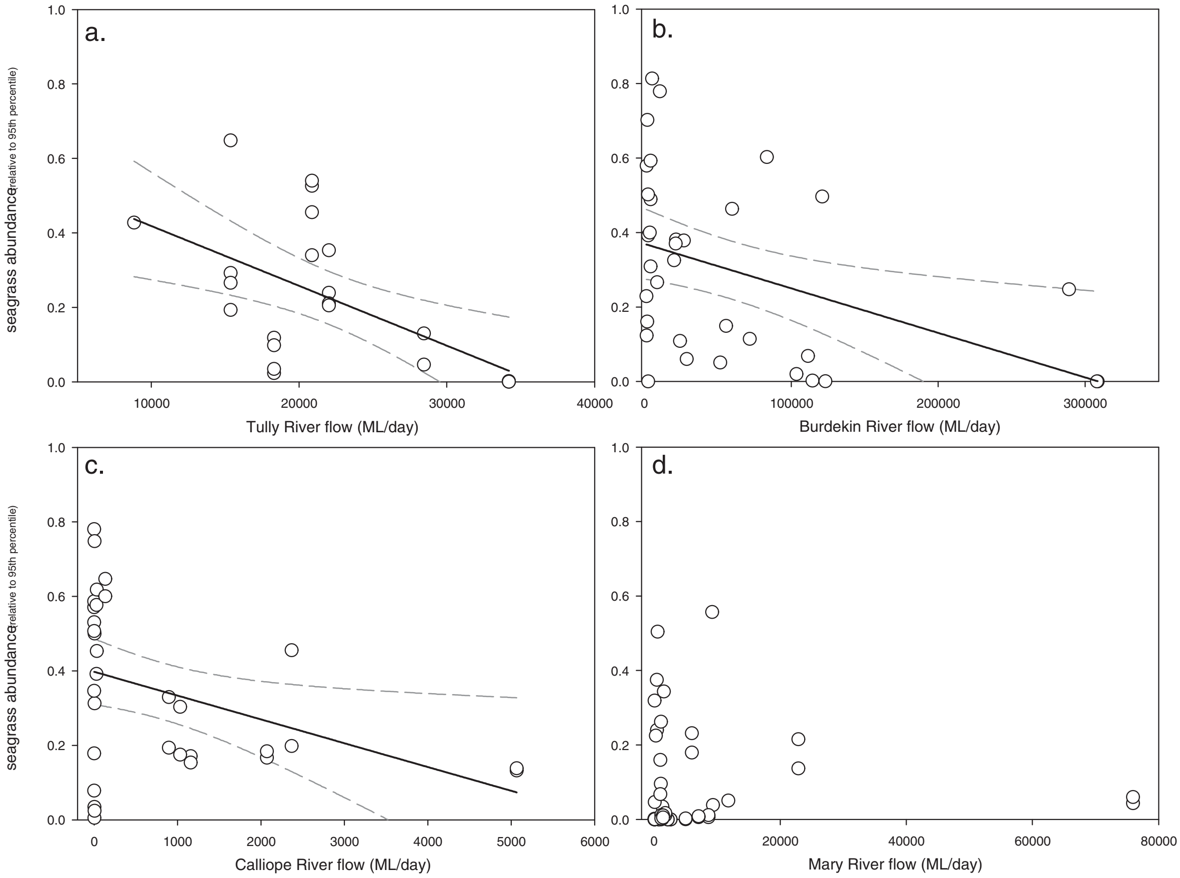
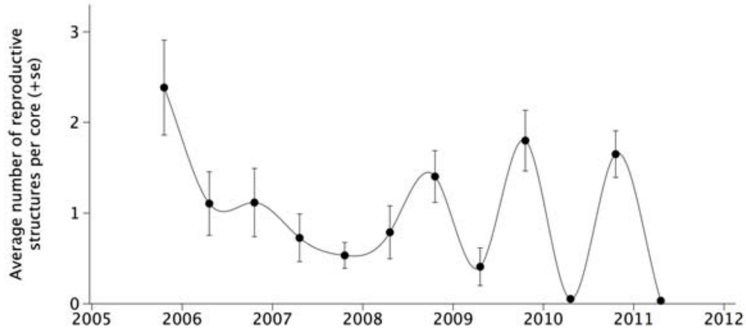


Figure 10. *Relationship between seagrass abundance (relative to the 95th percentile) in the monsoon-late monsoon period and average flows (60 days prior, ML/day) (95% confidence intervals displayed) which expose seagrass to freshwater-primary flood plumes from the (a) Tully River (r^2= 0.33), (b) Burdekin River (r^2= 0.18), (c) Calliope River (r^2= 0.15),and (d) Mary River (not significant).*

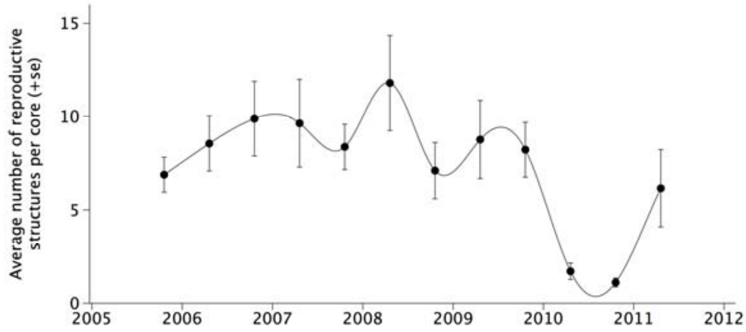
Seagrass reproductive status

Across the GBR as a whole, reproductive effort, representing per area estimates of the number of reproductive structures produced by any seagrass species during the sampling period, was found to be greater in coastal habitats by nearly 5 times that of reefal and estuarine habitats (Figure 11). Seasonality in reproductive effort is also to be noted, typically the wet season sample has very few reproductive structures present. We continue to focus on reporting dry season reproductive effort to provide the most comparative estimate of reproduction across sites.

a. reef



b. coastal



c. estuarine

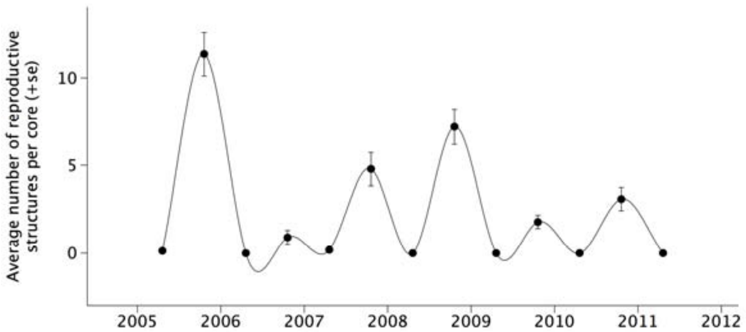


Figure 11. *Long term trends in total reproductive effort (mean total reproductive effort per core ± s.e.) across all inshore sites monitored for each major habitat type (a) reef, (b) coastal and (c) estuarine.*

In contrast to the observation of limited wet season propagule production for seagrasses in the GBR, reproductive effort across coastal sites was relatively high for the latest (2010/11) wet season. Inspection of the data from coastal sites reveals that one site, Bushland Beach in the Burdekin region, is responsible for the large numbers and this is principally due to the presence of a very large seed bank at the time of sampling (May 2011). There are several possible causes of the large number of *Halodule* seeds to be present at that time, most likely is that sediment movement, and the loss of seagrass cover, have allowed the seeds to come closer to the surface and accumulate in smaller areas. This phenomenon has previously been reported by Inglis (2000a) and was also observed in 1999 when loss of seagrass in the Shelly Beach area nearby to Bushland Beach, was followed by the movement of copious numbers of seeds to the surface of the sediment and subsequent germination. We have observed numerous recently germinated seeds at these sites in recent samples so it is likely these are inter-related. GBR wide, dry season reproductive effort estimates are moderate on average for estuarine sites, poor for coastal sites and moderate for reefal sites.

Observations of how seagrass meadows recover from recent poor ecological health will be important to evaluating the longer term capacity of seagrasses to recover from disturbance and therefore their resilience.

Status of the seagrass environment

Seagrass tissue nutrients

Tissue nutrient concentrations were variable between years, both across habitats and within habitats between years. It was necessary at some sites (refer Table 4) to pool across foundation species as the presence of individual species was not constant over time at all locations since monitoring was established. Exploratory analysis at sites where species co-occur, indicated that although elemental content differed, the ratios were not significantly different (e.g., at Pioneer Bay where *H. uninervis* and *Zostera* co-occur, paired T-test, T=-2.1, df=8, *p*=0.0689). By pooling across species and habitat types, some trends are apparent.

Tissue nutrient concentrations (%N and %P) appear to have increased since 2006 across all habitats (species pooled) (Figure 12). The 2005 values may be unreliable due to contamination of the samples during the grinding phase (see McKenzie *et al.,* 2006a) and should be interpreted with caution.

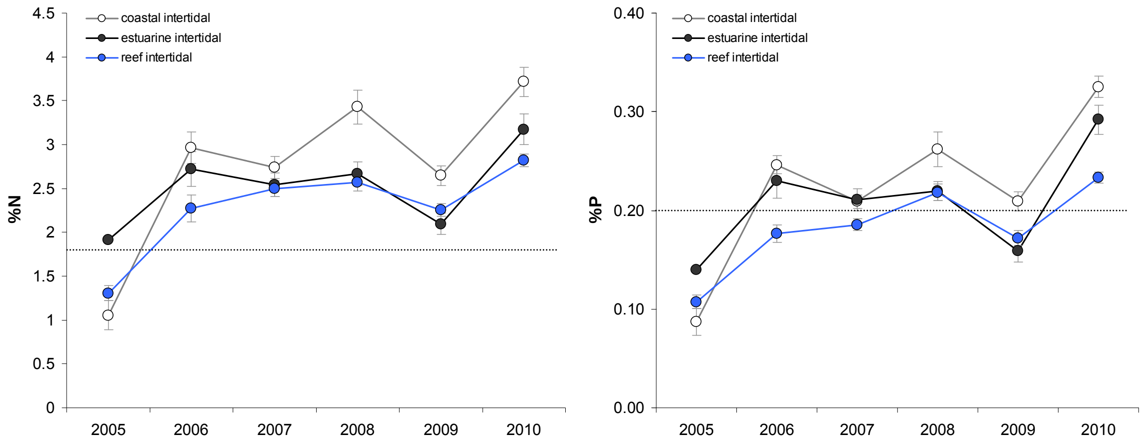


Figure 12. *Mean tissue nutrient concentrations (±Standard Error) in seagrass leaves for each habitat type (species pooled) over the entire monitoring program. Dashed lines indicate global average values of 1.8% and 0.2% for tissue nitrogen and phosphorus, respectively (Duarte 1990).*

Since 2005, mean tissue nitrogen concentrations for all habitats have exceeded the global value of 1.8% (Duarte 1990; Schaffelke *et al.,* 2005) (Figure 12). Mean tissue phosphorus concentrations for all habitats exceeded the global value of 0.2% (Duarte 1990; Schaffelke *et al.,* 2005) in 2010 after concentrations for reef and estuarine habitats dropped below the global average in 2009 (Figure 12). 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 all habitats have reached their highest levels in 2010 since monitoring commenced.

C:N ratios have been shown in a number of experiments and field surveys to be related to light levels (Abal *et al.,* 1994; Grice *et al.,* 1996; Cabaço and Santos 2007; Collier *et al.,* 2009). With increasing light availability, plants increase growth, thereby taking on more carbon relative to nitrogen. Experiments on seagrasses 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. 1992). In 2010, all three habitat types (coast, reef and estuary) had C:N ratios <20; these levels have mostly declined since 2005. These low C:N levels in 2010 potentially indicate reduced light availability (Figure 13), although the increase in tissue %N (Figure 12) across all habitats may exacerbate the reduction.

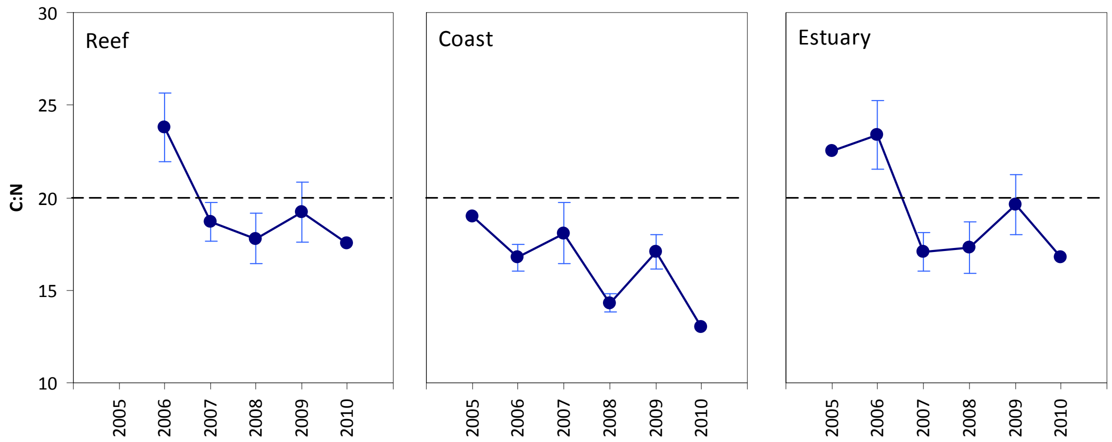


Figure 13. *Elemental ratios (atomic) of seagrass leaf tissue C:N for each habitat each year (foundation species pooled). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability.*

Coastal 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 14). Reef and estuarine habitats also became richer 2010 indicating an increasing P pool (Figure 14).

In 2010, N:P ratios decreased across all habitats possibly a consequence of the increase in %P in the leaf tissue (Figure 14). Reef and coastal habitats had N:P ratios between 25 and 30, indicating seagrass to be nutrient replete, and potentially nutrient saturated. Within coastal habitats these levels had consistently increased since 2005, until 2009 when they began falling (Figure 14). In estuary habitats, N:P ratios declined below 25 for the first time since monitoring commenced, suggesting the enrichment in P was greater than the N enrichment, resulting in the plants have becoming predominately N-limited (Figure 14).

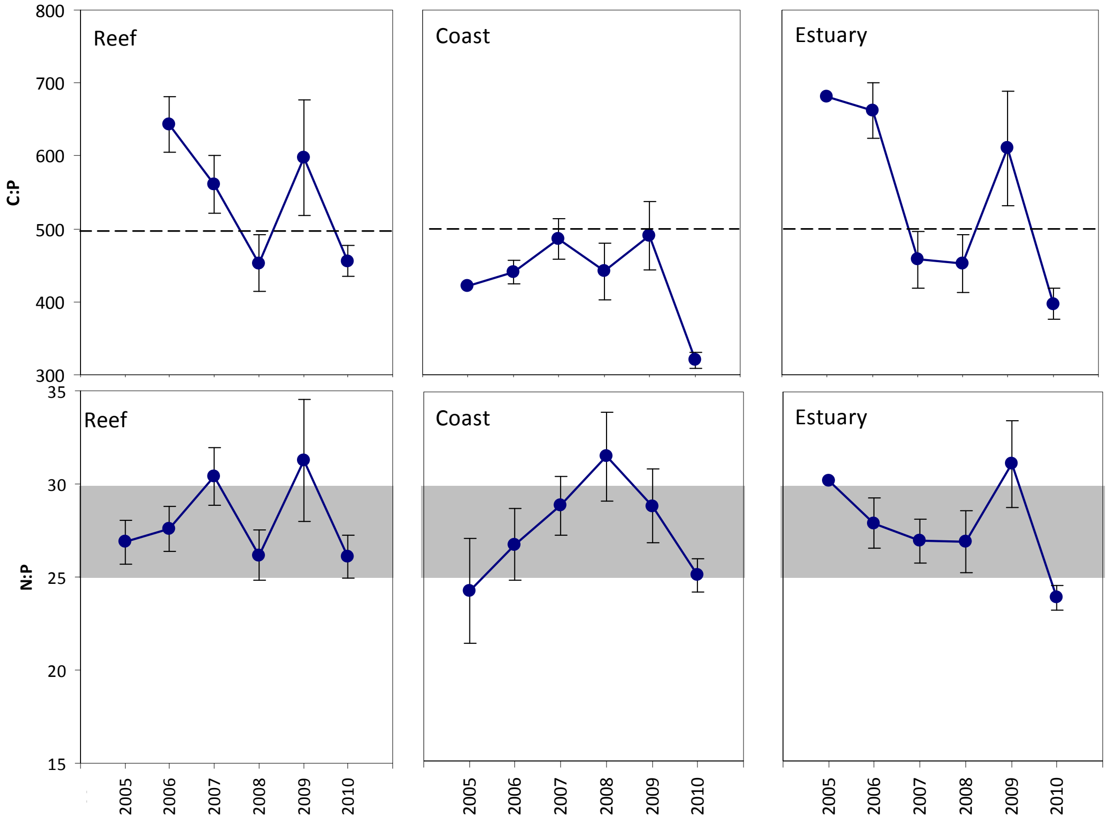


Figure 14. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for each habitat each year (foundation species pooled) (± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith, 1983; Duarte, 1990; Fourqurean et al., 1992; Fourqurean & 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).*

Locations where seagrass are growing in low light environments (C:N is low), with a relatively large P pool (C:P is rich) and an even larger N pool (N:P is P limited) indicate relatively poor water quality. Only one location met these criteria in 2010: Yule Point (Wet Tropics region) (Table 13). This is the third consecutive year where leaf tissue nutrient content has indicated poor water at Yule Point.

Seagrass meadows at locations previously identified with poor water quality (Sarina Inlet in 2008 and 2009; Lugger Bay and Townsville in 2008) subsequently declined substantially in abundance or were lost within the following year. It is likely that future declines in abundance may be expected at Yule Point in the near future.

Table 13. *Summary of elemental ratios (atomic) of seagrass leaf tissue condition at each seagrass monitoring location, values are Sep/Oct 2010 with the 2009 value in parentheses. Light orange = sites of concern with respect to water quality. Plant elemental C:N is a surrogate for light where moderate = adequate light availability on average required for growth (C:N>20:1), low = less available light on average than required for growth (C:N<20:1); C:P is a surrogate for nutrient status of the habitat where, rich = relatively large P pool (C:P <500:1), poor = relatively small P pool (C:P >500:1); N:P is the overall nutrient availability to the plant, where N-limited = N:P <25, replete N:P = 25 to 30; P-limited = N:P >30.*

Region	Catchment	Location *(habitat)*	$C:N_{plant}$ status	$C:P_{plant}$ status	$N:P_{plant}$ status
Cape York	Endeavour	Archer Pt *(reef)*	moderate *(low)*	poor *(poor)*	replete *(P-limited)*
Wet Tropics	Barron Russell - Mulgrave Johnstone	Yule Pt *(coast)*	low *(low)*	rich *(rich)*	P-limited *(P-limited)*
		Green Is *(reef)*	low *(moderate)*	rich *(poor)*	replete *(replete)*
	Tully – Murray	Lugger Bay *(coast)*	low *(low)*	rich *(rich)*	N-limited *(replete)*
		Dunk Is *(reef)*	low *(moderate)*	poor *(poor)*	replete *(replete)*
Burdekin	Burdekin	Townsville *(coast)*	low *(low)*	rich *(rich)*	N-limited *(replete)*
		Magnetic Is *(reef)*	low *(moderate)*	rich *(poor)*	replete *(P-limited)*
Mackay Whitsunday	Proserpine	Pioneer Bay *(coast)*	low *(low)*	rich *(poor)*	N-limited *(replete)*
		Hamilton Is* *(reef)*	low *(low)*	rich *(poor)*	N-limited *(P-limited)*
	Pioneer	Sarina Inlet *(estuary)*	low *(low)*	rich *(rich)*	N-limited *(P-limited)*
Fitzroy	Fitzroy	Shoalwater *(coast)*	low *(moderate)*	rich *(poor)*	N-limited *(replete)*
		Great Keppel *(reef)*	low *(low)*	rich *(poor)*	replete *(P-limited)*
	Boyne	Gladstone *(estuary)*	moderate *(moderate)*	poor *(poor)*	N-limited *(P-limited)*
Burnett Mary	Burnett	Rodds Bay *(estuary)*	low *(low)*	rich *(poor)*	N-limited *(P-limited)*
	Mary	Urangan *(estuary)*	low *(low)*	rich *(poor)*	N-limited *(replete)*

Epiphytes and macro-algae

Epiphyte abundance was dependent on seagrass presence and although higher at reef habitats, was not dependent on time of year/season. There was no difference in epiphyte abundance between seasons at coastal (ANOVA, d.f.=3,42, F=2.64, p=0.06), estuarine (ANOVA, d.f.=3,34, F=0.54, p=0.7), or reef habitats (ANOVA, d.f.=3,27, F=1.77, p=0.2) (Figure 15).

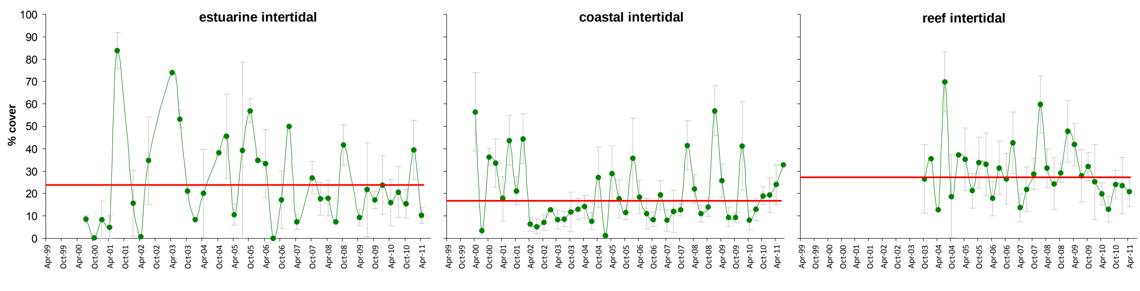


Figure 15. *Epiphyte abundance (% cover) at each seagrass habitat monitored (sites pooled) (±SE). Red line = GBR long-term average; estuarine = 25% coastal=17%, reef = 28%.*

Macro-algae abundance continued to decline across all habitats and was below the GBR long-term average during the 2010/11 monitoring period (Figure 16).

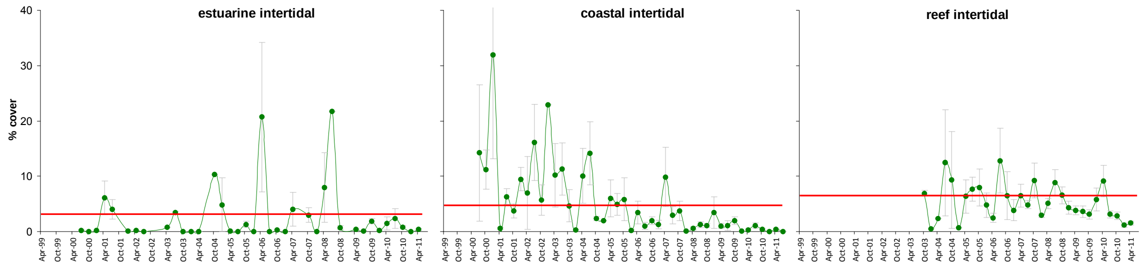


Figure 16. *Macro-algae abundance (% cover) at each seagrass habitat monitored (sites pooled) (±SE). Red line = GBR long-term average; estuarine = 3.2%, coastal=4.7%, reef = 6.2%.*

Rhizosphere sediment herbicides

As inshore seagrass meadows are exposed to water flows from catchments at least during flood seasons and periods of high water flow, seagrasses may be exposed to chemical contaminants within the water column or absorbed to sedimenting particles in the plume. However, none of the thirteen herbicides (organics) analysed were found above detectable limits in the sediments of the seagrass monitoring sites during the late monsoon 2011 (Figure 17).

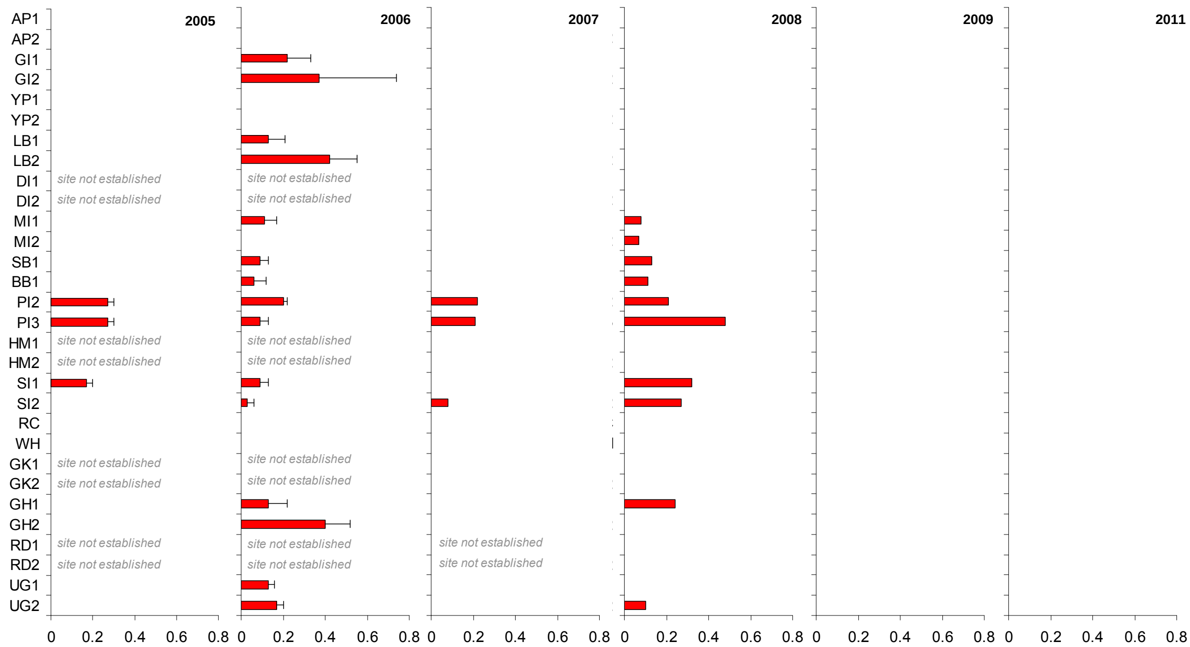


Figure 17. *Concentration of diuron (µg/kg DW) in sediments of inshore monitoring sites during the late Monsoon. It is estimated that diuron concentrations of ~10 µg kg^{-1} in sediments inhibit seagrass photosynthesis (Haynes et al. 2000).*

It is possible that diuron concentrations were below the level of detection in 2011 and 2009 as a consequence of dilution, since 2011, 2009 and to a lesser extend 2007 were monsoon periods which included large flood events across many of the regions.

As herbicides in Queensland are applied to prevent weed growth in agriculture the most likely time of detection in coastal waters would be close to the "first flush" of the rainfall season of November through to March. In the present study, sediment herbicide collections were generally conducted in conjunction with the seagrass monitoring in April. Herbicides have an uncertain half life in marine sediments as they have been developed purely for terrestrial application. Atrazine has a short half life of three - 30 days, Irgarol 100 days and diuron 120 days, but toxic breakdown products may extend the time these chemicals can cause damage (Ralf et al., 2006; Haynes et al., 2000).

Light

Daily irradiance (I_d) was combined for all sites by first standardizing light to median I_d for each site. There are peaks in GBR-wide I_d during the later half of the year (July to December), and lowest I_d during the wet season (Figure 18). There is a general trend for declining I_d since 2008, however, this is not being driven by reduced I_d during the wet season over the period 2008 to 2011. Instead the trend is being driven largely by conditions during the later half of the year. Turbidity is measured at just three sites (Magnetic Island, Dunk Island and Green Island). The largest and most frequent peaks in turbidity occur during the wet season, however large peaks in turbidity also occur during the second half of the year coinciding with periods of large tidal variation and strong wind (C. Collier unpubl. data). Early onset of the 2010/11 wet season and above average cloud cover could also have contributed to low light in late 2010. Analysis of the physical drivers of turbidity (run-off, wind, currents) and the contribution of turbidity to light (as opposed to clouds and changing sea level) is being conducted separately to this report. These analyses will highlight the primary drivers of the temporal variability in light. Light monitoring began in 2008, and has therefore only been in place since unusually big wet seasons have occurred. Therefore, I_d during the wet seasons has probably been anomalously low for the entire monitoring period.

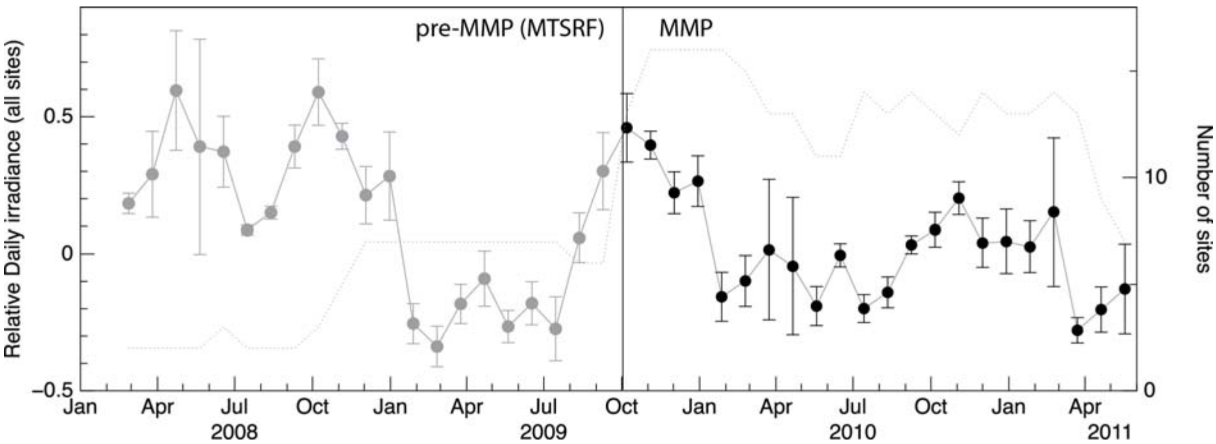


Figure 18. *Standardized I_d (28-day average) for all sites combined and number of sites contributing to the data (dashed line). Prior to the introduction of light monitoring into the MMP, only 8 sites (from 4 islands) were monitored in a MTSRF funded project, with the number of sites increasing to 15 in October 2009 to include sites across the GBR (Wet Tropics to Burnett). I_d was first standardized against median I_d for each site. Values are the mean 30-day standardised value of all sites and error bars are standard error among sites*

There was a poor correlation between daily irradiance (I_d) and either change in seagrass percent cover (percent change from post-wet 2010 to post-wet 2011; Figure 19) or total percent cover (post-wet 2011) when compared among all intertidal sites within the GBR. However, there was a strong correlation when comparing among subtidal sites (Figure 19). A number of site features affect total seagrass cover and seagrass dynamics including sediment type, nutrient concentration and the level of physical disturbance. For example Hamilton Island and Dunk Island, both have high daily irradiance at their intertidal sites, but total seagrass cover is typically low compared to intertidal Green Island, and this is probably due to a range of site-specific features (such as those listed above) that are not well understood at a site level. This among-site variability contributes to the poor spatial correlation of seagrass cover and Id. At any individual site, however, changes in light below specific thresholds can relate to either losses or gains of seagrass (see Appendix 1, and Collier et al., 2012), and among subtidal sites. For most sites, there is insufficient light data available to conduct analysis of changes in abundance vs light (as per Collier et al., 2012) at a site level.

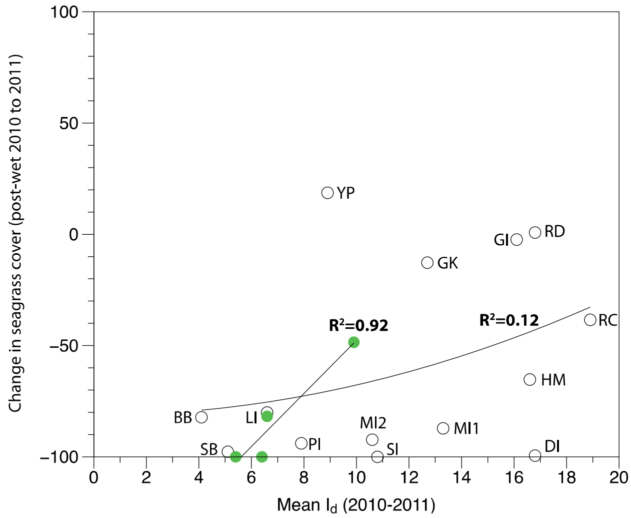


Figure 19. *Change in percent cover (post-wet 2010 to post-wet 2011) and average daily irradiance (I_d) for all monitoring sites (intertidal and subtidal). White circles are intertidal sites, green circles are subtidal sites.*

Light levels in the seagrass canopy have been the lowest in the wet season, when for a number of sites, daily irradiance (I_d) drops below the MLR for seagrasses. At some sites where severe seagrass loss has occurred (e.g. the Burdekin region) I_d have been extremely low (e.g. Bushland Beach and Magnetic Island subtidal).

At most intertidal sites (with some exception) I_d is generally well above MLR for most of the year. The short periods around MLR at many intertidal sites, would suggest that low light was the unlikely cause of seagrass loss. However, seagrass elemental ratios do indicate possible light limitation at many intertidal sites. It is likely that I_d is not the most suitable descriptor for light levels at intertidal sites due to the large contribution of intense high light at low tide. Other descriptors, such as hours of light saturating irradiance, might be more informative for intertidal sites. This requires knowledge of saturating light intensity, which is likely to vary among sites. Furthermore, a greater understanding of how much daytime high light levels contributes to overall productivity is required. We recommend this as a priority area for future research. Some of this is being conducted in Gladstone (DEEDI, unpublished data). Other factors may also contribute to seagrass loss at intertidal sites, such as high temperatures and low salinity both of which occur during the summer wet season.

At a GBR-wide scale, there has been a trend for declining light in seagrass meadows from 2008 to 2011. This downward trend does not appear to be driven by wet season light levels, which have been low in 2009, 2010 and 2011, but rather by conditions during the dry season. The dry season is the time when peak growth rates occur and meadows can recover from earlier impacts. It appears that, ongoing and worsening (with each successive year) low light throughout the year, has been hampering the ability of seagrass meadows to recover following wet season declines in seagrass abundance.

Cape York

2010/11 Summary

The majority of the land in Cape York Peninsula is relatively undeveloped and waters entering the lagoon are perceived to be of a high quality. Only one seagrass location, Archer Point, is monitored in the Cape York region. It is a reef habitat, located in the southern section of the region and seagrass growth is primarily controlled by physical disturbance from waves and swell and associated sediment movement. Seagrass abundance in 2010/11 remained relatively stable to previous monitoring periods, although in a very poor state (Table 14). The extent of the meadows declined near the shore due to the appearance of a drainage channel from an adjacent creek, however a persistent *Halodule uninervis* seed bank, indicates a higher recovery potential to disturbance.

Seagrass leaf tissue nutrient ratios changed little from the pervious year, suggesting the plants were nutrient replete with sufficient light availability for growth. Epiphyte fouling of seagrass leaves remained above the GBR long-term average. Climate in the region (Cooktown) was cooler, wetter, cloudier and calmer than the previous 3-4 monitoring periods, however within canopy temperatures were slightly higher than previous. The higher rainfall resulted in significantly higher flows than the previous 6 years from rivers, which could have impacted the nearby (12 km) seagrass meadows. Fortunately, no herbicides were found above detectable limits in the sediments of the meadows. Overall the status of seagrass condition in the region was rated as **moderate** (Table 14).

Table 14. *Report card for seagrass status (community & environment) for the Cape York region: July 2010 – May 2011 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	15	63	50	**43**
coastal intertidal	*not monitored*			
estuarine intertidal	*not monitored*			
Cape York	15	63	50	**43**

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, however there are several significant catchments which empty into the GBR. 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 from 19.2 – 32.1°C. The prevailing winds are from the south east and persist throughout the year (EarthTech, 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 lagoon is perceived to be of a high quality. Mining, agriculture, shipping tourism and commercial and recreational fishing are the major economic activities. All have potential to expand in this region and with this expansion the possible increase in pollutants.

Of the seagrass habitats types identified for the GBR (Figure 2), Reef Rescue MMP monitoring of intertidal seagrass meadows within this region is on a fringing reef platform. These 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). On fringing-reefs, physical disturbance from waves and swell and associated sediment movement primarily control seagrass growing in these habitats (Figure 20). Shallow unstable sediment, fluctuating temperature, and variable salinity in intertidal regions characterize these habitats. Sediment movement due to bioturbation and prevalent wave exposure creates an unstable environment where it is difficult for seagrass seedlings to establish or persist.

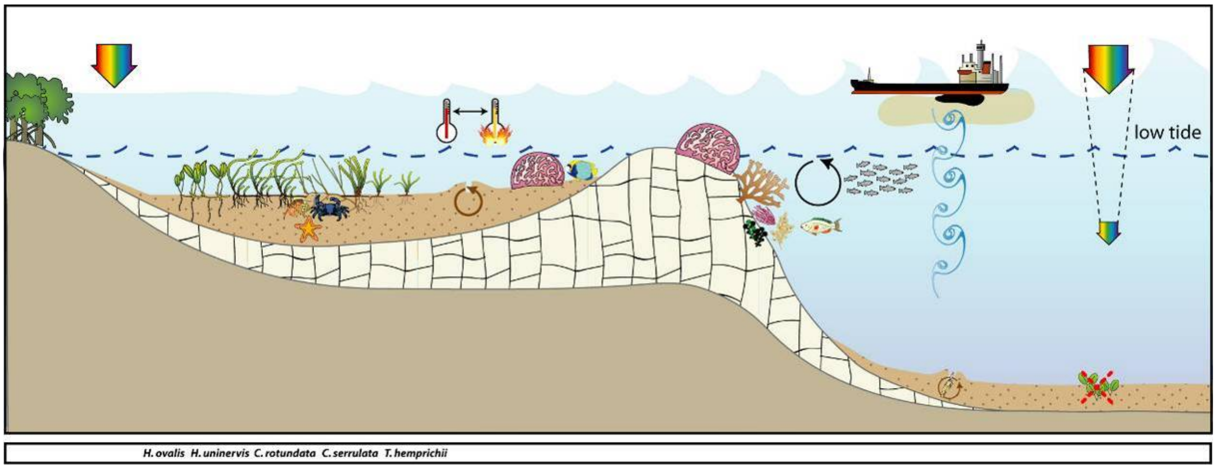


Figure 20. *Conceptual diagram of reef-platform habitat in the Cape York region – major control is pulsed physical disturbance, salinity and temperature extremes: general habitat and seagrass meadow processes (see Figure 4 for icon explanation).*

The monitoring sites at Archer Point were located in a protected section of bay adjacent to Archer Point, fringed by mangroves, approximately 15km south of Cooktown (Figure 22). There are two major rivers within the immediate region: 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 Pearson 1990). The Kuku Yalanji bama are the traditional people connected to country between Mowbray River (Port Douglas) and the Annan River.

Status of the seagrass community

Seagrass abundance and composition

Cape York region reef habitat seagrass cover long-term average was between 15.2% in the dry and 18.4% in late dry season (Figure 21). Seagrass abundance remained stable over the past 12 months at AP1 and decreased at AP2 in the late dry.

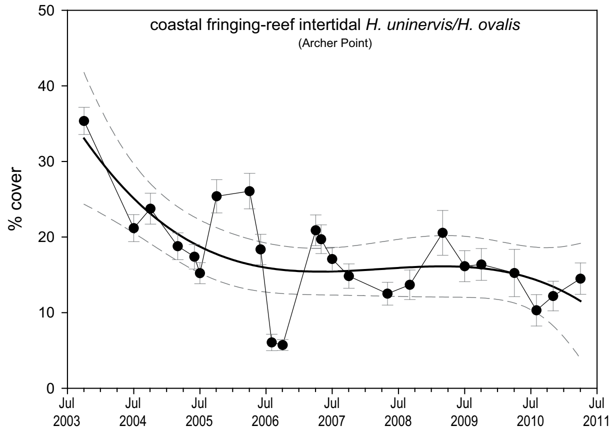


Figure 21. *Seagrass abundance (% cover, ± Standard Error) at Archer Point, inshore fringing-reef habitat (sites pooled). Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.471.*

The Cape York region reef sites were dominated by *Halodule uninervis* and *Halophila ovalis* with varying amounts of *Cymodocea rotundata* (Figure 22). Although sites were only 50m apart, AP2 had slightly more *Cymodocea* and *Thalassia* present. Species composition has varied since sampling began in 2003 with the composition of *Halophila ovalis* fluctuating seasonally with increases in the late monsoon following disturbance followed by deceases when the foundation species (*Halodule* and *Cymodocea*) increase.

Quadrat at 5m on transect 1 at AP1 on 03 November 2010 (left) and 15 April 2011 (right)

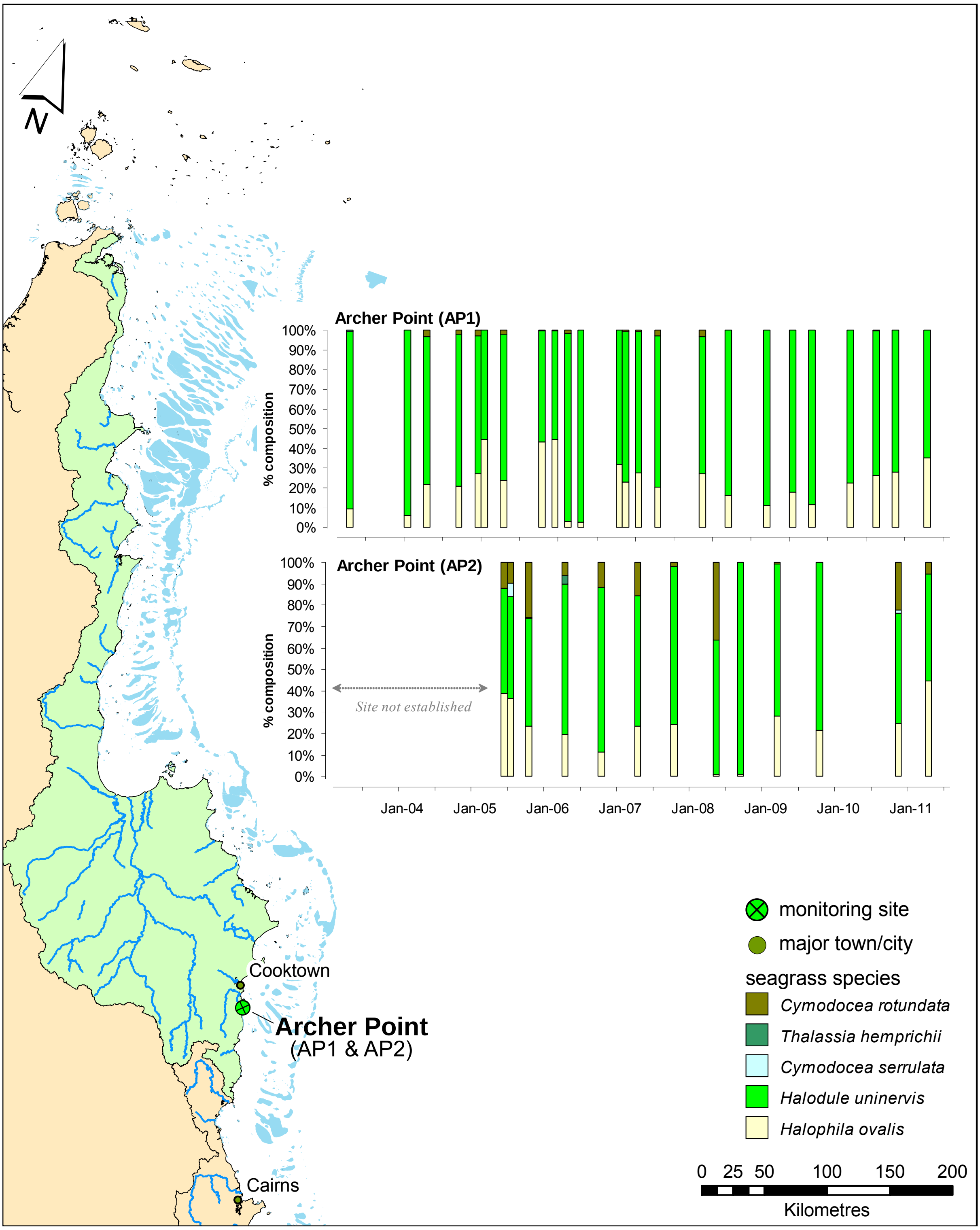


Figure 22. *Location of the Cape York region monitoring sites and seagrass species percent composition at each site since 2003. Please note: replicate sites within 500m of each other.*

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 to monsoon period (Figure 23). The seasonal trend at Archer Point site 2 (AP2) is less apparent.

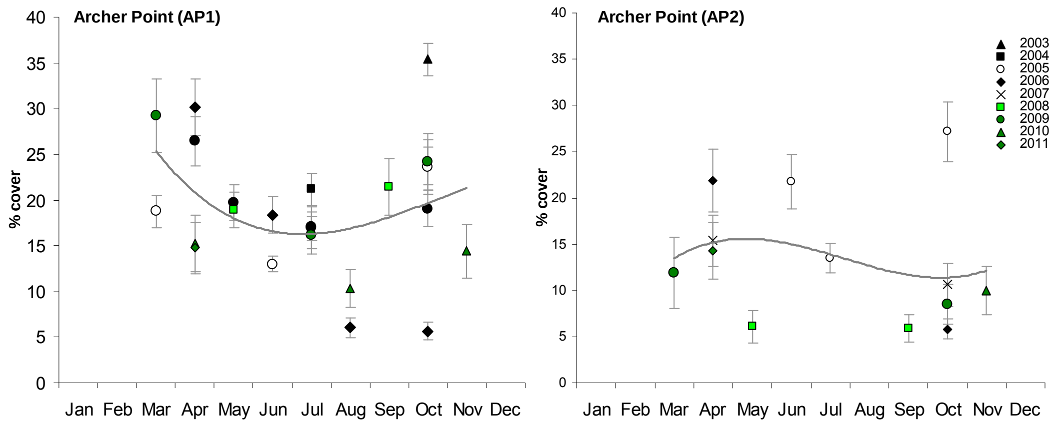


Figure 23. *Mean percentage seagrass cover (all species pooled) (± Standard Error) for inshore fringing-reef long-term monitoring sites in Cape York region at time of year. NB: Polynomial trendline for all years pooled.*

Seagrass meadow edge mapping was conducted within a 100m radius of both monitoring sites in the bay adjacent to Archer Point in October 2010 and April 2011 to determine if changes in abundance were a consequence of the meadow edges changing (**Error! Reference source not found.**, Table 15). Since October 2009, seagrass in the northern section of the bay (AP1) increased shoreward, until late monsoon 2011 (data not presented). The extent of the seagrass meadow in the southern section of the bay (AP2) similarly started to increase, but from October 2010 declined near the shore due to the appearance of a drainage channel from an adjacent creek (data not presented).

Table 15. *Area (ha) of seagrass meadow being monitored within 100m radius of each Archer Point site (AP1 and AP2). Value in parenthesis is % change from October 2005 baseline and description of change from previous mapping. Shading indicates decrease in meadow area since baseline.*

Site	AP1	AP2
October 2005 (baseline)	**3.667**	**3.710**
April 2006	3.330 *(-9.2%, decrease seaward)*	3.139 *(-15.4%, decrease seaward)*
October 2006	3.843 *(4.8%, increase shoreward)*	3.5865 *(-3.3%, increase shoreward)*
April 2007	4.212 *(14.9%, increase shoreward)*	4.0367 *(8.8%, decrease seaward)*
October 2007	4.173 *(13.8%, decrease seaward)*	4.053 *(9.28%, decrease seaward)*
April 2008	3.905 *(6.5%, decrease seaward)*	3.489 *(-5.98%, decrease seaward)*
October 2008	3.88 *(5.7%, decrease seaward)*	3.57 *(-3.73%, increase shoreward)*
April 2009	3.36 *(-8.3%, decrease seaward)*	3.26 *(-12.14%, decrease seaward)*
October 2009	3.70 *(-1%, increase shoreward)*	3.55 *(-4.2%, increase shoreward)*
October 2010	3.97 *(8.4%, increase shoreward)*	3.85 *(5.8%, decrease seaward)*
April 2011	3.85 *(-4.6%, decrease seaward)*	3.52 *(-13.3%, decrease seaward)*

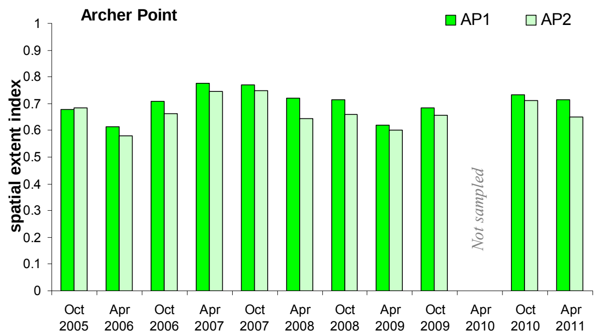


Figure 24. *Extent of area (100m radius of monitoring site) covered by seagrass at each monitoring site.*

Seagrass reproductive status

A persistent *Halodule uninervis* seed bank has been present at the Archer Point monitoring sites (Figure 25), however abundances in 2010/11 were lower in the late dry 2010 than the previous year. The abundance of germinated seeds fluctuates from year to year, but is generally higher in the late monsoon (Figure 25). Total reproductive effort is roughly equivalent to previous seasons and reflects a good status.

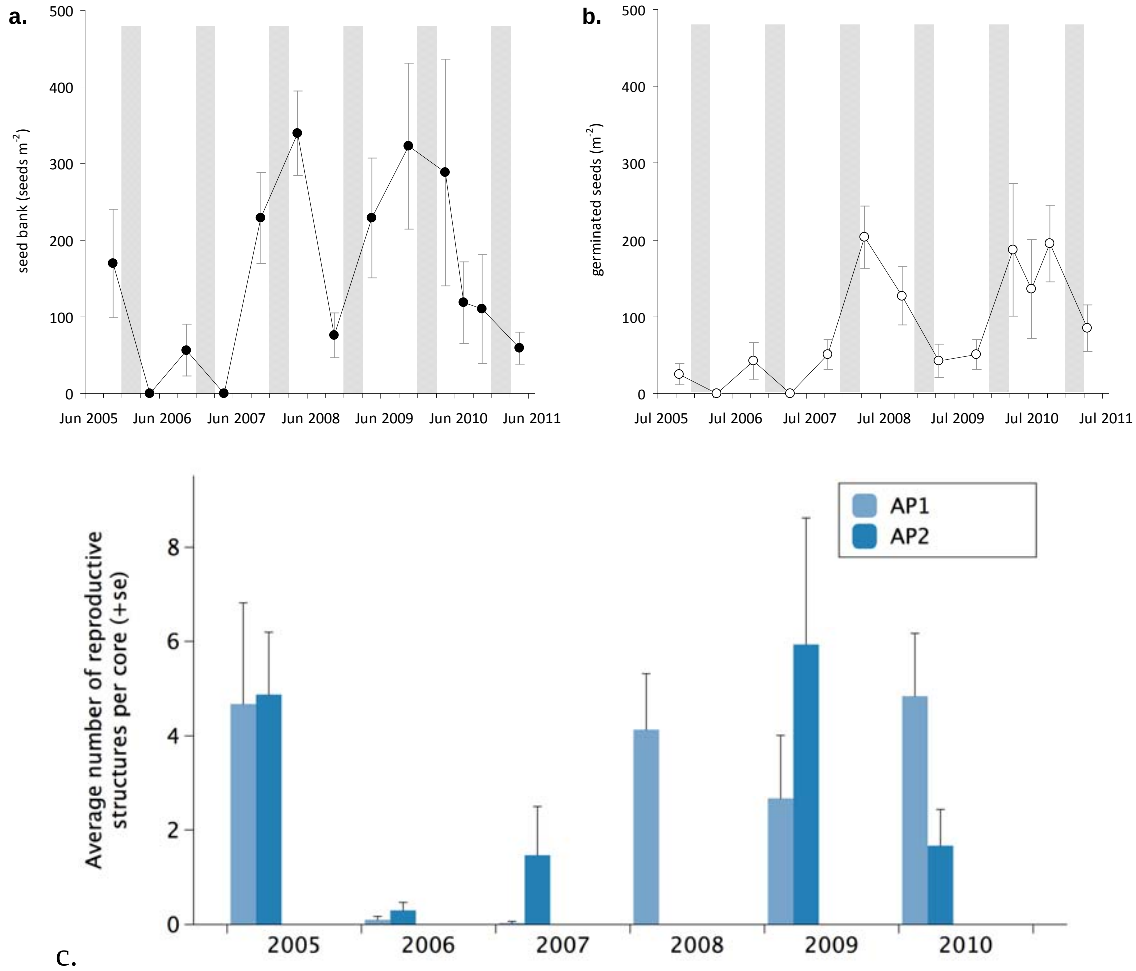


Figure 25. *Halodule uninervis seed bank (a), germinated seed abundance (b) at Archer Point (seed bank is represented as the total number of seeds per m^2 sediment surface) and (c) reproductive effort presented as the average number of reproductive structures per core(all species pooled) for each site sampled during the dry season. Grey bar = monsoon.*

The Cape York region sites, although reefal, are also strongly influenced by coastal processes and have experienced perturbations in recent years. The ongoing presence of reproductive structures indicates a good capacity to recover following disturbance.

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass species in Archer Point in late dry season 2010 all had molar C:N ratios above 20 (Figure 27). There was a slight increase in the C:N ratio in 2010 compared to the previous two monitoring periods, with the average of foundation species increasing above 20.

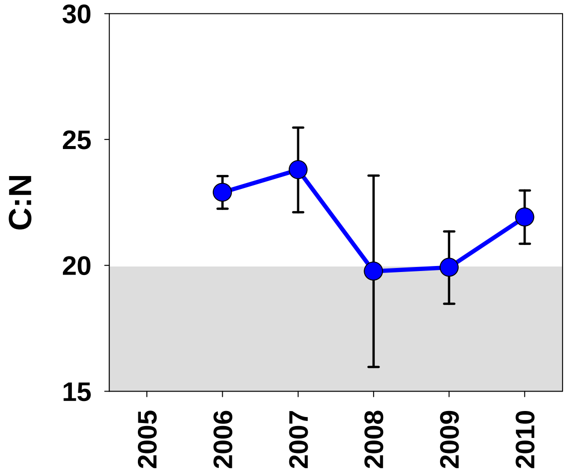


Figure 26. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation species in Cape York region at Archer Point each year (species pooled) (mean and SE displayed). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability.*

C:P ratios in 2009 were >500, indicating that the plants (*Cymodocea rotundata* and *Halodule uninervis*) were growing in an environment with a relatively small P pool, suggesting the habitat to be nutrient poor (Figure 27).

N:P ratios declined since the previous monitoring period. N:P ratios for the foundation species were all below 30, indicating the plants were replete (Figure 27). Results from leaf tissue elemental ratios suggest the habitat to have sufficient light availability, and the level of N may have decreased relative to P since the last monitoring period. Plants now appear to have sufficient nutrients (replete) for growth.

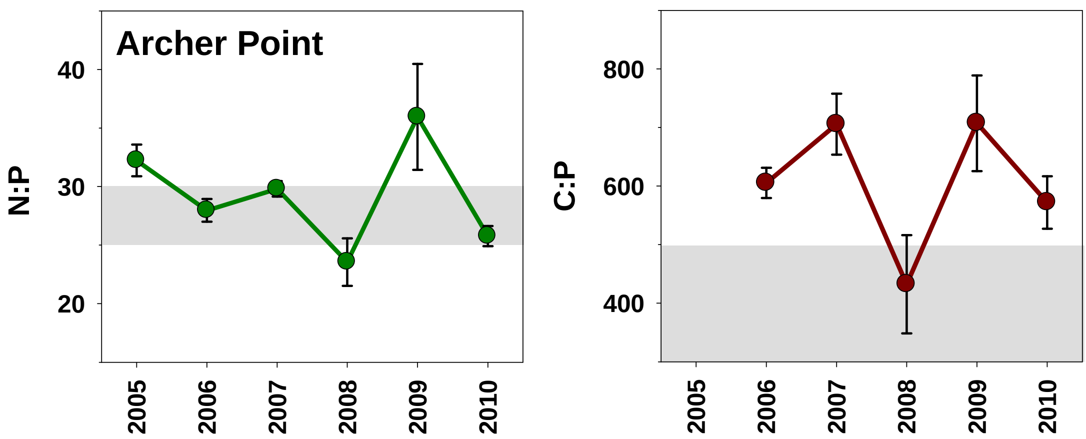


Figure 27. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation species in Cape York region at Archer Point each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith, 1983; Duarte, 1990; Fourqurean et al., 1992; Fourqurean & 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 macro-algae

Epiphyte cover on seagrass leaf blades at Archer Point increased during 2010. Although epiphyte cover decreased by late monsoon 2011, it remained above the GBR long-term average for reef habitats and was similar to when monitoring began in 2003 (Figure 28).

Percentage cover of macro-algae was variable between years, but appears to have declined since 2007. Over the 2010/11 monitoring period, macro-algae cover remained below the GBR long-term average for reef habitats (Figure 28).

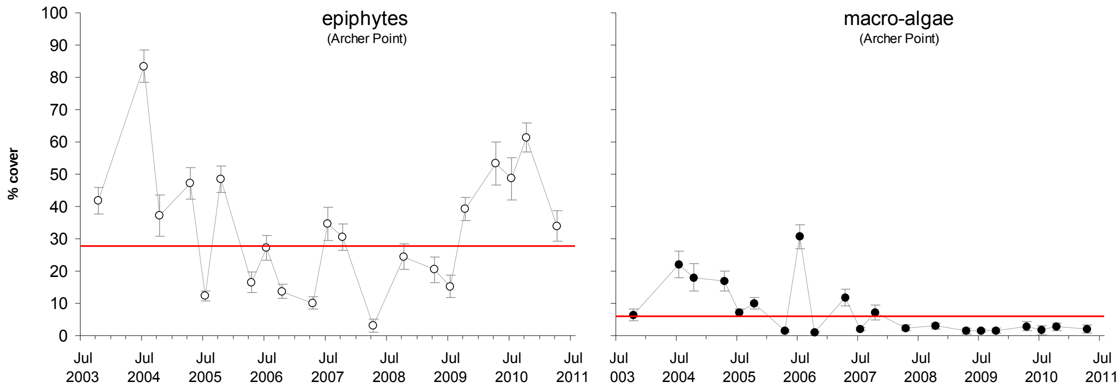


Figure 28. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at Archer Point (sites pooled). Red line = GBR long-term average; epiphytes=25%, macro-algae=3.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows at Sites in the Cape York region (Table 16).

Table 16. *Concentration of herbicides (mg kg^{-1}) in sediments of Archer Point seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
AP1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
AP2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within meadow canopy temperature

Autonomous temperature loggers were deployed at both sites over the monitoring period. High temperatures (>34°C) were recorded from December 2010 to March 2011, coinciding with the low spring tides, with the highest temperature (35.2°C) recorded on 3 December 2010 (Figure 29). Average within meadow canopy temperature since 2007/08 were progressively warmer each monitoring period (not significant, ANOVA, d.f.= 3,34,F=0.26, p =0.8565), with 2010/11 temperatures 0.2°C warmer than the previous year (Figure 30). Maximum within canopy temperatures were not as great in 2010/11 as reported in 2009/10 (Figure 30), indicating that any losses are unlikely to be a consequence of extreme temperature events.

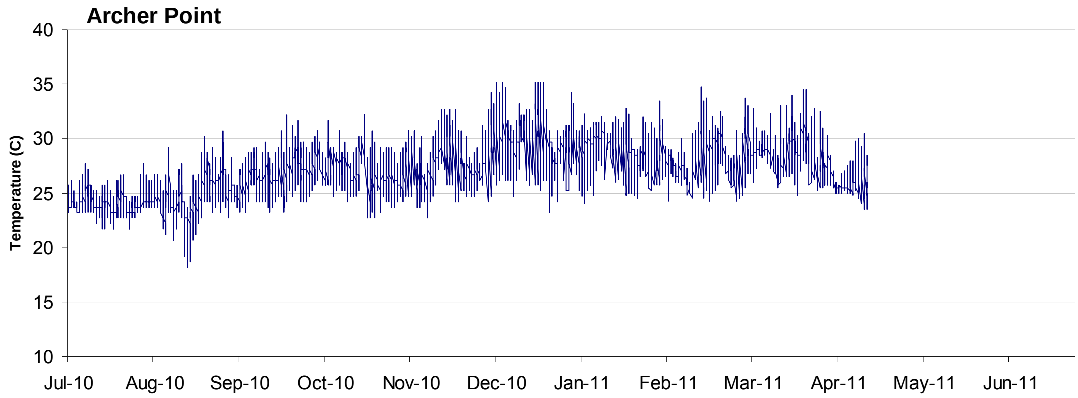


Figure 29. *Within seagrass canopy temperature (°C) at Archer Point intertidal meadow over the 2010/11 monitoring period.*

Figure 30. *Monthly mean and maximum within seagrass canopy temperatures (°C) at Archer Point intertidal meadow, Cape York region.*

Regional Climate

Climate in 2010/11 was cooler, wetter, cloudier and calmer than the previous 3-4 years. The mean maximum daily air temperature recorded in Cooktown during 2010/11 was 31.6°C; this was 2.7°C higher than the 80 year average and 0.7°C cooler than the decade average (Figure 31). The highest recorded daily maximum air temperature in 2010/11 was 35.7 °C.

2010/11 was a wet period, with mean annual monthly rainfall in 2010/11 of 157mm (Figure 31). This was 6% higher than the long-term average of 151mm, and 15% higher than the decadal average. Mean annual monthly cloud cover in 2010/11 was higher than the previous 4 periods, but 3% lower than the 80 year average. Mean monthly wind speed in 2010/11 was 20.8 km.hr^{-1}, this was higher than the 30 year average of 17.9 km.hr^{-1}, but less than the decade average of 21.9 km.hr^{-1}.

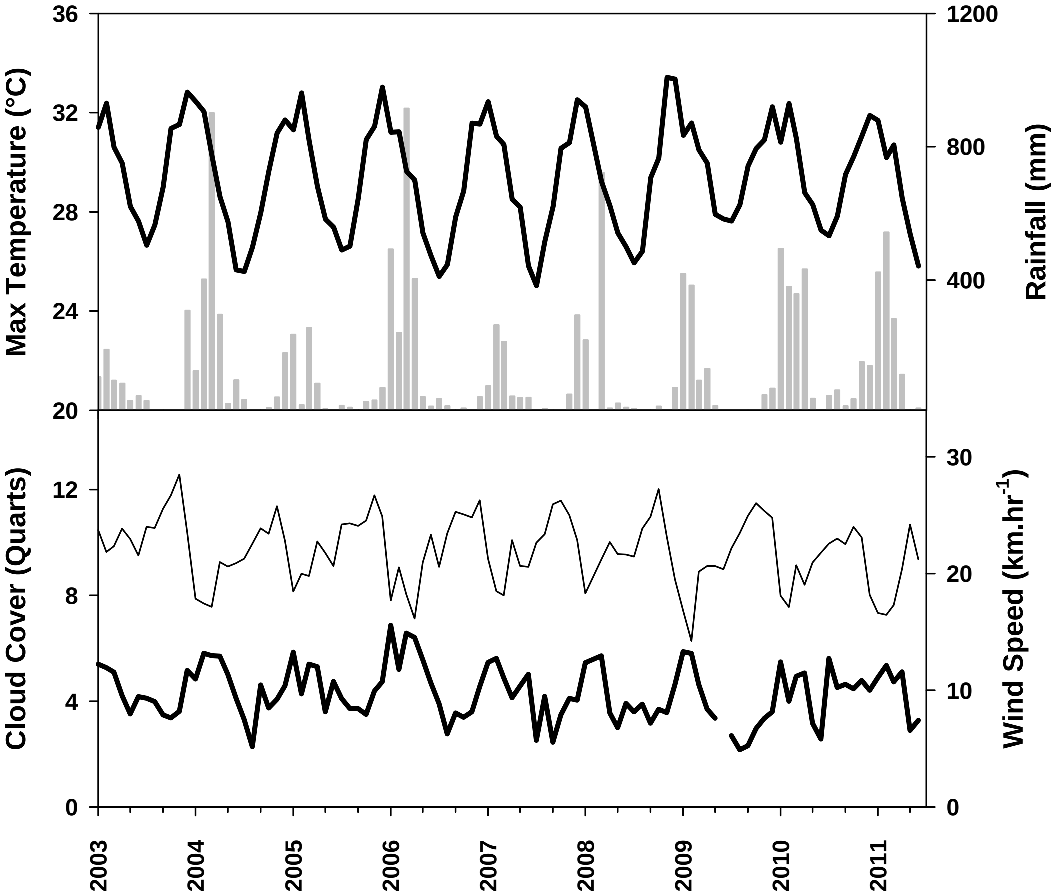


Figure 31. *Mean monthly daily maximum air temperature (°C), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km.hr^{-1}, lighter line) recorded at Cooktown airport (BOM station 031209) (source www.bom.gov.au). Cooktown Airport used as a surrogate for the climate at Archer Point.*

The presence of drainage channels across the intertidal banks, a consequence of the higher rainfall and subsequent discharge from the seasonal creeks, resulted in the decreased of seagrass along the shoreward edge of the meadows at Archer Point. The higher rainfall over the monitoring period also substantially increased the discharge of waters from rivers in the region.

River discharge

The Annan River is the closest river (12km) to the seagrass monitoring sites adjacent to Archer Point, however exposure to elevated Total Suspended Solids, Chlorophyll-*a* and PSII herbicides was rated as low, with a nil probability of exceeding the GBR WQ Guidelines in 2010 (pers. comm. Michelle Devlin, JCU).

As the rainfall in 2010/11 was 15% higher than the decadal average, similarly the resulting discharge from the Annan River was significantly higher than pervious 6 periods (ANOVA, d.f.=12, F=2.83, p=0.002)(Figure 32). The river flow over the monitoring period also peaked for a longer duration (February to April 2011)(Figure 32) and during the 2010 "dry" season (September to November) was higher than usually experienced (Figure 32).

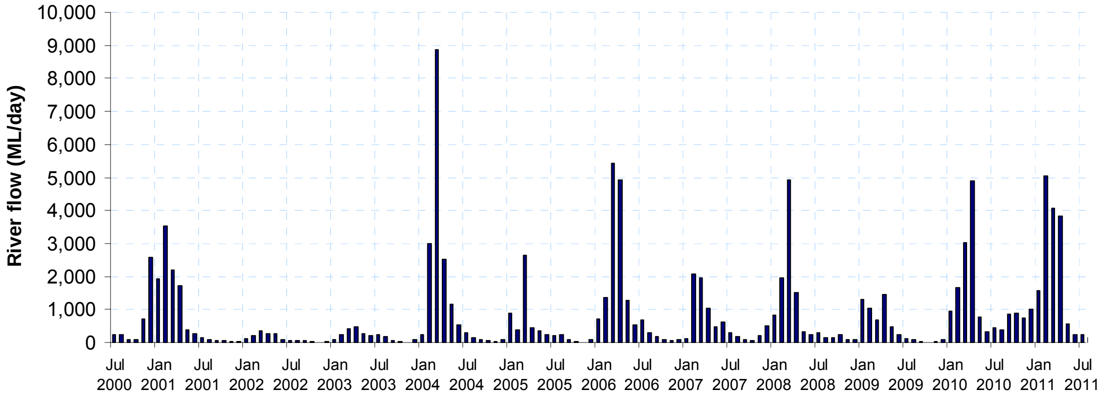


Figure 32. *Average daily flow (ML day^{-1}) per month from the Annan River recorded at Beesbike (DERM station 107003A, 15.68773S, 145.2085 E, Elev:115m) (source The State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

Wet Tropics

2010/11 Summary

The region includes two World Heritage Areas, however increases in intensive agriculture, coastal development and declining water quality have been identified as significant in the region. Seagrass monitoring was conducted on coastal and reef platform 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 nature of the coral sand sediments.

In February 2011, Tropical Cyclone Yasi (category 5) severely impacted the Wet Tropics, in particular the coastal and reef habitats (Mission Beach/Dunk Island area) to the south of the region. Prior to the extreme weather event, seagrass abundance across the Wet Tropics was lower than the previous period and there were some signs of disturbance/recovery with the increase of early colonising species at coastal sites. Post TC Yasi, the seagrass meadows in the south were either completely lost or reduced to scattered isolated shoots by the physical disturbance of the waves resulting in severe erosion or deposition of sediments. In the northern Wet Tropics, the effects of TC Yasi were less apparent, with seagrass abundance either changing little (reef habitat) or increasing substantially (coastal habitat). Similarly, the extent of seagrass in the north either remained similar to previous or increased. Seed banks and reproductive effort decreased below the GBR long-term average, indicating lower recovery potential to disturbances.

Canopy incident light and seagrass leaf tissue nutrient ratios suggest a potentially higher light environment in reef habitats than coastal, as would be expected given the reef habitats are located further from the shore, however lower C:N ratios at all habitats in 2010 indicate decreasing light availability which may be exacerbated by elevated epiphyte fouling (Brush and Nixon, 2002). Most seagrass habitats were nutrient rich or had a large P pool, and overall results suggest poor water quality at Yule Point with low light availability and nutrient loading (elevated N). Macro-algae abundance remained negligible. Although extreme water temperatures were recorded within the seagrass canopy at coastal sites in March 2011, in general, temperatures were cooler than the previous year. Climate across the region was on average wetter, cloudier and calmer in 2010/11 than the previous decade. The increase in rainfall resulted in the highest flows and discharges from rivers across the region in over a decade. The potentially exposure of the seagrass to elevated TSS, Chlorophyll-*a* and PSII herbicides in flood waters was rated as high for most of the monitoring sites, although reef habitats in the north would be exposed to TSS at a lesser extent and reef habitats in the south exposed to Chlorophyll-a and PSII herbicides at high extent. No herbicides were found above detectable limits in the sediments of the seagrass meadows. Overall the status of seagrass in the region was rated as **poor**.

Table 17. *Report card for seagrass status (community & environment) for the Wet Tropics region: Sept 2009 – May 2010. 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	25	19	42	**29**
coastal intertidal	46	0	7	**18**
estuarine intertidal	*not monitored*			
Wet Tropics	36	9	24	**23**

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 (Australian Government Land and Coasts 2010a). Other uses within the region include fisheries, mining and tourism. Declining water quality, due to sedimentation combined with other forms of pollutants, the disturbance of acid sulphate soils, and point source pollution have been identified as a major concern to the health of coastal estuary and marine ecosystems of which seagrass meadows are a major component (FNQ NRM Ltd and Rainforest CRC 2004). Two types of seagrass habitats are monitored in the region: coastal and reef.

Reef Rescue monitoring occurs at two coastal seagrass habitat locations: Yule Point, in the north and Lugger Bay in the south of the region. The seagrass meadows at Yule Point and Lugger Bay are located on naturally dynamic intertidal sand banks, protected by fringing reefs. These meadows are dominated by *Halodule uninervis* with some *Halophila ovalis* and are often exposed to regular periods of disturbance from wave action and consequent sediment movement. The sediments in these locations are relatively unstable restricting seagrass growth and distribution. A dominant influence of to these coastal meadows is terrigenous runoff from seasonal rains (Figure 33). The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these monitored meadows.

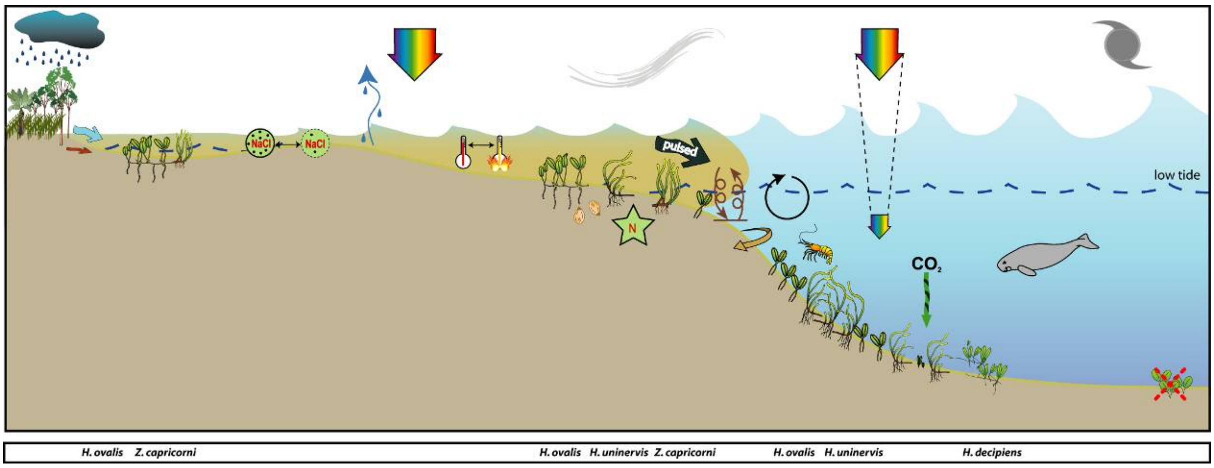


Figure 33. *Conceptual diagram of coastal habitat (<15m) in the Wet Tropics region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation).*

Monitoring of reef habitats occurs at two locations: Green Island and Dunk Island. Monitoring at Green Island occurs on the large intertidal reef-platform south west of the cay. The meadow is dominated by *Cymodocea rotundata* and *Thalassia hemprichii* with some *Halodule uninervis* and *Halophila ovalis*.

Shallow unstable sediment, fluctuating temperature, and variable salinity in intertidal regions characterize these habitats. Physical disturbance from waves and swell and associated sediment movement primarily control seagrass growing in these habitats (Figure 34). 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 types of carbonate sediments the primary limiting nutrient for seagrass growth is generally phosphate (Short *et al.,* 1990; Fourqurean *et al*., 1992; Erftemeijer and Middelburg 1993). This is due to the sequestering of phosphate by calcium carbonate sediments. In this region seagrass meadows inhabiting the near shore inner reefs and fringing reefs of coastal islands inhabit a mixture of terrigenous and carbonate sediments, such as Green Island. Seagrasses at this location in the 1990's were shown to be nitrogen limited (Udy *et al.* 1999).

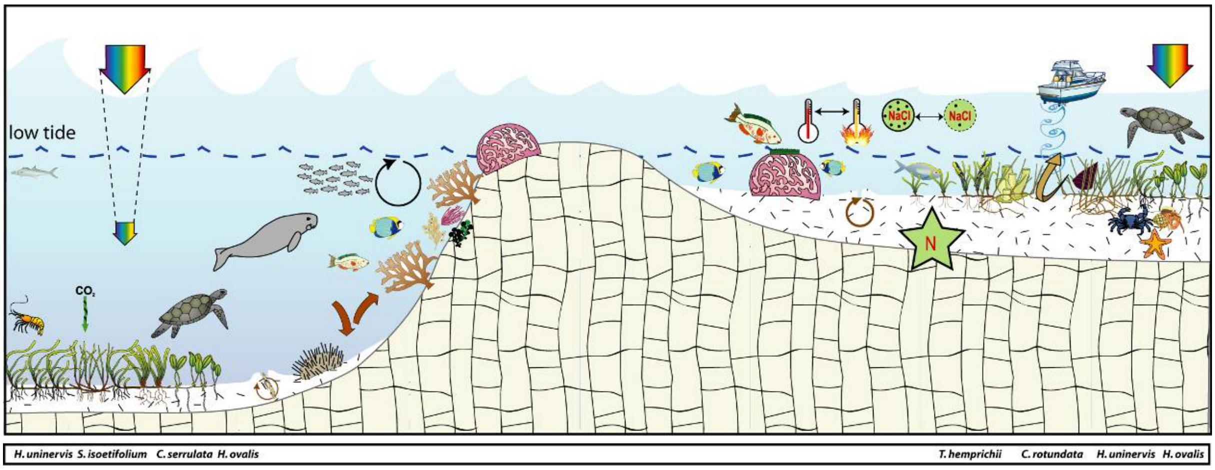


Figure 34. *Conceptual diagram of reef habitat (<15m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing: general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation).*

Status of the seagrass community

Seagrass abundance and composition

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 35).

Over the 2010/11 monitoring period, *Halophila ovalis* dominated the species composition for Yule Point site 1 (YP1) (Figure 35). As *H. ovalis* is an generally considered an early colonising species, this suggests that the site was greatly impacted/disturbed and was possibly in recovery mode. Species composition at Yule Point site 2 (YP2) however remained relatively stable. Overall, seagrass cover at Yule Point during the 2010/11 monitoring period was lower than expected in the late dry season when abundances typically reach their peak, but increased substantially in the monsoon and late monsoon (Figure 36).

The Lugger Bay meadow was only exposed as very low tides (<0.4m), and only *Halodule uninervis* occurs within the sites (Figure 35). Seagrass meadows at Lugger Bay have fluctuated greatly since monitoring was established in late 2004, primarily from acute disturbances (TC Larry in 2006). Seagrass cover declined in early 2010 and was completely lost in early 2011 following TC Yasi (Figure 36) (Appendix 1).

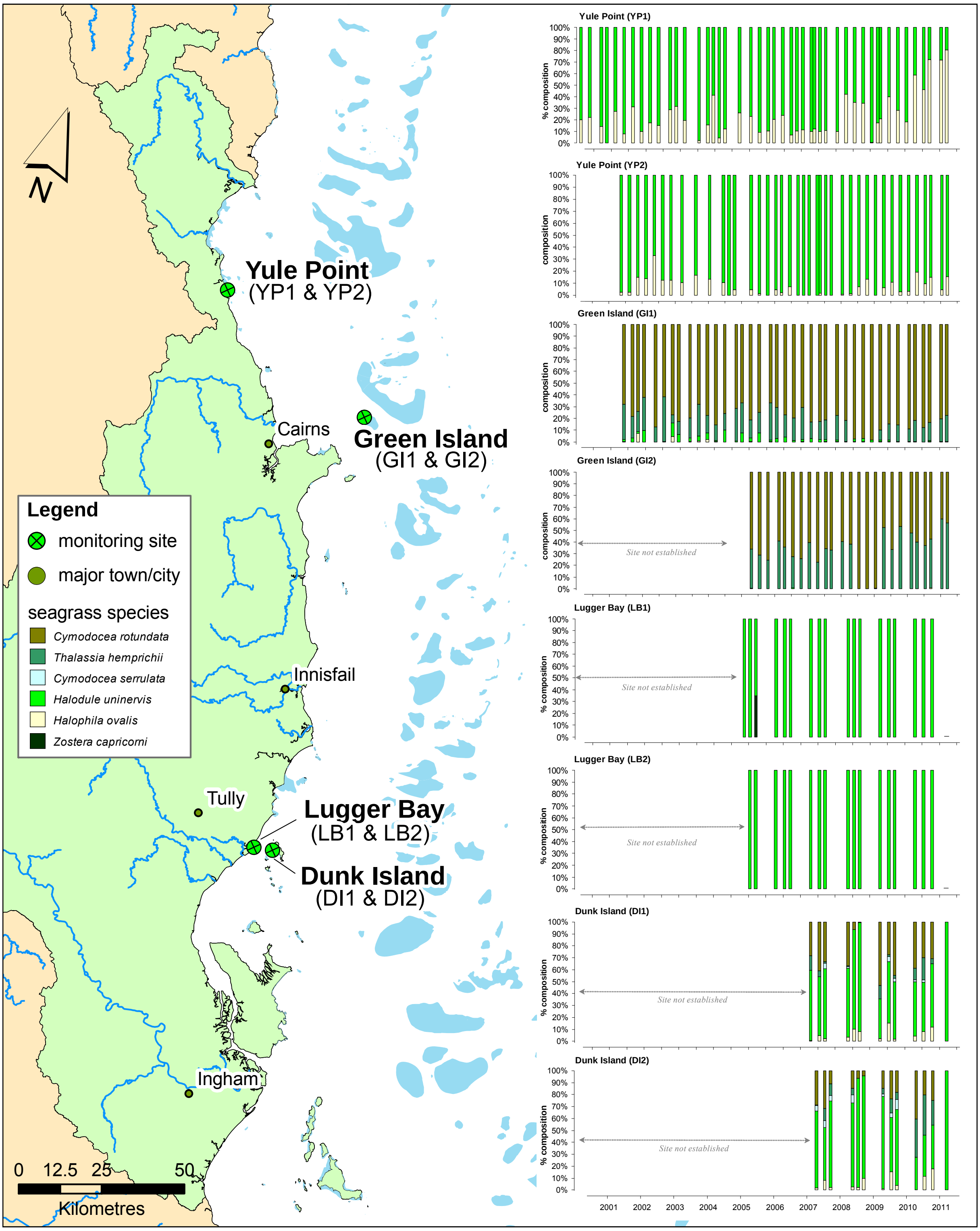


Figure 35. *Location of Wet Tropics region long-term monitoring sites and seagrass species composition at each site. Please note: replicate sites within 500m of each other.*

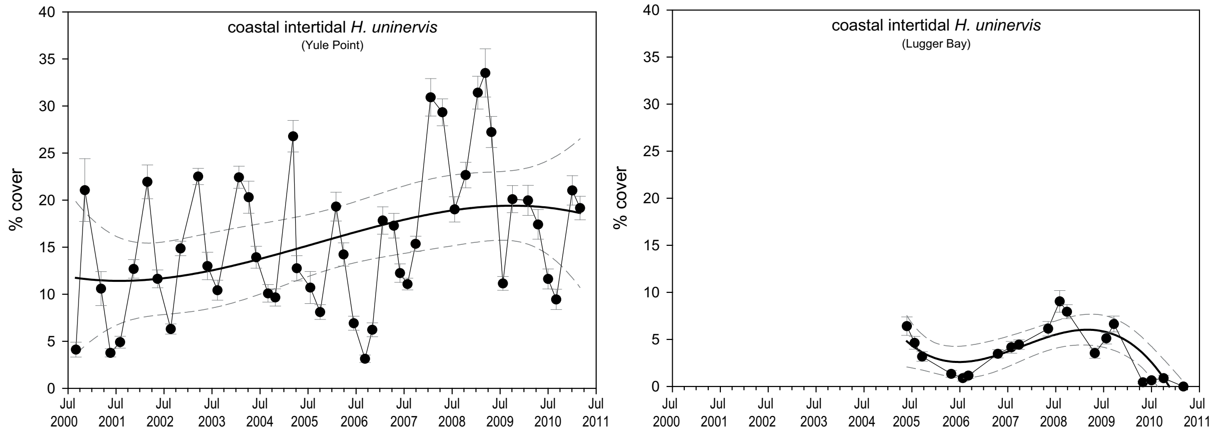


Figure 36. *Changes in seagrass abundance (% cover ±Standard Error) of coastal intertidal Halodule uninervis meadows monitored in the Wet Tropics region from 2000 to 2011. Trendline is 3rd order polynomial (95% confidence intervals displayed) where Yule Pt r^2 = 0.154 and Lugger Bay r^2 = 0.587)*

Quadrat at 5m on transect 1 at Yule Point site 1 (YP1), on 22 September 2010 (left) and 21 March 2011 (right)

Seagrass cover over the past 12 months at Yule Point continued to follow a seasonal trend with higher abundance over the period from late dry to late monsoon (Figure 37).

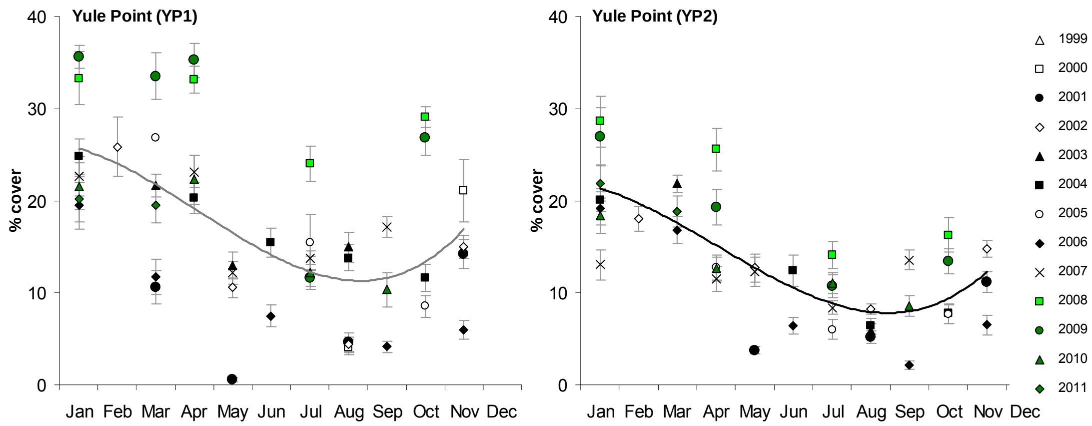


Figure 37. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Yule Point long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Dugong grazing trails at Yule Point site 2 (YP2): 21 January 2011 (L) and 03 March 2011 (R)

Although seagrass cover at Lugger Bay in 2010 was very low (<5%), seagrass abundance since monitoring was established has generally followed a seasonal pattern with abundances increasing throughout the year until the monsoon (Figure 38).

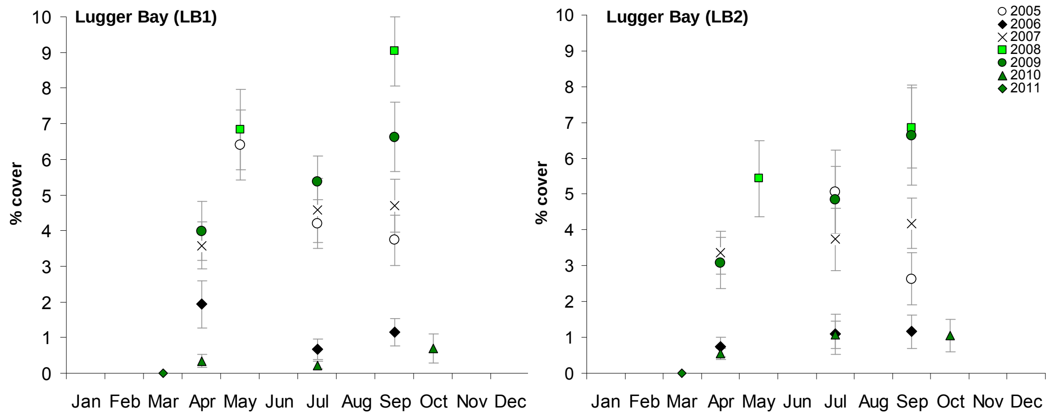


Figure 38. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Lugger Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Post TC Yasi, an aerial reconnaissance of intertidal banks from Lucinda to Mourilyan Harbour in the south of the region (20th March 2011) reported an estimated 2,350 ha of intertidal seagrass was no longer present as meadows and only isolated plants remain (Appendix 1). The intertidal banks examined within the region all showed evidence of physical disturbance (sediment erosion or deposition).

Although not monitored within the Reef Rescue MMP in the Wet Tropics region, estuarine seagrass was also reported in decline from Cairns and Mourilyan Harbours in late 2010 (Fairweather et al., 2011a; Fairweather et al., 2011b). Their condition post TC Yasi and associated flooding is unknown.

Green Island and Dunk Island sites were on offshore reef platforms. Dunk Island is a continental island offshore from Mission Beach. Seagrass species at Dunk Island sites included *H. uninervis* and *C. rotundata* with *T. hemprichii H. ovalis* and *C. serrulata* (Figure 35). Green Island is on a mid shelf reef, approximately 27 km north east of Cairns. The sites are located on the reef platform south west of the cay and dominated by *C. rotundata* and *T. hemprichii* with some *H. uninervis* and *H. ovalis* (Figure 35).

Seagrass abundance at Green Island has slightly declined over the past 5 years and although changed little throughout the 2010/11 monitoring period, it appeared to follow a seasonal pattern, with high cover in the monsoon and low cover in the dry; no substantial changes in species composition were observed (Figure 35, Figure 39 and Figure 40). Conversely, seagrass abundance at Dunk Island has been declining since 2009 and was nearly completely lost in early 2011 following TC Yasi (Appendix 1) when the meadow was reduced to a few isolated shoots (Figure 35, Figure 39). Since monitoring was established at Dunk Island, seagrass abundance has generally followed a seasonal pattern with abundances decreasing during the senescent season in the middle of the year (Figure 41).

Seagrass meadows on the reef platforms at Green Island, 20 January 2011 (L) and Dunk Island, 18 March 2011 (R).

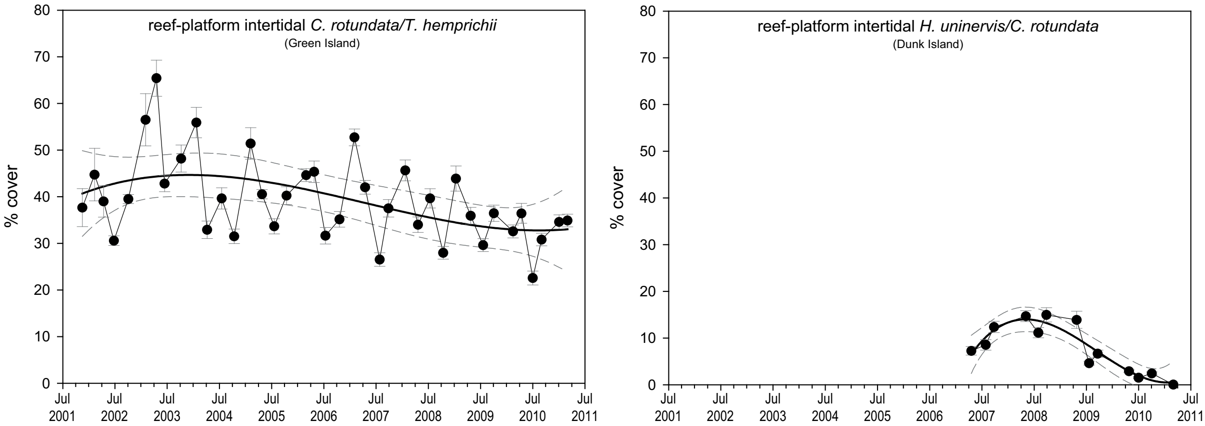


Figure 39. *Changes in seagrass abundance (% cover ±Standard Error) of reef intertidal meadows monitored in the Wet Tropics region from 2001 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, where Green Island r^2 = 0.249 and Dunk Island r^2 = 0.866.*

Quadrat at 25m, transect 3 at Green Island site 1 (GI1): 21 October 2010 (L) and 17 March 2011 (R).

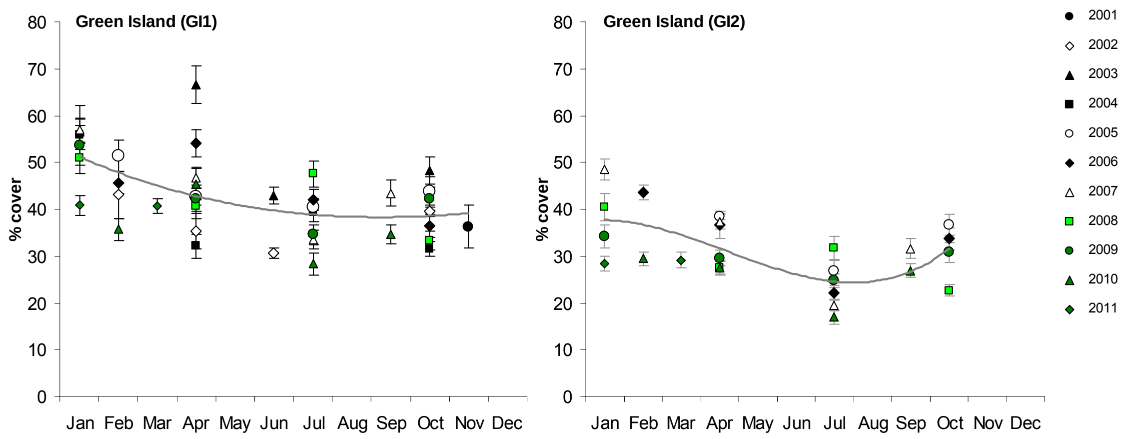


Figure 40. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Green Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Quadrat at 5m on transect 3 at Dunk Island site 1 (DI1): 10 July 2010 (L) and 18 March 2011 (R).

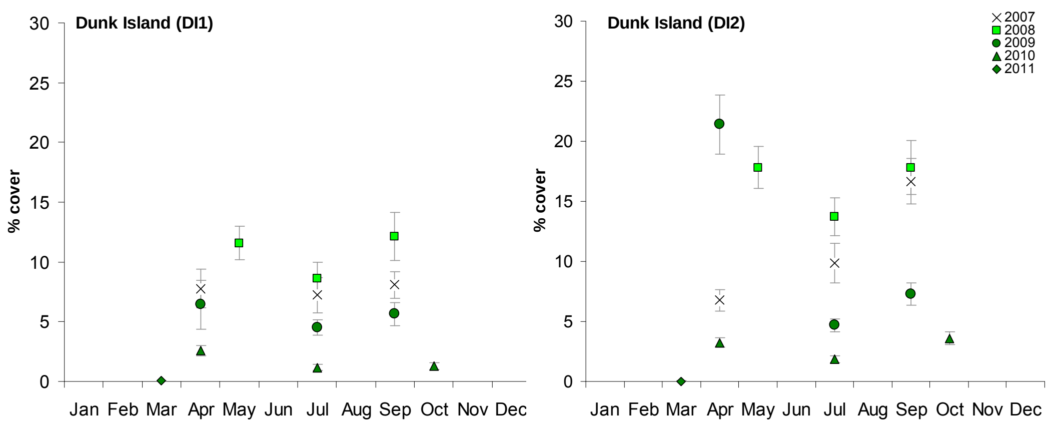


Figure 41. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Dunk Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

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 (Table 18). Over the 2010/11 monitoring period, the distribution of seagrass continued to increase across the intertidal banks at both sites. The drainage channels reported in the previous monitoring period persisted through part of Yule Point site 2 (YP2) (data not presented), however it had little impact (Figure 42). At Lugger Bay, the distribution of the seagrass meadow decrease throughout 2010, and then was completely lost during the monsoon 2011 after Tropical Cyclone Yasi (Table 18) (Figure 43).

There were no detectable differences in the seagrass meadow edges at Green Island over the 2010/11 monitoring period, however at Dunk Island the meadow which was increasing in 2010, was also severely impacted by TC Yasi with only a few isolated shoots remaining (Table 18, Figure 43).

Table 18. *Area (ha) of seagrass meadow within 100m radius of each site. Value in parenthesis is % change from baseline and description of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.*

	Yule Pt		**Green Island**		**Lugger Bay**		**Dunk Island**	
	YP1	**YP2**	**GI1**	**GI2**	**LB1**	**LB2**	**DI1**	**DI2**
October 2005 (baseline)	**1.326**	**3.596**	**5.257**	**4.632**	**1.675**	**1.801**	*NA*	*NA*
April 2006	1.789 *(34.9% increase shoreward)*	4.120 *(14.6% increase shoreward)*	5.319 *(1.2%, increase shoreward)*	4.647 *(0.3%, negligible)*	1.085 *(-35.2%, decrease landward)*	1.448 *(-19.6%, decrease landward)*	*NA*	*NA*
October 2006	1.768 *(33.3% decrease overall)*	3.697 *(2.8% decrease seaward)*	5.266 *(0.2% decrease seaward)*	4.674 *(0.9%, negligible)*	0.453 *(-73%, decrease overall)*	0.561 *(-68.8%, decrease overall)*	*NA*	*NA*
April 2007	2.452 *(84.9% increase overall)*	3.735 *(3.9% increase shoreward)*	5.266 *(0.2%, no change)*	4.605 *(-0.6%, negligible)*	0.953 *(-43.1%, increase overall)*	1.167 *(-35.2%, increase overall)*	**3.278**	**3.972**
October 2007	3.08 *(132.3%, increase overall)*	4.422 *(23%, increase overall)*	5.266 *(0.2%, no change)*	4.674 *(0.9%, negligible)*	1.183 *(-29.4% increase overall)*	1.6 *(-11.2% increase shoreward)*	3.479 *(6.1% increase overall)*	4.19 *(5.5% increase overall)*
April 2008	2.861 *(115.8%, decrease overall)*	4.724 *(31.9%, increase overall)*	5.32 *(1.2% increase shoreward)*	4.66 *(0.6%, negligible)*	1.046 *(-37.6% decrease seaward)*	1.442 *(-19.9% decrease seaward)*	3.36 *(2.5% decrease shoreward)*	4.425 *11.4% increase overall)*
October 2008	2.910 *(119.4%, decrease shoreward)*	4.432 *(23.2%, decrease overall)*	5.298 *(0.8%, no change)*	4.682 *(1.1%, negligible)*	1.607 *(-4.1% increase overall)*	1.945 *(8.0% increase shoreward)*	3.393 *(3.5% increase overall)*	4.332 *(9.1% decrease overall)*
April 2009	2.463 *(85.7%, decrease overall)*	4.712 *(31.0%, increase overall)*	5.316 *(1.1% negligible)*	4.703 *(1.5%, negligible)*	1.218 *(-27.3% decrease seaward)*	1.655 *(-8.1% decrease seaward)*	3.34 *(1.9% decrease shoreward)*	4.420 *(11.3% increase overall)*
October 2009	2.249 *(-69.6%, decrease seaward)*	4.645 *(-29.2%, negligible)*	5.288 *(0.5%, no change)*	4.671 *(0.9%, no change)*	1.256 *(25% increase overall)*	1.567 *(-13% decrease shoreward)*	3.412 *(4.1% increase overall)*	4.371 *(-10% negligible)*
April 2010	1.634 *(23.2%, decrease overall)*	4.464 *(-24.1%, decrease overall)*	5.345 *(1.6% negligible)*	4.675 *(0.9%, no change)*	0.464 *(-72.3% decrease overall)*	0.464 *(-74.2% decrease overall)*	3.398 *(-3.6% no change)*	4.179 *(-5.2% decrease shoreward)*
October 2010	1.665 *(25.6%, increase overall)*	4.243 *(-18%, increase overall)*	5.285 *(0.5% %, no change)*	4.612 *(-0.4%, no change)*	0.151 *(-91% decrease overall)*	0.151 *(-91.6% decrease overall)*	3.429 *(4.5%, increase overall)*	4.282 *(7.8% increase overall)*
April 2011	1.773 *(33.7%, increase overall)*	4.367 *(22.5%, increase overall)*	5.279 *(0.4% %, no change)*	4.614 *(-0.4%, no change)*	0 *(-100%, loss of meadow)*	0 *(-100%, loss of meadow)*	0 *(-100%, loss of meadow)*	0.013 *(-99.7% isolated patches)*

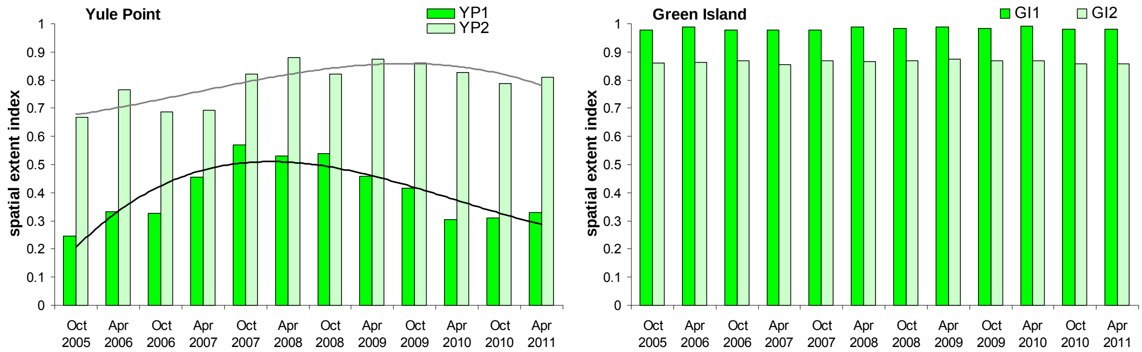


Figure 42. *Extent of area (100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Cairns locations (northern Wet Tropics region).*

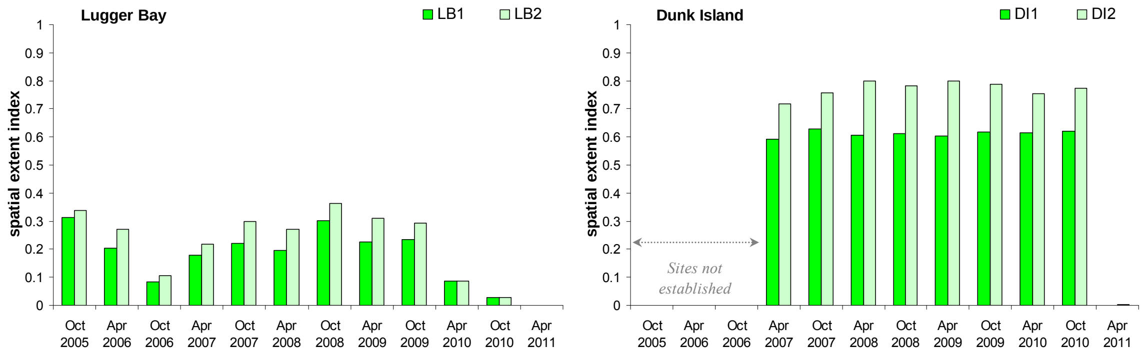


Figure 43. *Extent of area (100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Mission Beach locations (southern Wet Tropics region).*

Seagrass reproductive status

Seed banks and general reproductive effort across the region declined over the monitoring periods (Figure 44, Figure 45). The most substantial decline in reproductive effort was observed in the sites associated with the Barron River (Green Island and Yule Point, Figure 44). The decline in reproductive effort is not associated with a loss in meadow area (see above), but does appear coincident with the lowest cover values at Yule Point in recent years. This may reflect the more chronic ongoing loss of meadow condition at these sites which are generally in better state than those further south.

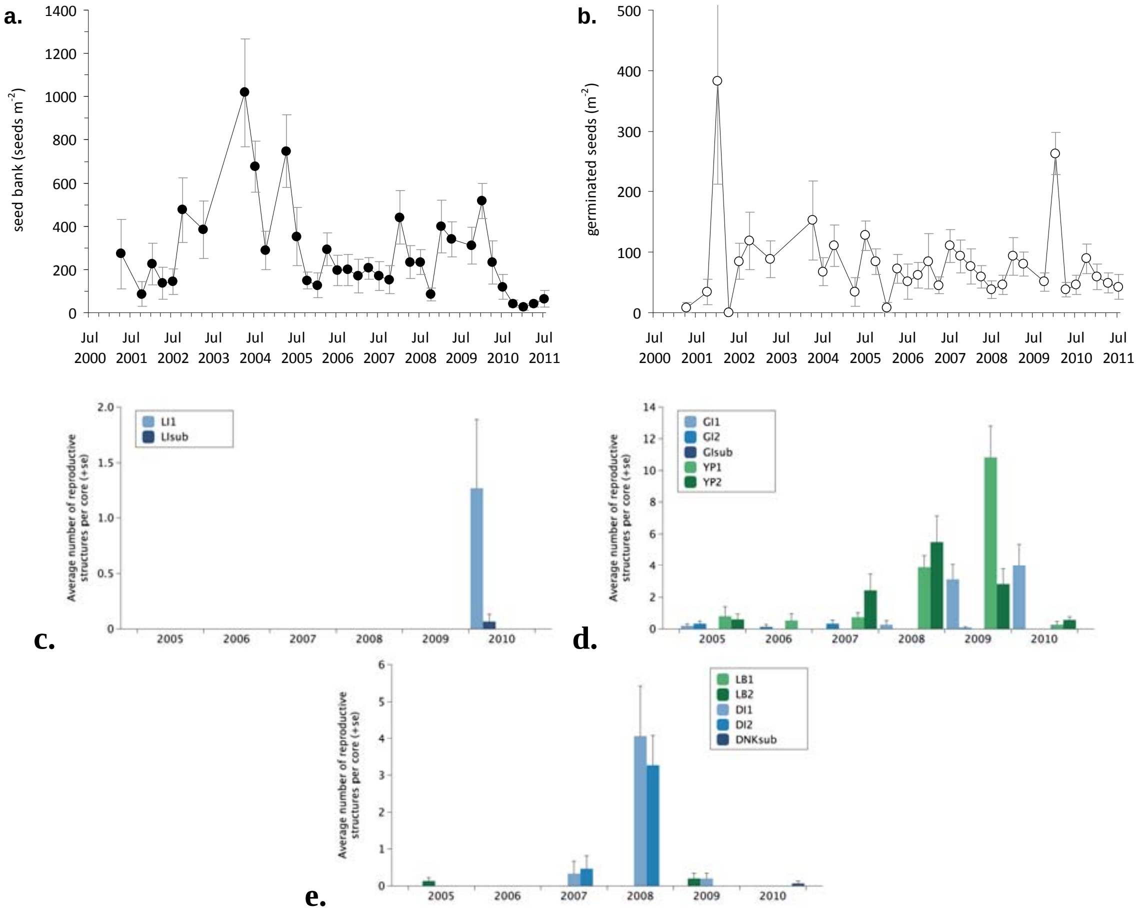


Figure 44. *Halodule uninervis seed bank (a) and germinated seed abundance (b) at coastal habitats in the Wet Tropics region (seed bank is represented as the total number of seeds per m^2 sediment surface) (c, d, e) reproductive effort of sites grouped by catchment influence, presented as the average number of reproductive structures per core for each site sampled during the dry season.*

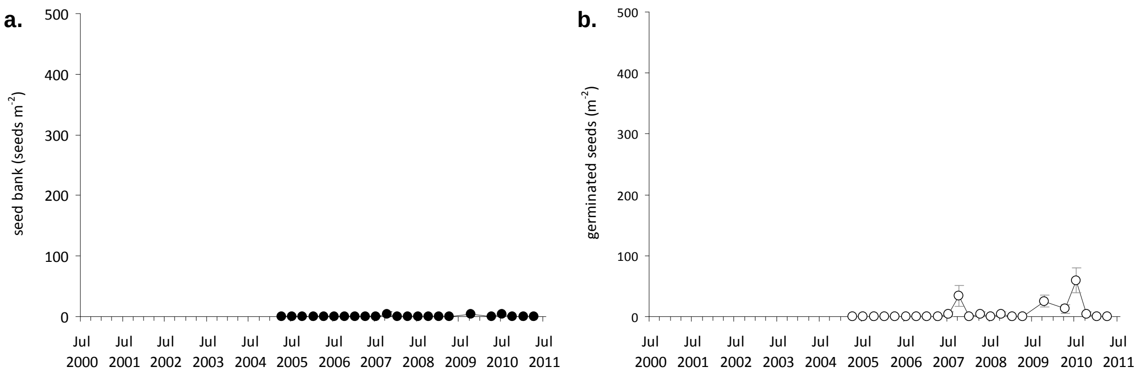


Figure 45. *Halodule uninervis seed bank (a) and germinated seed abundance (b) at reef habitats in the Wet Tropics region (seed bank is represented as the total number of seeds per m^2 sediment surface).*

Reproductive effort across the whole Wet Tropics region is classified as very poor. This suggests that sites within the region will take longer to recover following disturbance and may be at risk from repeated impacts.

Status of the seagrass environment

Seagrass tissue nutrients

Within the Wet Tropics region, seagrasses in reef environments (Dunk Island and Green Island) had higher C:N ratios than those in coastal environments (Yule Point and Lugger Bay) (Figure 46). This indicates a potentially higher light environment in reef habitats and possibly lower N loading. In 2010, C:N ratios were lower in all seagrass habitats than reported in 2009. Levels of the C:N ratio below 20 may be considered as indicative of environments where light may be limiting to growth.

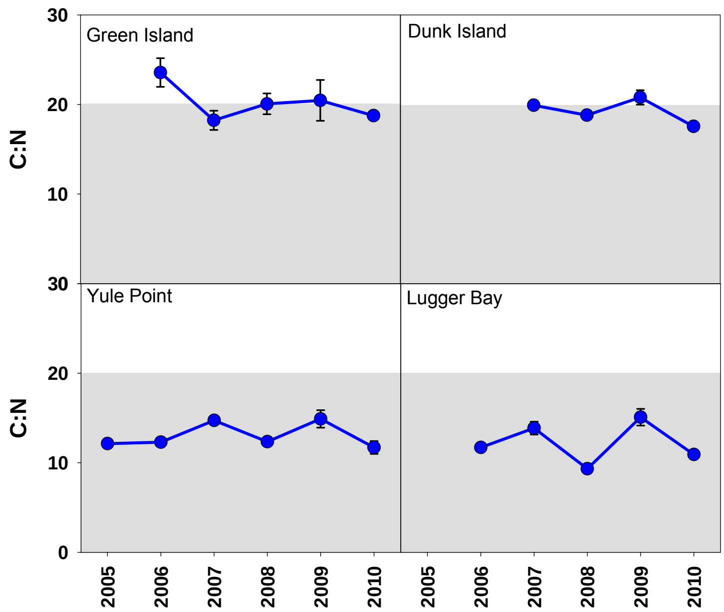


Figure 46. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each location in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line indicate reduced light availability.*

The late dry 2010, C:P ratios of the foundation seagrass species at Green Island, Yule Pt and Lugger Bay were all below 500; indicating these sites were nutrient rich or had a large P pool (Figure 47). Values below 500 were consistently recorded at Lugger Bay since monitoring was established in 2008, indicating a nutrient rich environment. The N:P ratios of the foundation seagrass species at reef habitats in 2010 indicated environments were replete. N:P ratios of the foundation seagrass species at coastal habitats declined in 2010, with Lugger Bay (in the south) becoming N-limited in 2010, and Yule Point remaining P-limited in 2010 (Figure 47). Overall results suggest poor water quality at Yule Point with low light availability and higher nutrient loading (elevated N).

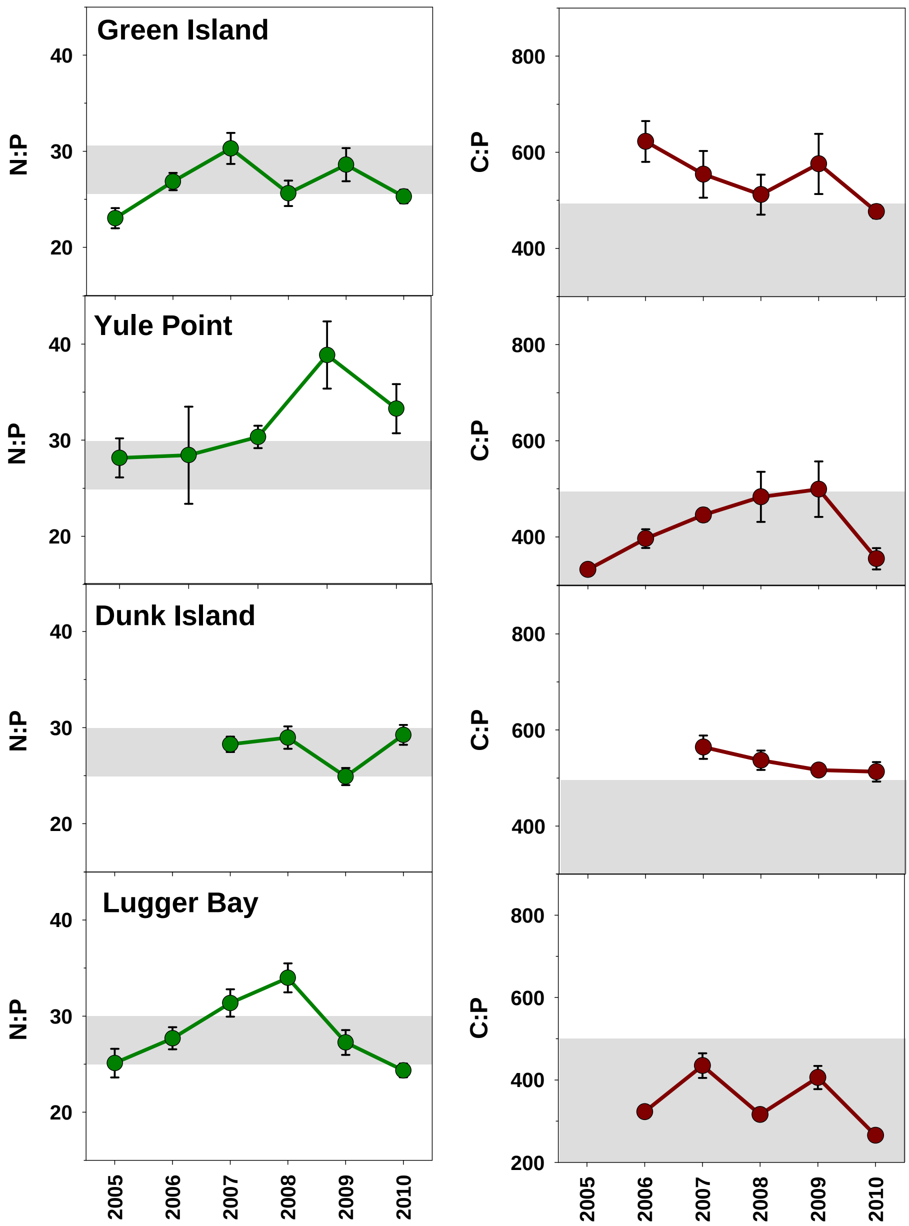


Figure 47. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith, 1983; Duarte, 1990; Fourqurean et al., 1992; Fourqurean & 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 macro-algae

Epiphyte cover on seagrass leaf blades at coastal sites was variable (Figure 48) and appears to fluctuate seasonally with higher value generally in the monsoon and late monsoon. Epiphyte cover has continued to remain high and predominately above the GBR long-term average at Yule Point over the last 3-4 years (Figure 48). At Lugger Bay however, the highly variable epiphyte cover has remained below the GBR long-term average (Figure 48). Percentage cover of macro-algae at coastal sites was consistently lower than the GBR long-term average (Figure 48).

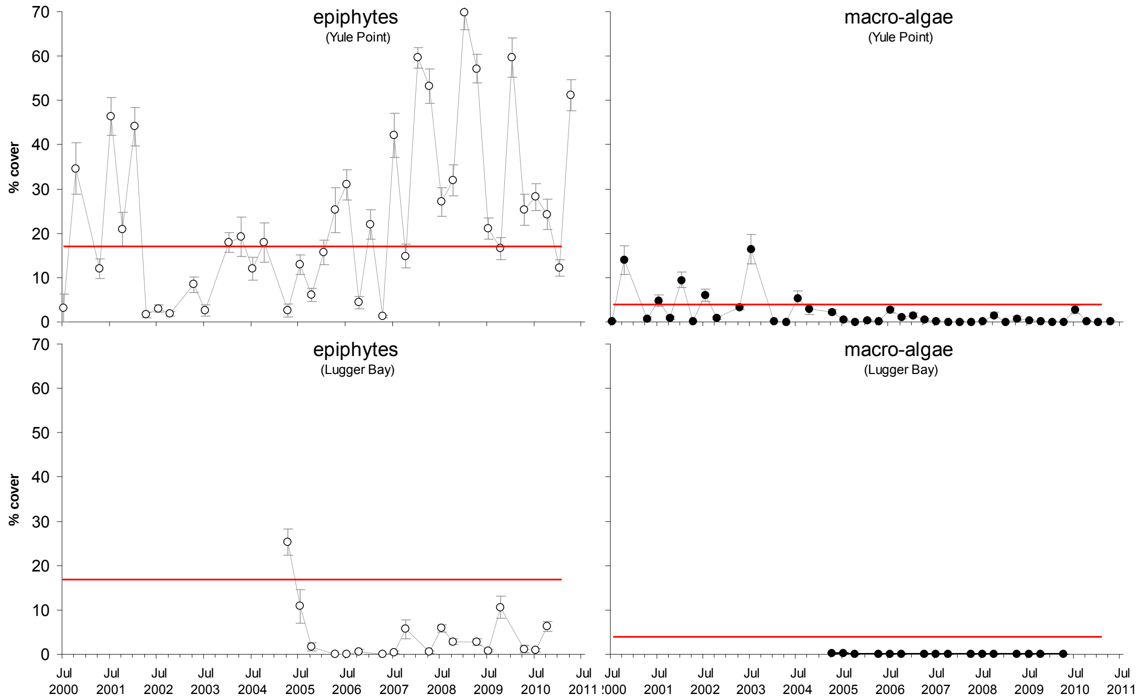


Figure 48. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at coastal intertidal seagrass monitoring locations (sites pooled) in the Wet Tropics region. Red line = GBR long-term average; epiphytes=17%, macro-algae=4.7%.*

Epiphyte cover at reef sites was variable and although not substantial, it appears to be increasing (Figure 49). Abundances at Green Island were above the GBR long-term average for reef habitats during the monsoon and late monsoon 2011, however at Dunk Island epiphytes remained below the GBR long-term average for the duration of the monitoring period. Macro-algae at both reef locations were predominately composed of *Halimeda* spp. and abundance was relatively stable, with mean covers less than 10% (Figure 49).

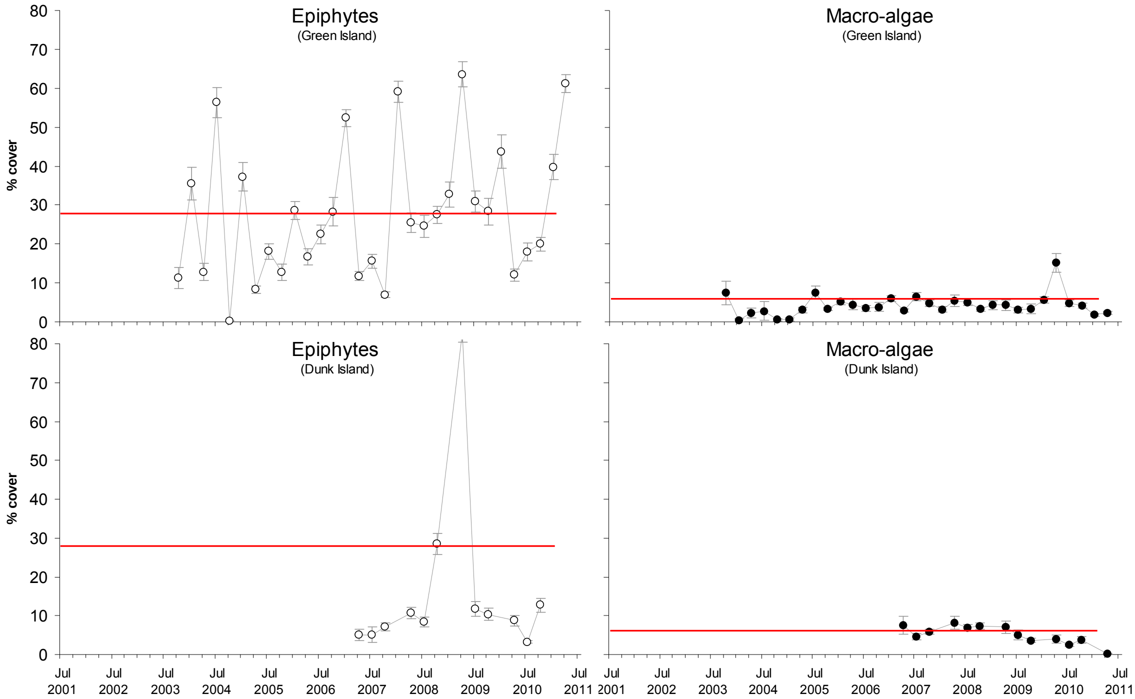


Figure 49. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at reef intertidal seagrass monitoring locations (sites pooled) in the Wet Tropics region. Red line = GBR long-term average; epiphytes=28%, macro-algae=6.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows across the Wet Tropics region (Table 19).

Table 19. *Concentration of herbicides (mg kg^{-1}) in sediments of coastal (Yule Point and Lugger Bay) and reef (Green Island and Dunk Island) seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
YP1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
YP2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
LB1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
LB2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GI1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GI2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
DI1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
DI2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within meadow canopy temperature

Temperature loggers were deployed within the seagrass canopy throughout the monitoring period at most locations monitored in the region (Figure 50). The loggers deployed at Lugger Bay were lost as a result of sediment movement and wave action (i.e. TC Yasi), and deployment was possible until a new permanent marker was established in July 2011. Higher temperatures were experienced from December 2010 to March 2011 across the region. Extreme temperatures (>39°C) were recorded at Yule Point in March 2011 during the low spring tides (Figure 51). Temperatures in 2010/11 at all sites in the Wet Tropics region were 0.1 – 0.5°C cooler than the previous year.

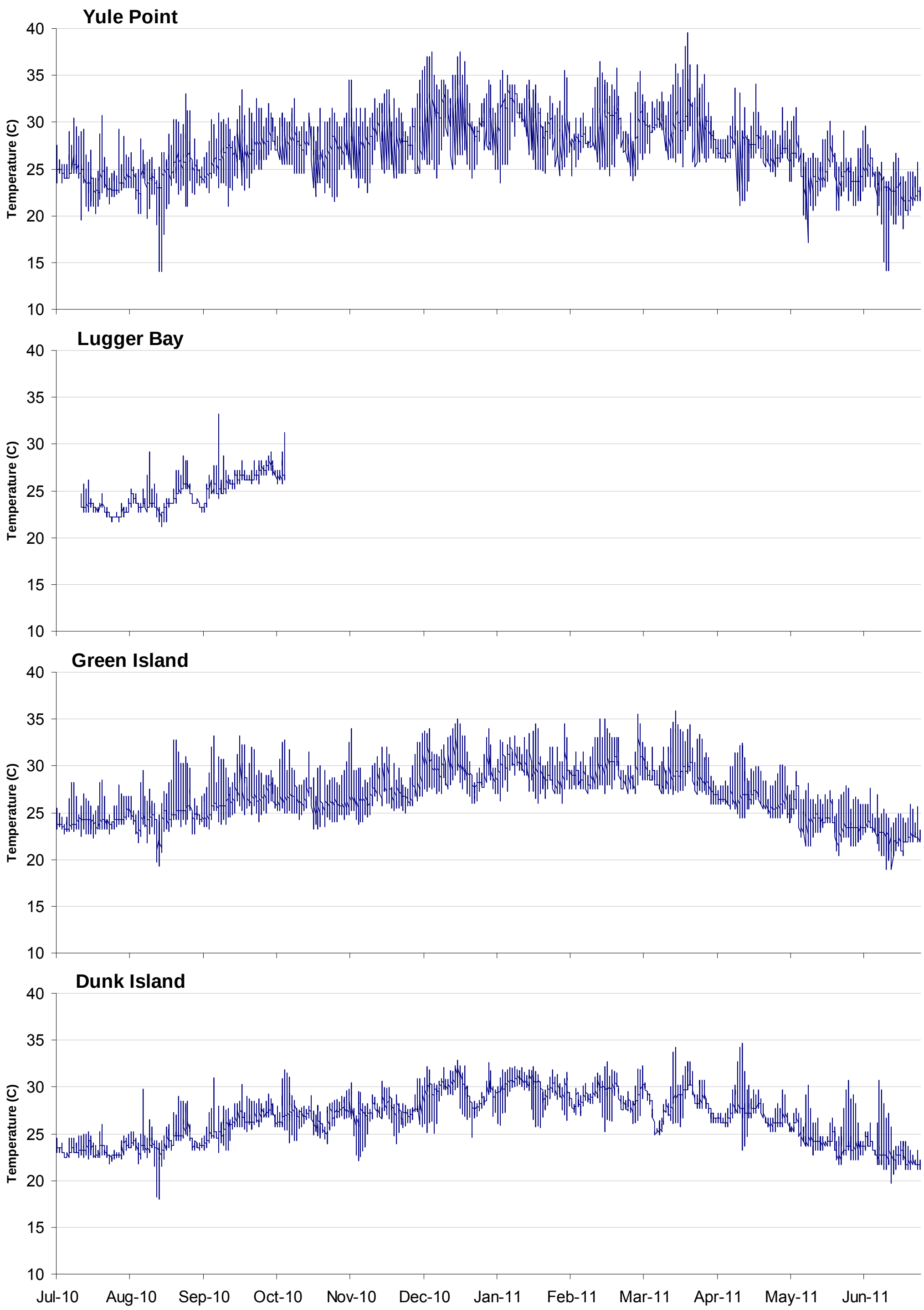


Figure 50. *Within seagrass canopy temperature (°C) at coastal (Yule Point and Lugger Bay) and offshore reef (Green Island and Dunk Island) intertidal meadows within the Wet Tropics region over the 2010/11 monitoring period.*

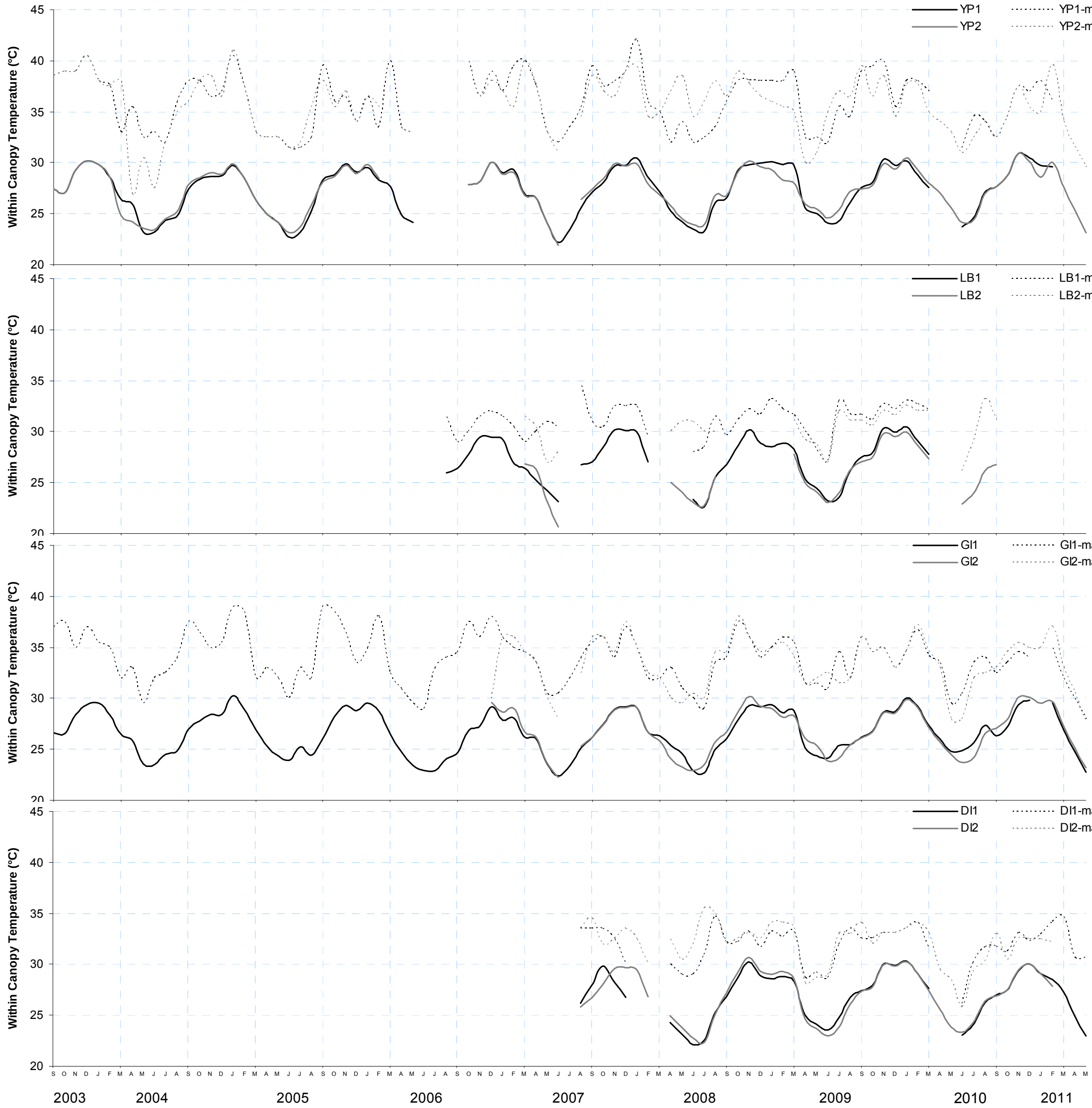


Figure 51. *Monthly mean and maximum within seagrass canopy temperatures (°C) at coastal (Yule Point and Lugger Bay) and fringing-reef (Green Island and Dunk Island) intertidal meadows within the Wet Tropics region.*

Canopy incident light

Daily irradiance (I_d) at the Low Isles intertidal site was generally well above minimum light requirements (MLR, ~4.7-7.9 mol m^{-2} d^{-1}) with an average I_d of 14.5 mol m^{-2} d^{-1} (Figure 52). However, there is large annual variability with I_d reaching a maximum during the dry season when extremely low tides during the day coincide with high surface irradiance and I_d was the lowest during the wet season dropping to around MLR for short periods of time (2-4 weeks). In the 2010/11 wet season, I_d was 13.3 mol m^{-2} d^{-1} compared to the long-term average of 11.8 mol m^{-2} d^{-1}. Despite I_d generally being well above MLR, there has been a steady decline in seagrass cover at the Low Isles intertidal site since 2008 declining from 18% in November 2008 to 3% in May 2011 (data not shown). The short periods that were spent around the MLR should not have led to such large declines in seagrass cover, particularly for *H. uninervis* and *T. hemprichii*, which can tolerate low light levels for over month before significant declines in shoot density occur (Collier et al. In Press). However, the intertidal environment is highly dynamic with massive variability in light and temperature being common features, and, as such, I_d may not fully capture stress associated with light levels (i.e. ranging from very high during low tide to very low when turbid), or the declines may be due to other factors such as reduced salinity which also occur in the wet season, or the combined effect of high water temperatures and reduced light during the wet season (Collier et al. 2011).

At the Low Isles subtidal site, for much of the time since 2008, I_d has been around or below the MLR for seagrasses with an average I_d of 5.7 mol m^{-2} d^{-1} (Figure 52). Large declines in I_d typically occurred in the late wet season, however in the 2011 wet season I_d was above average at 6.4 mol m^{-2} d^{-1}. Some low light periods also occur during winter at this site, which may relate to wind direction. Further detailed analysis of environmental drivers of turbidity (e.g. runoff, wind, currents) and of light (e.g. turbidity, clouds, sea level) are being undertaken in a separate analysis. During this monitoring time, there has also been a decline in seagrass cover at the subtidal site since 2008 declining from 20% in November 2008 to 2% in May 2011 (data not shown), with the most substantial reductions in cover occurring during the wet seasons of 2009, 2010, and 2011. *Halophila ovalis* was the dominant species at this site when monitoring began in 2008, and although it has a lower MLR than most other tropical species (1.5 to 2.9 mol m^{-2} d^{-1}), short periods below MLR (around 14 days) lead to die-off in this species as it has little capacity to buffer from reduced photosynthetic C uptake given its small carbohydrate stores (Longstaff et al. 1999). The co-occurring nature of seagrass declines and low light indicates low I_d as a likely cause for reductions in seagrass cover at the subtidal site. However, this decline has not been continuous, but instead has been interspersed with periods of recovery (e.g. in the late dry season in 2009 and 2010, and also some recovery following the 2011 wet season). The Low Isles subtidal site is comprised predominantly of colonizing species: *H. ovalis*, and a small form of *Halodule uninervis*. These species can grow and respond quickly to changes in environmental conditions, and this site might quickly show signs of further recovery if and when conditions improve.

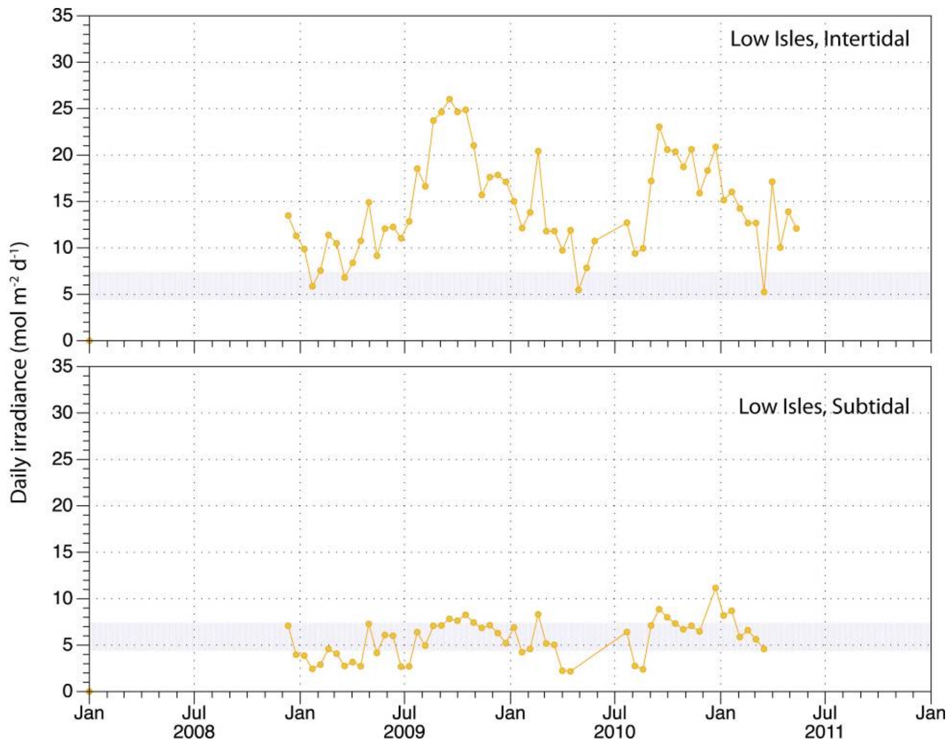


Figure 52. *Daily irradiance (14-day average) at Low Isles intertidal and subtidal sites. Shaded bar indicates seagrass minimum light requirements (see methods for description).*

There is limited data available for the Yule Point site, with logger failures occurring during the wet season of 2009/10 (Figure 53), a critical time for the interpretation of seagrass meadow responses. The wet season in 2010/11, indicates that I_d can drop substantially during the wet season for short periods of time reaching almost zero I_d for 4 weeks; however I_d was on average 7.6 mol m^{-2} d^{-1} during the 2011 wet season compared to an average of 12.2 mol m^{-2} d^{-1}. However, for most of the year, I_d is well above MLR at Yule Point (Figure 53).

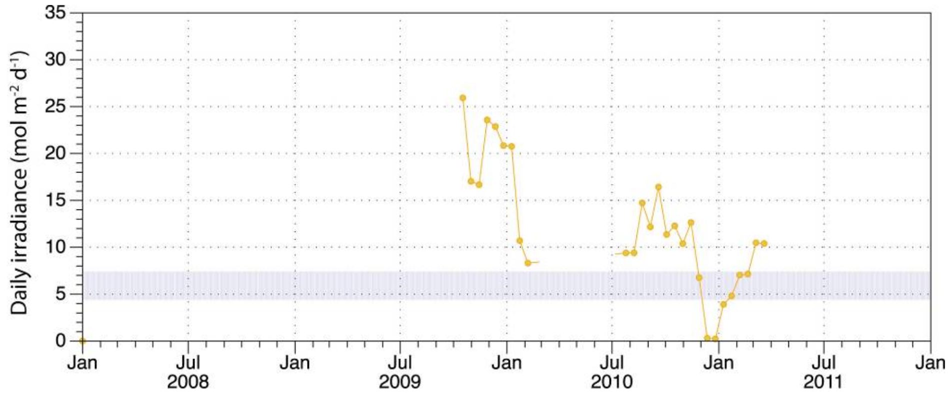


Figure 53. *Daily irradiance (14-day average) at Yule Point. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

Green Island typically has high light conditions at both the intertidal and subtidal monitoring sites with average I_d being 17.1 and 10.6 mol m^{-2} d^{-1}, respectively (Figure 54). I_d is the highest in the late dry season and the lowest during the wet season and post-wet season. I_d rarely drops to within MLR and this result is consistent with relatively stable meadows at both the intertidal and subtidal seagrass sites.

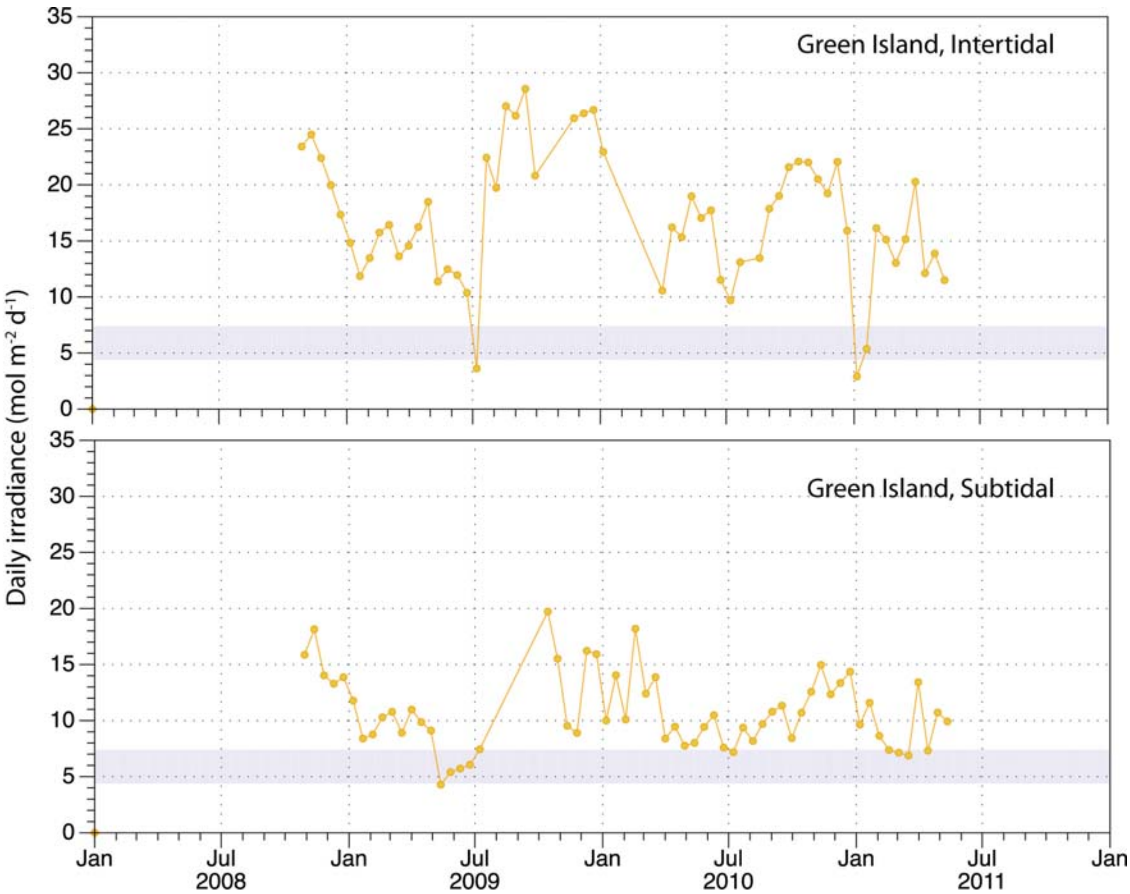


Figure 54. *Daily irradiance (14-day average) at Green Island intertidal and subtidal sites. Shaded bar indicates seagrass minimum light requirements (see methods for description).*

The Dunk Island intertidal site typically has very high I_d with the long-term average being 18.3 mol m^{-2} d^{-1} (Figure 55). The intertidal site is readily exposed at low tide (~0.5m) so very high instantaneous photosynthetically active radiation (PAR) are recoded often and contribute to an elevated I_d. Only rarely does I_d fall to within MLR (Figure 55). Despite this, there has been ongoing decline in seagrass cover at the Dunk Island intertidal site, followed by TC Yasi in February 2011, which removed almost all remaining seagrass. There is no clear link between I_d and seagrass decline at this site. Or as for other intertidal sites, I_d may not fully capture the extreme nature of the light environment at intertidal sites, where extremely high light occurs at low tide, but may not necessarily lead to high photosynthetic rates if photoinhibition occurs, or if plants are desiccation stressed or C-limited during exposure to the air and then, depending on turbidity, very low light can occur at high tide.

At the Dunk Island subtidal site I_d reaches maximum levels during the dry season and the lowest during the wet season, when I_d is well below MLR; however, there is considerable variation throughout the year. On average, I_d was 7.4 mol m^{-2} d^{-1}, which means it is only just around MLR. During the 2011 wet season, MLR was 7.2 mol m^{-2} d^{-1} on average, which is slightly higher than the long-term wet season average of 6.5 mol m^{-2} d^{-1}. It is very likely that low light levels have contributed to the declines in seagrass meadow cover at the Dunk Island subtidal site.

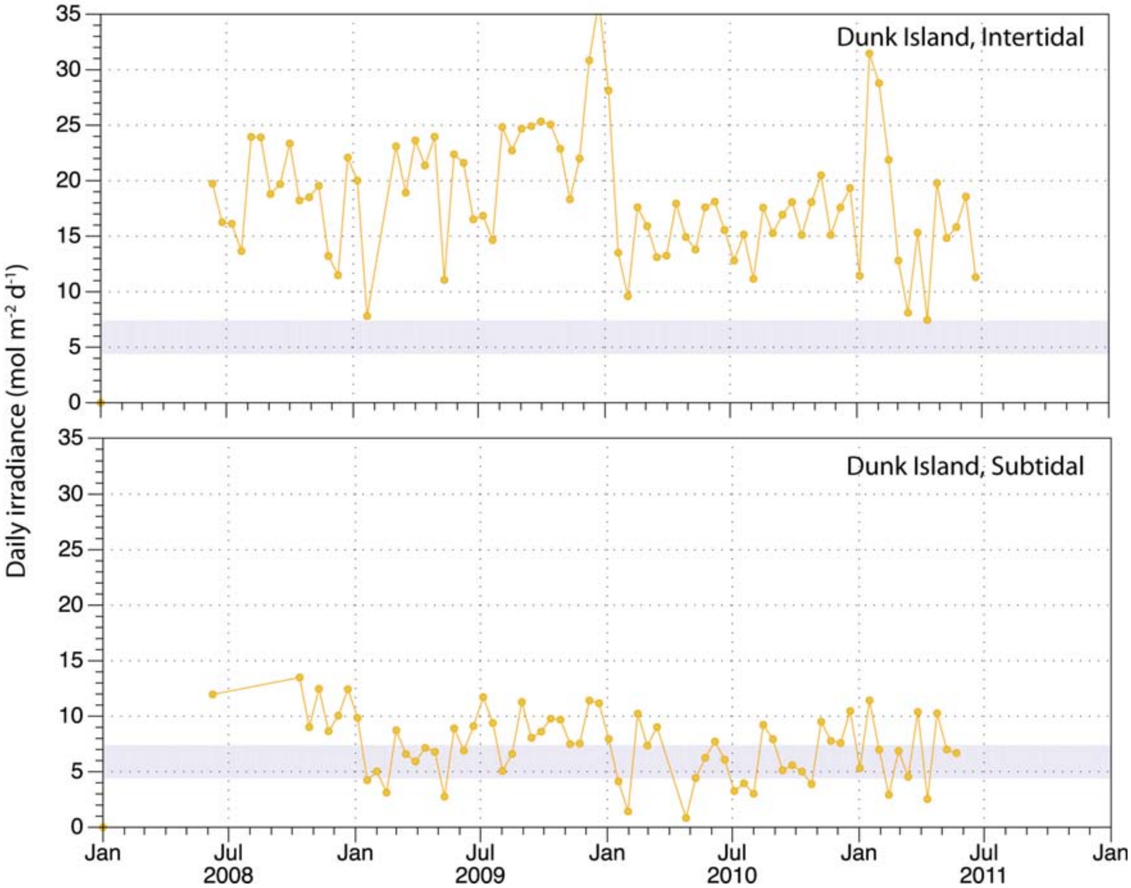


Figure 55. *Daily irradiance (14-day average) at Dunk Island intertidal and subtidal sites. Shaded bar indicates seagrass minimum light requirements (see methods for description).*

Regional Climate

Climate across the region was on average wetter, cloudier and calmer in 2010/11 than the previous decade. The most significant feature of the 2010/11 climate, was Tropical Cyclone Yasi in early February 2011 (Appendix 1).

After making landfall at Mission Beach in the early hours of 3 February 2011, severe TC Yasi (category 5) was rated as one of the most powerful cyclones to have affected Queensland since records commenced (Figure 56). With sustained winds of 205 km/h, gusting up to 285 km/h, and a 5 m tidal surge, the level of disturbance to coastal and nearshore environments in the south of the region was considerable.

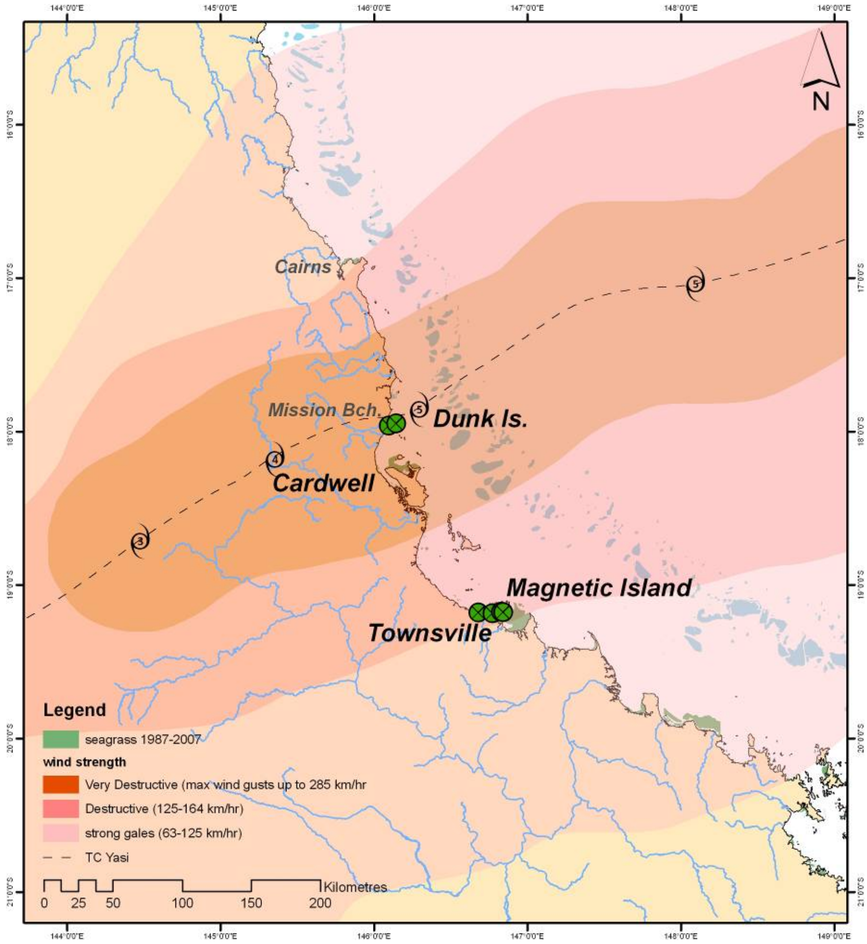


Figure 56. *Location of intertidal monitoring sites and the path and area impacted by Tropical Cyclone Yasi, 2-3 February 2011 (category level also shown).*

Cairns – Yule Point and Green Island

The mean maximum daily air temperature recorded in Cairns during 2010/11 was 29.4°C; this was 0.4°C higher than the 69 year average and similar to the previous decadal average (Figure 57). The highest recorded daily maximum air temperature in 2010/11 was 34.8°C.

2010/11 was a wet year relative to both the last decade and the long-term (66 year) average with 31% and 21% more rain than the long-term and decadal averages, respectively (Figure 57). Associated with the higher rainfall was an increase in cloud cover in 2010/11 with approximately 14% more cloud than the long-term and decadal averages (Figure 57). Mean wind speed however was lower in 2010/11 (20.7 km.hr^{-1}) than the decadal average (22.0 km.hr^{-1}), but remained nearly 14% higher than the long-term (69 year) average (Figure 57).

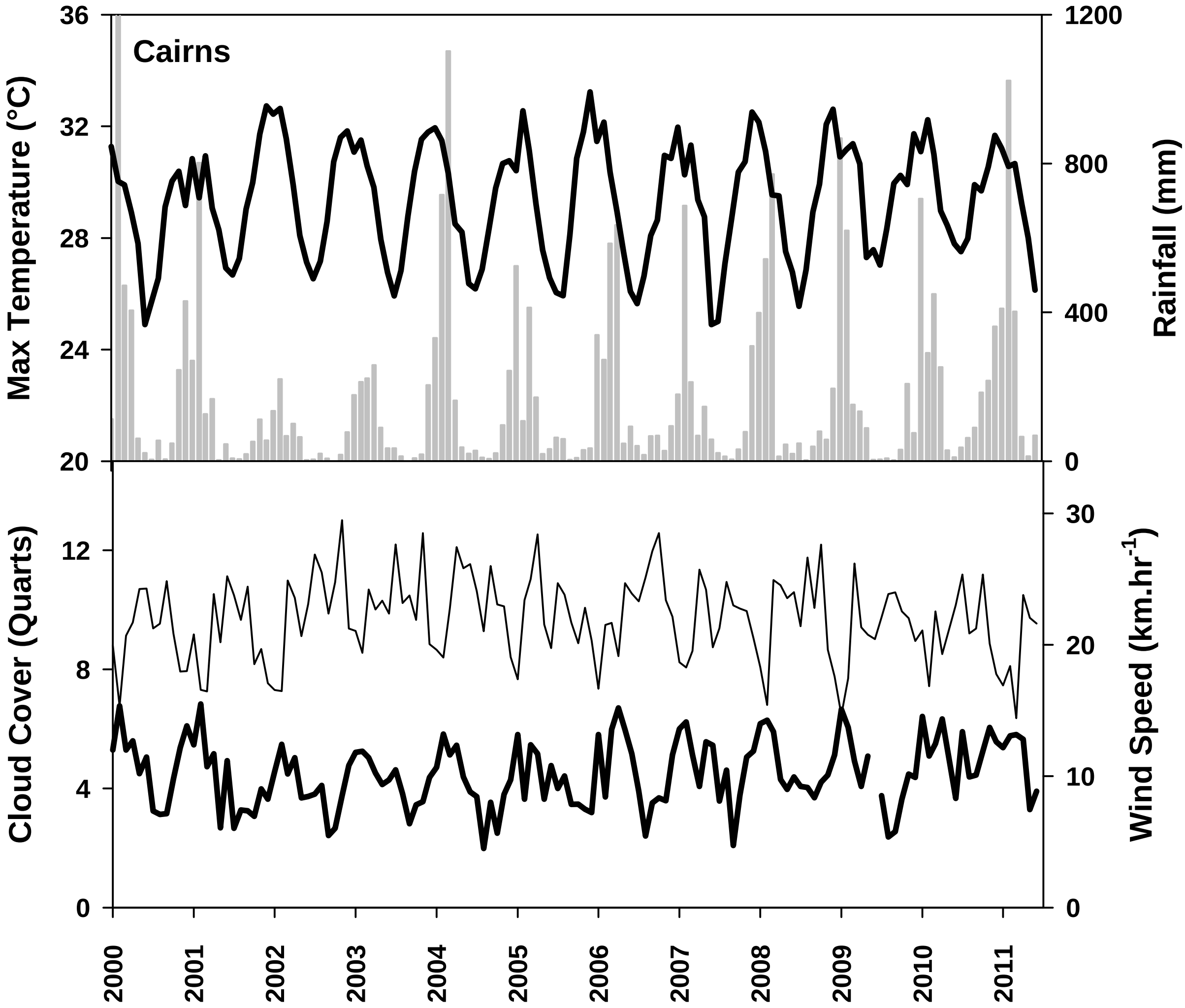


Figure 57. *Mean monthly daily maximum air temperature (°C), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km.hr^{-1}, lighter line) recorded at Cairns airport (BOM station 031011) (Source www.bom.gov.au). Cairns Airport used as a surrogate for the climate at Yule Point and Green Island.*

Innisfail – Lugger Bay and Dunk Island

The mean maximum daily air temperature recorded in Innisfail during 2010/11 was 28°C; this was similar to the long-term (103 year) average but 0.3°C cooler than the decadal average (Figure 58). The highest recorded daily maximum air temperature in 2010/11 was 33.7°C.

2010/11 was a wet year relative to both the last decade and the long-term (130 year) average with approximately 58% more rain than the long-term and decadal averages (Figure 58). Associated with the higher rainfall was an increase in cloud cover in 2010/11 with 25% and 14% more cloud than the long-term and decadal averages, respectively (Figure 58). Mean wind speed in 2010/11 was very low relative to the long-term and decade averages at 9.3 km.hr^{-1}.

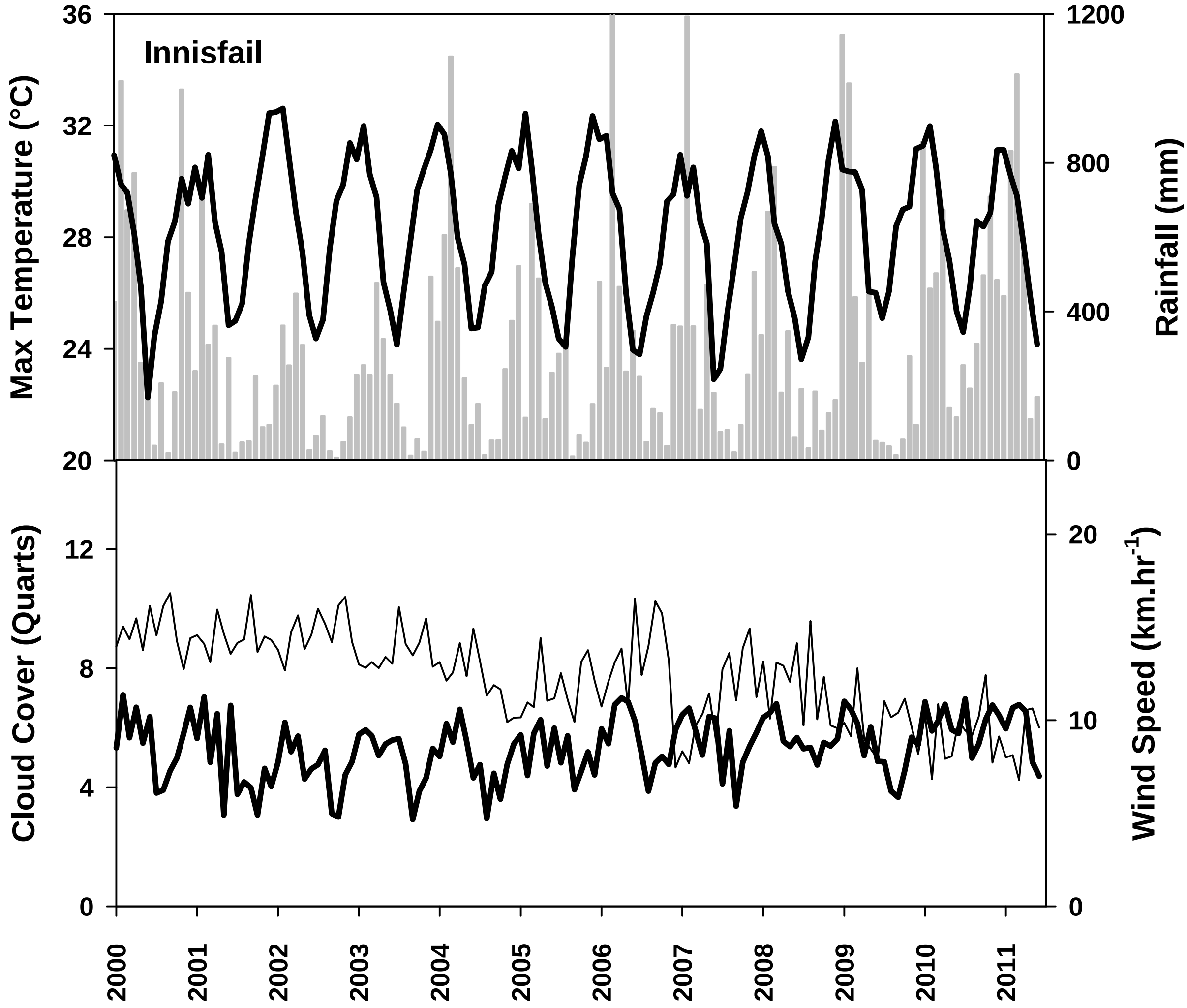


Figure 58. *Mean monthly daily maximum air temperature (°C), total monthly rainfall (mm, bar graph), mean monthly cloud cover (quarts, heavier line), and mean monthly 3pm wind speed (km.hr^{-1}, lighter line) recorded at Innisfail (BOM station 032025) (Source www.bom.gov.au). Innisfail used as a surrogate for the climate at Lugger Bay and Dunk Island.*

River discharge

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 are inundated by waters laden in nitrogen and phosphorus species for periods of days to several weeks in the monsoon (Devlin *et al.* 2001).

Flood plume modelling estimates that Yule Point is within a zone impacted yearly (Devlin *et al.* 2001). The major river impacting Yule Point would be the Barron. The Barron River discharges 0.1x10^6 tonnes of fine sediment, 70 tonnes of phosphorus and 500 tonnes of nitrogen per year (from Table 1 *in* Brodie *et al.* 2009). During major flood events, plumes from the Russell-Mulgrave and Johnstone Rivers could also impact Yule Point. The Russell-Mulgrave discharges 0.21 x10^6 tonnes of fine sediment, 320 tonnes of phosphorus and 2200 tonnes of nitrogen per year (Brodie *et al.* 2009). The Johnstone discharges 0.26 x10^6 tonnes of fine sediment, 580 tonnes of phosphorus and 2,250 tonnes of nitrogen per year (Brodie *et al.* 2009).

In the southern section of the Wet Tropics region, the coastal seagrass meadows of Lugger Bay would be influenced primarily by the Tully and Murray Rivers (approximately 8 km and 15 km south of Lugger Bay respectively) (Devlin and Schaffelke 2009). Both the Tully and Murray Rivers have been labelled as medium/high risk to inshore areas by the Great Barrier Reef Marine Park Authority (GBRMPA 2001). Of the two rivers, the Tully is the largest with an annual discharge of 0.12×10^6 tonnes of fine sediment, 125 tonnes of phosphorus and 1,300 tonnes of nitrogen (Brodie *et al.* 2009). The smaller river, the Murray, discharges 0.05×10^6 tonnes of fine sediment, 58 tonnes of phosphorus and, 620 tonnes of nitrogen per year (Brodie *et al.* 2009). The largest river in the region is the Herbert River, which is 60 km to the south and discharges 0.54×10^6 tonnes of fine sediment, 250 tonnes of phosphorus and 1,900 tonnes of nitrogen (Brodie *et al.* 2009).

Devlin and Schaffelke (2009) reported that approximately 93% of seagrass meadows within the Tully marine area were inundated every year by freshwater-primary flood plumes, exposing the seagrass to intermittently high sediment and high nutrient concentrations for periods of days to weeks and potentially high loads of particles settling on the plants and seafloor. The exposure to elevated Total Suspended Solids, Chlorophyll-a and PSII herbicides was rated as high for most of the seagrass monitoring sites, although reef habitats in the north (e.g. Green Island) were low exposure for TSS and reef habitats in the south (e.g. Dunk Island) were high for Chlorophyll-a and PSII herbicides. Overall, sites in the south had a high probability of exceeding the GBR WQ Guidelines for TSS in 2010, while coastal sites in the north had a medium probability (pers. comm. Michelle Devlin, JCU).

Significantly higher rainfall and subsequent flooding from the rains associated with TC Yasi in 2010/11 resulted in the highest average daily flows from the all the rivers across the region than any other period in the last decade (Barron ANOVA, d.f.=10, F=2.44, p=0.01; Mulgrave ANOVA, d.f.=12, F=3.56, p<0.001; Russell ANOVA, d.f.=10, F=2.22, p =0.02; Tully ANOVA, d.f.=12, F=5.09, p <0.001) (Figure 59) with flood plumes discharging from rivers into near shore environments in the region.

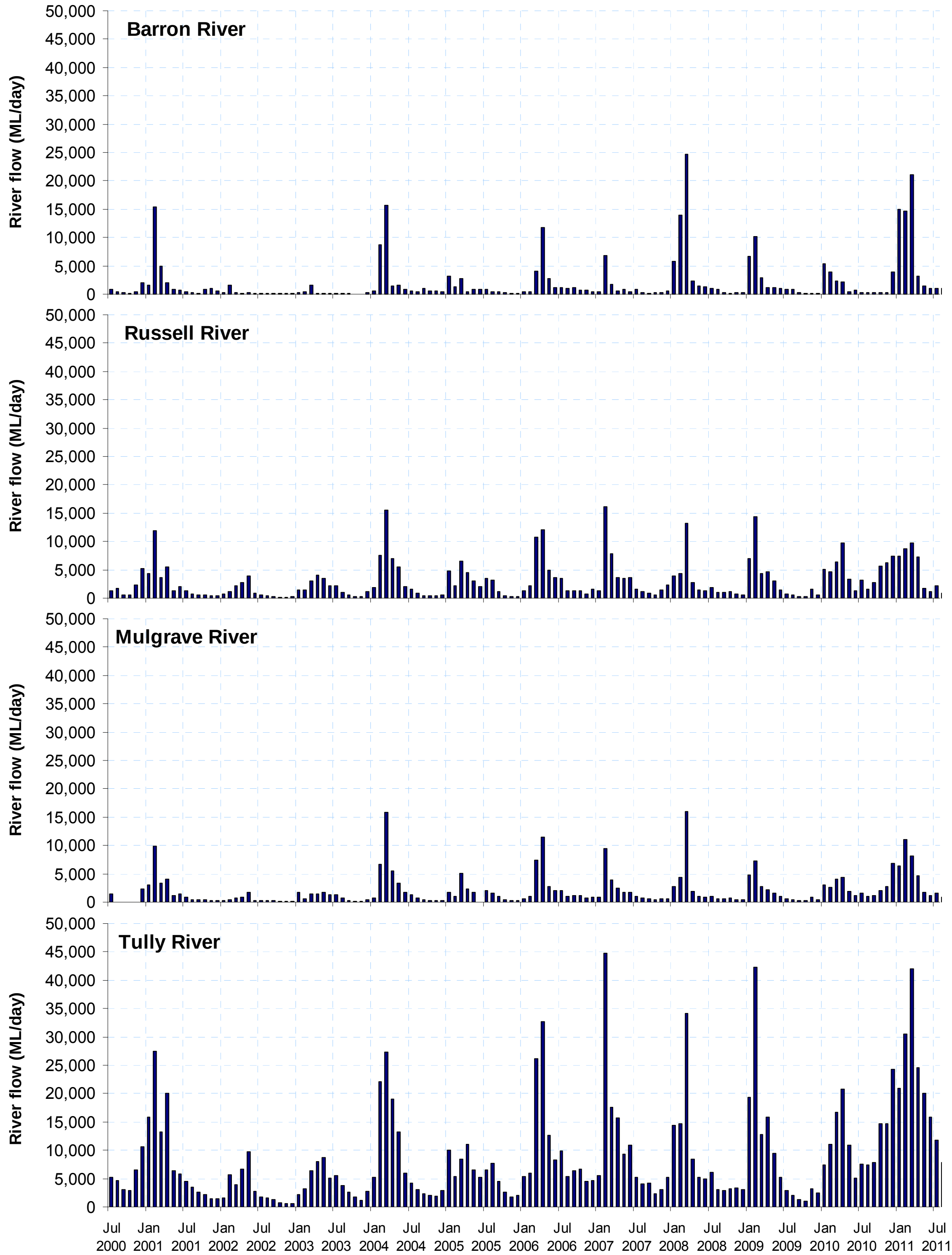


Figure 59. *Average daily flow (ML day^{-1}) per month from the main rivers impacting the seagrass monitoring sites in the Wet Tropics (DERM station 110001D - Barron River at Myola, 16.79983333°S 145.61211111°E, Elev 345m; 111007A - Mulgrave River at Peets Bridge, 17.13336111°S 145.76455556°E, Elev 27.1m; 111101D - Russell River at Bucklands 17.38595°S 145.96726667°E, Elev10m; 113006A - Tully River at Euramo, 17.99213889°S 145.94247222°E, Elev 8.76m) (source The State of Queensland (DERM) 2011, watermonitoring.derm.qld.gov.au).*

Burdekin

2010/11 Summary

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

In February 2011, Tropical Cyclone Yasi (category 5) impacted the region. Seagrass abundance and meadow extent continued to declined across the region until only a few isolated shoots remained after TC Yasi. Seed banks declined across the region and reproductive effort was in a very poor state, raising concerns about the ability of reef seagrass meadows to recover from environmental disturbances.

Seagrass tissue nutrient concentrations and light monitoring indicate decreasing light availability across the region since 2006 with nutrient loading from an increasing P pool. This has resulted in reef habitat seagrass becoming replete and the coast becoming N-limited. The low light availability was possibly exacerbated by higher epiphyte abundance (increasing above GBR long-term average). Macro-algae abundance remained negligible and no herbicides were found above detectable limits in the sediments of the seagrass meadows. Climate across the region in 2010/11 was cooler, wetter, cloudier, but not as windy, as the previous monitoring period. The increase in rainfall caused the Burdekin River to flow significantly higher than any other period in the last decade and above 100,000 ML day^{-1} for 5 consecutive months. The flood waters in high exposure of the seagrass monitoring sites to elevated TSS and Chlorophyll-*a*. Within seagrass canopy temperatures were cooler than the previous monitoring period and no extreme temperatures were recorded. Overall the status of seagrass condition in the region was rated as **very poor**.

Table 20. *Report card for seagrass status (community & environment) for the Burdekin region: July 2010 – May 2011. 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	9	25	28	**21**
coastal intertidal	6	0	6	**4**
estuarine intertidal	*not monitored*			
Burdekin	8	13	17	**13**

Background

The Burdekin region, includes an aggregation of the Black, Burdekin, Don, Haughton and Ross River catchments and includes several smaller coastal catchments, all of which empty into the Great Barrier Reef lagoon (Australian Government Land and Coasts 2010b). Because of its geographical location, rainfall in the region is lower than other regions within tropical Queensland. Annual rainfall averages approximately 1,150 mm from on average 91 rain days. However, there is considerable variation from year-to-year due to the sporadic nature of tropical lows and storms. Approximately 75% of the average annual rainfall is received during December to March (Schletinga and Heydon 2005).

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

The coastal sites are located on naturally dynamic intertidal sand flats and are subject to sand waves and erosion blowouts moving through the meadows. The Bushland Beach and Shelley Beach area is a sediment deposition zone, so the meadow must also cope with incursions of sediment carried by long shore drift. Sediments within this habitat are mud and sand that have been delivered to the coast during the episodic peak flows of the creeks and rivers (notably the Burdekin) in this area. While episodic riverine delivery of freshwater nutrients and sediment is a medium time scale factor in structuring these coastal seagrass meadows, it is the wind induced turbidity of the costal zone that is likely to be a major short term driver (Figure 60). In these shallow coastal areas waves generated by the prevailing SE trade winds are greater than the depth of water, maintaining elevated levels of suspended sediments, limiting the amount of light availability for photosynthesis during the trade season. Intertidal seagrasses can survive this by photosynthesizing during periods of exposure, but must also be able to cope with desiccation. Another significant feature in this region is the influence of ground water. The meadows are frequented by dugongs and turtles as witnessed by feeding trails and scars.

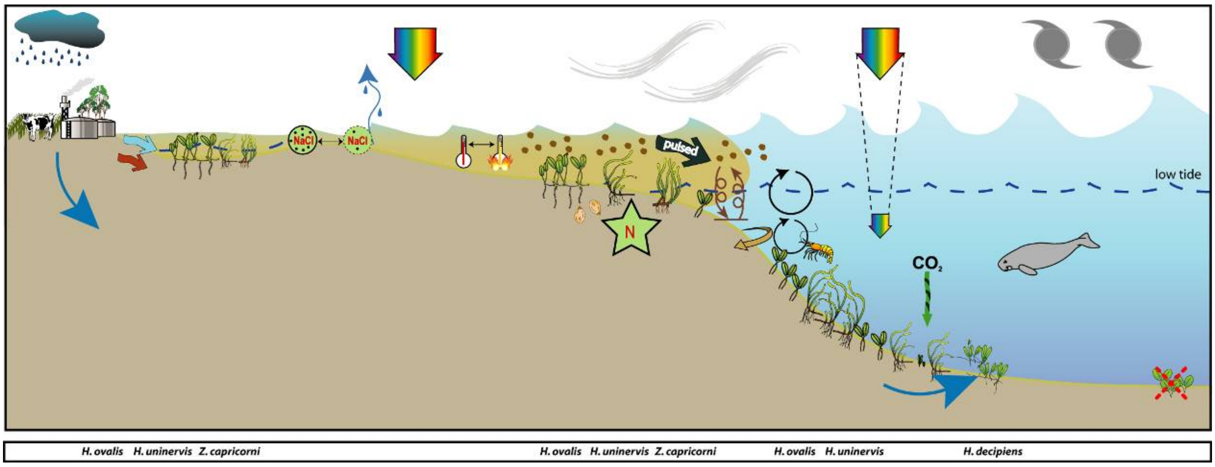


Figure 60. *Conceptual diagram of coastal habitat in the Burdekin region - major control is wind and temperature extremes, general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation).*

The reef habitats are mainly represented by fringing reefs on the many continental islands within this area. Most fringing reefs have seagrass meadows growing on their intertidal flats. Nutrient supply to these meadows is by terrestrial inputs via riverine discharge, re-suspension of sediments and groundwater supply (Figure 61). The meadows are typically composed of zones of seagrasses:

Cymodocea serrulata and Thalassia hemprichii often occupy the lower intertidal/subtidal area, blending with *Halodule uninervis* (wide leaved) in the middle intertidal region. *Halophila ovalis* and *Halodule uninervis* (narrow leaved) inhabit the upper intertidal zone. Phosphate is often the nutrient most limiting to reefal seagrasses (Short et *al.,* 1990; Fourqurean *et al.,* 1992). Experimental studies on reef top seagrasses in this region however, have shown seagrasses to be nitrogen limited primarily with secondary phosphate limitation, once the plants have started to increase in biomass (Mellors 2003). In these fringing reef top environments fine sediments are easily resuspended by tidal and wind generated currents making light availability a driver of meadow structure.

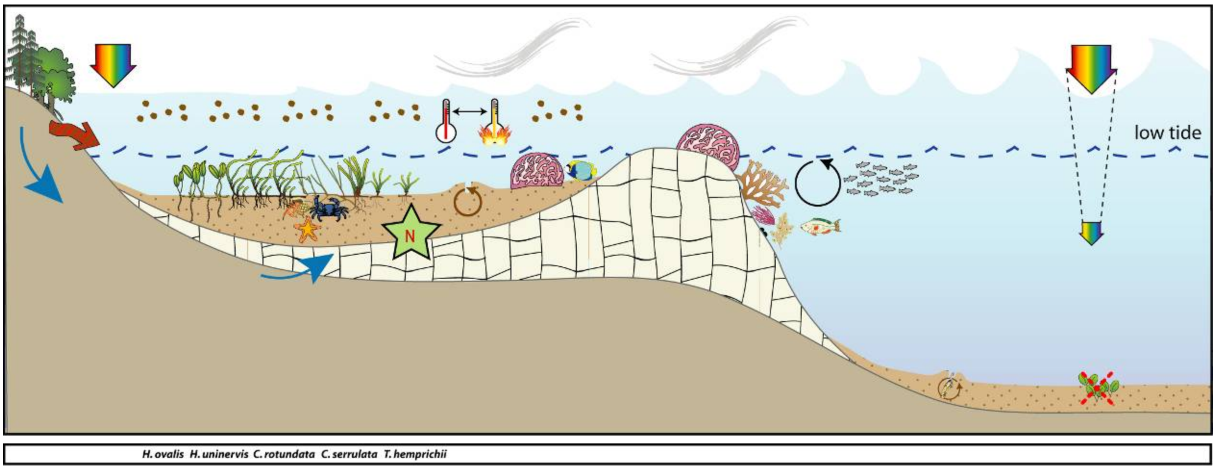


Figure 61. *Conceptual diagram of fringing reef habitat in the Burdekin region - major control is nutrient supply (groundwater), light and shelter: general habitat and seagrass meadow processes (see Figure 4 for icon explanation).*

Status of the seagrass community

Seagrass abundance and composition

Both meadows at coastal sites (Bushland Beach and Shelley Beach) were dominated by *Halodule uninervis* with small amounts of *Halophila ovalis* (Figure 63). Seagrass cover had been decreasing at both coastal sites since 2009 and the decline continued throughout 2010/11 until only a few isolated shoots remained after Tropical Cyclone Yasi impacted the region in February 2011 (Figure 62).

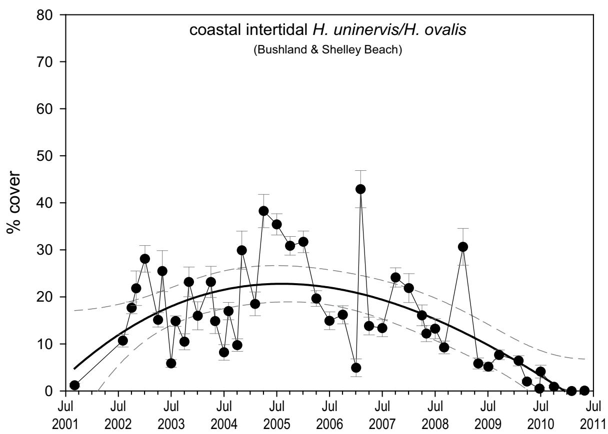


Figure 62. *Changes in seagrass abundance (% cover ±Standard Error) at coastal intertidal meadows in the Burdekin region from 2001 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.434.*

Since monitoring was established, both Bushland Beach and Shelley Beach have shown a seasonal pattern in seagrass cover; high in monsoon and low in the dry season (Figure 64).

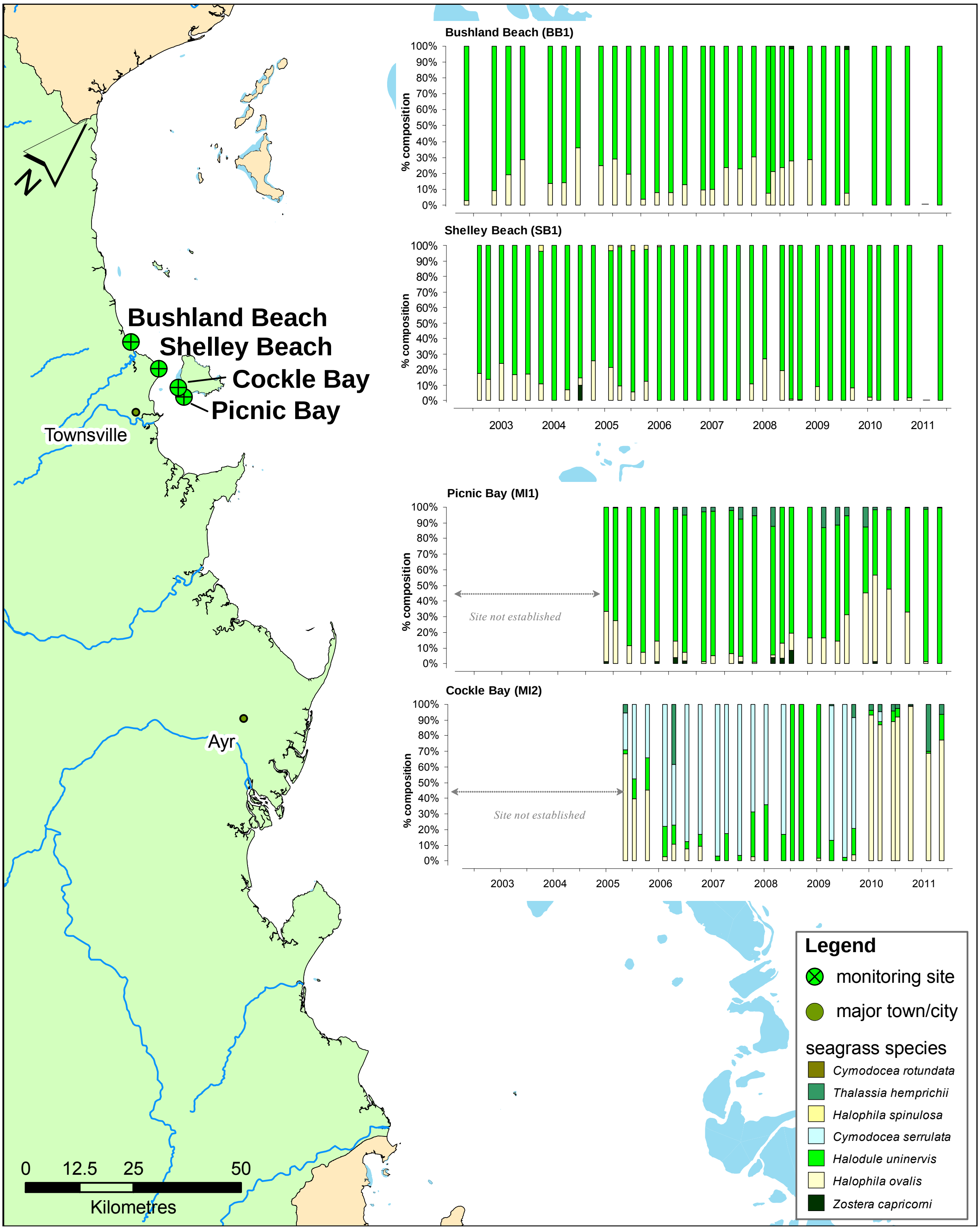


Figure 63. *Location of Burdekin region long-term monitoring sites in coastal (Bushland Beach and Shelley Beach) and reef (Picnic Bay and Cockle Bay, Magnetic Island) habitats, and the seagrass species composition at each site.*

Quadrat at 45m on transect 3 at Shelley Beach (SB1), on 12 July 2010 (left) and 16 May 2011 (right)

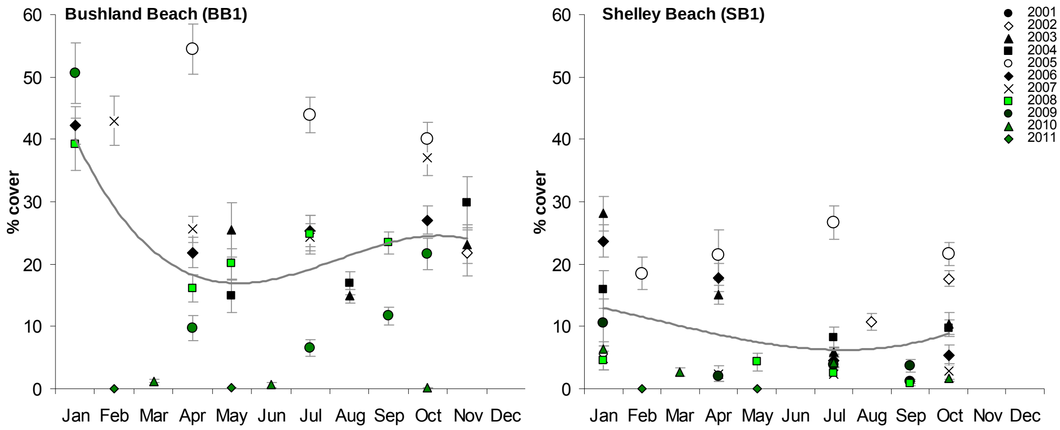


Figure 64. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Townsville coastal long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Offshore reef habitats are monitored on the fringing reef platforms of Magnetic Island, which during the 2010/11 monitoring period were dominated by *Halodule uninervis* (Picnic Bay) or *Halophila ovalis* (Cockle Bay). As *H. ovalis* is generally considered an early colonising species, it will dominated meadows which have been severely impacted/disturbed and possibly recovering. Since late 2009, the seagrass meadow at Cockle Bay (MI2) which was once dominated by *Cymodocea serrulata* and *Thalassia hemprichii* has become dominated by *H. ovalis* (Figure 63). This suggests the meadow has been severely impacted/disturbed. Conversely, in 2010 the species composition at Picnic Bay changed from *H. ovalis* to *H. uninervis* dominated, suggesting the meadow was recovering from disturbances in 2009/10 (Figure 63). In early 2011, both monitoring sites at Magnetic Island were further impacted by TC Yasi with only a few isolated shoots remaining (Figure 65).

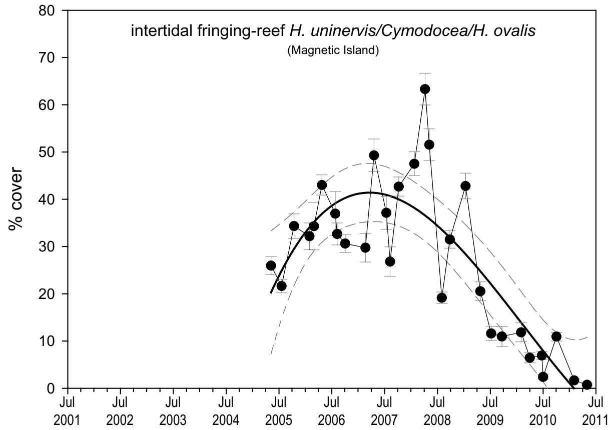


Figure 65. *Changes in seagrass abundance (% cover ±Standard Error) at inshore reef intertidal meadows in the Burdekin region from 2001 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.690.*

Quadrat at 25m on transect 3 at Picnic Bay (MI1), on 25 June 2010 (left) and 18 May 2011 (right)

Since monitoring was established, both reef habitat sites (Picnic Bay and Cockle Bay) have shown a seasonal pattern in seagrass cover; high in monsoon and low in the dry season (Figure 66).

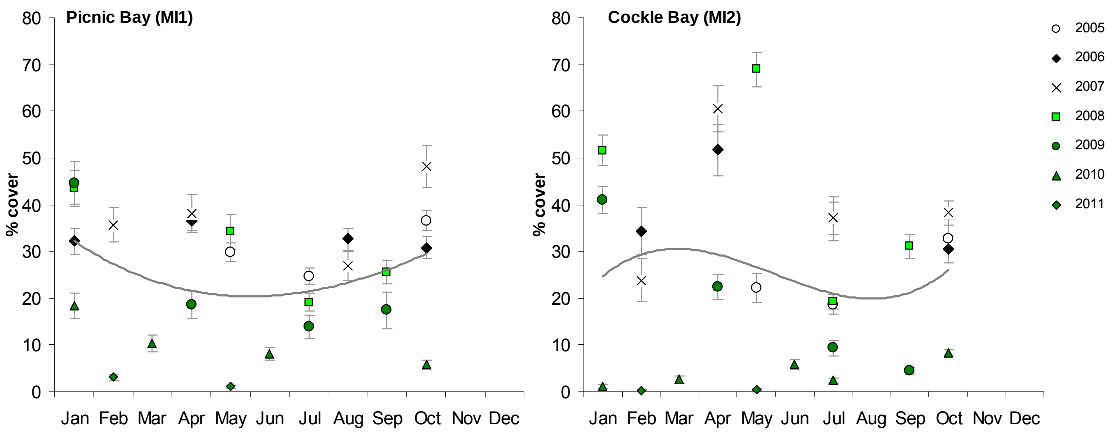


Figure 66*. Mean percentage seagrass cover (all species pooled) (± Standard Error) at Magnetic Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Seagrass meadows 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 (Table 21). Over the past two to three years, significant changes have occurred across the region with all seagrass meadows reducing in size and changing in landscape from continuous, to patchy, to isolated patches and finally to isolated shoots with the loss of meadow cohesion (Figure 67).

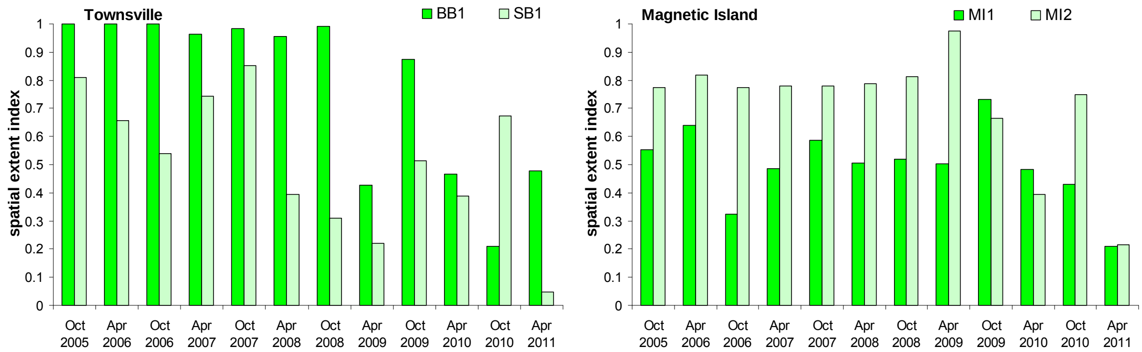


Figure 67. *Extent of area (within 100m radius of monitoring site) covered by seagrass at each coastal and offshore monitoring site at Townsville and Magnetic Island locations.*

Table 21. *Area (ha) of seagrass meadow within 100m radius of each site. Value in parenthesis is % change from the October 2005 baseline and description of change from previous mapping. Shading indicates decrease in meadow area since baseline.*

	Magnetic Island		**Townsville**	
	MI1	**MI2**	**BB1**	**SB1**
October 2005 (baseline)	**2.933**	**4.104**	**5.312**	**4.303**
April 2006	3.398 *(15.9%, increase shoreward)*	4.342 *(5.8, increase shoreward)*	5.312 *(no change)*	3.485 *(-19.1 decrease seaward)*
October 2006	1.723 *(-41.2% decrease seaward)*	4.112 *(0.2, negligible)*	5.312 *(no change)*	2.861 *(-33.5 decrease seaward)*
April 2007	2.587 *(-11.8%, increase shoreward)*	4.141 *(0.9%, increase shoreward)*	5.113 *(-3.7, decrease seaward)*	3.939 *(-8.5 increase shoreward)*
October 2007	3.119 *(6.3%, increase shoreward)*	4.144 *(1.0%, increase shoreward)*	5.221 *(-1.7,increase shoreward)*	4.529 *(-5.2 increase shoreward)*
April 2008	2.69 *(-8.3%, decrease seaward)*	4.191 *(2.1%, increase shoreward)*	5.08 *(-4.4, decrease seaward)*	2.095 *(-51.3 decrease overall)*
October 2008	2.76 *(-5.9%, increase shoreward)*	4.320 *(5.3%, increase shoreward)*	5.264 *(-0.9%, increase shoreward)*	1.648 *(-61.7%, decrease overall)*
April 2009	2.677 *(-8.7%, decrease seaward)*	5.179 *(26.2%, increase shoreward)*	2.275 *(57.2%, decrease seaward)*	1.178 *(-72.6%, decrease overall)*
October 2009	3.885 *(32.4%, increase seaward)*	3.525 *(-14.1%, decrease overall)*	4.645 *(12.6%, increase seaward)*	2.728 *(36.6%, increase overall)*
April 2010	2.560 *(-12.7%, decrease overall)*	2.086 *(-49.2%, decrease overall)*	2.483 *(-46.4%, decrease seaward)*	2.066 *(-52%, decrease overall)*
October 2010	2.287 *(-22%, decrease seaward)*	3.975 *(-3.2%, increase overall)*	1.116 *(-79%, isolated patches)*	3.579 *(-16.8%, increase overall)*
April 2011	1.111 *(-62.1%, isolated patches)*	1.146 *(-72.1%, isolated patches)*	2.542 *(-52.2%, isolated patches)*	0.248 *(-94.2%, isolated patches)*

Seagrass reproductive status

Seed banks across the region declined over the monitoring period and were below the GBR long-term average for both coastal and reef habitat (Figure 68, Figure 69). The abundance of germinated seeds at reef habitats in late monsoon 2011 was the highest recorded since monitoring was established, indicating recent, but possibly unsuccessful, recruitment (Figure 69). Monitoring effective recruitment of these germinated seeds will be informative to calibrate the expected rate of recovery following these larger scale disturbances. Reproductive effort overall is high for coastal sites in the Burdekin until the most recent season when the loss of seagrass cover has flowed onto a loss in ability to produce new propagules. At these sites the meadows have declined and will go into recovery phase during the 2011 post wet season growth. This is expected to follow species composition changes from later recruiting species to pioneer types such as *Halophila ovalis* and *Halodule uninervis*.

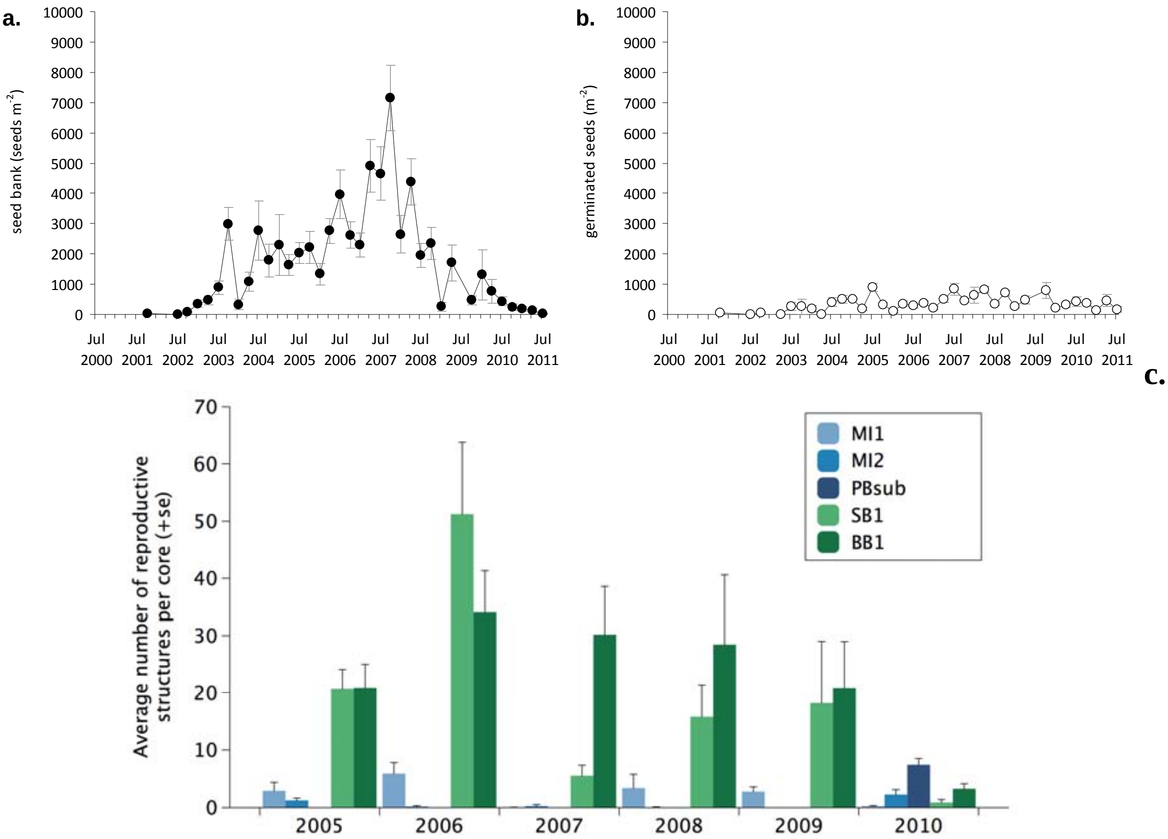


Figure 68. *Halodule uninervis seed bank (a) and germinated seed abundance (b) for coastal habitats in the Burdekin region (seed bank is represented as the total number of seeds per m^2 sediment surface), and total seagrass reproductive effort for all species (c).*

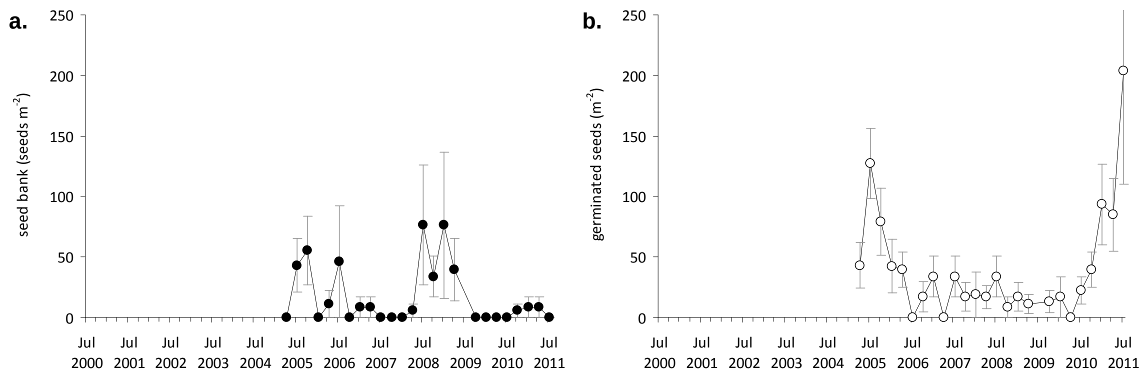


Figure 69. *Halodule uninervis seed bank (a) and germinated seed abundance (b) at reef habitats in the Burdekin region (seed bank is represented as the total number of seeds per m^2 sediment surface).*

Reproductive effort across the Burdekin region is classified as very poor. This suggests that sites within the region will take longer to recover following disturbance and may be at risk from repeated impacts.

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass leaf tissue C:N ratios for coastal sites (Bushland and Shelley Beaches, Townsville) were below 20 indicating a potentially low light environment. C:N rations at offshore reef sites (Cockle and Picnic Bays, Magnetic Island) went below 20 for the first time since monitoring was established (Figure 70). Decreasing C:N ratios across the region since 2006 may indicate decreasing light availability and N loading.

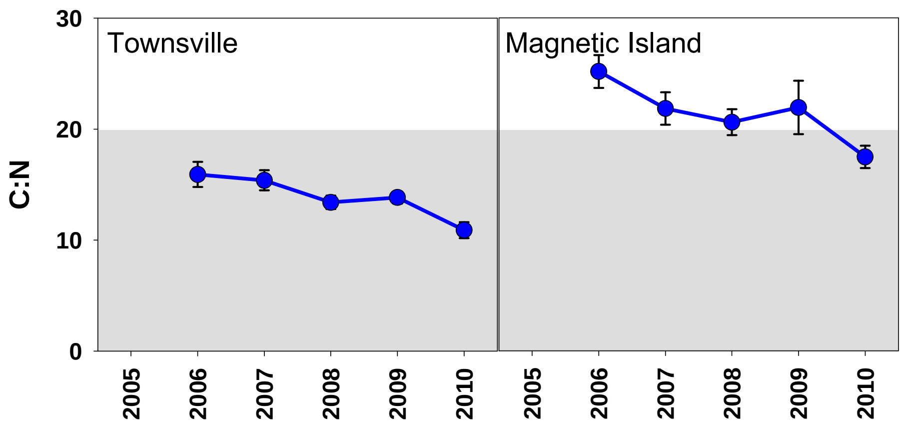


Figure 70. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield"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

The nutrient status (tissue C:P) of the coastal (Townsville) habitats indicates that these sites were nutrient rich, containing a large P pool (Figure 71). Tissue C:P ratios at reef habitats in 2010 declined below 500 for the first time since monitoring was established also indicating that these sites were nutrient rich, containing a large P pool. The coastal habitats have become increasing nutrient rich over the last three to four years. The N:P ratio indicates that both coastal and reef habitats in the region declined in N, with the reef replete and coast N-limited (N:P <25) (Figure 71). Tissue N:P ratios indicated that all seagrass species at reef habitats remained replete, however coastal habitats decreased from replete in 2009 to N limited in 2010. This suggests a small N pool relative to the increasing P pool.

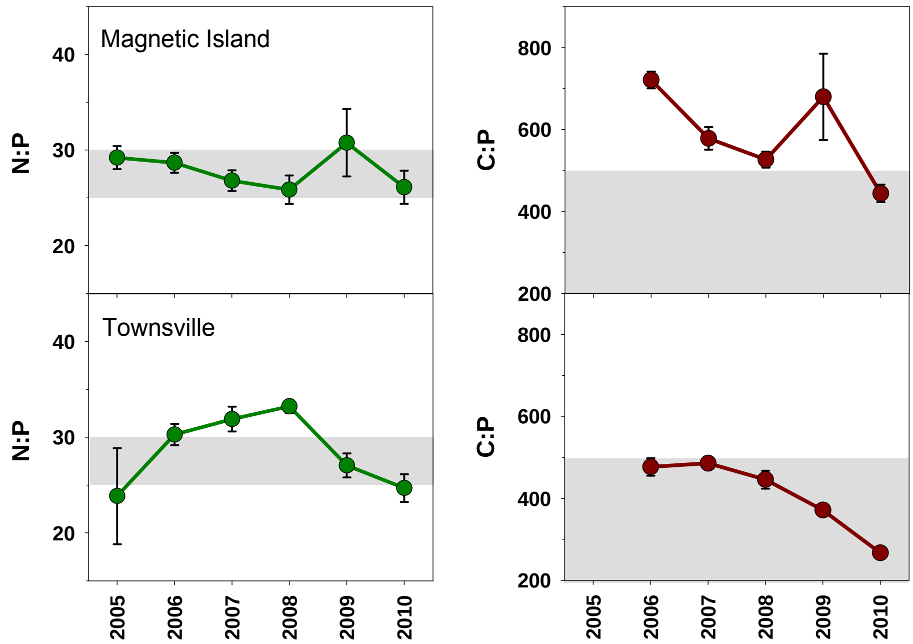


Figure 71. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with 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 macro-algae

Epiphyte cover on seagrass leaf blades at coastal sites was highly variable (Figure 72) and was higher over the 2010/11 monitoring period (above GBR long-term average) compared to the previous two monitoring periods, regardless of the extremely low seagrass cover. Percentage cover of macro-algae at coastal sites was also variable, but has remained low over the past couple of years (Figure 72), below the GBR long-term average.

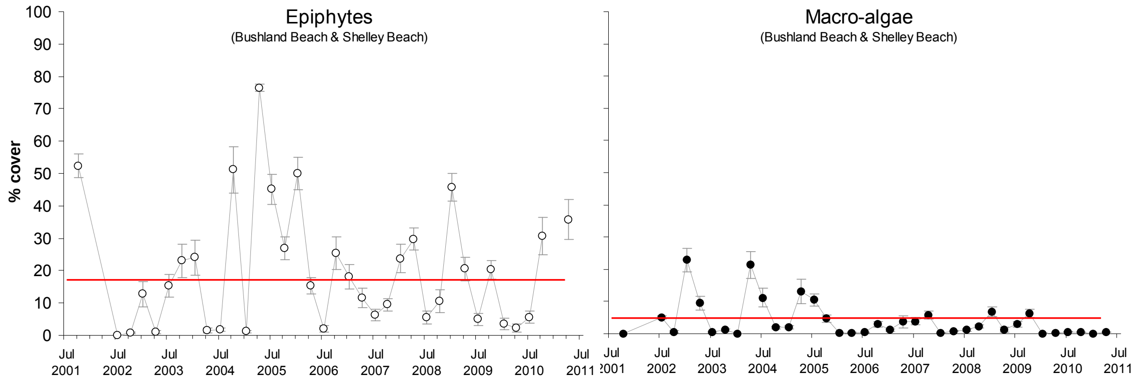


Figure 72. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at coastal intertidal seagrass monitoring locations (sites pooled). Red line = GBR long-term average; epiphytes=17%, macro-algae=4.7%.*

Epiphyte cover at reef habitats was similar over the 2010/11 monitoring period to the previous monitoring period, however it has differed greatly between sites in the past. In 2010/11, epiphyte cover was low; between 6.5 - 7.9% on average. This was similar to the long-term average at Picnic Bay (MI1 = 8.5%), but substantially lower than the long term average for Cockle Bay (MI2 = 50%).

Macro-algae were low at reef habitats, generally below the GBR average. The only time macro-algae was recorded above the GBR long-term average was during the late dry 2010 at Cockle Bay when *Hydroclathrus* spp. occurred in what appears to be a seasonal increase. There does not appear to be any clear long-term trend in abundance (Figure 73).

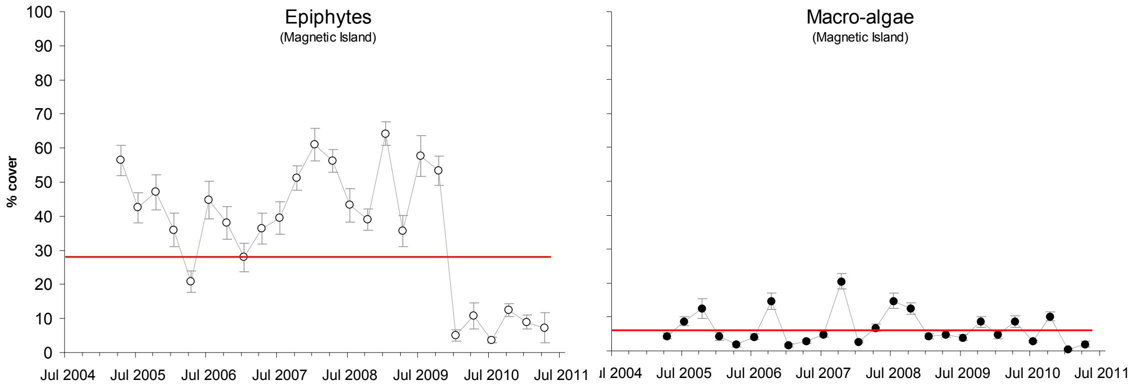


Figure 73. . *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal reef seagrass monitoring locations. Red line = GBR long-term average; epiphytes=28%, macro-algae=6.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows at either location in the Burdekin region (Table 22).

Table 22. *Concentration of herbicides (mg kg^{-1}) in sediments of coastal (Bushland Beach and Shelley Beach) and reef (Picnic Bay and Cockle Bay) seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
BB1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
SB1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
MI1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
MI2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within meadow canopy temperature

Within canopy water temperature was monitored at all coastal and reef-platform sites over the monitoring period (Figure 74). No extreme temperatures (>40°C) were recorded within the region, with the maximum of 39.0°C at Picnic Bay in March 2011. Mean temperatures were mostly within the 21 – 30°C range, with highest mean temperatures in March 2011 (Figure 75). The 2010/110 monitoring period was 1.0°C cooler at reef habitats than the previous monitoring period. Temperatures at coastal habitats were similar to the previous monitoring period.

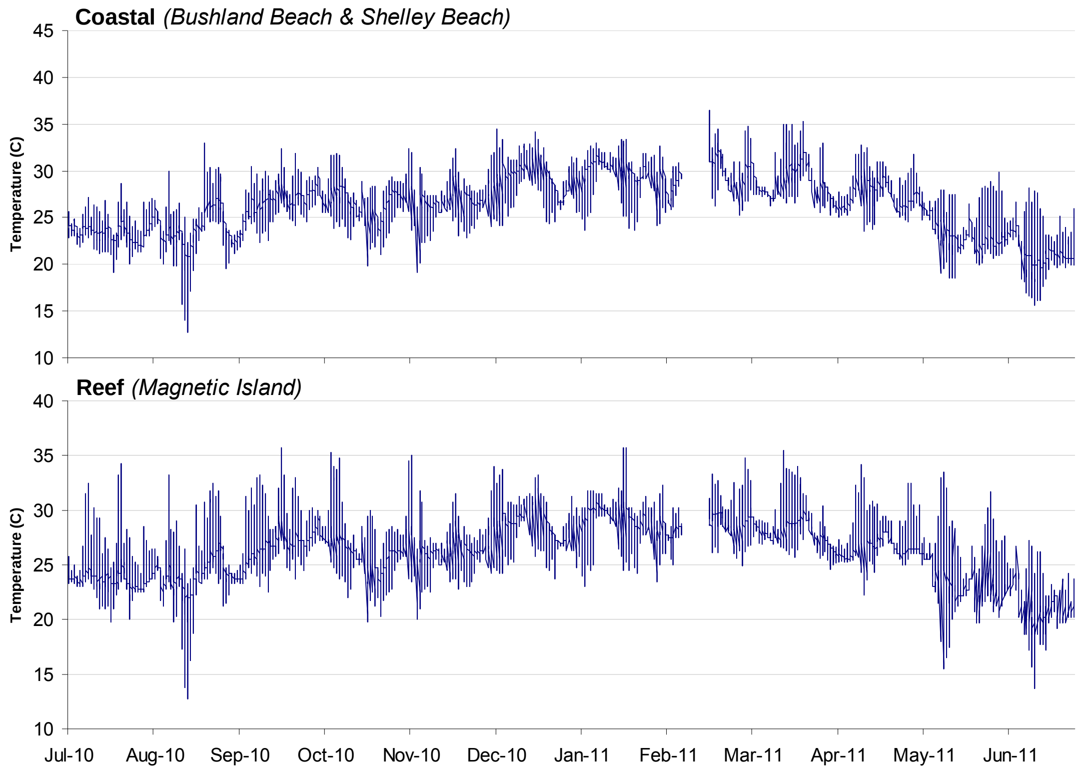


Figure 74. *Within seagrass canopy temperature (°C) at coastal (Bushland Beach and Shelley Beach) and offshore fringing-reef (Picnic Bay and Cockle Bay, Magnetic Island) intertidal meadows within the Burdekin region over the 2010/11 monitoring period.*

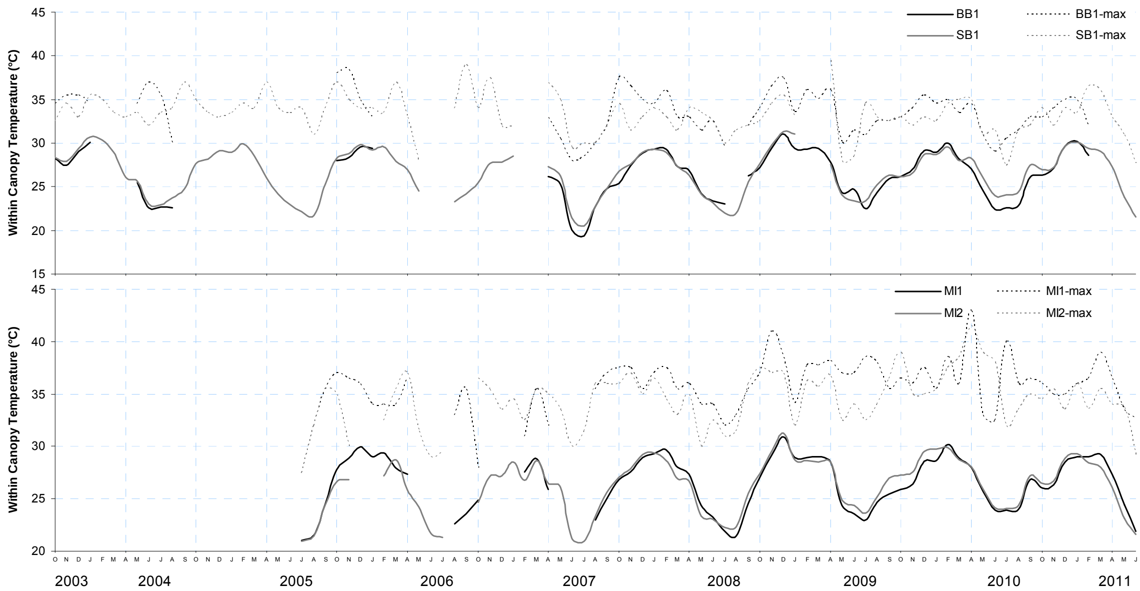


Figure 75. *Monthy mean and maximum within seagrass canopy temperature (°C) at intertidal meadows in coastal (Bushland Beach and Shelly Beach) and offshore fringing-reef (Picnic Bay and Cockle Bay, Magnetic Island) habitats within the Burdekin region.*

Canopy incident light

I_d at Bushland Beach has been, on average 4.0 mol m^{-2} d^{-1} since light monitoring began at this site; this well below the MLR required for seagrass survival (Figure 76). Concurrent with these low light conditions, there has been the almost complete loss of seagrass from this site, and low light levels are a very likely contributor. Even *Halophila* species, which have a lower MLR than that depicted here, would have difficulty surviving under the light conditions at Bushland Beach as very low I_d can occur for extended periods (almost 2 months in the 2009/2010 wet season). There is missing data from the early 2010/2011 wet season, which would probably further reduce average I_d at this site. I_d only gets above MLR for short periods during the dry season.

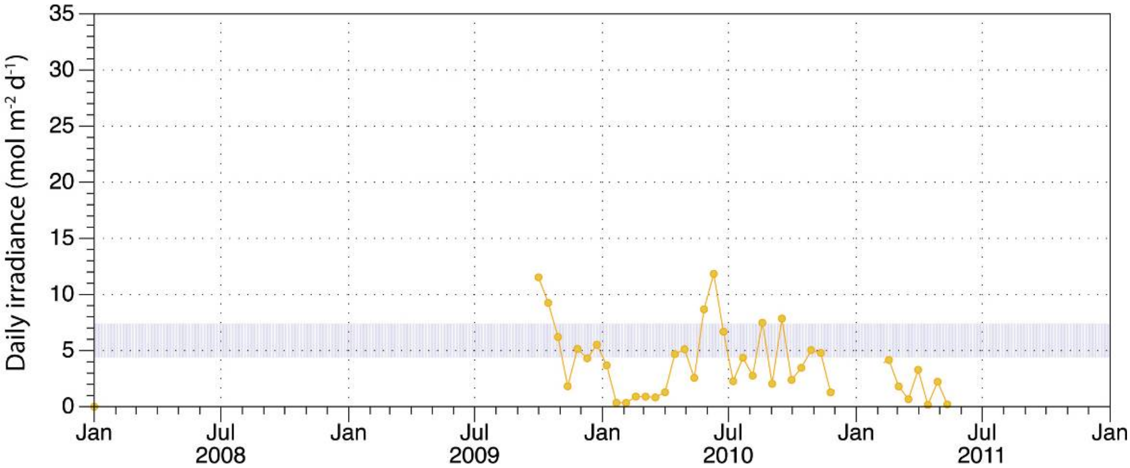


Figure 76. *Daily irradiance (14-day average) at Bushland Beach. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

Light resource conditions are much better at the Magnetic Island sites, compared to the mainland sites. At Cockle Bay, on average, I_d was 11.5 mol m^{-2} d^{-1} since monitoring began in late 2009; however, there are a number of data gaps at the Cockle Bay site due to logger and/or wiper failure (Figure 77). In the 2010/11 wet season I_d was 10.1 mol m^{-2} d^{-1} compared to a wet season average of 10.5 mol m^{-2} d^{-1}; however there is data missing from the time when TC Yasi, crossed the coast and when conditions were more turbid.

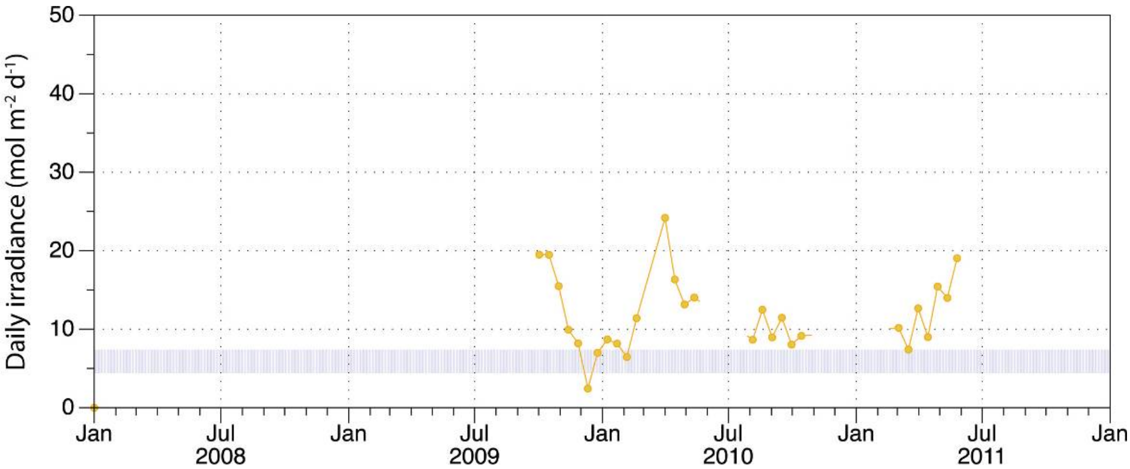


Figure 77. *Daily irradiance (14-day average) at Cockle Bay. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

At the Picnic Bay intertidal site I_d is, on average, well above MLR (long-term average is 14.3 mol m^{-2} d^{-1}) (Figure 78). However, there are extended periods when I_d is around or below MLR, particularly during the wet season, and on occasion during winter. Even during the wet season, I_d is, on average, well above MLR being 12.4 mol m^{-2} d^{-1} in 2011, which was similar to the long-term wet season average of 12.5 mol m^{-2} d^{-1}. These high wet season averages are due to low light periods being interspersed with high light periods. The short periods of low light have probably contributed to reduced resilience and declines in seagrass meadow cover at the Picnic Bay intertidal site. As for other intertidal sites, I_d may not be the best descriptor of the light environment and there may be factors associated with rainfall and run-off events that also contributed to the declines in seagrass cover, such as low salinity associated with surface and groundwater run-off and flood plumes.

At the Picnic Bay subtidal site I_d has been consistently low since 2008 and was almost always around or below the MLR for seagrass survival (Figure 78). Light levels at this site are considered very low. The long-term average I_d was 5.3 mol m^{-2} d^{-1} , which is around the lowest end of MLR (4.7 mol m^{-2} d^{-1}). The lowest I_d was during the wet season, when it was well below MLR for extended periods of time (greater than one month in 2009, 2010, and 2011). As for most other monitoring sites, the highest I_d occurred in the dry season, when some, if any, seagrass recovery tended to occur. The continual decline in seagrass cover at this site since 2009 is most likely due to consistently low I_d.

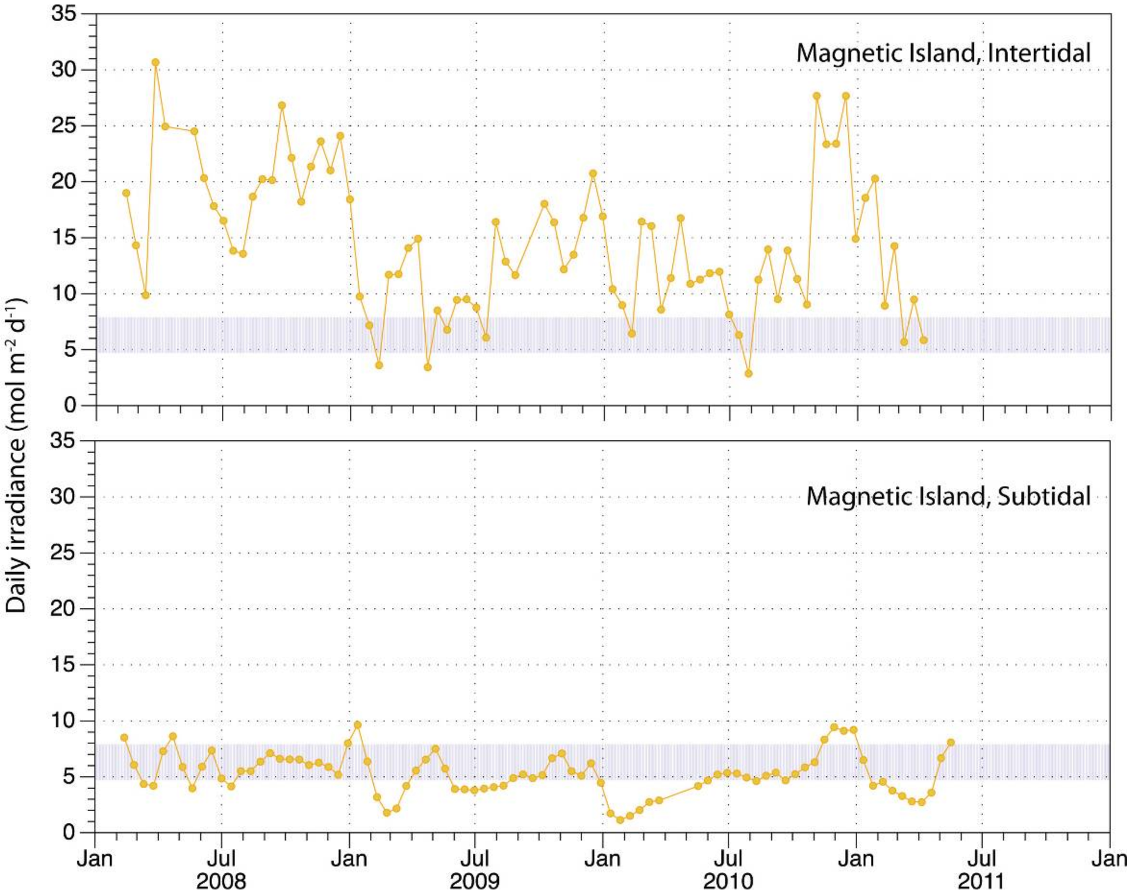


Figure 78. *Daily irradiance (14-day average) at Picnic Bay intertidal and subtidal sites. Shaded bar indicates seagrass minimum light requirements (see methods for description).*

Regional Climate

Climate across the Burdekin region (Townsville and Magnetic Island) in 2010/11 was cooler, wetter, cloudier, but not as windy, as the previous monitoring period. The most significant feature of the 2010/11 climate, was Tropical Cyclone Yasi in early February 2011 (Appendix 1).

After making landfall at Mission Beach in the early hours of 3 February 2011, severe TC Yasi (category 5) was rated as one of the most powerful cyclones to have affected Queensland since records commenced (Figure 56). With sustained winds of 205 km/h, gusting up to 285 km/h, and a 5 m tidal surge, the level of disturbance extended to include coastal and nearshore environments in the region.

The mean maximum daily air temperature recorded in Townsville during 2010/11 was 28.6°C; this was 0.2°C lower than the long-term (71 year) average and 1.1°C cooler than the decade average (Figure 79). The highest recorded daily maximum temperature in 2010/11 was 33.9°C.

2010/11 was a wet year relative to both the last decade and the long-term (71 year) average with approximately 70% more rain (Figure 79). More rain fell in 2010/11 than the previous monitoring period, however the 2008/09 period was the wettest since monitoring commenced. Cloud was 31% higher than long-term (71 year) and 16% higher than decade average (Figure 79). Mean wind speed in 2010/11 was 23.3 km.hr^{-1}, this was higher than the long-term but slightly lower than the decade average (Figure 79).

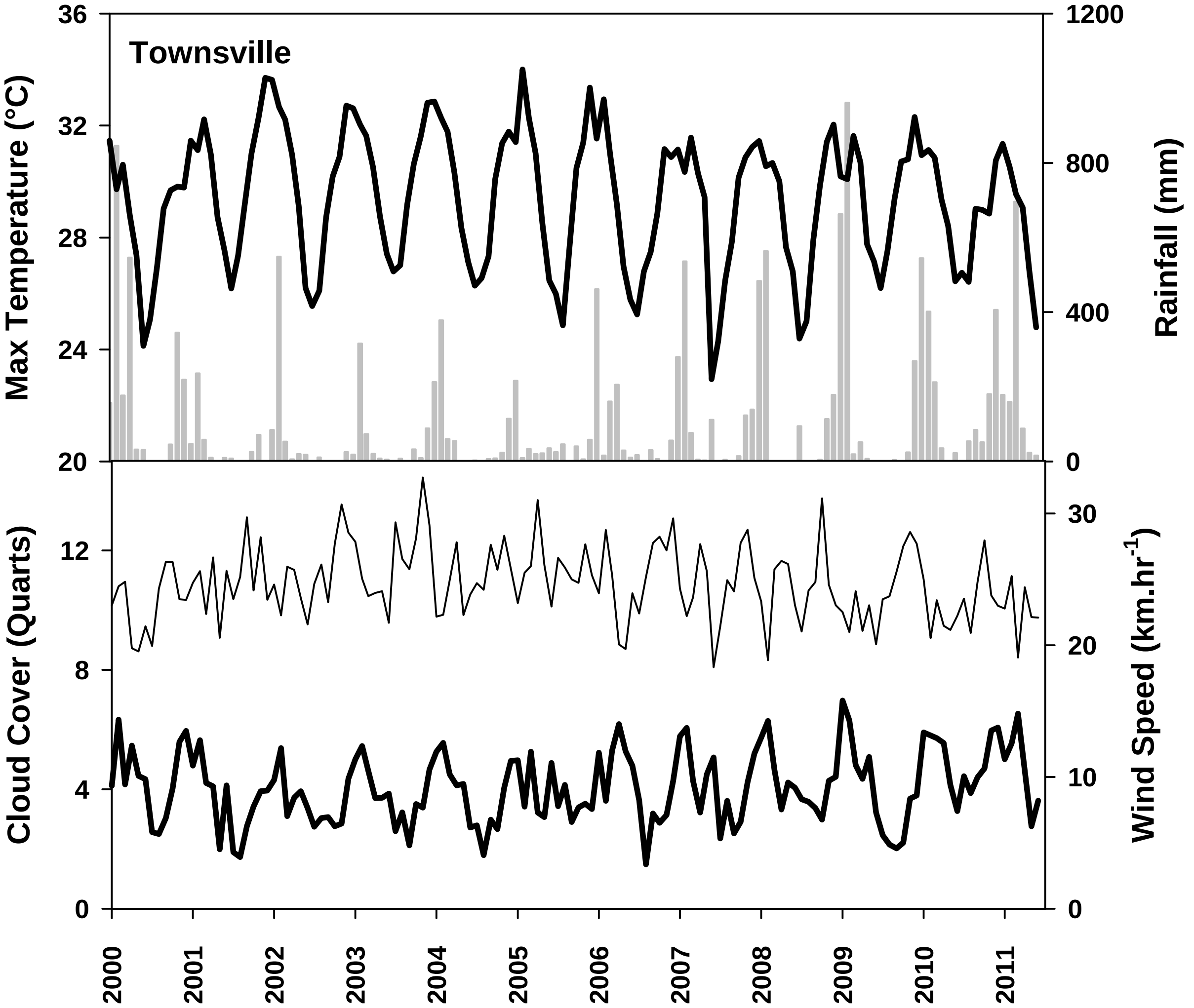


Figure 79. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr-1) recorded at Townsville Airport (BOM station 032040) (Source www.bom.gov.au). Townsville Airport used as a surrogate for the climate at coastal (Townsville) and reef (Magnetic Island) locations.*

River discharge

In the Burdekin region, the most significant river impacting seagrass meadows adjacent to Townsville is the Burdekin River. Modelling of the plumes associated with specific weather conditions has demonstrated that inshore areas between Townsville and Cooktown regularly experience extreme conditions associated with plumes. However, inshore areas north of the Burdekin River (including Magnetic Island) receive riverine waters on a less frequent basis, perhaps 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).

The exposure of the seagrass monitoring sites adjacent to Townsville and Magnetic Island to elevated Total Suspended Solids and Chlorophyll-*a* was rated as high, whereas PSII herbicides were rated as low. Overall, coastal sites had a medium to high probability of exceeding the GBR WQ Guidelines in 2010 (pers. comm. Michelle Devlin, JCU).

As the rainfall in 2010/11 was 70% higher than the decadal average, similarly the resulting discharge from the Burdekin River was significantly higher than any other period in the last decade (ANOVA, d.f.=12, F=2.18, p=0.015)(Figure 80). The river flow over the monitoring period also peaked for a longer duration with flow above 100,000 ML day^{-1} for 5 consecutive months (December 2010 to April 2011)(Figure 80).

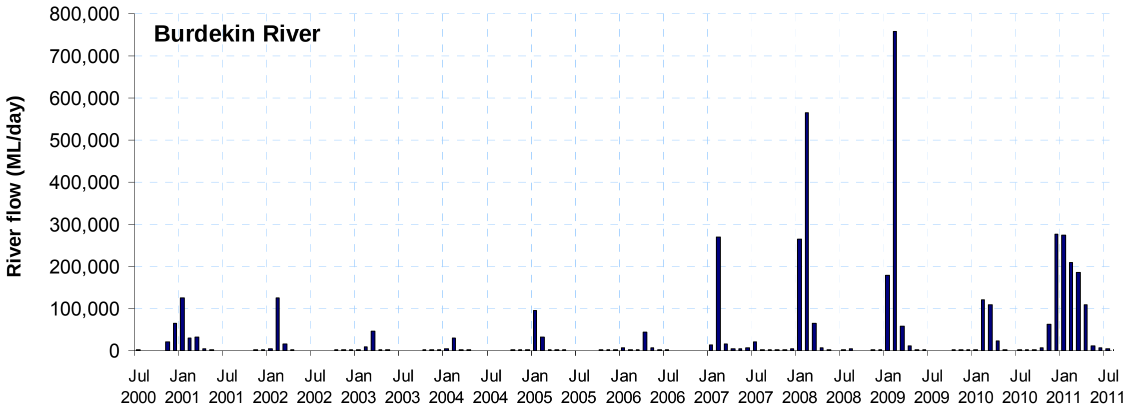


Figure 80. *Average daily flow (ML day^{-1}) per month from the Burdekin River impacting the seagrass monitoring sites in the Burdekin region (DERM station 120006B - Burdekin River at Clare, 19.75856°S 147.24362°E, Elev 29m) (source ©The State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

Mackay Whitsunday

2010/11 Summary

Intertidal seagrass meadows are found on the large sand/mud banks of sheltered estuaries and coastal fringes of the Mackay Whitsunday region; they are also present on top of the offshore fringing reefs. Key environmental drivers include exposure, desiccation and variable flood runoff during the wet season. Seagrass meadows are monitored at reef, coastal and estuarine locations in the Mackay Whitsunday region. Seagrass abundance continued to decline since 2008 to the lowest levels reported since 1999. Although seagrass cover slightly improved at reef habitats in late dry 2010, they similarly declined to one of the lowest levels since 2007 in late monsoon 2011. Meadows across the region all decreased in size, some their smallest extent since the baseline. Seed banks and reproductive effort declined across the region and were in a poor state, raising concerns about the ability of local seagrass meadows to recover from environmental disturbances. Canopy incident light and seagrass tissue nutrient concentrations indicate no improvement across region as light environments continue to decline. Tissue nutrient status indicated an increasing P pool (nutrient rich), resulting in possible N limitation to the plants. Epiphyte cover remained unchanged at reef habitats, but increased at coastal habitats and declined at estuarine habitats. Macro-algae abundance remained below the GBR long-term average and no herbicides were found above detectable limits in the sediments of the seagrass meadows across the region. Climate across the region was cooler, cooler, wetter, cloudier and calmer than the previous decade. Within canopy temperatures on average were 0.2-0.3°C cooler than the previous monitoring period. With rainfall twice that recorded on average, the average daily flow and estimated volume discharged from the main rivers was approximately twice, resulting in medium exposure to seagrass meadows by elevated TSS and high exposure to chlorophyll-*a* and PSII herbicides. Overall the status of seagrass condition in the region was rated as **very poor**.

Table 23. *Report card for seagrass status (community & environment) for the Mackay Whitsunday region: July 2010 – May 2011. 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	20	**9**
coastal intertidal	8	0	12	**7**
estuarine intertidal	0	0	9	**3**
Mackay Whitsunday	5	0	14	**6**

Background

The Mackay Whitsunday region comprises an area of almost 940,000 ha and includes the major population centres of Mackay, Proserpine, Airlie Beach and Sarina; encompassing the Proserpine, O'Connell, Pioneer and Plane Creek river systems (Australian Government Land and Coasts 2010c). The region's climate is humid and tropical with hot wet summers and cool dry winters. Annual rainfall varies substantially with as much as 3000 mm a year in elevated sections of the coastal ranges. Most (~70%) of the region's rainfall occurs between December and March. Average daily temperatures for Mackay range between 23° and 31°C in January and 11° and 22°C in July. The south-easterly trades are the prevailing winds, with occasional gale force winds occurring during cyclonic and other storm events (Mackay Whitsunday Natural Resource Management Group Inc 2005). The major industries in the Mackay Whitsunday region are agriculture and grazing, tourism, and fishing and aquaculture. Reef Plan monitoring sites are located on three of the generalised seagrass habitats represented in the region, including estuarine, coastal and reef.

Estuarine seagrass habitats in the Mackay Whitsunday region tend to be intertidal on the large sand/mud banks of sheltered estuaries. Run-off through the catchments connected to these estuaries is variable, though the degrees of variability is moderate compared to the high variability of the Burdekin and the low variability of the Tully (Brodie 2004). Seagrass in this habitat must cope with extremes of flow, associated sediment and freshwater loads from December to April when 80% of the annual discharge occurs (Figure 81).

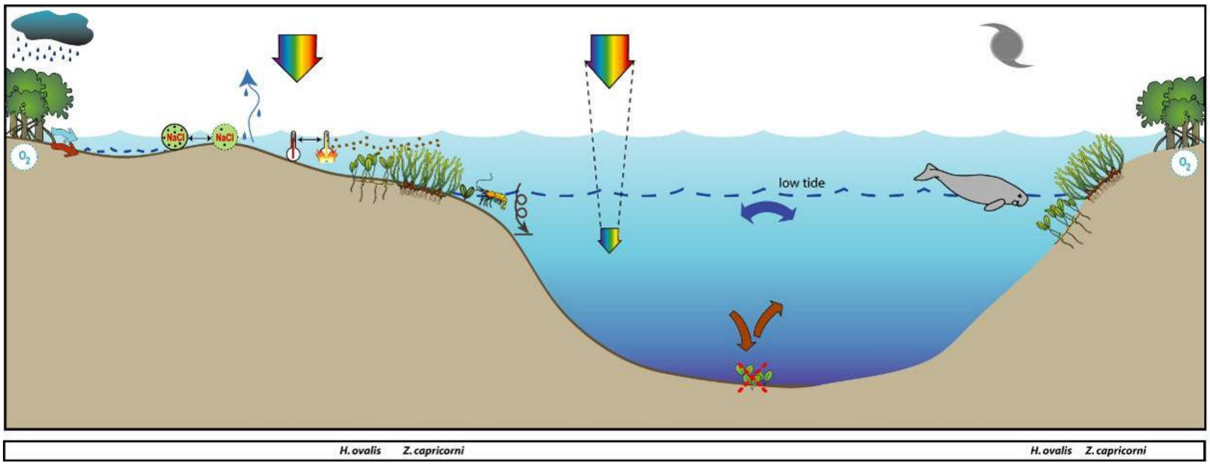


Figure 81. *Conceptual diagram of estuary habitat in the Mackay Whitsunday region: general habitat and seagrass meadow processes (see Figure 4 for icon explanation).*

Coastal seagrass habitats are found in areas such as the leeward side of inshore continental islands and in north opening bays. These areas offer protection from the south-easterly trades. Potential impacts to these habitats are issues of water quality associated with urban, marina development and agricultural land use (Figure 82). Monitoring sites of intertidal coastal seagrass habitat were located on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay.

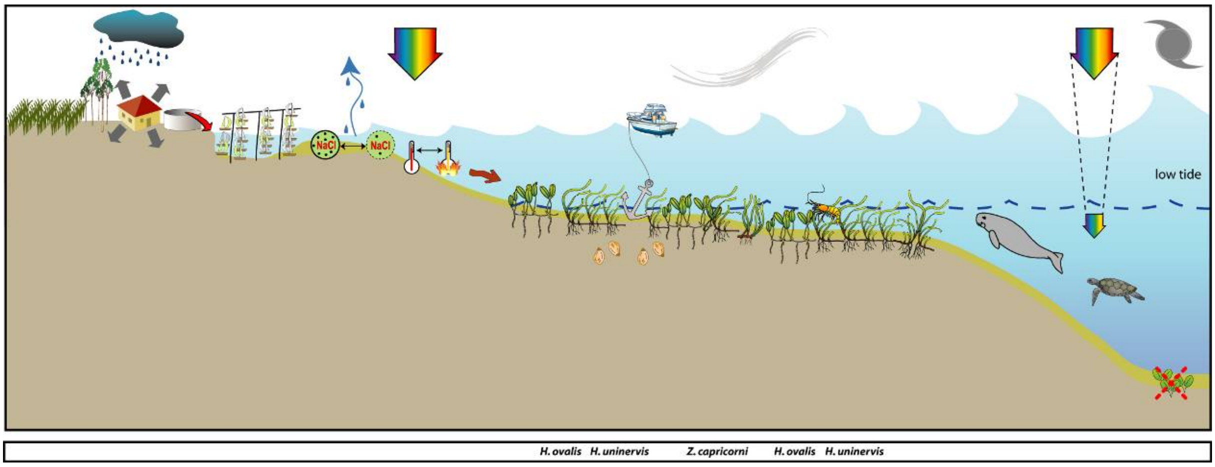


Figure 82. *Conceptual diagram of coastal habitat in the Mackay Whitsunday region – major control is shelter and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation)*

Reef habitat seagrass meadows are found intertidally on the top of the coastal fringing reefs or fringing reefs associated with the many islands in this region. The drivers of these habitats is exposure, and desiccation (intertidal meadows) (Figure 83). Major threats would be increased tourism activities including marina and coastal developments.

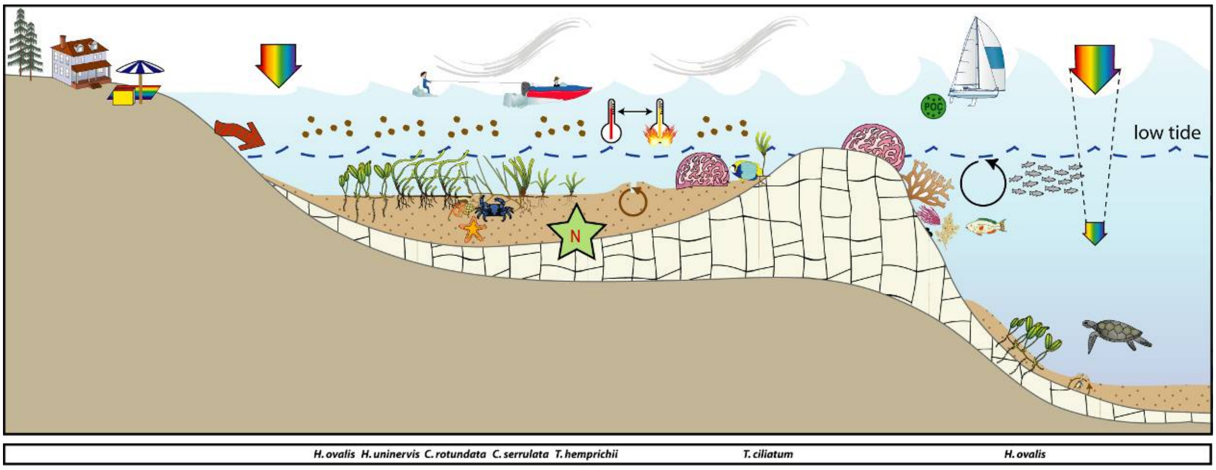


Figure 83. *Conceptual diagram of reef habitat in the Mackay Whitsunday region - major control is light and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation).*

Status of the seagrass community

Seagrass abundance and composition

The coastal seagrass monitoring sites were located on intertidal sand/mud flats adjacent to Cannonvale in southern Pioneer Bay. Seagrass abundance has fluctuated at the coastal sites between and within years indicating disturbance regimes at longer time periods than annually (Figure 85). Abundances during the 2010 calendar year were low, declining to the lowest levels since 1999 in the late monsoon 2011. The meadows were dominated by *Halodule uninervis* and *Zostera capricorni* mixed with *Halophila ovalis*. Species composition has changed over the past decade of monitoring (Figure 84), with the composition of *Z. capricorni* in the Pioneer Bay site 2 (PI2) fluctuating greatly. In late monsoon 2011, the seagrass meadows were predominately *H. uninervis* (Figure 84).

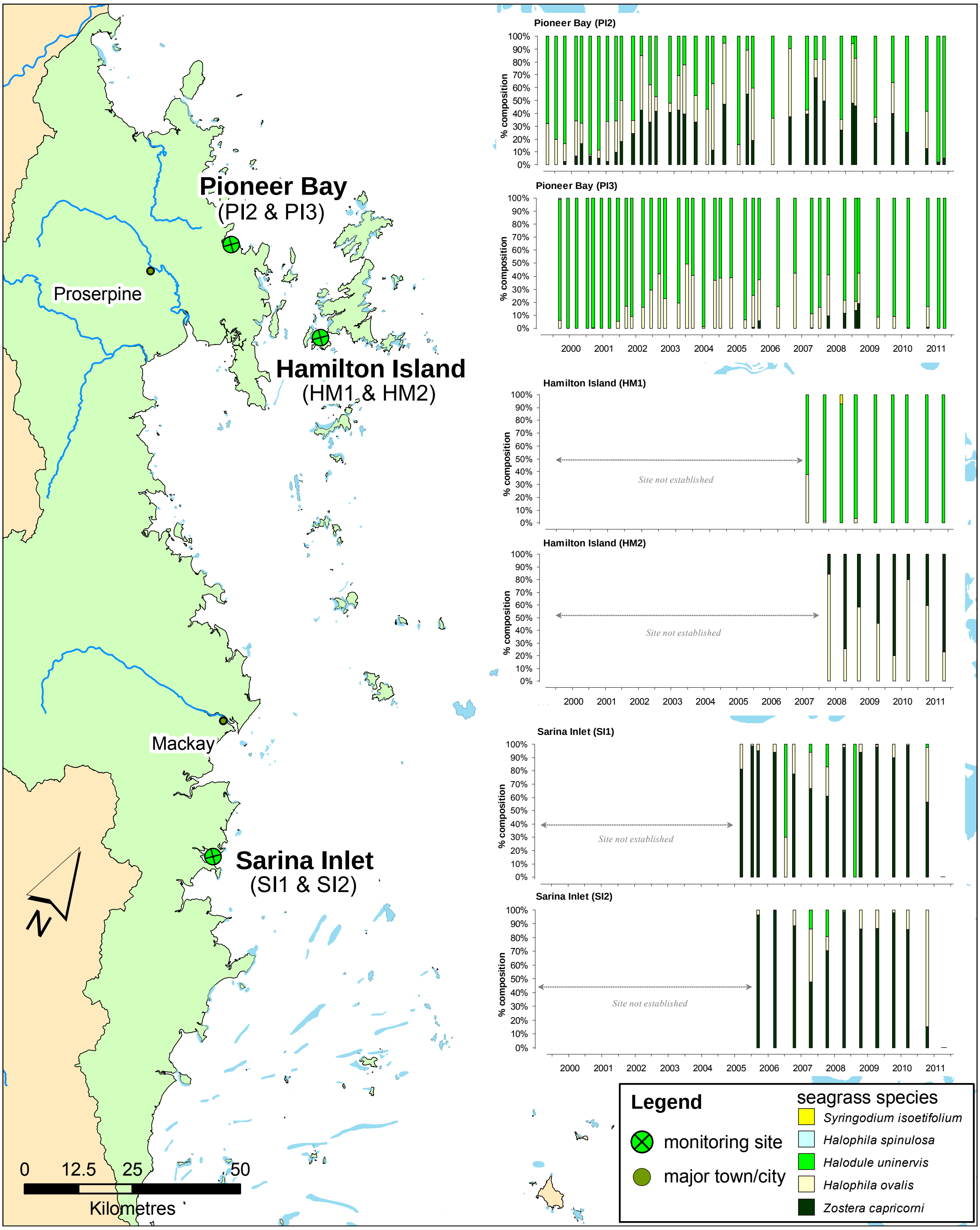


Figure 84. *Location of Mackay Whitsunday region long-term monitoring sites and the seagrass species composition at each site. Please note: replicate sites within 500m of each other.*

A seasonal pattern in abundance is generally observed at Pioneer Bay, with abundances increasing throughout the year to the monsoon (Figure 86).

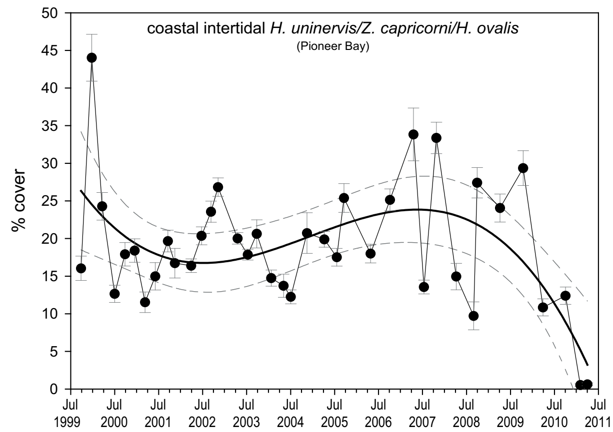


Figure 85. *Changes in seagrass abundance (% cover ±Standard Error) at coastal intertidal meadows in the Mackay Whitsunday region from 1999 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.338.*

Quadrat at 5m on transect 3 at Pioneer Bay site 2 (PI2), on 7 October 2010 (left) and 17 April 2011 (right).

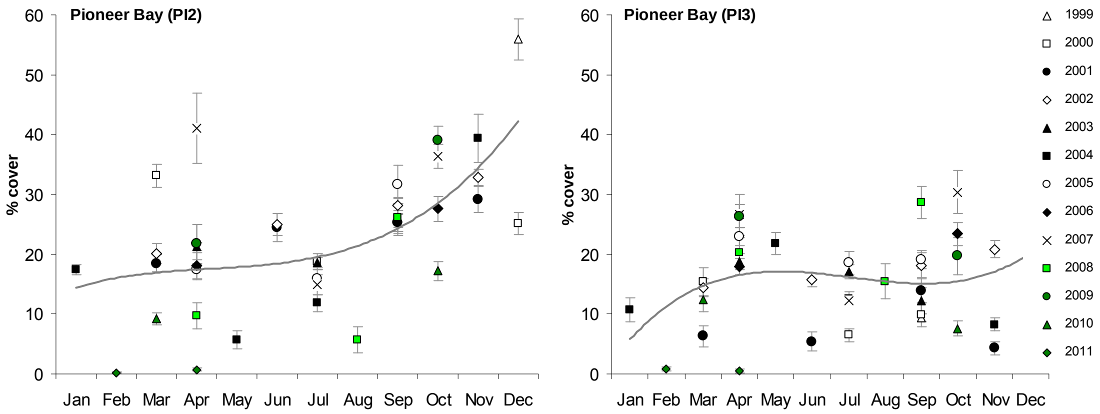


Figure 86. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Pioneer Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

The estuarine monitoring sites are located on an intertidal sand/mud bank in Sarina Inlet south of Mackay. These sites are dominated by *Zostera capricorni* with some *Halophila ovalis* (Figure 84). Seagrass cover has fluctuated greater since monitoring was established in early 2005, with seagrass dramatically declining in the late wet season of 2006, and recovering within 18 months, to only start declining again in 2008 (Figure 87). Seagrass cover has continued to decline at Sarina Inlet since 2008

(Figure 87), but although there is insufficient spread of sampling across months within years, the seagrass abundance appears greater in the late dry than late monsoon (Figure 88).

Seagrass meadow on the intertidal mud banks in Sarina Inlet site 1 (SI1): 08 October 2010.

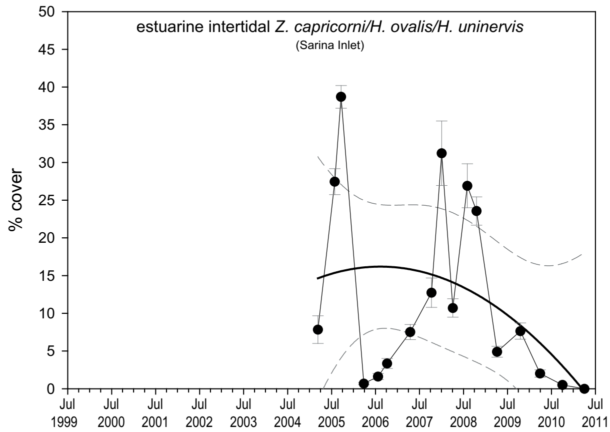
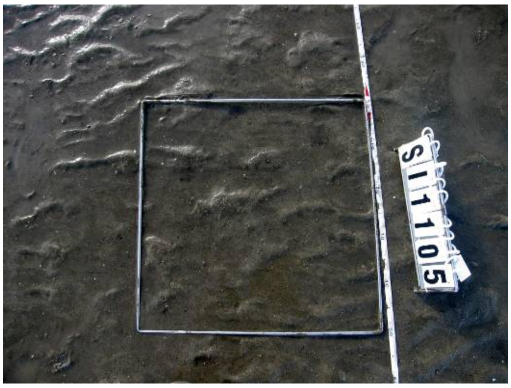


Figure 87. *Changes in seagrass abundance (% cover ±Standard Error) at estuarine intertidal meadows in the Mackay Whitsunday region from 1999 to 2011. Trendline is 2nd order polynomial, 95% confidence intervals displayed, r^2 = 0.163.*



Quadrat at 5m on transect 1 at Sarina Inlet site 1 (SI1), on 8 October 2010 (left) and 16 April 2011 (right).

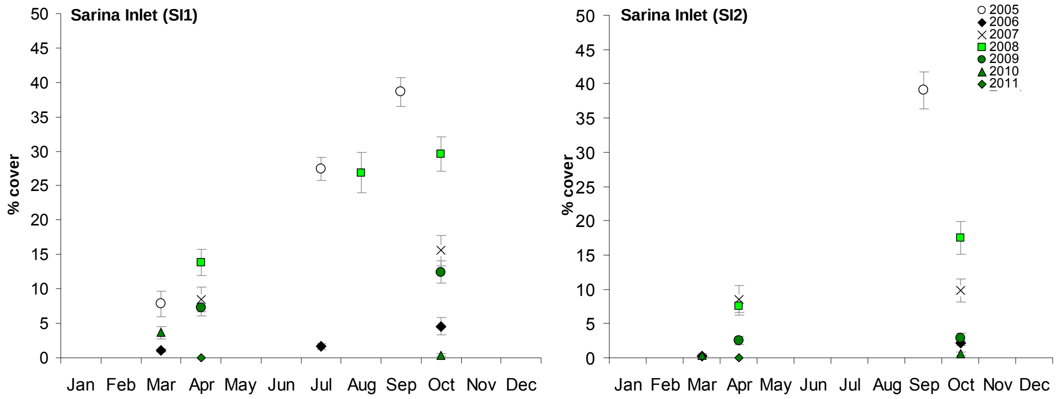


Figure 88. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Sarina Inlet long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

The reef monitoring sites are located on an intertidal fringing reef at Catseye Bay (Hamilton Island). These sites are dominated by *Halodule uninervis* or *Zostera capricorni* with some *Halophila ovalis* (Figure 84). The site at the eastern end of Catseye Bay (HM2) was dominated by *Z. capricorni* and the site at the western end (HM1) was dominated by *H. uninervis*. Seagrass cover slightly improved in late dry 2010, however declined to one of the lowest levels since 2007 in late monsoon 2011 (Figure 89). Seagrass cover appears to increase during each year until the monsoon (Figure 90).

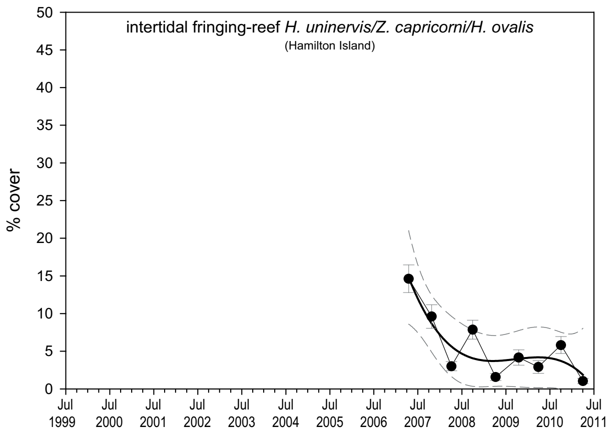


Figure 89. *Changes in seagrass abundance (% cover ±Standard Error) at reef intertidal meadows in the Mackay Whitsunday region from 1999 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.795.*

Halodule uninervis meadow at Hamilton Island site 1 (HM1) in front of main resort (left) and with dugong grazing trail in foreground at Hamilton Island site 2 (HM2) (right): 6 October 2010.

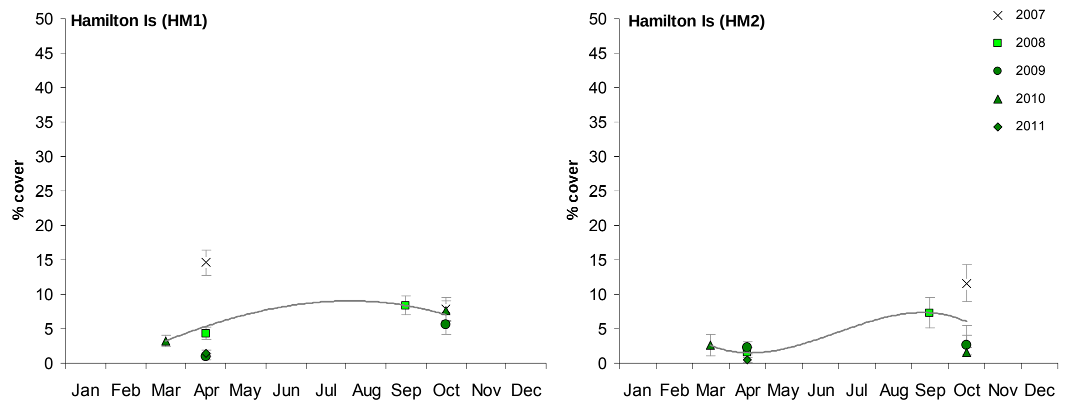


Figure 90. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Hamilton Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Table 24) to determine if changes in abundance were a consequence of the meadow edges changing. Over the past 12 months, meadows across the region all decreased in late monsoon 2011 after increasing in late dry 2010 (Table 24, Figure 92). The coastal and estuarine meadows, at Pioneer Bay and Sarina Inlet respectively, decreased to their lowest extent below the baseline (Table 24, Figure 92).

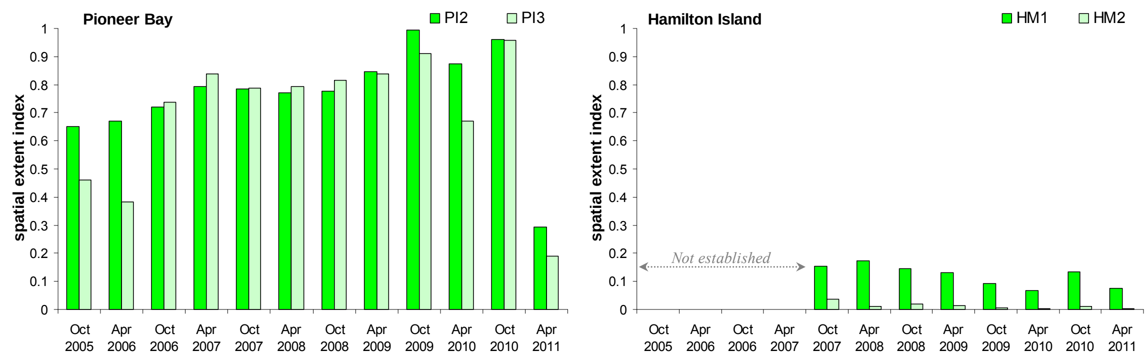


Figure 91. *Extent of area (100m radius of monitoring site) covered by seagrass at each coastal (Pioneer Bay) and reef (Hamilton Is) monitoring locations.*

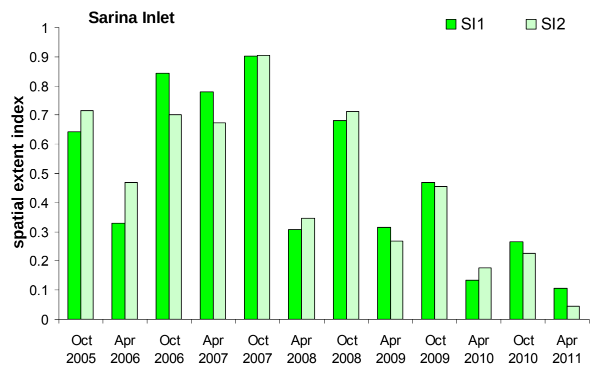


Figure 92. *Extent of area (100m radius of monitoring site) covered by seagrass at estuarine (Sarina Inlet) monitoring sites.*

Table 24. *Area (ha) of seagrass meadow within 100m radius of site. Value in parenthesis is % change from the baseline (bold) and description of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.*

	Pioneer Bay		Hamilton Island		Sarina Inlet	
	PI2	**PI3**	**HM1**	**HM2**	**SI1**	**SI2**
October 2005 (baseline)	**3.432**	**2.432**	*NA*	*NA*	**3.374**	**3.747**
April 2006	3.534 *(3.0%, increase shoreward)*	2.026 *(-16.7%, decrease shoreward)*	*NA*	*NA*	1.726 *(-48.8%, decrease seaward)*	2.46 *(-34. %,3 decrease shoreward)*
October 2006	3.812 *(11.1%, increase shoreward)*	3.891 *(60%, increase shoreward)*	*NA*	*NA*	4.425 *(31.2%, increase shoreward)*	3.679 *(-1.8%, decrease seaward)*
April 2007	4.193 *(22.2%, increase shoreward)*	4.418 *(81. %, increase shoreward)*	*NA*	*NA*	4.092 *(21.0%, increase shoreward)*	3.536 *(-5.6%, decrease seaward)*
October 2007	4.145 *(20.8%, decrease seaward)*	4.159 *(71%, decrease seaward)*	**0.810**	**0.164**	4.736 *(40.4%, increase overall)*	4.739 *(26.5%, increase overall)*
April 2008	4.068 *(18.5%, decrease seaward)*	4.183 *(72%, increase shoreward)*	0.917 *(13.2 %, increase shoreward)*	0.05 *(69.2%, decrease overall)*	1.608 *(52.4%, decrease overall)*	1.821 *(51.4%, decrease overall)*
October 2008	4.094 *(19.3%, increase shoreward)*	4.300 *(76.8%, increase shoreward)*	0.763 *(5.8 %, decrease overall)*	0.09 *(44.4%, increase overall)*	3.58 *(6.15%, increase overall)*	3.732 *(0.4%, increase overall)*
April 2009	4.471 *(30.2%, increase shoreward)*	4.430 *(82.2%, negligible)*	0.687 *(15.2 %, decrease overall)*	0.06 *(64.1%, decrease overall)*	1.661 *(50.8%, decrease overall)*	1.409 *(62.4%, decrease overall)*
October 2009	5.247 *(52.9%, increase shoreward)*	4.814 *(97.9%, increase shoreward)*	0.491 *(-39.4%, decrease overall)*	0.023 *(-85.8%, decrease overall)*	2.467 *(26.9%, increase overall)*	2.393 *(36.1%, increase overall)*
April 2010	4.615 *(34.5%, decrease seaward)*	3.539 *(45.5%, decrease seaward)*	0.356 *(-56%, decrease overall)*	0.016 *(-89.7%, decrease overall)*	0.698 *(-253.5%, decrease overall)*	0.916 *(-161.2%, decrease overall)*
October 2010	5.071 *(47.8%, increase shoreward)*	5.063 *(108.2%, increase shoreward)*	0.715 *(-11.7%, increase overall)*	0.052 *(-68.4%, increase overall)*	1.393 *(-58.7%, increase overall)*	1.191 *(-68.2%, increase overall)*
April 2011	1.544 *(-55%, decrease seaward)*	1.001 *(-58.8%, decrease seaward)*	0.400 *(-50.7%, decrease overall)*	0.019 *(-88.6%, decrease overall)*	0.559 *(-83.4%, decrease overall)*	0.241 *(-93.6%, decrease overall)*

Seagrass reproductive status

Seed banks across the region continued to decline over the 2010/11 monitoring period, although seed banks have remained low since 2005 (Figure 93, Figure 94). No seeds and very few reproductive structures were reported from reef habitats. The lack of reproductive effort at Sarina Inlet coincides with the loss of seagrass at this site.

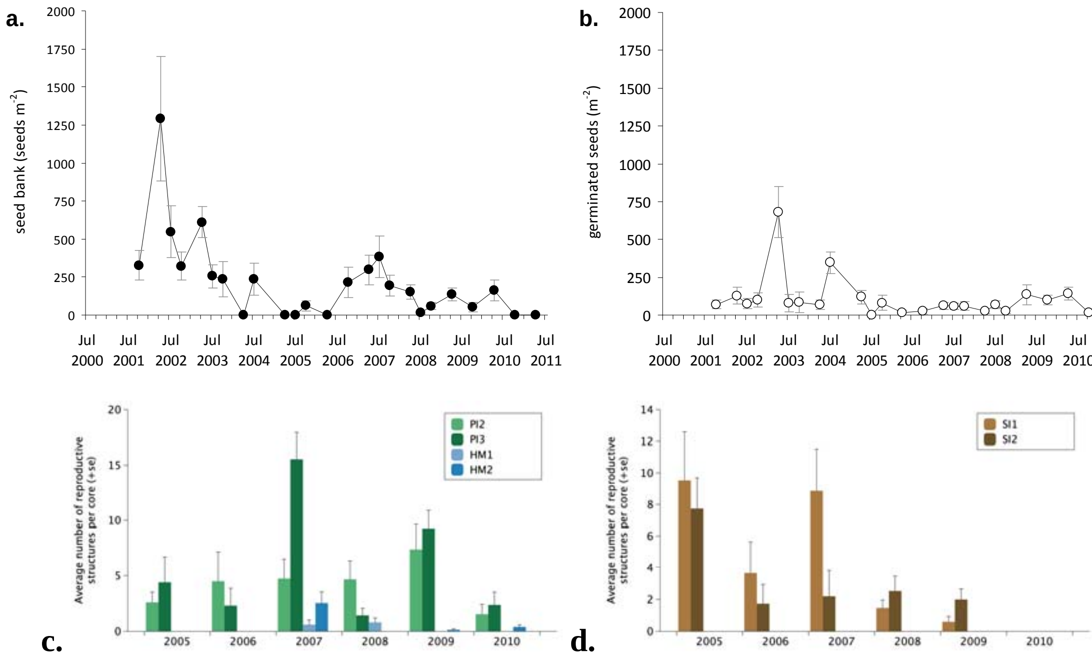


Figure 93. *Halodule uninervis seed bank (a) and germinated seed abundance (b) at coastal habitats in the Mackay Whitsunday region (seed bank is represented as the total number of seeds per m^2 sediment surface) and (c) average total number of reproductive structures per core for sites in the Mackay Whitsunday region.*

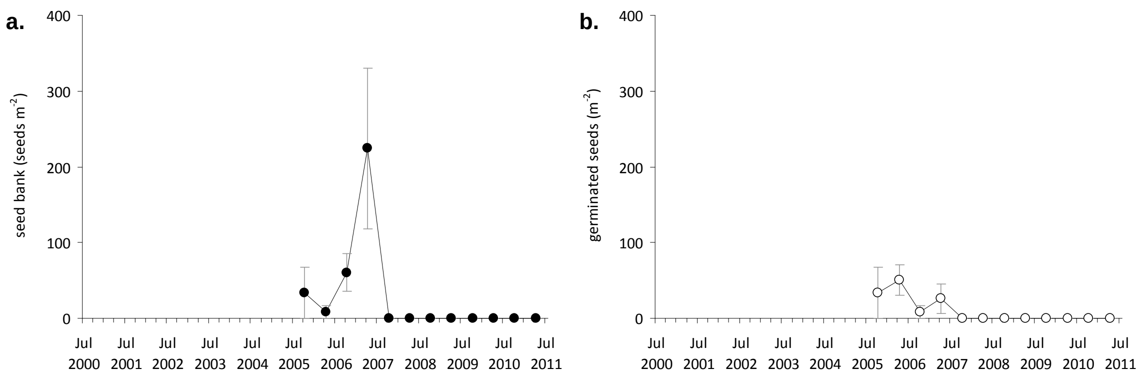


Figure 94. *Halodule uninervis seed bank (a) and germinated seed abundance (b) at estuary habitats in the Mackay Whitsunday region (seed bank is represented as the total number of seeds per m^2 sediment surface).*

Reproductive effort across the whole Mackay Whitsunday region is classified as very poor in 2010 and declining compared to previous years. This suggests that sites within the region will take longer to recover following larger scale disturbance and may be at risk from repeated impacts.

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass tissue C:N ratios in the Mackay Whitsunday region have all remained below 20 since 2007 (Figure 95), and all decreased in 2010 compared to 2009, indicating reduced light availability. Levels of C:N substantially decreased in 2010 and at their lowest since measurement commenced.

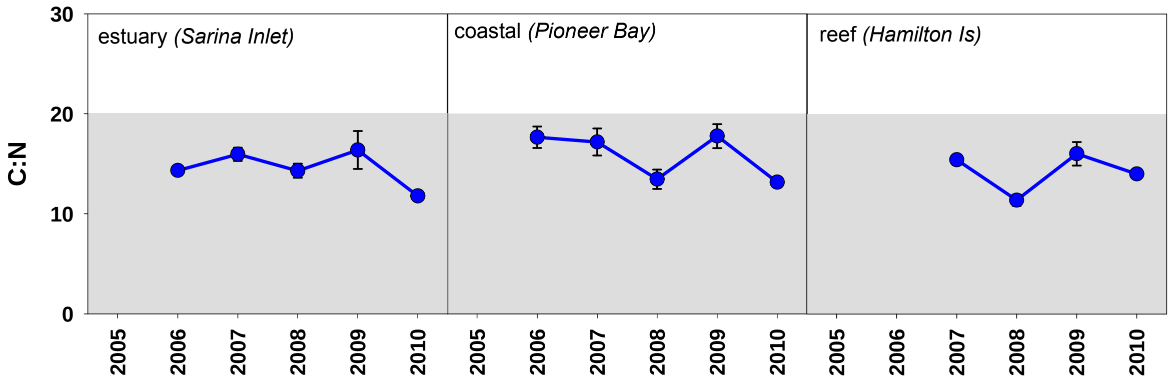


Figure 95. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in Mackay Whitsunday region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability.*

The C:P ratios of foundation seagrass species in the Mackay Whitsunday region decreased in 2010 across all habitats compared to the previous monitoring period (Figure 96). This indicates meadows have increasing P pools (nutrient rich).

N:P ratios within the Mackay Whitsunday region declined across all habitats in 2010 compared to 2009, however there is no consistent long-term trend (Figure 96). In 2010, N:P ratios all declined to below 25, indicating possible N limitation to the plants.

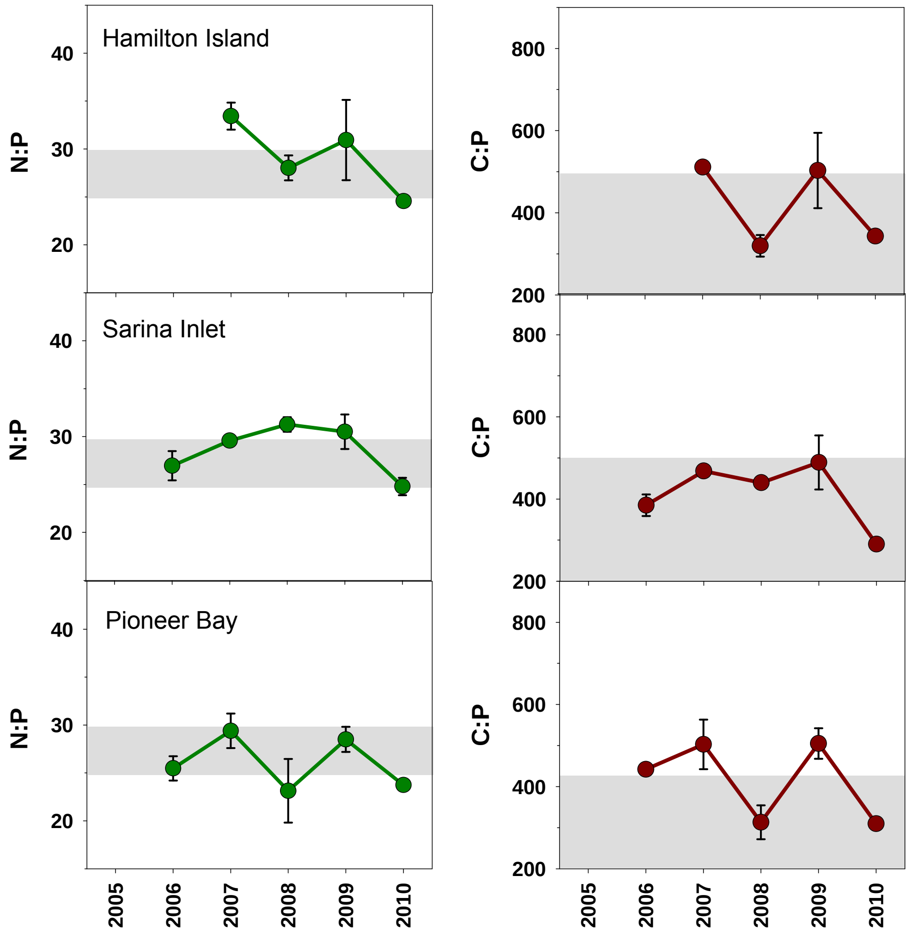


Figure 96. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in Mackay Whitsunday region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith, 1983; Duarte, 1990; Fourqurean et al., 1992; Fourqurean & 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 macro-algae

Epiphyte cover on seagrass leaf blades was highly variable across the region (Figure 97, Figure 98, Figure 99). Although epiphyte cover appears seasonal, with higher abundance in the late dry season of each year, cover at coastal sites over the 2010/11 period was higher than the previous monitoring period (Figure 97). Epiphyte cover declined at the estuarine habitat sites (Sarina Inlet) over the monitoring period and remained below the long-term average (Figure 98)

Percentage cover of macro-algae at all habitats during the 2010/11 monitoring period and was below the GBR long-term average for each respective habitat (Figure 97, Figure 98, Figure 99).

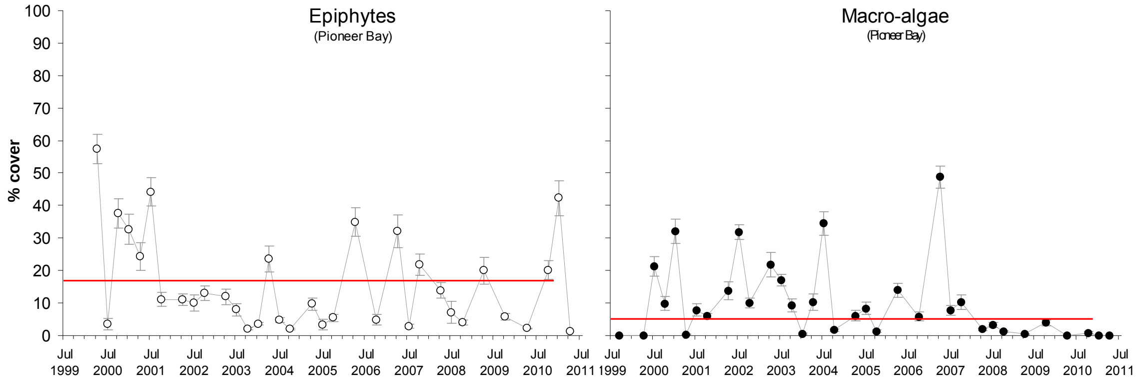


Figure 97. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal coastal (Pioneer Bay) seagrass monitoring sites. Red line = GBR long-term average; epiphytes=17%, macro-algae=4.7%.*

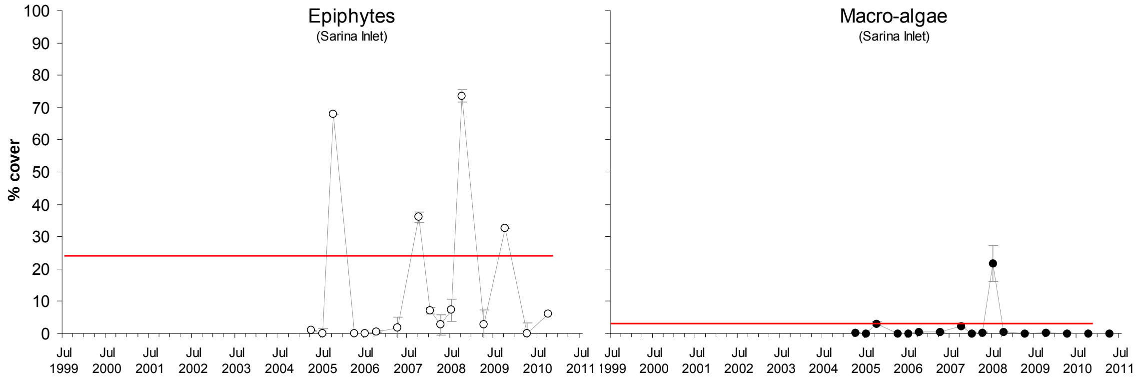


Figure 98. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at estuarine (Sarina Inlet) seagrass monitoring sites. Red line = GBR long-term average; epiphytes=25%, macro-algae=3.2%.*

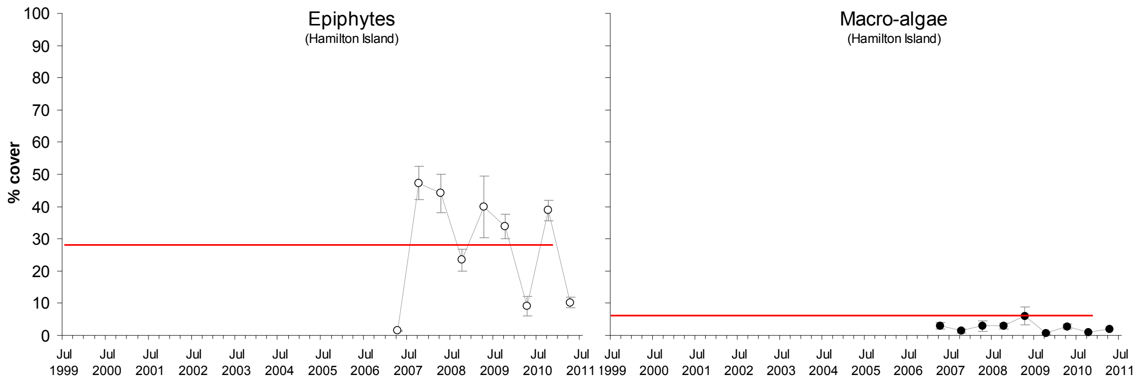


Figure 99. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal reef seagrass monitoring location. Red line = GBR long-term average; epiphytes=28%, macro-algae=6.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows across the Mackay Whitsunday region (Table 25).

Table 25. *Concentration of herbicides (mg kg^{-1}) in sediments of Pioneer Bay, Hamilton Island and Sarina Inlet seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
PI2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
PI3	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
HM1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
HM2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
SI1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
SI2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within meadow canopy temperature

Temperature loggers were deployed at all sites monitored in the region (Figure 100). Within canopy temperature at coastal and estuarine locations (Figure 100) generally follows a similar pattern. No extreme temperatures (>40°C) were recorded over the last 12 months. Maximum temperatures peaked several times throughout the year at all locations, generally during the time of low spring tide (Figure 100).

Mean within canopy temperatures monitored at Pioneer Bay were within the 22 – 30°C range, with highest mean temperatures in March 2011. Hamilton Island within canopy temperatures were slightly lower within the 21-29°C range and similar to Pioneer Bay recording highest temperatures in March 2011. At Sarina Inlet, within canopy temperatures were slightly cooler again within 20-29°C range and the warmest month on average was February 2011 (Figure 101). Within canopy temperatures on average were 0.2-0.3°C cooler over the last monitoring period than the previous monitoring period.

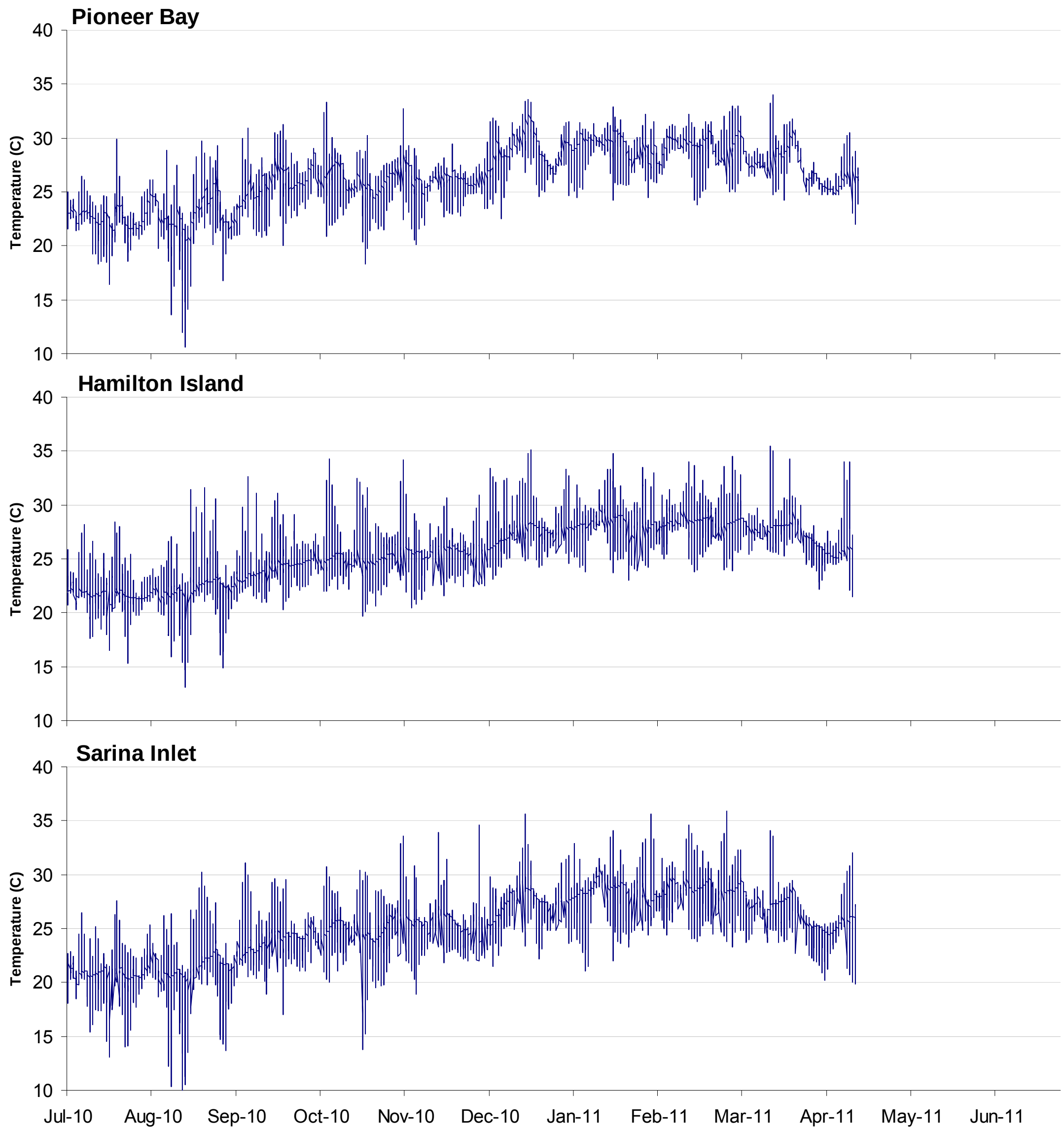


Figure 100. *Within seagrass canopy temperature (°C) at coastal (Pioneer Bay), estuarine (Sarina Inlet) and offshore fringing-reef (Hamilton Island) intertidal meadows within the Mackay Whitsunday region over the 2010/11 monitoring period.*

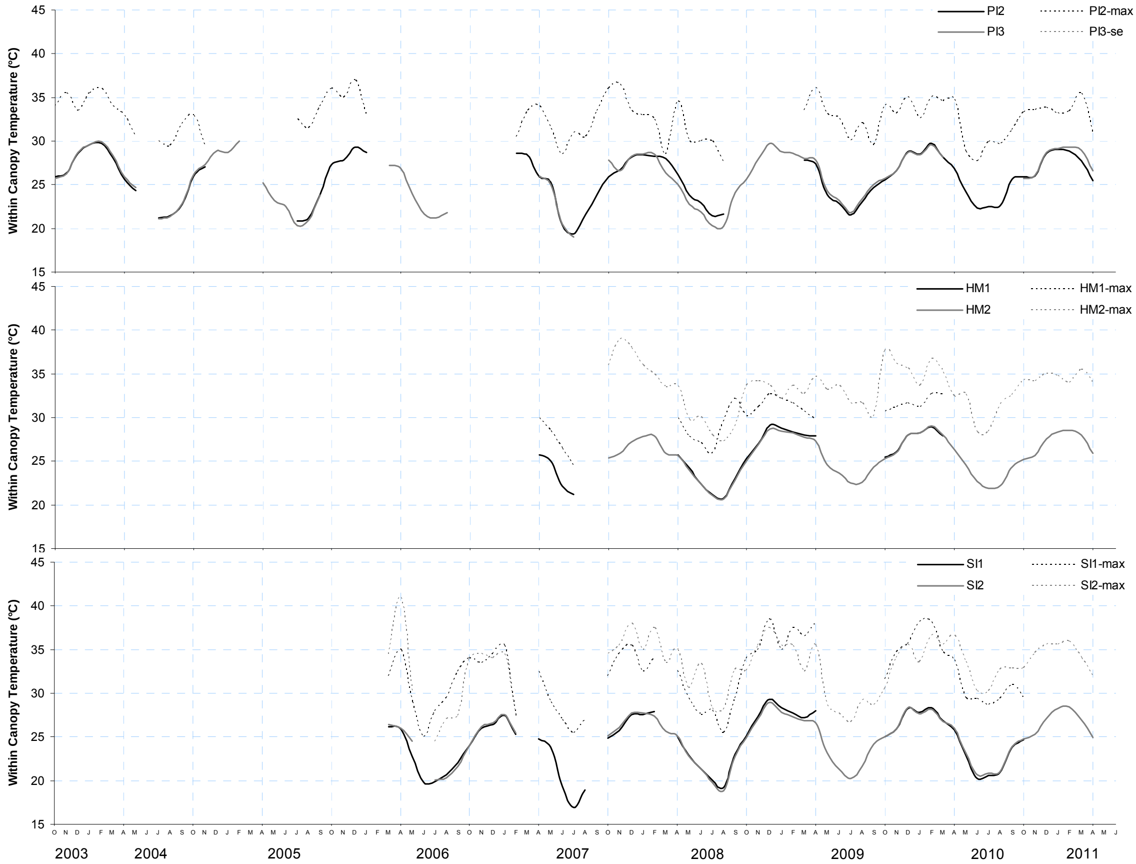


Figure 101. *Monthly mean and maximum within seagrass canopy temperature (°C) at intertidal meadows in coastal (Pioneer Bay), fringing-reef (Hamilton Island) and estuarine (Sarina Inlet) habitats within the Mackay Whitsunday region.*

Canopy incident light

At Pioneer Bay, I_d was on average 7.9 mol m^{-2} d^{-1} which was low compared to most other intertidal sites. I_d was generally highest during the late dry season. There are no data for the 2011 wet season, as the light logger unit was lost. During the 2010 wet season, average I_d was below MLR for an extended period (4 months) (Figure 103). This is consistent with large declines in seagrass percent cover during the 2010 wet season.

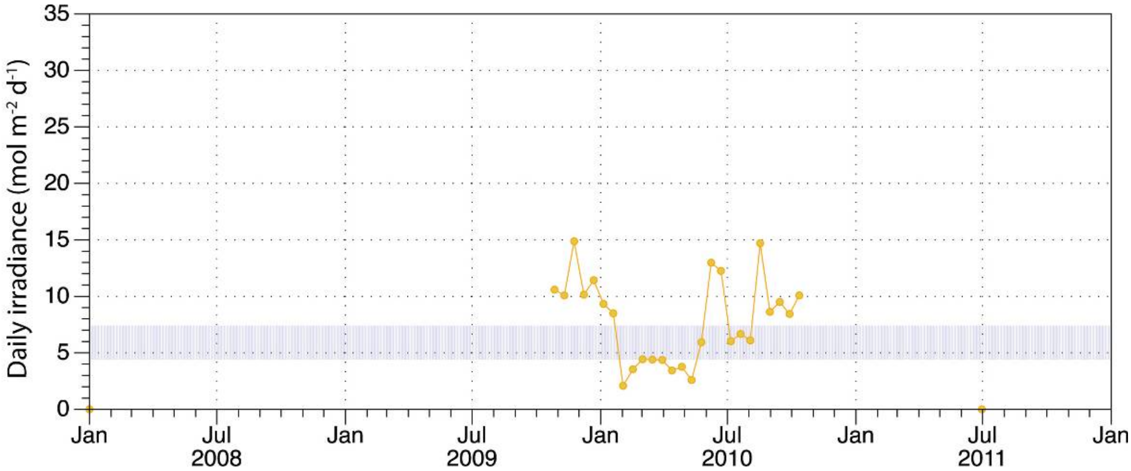


Figure 102. *Daily irradiance (14-day average) at Pioneer Bay. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

At Sarina Inlet, I_d was on average 10.8 mol m^{-2} d^{-1} and during the 2010-2011 wet season was 8.7 mol m^{-2} d^{-1} (Figure 103). There is insufficient data to describe trends at this site.

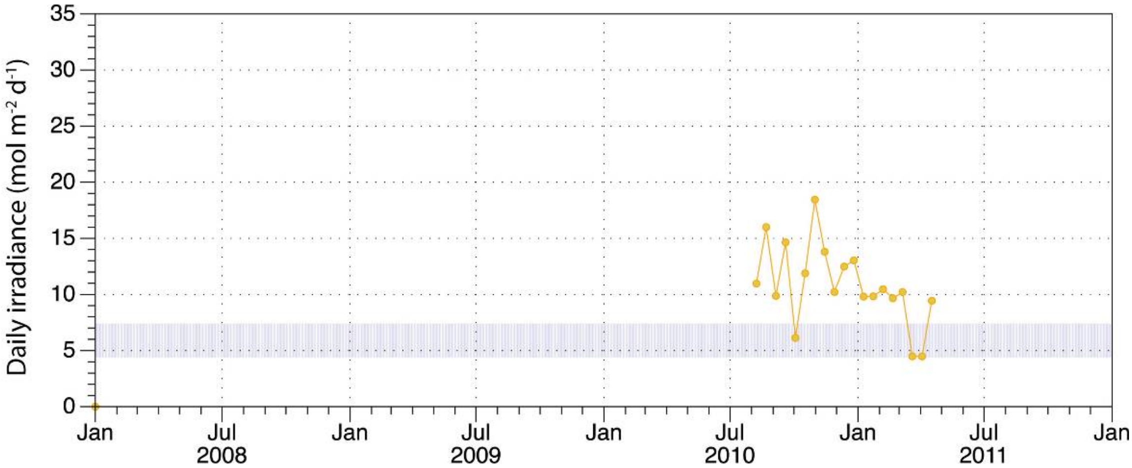


Figure 103. *Daily irradiance (14-day average) at Sarina Inlet. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

At Hamilton Island, I_d was one of the highest of all monitoring sites, being, on average, 16.3 mol m^{-2} d^{-1} (Figure 104). There was a short reduction in I_d in the late 2010/11 wet season and future monitoring will indicate whether this was just a short aberration.

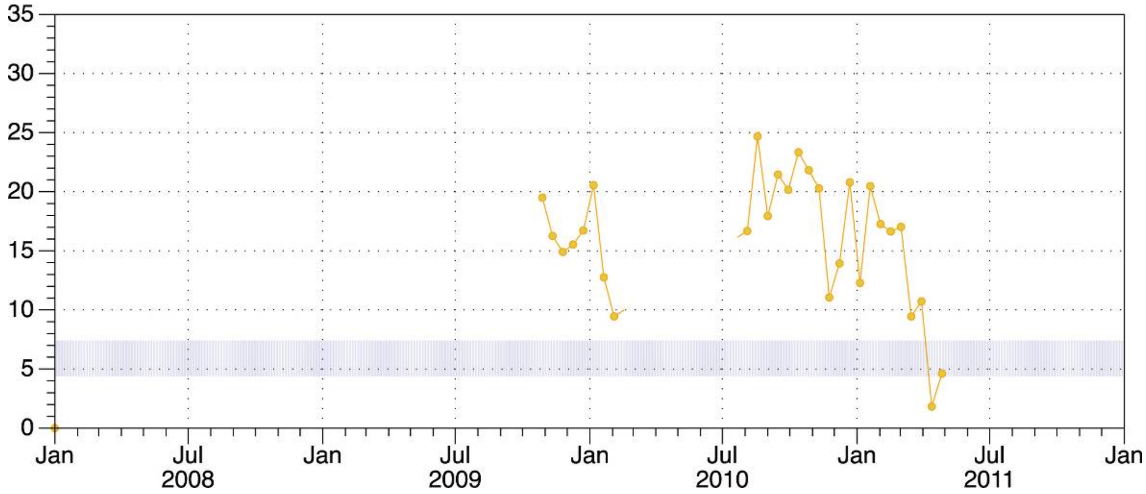


Figure 104. *Daily irradiance (14-day average) at Hamilton Island. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

Regional Climate

Climate across the Mackay Whitsunday region during the 2010/11 monitoring period was cooler, cooler, wetter, cloudier and calmer than the previous decade.

Whitsundays – Hamilton Island and Pioneer Bay

The mean maximum daily air temperature recorded at Hamilton Island during 2010/11 was 23.7°C, this was less than both the previous 6 years and long-term (17 year) averages (Figure 105). The highest recorded daily maximum temperature in 2010/11 was 31.1 °C.

2010/11 was a wet year, with nearly twice the amount of rain falling over the period than recorded in both the last 6 years and the long-term (17 year) averages (Figure 105). Mean wind speed in 2010/11 was 28.9 km.hr^{-1}, this was higher than the long-term (17 year) but slightly lower than experienced over the last 6 years on average (Figure 105).

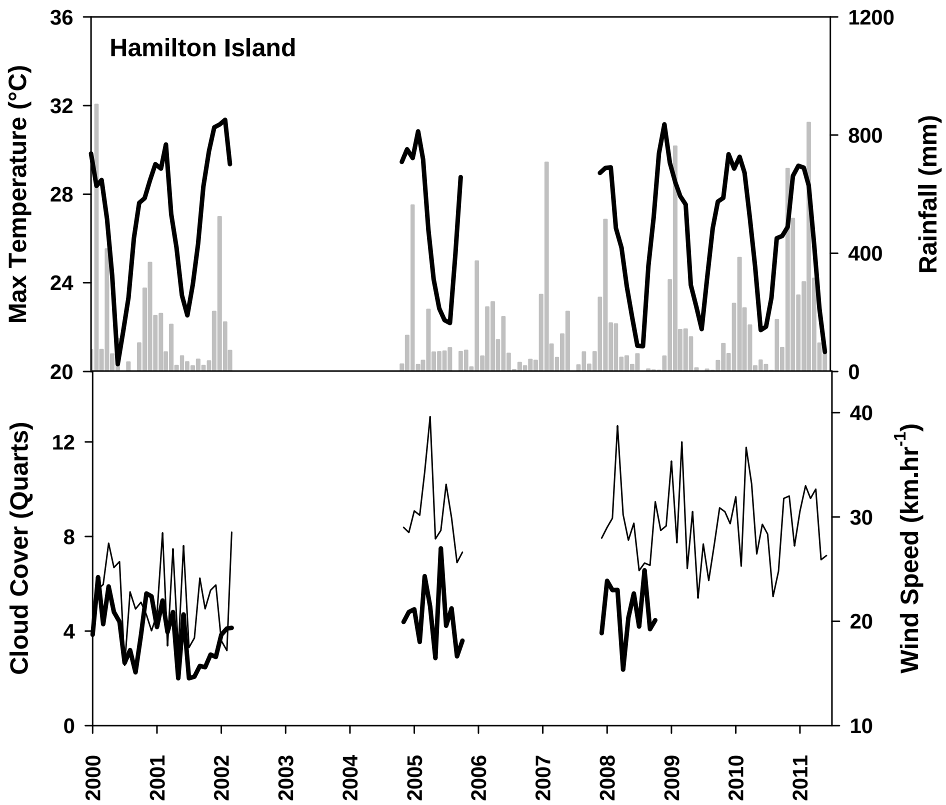


Figure 105. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr^{-1}) recorded at Hamilton Island (BOM station 033106) (Source www.bom.gov.au). Hamilton Island also used as a surrogate for the climate at Pioneer Bay.*

Mackay – Sarina Inlet

The mean maximum daily air temperature recorded in Mackay during 2010/11 was 25.9°C, this was 1.2°C cooler than the long-term (61 year) average and 1.4°C cooler than the decade average. The highest recorded daily maximum temperature in 2010/11 was 32.8°C.

2010 was a wet year relative to the last decade and the long-term (61 year) average, with 138% and 111% more rainfall (Figure 106). Cloud cover was approximately 14% higher than the long-term and decade averages. Mean wind speed in 2010/11 was 17.4 km.hr^{-1}, this was more than 20% less than the both the long-term and decade averages.

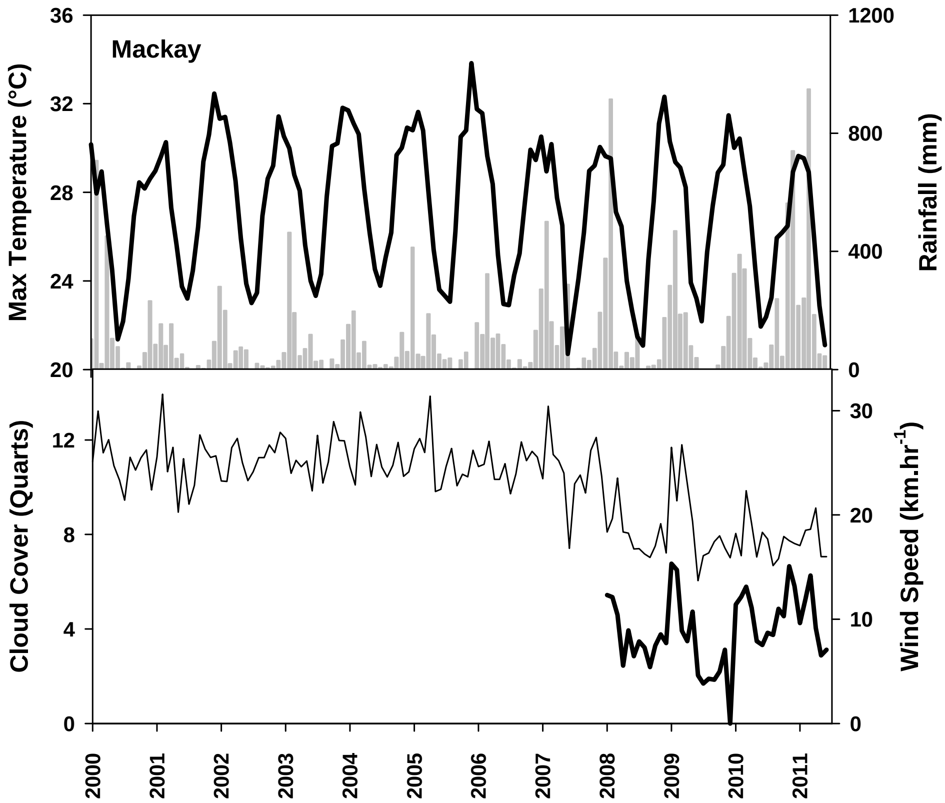


Figure 106. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr-1) recorded at Mackay Airport (BOM station 033045) (Source www.bom.gov.au). Mackay Airport used as a surrogate for the climate at Sarina Inlet.*

River discharge

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). No major river discharges into Sarina Inlet where the estuarine seagrass monitoring sites are located, however it could be expected that flows from the Pioneer River during floods could travel south for some extent to expose Sarina Inlet (30 km to the south) to primary-secondary plumes.

The exposure of the seagrass monitoring sites to elevated Total Suspended Solids was rated as medium in 2010, whereas chlorophyll-*a* and PSII herbicide exposure was rated as high. Overall, the probability of exceeding the GBR WQ Guidelines for chlorophyll-*a* at estuarine sites was high*,* reef sites was medium-high and coastal sites was medium (pers. comm. Michelle Devlin, JCU).

As the rainfall in 2010/11 was twice that recorded on average, the average daily flow of the Proserpine River was significantly higher than any other period in over the last decade (ANOVA, d.f.=12, F=3.49, p<0.001)(Figure 107). Although the daily flows from the O'Connell and Pioneer Rivers were not significantly different to previous monitoring periods (ANOVA, d.f.=4, F=0.93, p=0.45 and ANOVA, d.f.=4, F=1.76, p=0.15, O'Connell and Pioneer respectively), the estimated volume discharged over the 2010/11monitoring period (591,395 ML and 3,379,131 ML, O'Connell and Pioneer respectively) was approximately twice that discharged in any other monitoring period since monitoring was established at Sarina Inlet (Figure 107, Figure 108). Such high discharge would be expected to exposure seagrass meadows across the region to periods of reduced light, and increase nutrient and herbicide loading.

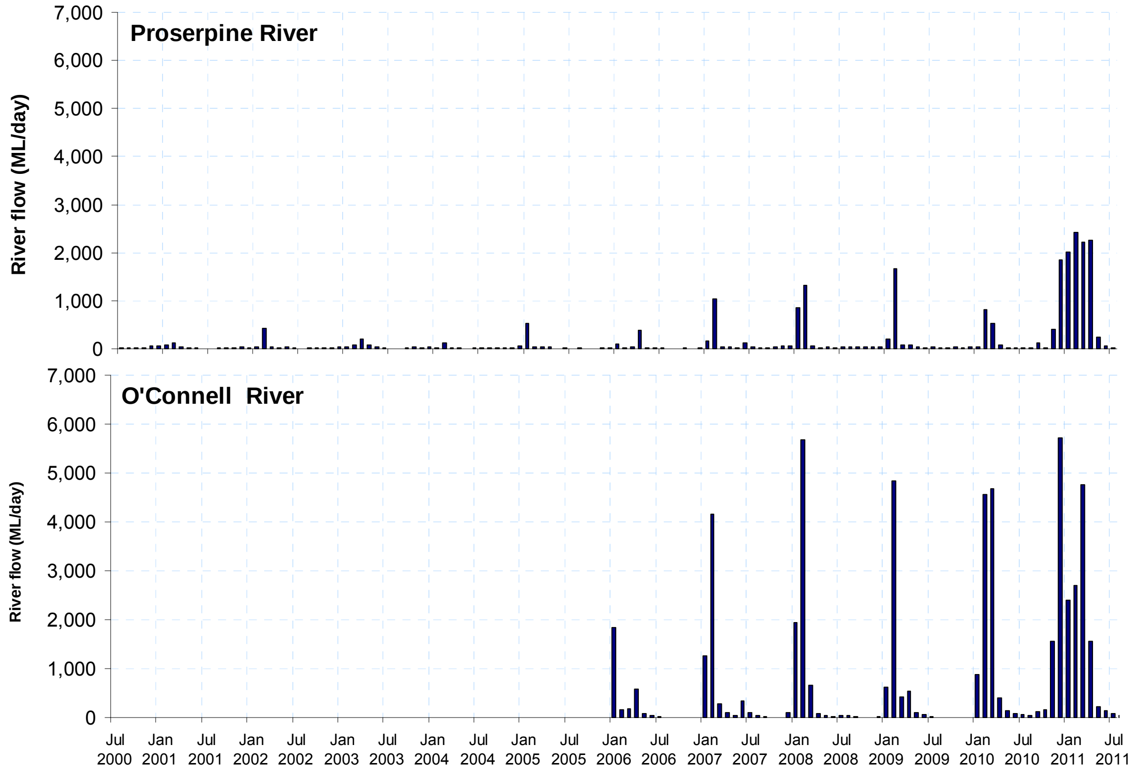


Figure 107. *Average daily flow (ML day^{-1}) per month from the main rivers impacting coastal and reef seagrass monitoring sites in the Mackay Whitsunday region (DERM station 122005A - Proserpine River at Proserpine, 20.39166667°S 148.59833333°E, Elev 7m; 124001B - O'Connell River at Stafford's Crossing 20.65255556°S 148.573°E, Elev:0m) (source ©The State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

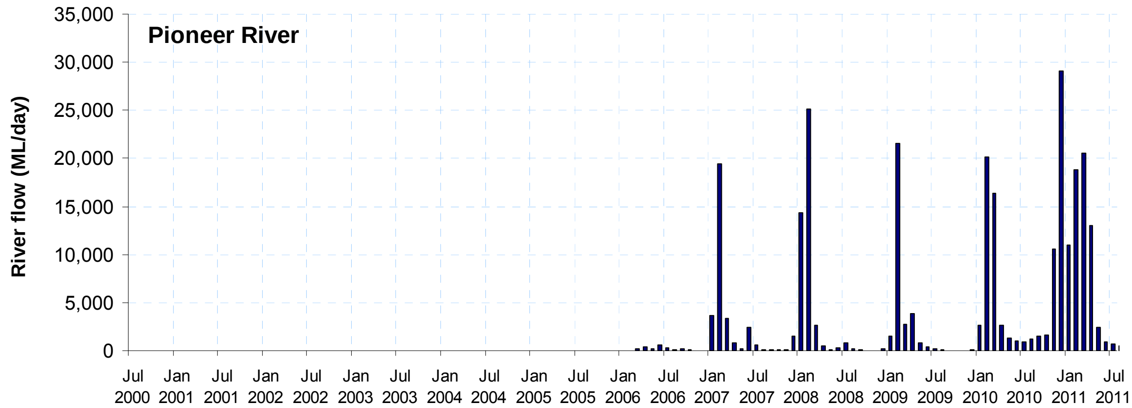


Figure 108. *Average daily flow (ML day^{-1}) per month from the main river impacting estuarine seagrass monitoring sites in the Mackay Whitsunday region (DERM station 125016A - Pioneer River at Dumbleton Weir T/W 21.14236111°S 149.07625°E, Elev 10m) (source ©The State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

Fitzroy

2010/11 Summary

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

The most significant feature of 2010/11, was the occurrence of the highest floods across the region in over 30 years, following a wetter than average spring. Prior to the extreme weather event, seagrass in the region was moderate state, but seagrass had been decreasing at coastal and reef sites since 2009, while at estuarine sites seagrass was continuing to recover from losses in 2006. Post the extreme weather event, seagrass abundance continued to decrease at the coastal sites, however meadow extent has remained stable. Estuarine seagrass abundance similarly declined to the highest level since the meadow was lost in 2006-2007 for 18 months. Reef seagrass abundance remained well below the GBR long-term average as the meadows continued to decreased in size. With slightly larger seed banks and higher reproductive effort at the estuarine and reef habitats, the meadows have a high capacity to recover.

Although canopy incident light remains well above the seagrass minimum light requirement for growth, seagrass tissue nutrient concentrations indicate a deteriorating light environment in coastal and reef habitats, while estuarine habitats remained stable with sufficient light. Seagrass leaf tissue nutrient concentrations increased in available P across the region, indicating that the environment was saturated with P and the plants possibly N-limited or replete. Epiphyte and macro-algae cover has changed little, and remained below the GBR long-term average.

As a consequence of the extreme weather event, climate in the region was cooler, wetter and calmer than the previous decade. Extreme temperatures were recorded within the seagrass canopy of coastal and estuarine habitats, although mean within canopy temperatures were cooler. As a consequence of approximately twice the average rain volume falling in the catchments of the region, river flows and discharges in 2010/11 were high. The probability of exposure to elevated TSS and PSII herbicides was high for coastal and estuarine meadows and medium for reef meadows. No herbicides were found above detectable limits in the sediments of the meadows Overall the status of seagrass condition in the region was rated as **poor** (Table 26).

Table 26. *Report card for seagrass status (community & environment) for the Fitzroy NRM region: July 2010 – May 2011. 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	13	63	22	**32**
coastal intertidal	31	0	41	**24**
estuarine intertidal	34	75	66	**58**
Fitzroy	28	46	43	**39**

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 to the Gemfields in the west and encompasses the major systems of the Fitzroy, Boyne, and Calliope rivers as well as the catchments of the smaller coastal streams of the Capricorn and Curtis Coasts (Australian Government Land and Coasts 2010d). 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 (Fitzroy Basin Association 2004). Agricultural production constitutes the largest land use in Central Queensland, with nearly 90% of the land under agricultural production. Concomitant with this land use is the usual concern of the quality of the water that is entering the GBR lagoon. While streams further north deliver water to the lagoon every year, about once per decade the Fitzroy floods to an extent that affects the Reef. However, the smaller annual flows deliver sediments and nutrients affecting coastal habitats.

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

Reef Rescue monitoring sites within this region are located in coastal, estuarine or fringing-reef seagrass habitats. Coastal sites are monitored in Shoalwater Bay and are located on the large intertidal flats of the north western shores of Shoalwater Bay. The remoteness of this area (due to its zoning as a military exclusion zone) represents a near pristine environment, removed form anthropogenic influence. In contrast, the estuarine sites are located within Gladstone Harbour: a heavily industrialized port. Offshore reef sites are located at Monkey Beach, Great Keppel Island.

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 109). As part of this tidal regime, large intertidal banks are formed which are left exposed for many hours. Pooling of water in the high intertidal, results in small isolated seagrass patches 1-2m above Mean Sea Level (MSL).

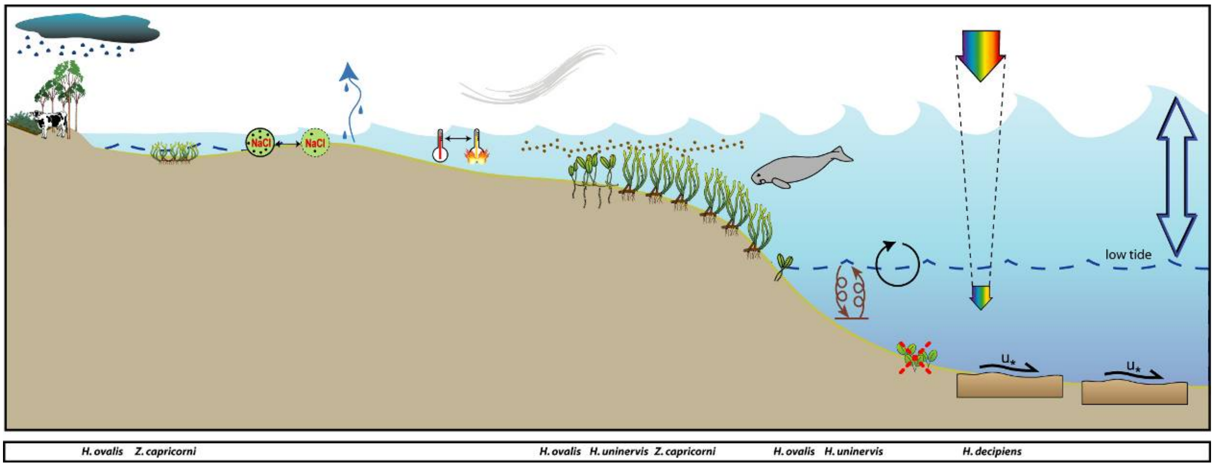


Figure 109. *Conceptual diagram of coastal habitat in the Fitzroy region – major control is pulsed light, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see Figure 4 for icon explanation).*

Estuarine seagrass habitats in the southern Fitzroy region tend to be intertidal, on the large sand/mud banks in sheltered areas of the estuaries. Tidal amplitude is not as great as in the north and estuaries that are protected by coastal islands and headlands support meadows of seagrass. These habitats feature scouring, high turbidity and desiccation (linked to this large tide regime), and are the main drivers of distribution and composition of seagrass meadows in this area (Figure 110). 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.

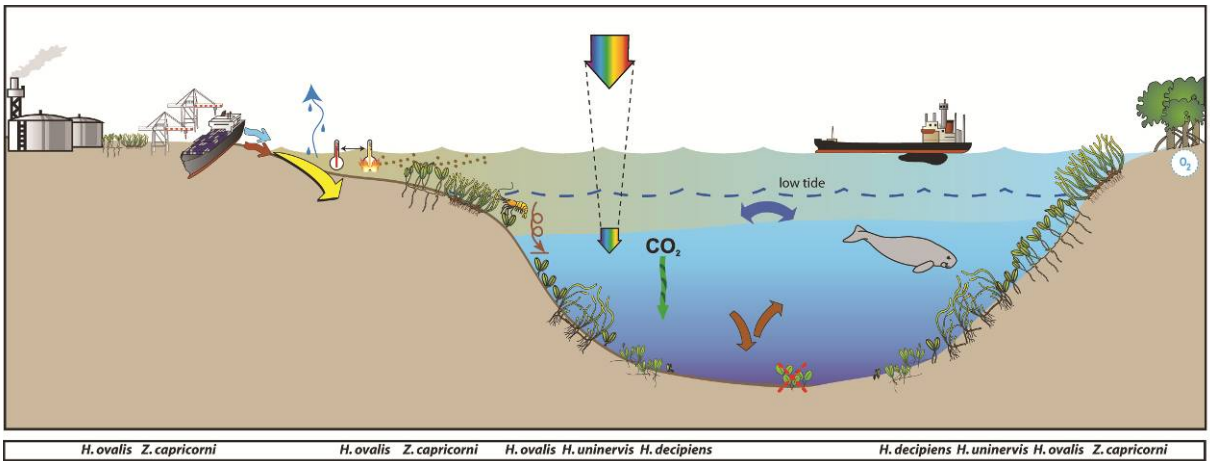


Figure 110. *Conceptual diagram of estuary habitat in the Fitzroy region – major control variable rainfall and tidal regime: general habitat, seagrass meadow processes and threats/impacts (see Figure 2 for icon explanation).*

Status of the seagrass community

Seagrass abundance and composition

Seagrass species composition differed greatly between inshore (coastal and estuarine) and offshore (reef) habitats. Inshore coastal sites monitored in Shoalwater Bay at Ross Creek (RC1) and Wheelans Hut (WH1) were dominated by *Zostera capricorni* with some *Halodule uninervis* and minor quantities of *Halophila ovalis* (Figure 111). Seagrass abundance has been decreasing at the coastal sites since

2009 and was substantially lower during the 2010/11 monitoring period than the previous monitoring period (Figure 112).

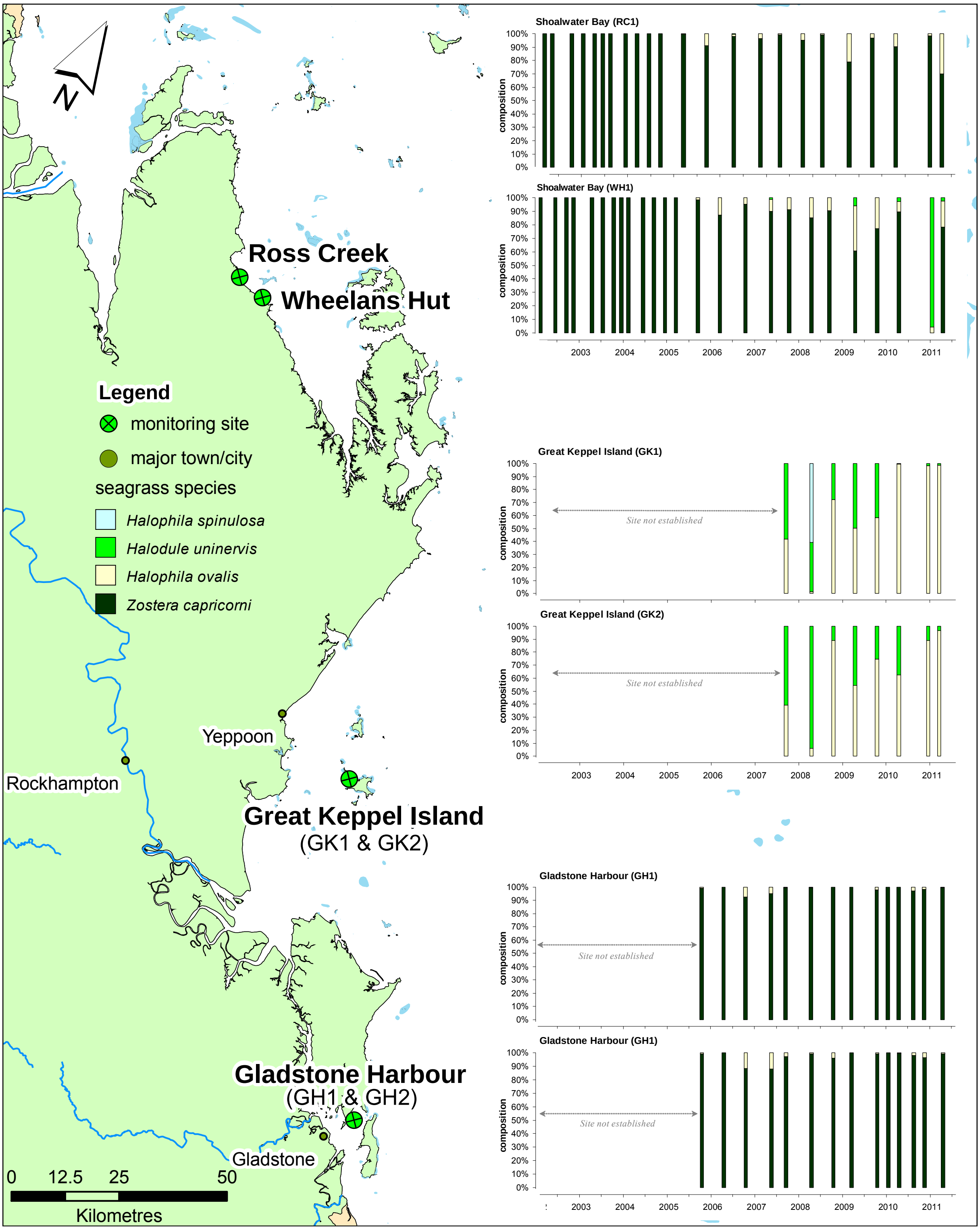


Figure 111. *Location of Fitzroy region long-term monitoring sites and the seagrass species composition at each site. Please note: some replicate sites within 500m of each other.*

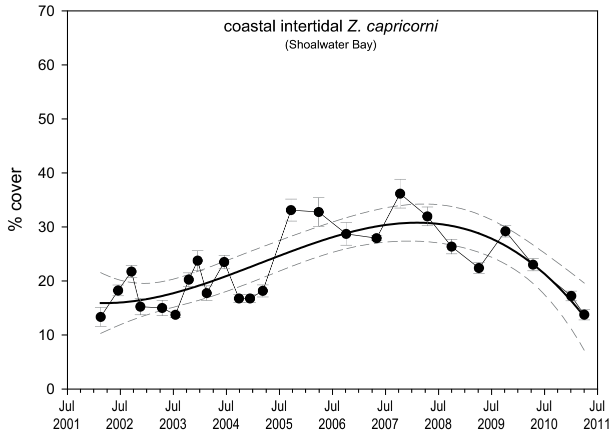
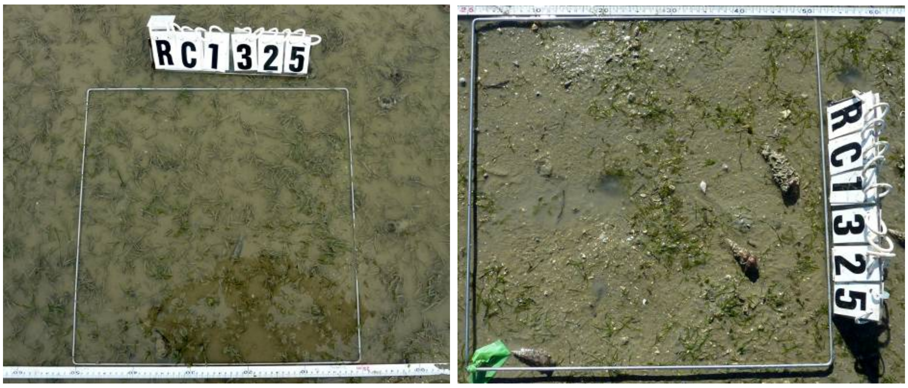


Figure 112. *Changes in seagrass abundance (% cover ±Standard Error) at coastal intertidal meadows in Shoalwater Bay (Fitzroy region) from 2001 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.665.*



Quadrat at 25m on transect 3 at Ross Creek (Shoalwater Bay RC1), on 13 April 2010 (left) and 15 April 2011 (right)

Shoalwater Bay seagrass abundance appears to increase during the year until the monsoon (Figure 113).

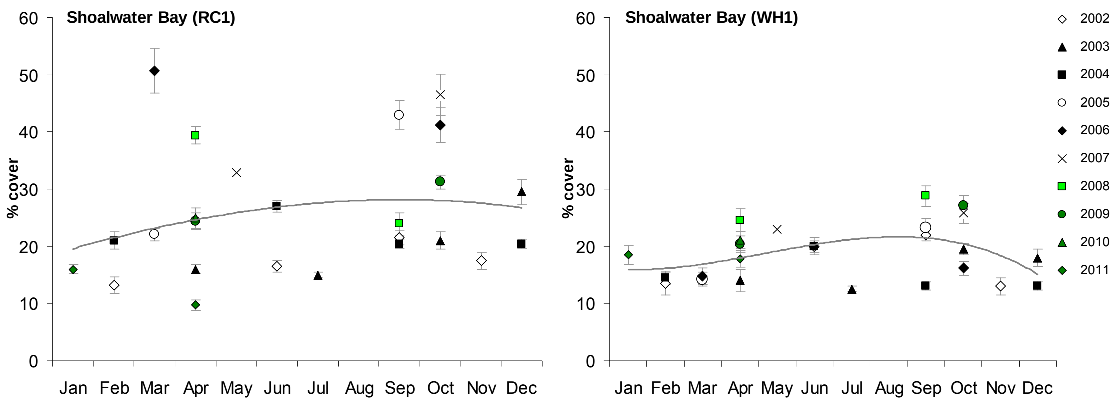


Figure 113. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Shoalwater Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Gladstone Harbour estuarine sites were located in a large *Zostera capricorni* dominated meadow (Figure 111) on the extensive intertidal Pelican Banks south of Curtis Island. Species composition has remained stable; however abundance has differed greatly between years (Figure 114). Abundances observed in late 2010 were some of the highest recorded since monitoring was established in 2005. However, in early 2011 abundances declined below the GBR long-term average, but remained higher than reported in 2006 (Figure 114). Estuarine seagrasses appear to change seasonally, increasing throughout the year until the late monsoon (Figure 115).

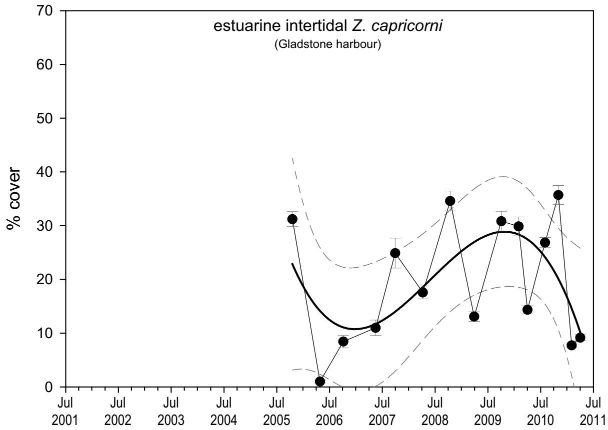


Figure 114. *Changes in seagrass abundance (% cover ±Standard Error) at estuarine intertidal meadows in Gladstone Harbour (Fitzroy region) from 2005 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.353.*

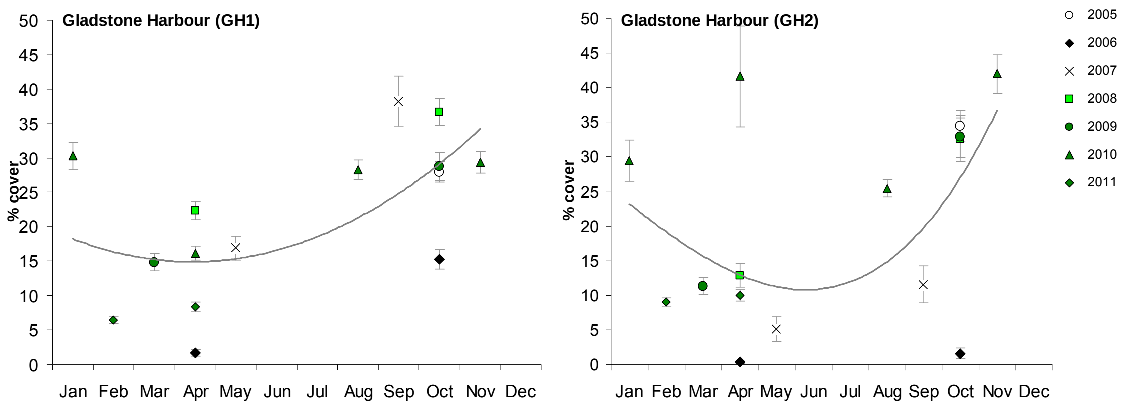


Figure 115. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Gladstone Harbour long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

The monitoring sites at Great Keppel Island (GK1 and GK2) differ greatly from the inshore sites, being composed predominately of *H. uninervis* on sand substrate (Figure 111). Seagrass abundance has continued to remain well below the GBR long-term average since monitoring was established in 2007 (Figure 116), and due to the paucity of data no seasonal patterns are apparent (Figure 117).

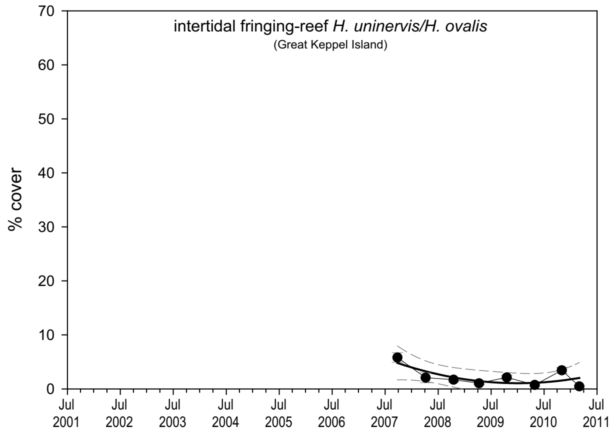


Figure 116. *Changes in seagrass abundance (% cover ±Standard Error) at intertidal fringing –reef meadows at Great Keppel Island (Fitzroy region) from 2005 to 2011. Trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.531.*

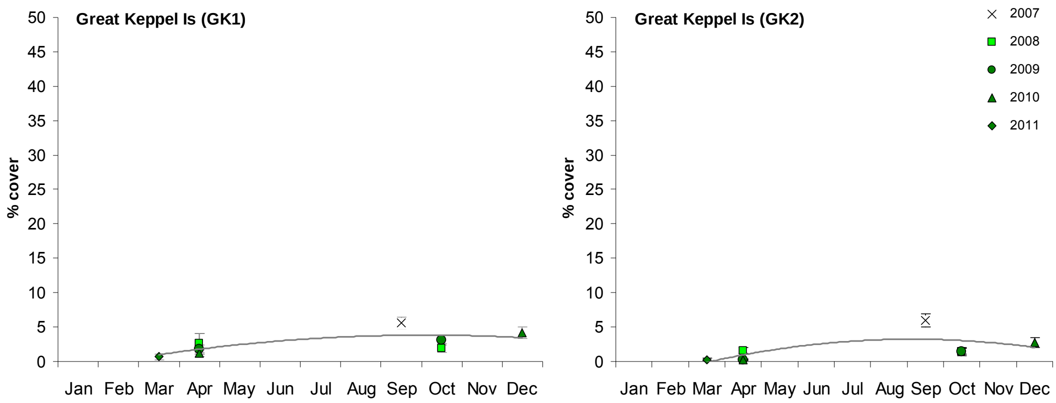


Figure 117. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Great Keppel Island long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Table 27) to determine if changes in abundance were a consequence of the meadow edges changing. The coastal meadows in Shoalwater Bay (RC1 and WH1) have remained stable in extent since monitoring began, however the meadows at the reef (Great Keppel Island) habitat have decreased overall (Figure 118). At Great Keppel Island, the meadows reduced by 30% and 85% (at sites GK2 and GK1 respectively), which is similar to what was experienced in early 2008 (Table 27, Figure 118). The Gladstone Harbour meadow, which was absent in early 2006, has since recovered and stabilised over the last three monitoring periods (Table 27, Figure 118), with only a minor decrease (<10%) during the 2010/11 monitoring period.

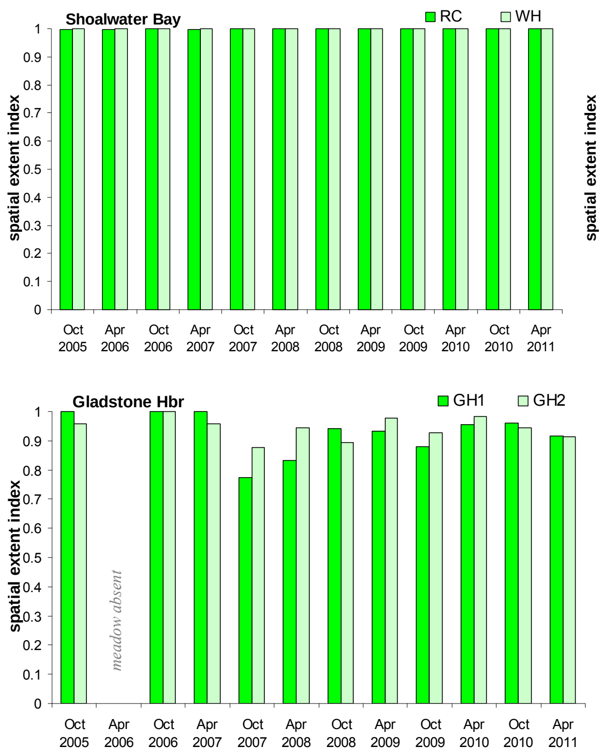


Figure 118. *Extent of area (100m radius of monitoring site) covered by seagrass at each monitoring site at Shoalwater Bay, Great Keppel Island and Gladstone Harbour locations.*

Table 27. *Area (ha) of seagrass meadow within 100m radius of each monitoring site. Value in parenthesis is % change from the baseline and description of change from previous mapping. Shading indicates decrease in area since baseline. NA=no data available as site not established.*

	Shoalwater Bay		Gladstone Harbour		Great Keppel Island	
Date	**RC1**	**WH1**	**GH1**	**GH2**	**GK1**	**GK2**
October 2005 (baseline)	**5.38**	**5.397**	**5.394**	**5.174**	*NA*	*NA*
April 2006	5.38 *(No change)*	5.397 *(No change)*	0 *(-100%, meadow absent)*	0 *(-100%, Meadow absent)*	*NA*	*NA*
October 2006	5.396 *(0.3%, increase shoreward)*	5.397 *(No change)*	5.394 *(meadow recovered)*	5.394 *(4.3%, Meadow recovered)*	*NA*	*NA*
April 2007	5.384 *(0.01%, increase shoreward)*	5.397 *(No change)*	5.394 *(meadow recovered)*	5.174 *(0.01%, decrease seaward)*	*NA*	*NA*
October 2007	5.396 *(0.3%, negligible)*	5.397 *(No change)*	4.179 *(-22.5%, decrease overall)*	4.733 *(-8.5%, decrease seaward)*	**2.513**	**3.998**
April 2008	5.396 *(0.3%, stable)*	5.397 *(No change)*	4.487 *(-16.8%, increase overall)*	5.087 *(-1.7%, increase shoreward)*	0.526 *(-79.1%, decrease overall)*	2.368 *(-40.8%,decrease overall)*
October 2008	5.396 *(0.3%, stable)*	5.397 *(No change)*	5.074 *(-5.9%, increase overall)*	4.829 *(-6.7%, decrease seaward)*	0.933 *(-62.9%, increase overall)*	3.201 *(-19.9%, increase overall)*
April 2009	5.396 *(0.3%, stable)*	5.397 *(No change)*	5.027 *(-6.8%, decrease shoreward)*	5.281 *(2.1%, increase shoreward)*	1.814 *(-27.8%, increase overall)*	2.234 *(-44.1%, decrease overall)*
October 2009	5.396 *(no change)*	5.397 *(no change)*	4.742 *(-12.1%, decrease overall)*	4.997 *(-3.4%, decrease overall)*	2.444 *(-2.8%, increase overall)*	3.712 *(-7.2%, increase overall)*
April 2010	5.396 *(no change)*	5.397 *(no change)*	5.158 *(-4.4%, increase overall)*	5.301 *(2.5%, increase overall)*	2.384 *(-5.1%, decrease shoreward)*	3.821 *(-4.4%, increase overall)*
October 2010	5.396 *(no change)*	5.397 *(no change)*	5.179 *(-4.0%, increase overall)*	5.098 *(2.3, decrease overall)*	0.933 *(-62.9%, decrease overall)*	3.770 *(-5.7%, decrease overall)*
April 2011	5.396 *(no change)*	5.397 *(no change)*	4.941 *(-8.4%, decrease overall)*	4.927 *(-1.5%, decrease overall)*	0.382 *(-84.8%, decrease overall)*	2.805 *(-29.9%, decrease overall)*

Seagrass reproductive status

Seed banks across the region remained below the GBR long-term average for estuarine habitats and no seeds were found at either coastal or reef habitats (Figure 119). Overall reproductive effort is moderate and relatively high for the Great Keppel Island sites for 2010.

Although there were no seed banks, the moderate reproductive effort (Figure 119) suggests the meadows have a reasonable capacity to recover following disturbance.

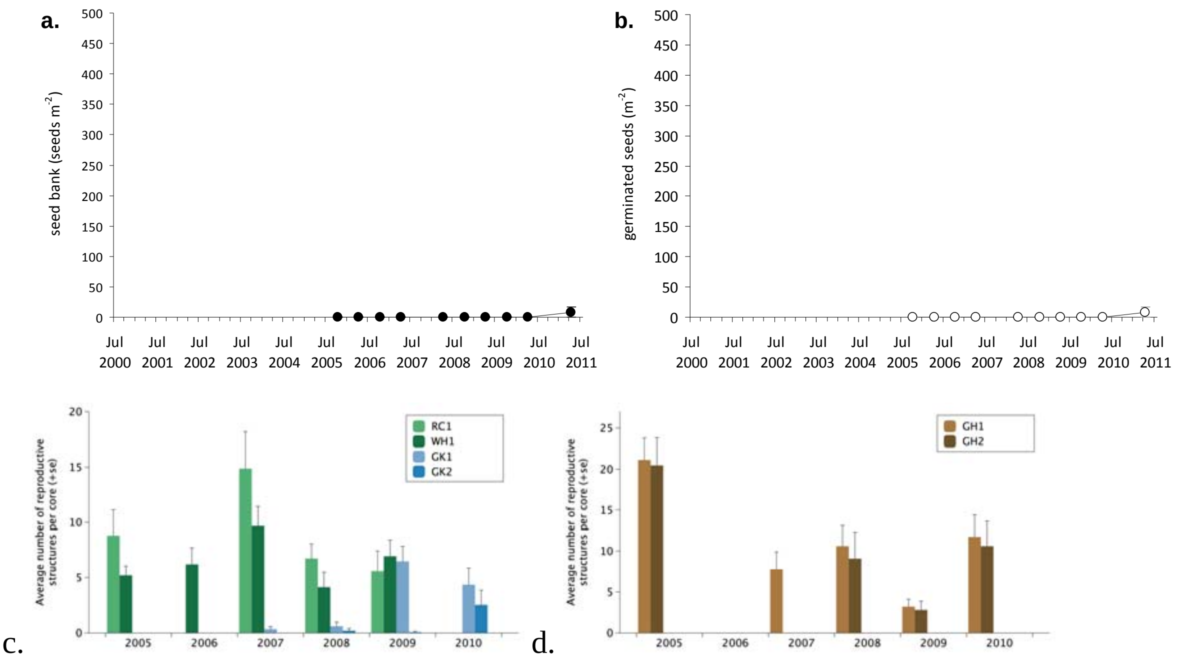


Figure 119. *Seed bank (a) and germinated seed abundance (b) at estuary habitats in the Fitzroy region (seed bank is represented as the total number of seeds per m² sediment surface) and (c, d) average total reproductive effort for all species for sites in the Fitzroy region.*

Status of the seagrass environment

Seagrass tissue nutrients

Seagrass growing in the Fitzroy region at Great Keppel Island appear to be in low light environments due to their low C:N ratios (C:N < 20) (Figure 120). Plants in Shoalwater Bay have declined in carbon relative to nitrogen in 2010, which may indicate either reduced light availability or increased N. C:N ratios in Gladstone Harbour however indicates sufficient light availability with C:N ratios remaining above 20 in 2010.

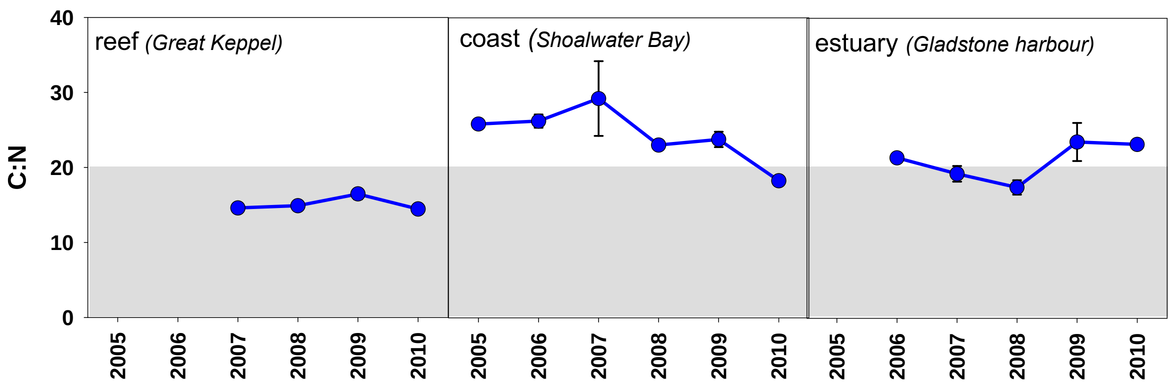


Figure 120. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Fitzroy region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability.*

C:P ratios for foundation species declined across the region in late dry 2010, indicating an increase in P (Figure 121). At coastal and reef habitats in the Fitzroy region, C:P ratios were below 500 in 2010, indicating indicate nutrient rich habitats (large P pool). At Gladstone Harbour, C:P ratios remained above 500, indicating a nutrient poor environment.

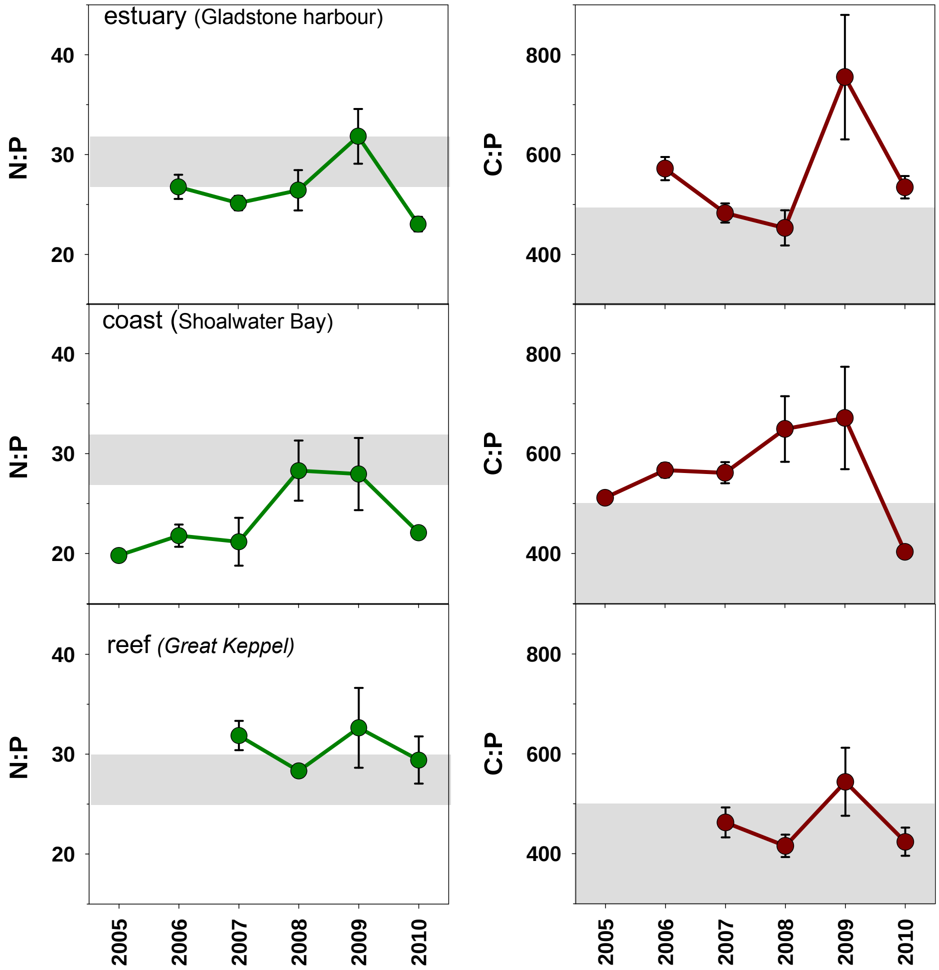


Figure 121. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in the Fitzroy region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with 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).*

N:P ratios for foundation species all declined in late dry 2010, indicating an increase in P relative to N (Figure 121). N:P ratios at estuary and coast habitats in the Fitzroy region were below 25 in late dry 2010 (Figure 121); indicating that the environment was saturated with P and the plants possibly N-limited. At Great Keppel Island however, N:P ratios were between 25 and 30 suggesting plants were replete.

Epiphytes and Macro-algae

Epiphyte cover on seagrass leaf blades across the region remained below the GBR long-term average for all habitats over the 2010/11 monitoring period (Figure 122, Figure 123, Figure 124). Macro-algae cover similarly remained low below the GBR long-term average for all habitats (Figure 122, Figure 123, Figure 124).

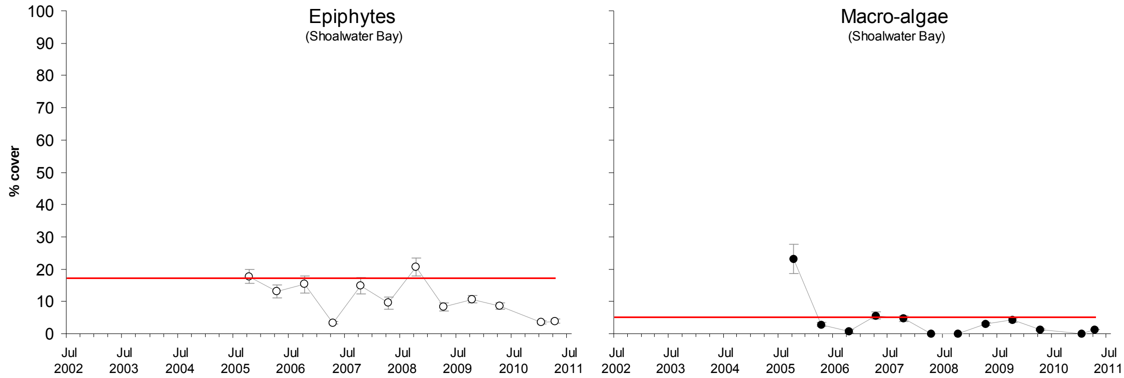


Figure 122. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal coastal (Shoalwater Bay) seagrass monitoring sites. Red line = GBR long-term average; epiphytes=17%, macro-algae=4.7%.*

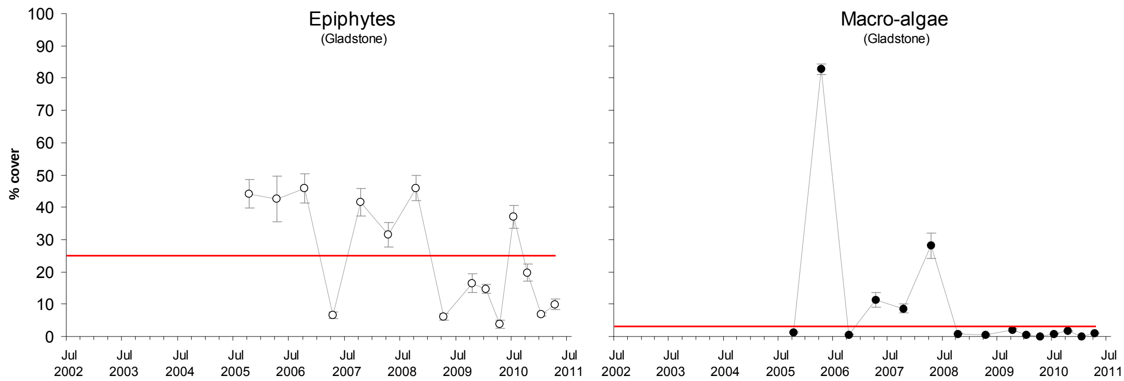


Figure 123. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal estuarine (Gladstone Harbour) seagrass monitoring sites. Red line = GBR long-term average; epiphytes=25%, macro-algae=3.2%.*

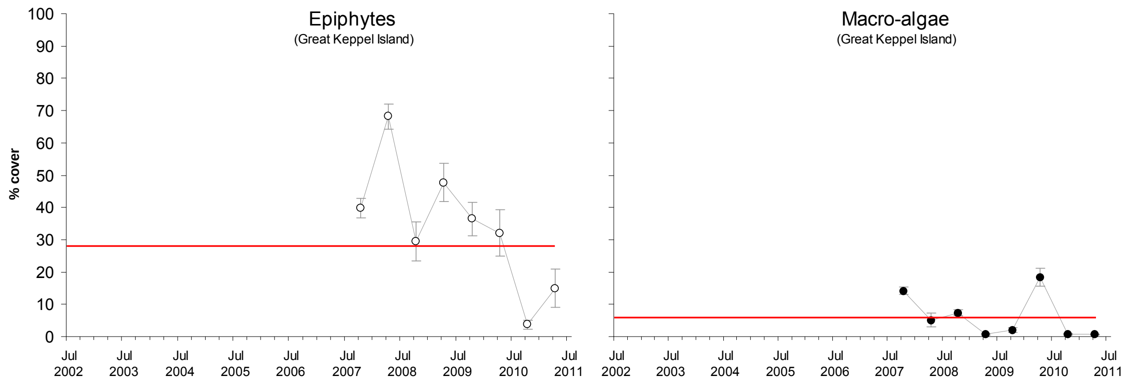


Figure 124. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at the intertidal offshore reef (Great Keppel Island) seagrass monitoring location. Red line = GBR long-term average; epiphytes=28%, macro-algae=6.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows across the Fitzroy region (Table 28).

Table 28. *Concentration of herbicides (mg kg^{-1}) in sediments of Shoalwater Bay, Great Keppel Island and Gladstone harbour seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
RC1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
WH1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GK1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GK2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GH1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
GH2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within meadow canopy temperature

Temperature loggers were deployed at all monitoring sites over the monitoring period (Figure 125). Mean within canopy temperature monitored at Shoalwater Bay ranged from 20 - 28°C, while at Great Keppel Island it ranged from 19 - 28°C and Gladstone harbour 18-28°C. The lowest mean temperatures across the region occurred in June/July and highest in January/February. Extreme temperatures (>38) were recorded across the region, with maximum temperatures reaching 39.7°C in Gladstone harbour (GH2, March 2011) and 38.6°C in Shoalwater Bay (RC1, December 2010). Maximum temperatures in Gladstone harbour were the highest on average since monitoring commenced (Figure 126). Nevertheless, mean within canopy temperatures were 0.3 – 0.5°C cooler across the region than the previous two monitoring periods (2008/09 and 2009/10).

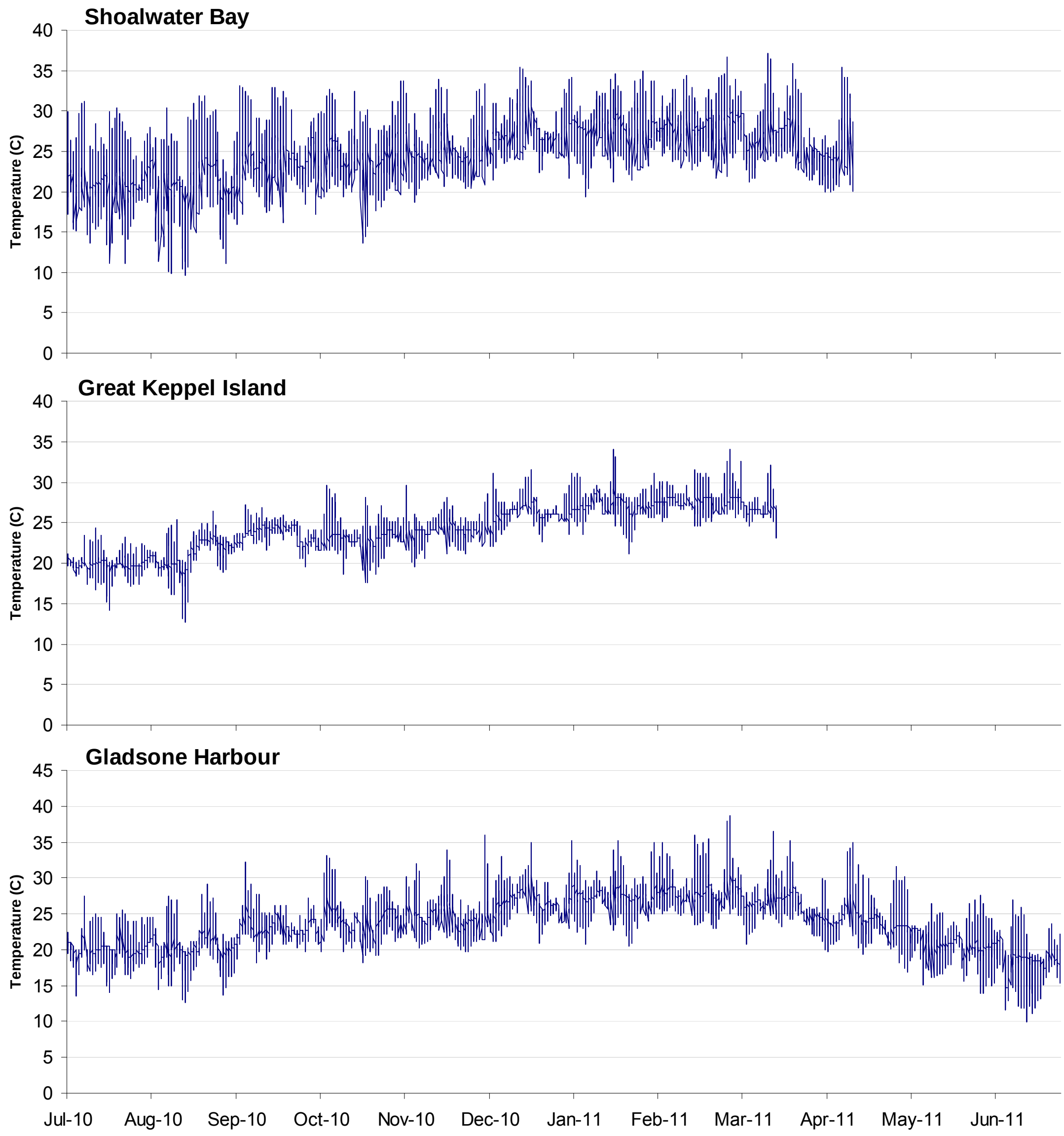


Figure 125. *Within seagrass canopy temperature (°C) at coastal (Shoalwater Bay), offshore fringing-reef (Great Keppel Island) and estuarine (Gladstone Harbour) intertidal meadows within the Fitzroy region over the 2010/11 monitoring period.*

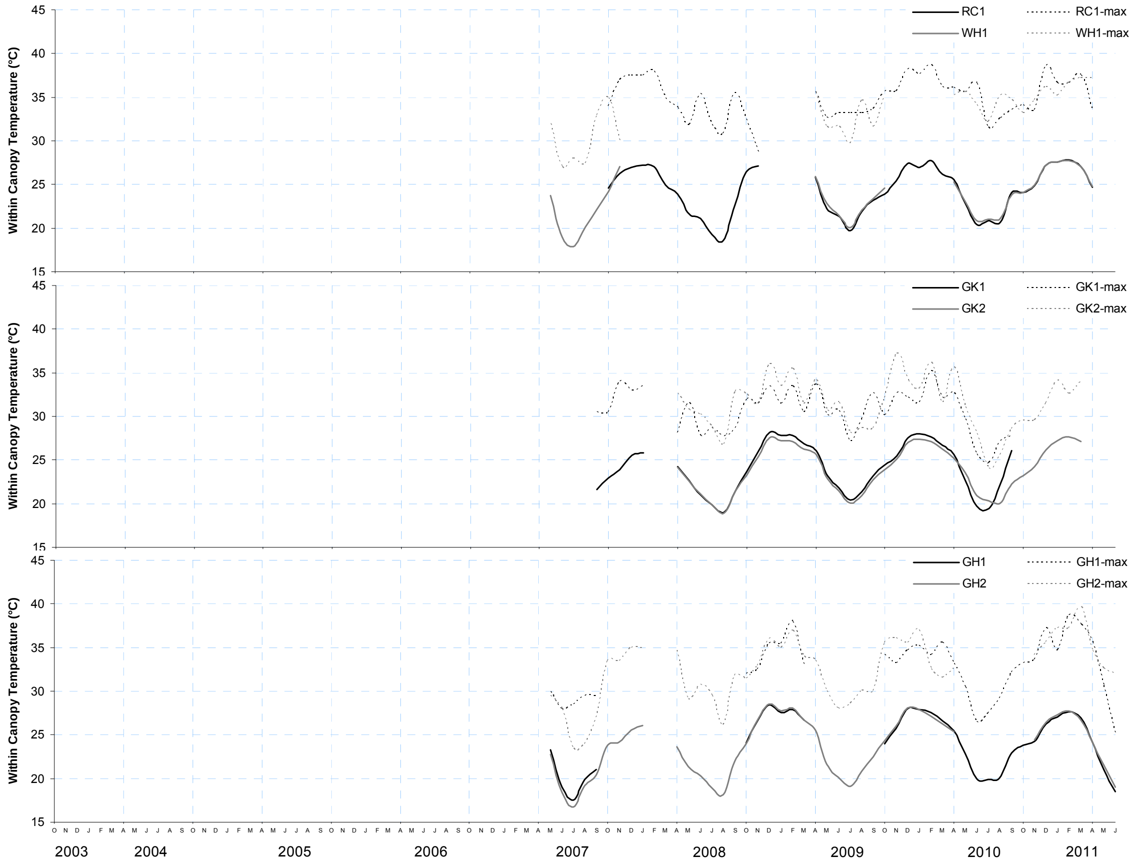


Figure 126. *Monthly mean and maximum within seagrass canopy temperature (°C) at intertidal meadows in coastal (Shoalwater Bay), fringing-reef (Great Keppel Island) and estuary (Gladstone Harbour) monitoring habitats within the Fitzroy region.*

Canopy incident light

Shoalwater Bay has the highest I_d of all monitoring sites being, on average 24 mol m^{-2} d^{-1}. There is limited data available for the 2010/11 wet season, with the end of currently available data finishing at the end of January 2011. For this short part of the 2010-2011 wet season and the 2009-2010 wet season, I_d remained very high being on average, 19 mol m^{-2} d^{-1} and 19.3 mol m^{-2} d^{-1}, respectively (Figure 127).

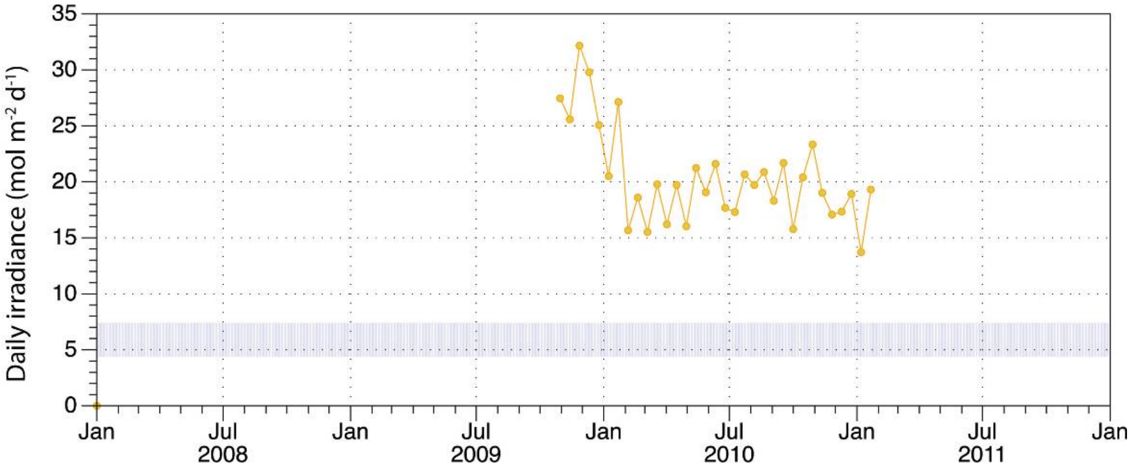


Figure 127. *Daily irradiance (14-day average) at Shoalwater Bay. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

I_d at Keppel Island has remained largely above MLR, with average I_d being 13.5 mol m^{-2} d^{-1} (Figure 128). There was a short decline to within MLR in January 2011. During the 2010/11 wet season I_d was 11 mol m^{-2} d^{-1}compared to 11.5 mol m^{-2} d^{-1}on average. I_d was also higher in the 2009 dry season than the 2010 dry season. The low average seagrass cover at this site is unlikely due to light levels alone, given light is generally relatively high.

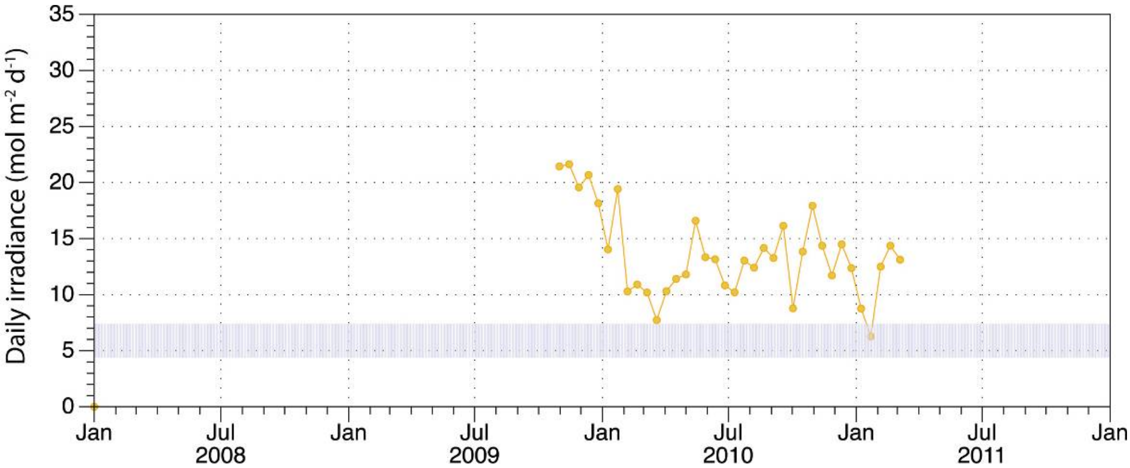


Figure 128. *Daily irradiance (14-day average) at Keppel Island. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

Regional Climate

Climate across the region during the 2010/11 monitoring period was on average cooler, wetter and calmer than the previous decade. The most significant feature of the 2010/11 climate, was from mid December 2010 to mid January 2011, when after following a wetter than average spring, heavy rainfall across central and southern Queensland river catchments, due to TC Tasha combining with a trough during the strongest La Niña weather pattern since 1973, resulted in some of the highest floods in over 30 years (Appendix 1).

Yeppoon – Great Keppel Island and Shoalwater Bay

The mean maximum daily air temperature recorded in Yeppoon during 2010/11 was 28.8°C, this was 0.8°C cooler than the decade average and 3°C warmer than the long-term (18 year) average (Figure 129). The highest recorded daily maximum air temperature in 2010/11 was 34.6 °C.

2010/11 was a wet period with approximately twice the average rainfall relative to both the long-term (17 year) and decadal averages (Figure 129). Mean wind speed in 2010/11 was 17.3 km.hr^{-1}, this was lower than both the long-term and decade average (Figure 129).

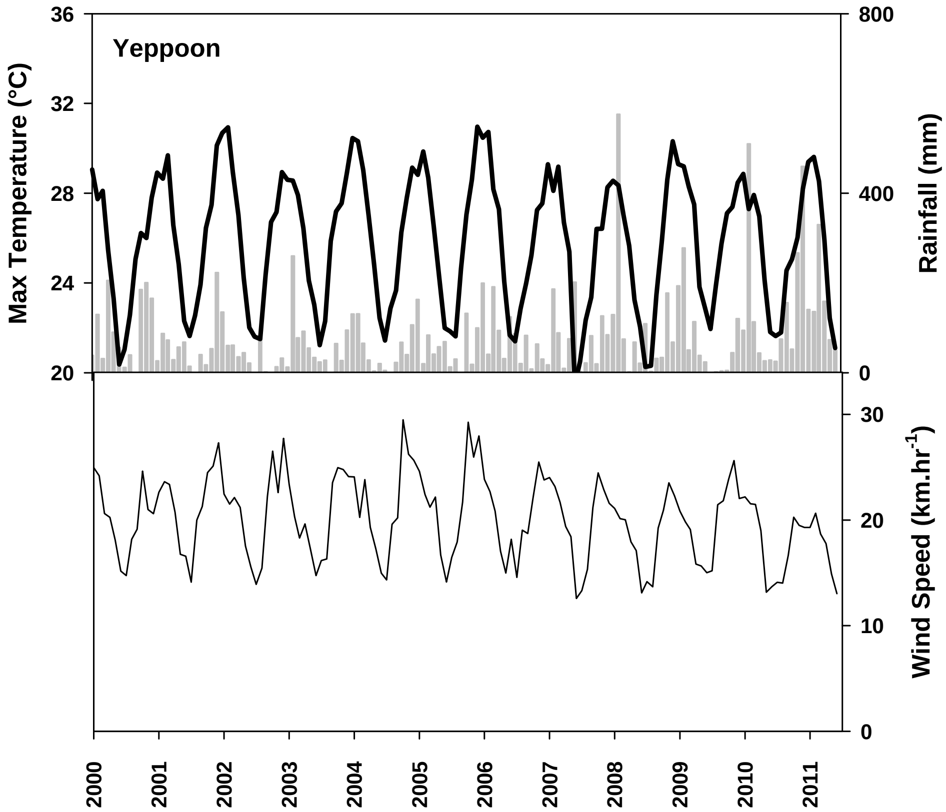


Figure 129. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr-1) recorded at Yeppoon (BOM station 033106) (Source www.bom.gov.au). Yeppoon used as a surrogate for the climate at Great Keppel Island and Shoalwater Bay*

Gladstone – Gladstone Harbour

The mean maximum daily air temperature recorded in Gladstone during 2010/11 monitoring period was 30.8°C, this was 3.4°C higher than the long-term (54 year) average and 1.1°C lower than the decade average (Figure 130). The highest recorded daily maximum temperature in 2010/11 was 35.5°C.

2010/11 was a wet monitoring period relative to both the long-term (54 year) and decade averages, with approximately 55% more rain (Figure 130). Mean wind speed in 2010/11 was 19.8 km.hr^{-1}, this was lower than both the long-term and decade averages (Figure 130).

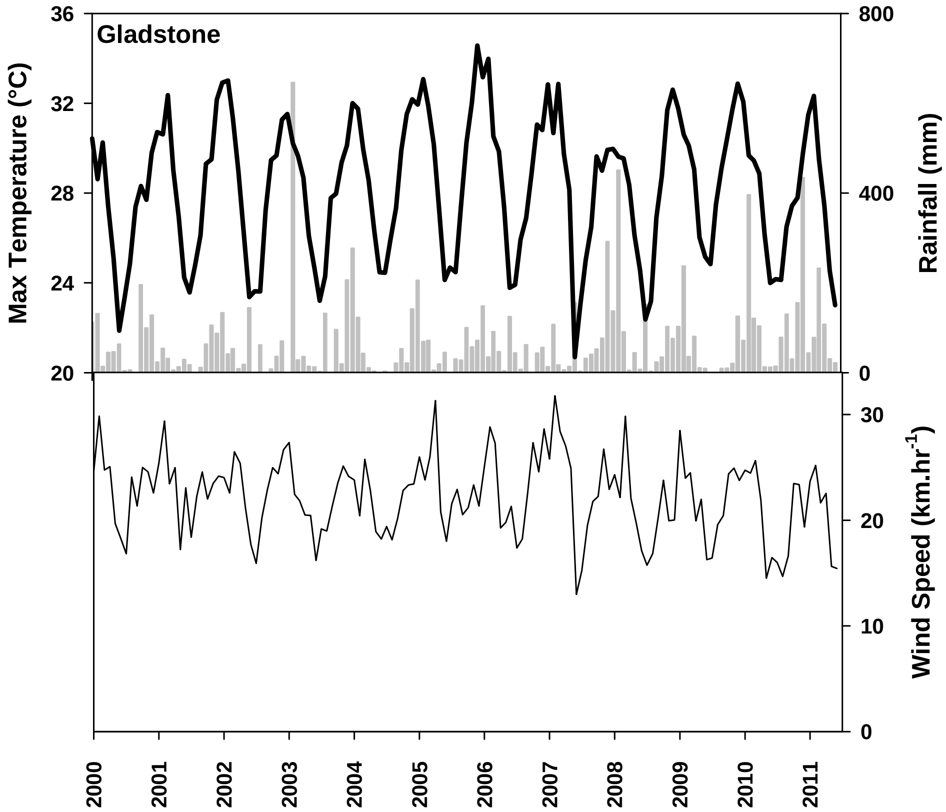


Figure 130. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr-1) recorded at Gladstone Airport (BOM station 039123) (Source www.bom.gov.au). Gladstone Airport used as a surrogate for the climate at Gladstone Harbour*

River discharge

Several rivers discharge into the coastal waters of the Fitzroy, but the largest by far is the Fitzroy River and during floods its plumes extend 100's of km north to locations where coastal and reef seagrass monitoring sites occur. Primary-secondary flood waters from the Fitzroy River extend into Shoalwater Bay (200 km to the north) and secondary-tertiary flood waters extend out to Great Keppel Island (34 km to the north) (Appendix 1).

The exposure of the seagrass monitoring sites in Shoalwater Bay to elevated Total Suspended Solids and PSII herbicides was rated as High in 2010, whereas chlorophyll-*a* exposure was rated as medium. The exposure of the seagrass meadows on the reef flat at Great Keppel Island to Total Suspended Solids, chlorophyll-*a* and PSII herbicides however, was rated as medium. Overall, the probability of exceeding the GBR WQ Guidelines for chlorophyll-*a* at coastal and reef sites was high and medium, respectively (pers. comm. Michelle Devlin, JCU).

The rivers that discharge into Gladstone Harbour are the Calliope and the Boyne, which are within 10 km of the estuarine monitoring sites on Pelican Banks (Port Curtis). During floods, freshwater-primary flood waters extend out to the sites, and the exposure of the seagrass to elevated Total Suspended Solids and PSII herbicides was rated as High in 2010, whereas chlorophyll-*a* exposure was rated as medium. The probability of exceeding the GBR WQ Guidelines at these sites for TSS and chlorophyll-*a* was medium and high, respectively (pers. comm. Michelle Devlin, JCU).

As a consequence of approximately twice the average rain volume falling in the catchments of the region in 2010/11, rivers flows and discharges were high. Although the daily flows from the Fitzroy River were highly variable between months and years (ANOVA, d.f.=12, F=1.73, p=0.07), the estimated volume discharged over the 2010/11monitoring period (38,537,354ML) was over three times that discharged in any other monitoring period since seagrass monitoring was established in the region (Figure 131).

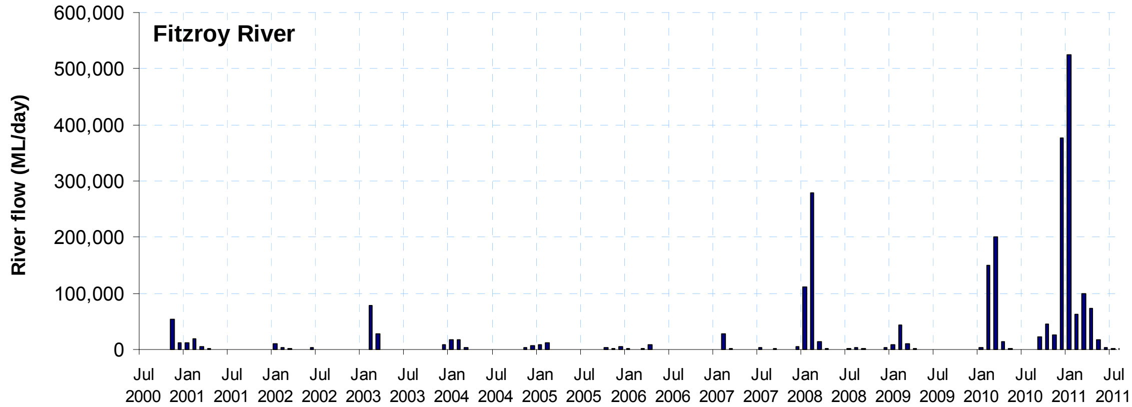


Figure 131. *Average daily flow (ML day^{-1}) per month from the Fitzroy River which impacts coastal and reef seagrass monitoring sites in the Fitzroy region (DERM station 130005A - Fitzroy River at The Gap, 23.08897222°S 150.10713889°E, Elev 0m)(source ©The State of Queensland (DERM) 2011, watermonitoring.derm.qld.gov.au).*

From late December 2010 to early January 2011 the Fitzroy River peaked at 9.2 metres just short the of the predicted 9.4 metres maximum. Significant volumes of floodwater were observed discharging into Keppel Bay and moving northward into the most northern reaches of Shoalwater Bay (Figure 132).

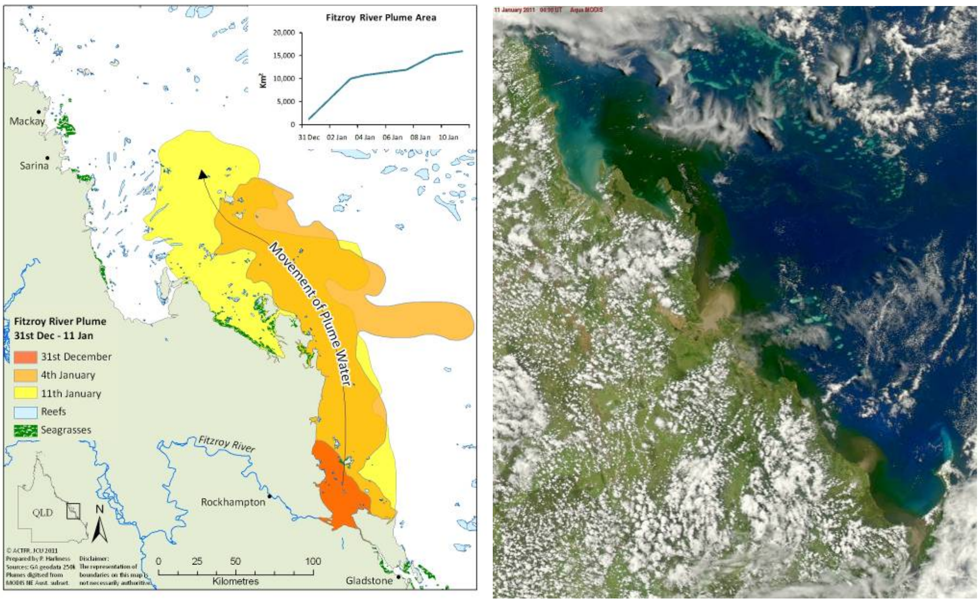


Figure 132. *Draft flood plume map (left) provided by ACTFR (Michelle Devlin) indicating the area of impact of the Fitzroy River flood plume in January 2011, and AquaMODIS image from 11 January 2011 (right) showing plumes entering northern section of Shoalwater Bay.*

Similarly, in 2010/11 the flows in the Calliope River were significantly higher that the previous 12 years (ANOVA, d.f.=12, F=2.97, p=0.001) and the Boyle flowed for the first time in over a decade (Figure 122).

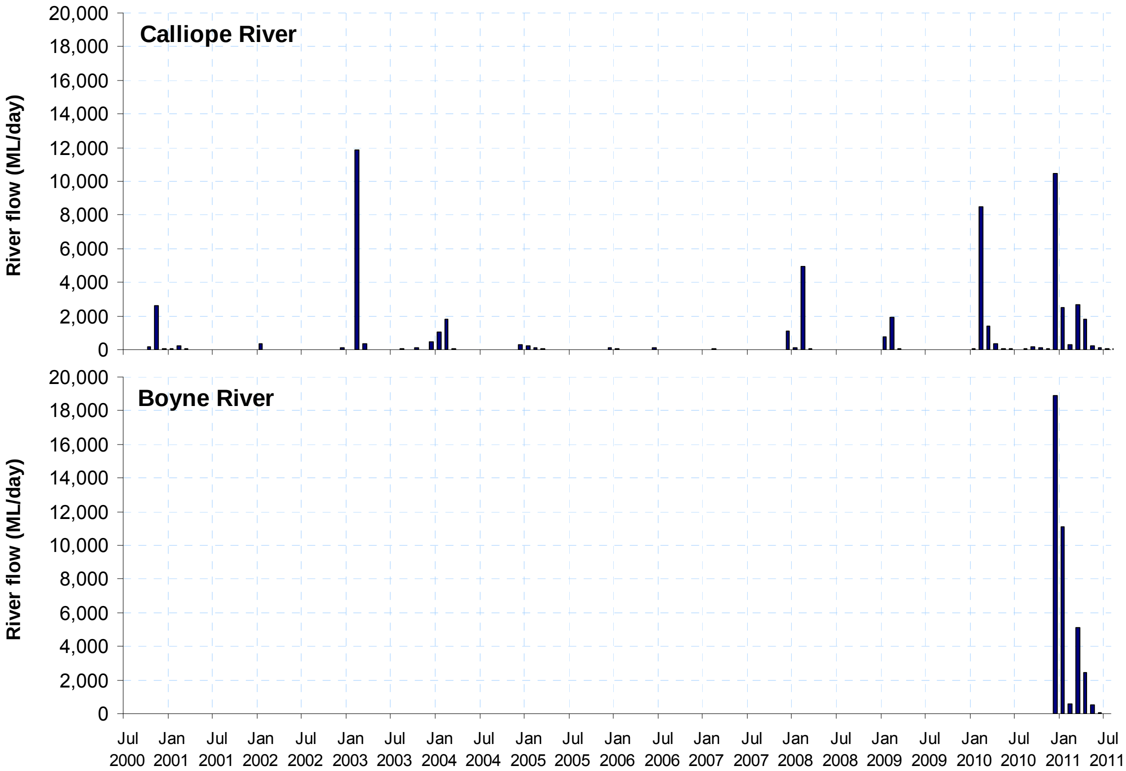


Figure 133. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact estuarine seagrass monitoring sites in the Fitzroy region (DERM stations 132001A - Calliope River at Castlehope 23.98498333°S 151.09756389°E, Elev:21m; 133005A - Boyne River at Awoonga Dam Headwater 24.07008611°S 151.32162528°E, Elev:45m)(source the State of Queensland (DERM) 2011, watermonitoring.derm.qld.gov.au).*

Burnett Mary

2010/11 Summary

Only intertidal estuarine seagrass meadows located in bays protected from SE winds and wave action were monitored in the Burnett Mary region. The main ecological drivers in these environments are temperature and desiccation stress, flood runoff and turbidity. Seagrasses are monitored at locations in the north and south of the Burnett Mary Region.

The meadow in the south showed significant recovery over the 2010 calendar year with an increase in abundance and extent, however declined to pre-2008 levels in early 2011. In the north, the onset of recovery was observed with the presence of early colonising species, although the meadow was primarily isolated patches. Seed banks and reproductive effort declined across the region and were in a very poor state, raising concerns about the ability of local seagrass meadows to recover from environmental disturbances.

Seagrass leaf tissue nutrient concentrations and canopy incident light measurements indicate light environments across region remain low (limited) and although deteriorating in the north, remained above minimum light requirements for growth. Seagrass tissue nutrient status indicated that locations were enriched with P (large P pool). Epiphyte abundance remained variable in the south, but decreased in the north. Climate across the region was on average cooler, wetter, and calmer than the previous decade and within seagrass canopy temperatures were cooler than previous. As a result of 55% more rainfall, average daily flows from the rivers which can possibly impact the seagrass meadows, were significantly higher than any other period in over the last decade. No herbicides were found above detectable limits in the sediments of seagrass meadows in the region. Overall the status of seagrass condition in the region was rated as **very poor**.

Table 29. *Report card for seagrass status (community & environment) for the Burnett Mary NRM region: July 2010 – May 2011. 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	5	0	30	**12**
Burnett Mary	5	0	30	**12**

Background

The Burnett-Mary region covers an area of 88,000km^2 and supports a population of over 257,000 people, largely in the main centres of Bundaberg, Maryborough, Gympie and Kingaroy. The region is comprised of a number of catchments including the Baffle Creek, Kolan, Burnett, Burrum and Mary Rivers (Australian Government Land and Coasts 2010e). Only the northern most catchment of the Burnett Mary region, the Baffle Basin, is within the GBR. Meadows in the north of the Burnett Mary region generally face low levels of anthropogenic threat, and monitoring sites are located within Rodd's Bay. The only other location that is monitored within this region is in the south, at Urangan (Hervey Bay). This location is adjacent to the Urangan marina and in close proximity to the mouth of the Mary River.

Estuarine habitats occur in bays that are protected from the south easterly-winds and consequent wave action. The seagrasses in this area must survive pulsed events of terrestrial run-off, sediment turbidity and drops in salinity. Estuary seagrasses in the region are susceptible to temperature related threats and desiccation due to the majority being intertidal (Figure 134).

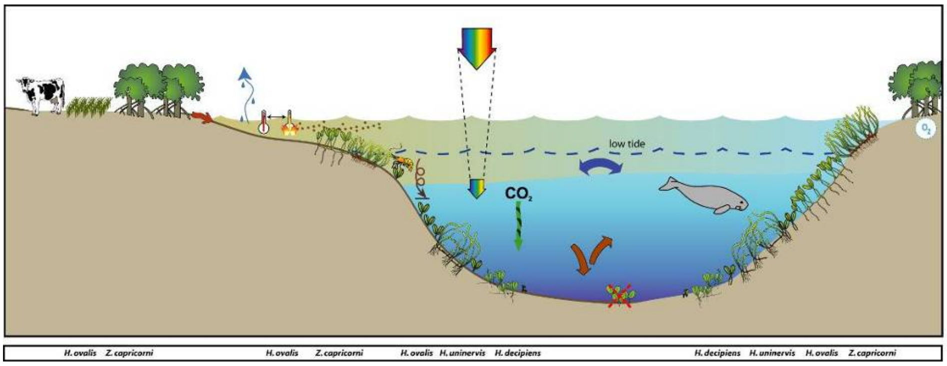


Figure 134. *Conceptual diagram of Estuary habitat in the GBR section of the Burnett Mary region – major control is shelter from winds and physical disturbance: general habitat and seagrass meadow processes (see Figure 4 for icon explanation).*

Status of the seagrass community

Seagrass abundance and composition

The estuarine seagrass habitats in the region were dominated by *Zostera capricorni* with minor components of *Halophila ovalis* and some *Halodule uninervis* (Figure 136). The meadow at Urangan showed significant recovery over the 2010 calendar year, however declined back to pre-2008 levels in early 2011 (Figure 135).

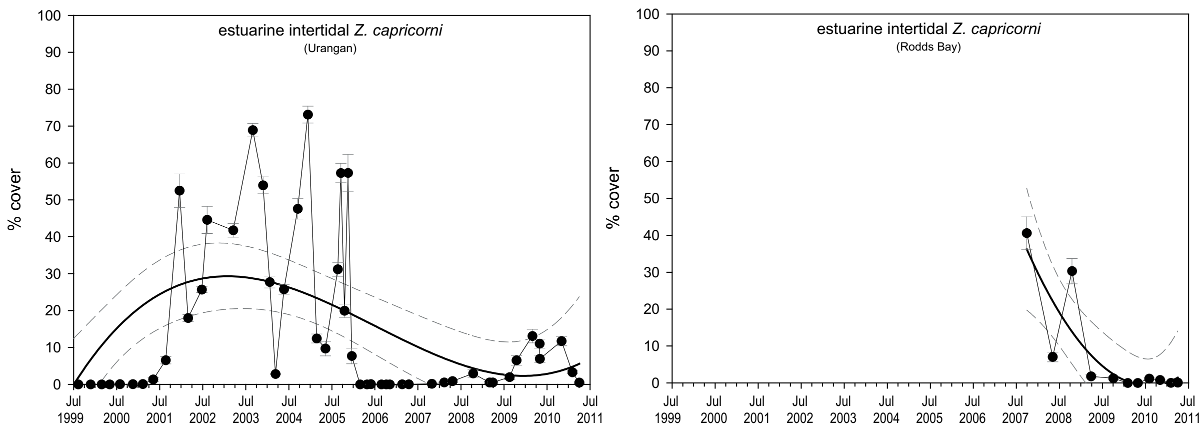


Figure 135. *Changes in seagrass abundance (% cover ±Standard Error) at estuarine meadows in Burnett Mary region from 1999 to 2011. Urangan trendline is 3rd order polynomial, 95% confidence intervals displayed, r^2 = 0.290. Rodds Bay trendline is 2nd order polynomial, 95% confidence intervals displayed, r^2 = 0.720.*

At Rodds Bay, the onset of recovery was observed throughout the 2010/11 monitoring period after the seagrass meadows were lost/absent in the late monsoon 2010 (Figure 135). The sites were dominated by *Halophila ovalis*, which is generally considered an early colonising species, supporting the understanding that the site was in recovery mode (Figure 136).

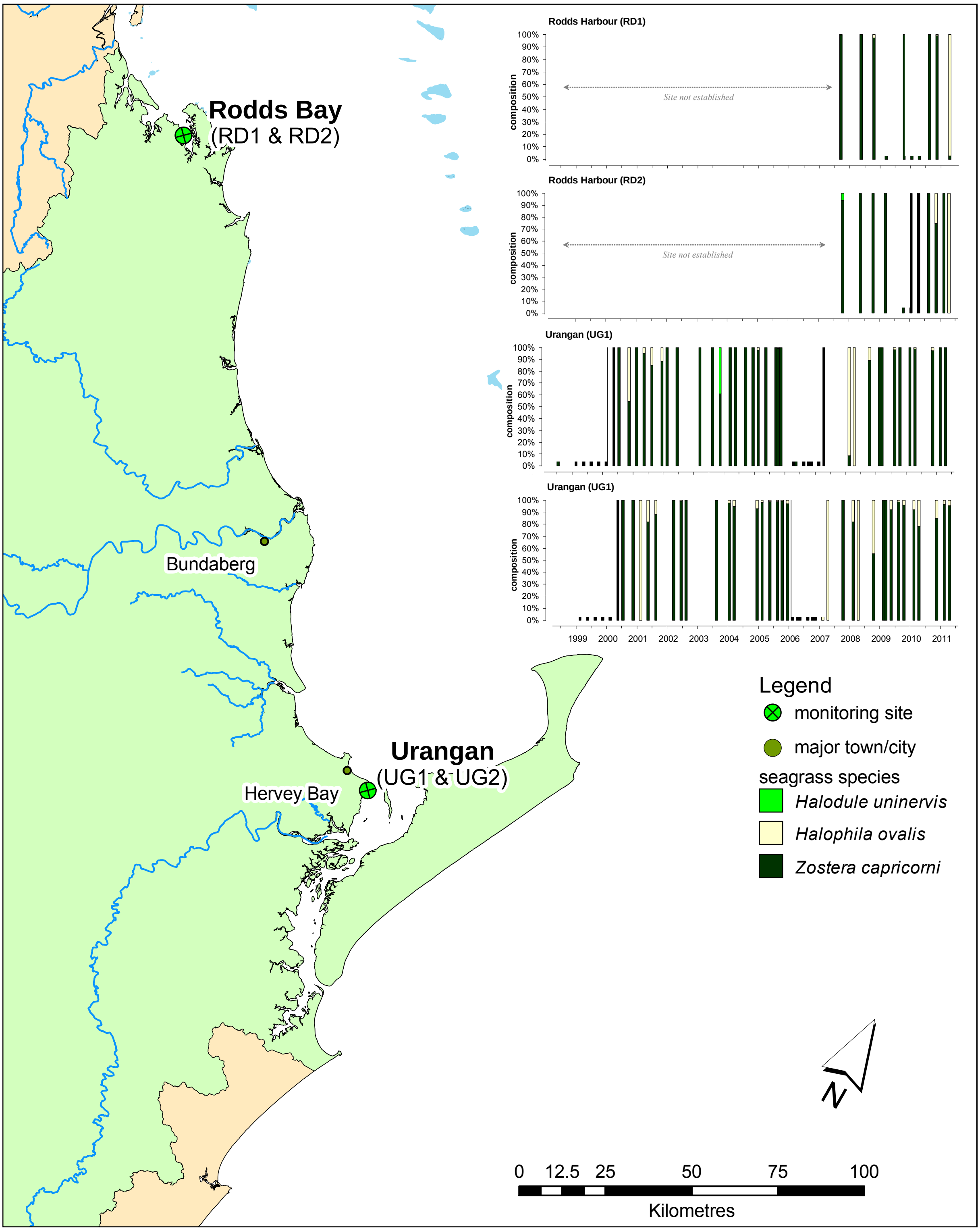


Figure 136. *Location of Burnett Mary region long-term monitoring locations and the seagrass species composition at each site. Please note: replicate sites are within 500m of each other.*

Since monitoring was established at this location in 1998 as part of the Seagrass-Watch program, the Urangan meadow has come and gone on an irregular basis. It is unknown if this is a long-term pattern. Within years however, a seasonal pattern is apparent across both sites, with greater abundance in the late dry season (Figure 137). Abundance is also substantially higher during the late dry season in Rodds Bay, however the dataset has become limited with the recent losses (Figure 138).

Quadrat at 45m on transect 2 at Urangan site 1 (UG1) on 4 November 2010 (left) and 4 April 2011 (right).

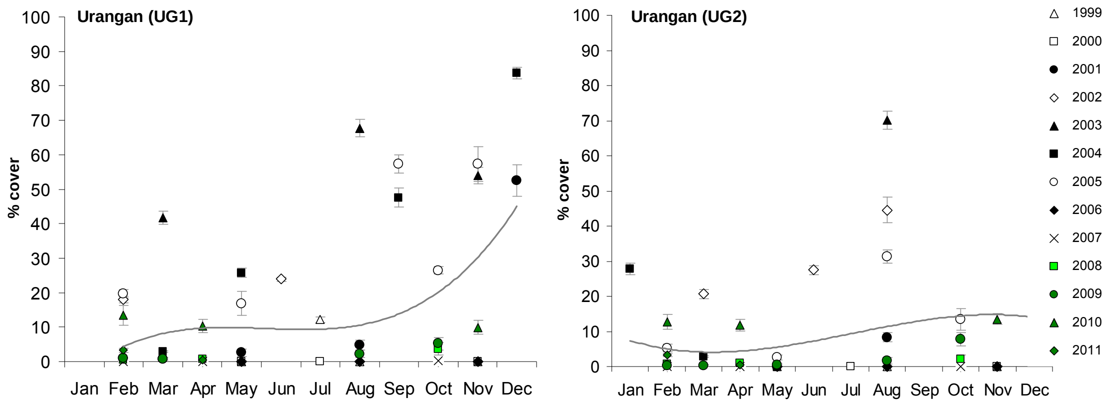


Figure 137. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Urangan long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

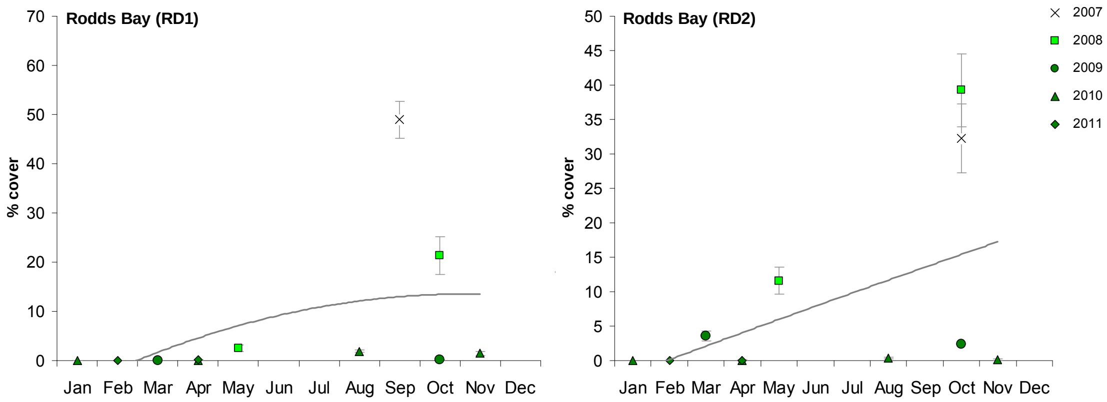


Figure 138. *Mean percentage seagrass cover (all species pooled) (± Standard Error) at Rodds Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.*

Seagrass meadow edge mapping was conducted within a 100m radius of all monitoring sites in September/October and March/April of each year (Table 30) to determine if changes in abundance were a consequence of the meadow edges changing. Over the last 12 months the seagrass meadows at Urangan increased in 2010, but subsequently decreased again in early 2011 (Figure 139, Table 30). In late 2010, isolated patches of seagrass appeared at Rodds Bay site 1 (RD1) indicating the onset of recovery. In early 2011, isolated patches of seagrass also appeared at Rodds Bay site 2 (RD2), however by late monsoon 2011, <5% of the seagrass at the sites had recovered (Figure 139, Table 30).

Table 30. *Area (ha) of seagrass meadow within 100m radius of each monitoring site. Value in parenthesis is % change from baseline and direction of change from previous mapping. Shading indicates decrease in meadow area since baseline. NA=no data available as site not established.*

	Urangan (Hervey Bay)		**Rodds Bay**	
	UG1	**UG2**	**RD1**	**RD2**
October 2005 (baseline)	**5.266**	**5.326**	*NA*	*NA*
April 2006	0 *(meadow absent)*	0 *(meadow absent)*	*NA*	*NA*
October 2006	0 *(meadow absent)*	0 *(meadow absent)*	*NA*	*NA*
April 2007	0 *(meadow absent)*	0 *(meadow absent)*	*NA*	*NA*
October 2007	0.003 *(-99.9%, increase overall)*	0 *(meadow absent)*	**0.96**	**3.573**
April 2008	0.386 *(-92.7%, increase overall)*	1.559 *(-70.7%, increase overall)*	1.291 *(34.5%, increase seaward)*	3.511 *(-1.7%, decrease shoreward)*
October 2008	0.343 *(-93.5%, negligible)*	2.778 *(-47.8%, increase overall)*	1.207 *(25.8%, decrease shoreward)*	3.618 *(1.3%, increase seaward)*
April 2009	0.044 *(-99.2%, decrease overall)*	0.470 *(-91.2%, decrease overall)*	0 *(meadow absent)*	3.527 *(0.4%, negligible)*
October 2009	0.333 *(-93.7%, increase overall)*	0.998 *(-81.3%, increase overall)*	0.041 *(95.8%, increase overall)*	2.770 *(22.5%, decrease shoreward)*
April 2010	1.812 *(-65.6%, increase overall)*	3.730 *(-30%, increase overall)*	0 *(meadow absent)*	0 *(meadow absent)*
October 2010	1.426 *(-72.9%, decrease overall)*	3.726 *(-30%, negligible)*	0.541 *(-43.7, increase overall)*	0 *(meadow absent)*
April 2011	0.296 *(-94.4%, decrease overall)*	2.035 *(-61.8%, decrease overall)*	0.199 *(-79.3, decrease overall)*	0.082 *(-97.7%, isolated patches)*

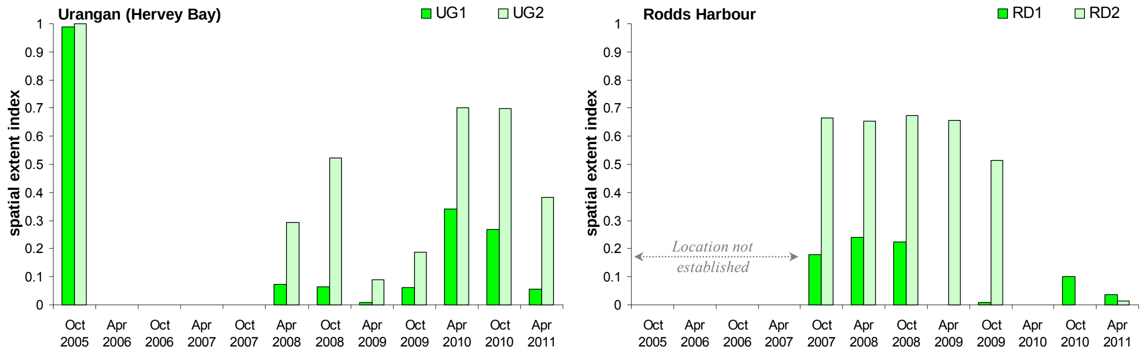


Figure 139. *Extent of area (100m radius of monitoring site) covered by seagrass at each monitoring site at Rodds Bay and Urangan locations.*

Seagrass reproductive status

Seed banks were non-existent in the region and only one seed has ever been found since seed monitoring commenced in 2005 (at RD2 on 26/10/2007). This is likely to be due to the relatively small proportion of *Halodule uninervis* in the region and the seeds of the dominant species *Zostera capricorni* appear to be poorly retained by the 2mm mesh sieves. Reproductive effort across the Burnett Mary region was classified as very poor in 2010 and reflects an ongoing declining trend (Figure 140). This suggests that sites within the region will take longer to recover following disturbance and may be at risk from repeated impacts.

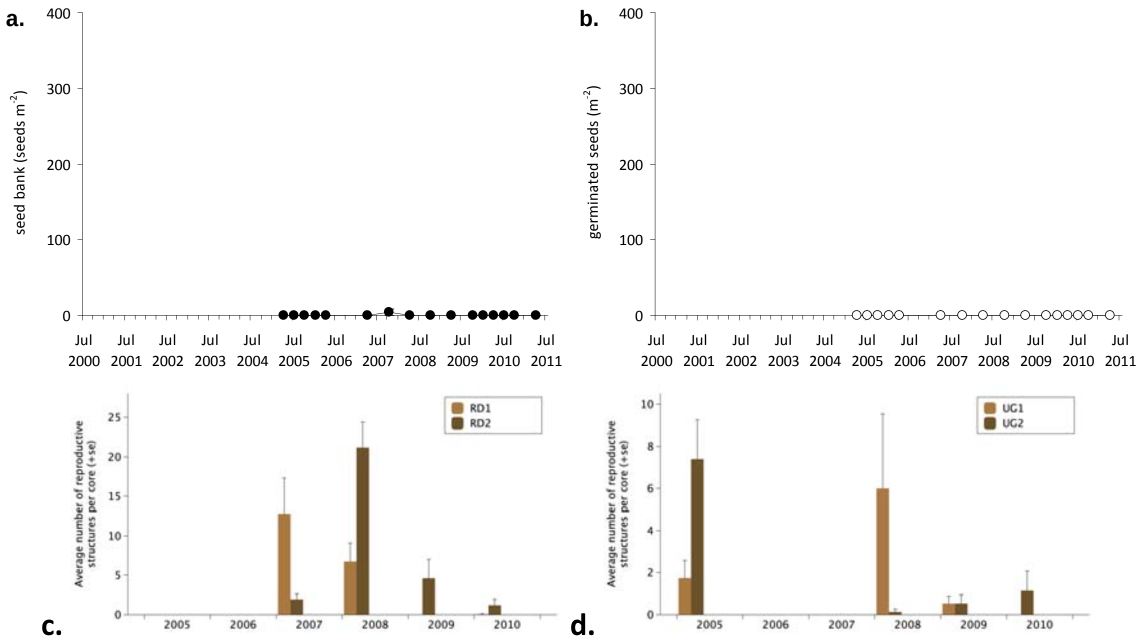


Figure 140. *Seed bank (a) and germinated seed abundance (b) at estuary habitats in the Burnett Mary region (seed bank is represented as the total number of seeds per m^2 sediment surface) and (c, d) average total number of reproductive structures per site in the Burnett Mary region.*

Status of the seagrass environment

Seagrass tissue nutrients

In 2010, C:N ratios were below 20 for both Rodds Bay and Urangan (Hervey Bay) (Figure 141), indicative of a low light environment. At Rodds Bay, levels have consistently decreased since monitoring commenced indicating a possibly deteriorating light environment.

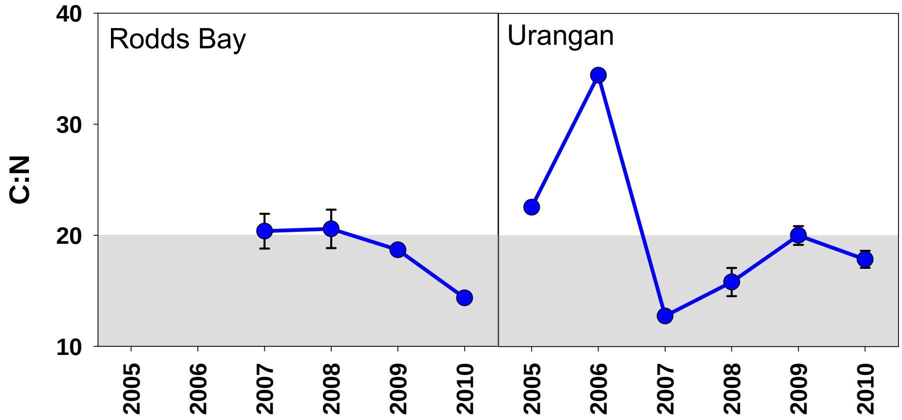


Figure 141. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Burnett Mary region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability.*

The late dry season 2010 C:P ratios of seagrass in the Burnett Mary region decreased below 500, indicating a nutrient rich environment with a relatively large P pool (Figure 142). Tissue ratios of N:P ratio similarly decreased across the Burnett Mary region in 2010 indicating P enrichment (Figure 142).

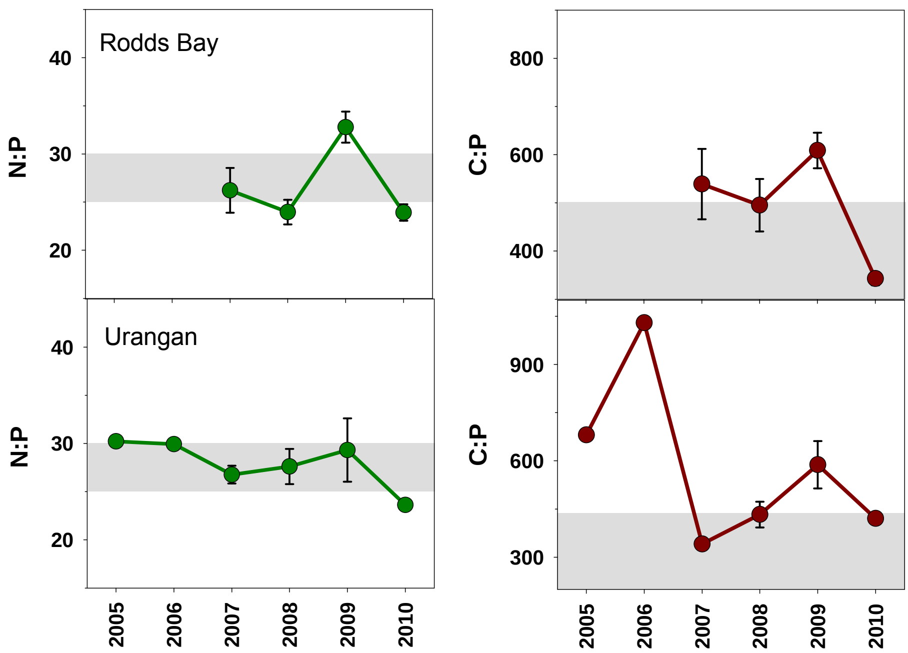


Figure 142. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each location in the Burnett Mary region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith, 1983; Duarte, 1990; Fourqurean et al., 1992; Fourqurean & 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 macro-algae

Epiphyte cover on the seagrass leaf blades at Urangan was highly variable over the years of monitoring, irrespective of seagrass abundance. At Rodds Bay however, epiphyte cover in 2010/11 was lower than previous years and remained lower than the GBR long-term average for estuary habitats (Figure 143). Percentage cover of macro-algae has continued to remain low at both locations (Figure 143).

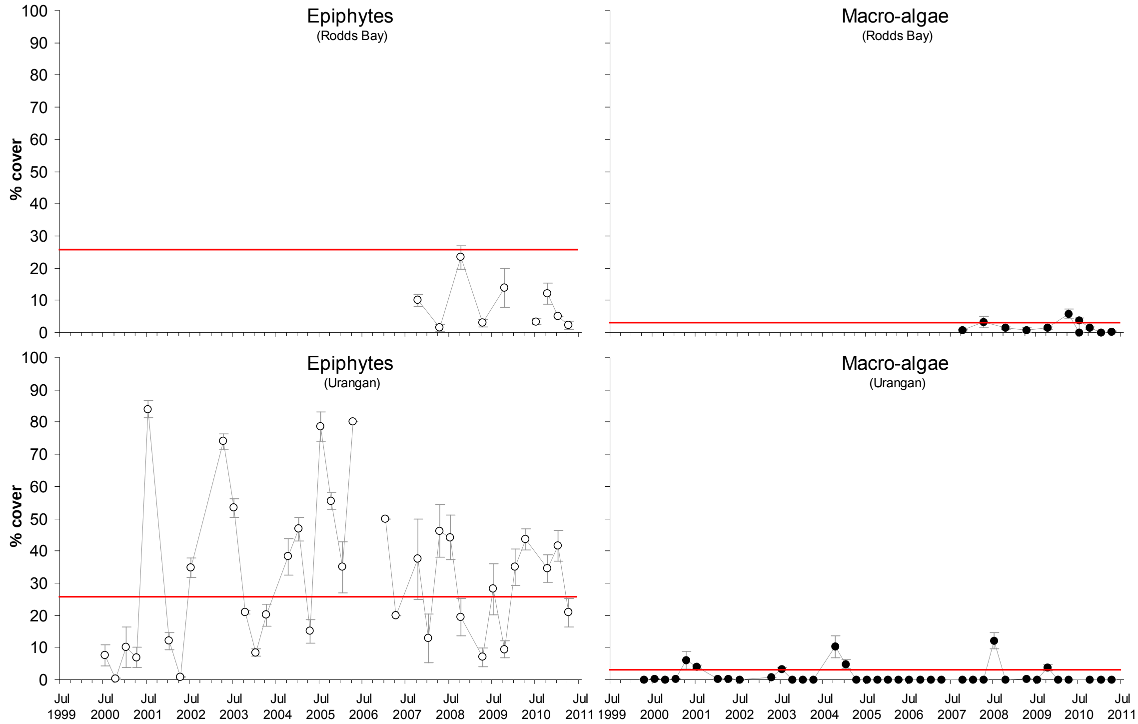


Figure 143. *Mean abundance (% cover) (± Standard Error) of epiphytes and macro-algae at intertidal estuarine (Rodds Bay and Urangan) seagrass monitoring locations. Red line = GBR long-term average; epiphytes=25%, macro-algae=3.2%.*

Rhizosphere sediment herbicides

No herbicides were found above detectable limits in the sediments of the seagrass meadows at either location in the Burnett Mary region (Table 31).

Table 31. *Concentration of herbicides (mg kg^{-1}) in sediments of Rodds Bay and Urangan seagrass monitoring sites in post monsoon 2011. ND=not detectable above limit of 0.001 mg kg^{-1}*

Site	Flumeturon	Diuron	Simazine	Atrazine	Desethyl Atrzine	Desisopropyl Atrzine	Hexazinone	Tebuthiuron	Ametryn	Prometryn	Bromacil	Imidacloprid	Terbutryn	Metolachlor
RD1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
RD2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
UG1	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
UG2	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

Within canopy temperature

Within canopy temperatures were monitored at Rodds Bay and Urangan (Hervey Bay) over the past 12 months (Figure 144). No extreme temperatures (>38°C) were recorded across the region during the monitoring period, although maximum temperatures were experienced in February 2011 at Rodds Bay site 1 (36.7°C) (Figure 144). Mean within canopy temperatures monitored at Urangan and Rodds Bay were within 18 – 28°C range, with highest mean temperatures in January and February 2011. The 2010/11 monitoring period was 0.7 – 1.2°C cooler than the previous monitoring period (Figure 145) and at Rodds Bay it was the coolest year since monitoring commenced.

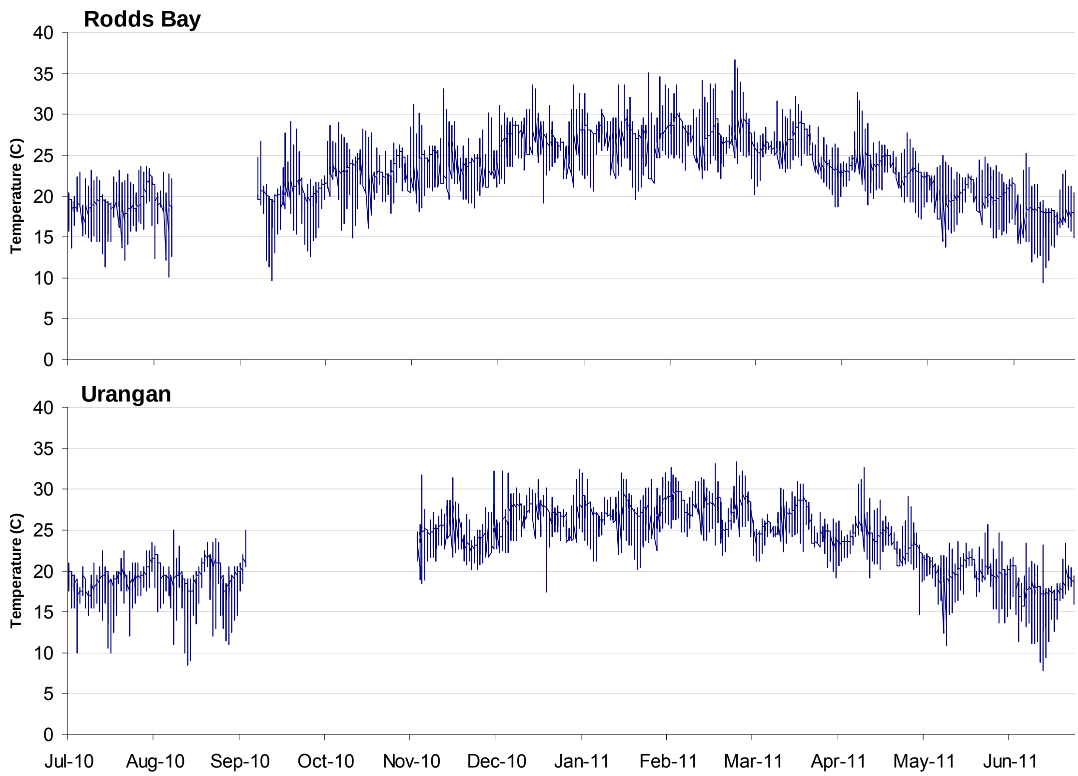


Figure 144. *Within seagrass canopy temperature (°C) at Rodds Bay and Urangan intertidal meadows over the 2010/2011 monitoring period.*

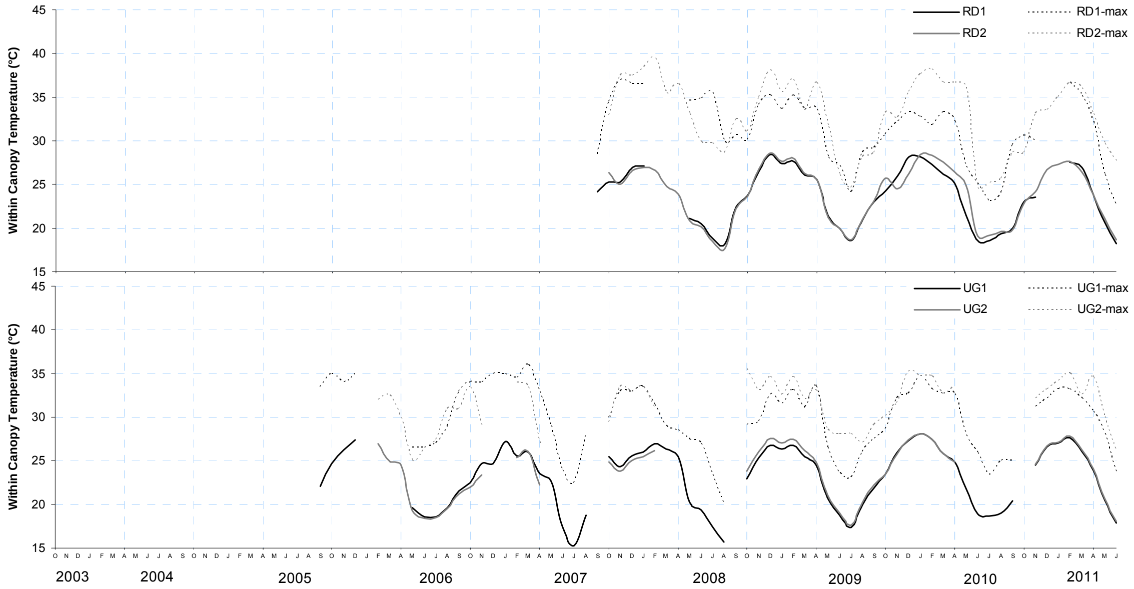


Figure 145. *Monthly mean and maximum within seagrass canopy temperature (°C) at intertidal meadows in estuarine (Rodds Bay and Urangan) monitoring habitats within the Burnett Mary region.*

Canopy incident light

There is limited light data available for Rodds Bay due to *in situ* light logger failure and low deployment frequency. Based on the limited data available, I_d is generally high, on average it was 19.7 mol m^{-2} d^{-1} (Figure 146).

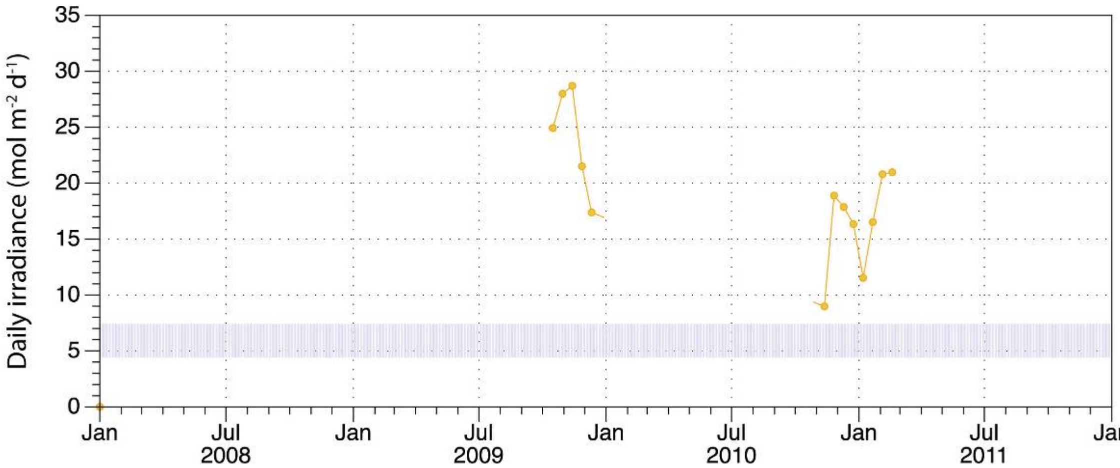


Figure 146. *Daily irradiance (14-day average) at Rodds Bay. The shaded bar indicates seagrass minimum light requirements (see methods for description).*

Regional Climate

Climate across the Mary Burnett region during the 2010/11 monitoring period was on average cooler, wetter, and calmer than the previous decade.

Hervey Bay - Urangan

The mean maximum daily air temperature recorded in Hervey Bay during the 2010/11 monitoring period was 25.9°C, this was 0.2°C cooler than the decade average but long-term averages are not available. The highest recorded daily maximum air temperature in 2010/11 was 33.6°C.

2010/11 was a wet monitoring period relative to the decade average, with approximately 50% more rain (Figure 147). Mean monthly wind speed during 2010/11 was 18.1 km.hr^{-1}, this was lower than the decade average of 19.3 km.hr^{-1} (Figure 147).

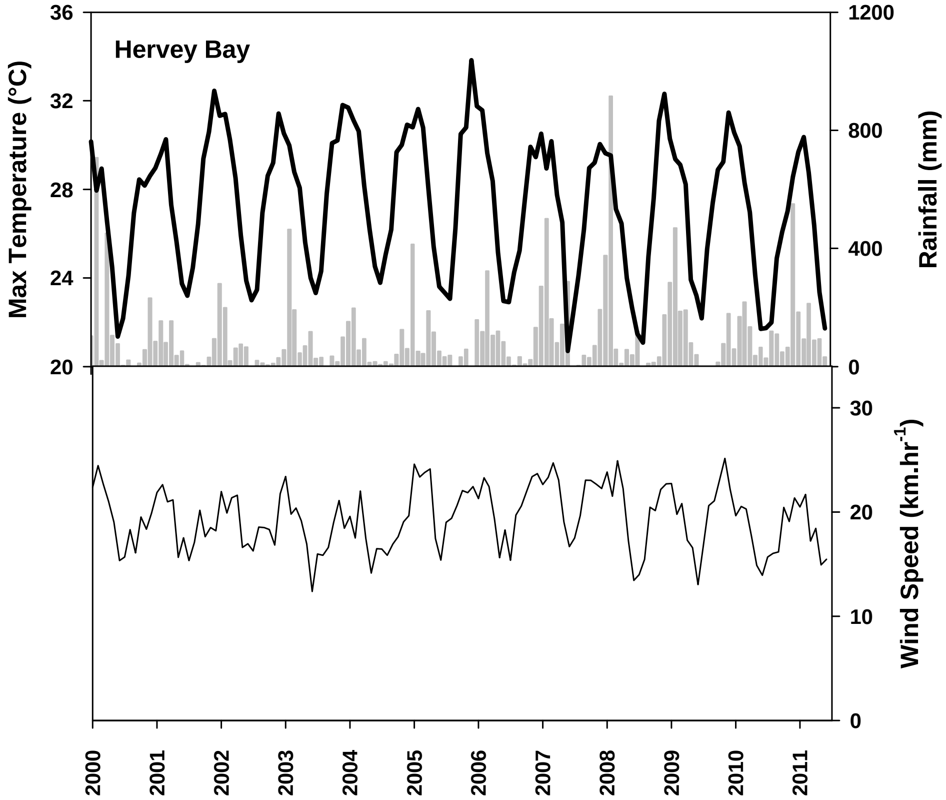


Figure 147. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr-1) recorded at Hervey Bay Airport (BOM station 040405) (Source www.bom.gov.au). Hervey Bay airport used as a surrogate for the climate at Urangan.*

Gladstone – Rodds Bay

The mean maximum daily air temperature recorded in Gladstone during 2010/11 monitoring period was 30.8°C, this was 3.4°C higher than the long-term (54 year) average and 1.1 °C lower than the decade average (Figure 148).The highest recorded daily maximum temperature in 2010/11 was 35.5°C.

2010/11 was a wet monitoring period relative to both the long-term (54 year) and decade averages, with approximately 55% more rain (Figure 148).Mean wind speed in 2010/11 was 19.8 km.hr^{-1}, this was lower than both the long-term and decade averages (Figure 148).

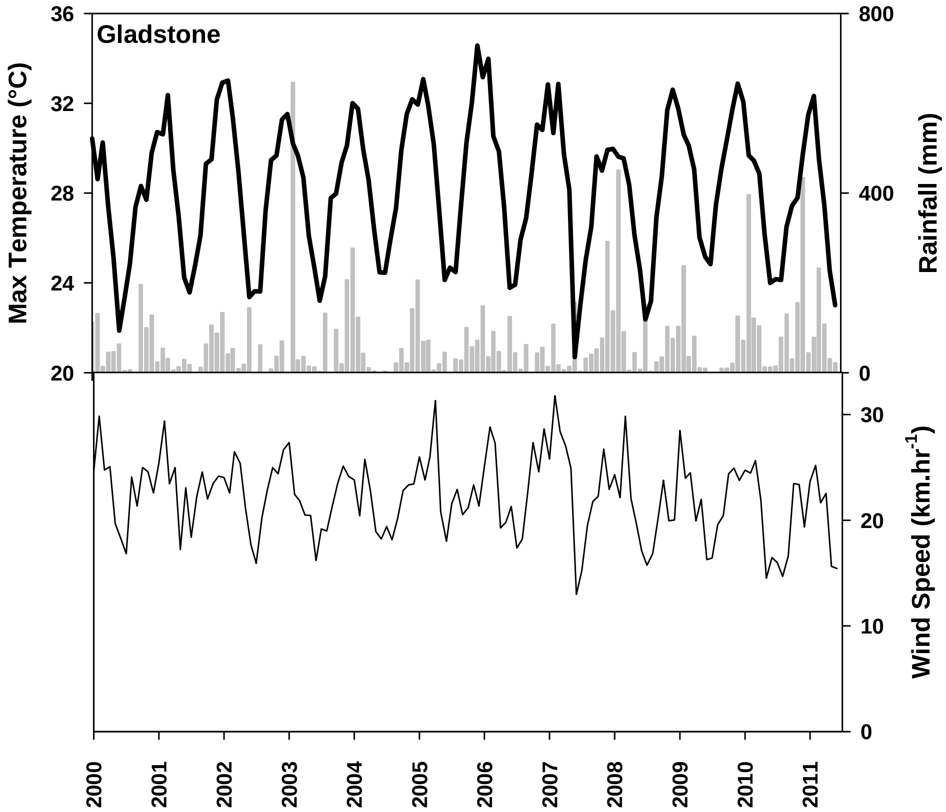


Figure 148. *Mean monthly daily maximum temperature (°C), total monthly rainfall, mean monthly cloud cover (quarts), and mean monthly 3pm wind speed (km.hr^{-1}) recorded at Gladstone Airport (BOM station 039123) (Source www.bom.gov.au). Gladstone airport used as a surrogate for the climate at Rodds Bay.*

River discharge

Several large rivers discharge into the coastal waters of the Burnet Mary region and during floods their plumes extend to locations where seagrass monitoring sites are located. In the north, no major rivers discharge directly into Rodds Bay where the estuarine seagrass monitoring sites are located, however it could be expected that flood waters from the Calliope and Boyne Rivers would travel slightly southward exposing Rodds Bay (41 km to the south) to plumes. In 2010/11, the flows in the Calliope River were significantly higher that the previous 12 years (ANOVA, d.f.=12, F=2.97, p=0.001) and the Boyle flowed for the first time in over a decade (Figure 149).

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). Approximately 55% more rain fell in 2010/11, resulting in significantly higher average daily flows of the Mary River than any other period in over the last decade (ANOVA, d.f.=12, F=7.27, p<0.001)(Figure 150, Figure 107).

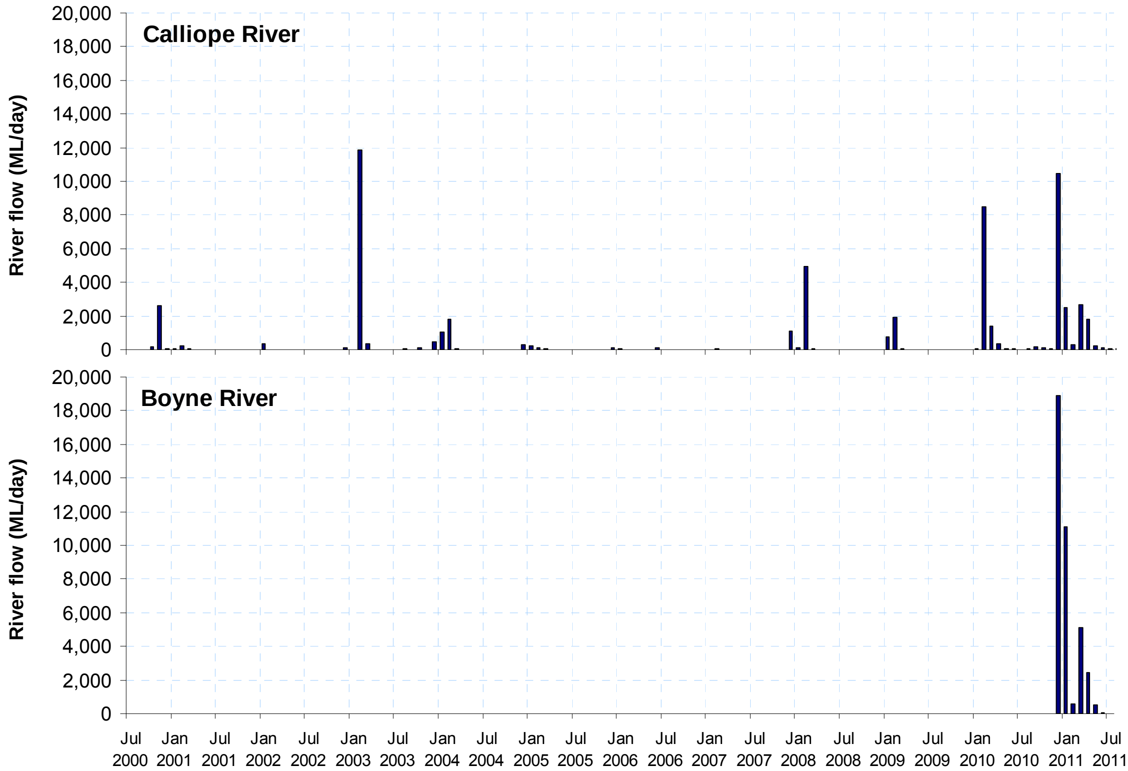


Figure 149. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact estuarine seagrass monitoring sites in Rodds Bay, northern Burnett Mary region (DERM station 132001A - Calliope River at Castlehope 23.98498333°S 151.09756389°E, Elev:21; 133005A - Boyne River at Awoonga Dam Headwater 24.07008611°S 151.32162528°E, Elev:45)(source the State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

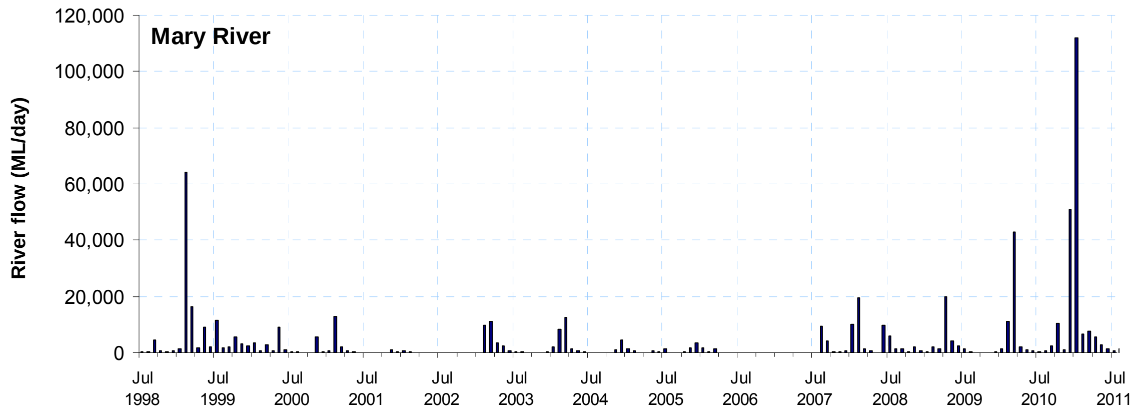


Figure 150. *Average daily flow (ML day^{-1}) per month from the Mary River which would impact estuarine seagrass monitoring sites at Urangan, southern Burnett Mary region (DERM station 138014A - Mary River at Home Park 25.76832547°S 152.5273595°E, Elev 0m) (source the State of Queensland (Department of Environment and Resource Management) 2011, watermonitoring.derm.qld.gov.au).*

4. Discussion

Water quality and ecological integrity of some coastal waters of the GBR are affected by material originating in adjacent catchments as a result of human activity, including primary industries and urban and industrial development. The coastal zone receives an average annual input of sediment on the order of 14 – 28 Mt y^{-1}; an estimated increase by at least four times compared to estimates from before 1850 (Schaffelke *et al*. 2005; Alongi and McKinnon 2005). Most sediments are deposited within the first few kilometres of river mouths (Larcombe and Woolfe 1999; Wolanski 1994), however fine sediment particles can travel large distances (Wolanski *et al*. 1981; Devlin and Brodie 2005). These sediments settle out of the water column, particularly in the protected waters of estuaries, fringing reefs on the leeward margins of islands and coastal north-facing bays; areas where seagrasses are most likely to be found (Lee Long *et al*. 1993; Wolanski *et al*. 2005).

Abal and Dennison (1996) predicted that detectable impacts on seagrass meadows may occur if higher sediment and associated nutrients were transported into the nearshore areas of the GBR region. While nitrogen and phosphorous play an important role in the growth of seagrass meadows, studies in the GBR in the early to mid 1990's reported that seagrass growth was generally limited by nitrogen (Udy *et al.* 1999; Mellors, 2003). Studies' assessing the response of seagrass to enhanced nutrient levels found a response to both nitrogen and phosphorus additions, but nitrogen was the primary limiting element. This indicated that seagrasses had the capacity to absorb additional nutrients enhancing their growth and it appeared that nutrient loadings in the GBR in the 1990's had not reached saturated levels for seagrass growth and distribution (Mellors *et al.,* 2005). The current findings suggest seagrasses in the inshore waters of the Great Barrier Reef in 2010 were no longer nitrogen limited in coastal and reef habitats, but rather, nitrogen replete (in equilibrium). Leaf tissue nutrient concentrations (%N and %P) have been increasing since the MMP was established and have exceeded the global values over the last 5 years.

Although little is known about the physiological mechanisms that control seagrass responses to nutrient enrichment, increased growth is generally expected until light interactions result in seagrass decline (Touchette and Burkholder, 2000; Burkholder *et al.* 2007). Seagrasses also respond at the meadow scale (a state change) to nutrient enrichment. Shifts in seagrass dominance as a consequence of nutrient enrichment have been reported in tropical seagrasses, where species with higher elemental requirements have a competitive advantage (Fourqurean *et al*. 1995; Burkholder *et al.* 2007). Elevated nutrient content of plants can also increase rates of herbivory. For example, Boyer *et al*. (2004) reported nutrient enrichment increased consumption by 30%. Grazing by macro-herbivores (dugong, green sea turtle), has a significant impact on the structure of seagrass communities in northern Australia (Carruthers *et al*. 2002).

Research has shown that seagrass cover significantly declined at low (14% surface irradiance) and very low (1%) light levels in the following sequence: metabolic and physiological changes (reduced growth, increased pigment concentrations and photosynthetic efficiency); shedding (leaf loss, followed by shoot loss); and production of new, altered tissue (leaves with different dimensions including leaf length, width and thickness) (Collier *et al.* 2010). *Z. capricorni* was impacted the fastest and with greatest magnitude, followed by *H. uninervis*. Seagrasses in low light were observed to be impacted more slowly and to a lesser degree than very low light (Collier *et al.* 2010). Among the MMP sites, observations of light levels suggest that at times light levels will reach very low light levels. As a result, there will be ongoing declines in seagrass meadows where repeated or extended periods of low light are observed. In the context of water quality, efforts to keep water quality degradation to a minimum will be rewarded with reduced impacts to seagrasses. Further inferences will require additional evaluation of specific indictor responses as a result of the conditions associated with water quality in GBR coastal ecosystems (see Waycott and McKenzie 2010). This will become possible as longer term monitoring data sets become available and research gaps the currently exist (Waycott and McKenzie 2010).

The 2011 extreme weather events resulted in some of the highest floods in over 30 years and three-quarters of the state of Queensland was declared a disaster zone. Almost the entire state has experienced above average rainfall in the summer 2011 compared to the long-term average. This followed a wetter than average spring, resulting in the catchments being soaked as the wet summer descended. From mid December 2010 to mid January 2011, heavy rainfall across central and southern Queensland river catchments, due to TC Tasha combining with a trough during the strongest La Niña weather pattern since 1973, resulted in some of the highest floods in over 30 years. In addition, in early February 2001, the northern and central sections of the Great Barrier Reef World Heritage Area were impacted by severe Tropical Cyclone Yasi and associated flooding. TC Yasi (category 5) was rated as one of the most powerful cyclones to have affected Queensland since records commenced. The extreme wind generated waves and tides caused severe erosion/deposition and the level of disturbance to coastal and nearshore environments from south of Cairns to Townsville was considerable. Subsequent flooding from the associated rains also resulted in flood plumes discharging from rivers into near shore environments in the region.

The impact of the extreme weather resulted in substantial loss of seagrass in the areas directly affected by the path of TC Yasi. In addition, the broader scale impacts of the 2010/11 wet season across the regions exposed to flooding appear to have resulted in further impacts on seagrass meadows in the GBR. These impacts exacerbate the already stressed seagrass ecosystems of the GBR and accelerated the seagrass loss reported over the last 3 years.

The relationship between tropical seagrass abundance and long-term climatic cycles (e.g. El Niño, La Niña), is relatively poorly resolved. Climate related influences on seagrass systems relate to the periodicity and amplitude of rainfall and storms (Waycott et al. 2011). A dominant controlling factor for tropical seagrass habitats near coasts are the pulses of terrigenous runoff discharged into inshore areas from adjacent catchments during the annual wet season (Carruthers et al. 2001). The impacts on inshore seagrasses, however, may differ depending on the level of modification of adjacent catchments and the nutrient environment in which the seagrasses persist. For example, long-term monitoring has demonstrated that river flow from a predominately unmodified catchment was positively correlated with seagrass biomass (Rasheed and Unsworth 2011). However, the converse has been shown for seagrass meadows in nutrient rich environments impacted by discharges from heavily modified catchments (Campbell and McKenzie 2003; McKenzie et al. 2007). Clearly, in seasons where flow from catchments is higher, the loads of sediments, nutrients, toxicants is higher leading to a greater impact on seagrsas meadows. This has signficant management implications as it indicates that the patterns we observe between years may be climate related. However, the impact of discharges is the product of complex interacting factors that requires an improved understanding, analysis and further resolution of ecosystem models.

Recovery of seagrass meadows from such extreme weather events against a background of degraded capacity to recover, may take many years (Birch and Birch 1984). There are a number of factors that will facilitate recovery of seagrass meadows including seed banks, connectivity and improvement in environmental conditions such as light available for photosynthesis (Campbell and McKenzie 2003). It is estimated that recover 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 (further discussed in Appendix 1).

5. Conclusions

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

Prior to the extreme weather events of 2011 the seagrass meadows of the GBR were in a vulnerable condition with declining trajectories reported throughout much of the GBR. These impacts exacerbate the already stressed seagrass ecosystems. Overall there are indications that seagrass meadows along the GBR urban coast are continuing to decline and are now in a very poor state, particularly south of Cairns. The indicators of this decline are: 73% of sites have declined in abundance over the last 12 months (below the seagrass guidelines) and 80% show a declining long-term trend (5-10 years); 55% sites exhibiting shrinking meadow area, majority of sites have limited or are not producing seeds that would enable rapid recovery; indications of light limitation at 90% of sites; nutrient enrichment at 83% sites and 40% of sites with either high or elevated nitrogen. Elemental ratios of tissue nutrients indicate some sites in the Wet Tropics have degraded water quality with an excess of nutrients compared to light availability. Increased epiphyte loads, possibly stimulated by nutrient loading, further exacerbate light limitation on the surfaces of slower-growing seagrass leaves in coastal habitats.

Other interactions will also be important to consider. Under limiting light levels, elevated nutrient levels will saturate the seagrass more rapidly. As seagrass reproduction is positively correlated with nutrient saturation in some circumstances seagrasses experiencing low light but elevated nutrients may be expected to have increased reproductive effort – until light levels result in compromised survival due to respiration demands being greater than photosynthesis. 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, GBR seagrass meadows appear the have variable recovery potential due to changeable light levels and seed availability both spatially and temporally.

In their current state seagrass meadows are declining along the agricultural and urban GBR coast, apparently as a result of river discharge water quality in flood plumes. Continued monitoring is important to measure if the trends abate and possibly reverse, which would indicate water quality and more generally that aquatic ecosystem health has improved. The conditions required to alleviate these pressures associated with catchment loads require further research. In particular, increasing urban and catchment development introducing higher levels of different pollutants into GBR waters further emphasises our need to understand the synergistic effects between high nutrient availability and exposure to pollutants. In addition, further evaluation of the relationships between water quality parameters and other disturbance factors that influence health and productivity of seagrass meadows are required. Finally, the capacity of seagrass meadows to recover from substantial losses of area is a critical component of ecosystem resilience and our understanding of these processes remains poor in the GBR.

6. References

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

Abal, E.G., Loneragan, N., Bowen, P., Perry, C.J., Udy, J.W. and Dennison, W.C. 1994, Physiological and morphological responses of the seagrass *Zostera capricorni* Aschers. to light intensity. *Journal of Experimental Marine Biology and Ecology* 178: 113-129.

Alongi, D.M. and McKinnon, A.D. 2005, The cycling and fate of terrestrially-derived sediments and nutrients in the coastal zone of the Great Barrier Reef shelf. *Marine Pollution Bulletin* 51: 239–252.

Aragones, L. and Marsh, H. 2000, Impact of dugong grazing and turtle cropping on tropical seagrass communities. *Pac. Cons. Biol*. 5: 277–288.

Armitage, A.R. and Fourqurean, J.W. 2006, The short-term influence of herbivory near patch reefs varies between seagrass species*. Journal of Experimental Marine Biology and Ecology* 339: 65-74.

Atkinson, M.S. and Smith, S.V. 1983, C:N:P ratios of benthic marine plants. *Limnology and Oceneanography*. 28: 568-574.

Australian Government Land and Coasts 2010a, *Wet Tropics - Natural Resource Management region,* http://www.nrm.gov.au/nrm/qld-wetr.html accessed 30 September 2010.

Australian Government Land and Coasts 2010b, *Burdekin - Natural Resource Management region,* http://www.nrm.gov.au/nrm/qld-burd.html accessed 30 September 2010.

Australian Government Land and Coasts 2010c, *Mackay Whitsunday - Natural Resource Management region,* http://www.nrm.gov.au/nrm/qld-mwhs.html accessed 30 September 2010.

Australian Government Land and Coasts 2010d, *Fitzroy - Natural Resource Management region*, http://www.nrm.gov.au/nrm/qld-fitz.html accessed 30 September 2010.

Australian Government Land and Coasts 2010e, *Burnett Mary - Natural Resource Management region*, http://www.nrm.gov.au/nrm/qld-bmar.html accessed 30 September 2010.

Baca, B.J., Snedaker, S.C., Dodge, R.E., Knap, A.H. and Sleeter, T.D. 1996, The effects of crude oil and dispersed crude oil on tropical ecosystems: Long-term seagrass, mangrove, and coral studies. *Oceans Conference Record (IEEE)* 1: 469-486.

Badalamenti, F., Di Carlo, G., D'Anna, G., Gristina, M. and Toccaceli, M. 2006, Effects of dredging on population dynamics of *Posidonia oceanica* (L.) Delile in the Mediterranean Sea: The case study of Capo Feto (SW Sicily, Italy). *Hydrobiologia* 555: 253–261.

Baker, D.E. and Eldershaw, V.J. 1993, *Interpreting soil analysis for agricultural land use in Queensland*, Department of Primary Industries, Queensland, Project Report Series QO93014.

Balestri, E., Benedetti-Cecchi, L. and Lardicci, C. 2004, Variability in patterns of growth and morphology of *Posidonia oceanica* exposed to urban and industrial wastes: Contrasts with two reference locations. *J Exp Mar Biol Ecol* 308: 1–21.

Beal, J.L. and Schmit, B.S. 2000, The effects of dock height on light irradiance (PAR) and seagrass (*Halodule wrightii* and *Syringodium filiforme*) cover, in *Seagrasses: Monitoring, Ecology, Physiology and Management*, ed S.A. Bortone, CRC, Boca Raton, Florida, pp.49–63.

Birch, W. 1975, Some chemical and calorific properties of tropical marine angiosperms compared with those of other plants. *Journal of Applied Ecology* 12: 201–212.

Birch, W.R. and Birch, M. 1984, Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia: A decade of observations. *Aquatic Botany* 19: 343-367.

Bishop, M.J. 2008, Displacement of epifauna from seagrass blades by boat wake. *Journal of Experimental Marine Biology and Ecology* 354: 111–118.

Boyer, K.E., Fong, P., Armitage, A.R. and Cohen, R.A. 2004, Elevated nutrient content of tropical macroalgae increases rates of herbivory in coral, seagrass, and mangrove habitats. *Coral Reefs* 23: 530–538.

Brodie, J. 2004, *Mackay Whitsunday Region: State of the Waterways Report 2004* ACTFR Report No. 02/03 for the Mackay Whitsunday Natural Resource Management Group, http://www-public.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_015439.pdf accessed 30 September 2010.

Brodie, J.E. and Mitchell, A.W. 2005, Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments. *Mar. Freshwat. Res*. 56: 279–302.

Brodie, J., Binney, J., Fabricius, K., Gordon, I., Hoegh-Guldberg, O., Hunter, H., O'Reagain, P., Pearson, R., Quirk, M., Thorburn, P., Waterhouse, J., Webster, I. and Wilkinson, S. 2008, *Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef*, Unpublished report to Reef Water Quality Partnership. October 2008. 84pp.

Brodie, J., Waterhouse, J., Lewis, S., Bainbridge, Z. and Johnson, J. 2009, *Current loads of priority pollutants discharged from Great Barrier Reef Catchments to the Great Barrier Reef*, Australian Centre for Tropical Freshwater Research, Townsville, Report Number 09/02. 125 pp.

Burkholder, J.M., Tomasko, D.A. and Touchette, B.W. 2007, Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology* 350: 46–72.

Burnett Mary Regional Group 2005a, *Country to Coast – A Healthy Sustainable Future Volume 1a Background Report*, http://www.bmrg.org.au/downloads/NRM_Plan/Vol1aBackgroundReport06Feb05.pdf accessed 30 September 2010.

Cabaço, S. and Santos, R. 2007, Effects of burial and erosion on the seagrass *Zostera noltii*. *Journal of Experimental Marine Biology and Ecology* 340: 204-212.

Campbell, S.J. and McKenzie, L.J. 2001, *Community based monitoring of intertidal seagrass meadows in Hervey Bay and Whitsunday 1998–2001*, DPI Information Series Q101090. Department of Primary Industries, Cairns. 32pp.

Campbell, S.J. and McKenzie, LJ. 2004, Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. *Estuarine Coastal and Shelf Science* 60: 47-490.

Campbell, S.J., Roder, C.A., McKenzie, L.J. and Lee Long, W.J. 2002, *Seagrass Resources in the Whitsunday Region 1999 and 2000*, DPI Information Series QI02043, DPI, Cairns, 50 pp.

Carruthers, T.J.B., Dennison, W.C., Longstaff, B.J., Waycott, M., Abal, E.G., McKenzie, L.J. and Lee Long, W.J. 2002, Seagrass habitats of north east Australia: Models of key processes and controls. *Bulletin of Marine Science* 71: 1153–1169.

Chesworth, J.C., Donkin, M.E. and Brown, M.T. 2004, The interactive effects of the antifouling herbicides Irgarol 1051 and Diuron on the seagrass *Zostera marina* (L.). *Aquatic Toxicology* 66: 293–305

Coles, R.G., McKenzie, L.J. and Campbell, S.J. 2003, The seagrasses of eastern Australia, in *The World Atlas of Seagrasses: present status and future conservation,* eds E.P. Green, F.T. Short and M.D. Spalding, University of California Press, Chpt 11, pp.131 – 147.

Coles, R.G., McKenzie, L.J., De'ath, G., Roelofs, A. and Lee Long, W. 2009, Spatial distribution of deepwater seagrass in the inter-reef lagoon of the Great Barrier Reef World Heritage Area. *Marine Ecology Progress Series*. 392: 57–68.

Coles, R.G., McKenzie, L.J., Rasheed, M.A., Mellors, J.E., Taylor, H., Dew, K., McKenna, S., Sankey, T.L., Carter, A.B. and Grech, A. 2007, *Status and Trends of seagrass in the Great Barrier Reef World Heritage Area: Results of monitoring in MTSRF project 1.1.3,* Marine and Tropical Sciences Research Facility, Cairns, 108 pp.

Collier, C.J., Lavery, P.S., Ralph, P.J. and Masini, R.J. 2009, Shade-induced response and recovery of the seagrass *Posidonia sinuosa*. *Journal of Experimental Marine Biology and Ecology* 370: 89-103.

Collier, C.C., Waycott, M. and Giraldo Ospina, A. 2010, Impacts of light reduction on four tropical seagrass species: timelines and thresholds (Attachment 2). in *Final report project 113 to the Marine and Tropical Sciences Research Facility: Condition, trend and risk in coastal habitats: Seagrass indicators, distribution and thresholds of potential concern,* eds M. Waycott and L.J. McKenzie, Reef and Rainforest Research Centre Limited, Cairns, Australia.

Collier, C. J., Uthicke, S. and Waycott, M. 2011, Thermal tolerance of two seagrass species at contrasting light levels: implications for future distribution in the Great Barrier Reef, Limnol. Oceanogr, 56(6): 2200–2210.

Collier, C.J., Waycott, M. and Giraldo-Ospina, A. (in press), Responses of four Indo-West Pacific seagrass species to shading. *Mar Pollut Bull*

Collier C and Waycott M (2009). *Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature Review and Gaps Analysis*. Cairns, Marine and Tropical Sciences Research Facility: 55 pp.

Colwell, J.D. 1963, The estimation of the phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* 3: 190–198.

Costanzo, S.D., O'Donnohue, M.K. and Dennison, W.C. 2003, Assessing the Seasonal Influence of Sewage and Agricultural Nutrient Inputs in a Subtropical River Estuary. *Estuaries* 26(4A): 857–865.

Costanzo, S.D., O'Donohue, M.J. and Dennison, W.C. 2004, Assessing the influence and distribution of shrimp pond effluent in a tidal mangrove creek in north-east Australia. *Marine Pollution Bulletin* 48: 514–525.

Costanzo, S.D., Udy, J., Longstaff, B. and Jones, A. 2005, Using nitrogen stable isotope ratios ($\delta^{15}N$) of macroalgae to determine the effectiveness of sewage upgrades: changes in the extent of sewage plumes over four years in Moreton Bay, Australia. *Marine Pollution Bulletin* 51: 212–217.

De'ath, G. 2005, Water Quality Monitoring: From River to Reef (AIMS, Townsville) 108pp

Deis, D.R. 2000, Monitoring the effects of construction and operation of a marina on the seagrass Halophila decipiens in Ft. Lauderdale, Florida. in *Seagrasses: Monitoring, Ecology, Physiology and Management,* ed S.A. Bortone, CRC, Boca Raton, FL, USA, pp 147–155.

Den Hartog, C. 1970, *The Sea-Grasses of the World*, Verhandelingen der Koninklijke Nederlandse Adademie Van Wetenschappen, AFD. Natuurkunde, Tweede Reeks, Dee1 59, No. 1. North Holland Publishing Company, Amsterdam.

Dennison, W.C. and Abal, E.G. 1999, *Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign*. South East Queensland Regional Water Quality Management Strategy, Brisbane, Australia.245pp.

Dennison, W.C., Aller, R.C. and Alberte, R.S. 1987, Sediment ammonium availability and eelgrass (*Zostera marina*) growth. *Marine Biology* 94: 469–477.

Department of Environment and Resource Management 2009, Queensland Water Quality Guidelines, Version 3. ISBN 978-0-9806986-0-2

Devlin, M.J. and Brodie, J. 2005, Terrestrial discharge into the Great Barrier Reef Lagoon: nutrient behavior in coastal waters. *Marine Pollution Bulletin* 51: 9-22.

Devlin, M. and Schaffelke, B. 2009, Spatial extent of riverine flood plumes and exposure of marine ecosystems in the Tully coastal region, Great Barrier Reef. *Marine and Freshwater Research* 60: 1109–1122.

Devlin, M., Waterhouse, J., Taylor, J. and Brodie, J. 2001, Flood plumes in the Great Barrier Reef: spatial and temporal patterns in composition and distribution. GBRMPA Research Publication No 68, Great Barrier Reef Marine Park Authority, Townsville, Australia

Duarte, C.M. 1990, Seagrass nutrient content. *Marine Ecology Progress Series* 67: 201-207.

Duarte, C.M. 1999, Seagrass ecology at the turn of the millennium: challenges for the new century. *Aquatic Botany* 65: 7–20.

Duarte, C.M. 1990, Seagrass nutrient content. *Marine Ecological Progress Series* 67: 201–207.

Duarte, C.M., Borum, J., Short, F.T. and Walker, D.I. 2005a, Seagrass Ecosystems: Their Global Status and Prospects, in *Aquatic Ecosystems: Trends and Global Prospects*, ed N.V.C. Polunin, Cambridge Univ. Press.

Eklöf, J.S., and de la Torre-Castro, M. 2008, Sea urchin overgrazing of seagrasses: A review of current knowledge on causes, consequences, and management. *Estuarine, Coastal and Shelf Science* 79: 569-580.

Engeman, R.M., Duquesnel, J.A., Cowan, E.M., Smith, H.T., Schiff, S.A. and Karlin, M. 2008, Assessing Boat Damage to Seagrass Bed Habitat in a Florida Park from a Bioeconomics Perspective. *Journal of Coastal Research*. 24(2): 527-532.

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

Erftemeijer, P.L.A., Stapel, J., Smeckens, M.J.E. and Drossaert, W.M.E. 1994, The limited effect of in situ phosphorus and nitrogen additions to seagrass beds on carbonate and terrigenous sediments in South Sulawesi, Indonesia. *Journal of Experimental Marine Biology and Ecology* 182: 123–140.

Erftemeijer, P.L.A. and Middelburg, J.J. 1993, Sediment interactions in tropical seagrass beds: a comparison between a terrigenous and a carbonate sedimentary environment in South Sulawesi (Indonesia). *Marine Ecology Progress Series* 102: 187 – 198

Fairweather, C.L., McKenna, S.A. and Rasheed, M.A. 2011a, *Long-term seagrass monitoring in Cairns Harbour and Trinity Inlet – December 2009 and 2010*, DEEDI Publication, Fisheries Queensland, Cairns, 36 pp.

Fairweather, C.L., McKenna, S.A. and Rasheed, M.A. 2011b, *Long-Term Seagrass Monitoring in the Port of Mourilyan – November 2010*, DEEDI Publication, Fisheries Queensland, Cairns, 27pp.

Fitzroy Basin Association 2004, *The Central Queensland Strategy for Sustainability – 2004 and Beyond* CQSS2, www.fba.org.au/investments/regionalplan.html

FNQ NRM Ltd and Rainforest CRC 2004, *Sustaining the Wet Tropics: A regional Plan for Natural Resource management 2004-2008*.

Fourqurean, J.W.and Cai,Y. 2001, Arsenic and phosphorus in seagrass leaves from the Gulf of Mexico. *Aquat. Bot.* 71: 247–258.

Fourqurean, J.W, Zieman, J., and Powell, G. 1992, Relationships between porewater nutrients and seagrasses in a subtropical carbonate environment. *Marine Biology* 114: 57–65.

Fourqurean, J.W., Moore, T.O., Fry, B. and Hollibaugh, J.T. 1997, Spatial and temporal variation in C:N:P ratios, δ^{15}N, and δ^{13}C of eelgrass *Zostera marina* as indicators of ecosystem processes, Tomales Bay, California, USA. *Marine Ecology Progress Series* 157: 147-157.

Freeman, A.S., Short, F.T., Isnain, I., Razak, F.A. and Coles, R.G. 2008, Seagrass on the edge: Land-use practices threaten coastal seagrass communities in Sabah, Malaysia. *Biological Conservation* 141(12): 2993-3005

Furnas, M. 2003, *Catchments and corals: terrestrial runoff to the Great Barrier Reef*. AIMS & CRC Reef Research Centre.

Gagan, M.K., Ayliffe, L.K., Opdyke, B.N., Hopley, D., Scott-Gagan, H. and Cowley, J. 2002, Coral oxygen isotope evidence for recent groundwater fluxes to the Australian Great Barrier Reef, *Geophys. Res. Lett.,* 29(20): 1982.

Goldsworthy, P.M. 1994, Seagrasses, in *Townsville Port Authority Capital Dredging Works 1993: Environmental Monitoring Program*, eds L. Benson, P. Goldsworthy, R. Butler and J. Oliver, Townsville Port Authority, Townsville, pp89-115.

Garel, E., López Fernández, L and Collins, M. 2008, Sediment resuspension events induced by the wake wash of deep-draft vessels. *Geo-Marine Letters* 28(4):205-211

González-Correa, J.M., Fernández-Torquemada, Y. and Sánchez-Lizaso, J.L. 2009, Short-term effect of beach replenishment on a shallow *Posidonia oceanica* meadow. *Marine Environmental Research* 68: 143–150

Grech, A., Coles, R. and Marsh, H. 2011, A broad-scale assessment of the risk to coastal seagrasses from cumulative threats. *Marine Policy* 35(5): 560 - 567.

Great Barrier Reef Marine Park Authority 2001, *Water Quality Action Plan: A Report To Ministerial Council on targets for pollutant loads*, http://www.gbrmpa.gov.au/corp_site/key_issues/water_quality/action_plan Accessed 30 September 2010.

Green, E.P. and Short, F.T. (eds) 2003, *The World Atlas of Seagrasses*. Prepared by the UNEP World Conservation Monitoring Centre, University of California Press, Berkeley, USA. 298pp.

Grice, A.M., Loneragan, N.R. and Dennison, W.C. 1996, Light intensity and the interactions between physiology, morphology and stable isotope ratios in five species of seagrass. *Journal of Experimental Marine Biology and Ecology* 195: 91-110.

Hamilton, L.J. 1994, Turbidity in the northern Great Barrier Reef Lagoon in the wet season, March 1989. *Aus. J. Mar. Freshw. Res*. 45: 585–615.

Hastings, K., Hesp, P. and Kendrick, G.A. 1995, Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. *Ocean & Coastal Management* 26(3): 225-246.

Haynes, D., Müller, J. and Carter, S. 2000, Pesticide and Herbicide Residues in Sediments and Seagrasses from the Great Barrier Reef World Heritage Area and Queensland Coast. *Marine Pollution Bulletin* 41(7-12): 279-287.

Haynes, D., Ralph, P., Prange, J. and Dennison, W. 2000b, The impact of the herbicide diuron on photosynthesis in three species of tropical seagrass. *Marine Pollution Bulletin* 41(7-12): 288-293.

Haynes, D., Brodie, J., Christie, C., Devlin, M., Michalek-Wagner, K., Morris, S., Ramsay, M., Storrie, J., Waterhouse, J. and Yorkston, H. 2001, *Great Barrier Reef Water Quality Current Issues.* Great Barrier Reef Marine Park Authority, Townsville.

Heap, A.D., Dickens, G.R. and Stewart, L.K. 2001, Late Holocene sediment in Nara Inlet, central Great Barrier Reef platform, Australia: sediment accumulation on the middle shelf of a tropical mixed clastic/carbonate system. *Marine Geology* 176: 39 – 54

Heck, K.L.; Carruthers, T.J.B.; Duarte, C.M.; Hughes, A.R.; Kendrick, G.; Orth, R.J. and Williams, S.W. 2008, Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems* 11: 1198-1210.

Hoven, H.M. 1998, Eelgrass (*Zostera marina* L.) as a sentinel accumulator of lead in Portsmouth Harbor, New Hampshire – Maine*. Diss Abstr Int B Sci Eng* 59: 4600.

Inglis, G.J. 2000, Variation in the recruitment behaviour of seagrass seeds: implications for population dynamics and resource management. *Pacific Conservation Biology* 5: 251-259.

Jackson, J.C.B., Cubit, J.D., Keller, B.D., Batista, V., Burns, K., Caffey, H.M., Caldwell, R.L., Garrity, S.D., Getter, C.D., Gonzalez, C., Guzman, H.M., Kaufmann, K.W., Knap, A.H., Levings, S.C., Marshall, M.J., Steger, R., Thompson, R.C. and Weil, E. 1989, Ecological effects of a major oil spill on Panamanian Coastal marine Communities. *Science* 243: 7-44.

Jacobs, R.P.W.M. 1980, Effects of the 'Amoco Cadiz' oil spill on the seagrass community at Roscoff with species reference to benthic infauna. *Marine Ecology Progress Series* 2: 207-212.

Johnson, M. Heck Jnr, K, and Fourqurean, J. 2006, Nutrient content of seagrasses and epiphytes in the northern Gulf of Mexico: Evidence of phosphorus and nitrogen limitation. *Aquatic Botany* 85: 103-111.

Klumpp, D.W., Done, T., McKinnon, A.D., Brunskill, G.J., and Robertson, A.I. 1997, *Response of nearshore reefs to nutrient enhancement: baseline information on nutrient concentrations, primary production and coral reef community structure*, Unpublished report to the Great Barrier Reef Marine Park Authority, Townsville.

Lanyon, J. 1991, The nutritional ecology of the dugong (*Dugong dugon*) in tropical north Queensland. PhD Thesis. Monash University, Melbourne, Australia

Lanyon, J. and Marsh, H. 1995, Temporal changes in the abundance of some tropical intertidal seagrasses in northern Queensland. *Aquatic Botany* 49: 217–237

Lanyon, J.M., Limpus, C.J. and Marsh, H. 1989, Dugong and turtles: grazers in the seagrass system, in *Biology of seagrasses: a treatise on the biology of seagrasses with special reference to the Australian region,* eds A.W.D. Larkum, A.J. McComb and S.A. Shepherd, Elsevier, Amsterdam, pp.610–634.

Larcombe, P. and Woolfe, K.J. 1999, Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. *Coral Reefs* 18: 163–169.

Lee Long, W.J., Mellors, J.E. and Coles, R.G. 1993, Seagrasses between Cape York and Hervey Bay, Queensland, Australia, *Australian Journal of Marine and Freshwater Research* 44: 19-32.

Lee Long, W.J., McKenzie, L.J. and Coles, R.G. 1997, *Seagrass communities in the Shoalwater Bay region, Queensland - Spring (September) 1995 and Autumn (April)1996*, Queensland Department of Primary Industries Information Series QI96042, QDPI, Brisbane, 38 pp.

Lee Long, W.J., McKenzie, L.J., Roelofs, A.J., Makey, L., Coles, R.G. and Roder, C.A. 1998, *Baseline Survey of Hinchinbrook Region Seagrasses -October (Spring) 1996*, Great Barrier Reef Marine Park Authority Research Publication No. 51, 26 pp.

Lee, K-S., Park, S.R., Kim, Y.K. 2007, Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: A review. *J Exp Mar Biol Ecol* 350: 144-175.

Lewis, M.A. and Devereux, R. 2009, Non-nutrient anthropogenic chemicals in seagrass ecosystems: fate and effects. *Environmental Toxicology and Chemistry*. 28(3): 644–661, 2009.

Lewis, S.E., Brodie, J.E., Bainbridge, Z.T., Rohde, K.W., Davis, A,M,, Masters, B.L., Maughan, M., Devlin, M.J., Mueller, J.F. and Schaffelke, B. 2009, Herbicides: A new threat to the Great Barrier Reef. *Environmental Pollution* 157: 2470–2484.

Lewis, S.E., Bainbridge, Z.T. and Brodie, J.E. 2007, A review of load tools available for calculating pollutant exports to the Great Barrier Reef lagoon: a case study of varying catchment areas. in *MODSIM 2007 International Congress on Modelling and Simulation*, eds L. Oxley and D. Kulasiri, Modelling and Simulation Society of Australia and New Zealand, pp.2396–2402.

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

Longstaff, B.J. 2002, *Investigations into the light requiements of seagraes in Northeast Australia*, PhD Thesis, University of Queensland Brisbane, Department of Botany

Longstaff, B.J., Loneragan, N.R., O'Donohue, M.J., Dennison, W.C. 1999, Effects of light deprivation on the survival and recovery of the seagrass *Halophila ovalis* (R.Br.) Hook. *J Exp Mar Biol Ecol* 234: 1-27.

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J. and Barnes, D. 2003, Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature* 421: 727–730.

Mackay Whitsunday Natural Resource Management Group Inc (2005). Mackay Whitsunday Natural Resource Management Plan. www.mwnrm.org.au/publications/regionalplans.html

Macinnis-Ng, C.M.O. and Ralph, P.J. 2004, *In situ* impact of multiple pulses of metal and herbicide on the seagrass, *Zostera capricorni Aquatic Toxicology* 67: 227–237.

Maughan M., Brodie J. and Waterhouse J. 2008, What river impacts this reef? A simple exposure model, *Proceedings of Water Down Under 2008, incorporating 31 st Hydrology and Water Resources Symposium and 4 th International Conference on Water Resources and Environment Research, 14-17 April 2008, Adelaide,* eds M.Lambert, T.Daniell and M. Leonard, pp.1912-1923.

McKenzie, L.J. 1994, Seasonal changes in biomass and shoot characteristic of a *Zostera capricorni* (Aschers.) dominant meadows in Cairns Harbour, Northern Queensland. *Australian Journal of Marine and Freshwater Research* 45: 1337 - 1352.

McKenzie, L.J. 2009, Observing change in seagrass habitats of the GBR– Seagrass-Watch monitoring: Deriving seagrass abundance indicators for regional habitat guidelines, in *Marine and Tropical Sciences Research Facility Milestone and Progress Report #3, 2008-2009 (ARP 3) Project 1.1.3 Report 3, 11th June 200*, L.J. McKenzie and M. Waycott, pp.7-15. http://www.rrrc.org.au/publications/downloads/113-QDPIF-McKenzie-L-2009-June-Milestone-Report.pdf accessed 27 August 2010.

McKenzie, L.J. and Unsworth, R.K.F. 2009, *Reef Rescue Marine Monitoring Program: Intertidal Seagrass, Final Report 2008/2009*, Fisheries Queensland, Cairns, 127pp.

McKenzie, L.J., Campbell, S.J., Vidler, K.E. and Mellors, J.E. 2007, *Seagrass-Watch: Manual for Mapping & Monitoring Seagrass Resources*, Seagrass-Watch HQ, Cairns, 114pp.

McKenzie L.J., Finkbeiner, M.A. and Kirkman, H. 2001, Methods for mapping seagrass distribution, in *Global Seagrass Research Methods,* eds F.T. Short and R.G. Coles, Elsevier Science B.V., Amsterdam, Chapter 5, pp.101-122.

McKenzie, L.J., Lee Long, W.J., Coles, R.G. and Roder, C.A. 2000, Seagrass-Watch: Community based monitoring of seagrass resources. *Biologia Marina Mediterranea* 7(2): 393 – 396

McKenzie, L.J., Lee Long, W.J. and Yoshida, R. 2004, Green Island seagrass monitoring and dynamics, in *Catchment to Reef: Water Quality issues in the Great Barrier Reef Region, 9–11 March, 2004, Townsville Conference Abstracts,* eds D. Haynes, and B. Schaffelke, CRC Reef Research Centre Technical Report No. 53, p.47.

McKenzie, L.J., Lee Long, W.J., Roelofs, A.J., Roder, C.A. and Coles, R.G. 1998, Port of Mourilyan Seagrass Monitoring - First 4 Years, EcoPorts Monograph Series No 15, Ports Corporation of Queensland, Brisbane, 34 pp.

McKenzie, L.J., Mellors, J., and Waycott, M. (2007) Great Barrier Reef Water Quality Protection Plan (Reef Rescue) – Marine Monitoring Program, Intertidal Seagrass Final Report 2006/2007. Marine and Tropical Sciences Research Facility, Cairns (124pp)

McKenzie, L.J., Mellors, J.E., Waycott, M., Udy, J. and Coles, R.G. 2006, Intertidal seagrass monitoring, in *Water Quality and Ecosystem Monitoring Program - Reef Water Quality Protection Plan. Final Report August 2006 (revised November 2006),* eds B. Schaffelke and J. Waterhouse, unpublished report to the Great Barrier Reef Marine Park Authority, CRC Reef Research, Townsville, Chapter 6, pp.230 -275.

McKenzie, L., Mellors, J., Waycott, M., Unsworth, R. and Collier, C. 2010, Intertidal seagrass monitoring, in *Reef Rescue Marine Monitoring Program: Quality Assurance/Quality Control Methods and Procedures Manual,* ed Reef & Rainforest Research Centre Ltd., report prepared for the Great Barrier Reef Marine Park Authority, Reef & Rainforest Research Centre Ltd, Cairns, Chapter 7, pp.42-56.

McKenzie, L.J., Roder, C.A., Roelofs, A.J. and Lee Long, W.J. 2000, *Post-flood monitoring of seagrasses in Hervey Bay and the Great Sandy Strait, 1999: Implications for dugong, turtle & fisheries management*, DPI Information Series QI00059, DPI,Cairns, 46pp.

McKenzie, L.J., Yoshida, R.L., and Coles, R.G. 2009, Seagrass-Watch. www.seagrasswatch.org. 228pp, accessed 29 February 2012.

McKenzie, L., Yoshida, R., Grech, A. and Coles, R. 2010, *Queensland seagrasses. Status 2010 - Torres Strait and East Coast*, Fisheries Queensland (DEEDI), Cairns, 6pp.

Mcleod, E,, Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H., Silliman, B. 2011, *A Blueprint for Blue Carbon: Towards an improved understanding of the role of vegetated coastal habitats in sequestering CO2*, Frontiers Ecol. Environ. doi:10.1890/110004

McMahon, K., Bengtson Nash, S., Eaglesham, G., Müller, J.F., Duke, N.C. and Winderlich, S. 2005, Herbicide contamination and the potential impact to seagrass meadows in Hervey Bay, Queensland, Australia. *Marine Pollution Bulletin* 51: 325–334.

Mellors, J. 2003, *Sediment and nutrient dynamics in coastal intertidal seagrass of north eastern tropical Australia*, PhD Thesis, James Cook University. 278 pp. Available from www.jcu.edu.au.

Mellors, J.E., Waycott, M. and Marsh, H. 2005, Variation in biogeochemical parameters across intertidal seagrass meadows in the central Great Barrier Reef region. *Marine Pollution Bulletin* 51: 335–342.

Mellors, J., Fabricius, K. and De'ath, G. 2007, Seasonal variation in biomass and tissue nutrients of intertidal seagrasses (*Halophila ovalis* and *Halodule uninervis*) in relation to sediment nutrient contents in North Queensland. in *Candidate bioindicator measures to monitor exposure to changing water quality on the Great Barrier Reef: Interim report,* eds K. Fabricius, S.Uthicke, T.Cooper, C. Humphrey, G. De'ath and J.Mellors, chapter 9, pp.179-193.

Mengel, K. and Kirkby, E.A. 1987, *Principles of Plant Nutrition,* International Potash Institute: Switzerland. 687pp.

Meysman, F.J.R., Middelburg, J.J. and Heip, C.H.R. 2006, Bioturbation: a fresh look at Darwin's last idea. *TRENDS in Ecology and Evolution* 21(12): 688-695.

Milazzo, M., Badalamenti, F., Ceccherelli, G. and Chemello, R. 2004, Boat anchoring on Posidonia oceanica beds in a marine protected area (Italy, western Mediterranean): Effect of anchor types in different anchoring stages*. J Exp Mar Biol Ecol* 299: 51–62.

Monitoring River Health Initiative 1994, *River Bioassessment Manual*, National River Processes and Management Program, Tasmania, 44pp. http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/bioassess.html, accessed 03 February 2012.

Mueller, B. 2004, Quality of *Halodule wrightii* growing near marinas. *Bios* 75(2): 53–57

Neckles, H. 1993, *Seagrass monitoring and research in the Gulf of Mexico National Biological Survey* National Wetlands Research Center Lafayette Louisiana. pp75.

Neil, D.T. 1998, Moreton Bay and its catchment: seascape and landscape, development and degradation, in *Moreton Bay and catchment,* eds I. R. Tibbets, N. J. Hall and W. C. Dennison, School of Marine Science, University of Queensland, Brisbane, pp.3–54.

Nellemann, C., Corcoran, E., Duarte, C.M., Valdés, L., De Young, C., Fonseca, L. and Grimsditch, G. 2009, *Blue Carbon. A Rapid Response Assessment*, United Nations Environment Programme, GRID-Arendal.

Ogden, J.C. and Ogden, N.B. 1982, A preliminary study of two representative seagrass communities in Palau, Western Caroline Islands (Micronesia). *Aquat. Bot.* 12: 229–244.

Orth, R.J.; Carruthers, T.J.B.; Dennison, W.C.; Duarte, C.M.; Fourqurean, J.W.; Heck, K.L. Jr; Hughes, A.R.; Kendrick, G.A.; Kenworthy, W.J.; Olyarnik, S.; Short, F.T.; Waycott, M. and Williams, S.L. 2006, A Global Crisis for Seagrass Ecosystems. *Bioscience* 56: 987-996.

Pollard, P.C. and Greenway, M. 1993, Photosynthetic characteristics of seagrasses (Cymodocea serrulata, Thalassia hemprichii and Zostera capricorni) in low light environment with a comparison of leaf marking and lacunal –gas measurements of productivity. *Australian Journal of Marine and Freshwater Research.* 44(1): 141-154.

Preen, A.R. 1995, Impacts of dugong foraging on seagrass habitats: Observational and experimental evidence for cultivation grazing. *Mar. Ecol. Prog. Ser*. 124: 201–213.

Preen, A.R., Lee Long, W.J. and Coles, R.G. 1995, Flood and cyclone related loss, and partial recovery, of more than 1000 km-2 of seagrass in Hervey Bay, Queensland, Australia. *Aquat. Bot*. 52: 3–17.

Ralph, P.J. and Burchett, M.D. 1998, Impact of the petrochemicals on the photosynthesis of *Halophila ovalis* using chlorophyll fluorescence. *Marine Pollution Bulletin* 36: 429-436.

Ralph, P.J., Tomasko, D., Moore, K., Seddon, S. and Macinnis-Ng, C.M.O. 2006, Human impact on Seagrasses: Eutrophication, Sedimentation and Contamination, in *Seagrasses: Biology, Ecology and Conservation*, eds AWD. Larkum, , Orth, RJ. and Duarte, CM Chapter 24, *In* (Eds).. Springer, The Netherlands. pp 567 - 593

Ralph, P.J., Durako, M.J., Enríquezc, S., Collier, C.J., Doblin, M.A. (2007) Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology* 350: 176–193

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

Rasheed, M.A., Thomas, R., Roelofs, A.J., Neil, K.M. and Kerville, S.P. 2003, *Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey, November/December 2002*, DPI Information Series QI03058, DPI, Cairns, 47 pp.

Rayment, G.E. and Higginson, F.G. 1993, *Australian laboratory handbook of soil and water chemical methods*, Inkata Press: Sydney.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963, The influence of organisms on the composition of seawater, in *,* ed M.N. Hill, Wiley Interscience, New York, vol. 2, pp.26-79.

Sabol, B., Shafer, D. and Lord, E. 2005, *Dredging effects on eelgrass (Zostera marina) distribution in a New England small boat harbor*, Technical Report ERDC/EL-TR-05-8. Army Engineer Waterways Experimental Station, Vicksburg, MS, USA.

Sargent, F.J., Leary, T.J. and Crewz, D.W. 1995, *Scarring of Florida's seagrasses: Assessment and management options*, FMRI Technical Report TR-1. Florida Department of Environmental Protection, St. Petersburg, FL, USA.

Schaffelke, B., Mellors, J. and Duke, N.C. 2005, Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin* 51: 279–296.

Scheltinga, D.M. and Heydon, L. (eds) 2005, *Report on the Condition of Estuarine, Coastal and Marine Resources of the Burdekin Dry Tropics Region*, Commissioned by the Burdekin Dry Tropics Board. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management 230pp.

Schoellhamer, D.H. 1996, Anthropogenic Sediment Resuspension Mechanisms in a Shallow Microtidal Estuary. *Estuarine, Coastal and Shelf Science* 43(5): 533-548

Short, F.T. 1987, Effects of sediment nutrients on seagrasses: Literature review and mesocosm experiment. *Aquat Bot* 27:41–57.

Short, F.T., Burdick, D.M., Granger, S. and Nixon, S.W. 1996, Long-term decline in eelgrass, *Zostera marina* L., linked to increased housing development, in *Seagrass Biology Proceedings, International Workshop*, eds J. Kuo, R.C. Phillips, D.I. Walker and H. Kirkman, Sciences UWA, Nedlands, Western Australia, pp 291–298.

Short, F.T., Dennison, W.C. and Capone, D.G. 1990, Phosphorus limited growth in the tropical seagrass *Syringodium filiforme* in carbonate sediments. *Marine Ecology Progress Series* 62: 169 – 174.

Spalding, M., Taylor, M., Ravilious, C., Short, F. and Green, E. 2003, Global Overview – The Distribution and Status of Seagrass, in *The World Atlas of Seagrasses: present status and future conservation,* eds E.P. Green, F.T. Short and M.D. Spalding, University of California Press, pp 526.

Stieglitz, T. 2005, Submarine groundwater discharge into the near-shore zone of the Great Barrier Reef, Australia. *Marine Pollution Bulletin* 51(1-4): 51-59.

Thomas, K.V. 2001, The environmental fate and behaviour of antifouling paint booster biocides: A review. *Biofouling* 17: 73-86.

Thorhaug, A. and Marcus, J. 1987, Oil spill clean up: The effect of three dispersants on three subtropical/tropical sea grasses. *Marine Pollution Bulletin* 18:124–126.

Tomasko, D.A., Dawes, C.J. and Hall, M.O. 1996, The effects of anthropogenic nutrient enrichment on turtle grass (*Thalassia testudinum*) in Sarasota Bay, Florida. *Estuaries* 19: 448–456.

Touchette, B.W. 2000, Review of nitrogen and phosphorous metabolism in seagrasses. *Journal of Experimental Marine Biology and Ecology* 250:133-167.

Touchette, B.W. and Burkholder, J.M. 2000, Review of nitrogen and phosphorus metabolism in seagrasses. *Journal of Experimental Marine Biology and Ecology*. 250: 133–167.

Tuya, F., Martín, J.A. and Luque, A. 2002, Impact of a marina construction on a seagrass bed at Lanzarote (Canary Islands). *Journal of Coastal Conservation* 8: 157-162

Udy, J.W. and Dennison, W.C. (1996) Estimating nutrient availability in seagrass sediments, *Seagrass Biology Proceedings, International Workshop*, eds J. Kuo, R.C. Phillips, D.I. Walker and H. Kirkman, Sciences UWA, Nedlands, Western Australia, pp. 163–172.

Udy, J.W. and Dennison, W.C. 1997, Growth and physiological responses of three seagrass species to elevated nutrients in Moreton Bay, Australia. *Journal of Experimental Marine Biology and Ecology* 217: 253–257.

Udy, J.W., Dennison, W.C., Lee Long, W.J. and McKenzie, L.J. 1999, Responses of seagrasses to nutrients in the Great Barrier Reef, Australia. *Marine Ecology Progress Series* 185: 257–271.

Unsworth, R.K.F., Taylor, J.D., Powell, A., Bell, J.J. and Smith, D.J. 2007, The contribution of parrotfish (scarid) herbivory to ecosystem dynamics in the Indo-Pacific. *Estuarine, Coastal and Shelf Science* 74: 53-62

Walker, D.I., Dennison, W.C. and Edgar, G. 1999, Status of seagrass research and knowledge, in *Seagrass in Australia; Strategic review and development of an R & D plan*, eds A. Butler and P. Jernakoff, FRDC.

Walker, D.I. and McComb, A.J. 1992, Seagrass degradation in Australian coastal waters. *Marine Pollution Bulletin* 25:191-195.

Waycott, M. and McKenzie, L.J. 2010, *Final report project 1.1.3 and 3.7.1 to the Marine and Tropical Sciences Research Facility: Indicators and thresholds of concern for seagrass ecosystem health for the Great Barrier Reef*, Reef and Rainforest Research Centre Limited, Cairns, Australia

Waycott, M., Duarte, C.M., Carruthers, T.J.B.; Orth, R.J., Dennison, W.C., Olyarnik, S.; Calladine, A., Fourqurean, J.W., Heck, Jr., K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T. and Williams, S.L. 2009, Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences*. 106(30): 12377-12381.

Waycott, M., McKenzie, L., Mellors, J., Ellison, J., Sheaves, M., Collier, C., Schwarz, A., Webb, A., Johnson, J. and Payri, C. 2011, Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change, in . *Vulnerability of fisheries and aquaculture in the Pacific to climate change,* eds J. Bell and J. Johnson, Secretariat of the Pacific Community, Noumea, New Caledonia, chapter 6, pp.97-168.

Wolanski, E. 1994, *Physical oceanographic processes of the Great Barrier Reef*, CRC Press, Inc., Florida. 194pp.

Wolanski, E., Fabricius, K., Spagnol, S. and Brinkman, R. 2005, Fine sediment budget on an inner-shelf coral-fringed island, Great Barrier Reef of Australia. *Estuarine, Coastal and Shelf Science* 65: 153 – 158.

Wolanski, E., Jones, M. and Willia, W.T. 1981, Physical properties of Great Barrier Reef lagoon waters near Townsville, II. Seasonal fluctuations. *Australian Journal of Marine and Freshwater Research* 32: 321-334.

www.seagrasswatch.org 2009, Seagrass-Watch Official website.

Zieman, J.C., Orth, R., Phillips, R.C., Thayer, G. and Thoraug, A. 1984, The effect of oil on seagrass ecosystems, in *Restoration of habitats impacted by oil spills*, eds J. Cairns Jr. and A.L. Buikema Jr, Butterworth Publishers, pp 37-64.

Appendix 1

Reef Rescue Extreme Weather Incident Response (EWIR) Program

Post-flood and Tropical Cyclone Yasi Assessment of Seagrass Status in Dugong and Green Turtle Feeding Grounds

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Summary

There have been substantial losses of seagrass in the areas directly affected by the path of Tropical Cyclone Yasi. In addition, the broader scale impacts of the 2010-2011 wet season across the regions exposed to flooding and cyclones appear to have compounded the affects of recent poor water quality experienced by seagrass meadows in the coastal GBR. There is the strong likelihood that further losses will be experienced over the next few months as the longer term impacts of flooding are experienced by seagrass meadows. Additional data on plant nutritional status will be forthcoming when analyses are completed by external providores. Additional survey's of Shoalwater Bay will take place later in 2011 when we are granted access to the region, currently being inaccessible due to military activities. The scale of losses are expected to have an impact on food resource availability for dugong and green turtles resulting in further losses of both.

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Background

The 2011 Queensland flood and cyclone disasters resulted in some of the highest floods in over 30 years and three-quarters of the state of Queensland was declared a disaster zone. Almost the entire state has experienced above average rainfall in the summer 2011 compared to the long-term average. This followed a wetter than average spring, resulting in the catchments being soaked as the wet summer descended. Early in the wet season, from mid December 2010 to mid January 2011, heavy rainfall across central and southern Queensland river catchments. Contributing to this was the affect of TC Tasha combining with a trough during the strongest La Niña weather pattern since 1973, which resulted in some of the highest floods in over 30 years.

In the southern Great Barrier Reef World Heritage Area, the largest river system discharging into reef waters is the Fitzroy River. In late December 2010 to early January 2011 the Fitzroy River peaked at 9.2 metres just short the of the predicted 9.4 metres maximum. Significant volumes of floodwater were observed discharging in Keppel Bay and moving northward into the most northern reaches of Shoalwater Bay (Figure 1). These turbid floodwaters would have contained varying amounts of freshwater, sediments, nutrients and pesticides as well as other potential contaminants and would have impacted seagrasses beneath the plumes to some degree.

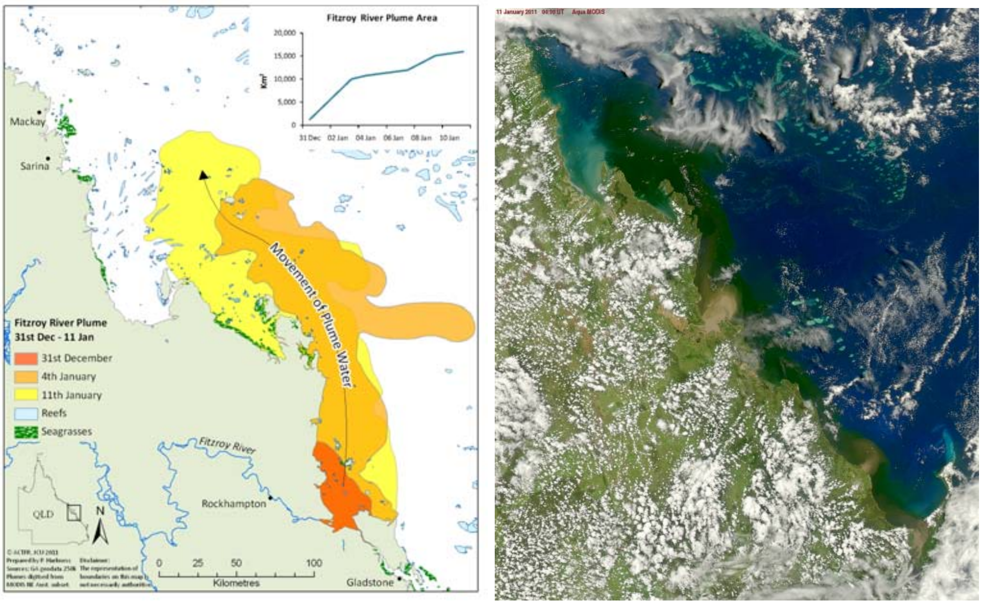

Figure 1. Draft flood plume map (left) provided by ACTFR (Michelle Devlin) indicating the area of impact of the Fitzroy River flood plume in January 2011, and AquaMODIS image from 11 January 2011 (right) showing plumes entering northern section of Shoalwater Bay.

In early February 2001, the northern and central sections of the Great Barrier Reef World Heritage Area were impacted by severe Tropical Cyclone Yasi and associated flooding. After making landfall at Mission Beach in the early hours of 3 February 2011, severe Tropical Cyclone Yasi (Category 5) was rated as one of the most powerful cyclones to have affected Queensland since records commenced (Figure 2). With sustained winds of 205 km/h, gusting up to 285 km/h, and a 5 m tidal surge, the level of disturbance to coastal and nearshore environments from south of Cairns to Townsville was considerable. Subsequent flooding from the associated rains also resulted in flood plumes discharging from rivers into near shore environments in the region.

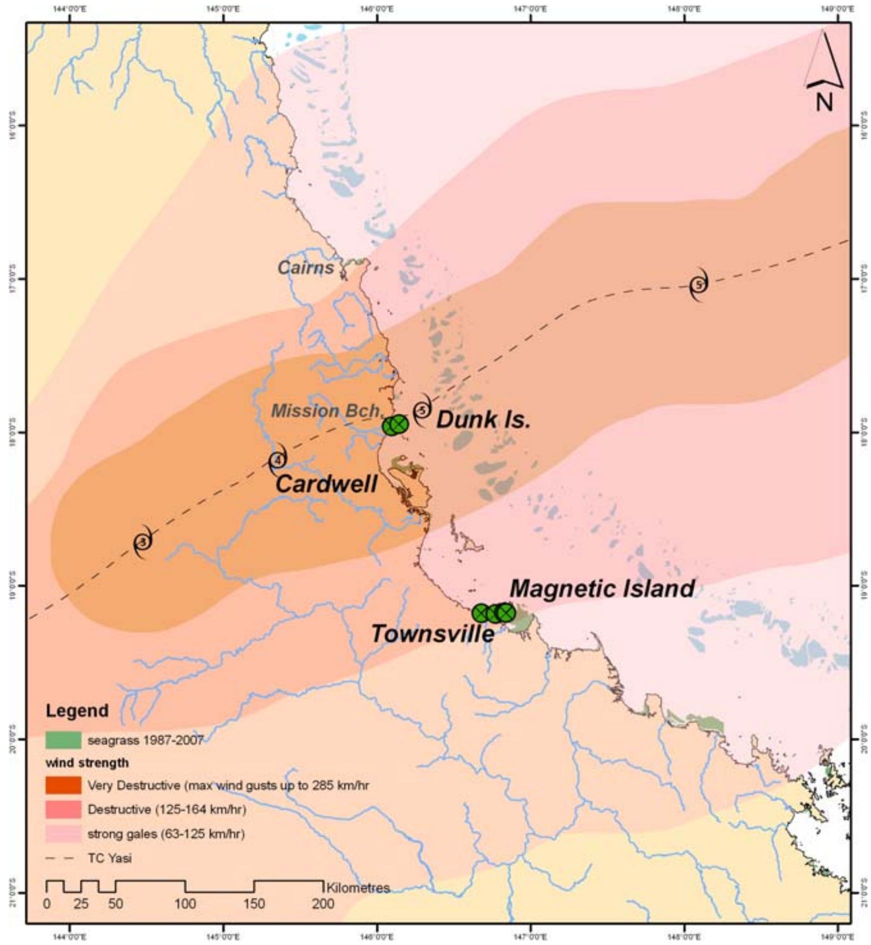

Figure 2. Location of intertidal monitoring sites and the path and area impacted by Tropical Cyclone Yasi, 2-3 February 2011 (category level also shown).

Coastal seagrass habitats, both intertidal and subtidal, will be the most impacted by river flood plume pollutants and physical disturbance from heightened wave activity which cause surges and scouring. Sediments transported by river flood plumes have an immediate effect on coastal seagrasses through sediment deposition (From Campbell & McKenzie 2004). In addition, while sediments remain suspended in the water column turbidity is high, and light reaching the seafloor is reduced, impacting coastal and deeper water seagrasses that are beneath the plume over much longer time periods (up to 2 years). Other pollutants (e.g. nutrients and pesticides) adsorbed to sediments and in solution can further impact seagrass, resulting in reduced growth or loss. Pesticides may reach sub-lethal or lethal concentrations close to river mouths and elevated water column nutrients can promote excessive epiphyte growth on the seagrass leaves within days to weeks, further limiting light available for photosynthesis. Ultimately, the impact of river flood plumes to seagrass will depend upon the amount of pollutant (including nutrients, pesticides and sediment) deposited and the persistence of the plume (i.e. exposure).

Typically seagrasses are expected to decline following heavy flooding events within 1-2 months, which probably results from severe light limitation (Longstaff & Dennison 1999). However, this decline may continue for 6-9 months; through the senescent season (Jun-Aug) when seagrass abundance is lower due to natural seasonal cycles and into the growing season (Sep-Dec) when seagrass abundance is expected higher, again due to the seasonal cycle. This "delayed" response is of significant concern as initial impacts to seagrass ecosystems may be greater than first observations following events may indicate. The rate of seagrass decline depends on the seagrass community, with some species of seagrass able to tolerate longer periods of light limitation than other species.

Prior to the 2010-2011 wet season, the seagrass meadows of the GBR were already in a vulnerable condition, declining trajectories had been previously reported throughout much of the GBR (McKenzie et al. 2010). In addition, data from a small number of subtidal meadows in the Burdekin and Wet Tropics regions of the GBR also show declining trajectories for the past three years. Further, over the last 10 years, intertidal seagrasses within these regions have shown a declining trend in abundance. Recent analysis of Reef Rescue MMP program data and longer term Seagrass-Watch datasets indicate that seagrass meadows not directly lost through physical disturbance associated with major flooding events have declined over longer periods (i.e. months to years) (McKenzie *et al.* 2010a, 2010b; www.seagrasswatch.org). Observations of the responses of seagrass meadows in a gradient from the flood plumes associated with the 2011 floods and TC Yasi will improve our understanding, not only of the specific responses to the unusual conditions, but also the broader scale trends in seagrass status across the GBR.

With the impacts from the combined extreme weather events being so widespread, there is now concern for the accessibility to food by dugongs and also green turtles throughout the GBR. Impacts to seagrass resources from floods and cyclones are know to have significant flow-on effects to the dugong and green turtle populations which are highly dependent on the local seagrass meadows which provide their primary food supply. For example, the loss of almost 1,000 km^2 of seagrass in Hervey Bay after a cyclone and prolonged flooding in 1992 almost decimated the local dugong population (e.g. Preen *et al.* 1995). Several locations impacted by the 2011 floods and TC Yasi have significant dugong and green turtle populations (e.g. Missionary Bay, Cleveland Bay, and Shoalwater Bay).

In early 2011, the Great Barrier Reef Marine Park Authority initiated the Reef Rescue Extreme Weather Incident Response (EWIR) Program. A component of the program was to assess the status of seagrass in some well known dugong feeding grounds. The most significant dugong feeding areas in the impacted areas include northern Hinchinbrook Island (Missionary Bay/Dunk Island), Cleveland Bay/Townsville and Shoalwater Bay.

The aims of this work were to assess the impact of the extreme weather events in 2011 on seagrass meadows of the GBR and to place these findings in the context of current trajectories. This report builds on work undertaken through the Reef Rescue MMP, MTSRF (Project 1.1.3), and also supported by light logger funding grant from the GBRMPA Climate Change group (2009) funded through the MTSRF project 1.1.3 ext B. The Department of Environment and Resource Management (DERM) supplied turbidity loggers. Seagrass probability coverage maps were provided by Alana Grech (CoE, JCU) and information relating to flood plume exposure was provided by Michelle Devlin (ACTFR, JCU).

Methods

General methodology

See the Great Barrier Reef–Reef Rescue Marine Monitoring Program (RRMMP) report and QA/QC documentation for general methodology related to this work (i.e. McKenzie et al. 2010).

Seagrass surveys followed general methodologies outlined in the Great Barrier Reef–Reef Rescue Marine Monitoring Program along with methods applied to seagrass surveys conducted by DEEDI (e.g. Fairweather et al. 2011). In the Hinchinbrook region, following TC Yasi, the foreshore at Cardwell was examined and photographed on the 19th February 2011 and the coastline flown by helicopter on 20th March 2011 with standard GIS mapping techniques used to identify and map intertidal meadows.

Sites

This report contains data from both subtidal sites and intertidal sites that are located in the central and Wet Tropics region of the GBR exposed to the influence of Tropical Cyclone Yasi in 2011. These sites reflect a gradient away from the primary influence of TC Yasi. The subtidal sites being routinely monitored are Magnetic Island, Dunk Island, and Green Island (Table 1). We also report on environmental variables for other intertidal sites in this region along with a survey of the seagrass meadows in the Hinchinbrook region. Both subtidal and intertidal seagrass sites are typically surveyed every 3 months, however we undertook additional surveys in May 2011 (13 – 24 May 2011), in between regular survey times. All data presented in this report was up to date as of May 2011.

Table 1. Reef Rescue MMP inshore seagrass long-term monitoring sites. NRM region from www.nrm.gov.au. Note: *Zostera capricorni = Zostera muelleri subsp. capricorni*.

GBR region	NRM region (*Board*)	Catchment	Monitoring location	Site		Latitude		Longitude		Seagrass community type
Northern	Wet Tropics (*Terrain*)	Barron Russell/Mulgrave Johnstone	Green Island *Intertidal offshore reef*	GI1	Green Island	16°	45.789	145°	58.31	*Cymodocea rotundata/Thalassia hemprichii* with *Halodule uninervis/Halophila ovalis*
				GI2	Green Island	16°	45.776	145°	58.501	*C. rotundata/T. hemprichii* with *H. uninervis/H. ovalis*
				Subtidal	Green Island	16°	45.29	145°	58.38	*H. uninervis, Cymodocea rotundata, C. serrulata, H. ovalis, Syringodium isoetifolium*
		Tully	Mission Beach *Coastal intertidal*	LB1	Lugger Bay	17°	57.645	146°	5.61	*H. uninervis*
				LB2	Lugger Bay	17°	57.674	146°	5.612	*H. uninervis*
			Dunk Island *Intertidal and subtidal offshore 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*
				Subtidal	Dunk Island	17°	55.91	146°	8.42	*H. uninervis, C. serrulata, H. ovalis, H. decipiens*
Central	Burdekin (*Burdekin Dry Tropics*)	Burdekin	Magnetic island *Intertidal and subtidal offshore reef*	MI1	Picnic Bay	19°	10.734	146°	50.468	*H. uninervis* with *H. ovalis & Zostera capricorni/T. hemprichii*
				Subtidal	Picnic Bay	19°	10.88	146°	50.63	*H. uninervis, C. serrulata, H. spinulosa*
				MI2	Cockle Bay	19°	10.612	146°	49.737	*C. serrulata/ H. uninervis* with *T. hemprichii/H. ovalis*
			Townsville *Coastal intertidal*	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*
				SI2	Sarina Inlet	21°	23.712	149°	18.276	*Z. capricorni* with *H. ovalis (H. uninervis)*
Southern	Fitzroy (*Fitzroy Basin Association*)	Fitzroy	Shoalwater Bay *Coastal intertidal*	RC	Ross Creek	22°	22.953	150°	12.685	*Z. capricorni* with *H. ovalis*
				WH	Wheelans Hut	22°	23.926	150°	16.366	*Z. capricorni* with *H. ovalis*
			Keppel Islands *Intertidal offshore 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*

Seagrass nutritional value for marine herbivores

Seagrass was collected for analysis of carbohydrates if there was seagrass present at the site. Three replicates were collected and analysed where there was sufficient material available i.e. at many sites, seagrass cover was so low that only enough plant material could be collected for one or two replicates. No seagrass material was available at Dunk Island and Magnetic island subtidal sites, and at Bushland Beach and Lugger Bay intertidal sites.

Soluble sugars were extracted in 80% ethanol at 80°C for 3 min (repeated 3 times and centrifuged at 2500 rpm for 5 min between each extraction). The supernatant was retained for soluble CHO determination**.** Total non-structural carbohydrates (TNSC) remaining in the pellet was then solubilised by mixing in deionised water and heating at 95°C for 1 h. The TNSC was then digested with amylase enzyme and incubated at 55°C for 2 h. The sample was then centrifuged and the supernatant filtered. The samples were then analysed colorimetrically using a ferricyanide reagent. The values for soluble and TNSC components were summed to derive total carbohydrates (%DW).

The total carbohydrate concentration of each species at each site was compared against the long-term average for the site. Long-term data were available for Green Island, Dunk Island and Magnetic Island, for *Halodule uninervis*, *Thalassia hemprichii* and *Cymodocea serrulata* only, and the data were sourced from MTSRF project 1.1.3 (2008-2010; Waycott and McKenzie 2010). For other sites and species (*Halophila ovalis* and *Zostera muelleri*), reference values were calculated from the literature and were not specific to the sites where samples were collected (Longstaff et al. 1999, Lawler et al. 2006, Collier et al. In Press) (Table 2).

Table 2. Reference values for carbohydrate concentration (percent dry weight–%DW) and the source of data for generating reference values.

Location	Site	Seagrass species analysed	Average carbohydrate concentration (%DW)	Data source	Based on this site
Green Island	Intertidal	*H. uninervis*	22.3	MTSRF 1.1.3^	Y
	Intertidal	*T. hemprichii*	23.4	MTSRF 1.1.3	Y
	Intertidal	*H. ovalis*		MTSRF 1.1.3	Y
	Subtidal	*H. uninervis*	20.9	MTSRF 1.1.3	Y
	Subtidal	*C. serrulata*	18.1	MTSRF 1.1.3	Y
Dunk Island	Intertidal	*H. uninervis*	21.1	MTSRF 1.1.3	Y
	Subtidal	None present			
Lugger Bay	Intertidal	None present			
Bushland Beach	Intertidal	None present			
Cockle Bay	Intertidal	*H. uninervis*	18.4	MTSRF 1.1.3	N, Average of LI, GI, DI, MI
	Intertidal	*T. hemprichii*	17.8	MTSRF 1.1.3	N, Average of LI, GI, DI, MI
Picnic Bay	Intertidal	*H. uninervis*	13.1	MTSRF 1.1.3	Y
	Intertidal	*T. hemprichii*	5.2	MTSRF 1.1.3	Y
	Subtidal	None present			
Shoalwater Bay WH	Intertidal	*H. uninervis*	27.2	MTSRF 1.1.3	N, Average of LI, GI, DI, MI
	Intertidal	*H. ovalis*	5.1	Lawler et al 2006 Longstaff et al 1999	N
	Intertidal	*Z. capricorni*	5.5	Lawler et al 2006 Collier et al In Press	N
Shoalwater Bay RC	Intertidal	*H. ovalis*	5.1	Lawler et al 2006 Longstaff et al 1999	N
		Z. capricorni	5.5	Lawler et al 2006 Collier et al In Press	N
Great Keppel	Intertidal	*H. uninervis*	27.2	MTSRF 1.1.3	N, Average of LI, GI, DI, MI
		H. ovalis	5.1	Lawler et al 2006 Longstaff et al 1999	N
Gladstone Harbour	GH1	*Z. muelleri*	5.5	Lawler et al 2006 Collier et al In Press	N
	GH2	*Z. muelleri*	5.5	Lawler et al 2006 Collier et al In Press	N
Burrum Heads		*H. uninervis*	27.2	MTSRF 1.1.3	N
Urangan		*Z. muelleri*	5.5	Lawler et al 2006 Collier et al In Press	N

^ Waycott and McKenzie 2010

Results and discussion

Seagrass surveys

Wet tropics/Hinchinbrook Island

The largest nearshore meadows in the Hinchinbrook region (Lucinda to Mourilyan Harbour) occur in Mourilyan Harbour, adjacent to Dunk Island, in Missionary Bay (northern Hinchinbrook Island), along the Cardwell, northern Hinchinbrook Channel and the Lucinda foreshores. These meadows have been monitored and/or mapped periodically since 1986. Unfortunately, surveys have not always included all meadows or the complete coastline. The most intensive mapping has been in the vicinity of the Port Hinchinbrook development and within the Port of Mourilyan. The most recent large scale mapping pre Tropical Cyclone Yasi and the associated severe weather event was for Lucinda and the Southern Hinchinbrook in March 2007 and Mourilyan Harbour in October 2010. Mapped information has also been incorporated into a predictive model (Grech and Coles 2010) of coastal seagrass likelihood which provides a coarse (at a local scale) two kilometre square grid cell representation of the meadows in the region.

Trend data collected using a consistent sampling design is available for the past 10 years from repeated mapping and monitoring of Mourilyan Harbour; Seagrass-Watch and RRMMP sampling sites at Dunk Island, Lugger Bay and Goold Island. Limited trend data is also available from repeated surveys at Port Hinchinbrook between 1994 and 1997.

Combined, this information is a comprehensive snapshot of the extent of seagrass possible in the region, the likely species composition and prevalence. Trend data adds to this the expected ranges of seasonal change and some measure of the consistency of meadow presence.

<u>Long-term monitoring sites</u>

Seagrass monitoring was conducted at existing long-term monitoring sites at intertidal coastal and reef habitat locations. The coastal location was at Lugger Bay, where *Halodule uninervis* meadows are located on naturally dynamic intertidal sand banks, protected by a fringing reef. These meadows are often exposed to regular periods of disturbance from wave action and consequent sediment movement. The intertidal meadow at Lugger Bay is only exposed on very low tides (<0.4m), and seagrass cover is generally low (< 10%) (Figure 3). The decline of seagrass at Lugger Bay in 2006 was a consequence of severe TC Larry, which crossed the coast 50km north of the location on 20 March 2006. In 2009, the meadow had recovered and *H. uninervis* abundance subsequently followed a seasonal pattern (lower in the late monsoon) In March 2011 (post TC Yasi), seagrass was absent from Lugger Bay.

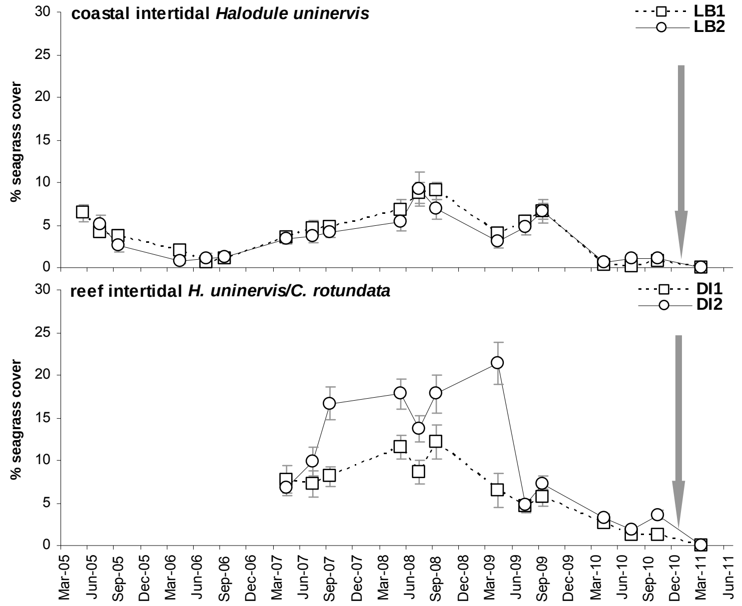

Figure 3. Mean percentage seagrass cover (± Standard Error) at each intertidal coastal (Lugger Bay) and reef (Dunk Island) long-term monitoring site. Grey arrow indicates Tropical Cyclone Yasi.

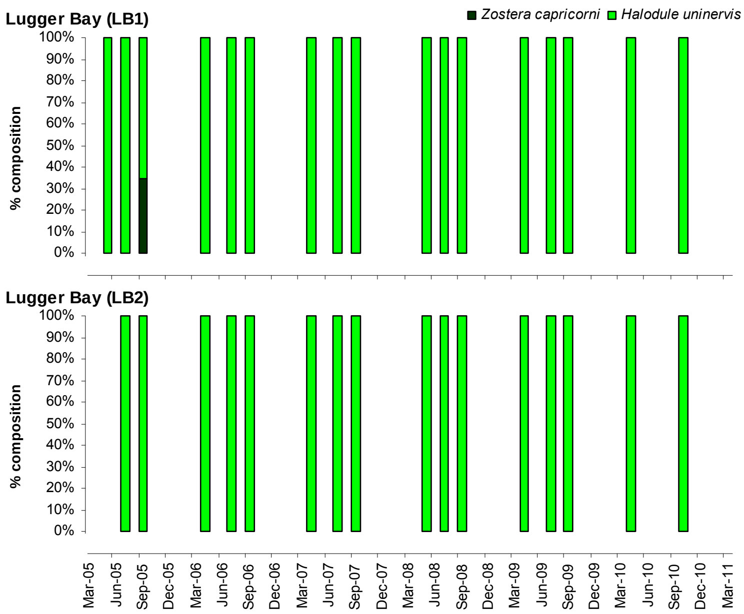

Figure 4. Seagrass species composition at each intertidal long-term monitoring site at Lugger Bay.

The reef habitat sites were located on the intertidal reef flat of Dunk Island, a continental island offshore from Mission Beach. The meadows at Dunk Island include five seagrass species: *Halodule uninervis* and *Cymodocea rotundata* with *Thalassia hemprichii, Halophila ovalis* and *C. serrulata* (Figure 3). Seagrass abundance has been declining at Dunk Island since 2009 and only a few isolated shoots of *H. uninervis* remained in March 2011 (Figure 3).

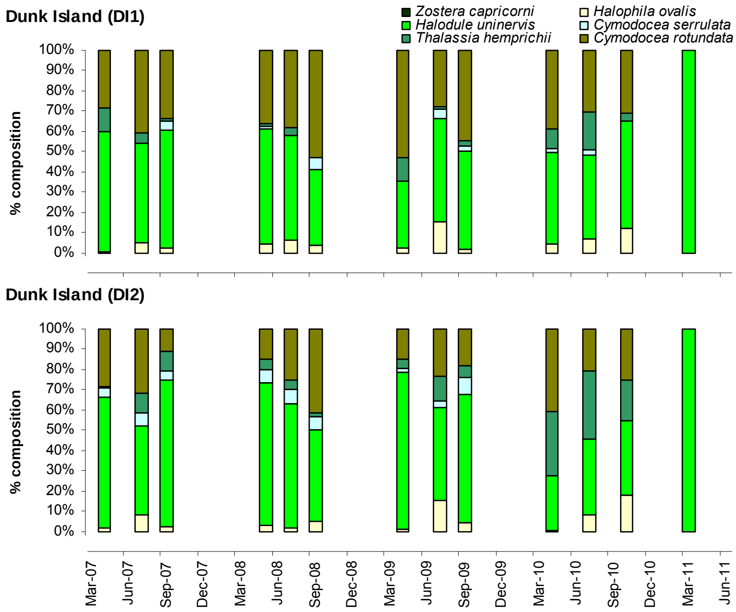

Figure 5. Seagrass species composition at each intertidal monitoring site at Dunk Island.

Physical disturbance was evident across both the coastal and reef intertidal seagrass meadows at locations with significant sediment movement. The seaward edge of the intertidal banks had eroded at Lugger Bay, and large volumes of sand had been deposited across the intertidal banks on Dunk Island (Figure 7).

At the Dunk Island subtidal site, there was also complete seagrass loss following TC Yasi. There was also substantial decline during 2010 following the wet season (Figure 6, 8)

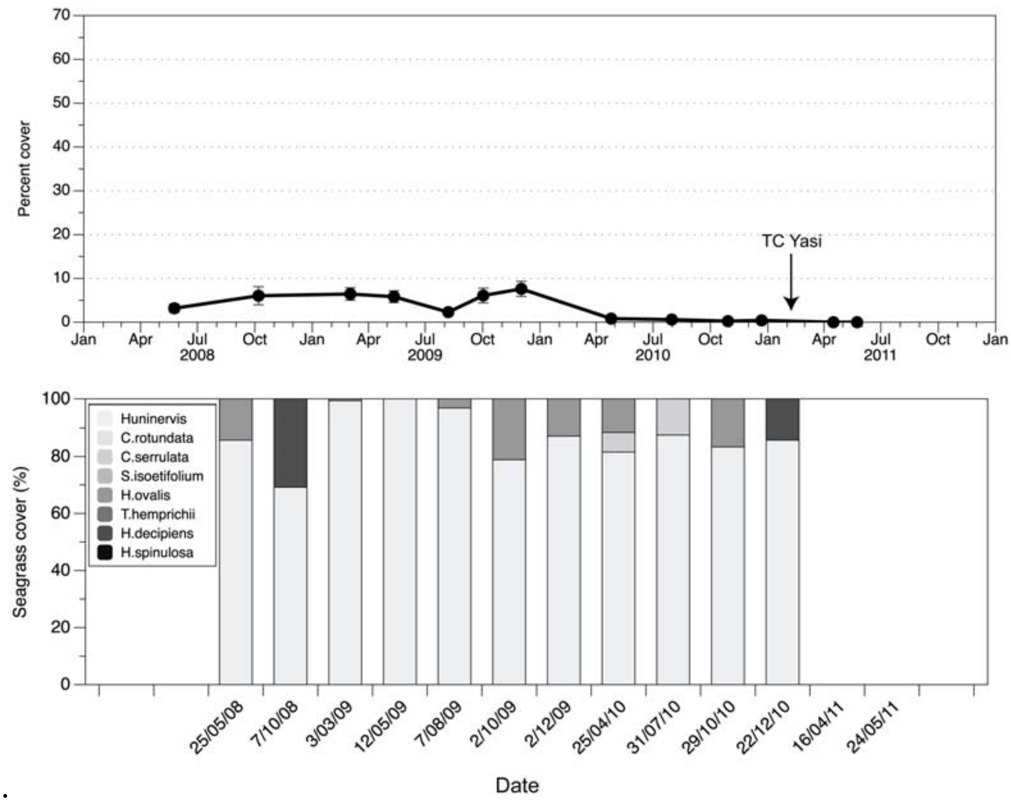

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Figure 6. Seagrass cover (top) and species composition (bottom) at the Dunk Island subtidal monitoring site.

Figure 7. Seagrass meadows on Dunk Island intertidal reef flat in: a) April 2008, b) October 2010, and c) March 2011

Figure 8. Seagrass meadows at the subtidal monitoring site in 2008 (left) and 2011 post-Yasi (right)

Aerial reconnaissance survey Lucinda to Mourilyan Harbour

Helicopter surveys of this region followed the coastline (Figure 9) and was aimed at getting the broadscale picture of where seagrasses occurred in the region. Sub-tidal information where available is mostly anecdotal – there has been no consistent collection of trend information for sub-tidal seagrass meadows in this region except for sub-tidal seagrass monitoring site at Dunk Island.

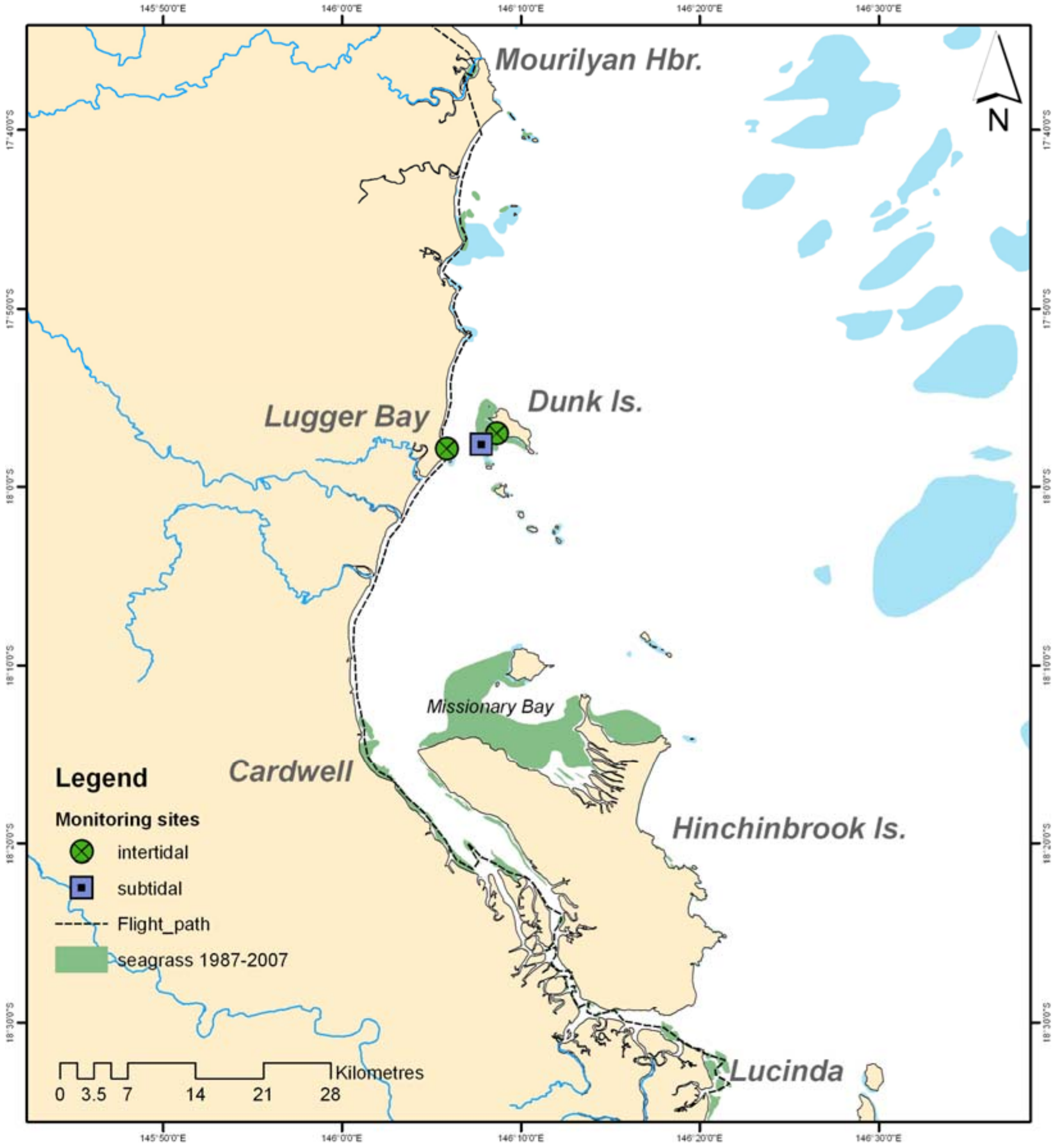


Figure 9. Location of intertidal monitoring sites and aerial reconnaissance flight path (20th March 2011).

The helicopter survey on 20th March 2011 commenced at 1300 hrs working 2 hours either side of low tide. In total 18 samples were taken when objects that where suspected of being seagrass were sighted. Six records of seagrass presence were made in Hinchinbrook Channel (at two sites) and two in Mourilyan Harbour (at two sites). The only seagrass plants recorded in Hinchinbrook were *Enhalus acoroides,* a species only found as isolated patches in the wet tropics. Only two patches of seagrass were found in the central channel (Figure 10). Only *Halophila ovalis* was found on the intertidal banks in Mourilyan Harbour and only as isolated plants.

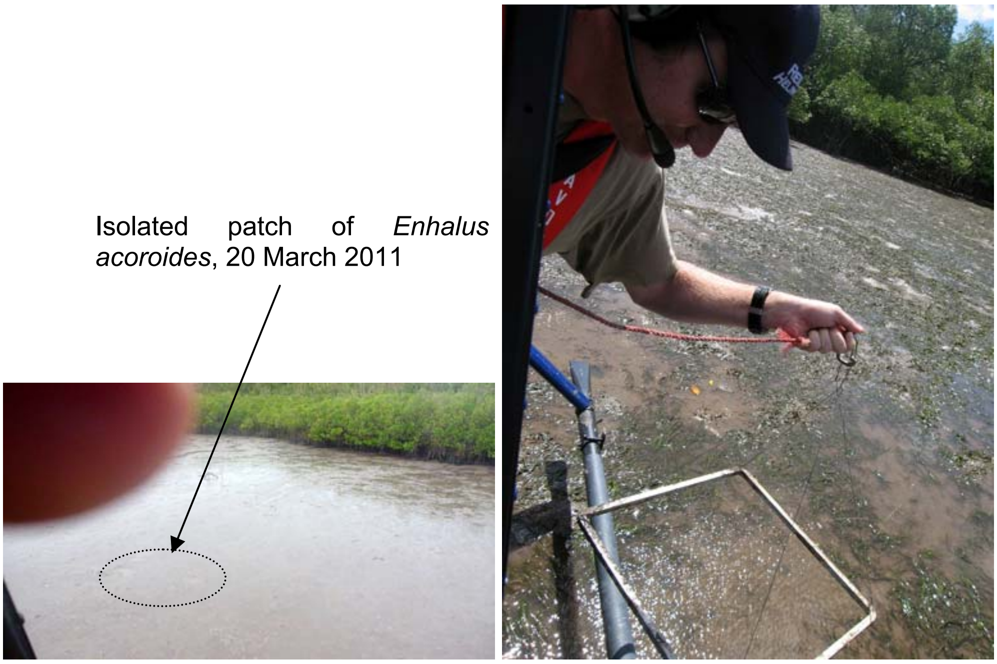


Figure 10. Intertidal bank of central Hinchinbrook Channel showing isolated patch of *Enhalus acoroides* on 20 March 2011 (left) and the large dense meadow which was present at the same location on 18 March 2007.

The intertidal banks examined within the region all showed evidence of physical disturbance. From photographs of Cardwell foreshore near the jetty, there appears to be several centimetres of erosion – the oyster clumps on the jetty posts are clear of the sediment (Figure 11). The seagrass meadow pre-cyclone extended under the jetty and it was common to see dugong feeding trails in the vicinity. The Port Hinchinbrook foreshore mud flat appeared less eroded but no seagrass was seen. A large amount of detrital material and unstable moving flotsam along the beach will make recovery of marine plants – seagrass and mangroves – unlikely in the short term unless at least the larger logs and pieces of timber are removed or secured (Figure 12).

Figure 11. Erosion at Cardwell jetty, 19 February 2011: left) from foreshore, and right) close-up showing height of fouling and clean lower portions of pylons.

Figure 12. Intertidal flats and foreshore adjacent to Port Hinchinbrook, 19 February 2011.

The intertidal banks adjacent to Lucinda and along the southern shores of Hinchinbrook Channel were all barren of seagrass and showed evidence of substantial sediment movement (Figure 13). A lot of the finer sediments (i.e. mud) also appeared to have been scoured from the intertidal banks, exposing the underlying sand and/or consolidated muds (Figure 14).

Figure 13. Intertidal banks adjacent to Lucinda, 20 March 2011

Figure 14. Intertidal banks in southern Hinchinbrook Channel where the overlying mud has been scoured/eroded by physical disturbance.

Surveys of seagrass in 2007 identified extensive seagrass meadows at Lucinda, in Hinchinbrook Channel and in Mourilyan Harbour (Figures 15, 16). There has been a consistent seagrass cover near the Cardwell township since surveys began in the mid 1980's, and at Mourilyan Harbour and Lucinda since the late 1990's.

Figure 15. Intertidal banks of Mourilyan Harbour with seagrass on 07 October 2007 (left) and barren on 06 October 2010 (right).

Figure 16. Seagrass meadows on the intertidal banks adjacent to Lucinda, 18 March 2007

There has been a dramatic change to seagrass meadows since then with almost complete loss of seagrass from the intertidal region. In March 2011, an estimated 2,350 Ha of intertidal seagrass is no longer present as meadows and only isolated plants remain. Some meadows had already been in decline prior to the cyclone and the effect of the weather events in early 2011 may have been synergistic to longer term processes (McKenzie *et al.* 2010).

The present survey data does not include subtidal seagrass as this is not observable from aerial surveys and the March survey was conducted in very difficult weather conditions. Near shore islands were not included in the aerial survey due to weather.

A more comprehensive survey is required including the nearshore islands and sub-tidal waters to assess fully the extent of the impact. Recovery, if occurring, needs to be assessed by resampling during late spring low tides when seagrass meadows in the region would be expected to be at their peak biomass.

Green Island

At the Green Island subtidal seagrass monitoring sites in May 2011 seagrass cover was 24.5% at Green Island (Figure 17). The meadow was comprised primarily of *H. uninervis* and *C. rotundata*. At Green Island, although cover is the lowest recorded, seasonal reductions in cover have occurred in previous years and this may not indicate any long-term trend of seagrass decline.

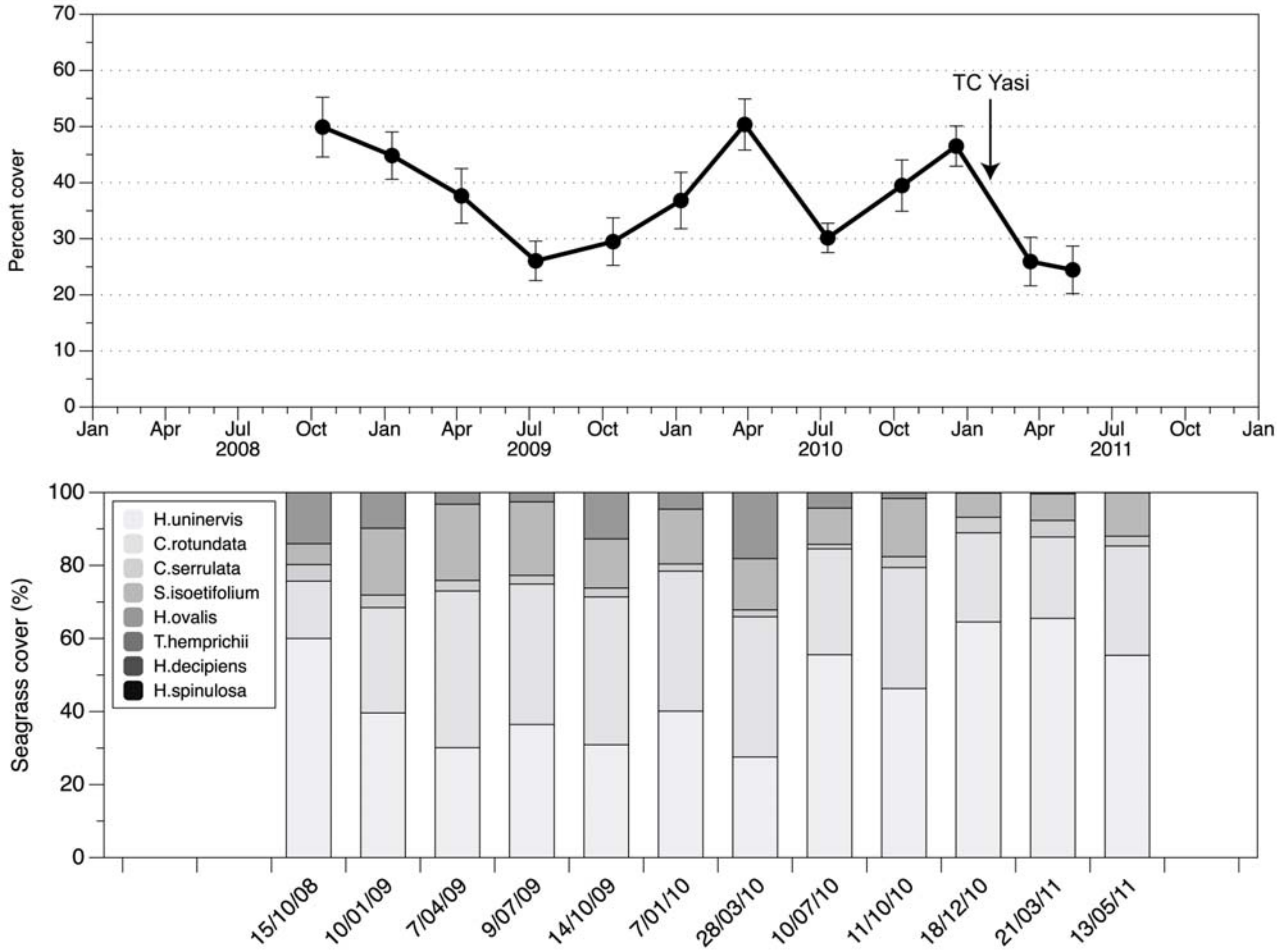


Figure 17. Seagrass cover and species composition at the Green island subtidal monitoring site.

Cleveland Bay (Townsville)

Large areas of seagrass were first mapped within the Townsville region during broad-scale surveys of the east coast of Queensland in 1987 (Coles *et al.* 1992). Detailed baseline surveys of the region were subsequently conducted in October 2007/2008 and June 2008 (Rasheed and Taylor 2008). Extensive intertidal and shallow subtidal seagrass meadows were identified (Figure 18) including one of the largest *Zostera capricorni* meadows in north Queensland. Many of these areas are important to commercial and recreational fisheries, as recognised by the declaration of two Fish Habitat Areas in the region; one in Bowling Green Bay (to the south of the port limits), and the other at the mouth of the Bohle River to the north of Townsville city.

The most recent mapping in the Townsville region was conducted as part of the annual Port of Townsville Ltd monitoring in October 2010, which reported the lowest seagrass distribution and abundance since 1987 (Taylor and Rasheed 2011).

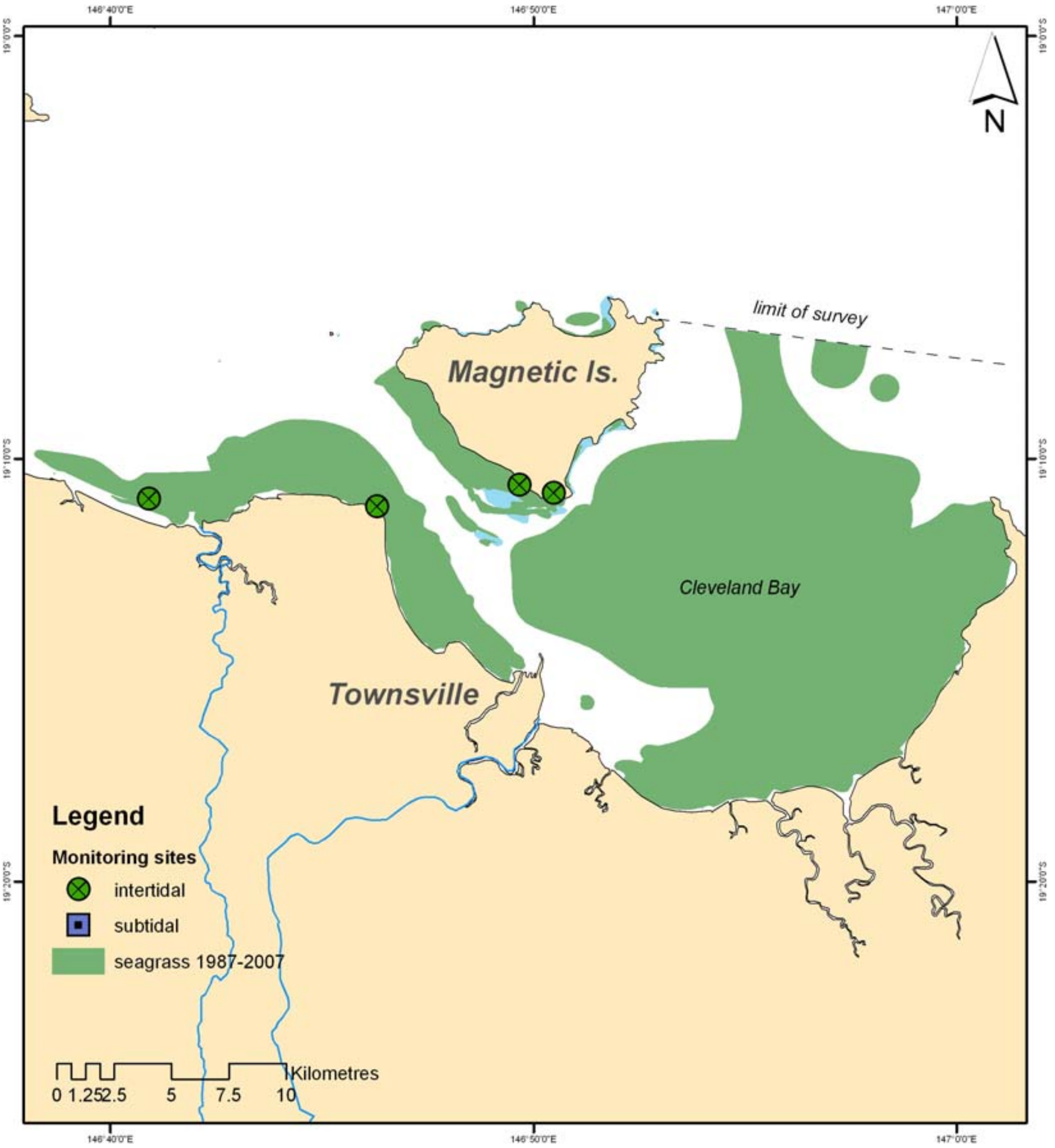


Figure 18. Location of long-term monitoring sites and seagrass composite (1987-2007) at Townsville and Magnetic Island.

Intertidal seagrass long-term monitoring sites in the region are located on both coastal and reef habitats. The coastal sites are located on naturally dynamic intertidal sand flats and are subject to sand waves and erosion blowouts moving through the meadows. The Bushland Beach and Shelley Beach area is a sediment deposition zone, so the meadow must also cope with incursions of sediment carried by long shore drift. Meadows at both coastal sites (Bushland Beach and Shelley Beach) are generally dominated by *Halodule uninervis* with small amounts of *Halophila ovalis*.

Offshore reef habitats are monitored on the fringing reef platforms of Magnetic Island. The meadows are dominated by *Halodule uninervis, Cymodocea serrulata, Thalassia hemprichii* with *Halophila ovalis, however* species composition has changed over the last 5-10 years. Since monitoring was established, seagrass cover generally follows a seasonal pattern; high in monsoon and low in the dry season.

In 2009, seagrass cover substantially decreased at all sites, including the subtidal sites across the region during the late monsoon and has continued to decline since (Figure 19, 23). The sites were examined two weeks after TC Yasi and no seagrass was found on the coastal intertidal banks. The intertidal reef meadows were also significantly impacted and only isolated patches of seagrass remained. In May 2011 the sites were re-examined. Only a few isolated shoots of *H. uninervis* were found on the coastal banks and at the subtidal monitoring sites, but the reef sites were predominately barren of seagrass with only a few isolated shoots of H. *ovalis*, *H. uninervis* and T. *hemprichii* (Figures 19–22).

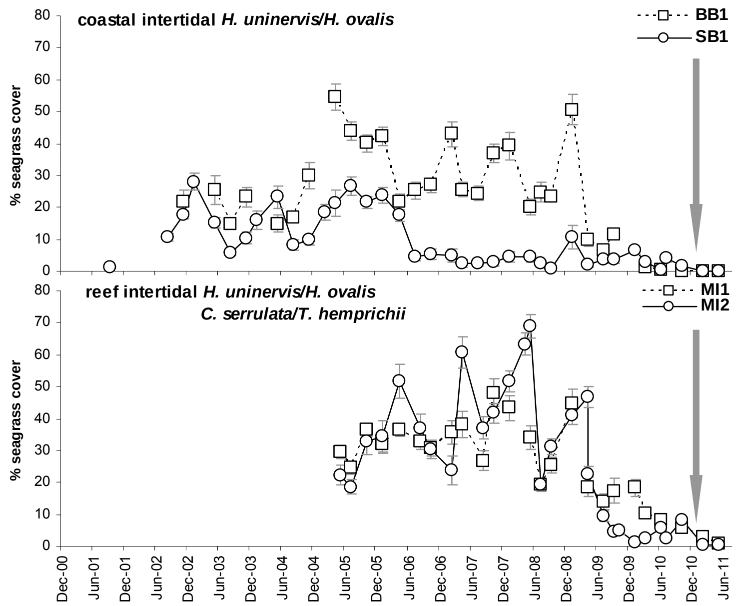


Figure 19. Mean percentage seagrass cover (± Standard Error) at each intertidal coastal (Townsville) and reef (Magnetic Island) long-term monitoring site. Grey arrow indicates Tropical Cyclone Yasi.

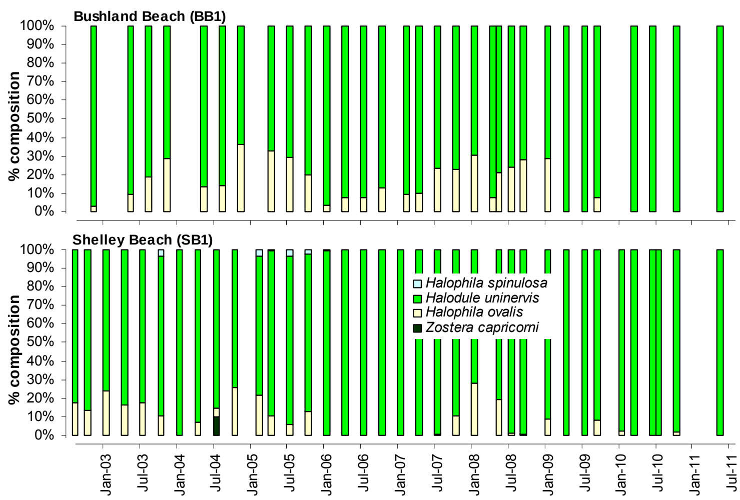


Figure 20. Seagrass species composition at each coastal intertidal long-term monitoring site at Townsville.

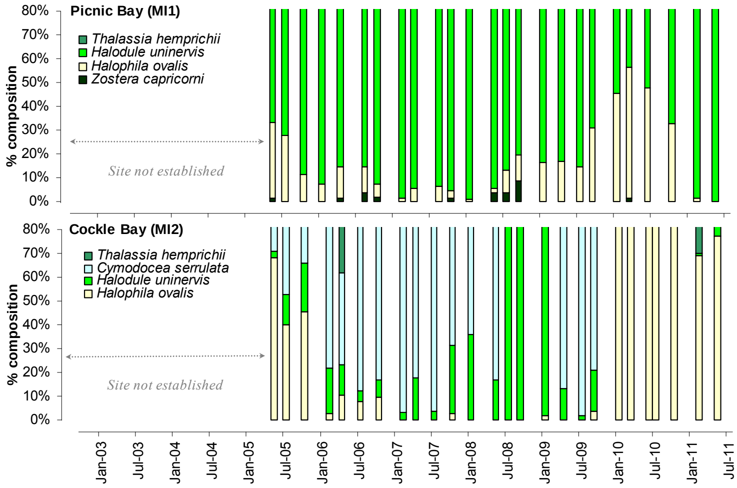


Figure 21. Seagrass species composition at each intertidal long-term monitoring site at Magnetic Island.

Figure 22. Seagrass meadows on the coastal intertidal banks at Shelley Beach (Cape Pallerenda, Townsville) on 05 November 2010 (left) and 16 May 2011 (right).

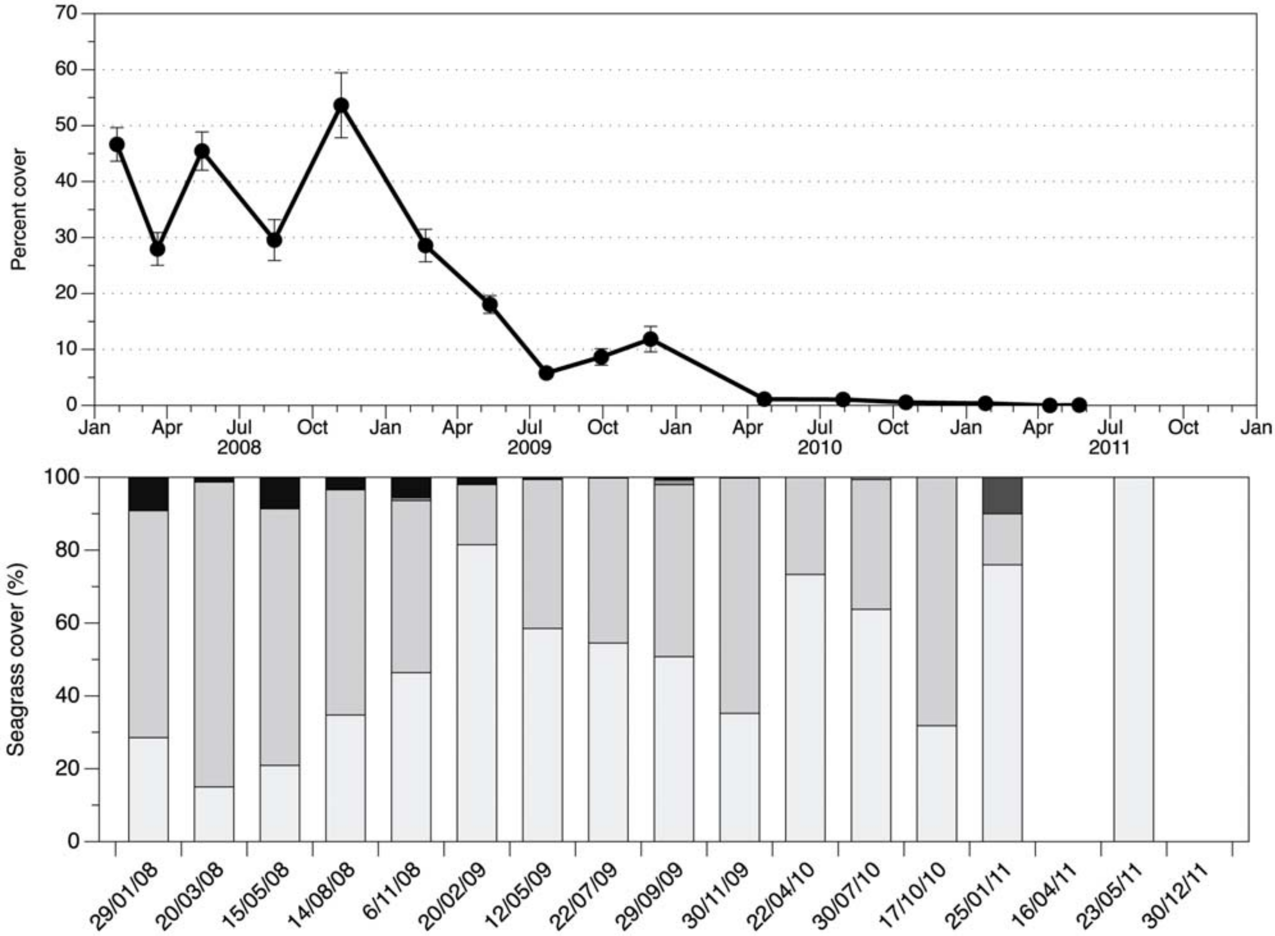


Figure 23. Seagrass cover and species composition at the Picnic Bay, Magnetic Island, subtidal monitoring site

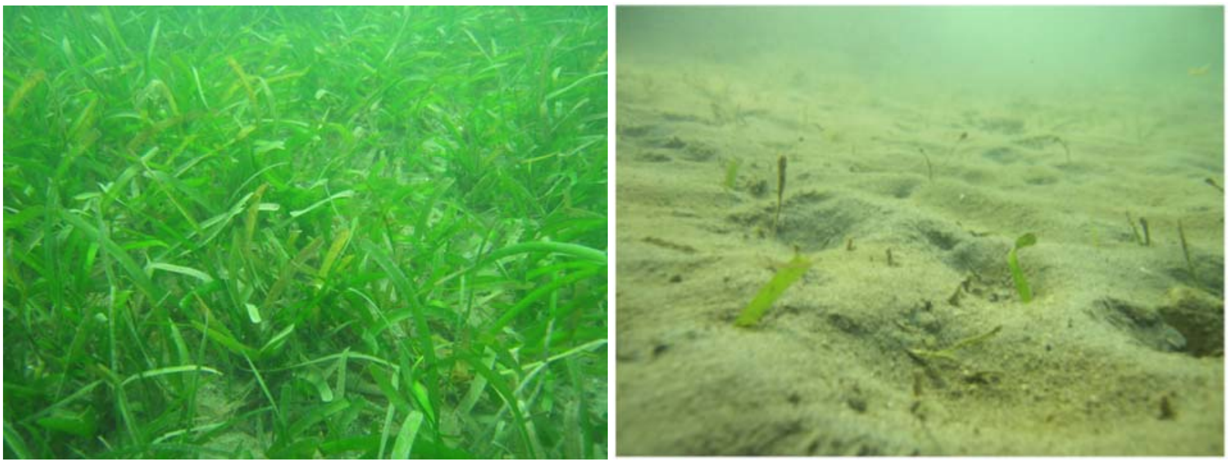


Figure 24. Subtidal seagrass meadow at Picnic Bay, January 2008 (left) and February 2011 (right).

Shoalwater Bay & Great Keppel Island

Shoalwater Bay is located in the southern section of the Great Barrier Reef Marine Park, and is a reserve for defence force training. Seagrass in the Shoalwater Bay are considered regionally important as nursery habitats for species of commercial and recreational fishing value (e.g., western king prawns and true endeavor prawns) and as feeding area for dugongs and green turtles. The

Shoalwater Bay area supports the largest dugong population between Cooktown and Hervey Bay and is considered the most important dugong habitat in the GBR region south of Cape York. Shoalwater Bay also supports the largest known feeding concentration of the southern Great Barrier Reef genetic stock of green turtles and is classified as a Ramsar wetland.

Approximately 13,000 Ha of seagrass meadows are located within Shoalwater Bay, mostly restricted to intertidal mud flats (Lee Long *et al.* 1997) (Figure 25). The area of subtidal seagrass habitat in Shoalwater Bay is small and restricted to north eastern waters. Strong tidal currents and associated high water turbidity in Shoalwater Bay limit light penetration and therefore the depth to which seagrasses can grow.

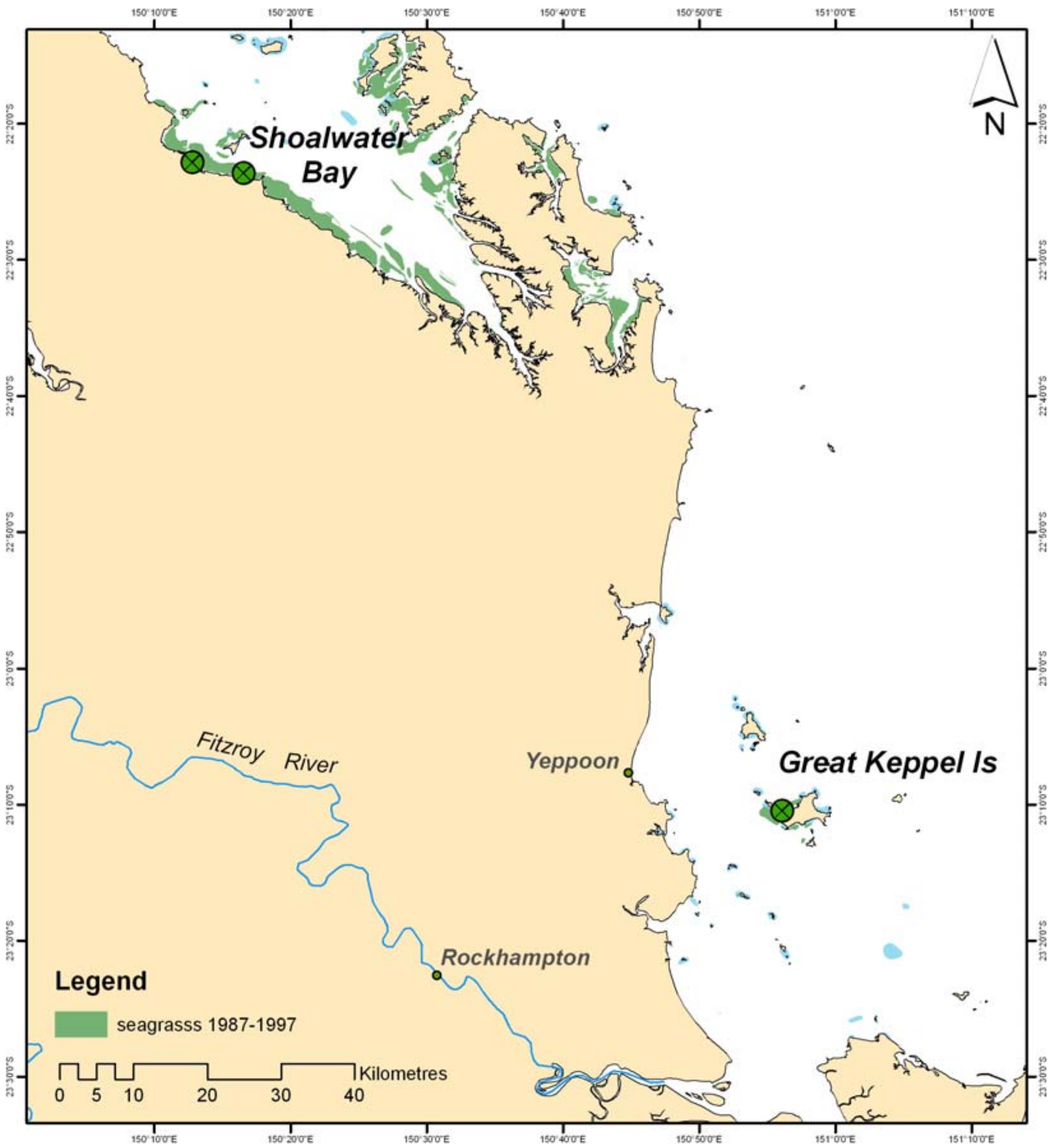


Figure 25. Location of long-term monitoring sites and seagrass composite (1987-1997) in Shoalwater Bay and around Great Keppel Island.

Long-term monitoring of intertidal seagrass meadows was established in the northern section of the bay in 2002. In 2010, the meadows were reported to have remained stable in extent and seagrass abundance was classified as in a good state. Although there were no seed banks, the reproductive effort suggested the meadows have a high capacity to recover following disturbance. Overall the status of seagrass condition in the region was rated as moderate (McKenzie et al. 2010). On the 18-19 January 2011, the seagrass meadows were examined and although the abundance was low, it was within levels usually reported for the monsoon period (Figure 26). The sites were re-examined on the 14-15 April 2011 and the seagrass abundance remained similar at one site, but had continued to decline at the other (Figure x). *Zostera capricorni* still dominated the sites in April 2011, however the amount of *Halophila ovalis* has increased, indicating possible disturbance to the meadows (Figure 26)

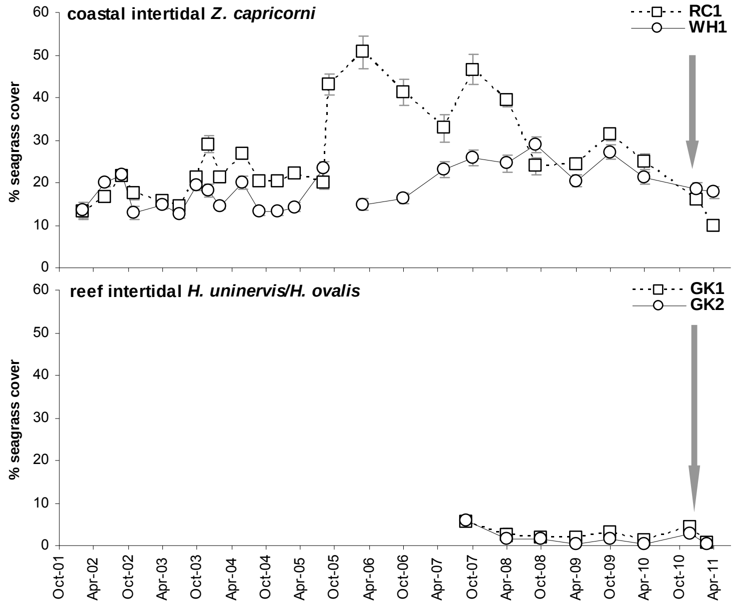


Figure 26. Mean percentage seagrass cover (± Standard Error) at each intertidal coastal (Shoalwater Bay) and reef (Great Keppel Island) long-term monitoring site. Grey arrow indicates Fitzroy River flood.

Figure 27. Seagrass meadows on intertidal banks at Wheelans Hut (Shoalwater Bay): left, April 2010; right, January 2011.

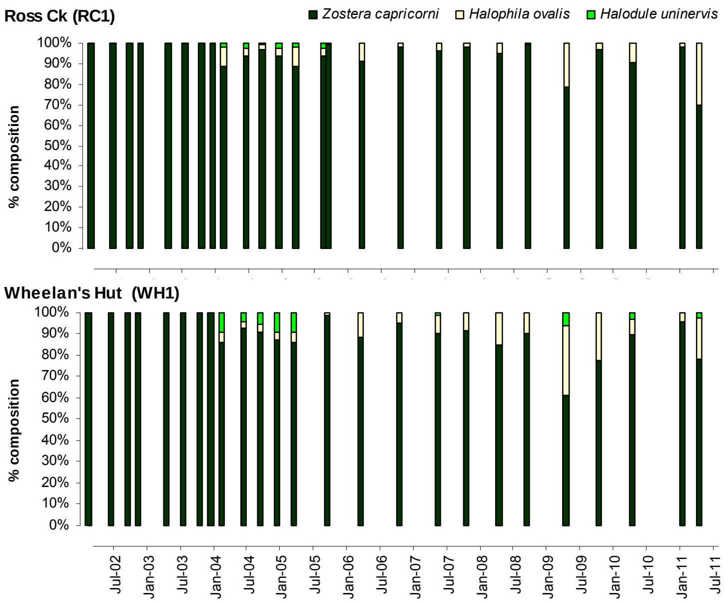


Figure 28. Seagrass species composition at each intertidal long-term monitoring site at Shoalwater Bay.

The offshore reef intertidal seagrass meadows at Great Keppel Island differ greatly from the coastal meadows, being composed predominately of *H. uninervis* on sand substrate. The intertidal meadows on Great Keppel Island cover an area of approximately 121 Ha (20% of the seagrass mapped around Great Keppel Island) and seagrass abundance is usually low (<10% cover). Two monitoring sites are located in the largest intertidal meadows at Monkey Beach. Seagrass abundance has continued to decline at these sites since monitoring was established in 2007. The most recent monitoring prior to the Fitzroy River flooding was 04 December 2010. The sites were revisited on the 18 March 2011 and seagrass abundance had declined by 85% compared to previous samples. Seagrass species are varying amounts of *Halodule uninervis* and *Halophila ovalis* with minor components of *Zostera capricorni* nearshore and *Halophila spinulosa* on the outer edge. Most recent assessments reported the meadows were dominated by *H. ovalis* (Figure 29), suggesting high levels of disturbance.

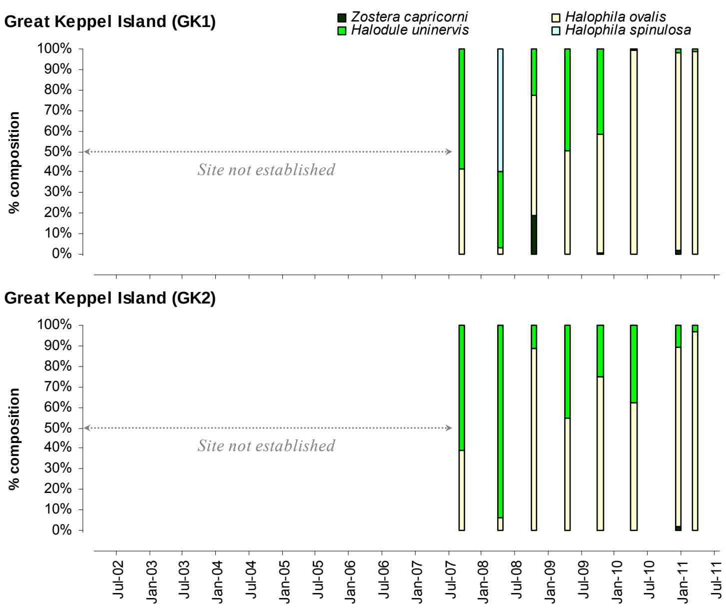


Figure 29. Seagrass species composition at each intertidal long-term monitoring site at Great Keppel Island.

Overall trends in seagrass abundance

Changes in total seagrass cover relative to the same season in the previous year, indicates that seagrass loss during the wet season has accelerated over the last 3 years (Table 3). For example, at Magnetic Island– Picnic Bay subtidal, there was a 60% decrease in seagrass cover in the 2009 wet season compared to the wet season of 2008, however after the 2010 wet season, cover was down by 95% compared to 2009 and in 2011, there was 100% loss. However, many of the changes in the last two years reflect very small percent cover values in 2009-2010 and 2010-2011 wet season samples. For example, the Picnic Bay subtidal site decline between 2008-2009 was the greatest change in actual % cover, by 2010, cover having reduced below 5% (see Figure 23).

Table 3. Seagrass cover at the end of the wet season compared to the previous wet season

			Change relative to wet season in previous year		
			2009	*2010*	*2011*
Wet Tropics/	*Green Island*	Intertidal	4.3	-15.7	-10.2
Hinchinbrook		Subtidal	NA	33.8	-48.5
DPA	*Dunk Island*	Intertidal	20.0	-84.9	-99.4
		Subtidal	82.9	-85.9	-100
Cleveland Bay	*Picnic Bay*	Intertidal	16.7	-88.3	-88.1
		Subtidal	-60.3	-93.8	-100
	Cockle Bay	Intertidal			
	Bushland Beach	Intertidal	-39.9	-87.0	-100
Shoalwater Bay	*Shoalwater Bay*	Intertidal	-38.0	2.1	-61.1
	Keppel Island	Intertidal	-82.9	-11.1	21.3
	Proportion of sites showing declines		50%	75%	88%

Seagrass presence relative to model outputs

Seagrass presence at the subtidal monitoring sites is compared to the GIS-based habitat suitability model (Grech & Coles 2010). Subtidal monitoring sites were overlaid on the habitat suitability maps (Figures 30-31). Green Island did not fall within the model area, which was developed for coastal seagrasses. Dunk Island and Magnetic Island each have a 20-50% chance of seagrass being present during the wet season. There is no seagrass remaining at these sites now (0.1% at Magnetic Island, 0% at Dunk Island).

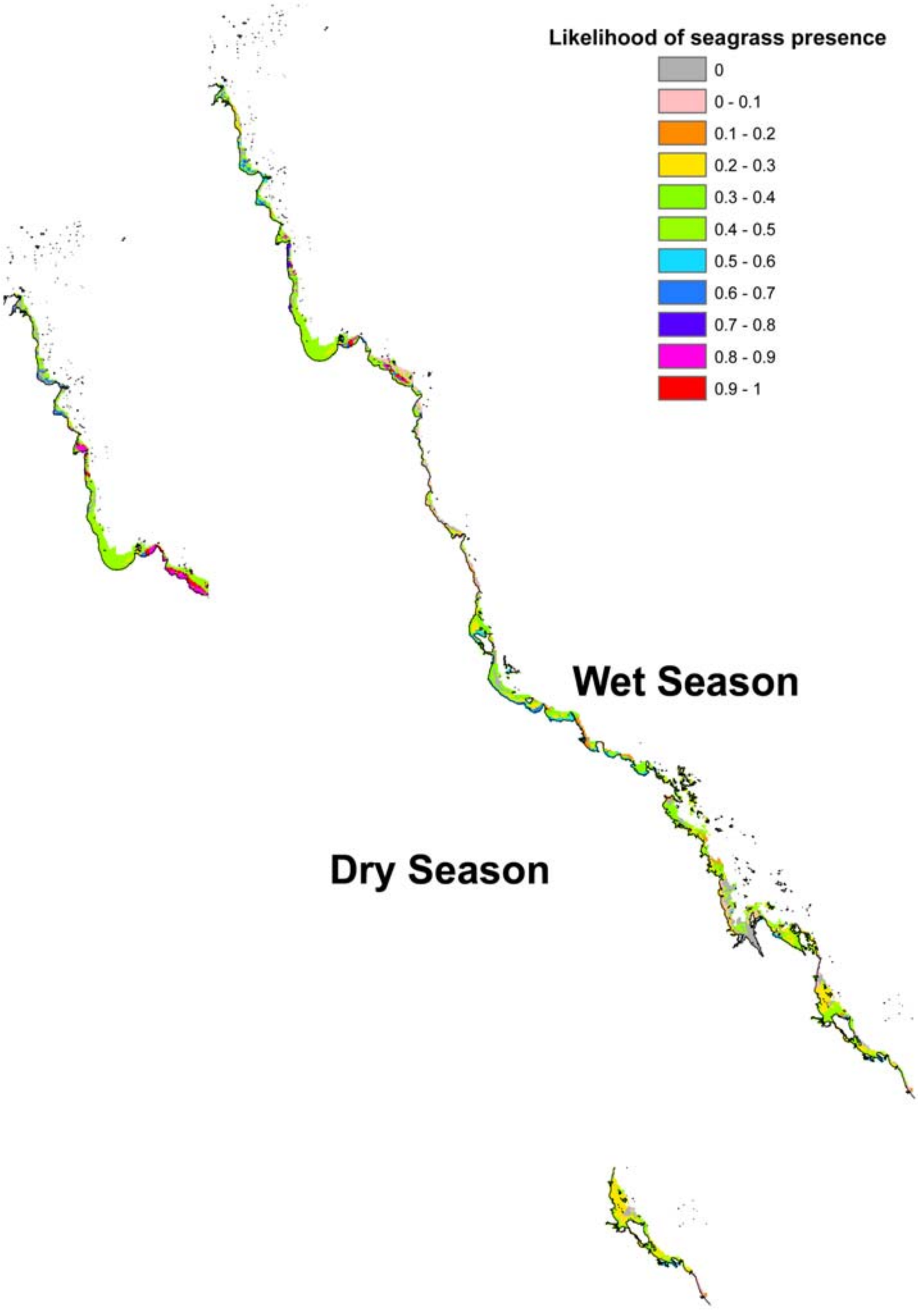


Figure 30. Habitat suitability maps of coastal seagrass distribution (Grech & Coles 2010)

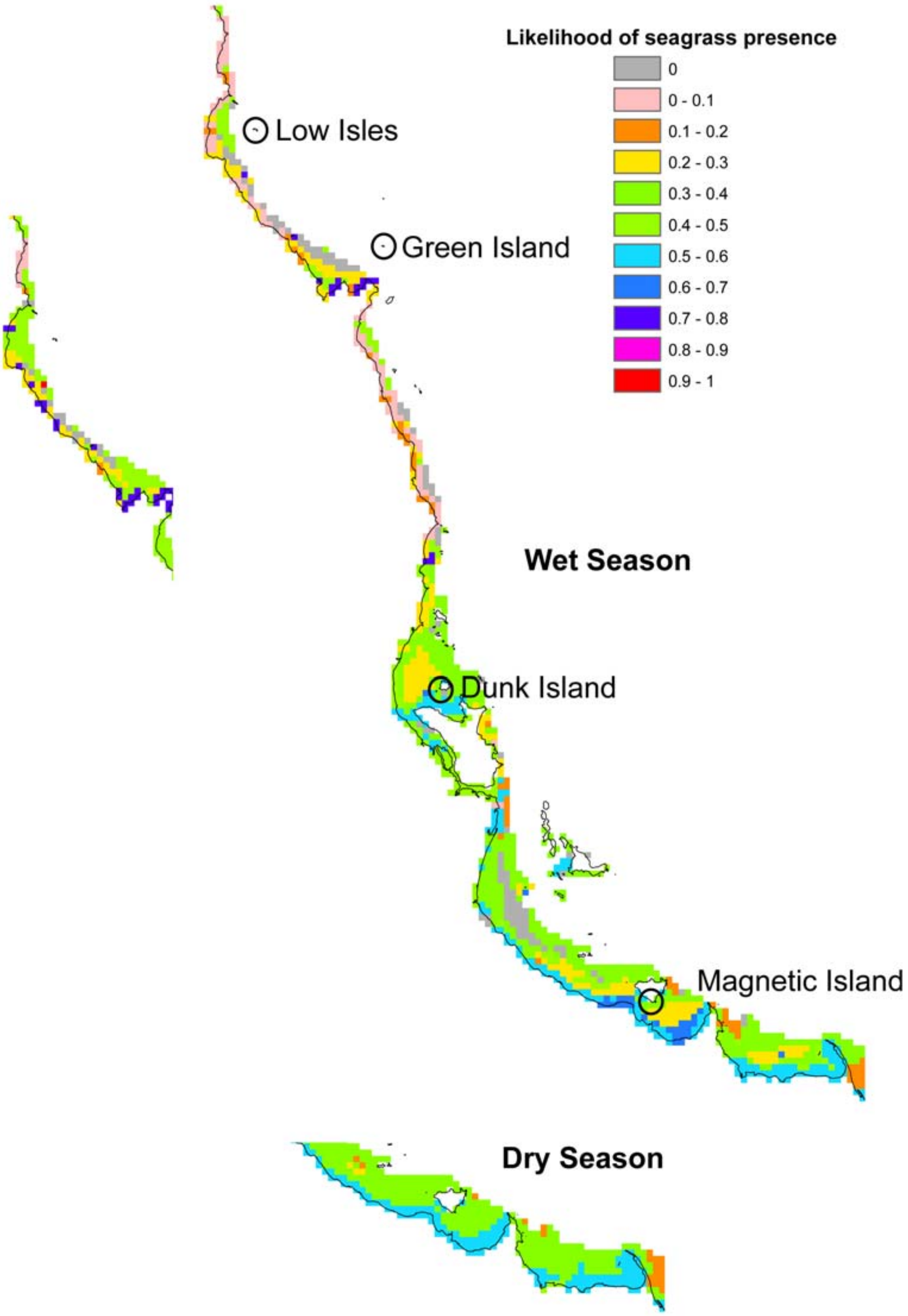


Figure 31. Habitat suitability of coastal seagrass for the region encompassing the subtidal seagrass monitoring sites (Grech & Coles 2010).

Seagrass nutritional status

Carbohydrate analysis

Tissue carbohydrate concentrations differences compared to long term averages against reference site data (see Table 2; Figures 32–40) were variable depending on seagrass species and seagrass meadow recovery status. Sites in decline where *Zostera muelleri* was still present, showed a higher than the long term average for this species, suggesting that these sites may have been light limited. The carbohydrate concentrations of *Halodule* and *Halophila* differed by site although *Halophila* was typically lower than the long term average.

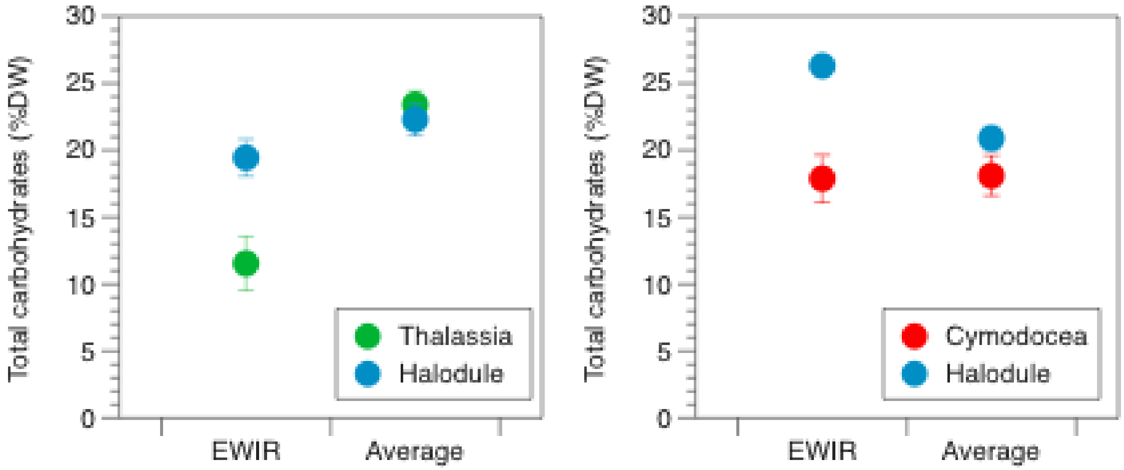


Figure 32. Total carbohydrate concentration (total soluble sugars and starch, %DW) at the Green Island intertidal (left) and subtidal (right) sites in May 2011 (EWIR). Reference values (average) were calculated from data collected from Green Island through MTSRF 1.1.3 (2008-2010)

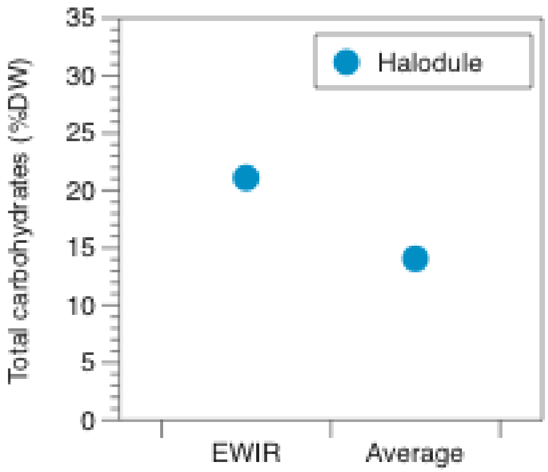


Figure 33. Total carbohydrate concentration (total soluble sugars and starch, %DW) at the Dunk Island intertidal site in May 2011 (EWIR). There was no seagrass present at the subtidal site in May 2011. Reference values (average) were calculated from data collected from Dunk Island in MTSRF project 1.1.3 (2008-2010)

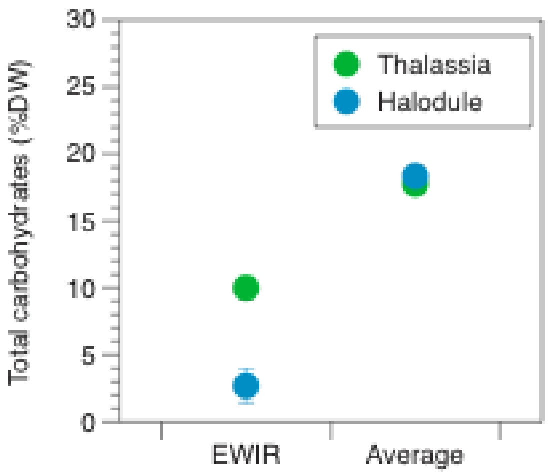


Figure 34. Total carbohydrate concentration (total soluble sugars and starch, %DW) at the Cockle Bay, Magnetic Island intertidal site in May 2011 (EWIR). Reference values (average) were calculated from data collected at a number of other sites in MTSRF project 1.1.3 (2008-2010).

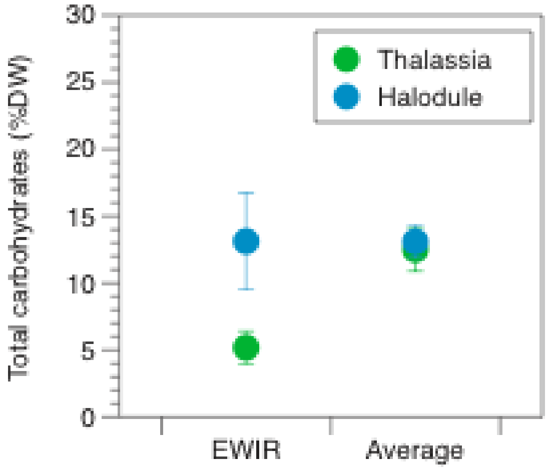
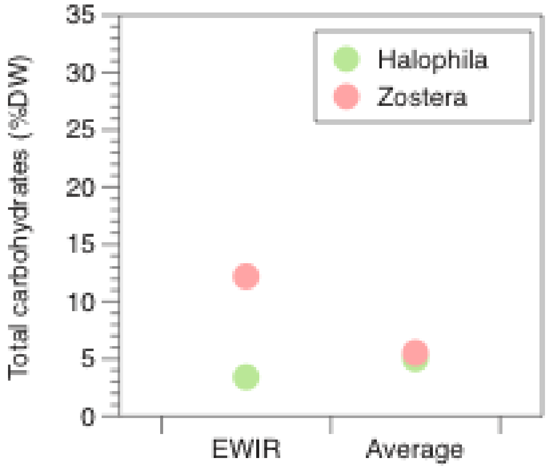


Figure 35. Total carbohydrate concentration (total soluble sugars and starch, %DW) at the Picnic Bay, Magnetic Island intertidal site in May 2011 (EWIR). There was no seagrass present at the subtidal site in May 2011. Reference values (average) were calculated from data collected from Picnic Bay in MTSRF project 1.1.3 (2008-2010).



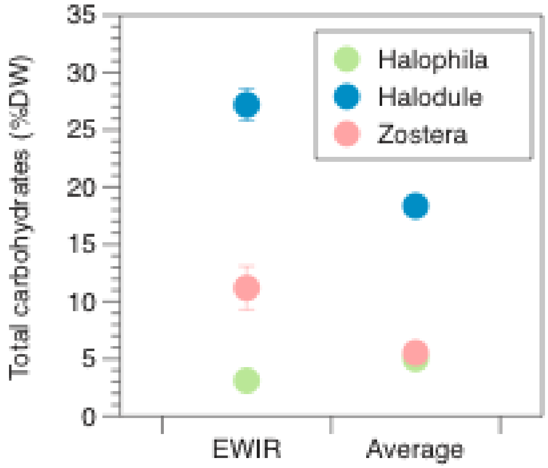


Figure 36. Total carbohydrate concentration (total soluble sugars and starch, %DW) at the Shoalwater Bay (RC, left & WH, right) intertidal sites in May 2011 (EWIR). Reference values (average) were calculated from data collected MTSRF project 1.1.3 (2008-2010) for *H. uninervis* and were derived from the literature for *H. ovalis* and *Z. muelleri* (Table 2).

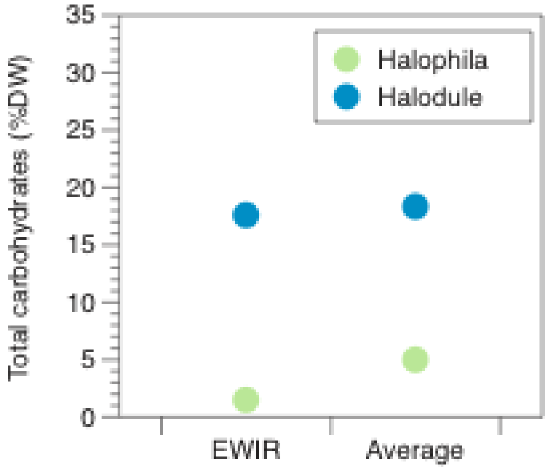


Figure 37. Total carbohydrate concentration (total soluble sugars and starch, %DW) at Keppel Island in May 2011 (EWIR). Reference values (average) were calculated from data collected MTSRF project 1.1.3 (2008-2010) for *H. uninervis* and were derived from the literature for *H. ovalis* (Table 2).

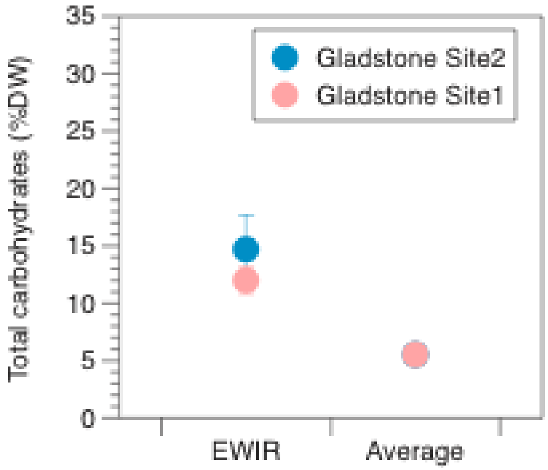


Figure 38. Total carbohydrate concentration (total soluble sugars and starch, %DW) at Gladstone Harbour in May 2011 (EWIR). Reference values (average) were derived from the literature for *Z. muelleri* (Table 2).

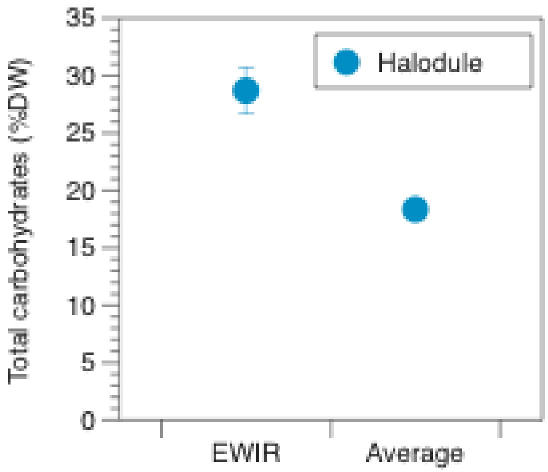


Figure 39. Total carbohydrate concentration (total soluble sugars and starch, %DW) at Burrum Heads in May 2011 (EWIR). Reference values (average) were calculated from data collected MTSRF project 1.1.3 (2008-2010) for *H. uninervis* (Table 2).

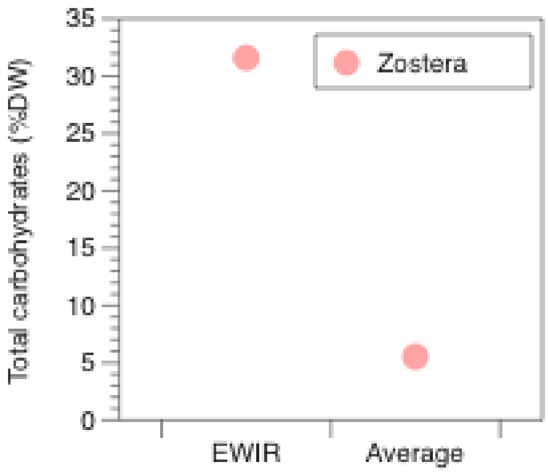


Figure 40. Total carbohydrate concentration (total soluble sugars and starch, %DW) at Urangan in May 2011 (EWIR). Reference values (average) were derived from the literature for *Z. muelleri* (Table 2).

Higher than average carbohydrate concentrations indicate that plants are able to store an excess of sugars compared to their ability to grow and produce new tissue. The ability to produce new tissue will be limited by firstly light availability, then nutrients but overall rates will also be affected by temperature. It is likely that the observations made here, indicate that sites in decline are showing elevated tissue carbohydrates, those where some recovery has started are showing reduced concentrations.

Tissue nutrients

The values obtained for tissue nutrient concentrations of seagrasses collected in intertidal sites during the wet season months are not directly comparable to those collected during the late dry season, when typical Reef Rescue Marine Monitoring is undertaken. During the wet season, plant growing conditions are very different, higher temperatures, different tidal regimes (lowest tides during the night for much of the area sampled) and general light levels due to cloud cover result in relatively low light availability for the available nutrients. This results in low C:N and C:P ratios. We observed this during the May sample taken in 2011 (Table 4) where compared to the long term average across all sites sampled in the late dry season (C:N=18.25) the wet season values were 25-35% lower.

Table 4 Tissue nutrient ratios for intertidal samples (across all species) collected in May 2011 compared to the long term average of C:N between 2005-2010 (RRMMP data).

Site	C:N (May 2011)	Difference to long term dry season average of C:N=18.25
Dunk Island	14.78	-3.47
Magnetic Island	13.75	-4.50
Shoalwater Bay	13.19	-5.06
Great Keppel	11.87	-6.38
Gladstone	13.18	-5.07
Hervey Bay	12.39	-5.86

Environmental conditions

Light availability

Light intensity is highly variable (Figures 41–43), so summary statistics are presented to help with the interpretation of spatial and temporal trends. Light intensity at seagrass canopy height was substantially lower at subtidal than at intertidal sites (Table 5). At subtidal sites, the average long-term light intensity was Magnetic Island< Dunk Island<Green Island. Light intensity (long-term average) at Green Island was two times the intensity at Magnetic Island. This was due in a large part to water clarity as the attenuation coefficient at Magnetic Island was considerably higher (0.35) than at Green Island (0.16). There are also differences in depth between sites that can account for some of the inter-site variability although a relatively small component given differences in water clarity. The wet season (Jan-Mar) average (2008-2011) light intensity was generally lower than the long-term average (all months, 2008-2011). This was quite pronounced at intertidal sites, and may be due to the tidal regime during the wet season i.e. there are fewer very low tides during the day, whereas during the dry season there are many daytime low tides. At Dunk Island, light intensity during the 2011 wet season was higher than wet season averages. At Green Island and Magnetic Island, light intensity was only slightly lower this wet season, compared to the average wet season intensity. At intertidal sites, light in the 2011 wet season was generally around the long-term average; however, for most intertidal sites, the duration of available data is short and represents only two wet seasons.

At intertidal sites, light intensity is well above the minimum light requirements for the long-term survival of seagrass (14-37% Surface irradiance, not including *Halophila* species), even during the wet season (Table 5). In contrast, at subtidal sites the long-term light intensity at all subtidal sites was at the lower end of the minimum light required to support growth, and pushed below it for extended periods during the wet season. This data will be related to broad-scale maps when they are available**.**

Light at intertidal only monitoring sites was the lowest at Bushland Beach at only 4.4 Mol photons m^{-2} d^{-1}; however, light was also highly variable, with frequent large spikes in light intensity associated with tidal exposure, particularly during winter months (Table 5). Light levels were highest at Shoalwater Bay followed closely by the offshore sites at Dunk Island and Green Island. For intertidal sites where light data is available for the 2011 wet season light during the 2011 wet season was not considerably lower than it had been in previous wet seasons (Table 5).

Light levels are lower than the minimum light requirement (MLR) for *Halodule uninervis* [9-12 Mol photons m^{-2} d^{-1} (Longstaff & Dennison 1999)] at the subtidal monitoring sites at, Dunk Island and Picnic Bay and seagrass cover confirms that conditions are unsuitable for the long-term survival of seagrasses at these sites. Light is also below MLR at the intertidal monitoring sites at Bushland Beach.

Light data from intertidal monitoring sites is patchier than data from subtidal/intertidal sites because logger maintenance and retrieval occurs during routine monitoring only, which can be every 3–6 months. In contrast, loggers at subtidal/intertidal sites at Green Island, Dunk Island and Magnetic Island (Picnic Bay) are checked and re-deployed every 6 weeks.

Table 5. Summary of light data at all seagrass monitoring sites reported for EWIR.

Region	Location	Site	Long-term average			Wet season	
			(Mol photons m^{-2} d^{-1})	% Surface	Attenuation (m^{-1})	Average (Mol photons m^{-2} d^{-1})	2011 (Mol photons m^{-2} d^{-1})
Wet Tropics/	Green Island	Intertidal	17.1	54.0		14.1	13.6
Hinchinbrook		Subtidal	10.6	32.8	0.16	10.6	9.2
DPA	Dunk Island	Intertidal	18.3	56.7		16.8	17.7
		Subtidal	7.4	24.1	0.29	6.5	7.2
Cleveland Bay	Picnic Bay	Intertidal	14.3	50.9		12.5	12.4
		Subtidal	5.3	18.6	0.35	3.9	3.6
	Cockle Bay	Intertidal	10.7			8.9	8.4
	Bushland Beach	Intertidal	4.0			1.1	2.0
Shoalwater Bay	Shoalwater Bay	Intertidal	20.4			19.0	19.3
	Keppel Island	Intertidal	13.5			11.5	11.0

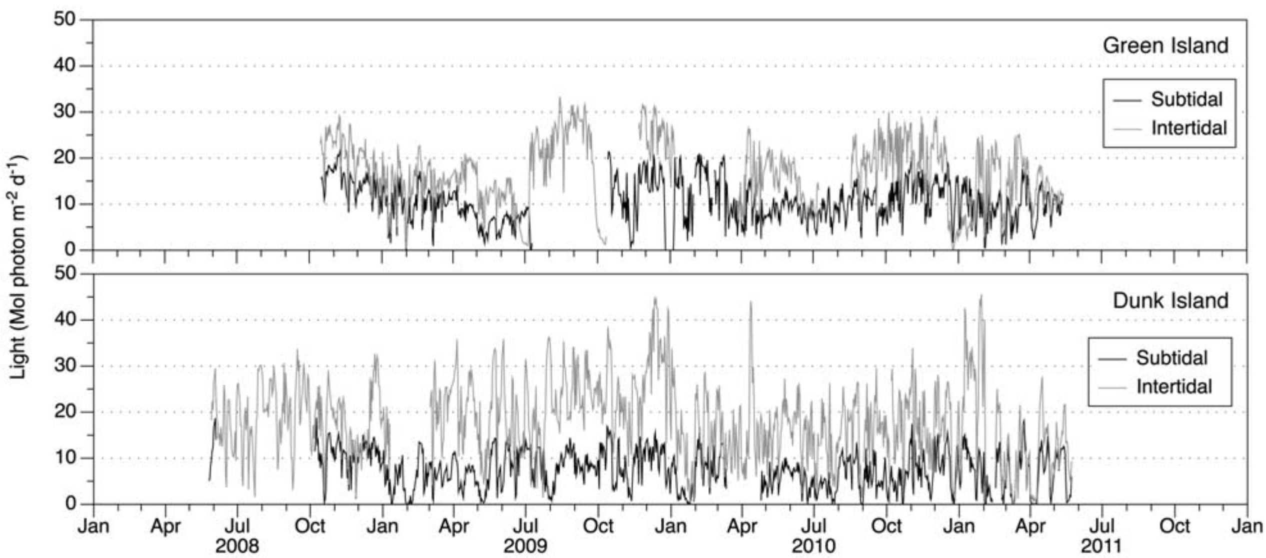


Figure 41. Light intensity at Wet Tropics/Hinchinbrook Island sites from 2008 to May 2011. Emersion correction has not been applied to intertidal light data for 2011 as sea level data is not yet available up to May 2011; therefore, the values for intertidal 2011 will be a slight overestimate.

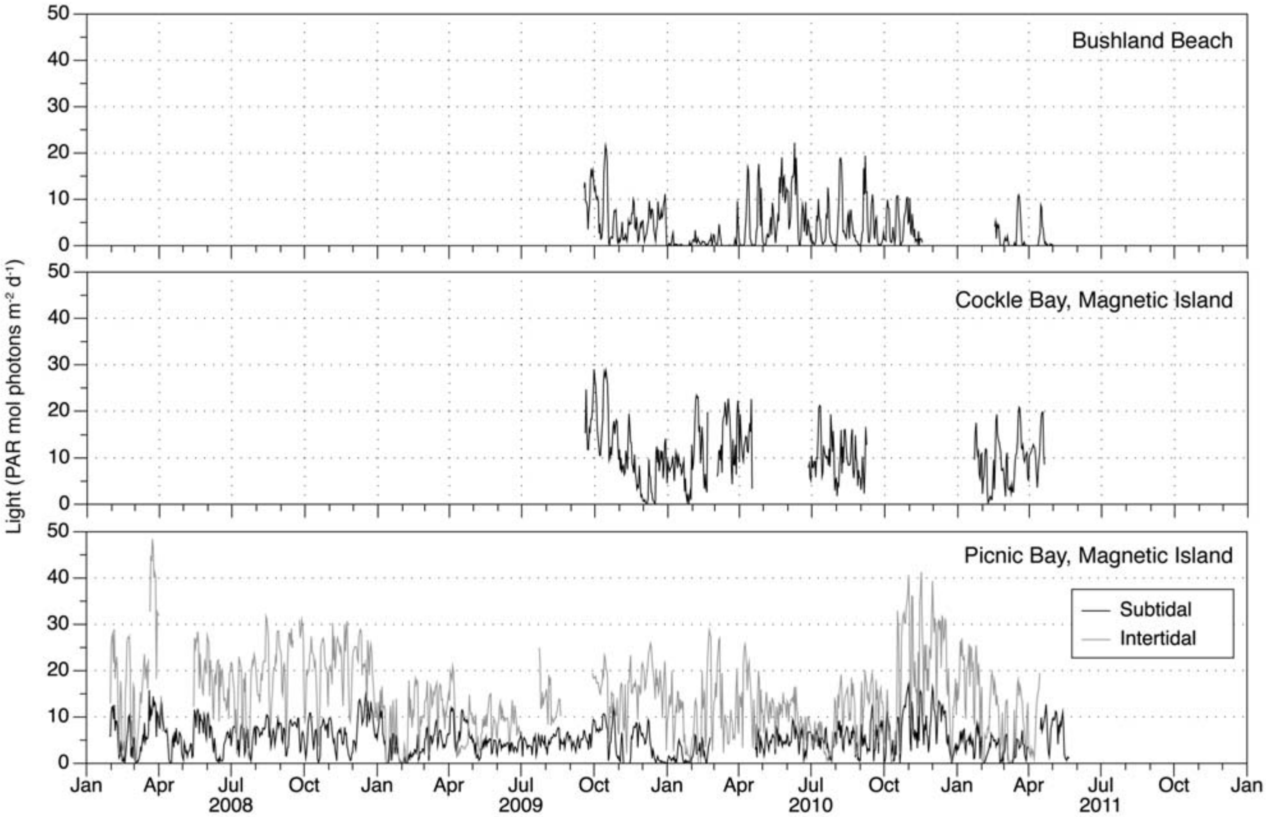


Figure 42. Light intensity at Cleveland Bay sites from 2008 to May 2011. Emersion correction has not been applied to intertidal light data for 2011 as sea level data is not yet available up to May 2011; therefore, the values for intertidal 2011 will be a slight overestimate.

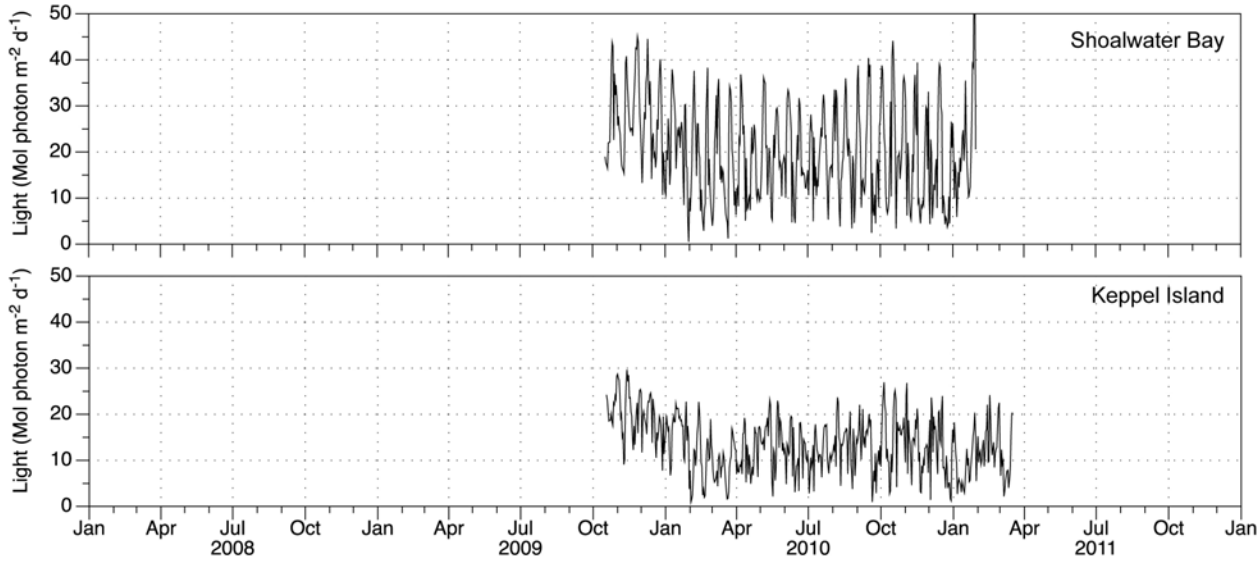


Figure 43. Light intensity at Shoalwater Bay/Keppel Island sites from 2008 to May 2011. Emersion correction has not been applied to intertidal light data for 2011 as sea level data is not yet available up to May 2011; therefore, the values for intertidal 2011 will be a slight overestimate.

Turbidity

Like light measurements, turbidity varies significantly over short periods of time, being influenced by tides, currents and wind (Figure 44). The relationship between turbidity and light is complex (Figure 45) where high levels of turbidity do not necessarily correlate to low light levels. Further exploration of this data is ongoing and will be reported along with other correlations when all data re available.

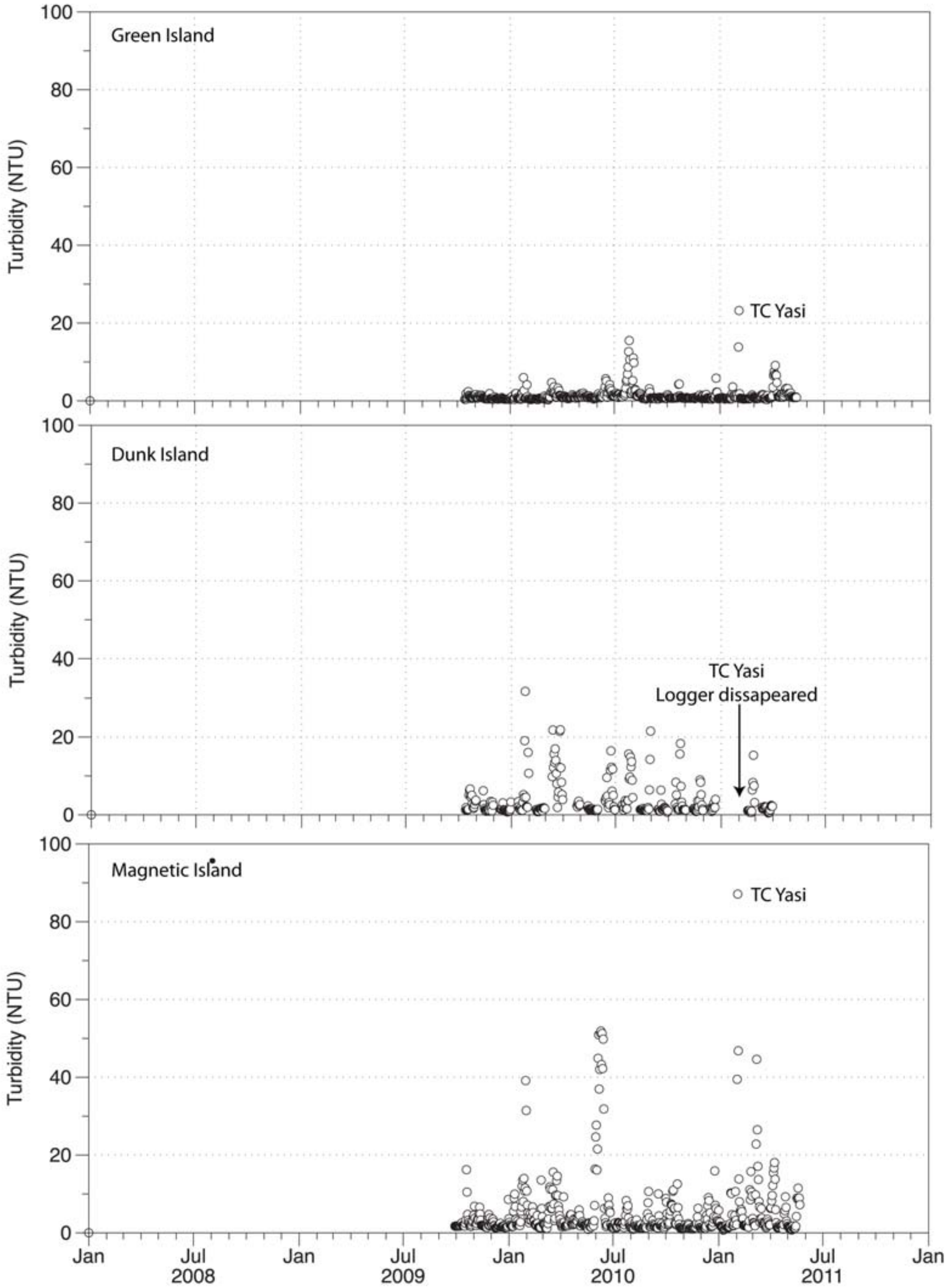


Figure 44. Turbidity (NTU) at subtidal Reef Rescue MMP sites since loggers were deployed (September 2009) until May 2011.

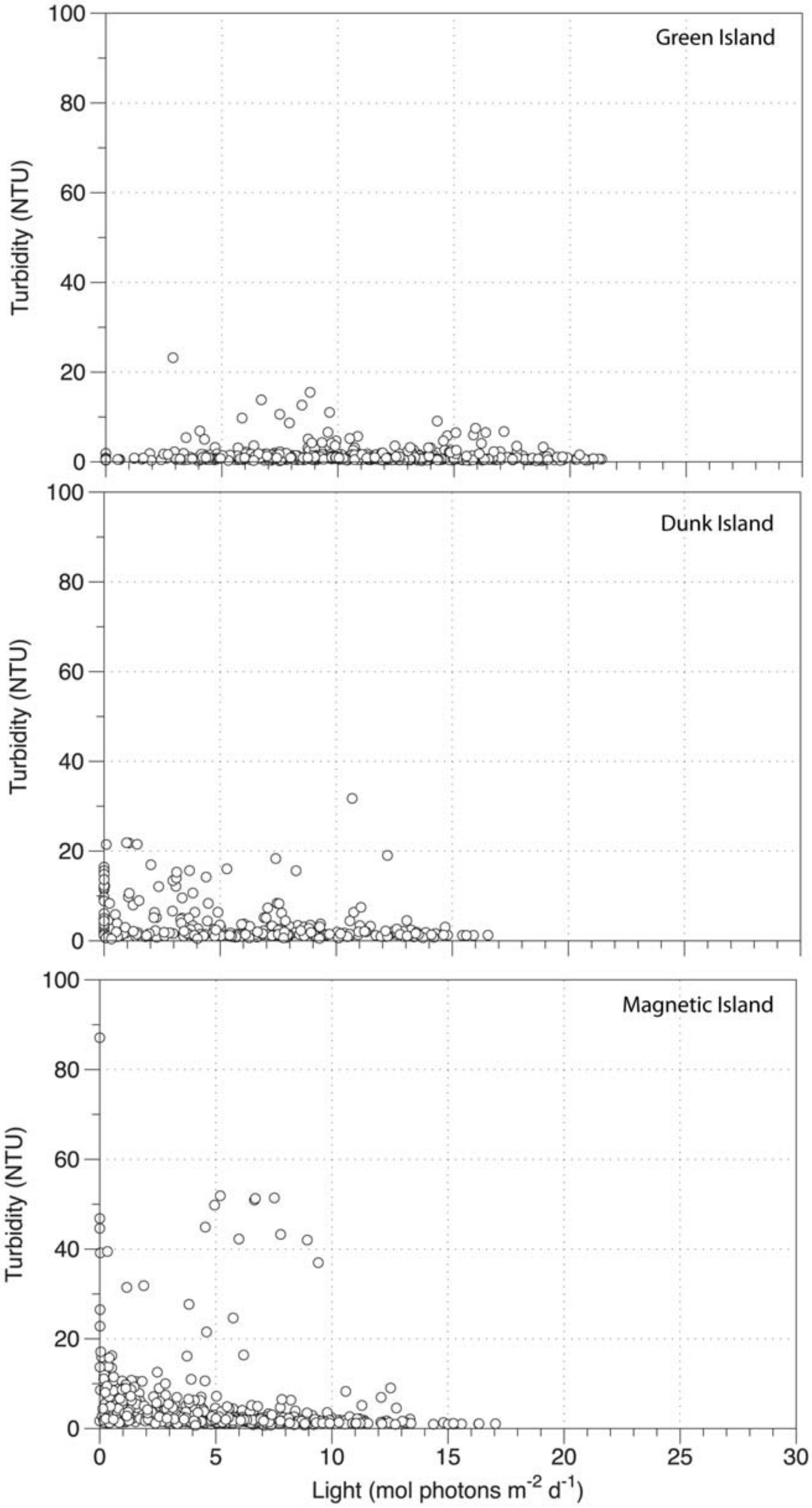


Figure 45. Relationship between turbidity and light at subtidal Reef Rescue MMP sites.

Sediment herbicides

No herbicides were found above detectable concentrations in sediments collected from meadows in May 2011 across the sampling range.

Environmental and biological correlations

Change in seagrass percent cover (change since previous measure, typically 3 months) is presented relative to light (average daily light since previous measure, typically 3 months) in Figure 46 for *Halodule uninervi*s only and in Figure 47 for total seagrass cover. There is a reasonably strong separation between light levels associated with seagrass gain and seagrass loss at subtidal sites under pressure (Magnetic Island and Dunk Island). At Magnetic Island, light levels associated with loss were 2.3 to 6 mol photons m^{-2} s^{-1} for *H. uninervis*, and complete loss in 2011 occurred at 3.4 mol photons m^{-2} s^{-1}. The levels associated with loss were higher at Dunk Island ranging from 5 to 8.3 mol photons m^{-2} s^{-1}, and Green Island, 6.5 to 14.2. This does not mean that low light was the cause of seagrass loss. For example, at Green Island, there was some seagrass loss during the wet season of 2009 when light was on average 14.2 mol photons m^{-2} s^{-1}, and therefore, light was unlikely to be the primary driver of seagrass loss at this time. This range in light indicates the light intensity that can be associated with seagrass loss if maintained for 3 months. These values do not represent a minimum light requirement (MLR), as MLRs typically refer to the light level at which the long-term survival of seagrass is possible which for *H. uninervis* has been estimated to be around 9 - 12 mol photons m^{-2} s^{-1} (Longstaff & Dennison 1999). Seagrass loss at intertidal habitats were not as clearly associated with low light (Figures 46,47). Even at Magnetic Island where light was clearly associated with seagrass loss in subtidal habitats, seagrass loss at intertidal habitats cannot be clearly linked to low light levels (Figures 46,47). The exception is at the Bushland Beach intertidal site where very low light levels occur, and where complete seagrass loss occurred. However, there has been some recruitment post-TC Yasi and we are yet to determine whether these recruits will establish.

There is some spatial correlation between average light and average seagrass cover at subtidal sites (Figure 48). The spatial correlation between average light and average seagrass cover at intertidal sites is extremely weak, indicating that other environmental factors are dominating patterns in seagrass cover in intertidal environments, including exposure to the air during low tide, salinity and sediment characteristics.

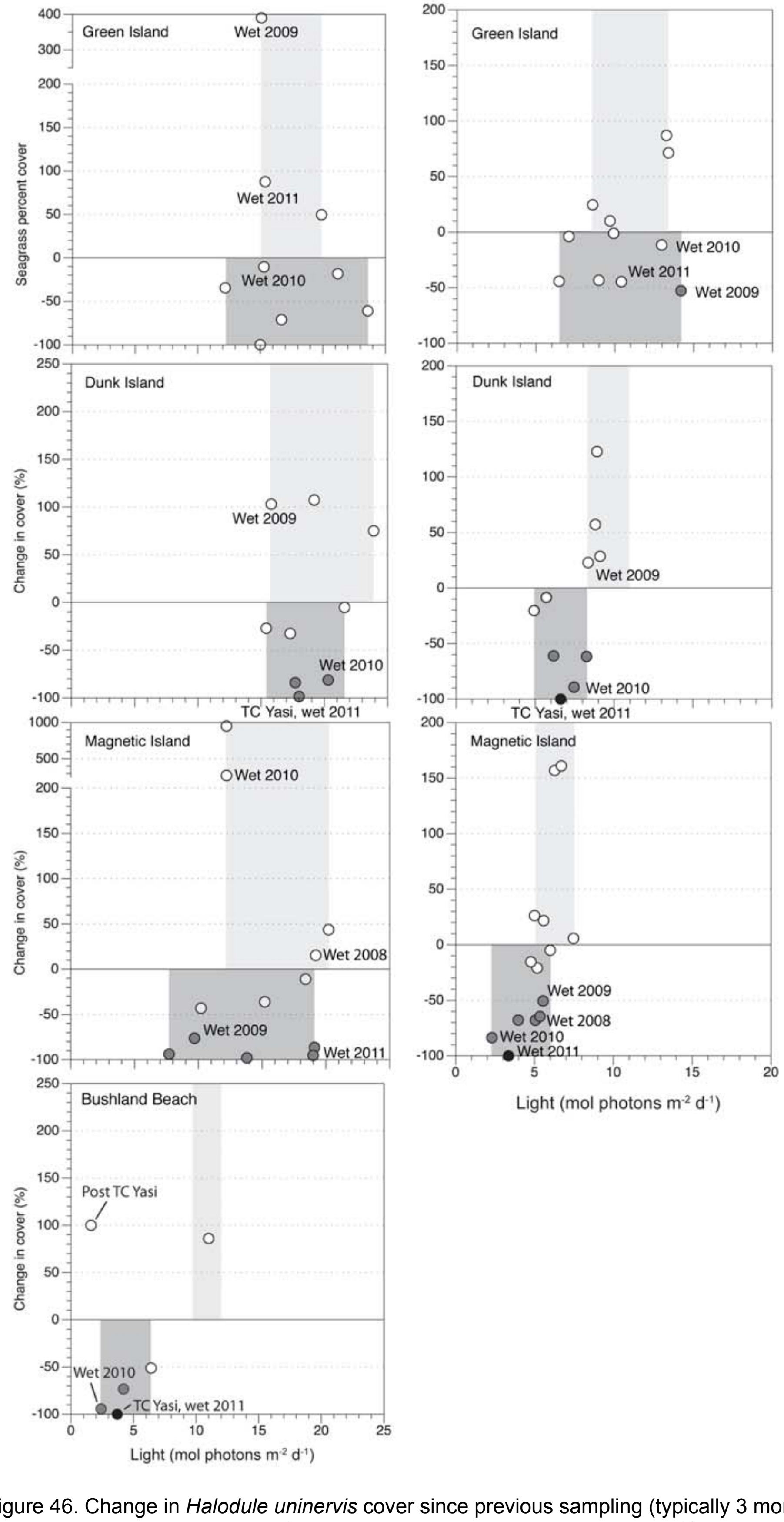


Figure 46. Change in *Halodule uninervis* cover since previous sampling (typically 3 months), at intertidal (left) and subtidal (right) monitoring sites. Grey circles (seagrass loss greater than 50%), black circles (100% loss) and average daily light over the same duration. Dark grey blocks indicate the range in light over which loss in seagrass occurred, light grey blocks indicate light range in which gains occurred.

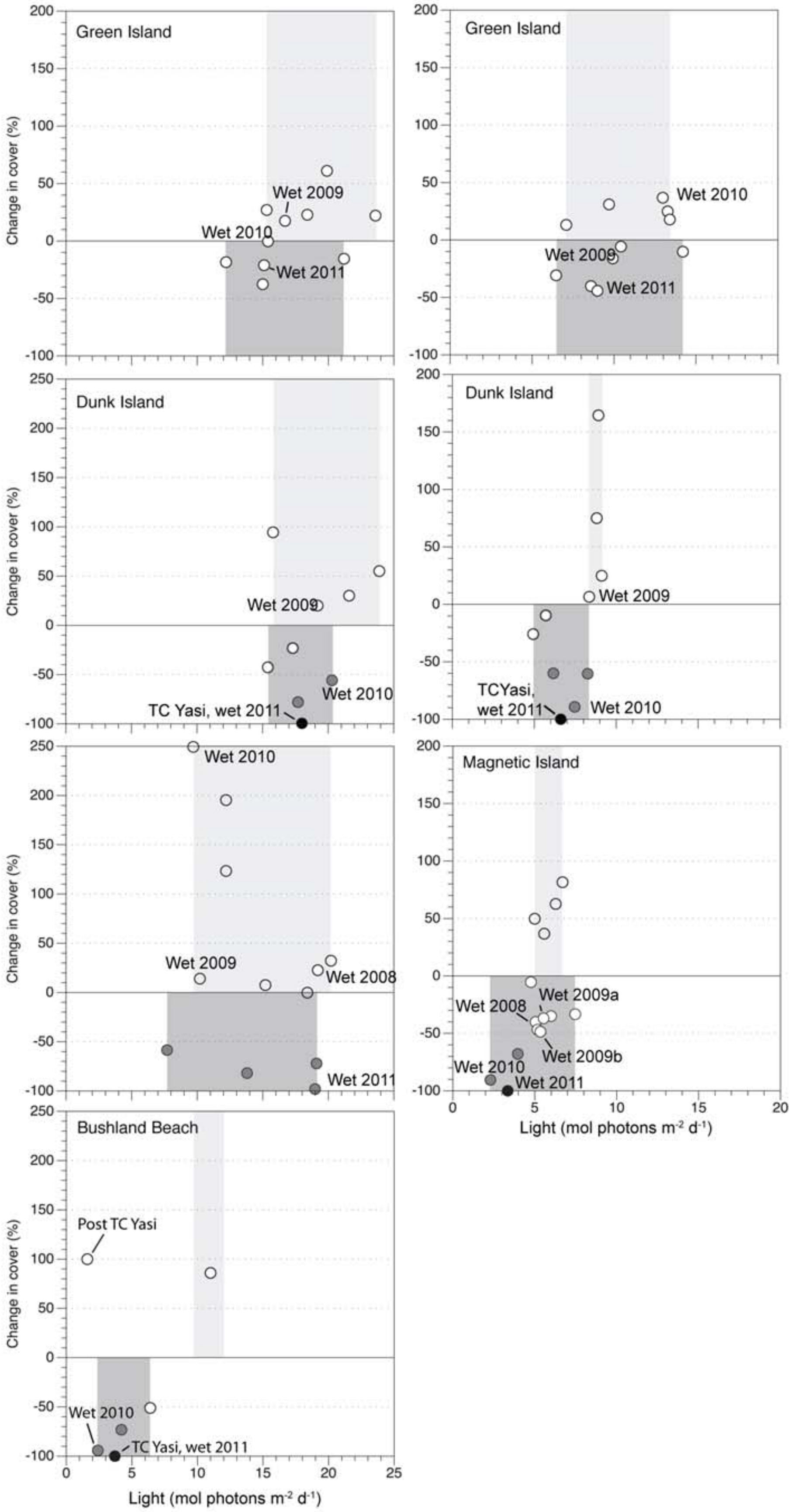


Figure 47. Change in total seagrass cover since previous sampling (typically 3 months), at intertidal (left) and subtidal (right) monitoring sites. Grey circles (seagrass loss greater than 50%), black circles (100% loss) and average daily light over the same duration. Dark grey blocks indicate the range in light over which loss in seagrass occurred, light grey blocks indicate light range in which gains occurred.

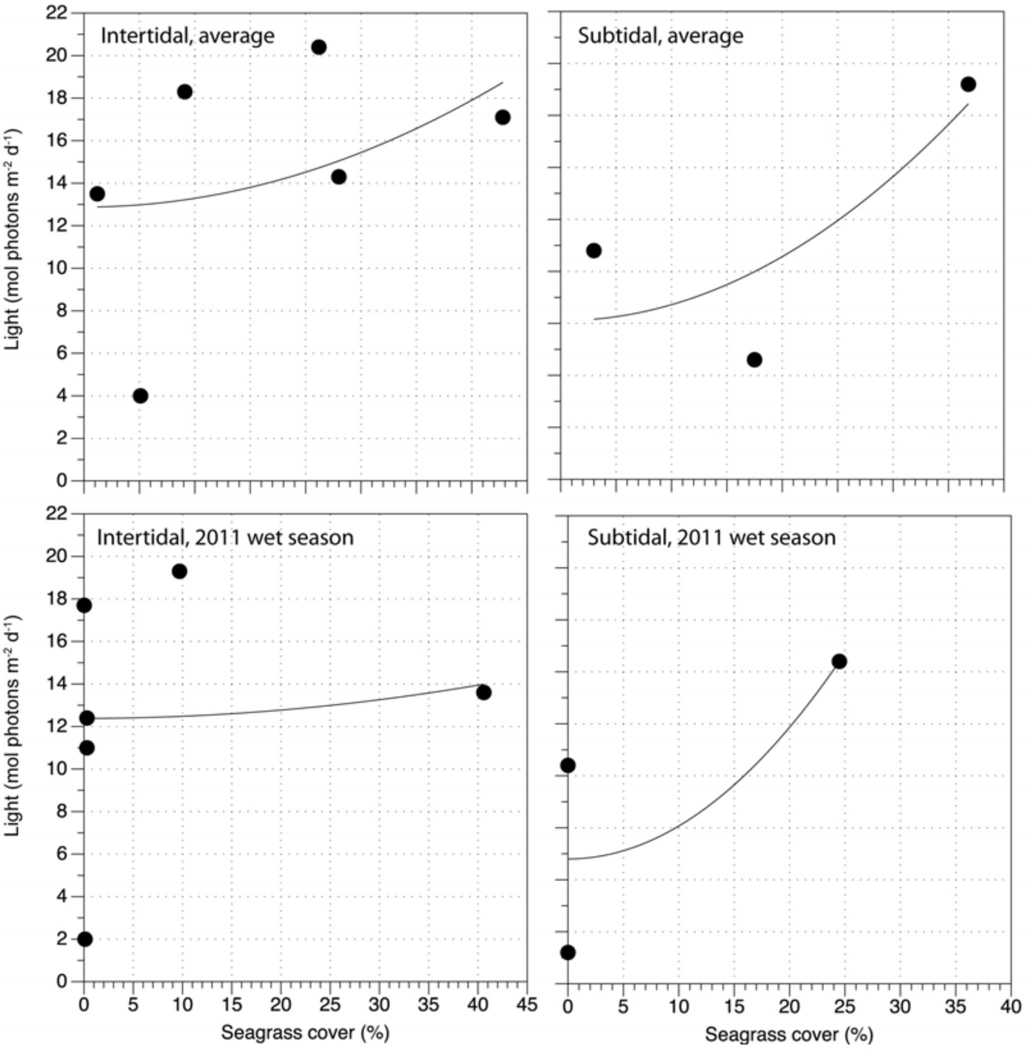


Figure 48. Seagrass cover and light, spatial comparison at intertidal (left) and subtidal (right) sites for average (2008-2011, top) and 2011 wet season (Jan-Mar, bottom).

Outcomes

Considerable seagrass loss has been documented during the 2011 wet season in the region that TC Yasi had primary influence over and south of this region. Explaining this trend we note that light levels during the 2011 wet season were similar to wet season conditions of previous years at most sites where there is long-term light data available. The cumulative impacts of multiple, harsh, wet seasons appears to have degraded seagrass resilience and made it more susceptible to wet season conditions this year, compared to previous years. As a result, seagrass cover is at its lowest at all monitoring sites reported here. Light and temperature (not reported here) are the only environmental variables measured in this program, and other factors may contribute to the loss. For example low salinity can impact seagrass health during the wet season (Kerr & Strother 1985, Torquemada et al. 2005). This is particularly so for intertidal sites where exposure to low salinity will be the most extreme as groundwater seepage and direct runoff over seagrass meadows can be much higher than for adjacent water bodies. Salinity thresholds and exposure to low salinity remains a knowledge gap.

Recovery of seagrass meadows from impacts such as documented here can take more than a decade (Birch & Birch 1984). There are a number of factors that will facilitate recovery of seagrass meadows including seed banks, connectivity and improvement in environmental conditions such as light available for photosynthesis. In this assessment of the status of seagrass meadows we have estimated the scale and cause of impact to seagrass meadows able to be determined as at May 2011, by utilising summary data from previous years monitoring information regarding nutrient and reproductive status, comparing results with current sampling, and an estimate of time to recovery based on expert opinion for two timescales (Table 6). The first estimate of time to recovery is for any type of seagrass, expected to be the pioneer species *Halophila ovalis* or *Halophila decipiens,* which appear very mobile and readily colonise exposed substrates when available. The second time to recovery is proposed which represents the time to recover a foundational community structure which has at least 70% the area of the seagrass community with greater than 50^{th} percentile of cover observed since 2008. This represents a seagrass meadow representative of recent history and makeup of species composition, meadow area and cover. These predictions are based on expectations without the specific knowledge gained from observing the outcomes the events of the 2011 wet season. Following the events of this year, more refined assessment of time to recovery following disturbance (effectively a resilience index) will be possible when there has been evaluation of ongoing documentation of species responses to large scale losses.

The primary outcome of results presented in this report is that the scale and nature of the impact to seagrass meadows in the northern Hinchinbrook region indicates it may be slow to recover. At this stage our data for Shoalwater Bay indicated a relatively short recovery time. Cleveland Bay should be intermediate between these two sites. The caveat on this interpretation is that there are some expected delayed responses to the impacts of flood plumes that may be experienced by the sites currently lacking the less direct affect of cyclonic affects, that upcoming wet seasons are relatively mild and that there is substrate available for recruitment to occur into.

Table 6. Summary of status and impacts to seagrass meadows in three regions of the GBR and predicted times to recovery based on expert opinion with the caveat that El Niño conditions return in the coming wet season.

Region	**Abundance Status** (pre-event)^	**Impact** (H=high, M=moderate, L=low)			**Reproductive** status	**Tissue nutrient** concentrations^	**Estimated time to recovery to *pioneer* community of 25% of previous mean cover** (*Halophila* dominated)	**Estimated time to recovery to *foundation* community †**
		Physical	Light levels	Salinity				
Northern Hinchinbrook	Poor	H^	L	L	Poor	Poor	1-2 years*	Slow (>5 years)
Cape Cleveland	Poor	M	L	L	Moderate	Fair	1-2 year*	Moderate (3-8 years)
Shoalwater Bay	Fair	L	M	H	Good	Fair	One season	Fair (1-3 years)

^ where substrate loss is significant, recovery times will be further delayed

* recovery of pioneer *Halophila* species via seed movement; will be a longer delay if substrate lost

† expert opinion of authors from observations and long term data from studies such as Birch and Birch (1984) to achieve >50th percentile (good) community and >70% distribution (as of 2008)

References

Birch, W.R. and Birch, M. 1984, Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia: A decade of observations. *Aquatic Botany* 19: 343-367

Campbell, S.J. and McKenzie, L.J. 2004, Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. *Estuarine, Coastal and Shelf Science* 60: 477-490

Collier, C.J., Waycott, M. and Giraldo-Ospina, A. In Press, Responses of four Indo-West Pacific seagrass species to shading. *Marine Pollution Bulletin*.

Fairweather, C.L., McKenna, S.A. and Rasheed, M.A. 2011, *Long-Term Seagrass Monitoring in the Port of Mourilyan – November 2010*. DEEDI Publication, Fisheries Queensland, Cairns, 27pp

Grech, A. and Coles, R.G. 2010, An ecosystem-scale predictive model of coastal seagrass distribution. Aquatic conservation. *Marine and Freshwater Ecosystems* 20: 437-444

Kerr, E.A. and Strother, S. 1985, Effects of irradiance, temperature and salinity on photosynthesis of *Zostera muelleri*. *Aquatic Botany* 23: 177-183

Lawler, I.R., Aragones, L., Berding, N., Marsh, H. and Foley, W. 2006, Near-Infrared reflectance spectroscopy is a rapid, cost-effective predictor of seagrass nutrients. *J Chem Ecol* 32: 1353-1365

Longstaff, B.J. and Dennison, W.C. 1999, Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*. *Aquatic Botany* 65: 101-121

Longstaff, B.J., Loneragan, N.R., O'Donohue, M.J. and Dennison, W.C. 1999, Effects of light deprivation on the survival and recovery of the seagrass *Halophila ovalis* (R.Br.) Hook. J *Exp Mar Biol Ecol* 234: 1-27

McKenzie, L.J., Unsworth, R.K.F. and Waycott, M. 2010, *Great Barrier Reef Water Quality Protection Plan (Reef Rescue) - Marine Monitoring Program: Intertidal seagrass, final report for the sampling period 1st September 2009 - 31st May 2010*, Fisheries Queensland, Cairns.

Torquemada, Y.F., Durako, M.J. and Lizaso, J.L.S. 2005, Effects of salinity and possible interactions with temperature and pH on growth and photosynthesis of *Halophila johnsonii* Eiseman. 148: 251(210)

Waycott, M. and McKenzie, L.J. 2010, *Final report project 1.1.3 to the Marine and Tropical Sciences Research Facility: Condition, trend and risk in coastal habitats: Seagrass indicators, distribution and thresholds of potential concern*, Reef and Rainforest Research Centre Limited, Cairns, Australia.

Waycott, M., McMahon, M., Mellors, J., Calladine, A. and Kleine, D. 2004, *A guide to the tropical seagrasses of the Indo-West Pacific*. James Cook University: Townsville. 72 pp.