Reef Rescue Marine Monitoring Program

Final Report of AIMS Activities 2012
Inshore Coral Reef Monitoring

Angus Thompson,
Paul Costello, Johnston Davidson,
Michelle Liddy, Britta Schaffelke, Sven Uthicke

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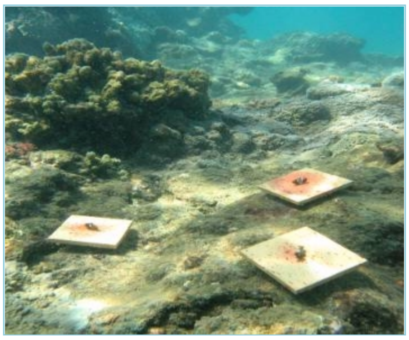

Australian Institute of Marine Science
PMB No 3
Townsville MC Qld 4810

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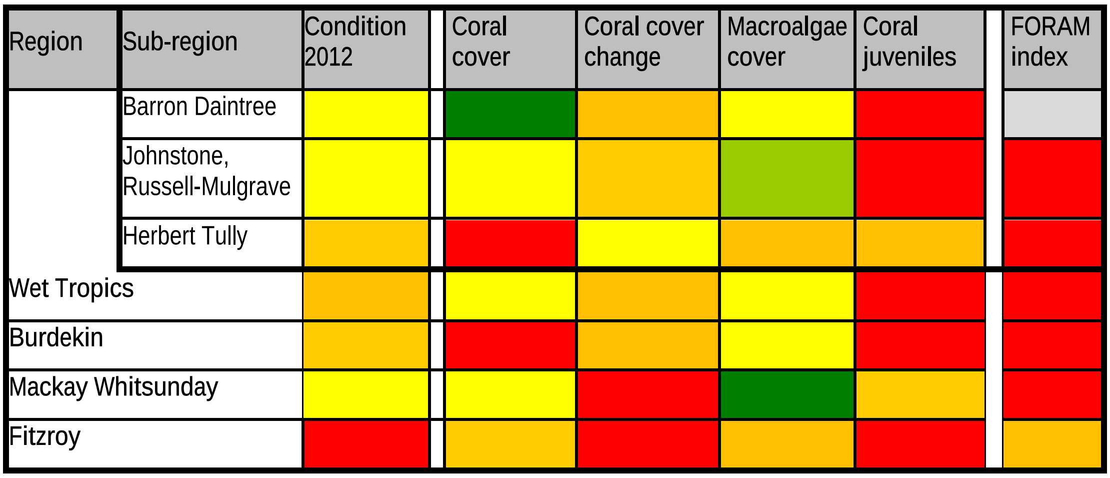
Executive Summary

- The coral reef monitoring component of the Reef Rescue Marine Monitoring Program (MMP) undertaken in 2012 was a continuation of activities under previous arrangements from 2005 to 2011. The coral monitoring program continued to survey the cover of benthic organisms, the numbers of coral genera, the number of juvenile-sized coral colonies and sediment quality at inshore reef locations in four Natural Resource Management (NRM) regions: Wet Tropics; Burdekin; Mackay Whitsunday; and Fitzroy. Monitoring of coral recruitment also continued at three core reef sites in each of the four Regions.
- The completion of the eighth inshore coral reef survey under the MMP allows for updated assessments of the overall condition of inshore coral reef communities (see Table below). In summary, the condition of coral communities continued to decline in all NRM regions. With the exception of declines that were directly attributable to exposure to extreme weather events, including tropical cyclones and flooding, the observed declines in coral condition are consistent with known responses to chronic environmental stress.
- Assessment based on the foraminiferal assemblages in the sediment continued with a declining trend. Based on the FORAM index, nearly all regions and sub-regions are ranked as in 'very poor' condition.
- These declines have occurred over a period of above median rainfall resulting in high end-of-catchment loads of sediments and nutrients. This indicates that at least some constituents in runoff are suppressing the resilience of coral reef communities on inshore reefs of the Great Barrier Reef.

Condition of coral reef communities in inshore waters of the Great Barrier Reef, 2012. The regional and sub-regional estimates of coral community condition aggregate assessments of four metrics: coral cover, coral cover change, macroalgal cover and juvenile hard coral density. The regional estimates of these metrics are, in turn, derived from the aggregation of assessments from the reefs within each region (see Section 3.2). The FORAM index assessments are included as a separate metric but are not included in the overall "Condition" assessment for each region. Grey cells indicate no evaluation of the metric in that location. The colour scheme is consistent with reporting to the Paddock to Reef Program with colours reflecting the relative condition of reef communities: red= very poor, orange= poor, yellow= moderate, light green= good, dark green= very good.



Region	Sub-region	Condition 2012	Coral cover	Coral cover change	Macroalgae cover	Coral juveniles	FORAM index
	Barron Daintree	🟨	🟩	🟧	🟨	🟥	▨
	Johnstone, Russell-Mulgrave	🟨	🟨	🟧	🟢	🟥	🟥
	Herbert Tully	🟧	🟥	🟨	🟧	🟧	🟥
Wet Tropics		🟧	🟨	🟧	🟨	🟥	🟥
Burdekin		🟧	🟥	🟧	🟨	🟥	🟥
Mackay Whitsunday		🟨	🟨	🟥	🟩	🟧	🟥
Fitzroy		🟥	🟧	🟥	🟧	🟥	🟧

Our assessments of coral reef community condition in 2012 are as follows:

- The overall condition of reefs in the Wet Tropics declined from ‘moderate’ in 2011 to ‘poor’ in 2012. The primary reasons for downgrading our condition assessment were the return of moderate to high cover of macroalgae that was temporarily removed from reefs in the Herbert Tully sub-region following Cyclone Yasi and a decline in the density of juvenile corals in the Barron Daintree sub-region. Importantly, the reefs in this region recently suffered cumulative impacts of Cyclone Yasi, elevated incidence of coral disease and high numbers of crown-of-thorns starfish at Snapper Is and Fitzroy Is in 2012. This resulted in reductions in coral cover, a period of low rates of increase in coral cover and the continuation of region-wide declines in the density of juvenile corals. The combination of low density of juvenile corals and projected loss of coral cover as a result of increasing crown-of-thorns feeding suggest that rapid recovery of the coral reefs in this region is unlikely.
- In 2012, the condition of coral reef communities in the Burdekin Region was again assessed as ‘poor’. In part this assessment reflects the legacy of Cyclone Yasi that severely impacted several reefs in 2011. Historically, reefs in this region have been slow to recover from such severe disturbances. Low rates of coral cover increase appear linked to regionally low densities of juvenile corals that are in turn suppressed as a result of a low supply of coral larvae and subsequent competition with the high cover of macroalgae on some reefs. In 2011, settlement of coral larvae was very low indicating that rapid recovery of coral cover remains unlikely in the short term.
- Coral reef communities in the Mackay Whitsunday Region maintained a ’moderate‘ condition estimate in 2012, though the underlying assessment score has declined (Figure 5). The positive indicators of condition of low cover of macroalgae and moderate cover of corals were balanced against low densities of juvenile colonies and slow rates of increase in hard coral cover. Sediments at the reefs in this region have high proportions of fine grained particles and water turbidity is high: conditions known to be stressful to some corals. Incidence of coral disease in this region peaked following the high discharge of local rivers in 2007 compared to a prolonged period of below median flows. The observed low rates of coral cover increase and declines in the density of juvenile corals were concurrent with a period of above median river flows indicating a possible link between elevated runoff and coral community condition.
- Coral reef communities in the Fitzroy Region maintained a ‘poor’ estimate of condition in 2012. It is too early for the coral communities in this region to show recovery from major disturbance due to inundation by low salinity flood waters in 2011, which caused a marked reduction in coral cover and juvenile densities down to at least 2m depth on reefs inshore of Great Keppel Is. The loss of coral cover resulted in a downgrading of this indicator from ‘moderate’ in to 2010 to “poor” in 2011. Similar to other regions the decline in the density of juvenile corals maintains a ‘very poor’ assessment for this indicator. Exacerbated by very low settlement of coral larvae over the summers of 2010/11 and 2011/12, there has been an on-going discrepancy in this region between high rates of coral larvae settling to tiles and the low density of juvenile corals. This lack of progression from available coral larvae through to juvenile colonies along with recently observed low rates of increase in coral cover is of concern for coral community resilience in this region. Levels of coral disease in this region are correlated to annual discharge from the Fitzroy River. Considering the major flooding of the Fitzroy River in 2008, 2010, 2011, and again in 2012, this link between elevated exposure to runoff and coral stress may explain the lower than expected rates of increase in coral cover over recent years.

- The foraminiferal assemblages in the inshore GBR changed significantly between 2007 and 2012. Trend analyses of FORAM index values (an indicator of environmental conditions based on the relative proportions of symbiont-bearing, opportunistic and heterotrophic species groups) demonstrated declines in all regions with most regions and individual reefs now scored as ‘very poor’. The concurrent change in foraminiferal community composition, declines in coral community condition and seagrass condition (evident in recent MMP seagrass monitoring results) combine to demonstrate that ecosystem responses coinciding with elevated levels of runoff are consistent across a wide range of benthic organisms.
- In all regions coral community condition has steadily declined, for two main reasons. Firstly, acute disturbances have variously impacted the majority of reefs (see above), resulting in decreases in overall coral cover. While these impacts *per se* do not constitute a loss of resilience, coral cover is included in our assessment of coral community resilience primarily as an indicator of the availability of broodstock for recovery after disturbances. Secondly, there are clear indications that the resilience of coral communities, i.e. the ability to recover from the acute disturbances, has declined, indicating a chronic change in the ambient environmental conditions at many sites, likely in response to the recent extreme flooding. Collectively, the resilience indicators of cover of macroalgae, juvenile density and rate of cover increase were either stable or declined on almost all reefs, as have the number of coral larvae settling to tiles.
- The recognition of the significance of extreme events for shaping the condition of inshore coral reefs is important to inform the management strategies employed to limit downstream impacts of land runoff. The improvements in GBR catchment management implemented under Reef Plan and Reef Rescue are realistically expected to improve inshore marine water quality on two levels. Firstly, the reduction of event loads of sediments and nutrients, e.g. by improved erosion control measures or timing and method of chemical application, would reduce the extreme levels of light limitation, sedimentation and nutrient and chemical contaminant supply associated with flood events. Secondly, and likely an expected side effect of land management practices to reduce event loads, a general reduction would also reduce baseline loads of contaminants during lower flow periods. The reduced loads of contaminants in runoff would (i) reduce sub-lethal and lethal stresses to species living close to their environmental thresholds, (ii) increase the area of substratum suitable for coral settlement and survival, due to increased light penetration and reduced fine sediment flux, (iii) foster the maintenance of larger adult populations with positive feedbacks to a higher supply of larvae for recovery after acute events and (iv) reduce the fitness of space-competitors such as macroalgae.
- Improvements in marine water quality and associated coral reef condition are likely to be slow and challenging to detect because of the highly variable baseline, lags in ecosystem responses and potentially long recovery periods. However, the continued monitoring of inshore coral reef condition and resilience, and the associated, on-going identification of relationships between coral reef condition and environmental drivers will enable us to detect improvements as land management practices progress towards the Reef Plan/Reef Rescue reduction targets.

Preface

The Reef Rescue Marine Monitoring Program (MMP), formerly known as Reef Water Quality Protection Plan Marine Monitoring Programme (Reef Plan MMP), was designed and developed by the Great Barrier Reef Marine Park Authority (GBRMPA) and is now funded by the Australian Government's Reef Rescue initiative. Since 2010, the MMP has been managed again by the GBRMPA. A summary of the MMP's overall goals and objectives and a description of the sub-programs are available at: http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/science-and-research/our-monitoring-and-assessment-programs/reef-rescue-marine-monitoring-program and http://e-atlas.org.au/content/rrmmp.

The MMP forms an integral part of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program*, which is a key action of Reef Plan 2009 and is designed to evaluate the efficiency and effectiveness of implementation and report on progress towards the Reef Plan and Reef Rescue goals and targets. A key output of the Paddock to Reef Program is an annual report card, including an assessment of Reef water quality and ecosystem condition to which the MMP contributes assessments and information. The first Annual Report Card (Anon. 2011), which serves as a baseline for future assessments, was released in August 2011 (available at www.reefplan.qld.gov.au).

The Australian Institute of Marine Science (AIMS) and the GBRMPA entered into a co-investment contract in May 2011 (updated in December 2011) to provide monitoring activities under the MMP from 2011 to 2013.

The AIMS monitoring activities in the current contract period of the MMP are largely an extension of activities established under a previous arrangements from 2005 to 2010 and are grouped into two components:

- Inshore Marine Water Quality Monitoring
- Inshore coral reef monitoring

This Report presents the results of AIMS coral reef monitoring activities from December 2011 to November 2012, with inclusion of data from previous monitoring years since the MMP began in 2005.

Detailed results from the sub-program "Inshore Marine Water Quality Monitoring" are reported separately (Schaffelke *et al.* 2012): relevant summaries of these data are included in this report to allow interpretation of water quality effects on coral reef condition.

1. Introduction to the MMP Inshore Coral Reef Monitoring

Coral reef communities occur in a wide range of environmental settings with their composition varying in response to environmental conditions such as light availability, sedimentation and hydrodynamics (e.g. Done 1982, Fabricius and De'ath 2001). Coral reefs in the coastal and inshore zones of the Great Barrier Reef (GBR), which are often fringing reefs around continental islands, are located in shallow, and generally more turbid, waters than reefs further offshore due to frequent sediment resuspension and episodic flood events. The reefs adjacent to the developed coast of the GBR are exposed to land runoff carrying excess amounts of fine sediments and nutrients that have increased since European settlement (Kroon *et al.* 2010, 2012). This increase has been implicated in the decline of some coral reefs and seagrass meadows in these zones (reviewed in Brodie *et al.* 2008). It is, however, difficult to quantify the changes to coral reef communities caused by runoff of excess nutrients and sediments because of the lack of historical biological and environmental data that predate significant land use changes on the catchment. Research approaches in the past have included a weight of evidence assessment (Fabricius and De'ath 2004) and studies along environmental gradients, in particular related to water quality variables (e.g., van Woesik *et al.* 1999, Fabricius 2005, Fabricius *et al.* 2005, Cooper *et al.* 2007, Uthicke and Nobes 2008, De'ath and Fabricius 2010).

Concerns about the negative effects of land runoff led to the formulation of the Reef Water Quality Protection Plan (Reef Plan) for catchments adjacent to the GBR World Heritage Area by the Australian and Queensland governments in 2003 (Anon. 2003). The Reef Plan was revised and updated in 2009 (Anon. 2009) and has two primary goals:

- immediate goal - to halt and reverse the decline in quality of water entering the Reef by 2013;
- long-term goal - to ensure that by 2020 the quality of water entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the Great Barrier Reef.

Reef Plan actions and the Reef Rescue initiatives aim to improve land management practices that are expected to result in measurable positive changes in the downstream water quality of creeks and rivers. These actions and initiatives should, with time, also lead to improved water quality in the coastal and inshore GBR (see Brodie *et al.* 2012 for a discussion of expected time lags in the ecosystem response). Given that the benthic communities on inshore reefs of the Great Barrier Reef show clear responses to gradients in water quality, especially of water turbidity, sedimentation rate and nutrient availability (De'ath and Fabricius 2010, Thompson *et al.* 2010a, Uthicke *et al.* 2010, Fabricius *et al*. 2012), improved land management practices have the potential to reduce levels of chronic environmental stresses impacting coral reef communities.

Reef Plan actions also include the establishment of water quality monitoring programs extending from the paddock to the Reef (Anon. 2010), to assess the effectiveness of the Reef Plan's implementation, which are predominantly funded by the Australian Government's Reef Rescue initiative. The MMP is now an integral part of this monitoring. The collected monitoring data should provide information on the key aspects of the biological communities that are likely to be sensitive to the environmental pressures of interest, in this case water quality. A significant attribute of a healthy coral community is that it should be self-perpetuating and 'resilient', that is, able to recover from disturbance. Common disturbances to inshore reefs include cyclones - often with associated flooding, and thermal bleaching, both of which can result in widespread mortality of corals (e.g. Sweatman *et al.* 2007). Recovery from such events is reliant on both the recruitment of new colonies and regeneration of existing colonies from remaining tissue fragments (Smith 2008, Diaz-Pulido *et al.* 2009). Laboratory and field studies show that elevated concentrations of nutrients, agrichemicals, and turbidity, can affect one or more of; gametogenesis, fertilisation, planulation, egg size, and embryonic development in corals (reviewed by Fabricius 2005, van Dam *et al.* 2011 Erftemeijer *et al.* 2012). High levels of sedimentation (i.e., rate of deposition and level of accumulation on surfaces) can affect larval settlement (Babcock and Smith 2002, Baird *et al.* 2003, Fabricius *et al.* 2003) and smother juvenile corals (Harrison and Wallace 1990, Rogers 1990, Fabricius and Wolanski 2000). Any of these water quality-related pressures on the early life stages of corals have the potential to suppress the resilience of communities reliant on recruitment for recovery. Suppression of recovery may lead to long-term degradation of reefs as extended recovery time increases the likelihood that further disturbances will occur before recovery is complete (McCook *et al.* 2001). For this reason, the MMP includes estimates of the supply of coral larvae, by measuring the number of spat that settle on deployed terracotta tiles, and the density and composition of juvenile coral communities to identify areas of the inshore GBR where there are declines or improvements in these key life history processes.

In addition to influences on the early life stages of corals, the position of a reef along environmental gradients can also influence the health and, hence, distribution of mature colonies. In very general terms, community composition changes along environmental gradients due to the differential abilities of species to derive sufficient energy for growth in a given environmental setting. Corals derive energy in two ways, by feeding on ingested particles and plankton organisms and from the photosynthesis of their symbiotic algae (zooxanthellae). The ability to compensate by feeding for a reduction in energy derived from photosynthesis, e.g. as a result of light attenuation in turbid waters, varies between species (Anthony 1999, Anthony and Fabricius 2000). Similarly, the energy required to shed sediments varies between species due to differences in the efficiencies of passive (largely depending on growth form) or active (such as mucus production) strategies for sediment removal (Rogers 1990, Stafford-Smith and Ormond 1992). At the same time, high nutrient levels may favour organisms that rely solely on particle feeding such as sponges and heterotrophic soft corals which are potential space competitors of hard corals. In addition, macroalgae have higher abundance in areas with high water column chlorophyll concentrations, indicating higher nutrient availability (De'ath and Fabricius 2010). High macroalgal abundance may suppress reef resilience (e.g., Hughes *et al.* 2007, Cheal *et al.* 2010; Foster *et al.* 2008; but see Bruno *et al.* 2009) by increased competition for space or changing the microenvironment for corals to settle and grow in (e.g. McCook *et al.* 2001, Hauri *et al.* 2010). The result is that the combination of environmental parameters at a given location will disproportionately favour some species and thus influence the community composition of coral reef benthos. Documenting and monitoring change in the absolute and relative cover of coral reef communities is an important component of the MMP as our expectations for the rate of recovery from disturbances will differ based on the community composition (Thompson and Dolman 2010).

It is important to note, however, that coral colonies exhibit a degree of plasticity in both their physiology (e.g. Falkowski *et al.* 1990 and Anthony and Fabricius 2000), and morphology (as reviewed by Todd 2008) which allows them, within limits, to adapt to their environmental setting. This plasticity has the potential to decouple the relationship between benthic communities and their environmental setting, especially in locations that have been spared major disturbance. In effect, stands of large (typically old) colonies may represent relics of communities that recruited and survived through juvenile stages under conditions different to those occurring today. The response of the coral reef community to chronic changes in environmental conditions may be delayed until a severe disturbance resets the community (through mortality of the relic community components) with subsequent recovery favouring species suited to the current conditions.

In recognition of the potential lagged response of coral communities to changing conditions, monitoring of benthic foraminifera communities was added to the suite of biological indicators as an indicator of environmental change that appears to respond faster and more specifically to changes in water quality (Schaffelke *et al.* 2008, Uthicke *et al.* 2010). The use of foraminifera as coral reef indicators on the GBR was tested at AIMS (see e.g. Uthicke and Nobes 2008, Nobes and Uthicke 2008, Uthicke *et al.* 2010, Uthicke and Altenrath 2010). This report includes the temporal profiles of the FORAM Index (Hallock *et al.* 2003), an indicator of water quality based on the relative proportions of symbiont-bearing, opportunistic and heterotrophic species groups from reefs samples collected in 2005 and 2006 under a MTRSF-funded research project and then in 2007, 2010, 2011 and 2012 as part of the MMP.

The key goal of the Inshore Coral Reef Monitoring component of the MMP is to accurately quantify temporal and spatial variation in inshore coral reef community condition and relate this variation to differences in local reef water quality. An additional detailed report (Thompson *et al.* 2010a) has linked the consistent spatial patterns in coral community composition observed over the first three years of the program with environmental parameters. To facilitate the identification of relationships between the composition and resilience of benthic communities and their environmental conditions it is essential that the environmental setting of each monitoring location be adequately described, to this end:

- Water temperature is continuously monitored at all locations to identify instances of thermal stress
- Assessments of the grain size distribution and nutrient content of sediments were added in 2006/07 as indicators for the accumulation of fine sediments and/or nutrients and to infer the general hydrodynamic setting of sites
- The MMP water quality monitoring sites are matched to the core coral reef monitoring locations (Schaffelke *et al*. 2008)

In order to relate inshore coral reef community health to variations in local reef water quality, this project has several key objectives:

1. Provide an annual time series of benthic community structure (viz. cover and composition of sessile benthos such as hard corals, soft corals and algae) for inshore reefs as a basis for detecting changes that correspond to changes in water quality;
2. Provide information about coral recruitment on GBR inshore reefs as a measure for reef resilience;
3. Provide information about sea temperature and sediment quality as indicators of environmental conditions at inshore reefs;
4. Provide an integrated assessment of coral community condition for the inshore reefs monitored to serve as a report card against which changes in condition can be tracked.

This report presents data from the eighth annual survey of coral reef sites under the MMP (undertaken from May 2012 to November 2012; hereafter called “2012”) and the seventh annual observations of coral settlement following spawning in late 2011. These data are presented as time series in the context of prior observations extending back to 2005 and the assessment of coral reef community condition is directly transferable into the Paddock to Reef Reporting (see Preface).

2. Methods

In this section an overview is given of the sample collection, preparation and analyses methods used to derive the results reported. Detailed documentation of the AIMS methods used in the MMP, including quality assurance and quality control procedures, are available in a separate report that is updated annually (GBRMPA in press).

2.1 Sampling design

The sampling design was selected for the detection of change in benthic communities on inshore reefs in response to improvements in water quality parameters associated with specific catchments, or groups of catchments (Region), and with disturbance events. Within each Region, reefs were selected along a gradient of exposure to run-off, largely determined as increasing distance from a river mouth in a northerly direction. To account for spatial heterogeneity of benthic communities within reefs, two sites were selected at each reef. Observations on a number of inshore reefs undertaken by AIMS in 2004, during a pilot study to the current monitoring program (Sweatman *et al.* 2007), highlighted marked differences in community structure and exposure to perturbations with depth; hence sampling within sites was stratified by depth. Within each site and depth, fine scale spatial variability was accounted for by the use of five replicate transects. Reefs within each region were designated as either 'core' or 'cycle' reefs. At core reefs all benthic community sampling methods were conducted annually, however, at cycle reefs sampling was undertaken every other year and coral recruitment estimates were not included. During the first two years of sampling, some fine tuning of the sampling design occurred. In 2005 and 2006 three mainland fringing reef locations were sampled along the Daintree coast. Concerns over increasing crocodile populations in this area led to the cessation of sampling at these locations in subsequent years. The sites at which coral settlement tiles were deployed changed over the first few years as a focus shifted from fine scale process to inter-regional comparisons (see Table 1).

2.1.1 Site Selection

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

1. Sampling locations in each catchment of interest were spread along a perceived gradient of influence away from a priority river;
2. Sampling locations were selected where there was either an existing coral reef community or evidence (in the form of carbonate-based substratum) of past coral reef development.

In the Wet Tropics region, where well-developed reefs existed on more than one aspect of an island, two reefs were included in the design. Coral reef communities can be quite different on windward compared to leeward reefs even though the surrounding water quality is relatively similar. Differences in wave and current regimes determine whether materials, e.g. sediments, fresh water, nutrients or toxins imported by flood events, accumulate or disperse and hence determine the exposure of benthic communities to environmental stresses. A list of the selected reefs is presented in Table 1 and the geographic locations are shown in Figure 1.

2.1.2 Depth Selection

From observations of a number of inshore reefs undertaken by AIMS in 2004 (Sweatman *et al.* 2007), marked differences in community structure and exposure to perturbations with depth were noted. The lower limit for the inshore coral surveys was selected at 5m below datum, because coral communities rapidly diminish below this depth at many reefs; 2m below datum was selected as the 'shallow' depth as this allowed surveys of the reef crest. Shallower depths were considered but discounted for logistical reasons, including the inability to use the photo technique in very shallow water, site markers creating a danger to navigation and difficulty in locating a depth contour on very shallow sloping substrata typical of reef flats.

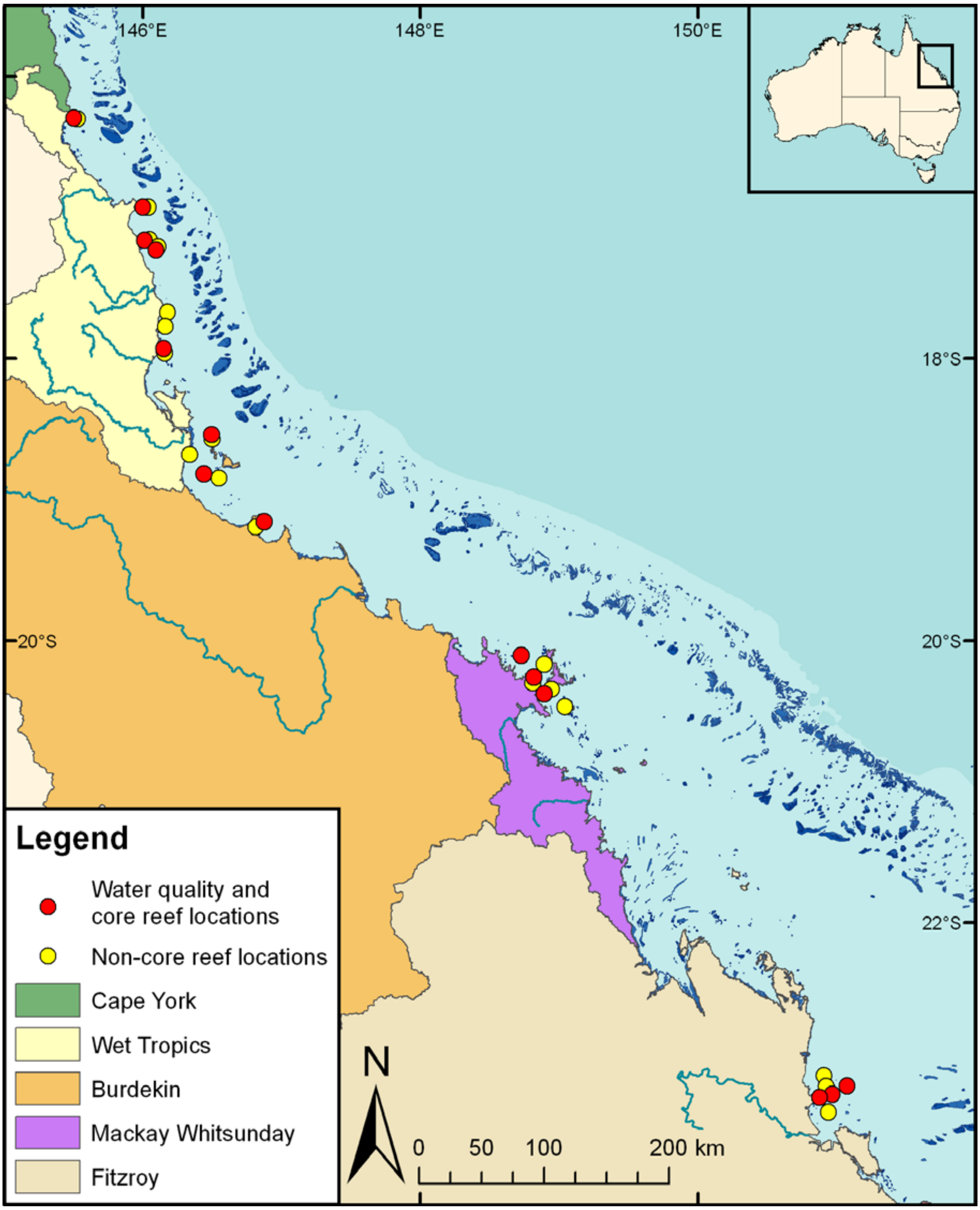


Figure 1: Sampling locations of the Reef Rescue MMP inshore coral monitoring. Core reef locations have annual coral reef benthos surveys, coral settlement assessments and regular water quality monitoring. Exceptions are Snapper Is and Dunk Is North (where coral settlement is not measured). Cycle reef locations (Non-core) have benthos surveys every two years and no water quality monitoring. NRM Region boundaries are represented by coloured catchment areas.

Table 1: Coral reef sampling 2005 to 2012. Coral reef monitoring completed (Y), coral settlement tiles deployed (T). The 14 core reefs are indicated by grey shading.

Region	Primary catchment	Coral monitoring locations	2005	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Barron Daintree	Cape Tribulation (North)	Y	Y						
		Cape Tribulation (Middle)	Y	Y						
		Cape Tribulation (South)	Y	Y						
		Snapper Is North	Y	Y	Y	Y	Y	Y	Y	Y
		Snapper Is South	Y	Y	Y	Y	Y	Y	Y	Y
	Johnstone Russell-Mulgrave	Fitzroy Is West	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Fitzroy Is East	Y^T	Y^T	Y^T	Y		Y	Y	Y
		High Is West	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		High Is East	Y^T	Y^T	Y^T		Y		Y	
		Frankland Group West	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Frankland Group East	Y^T	Y^T	Y^T		Y		Y	
	Herbert Tully	North Barnard Group	Y	Y	Y		Y		Y	
		King Reef	Y	Y		Y		Y		Y
		Dunk Is North	Y	Y	Y	Y	Y	Y	Y	Y
		Dunk Is South	Y	Y		Y		Y	Y	Y
Burdekin	Herbert	Pelorus / Orpheus Is West	Y	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Orpheus Is East	Y	Y		Y		Y	Y	Y
	Burdekin	Lady Elliot reef	Y	Y		Y		Y		Y
		Pandora Reef	Y	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Havannah Is	Y	Y	Y		Y		Y	
		Middle Reef	Y	Y	Y		Y		Y	
		Geoffrey Bay	Y	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
Mackay Whitsunday	Proserpine	Double Cone Is	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Hook Is	Y	Y		Y		Y		Y
		Daydream Is	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Shute & Tancred Islands	Y	Y		Y		Y		Y
		Dent Is	Y	Y	Y		Y		Y	
		Pine Is	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Seaforth Is	Y	Y	Y		Y		Y	
Fitzroy	Fitzroy	North Keppel Is	Y	Y	Y		Y		Y	
		Middle Is	Y	Y		Y		Y		Y
		Barren Is	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Humpy & Halfway Islands	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Pelican Is	Y	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T	Y^T
		Peak Is	Y	Y		Y		Y	Y	Y

2.2 Field survey methods

2.2.1 Site marking

At each reef (Table 1), sites are permanently marked with steel fence posts at the beginning of each of five 20m transects and smaller (10mm diameter) steel rods at the 10m mark and the end of each transect. Compass bearings and measured distances record the transect path between these permanent markers. Transects were set initially by running two 60m fibreglass tape measures out along the desired 5m or 2m depth contour. Digital depth gauges were used along with tide heights from the closest location included in 'Seafarer Tides' electronic tide charts produced by the Australian Hydrographic Service to set transects as close as possible to the desired depths of 5m and 2m below lowest astronomical tide (LAT). Consecutive 20m transects were separated by 5m. The position of the first picket of each site was recorded by GPS.

2.2.2 Sampling methods

Five separate sampling methodologies were used to describe the benthic communities of inshore coral reefs. These were each conducted along the fixed transects (for details see Table 2 and descriptions below).

Table 2: Summary of sampling methods applied in the MMP inshore coral reef monitoring

Survey Method	Information provided	Transect coverage	Spatial coverage
Photo point Intercept	Percentage covers of the substratum of major benthic habitat components.	Approximately 34cm belt along upslope side of transect from which 160 points were sampled.	Full sampling design
Demography	Size structure and density of juvenile (<10cm) coral communities.	34cm belt along the upslope side of transect.	Full sampling design
Scuba search	Incidence of factors causing coral mortality	2m belt centred on transect	Full sampling design
Settlement tiles	Larval supply	Clusters of six tiles in the vicinity of the start of the 1st, 3rd and 5th transects	12 core reefs and 5m depth only
Sediment sampling	Grain size distribution and the chemical content of nitrogen, organic carbon and inorganic carbon. Community composition of foraminifera	Sampled from available sediment deposits within the general area of transects.	5m depth only Forams on 14 core reefs

Photo point intercept transects (PPIT)

This method was used to gain estimates of the composition of the benthic communities. The method followed closely the Standard Operation Procedure Number 10 of the AIMS Long-Term Monitoring Program (Jonker *et al.* 2008). In short, digital photographs were taken at 50cm intervals along each 20m transect. Estimations of cover of benthic community components were derived from the identification of the benthos lying beneath five fixed points overlaid onto these images. At total of 32 images were analysed from each transect. For the majority of hard and soft corals, identification to at least genus level was achieved.

Juvenile coral surveys

These surveys aimed to provide an estimate of the number of both hard and soft coral colonies that were successfully recruiting and surviving early post-settlement pressures. In 2005 and 2006 these juvenile coral colonies were counted as part of a demographic survey that counted the number of all individuals falling into a broad range of size classes that intersected a 34cm wide belt along the first 10m of each 20m transect. As the focus narrowed to just juvenile colonies, the number of size classes was reduced allowing an increase in the spatial coverage of sampling. From 2007 coral colonies less than 10cm in diameter were counted along the full length of each 20m transect within a belt 34cm wide (data slate length) positioned on the upslope side of the marked transect line. Each colony was identified to genus and assigned to a size class of either, 0-2cm, >2-5cm, or >5-10cm. Importantly, this method aims to record only those small colonies assessed as juveniles, i.e. which result from the settlement and subsequent survival and growth of coral larvae, and does not include small coral colonies considered as resulting from fragmentation or partial mortality of larger colonies.

Scuba search transects

Scuba search transects document the incidence of disease and other agents of coral mortality and damage. Tracking of these agents of mortality is important, because declines in coral condition due to these agents are potentially associated with changes in water quality. This method follows closely the Standard Operation Procedure Number 9 of the AIMS Long-Term Monitoring Program (Miller *et al.* 2009). For each 20m transect a search was conducted within a 2m wide belt centred on the marked transect line for any recent scars, bleaching, disease or damage to coral colonies. An additional category not included in the standard procedure was physical damage. This was recorded on the same 5 point scale as coral bleaching and describes the proportion of the coral community that has been physically damaged, as indicated by toppled or broken colonies. This category may include anchor as well as storm damage.

Hard coral recruitment measured by settlement tiles

This component of the study aims to provide standardised estimates of availability and relative abundance of coral larvae competent to settle. Such estimates may be compared among years for individual reefs to assess, for example, recovery potential of an individual reef after disturbance, a key characteristic of reef health.

At each reef, tiles were deployed over the expected settlement period for each spawning season based on past observations of the timing of coral spawning events (Table 3). Tiles were deployed approximately 2-3 weeks prior to any expected settlement to allow a period of ‘conditioning’ (i.e. the development of a natural, site-specific microbial community that aids settlement, see Webster *et al*. 2004).

Each year tiles were fixed to small stainless steel base plates attached to the substratum with plastic masonry plugs, or cable ties (when no solid substratum was available). Each base plate holds one tile at a nominal distance of 10mm above the substratum. Tiles were distributed in clusters of six around the star pickets marking the start of the 1st, 3rd and 5th transect at each 5m depth site on 12 core reefs (see Table 1, Figure 1). Upon collection, the base plates were left in place for use in the following year. Collected tiles were stacked onto separate holders and tagged with collection details (retrieval date, reef name, site and picket number). Small squares of low density foam placed between the tiles prevented contact during transport and handling as this may dislodge or damage the settled corals. On return to land the stacks of tiles were carefully washed on their holders to remove loose sediment and then bleached for 12-24 hours to remove tissue and fouling organisms. Tiles were then rinsed and soaked in fresh water for a further 24 hours, dried and stored until analyses.

Hard coral recruits on retrieved settlement tiles were counted and identified using a stereo dissecting microscope. The taxonomic resolution of these young recruits was limited. The following taxonomic categories were identified: Acroporidae (excluding *Isopora spp.*), Acroporidae (*Isopora spp.*), Fungiidae, Poritidae, Pocilloporidae and 'other families'. A set of reference images pertaining to these categories has been compiled.

Table 3: Locations and periods of coral settlement tile deployment for 2011 spawning.

Region	Catchment	Coral monitoring locations	Coral settlement tile deployment	Coral settlement tile retrieval
Wet Tropics	Johnstone Russell-Mulgrave	Fitzroy Is West	03-Oct-11	09-Feb-12
		High Is West	04-Oct-11	10-Feb-12
		Frankland Group West	04-Oct-11	10-Feb-12
Burdekin	Burdekin	Geoffrey Bay	30-Sep-11	12-Jan-12
		Pandora Reef	30-Sep-11	11-Jan-12
		Orpheus Is & Pelorus Is West	01-Oct-11	11-Jan-12
Mackay Whitsunday	Proserpine	Double Cone Is	25-Sep-11	04-Jan-12
		Daydream Is	28/29-Sep-11	06-Jan-12
		Pine Is	28-Sep-11	06-Jan-12
Fitzroy	Fitzroy	Pelican Is	27-Sep-11	11-Feb-12
		Humpy Is & Halfway Is	26-Sep-11	05-Feb-12
		Barren Is	26-Sep-11	05-Feb-12

Foraminiferal abundance and community composition from sediment samples

The composition of foraminiferal assemblages were estimated from a subset of the surface sediment samples collected from the 5m depths at the 14 core coral monitoring sites (see Table 1). Sediments were washed with freshwater over a 63 μm sieve to remove small particles. After drying (>24 h, 60°C), haphazard subsamples of the sediment were taken and, using a dissection microscope, all foraminifera present in these were collected. This procedure was repeated until about 200 foraminifera specimens were collected from each sediment sample. Only intact specimens showing no sign of weathering were collected. Samples thus defined are a good representation of the present day biocoenosis (Yordanova and Hohenegger 2002), although not all specimens may have been alive during the time of sampling. Species composition of foraminifera was determined in microfossil slides under a dissection microscope following Nobes and Uthicke (2008).

The FORAM index (Hallock *et al*. 2003) summarises foraminiferal assemblages based on the relative proportions of species classified as either symbiont-bearing, opportunistic or heterotrophic and has been used as an indicator of coral reef water quality in Florida and the Caribbean Sea (Hallock *et al.* 2003). In general, a decline in the FORAM index indicates an increase in the relative abundance of heterotrophic species. Symbiotic relationships with algae are advantageous to foraminifera in clean coral reef waters low in dissolved inorganic nutrients and particulate food sources, whereas heterotrophy becomes advantageous in areas of higher turbidity and higher availability of particulate nutrients (Hallock 1981). The FORAM index has been successfully tested on GBR reefs and corresponded well to water quality variables (Uthicke and Nobes 2008, Uthicke *et al.* 2010).

To calculate the FORAM Index foraminifera are grouped into three groups: 1) Symbiont-bearing, 2) Opportunistic and 3) Other small (or heterotrophic).

The proportion of each functional group is then calculated as:

1) Proportion symbiont-bearing = $P_S = N_S/T$

2) Proportion opportunistic = $P_O = N_O/T$

3) Proportion heterotrophic = $P_h = N_h/T$

Where N_x = number of foraminifera in the respective group, T= total number of foraminifera in each sample.

The FORAM index is then calculated as $FI = 10P_s + P_o + 2P_h$

Thus, a maximum value of 10 is attained for samples containing only symbiont bearing taxa, and a minimum of 2 if only heterotrophic taxa are present.

2.3 Sediment quality monitoring

Sediment samples were collected from all reefs visited for analysis of grain size and of the proportion of inorganic carbon, organic carbon and total nitrogen. At each 5m deep site 60ml syringe tubes were used to collect cores of surface sediment from available deposits along the 120m length of the site. On the boat, the excess sediment was removed to leave 10mm in each syringe, which represented the top centimetre of surface sediment. This sediment was transferred to a sample jar, yielding a pooled sediment sample.. Another four cores were collected in the same way to yield a pooled sample for analysis of foraminiferal assemblage composition. The sample jars were stored in an ice box with ice packs to minimise bacterial decomposition and volatilisation of the organic compounds until transferred to a freezer on the night of collection and kept frozen until analysis.

The sediment samples were defrosted and each sample well mixed before being sub-sampled (approximately 50% removed) to a second labelled sample jar for grain-size analysis. The remaining material was dried, ground and analysed for the composition of organic carbon, inorganic carbon, and nitrogen.

Grain size fractions were estimated by sieving two size fractions (1.0 -1.4mm, >2.0mm) from each sample followed by MALVERN laser analysis of smaller fractions (<1.0mm). Sieving and laser analysis was carried out by the School of Earth Sciences, James Cook University for samples collected in 2005-2009 and subsequently by Geoscience Australia. .

Total carbon (combined inorganic carbon and organic carbon) was determined by combustion of dried and ground samples using a LECO Truspec analyser. Organic carbon and total nitrogen were measured using a Shimadzu TOC-V Analyser with a Total Nitrogen unit and a Solid Sample Module after acidification of the sediment with 2M hydrochloric acid. The inorganic carbon component was calculated as the difference between total carbon and organic carbon values. In purely reef-derived sediments ($CaCO_3$) the inorganic carbon component will be12% of the sample, values lower than this can be interpreted as including higher proportions of non-reefal, terrigenous material.

2.4 Sea temperature monitoring

Temperature loggers were deployed at, or in close proximity to, each survey location at both 2m and 5m depths and routinely exchanged at the time of the coral surveys (i.e. every 12 or 24 months). Initially Odyssey temperature loggers (http://www.odysseydatarecording.com/) were used prior to gradual change over to Sensus Ultra Temperature logger (http://reefnet.ca/products/sensus/). The Odyssey Temperature loggers were set to take readings every 30 minutes. The Sensus Temperature loggers were set to take readings every 10 minutes. Loggers were calibrated against a certified reference thermometer after each deployment and were generally accurate to ± 0.2°C.

As a reference point for the temperature at each reef during the survey year, a 9 year baseline of mean weekly temperatures over the period July 1999 to July 2008 was estimated for each region (separate baselines were estimated for the three sub regions in the Wet Tropics Region). These long-term means were derived from existing data sets (AIMS Long-term Temperature Monitoring Program) in combination with the first 3 years of sampling at MMP locations. In addition to MMP coral reef sites, data from loggers from the following locations were used for the long-term estimates:

- Wet Tropics: Coconut Beach, Black Rocks, Low Isles, pre-existing sites at Fitzroy Is, High Is and the Frankland Group;
- Burdekin Region: additional and pre-existing sites at Orpheus Is, Magnetic Is and Cleveland Bay
- Mackay Whitsunday Region: Hayman Is and pre-existing site at Daydream Is;
- Fitzroy Region: Halftide Rocks, Halfway Is and pre-existing sites at Middle Is and North Keppel Is.

2.5 Autonomous Water Quality Loggers

Instrumental water quality monitoring at the 14 core reefs was undertaken using WETLabs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors. These were deployed at 5m below LAT at the start of coral survey transects. Data from these instruments are included as additional information about the environmental conditions at the core survey reefs and are reported in more detail separately (Schaffelke *et al*. 2012).

The Eco FLNTUSB Combination instruments were deployed year round and perform simultaneous *in situ* measurements of chlorophyll fluorescence, turbidity and temperature. The fluorometer monitors chlorophyll concentration by directly measuring the amount of chlorophyll fluorescence emission, using blue LEDs (centred at 455 nm and modulated at 1 kHz) as the excitation source. Turbidity is measured simultaneously by detecting the scattered light from a red (700 nm) LED at 140 degrees to the same detector used for fluorescence. The instruments were used in 'logging' mode and recorded a data point every 10 minutes for each of the three parameters, which was a mean of 50 instantaneous readings.

The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2010, hereafter "the Guidelines") provide a useful framework to interpret the instrument water quality values obtained at the fourteen core sampling sites. The Guidelines trigger values are mean annual concentrations of 0.45 µg L^{-1} for chlorophyll and 2 mg L^{-1} for suspended solids. To allow direct comparison between the Guidelines turbidity trigger it was necessary to convert 2 mg L^{-1} into the NTU units derived from instrumental readings resulting in a converted trigger value of 1.54 NTU (Schaffelke *et al.* 2009).

2.6 Data analyses

Recent MMP reports presented comprehensive statistical analyses of spatial patterns in the inshore coral reef data and identified both regional differences in community attributes as well as the relationships between both univariate and multivariate community attributes and key environmental parameters such as water column particulates and sediment quality (Schaffelke *et al.* 2008, Thompson *et al.* 2010a). Statistical analysis of spatial relationships between coral communities and their environmental setting are not repeated here.

In this report results are presented to reveal temporal changes in coral community attributes and key environmental variables. Generalized linear mixed effects models were fitted to community attributes and environmental variables separately for each NRM region. In these analyses we were interested in identifying the presence and consistency of trends. To this end, observations for each variable were averaged to the reef level for each year and individual reefs treated as random factors. To allow flexibility in their form, trends are modelled as natural cubic splines. A log link function was used as we were explicitly interested in identifying the consistency of proportional changes in a given variable among reefs, acknowledging that the absolute levels of that variable may differ between reefs.

The results of these analyses are graphically presented in a consistent format for both, environmental variables (Section 3.1.1 to 3.1.3) and biological variables (Section 3.1.4): Predicted trends were plotted as bold black lines, the confidence intervals of these trends delimited by blue dashed lines; the observed trends at each survey reef were plotted in the background as thin grey lines. A point to note is that in some instances it appears that the predicted trends are slightly offset to the observed changes, which is due to the inclusion in the analysis of both core reefs (sampled every year) and cycle reefs (sampled every other year). Changes occurring on cycle reefs more than a year preceding the survey will be perceived as having occurred in the survey year.

2.6.1 Assessment of coral reef community condition

As expected, coral communities show clear relationships to local environmental conditions, however, these relationships do not easily translate into an assessment of the "health" of these communities as gradients in both environmental condition and community composition may naturally occur. The assessment of coral community condition presented here considers the levels of key community attributes that may each indicate the potential of coral communities to recover from inevitable disturbances. The attributes assessed were: coral cover, macroalgae cover, the rate of coral cover increase, and the density of juvenile hard corals. Thompson *et al.* (2010b) presented a baseline assessment of coral community condition based on data collected between 2005 and 2009, which was included in the First Report of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Anon. 2011).

Subsequent to this baseline assessment, the estimation of coral community condition was revised with the view to enhancing the sensitivity of the assessment to change. In short, the period over which the metric based on rates of increase in cover of hard corals was restricted to three years and coral settlement was removed as a metric due to high inter-annual variability the causes of which remain unresolved. The 2010 MMP inshore coral monitoring report used this revised assessment protocol (Thompson *et al.* 2011). For comparative purposes, the regional condition scores from 2008 based on the revised metrics are presented in Figure 5. The rationale for, and calculation of, the four metrics used to generate the regional condition scores are outlined below.

Combined cover of hard corals and soft corals

For coral communities, the underlying assumption for resilience is that recruitment and subsequent growth of colonies is sufficient to compensate for losses resulting from the combination of acute disturbances and chronic environmental limitations. High abundance, expressed as proportional cover of the substratum, can be interpreted as an indication of resilience as the corals are clearly adapted to the ambient environmental conditions. Also, high cover equates to a large broodstock, a necessary link to recruitment and an indication of the potential for recovery of communities in the local area. The selection of critical values ("decision rules" in Table 4) for cover from which to derive community condition scores (Table 4) were largely subjective, however, approximate the lower, central and upper thirds of cover data observed in 2005 for the monitored communities. Setting reference points at these baseline levels will reveal relative changes in cover through time, and allows comparisons of this indicator at the regional level.

Rate of increase in cover of hard corals

While high coral cover can justifiably be considered a positive indicator of community condition, the reverse is not necessarily true of low cover. Low cover may occur following acute disturbance and, hence, may not be a direct reflection of the community's resilience to underlying environmental conditions. For this reason, in addition to considering the actual level of coral cover (as per above) we also assess the rate at which coral cover increases as a direct measure of recovery potential. The assessment of rates of cover increase is possible as rates of change in coral cover on inshore reefs have been modelled (Thompson and Dolman 2010); allowing estimations of expected increases in cover for communities of varying composition to be compared against observed changes. In brief, the model used observations of annual change in benthic cover derived from 47 near-shore reefs sampled over the period 1987-2007 to parameterise a multi-species form of the Gompertz growth equation (Dennis and Taper 1994; Ives *et al.* 2003). The model returned estimates of growth rates for three coral groups; soft corals, hard corals of the family Acroporidae and hard corals of all other families. Importantly, growth rate estimates for each coral group are dependent on the cover of all coral groups and also the cover of macroalgae which in combination represent potential space competitors. It should be noted that the model projections of future coral cover on GBR inshore reefs indicate a long-term decline (Thompson and Dolman 2010) if disturbances, especially bleaching events, would occur with the same frequency and severity as in the recent past. For this reason, only increases in cover that exceeded the upper confidence level of those predicted by the model were considered positive, while observations falling within the upper and lower confidence intervals of the change in cover predicted by the model were scored as neutral and those not meeting the lower confidence interval of the predicted change were scored as negative (Table 4). Initially the rate of change was averaged over the years 2005-2009 as a baseline estimate for this metric (Thompson *et al*. 2010b, Anon. 2011), subsequently, the period over which the rate of change was averaged was reduced to three years of observations including in the most recent.

Cover of macroalgae

Macroalgal recruitment, growth and biomass are controlled by a number of environmental factors such as the availability of suitable substratum, sufficient nutrients and light, and rates of herbivory (Schaffelke *et al.* 2005). Abundant fleshy macroalgae on coral reefs are considered to be a consequence and, mostly, not a cause of coral mortality (McCook *et al.* 2001, Szmant 2002). However, high macroalgal abundance may suppress reef resilience (e.g., Hughes *et al.* 2007, Foster *et al.* 2008, Cheal *et al.* 2010; but see Bruno *et al.* 2009) by increased competition for space or changing the microenvironment for corals to settle and grow in (e.g. McCook *et al.* 2001, Hauri *et al.* 2010). On the GBR, high macroalgal cover correlates with high concentrations of chlorophyll, a proxy for nutrient availability (De'ath and Fabricius 2010). Once established, macroalgae pre-empt or compete with corals for space that might otherwise be available for coral growth or recruitment (e.g. Box and Mumby 2007, Hughes *et al.* 2007). However, as the interactions between corals and algae are complex, likely species-specific and, mostly, un-quantified (McCook *et al.* 2001), it is difficult to determine realistic thresholds of macroalgal cover from which to infer impacts to the resilience of coral communities. Similar to the assessment of coral cover, we have decided on subjective thresholds based on the distribution of observed macroalgal cover data (Table 4). These thresholds clearly identify, and score positively, reefs at which cover of large fleshy algae is low and unlikely to be influencing coral resilience. Conversely, the distinction between moderate and high levels of macroalgal cover score negatively those reefs at which cover of macroalgae is high or has rapidly increased and where there is a high likelihood of increased coral-algal competition. For the purpose of this metric macroalgae are considered as those species of the families, Rhodophyta, Phaeophyta and Chlorophyta excluding crustose coralline algae and species with a short “hair-like” filamentous growth form, collectively considered as turfs.

Density of juvenile hard corals

Recruitment is an important process for the resilience of coral communities. The abundance of juvenile corals provides an indication of the scope for recovery of populations following disturbance or of those exposed to chronic environmental pressures. Juvenile colonies have been shown to be disproportionately susceptible to the effects of poor water quality (Fabricius 2005), which makes them an important indicator to monitor. However, as the quantification of the density of juvenile corals is a relatively new addition to monitoring studies on the GBR there is little quantitative information about adequate densities of juveniles to ensure the resilience of coral communities. At present, we can only assess juvenile densities in relative terms among reefs or over time. The number of juvenile colonies observed along fixed area transects may also be biased due to the different proportions of substratum available for coral recruitment. For example, live coral cover effectively reduces the space available for settlement, as do sandy or silty substrata onto which corals are unlikely to settle. To create a comparative estimate of juvenile colonies between reefs, the numbers of recruits per square metre were converted to standardised recruit densities per square metre of ‘available substratum’ by considering only the proportion of the substratum that was occupied by turf algae, and hence potentially available to coral recruitment. Based on current knowledge, there is no adequate description of what density of juveniles would represent a resilient coral community. In the interim, we have opted to set the densities observed over all reefs during the first five years of survey as a baseline against which future change can be assessed (Table 4).

Hard coral recruitment measures by settlement to tiles

The number of coral spat settling to terracotta tiles provides a further estimate of recruitment potential at a subset of the monitored reefs (Table 1). Low densities of juvenile corals may result as consequence of a lack of supply of competent larvae, low survivorship of new recruits or a combination of both. The monitoring of settlement to tiles is aimed at helping to identify the possible cause of trends observed in juvenile densities. This indicator was included in the Paddock to Reef Baseline Report Card (Anon. 2011), however due to high levels of unexplained variability between years, it has been removed from the report card metrics after the 2009 baseline assessment. We do, however, continue to monitor settlement and include scores in our assessment of those reefs at which tiles are deployed. As for juvenile density, the threshold values for numbers of coral spat per tile were based on the upper, lower and central thirds of all observations between 2005 and 2009 (Table 4).

Aggregating indicator scores to reef and regional-scale assessments

The assessment of coral communities based on the above indicators is made at spatial scales from the individual reefs through to regions by aggregating over scores for each indicator and reef combination. At the reef level, observations for each indicator were scored on a three point scale of negative, neutral or positive as per rules detailed above and summarised in Table 4. For reef level comparisons these scores were aggregated across the indicators with negative scores cancelling out positive scores and neutral scores ignored, so that reef scores can range from 4+ to 4-. For example, a reef at which coral cover was >50% (+), the rate of increase was within the predicted range (neutral), cover of macroalgae was <5% (+), and juvenile density <7 per m2 (-) the reef would be scored as a single +.

To aggregate indicator scores to sub-regional or regional level, the assessments for each indicator were converted to numeric scores whereby: positive = 1, neutral = 0.5, and negative = 0. The average of these numeric scores across reefs for each indicator and also across all indicators resulting in either indicator specific or across indicator average assessment scores that range between 0 and 1. Lastly the assessment scores were converted to a five point rating and colour scheme: Scores of

- 0 to 0.2 were rated as ‘very poor’ and coloured red
- >0.2 to 0.4 were rated as ‘poor’ and coloured orange
- >0.4 to 0.6 were rated as ‘moderate’ and coloured yellow
- >0.6 to 0.8 were rated as ‘good’, and coloured light green
- >0.8 were rated as ‘very good’ and coloured dark green.

Table 4: Threshold values for the assessment of coral reef condition and resilience. *Settlement of coral spat is not considered in regional assessments.

Community attribute	Assessment category	Decision rule
Combined hard and soft coral cover	+	> 50%
	neutral	between 25% and 50%
	-	< 25%
Rate of increase in hard coral cover (preceding 3 years)	+	above upper confidence interval of model-predicted change
	neutral	within confidence intervals of model-predicted change
	-	below lower confidence interval of model-predicted change
Macroalgae cover	+	< 5%; or <10% and declining from a high cover following disturbance
	neutral	stable between 5-15%, or declining and between 10-20%
	-	> 15% or increasing
Density of hard coral juveniles	+	> 10.5 juvenile colonies per m^2 of available substratum (2m depth), or > 13 juvenile colonies per m^2 of available substratum (5m depth)
	neutral	- between 7 and 10.5 juvenile colonies per m^2 of available substratum (2m depth), or - between 7 and 13 juvenile colonies per m^2 of available substratum (5m depth)
	-	< 7 juvenile colonies per m^2 of available substratum
Settlement of coral spat*	+	> 70 recruits per tile
	neutral	between 30 and 70 recruits per tile
	-	< 30 recruits per tile

Foraminifera

Foraminiferal assemblages were assessed separately from the coral community metrics and so assessment scores do not influence the overall assessments for the (sub-) regions. Assemblages at each reef were assessed relative to their deviation from baseline observations over the period 2005-2007 as the assemblage composition is expected to vary between reefs due to the underlying differences in the ambient environmental conditions. The baseline was calculated as the average of the FORAM index (sensu Hallock *et al.* 2003) calculated from observations in each year during the period 2005-2007 for each reef (Table A1-11). For each reef, subsequent observations scored positive if the FORAM index exceeded the baseline mean by more than one standard deviation of the mean, neutral if observed values were within one standard deviation of the mean, and negative if values were more than one standard deviation below the baseline mean. Other calculations and the application of the colour scheme were as described above for the assessment of coral reef communities.

3. Results and discussion

Results of the inshore coral reef monitoring of the MMP are presented in three main sections. Firstly, temporal profiles of key environmental (section 3.1) and community attributes (section 3.2) are presented at the scale of geographic regions, corresponding to the main NRM regions. This was done to highlight any major changes in the benthic communities and reef-level environmental parameters, and to provide a summary of the condition of communities within each region. Spatial differences among regions are also evident in the figures presented; however, for the most part, the discussion of results focuses on the comparison of trends within regions rather than on inter-regional differences. For a full analysis of the spatial differences in community attributes between regions and associations between these spatial patterns and environmental conditions, see (Schaffelke *et al.* 2008, Thompson *et al.* 2010a, Uthicke *et al.* 2010).

Section 3.3 provides detailed reef-level data within each region. For the Wet Tropics Region, data are presented for sub-regions corresponding to major catchments.

3.1 GBR-wide summary of changes in environmental variables

3.1.1 Sediment quality

This section provides an overview of sediment data collected from all coral monitoring sites (detailed data provided in Appendix Table A1-1 to A1-4). The grain size and nutrient content of sediments may influence coral community composition (Fabricius *et al.* 2005, Thompson *et al.* 2010a). The accumulation of fine grained sediments at a location is an indication of a low energy hydrodynamic setting that allows for the settlement of sediments rather than re-suspension and transport of fine sediments away from the site. Combined with measures of turbidity, this gives an indication of exposure to sedimentation. Sedimentation is detrimental to corals in a number of ways (reviewed by Fabricius 2005, Erftemeijer *et al.* 2012), e.g., impeding development and settlement of coral larvae (Babcock and Smith 2002, Baird *et al.* 2003, Fabricius *et al.* 2003, Birrell *et al.* 2005, Humphrey *et al.* 2008), smothering of juveniles (Harrison and Wallace 1990, Rogers 1990, Fabricius and Wolanski 2000), and incurring a metabolic cost as sediment is actively shed (Stafford-Smith and Ormond 1992). High nutrient content in sediments can compound the negative effects of sediment on corals by promoting microbial communities detrimental to coral health (Weber *et al.* 2012).

Overview of trends in sediment quality

Higher than median river flows in recent years (Table 5) delivered large quantities of fine sediments and nutrients into inshore waters of the GBR (Joo *et al.* 2012, Kroon *et al.* 2012). Concurrent with this increased delivery are regional increases in the proportion of clay and silt size particles (<63µm), nitrogen and organic carbon in reef sediments (Figure 2a-c). These increases, along with regional increases in turbidity (Figure 3), and seasonal peaks in the rate of sediment accumulation (Appendix Figure A3-1), highlight the link between increased discharge from rivers, turbidity in inshore waters, and changes in sediment composition on inshore reefs. This relationship between sediment supply and conditions at reef sites implies that sediment dynamics include an influence of runoff supplied material that is additive to any underlying process of supply and accumulation governed by the resuspension of long-term (millennia) accumulations of sediments. Because fine grained nutrient rich sediments have been demonstrated to be the most damaging to corals (as discussed above) these increases are likely to be contributing to the general declines in coral community condition in recent years (see section 3.2.1).

Table 5: Annual freshwater discharge for the major GBR Catchments. Values for each water year (October to September) represent the proportional discharge relative to long-term medians for each river (in ML). Median discharges were estimated from available long-term time series supplied by the Queensland Department of Environment and Resource Management and included data up until 2000: years with 40 or more daily flow estimates missing were excluded. Colours highlight those years for which flow was 1.5 to 2 times the median (yellow), 2 to 3 times the median (light orange), 3 to 4 times the median (dark orange), and more than four times the median (red). *** Indicates years for which >15% of daily flow estimates were not available, ** similarly indicate years for which >15% of daily flow was not available but these missing records are likely have been zero flow and so annual flow estimates valid, where as an * indicates that between 5% and 15% of daily observations were missing.

Region	River	Median discharge (ML)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Daintree	727,872	1.4*	0.1***	0.2	2.0	0.7	1.7	1.0	1.2	0.9	1.7	2.3	1.2
	Barron	604,729	1.4	0.3	0.2	1.6	0.6	1.2	0.7	2.7	1.3	0.8	3.2	1.3
	Mulgrave	751,149	1.0***	0.2	0.4	1.5	0.6***	1.2	1.0	1.3	1.0	1.0	2.0	1.4
	Russell	1,193,577	1.0	0.4	0.5	1.1	0.8	1.1	1.1	0.9	1.0	1.1	1.4	1.1
	North Johnstone	1,746,102	1.2	0.4	0.5	1.3	0.8	1.2	1.2	1.1	1.1	1.0	2.0	1.9
	South Johnstone	820,304	1.0*	0.4	0.4	0.5	0.7	1.2	1.1	1.0	1.2	0.9	1.9	1.1
	Tully	3,074,666	1.2	0.4	0.5	1.1	0.7	1.2	1.3	1.0	1.2	1.0	2.0	1.2
	Herbert	3,067,947	1.5	0.3	0.2	1.1	0.4	1.3	1.3	1.1	3.1	1.0	3.7	1.5
Burdekin	Burdekin	5,982,681	1.5	0.7	0.3	0.3	0.7	0.4	1.6	4.6	4..9	1.3	5.8	2.6
Mackay Whitsunday	Proserpine	17,140	0.8	1.2	1.1	0.6	1.4	1.2	2.6	4.5	3.8	3.1	20.2	3.0
	O'Connell	145,351	1.0	0.6	0.2*	0.2***	0.5	0.6	1.2	1.8	1.3	2.3	4.0	2.0
	Pioneer	355,228	2.1	0.6	0.3	0.1	0.6	0.2	2.0	3.7	2.3	3.3	9.3	3.8
Fitzroy	Fitzroy	2,827,222	1.1	0.2	0.9**	0.5**	0.3*	0.2	0.4	4.4	0.7	4.2	13.4	2.8

However, results from the Herbert Tully sub region and the Burdekin region are likely to be confounded by resuspension and redistribution of sediments occurring during the passage of Cyclone Yasi in early 2011.

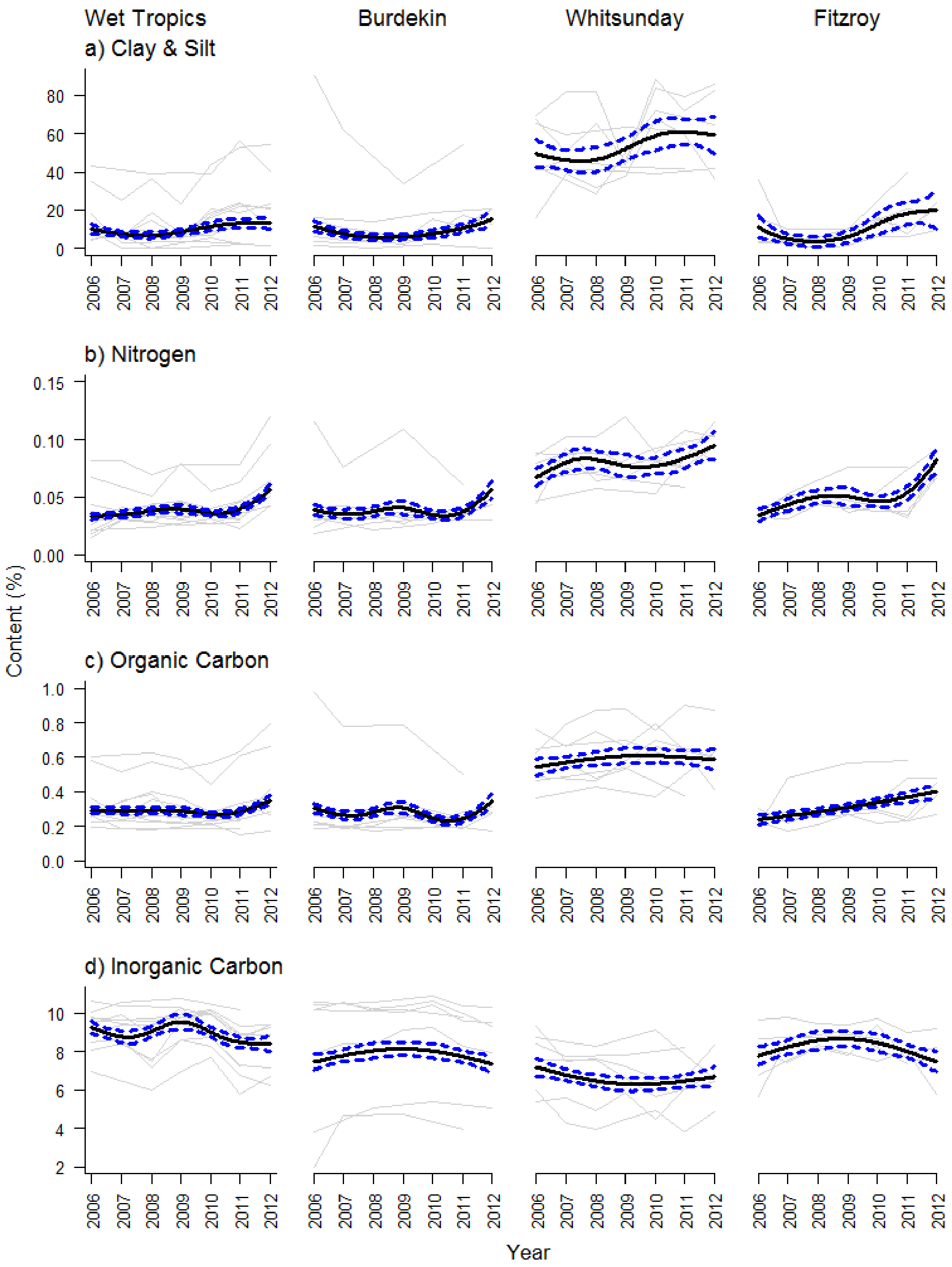


Figure 2: Regional trends in sediment composition. Proportion of sediment consisting of a) clay and silt-sized grains, b) nitrogen, c) organic carbon, and d) inorganic carbon for reefs within each region. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

Regional sediment quality

Reef sediments in the Mackay Whitsunday Region have the highest proportion of clay and silt-sized particles (<63µm), nitrogen and organic carbon and the lowest levels of inorganic carbon in this study (Figure 2). In addition, sediment trap data indicate very high rates of sedimentation (Appendix Table 3-1). These results suggest that the hydrodynamic setting of these reefs, in combination with regional sedimentary processes, expose corals to the chronic stresses associated with high rates of deposition of nutrient rich sediment. Although not quantified, we observe greater accumulation of sediments on coral colonies, substratum and also on coral settlement tiles in this compared to other regions; all of which imply negative effects on coral communities form settlement through to condition of adult colonies.

On average sediments from reefs in the Wet Tropics Region have moderate proportions of clay and silt-sized particles and sediment nutrients. While individual reefs (Snapper Is North, Frankland Group West, High Is West) are exposed to hydrodynamic settings conducive to the accumulation of clay and silt-sized particles, changes at these reefs are buffered by the lack of these grain-sizes elsewhere. However, there has been a recent upward trend in nitrogen and organic carbon, and a downward trend for inorganic carbon implying increased exposure to runoff derived material.

The Burdekin and Fitzroy regions have a dry tropical climate and are the largest river catchments in the GBR Region. When these catchments receive flooding rains, the discharge dominates the river inputs into the coastal receiving waters (Table 5). The land use in both regions is predominately pasture for cattle grazing, though there are large areas of sugar cane on the lower flood plains (Brodie *et al.* 2003, Australian Natural Resource Atlas (electronic resource)). The sediments of reefs in both regions had broadly similar values of clay and silt, nitrogen, organic and inorganic carbon from 2006 to 2012 (Figure 2). The relatively low proportion of clay and silt-sized particles in sediment samples reflect the relatively exposed aspects of many of the survey locations, with incident waves frequently re-suspending and transporting fine particles away from the reefs (Wolanski *et al.* 2005). Despite local hydrodynamics that tend to limit the accumulation of fine particles, the proportion of clay and silt-sized particles show increases in recent years (Figure 2a).
For the Burdekin, the upward trend in clay and silt-sized particles was mirrored by a slight downturn in the inorganic content of the sediments (Figure 2d). The levels of nitrogen and organic carbon show a recent increasing trend, reflecting the increase in fine particles to which nutrients tend to adsorb (Furnas 2003). As the most inshore of the core reefs, Geoffrey Bay steadily accumulated fine sediments through the 2012 summer (Appendix 3-1). However, Pelorus Is West captured more sand-sized particles in the same season, most likely the result of a localised storm that re-suspended a large amount of material left by Cyclone Yasi the previous year.

Flood plumes in Keppel Bay are usually confined to the inshore by prevailing SE winds, with fine sediment eventually transported out of the bay; a process that may take several years (Webster and Ford 2010) and result in prolonged elevation of turbidity and sedimentation. However, the extreme flood of the Fitzroy River in 2011 (Table 5) also transported fine sediments out to Barren Is, where clay and silt content quadrupled from normally very low levels to 18% and has remained elevated into 2012 (Appendix Table A1-1). For the entire region sediments show a distinct trend of increasing accumulation of clay and silt particles, nitrogen and organic carbon levels, with a corresponding decline in inorganic carbon content. These changes are especially evident at reefs with some protection from wave driven resuspension such as sites at Halfway Is and North Keppel Is (Appendix Table A1-1), or those reefs, like Peak Island, that are closest to the discharge of the Fitzroy River. Nutrients and the proportion of clay and silt-sized sediment are higher at these locations. At Pelican Is although levels of clay/silt are relatively low due to the exposure of the sites to wave driven resuspension, the location of this reef close to the coast and river mouth ensures high turbidity. Sediment traps deployed at this reef indicate a high rate of sedimentation (Appendix Figure 3-1). However, this is does not lead to the accumulation of clay and silt-sized fractions in sediment samples which indicates the rapid flux of sediments due to the combination of high turbidity and frequent resuspension.

3.1.2 Turbidity

Turbidity is influenced by the quality and composition of the sediment (see above) that is resuspended by physical factors such as wind, waves and tides as well as by increased imports of suspended solids into the coastal zone by rivers (Fabricius *et al.* 2013a). Turbidity is a fundamental physical environmental variable in coastal marine environments as it directly reduces irradiance available to benthic organisms (Davies-Colley and Smith 2001). In addition, suspended particles carry nutrients and organic carbon, e.g. influencing food availability for suspension feeders or smothering benthic biota such as corals (Weber *et al.* 2006), as well as bacteria and other pathogens, pesticides, trace metals and other contaminants (Smith and Schindler 2009). The MMP inshore water quality monitoring component has measured turbidity since late 2007 using logging instruments at 14 sites, co-located with the core reef survey sites (Schaffelke *et al.* 2012).

All four monitoring regions show clear trends of increasing water turbidity, with highest values in 2011 (Figure 3). This increase in turbidity corresponds to a period of high river flows culminating in the extreme flooding in of 2011 (Table 5) and with resuspension associated with cyclones Yasi and Anthony. Although 2012 again saw higher than median flows in all catchments, turbidity decreased slightly from the extreme values of 2011 (Figure 3). It should be noted that for the period of the turbidity monitoring rivers in the Burdekin, Mackay Whitsunday and Fitzroy Regions have had above median flows. The slight declines observed in 2012 may be evidence of a reduction in availability of fine sediments due to catchment exhaustion following extreme flows in 2011 or high vegetation cover resulting from high rainfall. Also, the presented data have not been corrected for differences in physical forcing such as wind conditions tidal amplitude, which may add variability between years. In the context of this report, we are interested in the actual turbidity experienced by coral reef communities as the environmental driver of a potential ecological response.

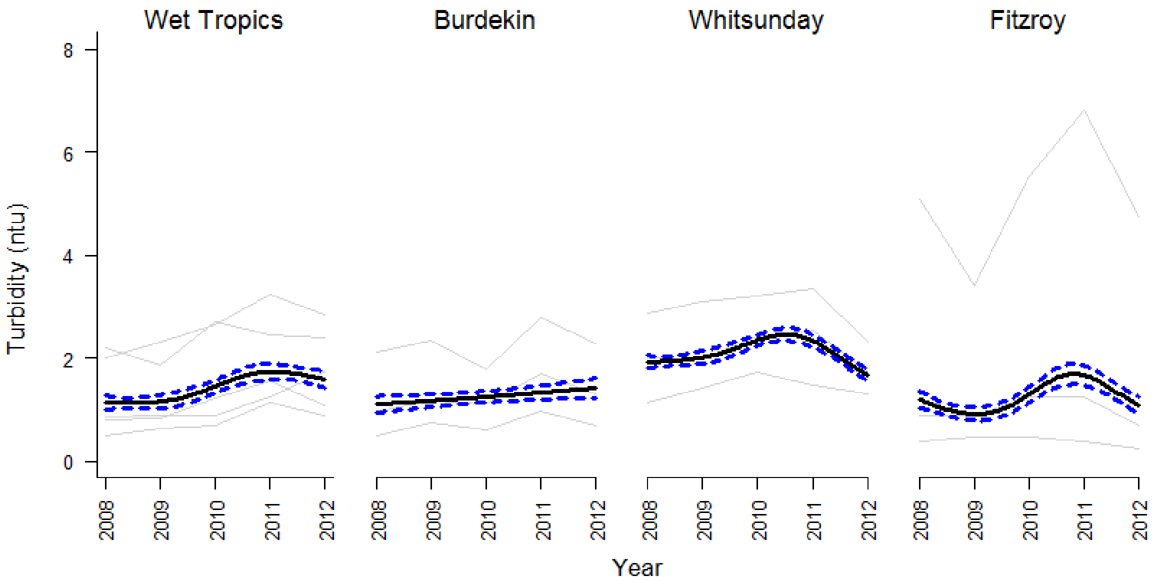


Figure 3: Regional trends in turbidity. Turbidity measured by FLNTU loggers on the core reefs within each region. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

Reefs in the Whitsunday Region are exposed to higher turbidity than those in other regions (Figure 3). However, in all regions turbidity varies markedly between reefs with reefs closer to river mouths and the coast having generally higher and more variable turbidity compared with those further offshore (Figure 3; Schaffelke *et al*. 2012). Highest turbidity values were generally found at Snapper and Dunk Is (Wet Tropics), Magnetic Is (Burdekin), Pine Is (Mackay Whitsunday) and Pelican Is (Fitzroy); the latter sites had the highest average and maximum turbidity of all 14 monitoring sites (reef level turbidity distributions can be found in section 3.3).

3.1.3 Sea temperature monitoring

Sea temperature data are reported for the period of July 2005 to June 2012 (Figure 4). Data for each region are represented as the deviation from long-term (9 years from July 1999 to June 2008) weekly averages. Prolonged exposures to high temperatures, atypical for a given season, have been shown to cause stress to corals that may increase susceptibility to disease (e.g. Bruno *et al.* 2007, Ward *et al*. 2007), cause coral bleaching, and in severe cases, mortality (e.g. Berkelmans 2002).

Seasonal average temperatures were exceeded for prolonged periods in the summer of 2005/06 in the Burdekin, Mackay Whitsunday and Fitzroy Regions (Figure 4). In the Fitzroy Region these high summer temperatures resulted in widespread bleaching (Diaz-Pulido *et al.* 2009) and subsequent loss of coral on most of the reefs included in this study (Figure 6, Appendix Table A1-5). Higher than median summer temperatures may also have contributed to slight declines in coral cover observed over this period on reefs in the Burdekin and Mackay Whitsunday Regions (Figure 6).

Since April 2006 deviations from median temperatures have been relatively minor and/or short lived and have not caused observable mortality of corals in any regions. A period of higher than median temperature was observed between March and July in 2011; however, as this coincided with typically cooler winter temperatures no heat stress was likely. The winter of 2012 was, however, unusually cool with bleaching observed amongst stands of branching *Acropora* at Daydream Is in the Mackay Whitsunday Region during September of that year.

Bleaching was also observed in the Fitzroy Region in winter of 2011 though we consider this to have been in response exposure to a combination of low salinity and high turbidity associated with extreme flooding of the Fitzroy River (Devlin *et al*. 2011, Berkelmans *et al*. 2012).

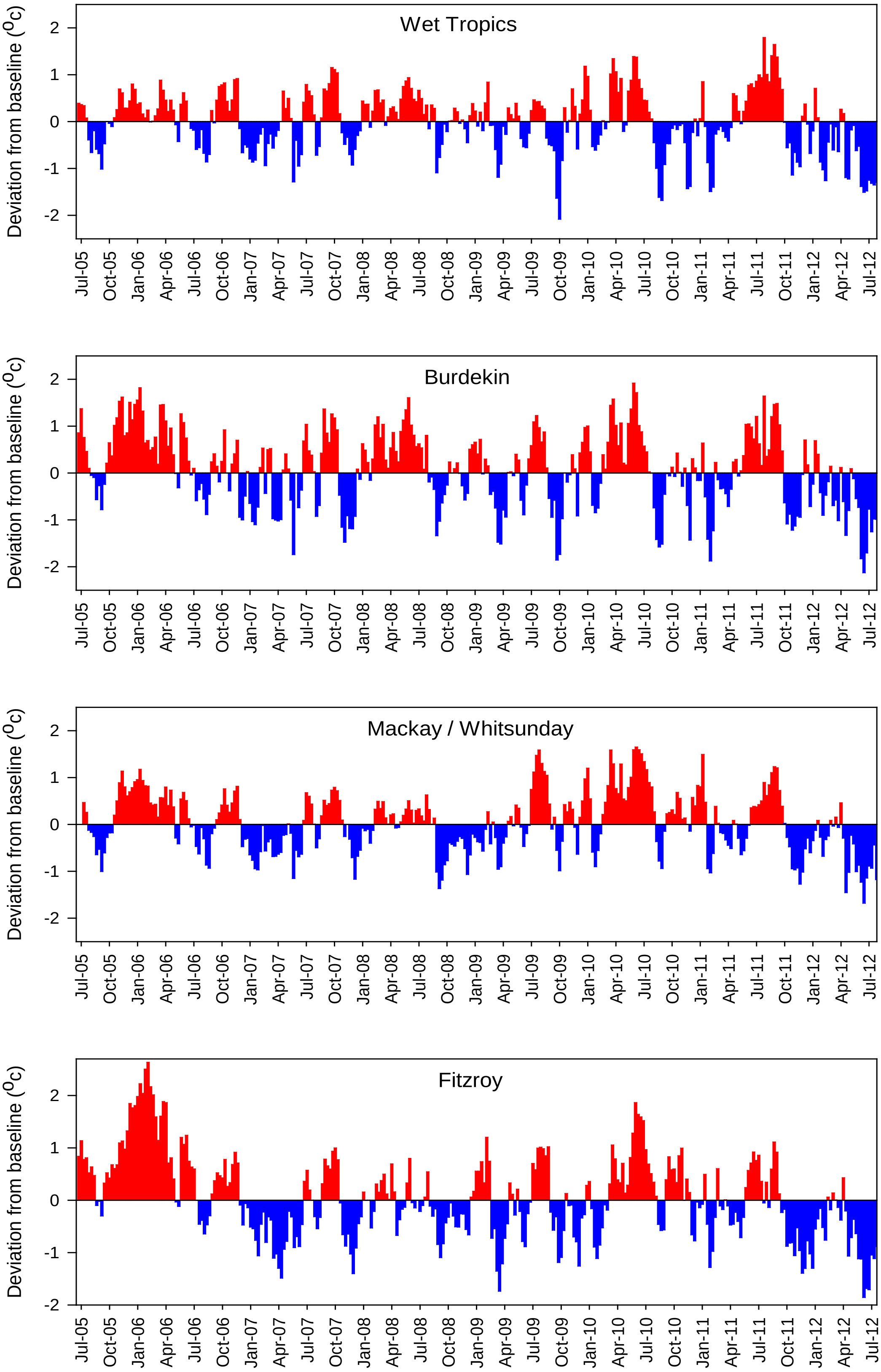


Figure 4: Sea temperature anomalies. Data presented are weekly deviations from regional long-term records (July 1999 to June 2008).

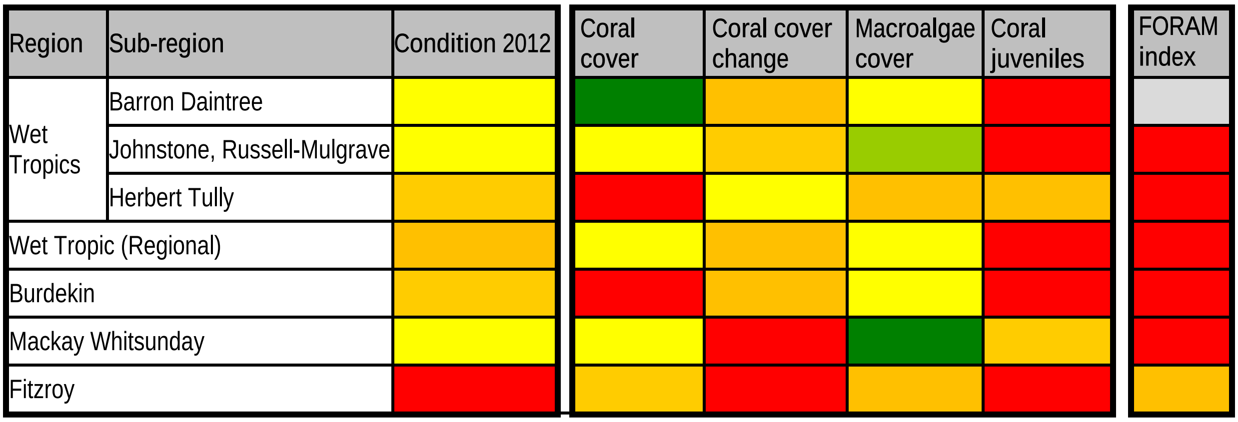
3.2 GBR-wide summary of coral reef benthic communities

3.2.1 Report card of inshore reef condition assessments

The assessment of coral reef community condition was based on a combination of their current condition (cover of corals and macroalgae) and their potential to recover from disturbance (rate of coral cover increase and density of juvenile corals). The underlying assumption is that a 'healthy' community should show clear signs of recovery after inevitable acute disturbances, such as cyclones and coral bleaching events, or, in the absence of disturbance, maintain a high cover of corals and successful larval recruitment and survival of juveniles.

The assessment of condition was first undertaken for observations between 2005 and 2009 and presented in Thompson *et al.* (2010b) and in Anon. (2011) as part of the Paddock to Reef reporting. The subsequent assessment (Thompson *et al.* 2011, Table 6) updated the first assessment but also revised the calculation of condition scores as discussed in section 2.6.1. Here we present the assessment of coral communities based on the revised methodology for observations from 2011 (Table 6). Additionally, to allow for comparisons of conditions across years, we presented assessment scores for all assessments recalculated using the revised metrics (Figure 5).

Table 6: Regional and sub-regional estimates of coral community condition. The overall Condition for 2012 aggregates assessments of four metrics, coral cover, coral cover change, macroalgal cover and juvenile hard coral density. The regional estimates of these metrics are, in turn, derived from the aggregation of assessments from the reefs within each region (see Section 3.2). The FORAM index assessments are included as a separate metric but are not included in the overall "Condition" assessment for each region. Grey cells indicate no evaluation of the metric in that location. The colour scheme is consistent with reporting to the Paddock to Reef Program with colours reflecting the relative condition of reef communities: red= very poor, orange= poor, yellow= moderate, light green= good, dark green= very good.



Region	Sub-region	Condition 2012	Coral cover	Coral cover change	Macroalgae cover	Coral juveniles	FORAM index
Wet Tropics	Barron Daintree	🟨	🟩	🟧	🟨	🟥	⬜
	Johnstone, Russell-Mulgrave	🟨	🟨	🟧	🟢	🟥	🟥
	Herbert Tully	🟧	🟥	🟨	🟧	🟧	🟥
Wet Tropic (Regional)		🟧	🟨	🟧	🟨	🟥	🟥
Burdekin		🟧	🟥	🟧	🟨	🟥	🟥
Mackay Whitsunday		🟨	🟨	🟥	🟩	🟧	🟥
Fitzroy		🟥	🟧	🟥	🟧	🟥	🟧

The current (2012) regional estimates of inshore reef condition are as follows:

- The overall condition of reefs in the Wet Tropics declined from 'moderate' in 2011 to 'poor' in 2012. The primary reasons for this downgrade in condition assessment were the return of macroalgae that was temporarily removed from reefs in the Herbert Tully sub-region following Cyclone Yasi, and a decline in the density of juvenile corals in the Barron-Daintree sub-region. These declines compound; recent reductions in cover caused predominantly by Cyclone Yasi, a period of low rates of cover increase coinciding with elevated incidence of coral disease, high numbers of crown-of-thorns starfish at Snapper Is and Fitzroy Is in 2012, and the continuation of region wide declines in the density of juvenile corals. The combination of low density of juvenile corals and projected loss of coral cover as a result of crown-of-thorns feeding suggest short term recovery of condition is unlikely in this region.

- The condition of coral reef communities in the Burdekin Region has continued to decline since 2009 (Figure 5). The current ‘poor’ condition has been influenced by low coral cover as a result of disturbances, particularly Cyclone Yasi, and slow rates of cover increase during disturbance free periods. Cover of macroalgae has been persistently high on several reefs and may have contributed to poor rates of coral cover increase on those reefs. Of concern for the immediate future were the low densities of juvenile corals on most reefs in 2012 as a deficit of juveniles will further suppress the rate at which coral communities can recover in the near future. Regionally the settlement of coral larvae has been low implying reduced larval supply, a point consistent with the low cover of corals.
- Coral reef communities in the Mackay Whitsunday Region maintained a ’moderate‘ condition estimate in 2012, though the underlying total assessment score has declined annually for the past three years (Figure 5). The positive indicators of condition of low cover of macroalgae and moderate cover of corals were balanced against low densities of juvenile colonies and slow rates of increase in hard coral cover. Sediments at the reefs in this region have high proportions of fine grained particles and water turbidity is high: such environmental conditions are known to be stressful to some corals. The incidence of coral disease in this region corresponds to increases in river flows that in turn correspond to increases in turbidity and sedimentation, indicating a possible link between elevated runoff declines in coral community condition.
- Coral reef communities in the Fitzroy Region declined to a ‘very poor’ estimate of condition in 2012. Exposure to low salinity flood waters in 2011 caused a marked reduction in coral cover and juvenile densities down to at least 2m depth on reefs inshore of Great Keppel Is. Elsewhere cover also declined with high levels of disease observed during surveys in 2011. This on-going disease likely explains further loss of cover observed in 2012. The loss of coral cover resulted in a downgrading of this indicator from ‘moderate’ in to 2010 to ‘very poor’ in 2012. The density of juvenile corals has been consistently low in this region and so recent declines along with very low settlement of larvae in 2012 are of concern. With the exception of Barren Island, the reef least exposed to runoff, coral cover has not increased strongly during years free from the multiple disturbances of floods storms and thermal bleaching. This low rate of increase in coral cover reflects the on-going disease following floods in 2008, 2010 and 2011, which can be a considered a medium term stress in addition to acute impacts of runoff on coral communities. Finally, the floods in 2011 temporarily reduced the cover of macroalgae on some reefs resulting in an improvement in the score for this metric. By 2012 the cover of macroalgae had returned resulting in again a “poor” condition categorisation.
- FORAM index-based assessments of the reef conditions observed in 2012 were similar to those in last year’s assessment. However, several reefs which did not have a 'very poor' score 2011 are now in that category. With the exception of the Fitzroy Region, all regions and sub-regions are now scored as 'very poor'. As was the case for benthic communities, we interpret this decline as being caused by increased sediment and nutrient inputs to the inshore areas facilitated by strong wet seasons in recent years. In general, the community condition as indicated by the FORAM index results in a more negative assessment of the condition of the regions than indicated from the coral community assessments. Whether this reflects higher sensitivity of the foraminiferal indicators to changes in environmental conditions needs to be further evaluated. The FORAM index provides an independent diagnostic aid to the interpretation of changes occurring in the coral communities and clearly suggests a general change in environmental conditions between 2007 and 2012 that favours heterotrophic species; i.e. too high inorganic nutrient load for symbiont bearing species and higher food availability for heterotrophic species.

Figure 5: Regional report card score trends. For Paddock to Reef reporting scores are categorized in to a five point scale (see section 2.6.1) here the underling scores are presented allowing a more sensitive depiction of coral reef community condition through time. Yellow symbols represent communities that were assessed to be in moderate condition, while orange symbols represent communities assessed as being in poor condition.

3.2.2 Cover of hard corals

A combination of impacts associated with tropical cyclones Yasi and, to a lesser degree, Tasha, and the acute and chronic effects of flooding, have resulted in declines in coral cover in all regions of the period 2005-2012 (Figure 6).

The most dramatic change in hard coral cover in the period 2005 to 2012 has occurred in the Fitzroy region. These declines are due primarily to coral bleaching caused by high temperatures in early 2006 and then record breaking flooding of the Fitzroy River in 2011. The bleaching event in 2006 caused substantial declines in cover particularly among the branching *Acropora* species common to reefs in this region. Recovery from this event was variable among reefs and while rapid at some locations (Diaz-Pulido *et al.* 2009) recovery was suppressed at others by a combination of exposure to minor storm events and on-going incidence of coral disease. Flooding of the Fitzroy River in 2011 caused an overall reduction in coral cover similar to that caused by thermal bleaching in 2006. High levels of mortality occurred at sites at 2m depths on all reefs inshore of Great Keppel Island, consistent with exposure to low salinity waters in the Fitzroy flood plume. At these reefs cover also declined at deeper sites though salinity profiles suggest this was not due to direct exposure to reduced salinity (Devlin *et al.* 2011). High levels of coral disease following flood events are emerging as a chronic effect of flooding both here and in other regions (Thompson *et al.* 2012). The most likely mechanisms are that corals are chronically stressed by the prolonged high levels of turbidity and sedimentation in the inshore GBR lagoon, although other pathways including alteration of microbial communities leading to increased levels of disease, as a consequence of flood plume exposure, cannot be discounted (Haapkyla *et al*. 2011).

In the Wet Tropics Region there have also been two distinct disturbances that have been responsible for the majority of declines in the cover of hard corals. Cyclone Larry in 2006 caused dramatic loss of cover on reefs in the Herbert Tully sub-region where approximately 60% of hard coral cover was lost (section 3.2.3) and also the Eastern reefs of the Frankland Group in the Johnstone Russell-Mulgrave sub-region (section 3.2.2). Following this disturbance, coral cover showed signs of recovery until Cyclone Yasi caused a further loss of corals in the Herbert Tully sub-region and, in combination with Cyclone Tasha, on the eastern reefs in the Johnstone Russell-Mulgrave sub-region. In addition to the influence of cyclones Yasi and Tasha, high levels of disease observed in 2010 at Snapper Is North and Fitzroy Is appear to have resulted in continued declines in coral cover through to 2011. An emerging issue for reefs in the Daintree and Johnstone Russell-Mulgrave sub-regions are the high densities of crown-of-thorns starfish observed on some reefs in 2012. High densities of these coralivorous starfish have the potential to rapidly reduce coral cover.

In the Mackay Whitsunday Region the cover of hard corals remained stable for the period 2005-2009. During this period there were no acute disturbances in the region and the lack of increase in coral cover is of potential concern. In 2010 Cyclone Ului passed through the Whitsunday Islands. This event was the primary cause of the observed decline in hard coral cover in 2010 in that region (Figure 6). The cyclone passed almost directly over the monitoring sites at Daydream Island, and resulted in reductions in cover (see Figure 35) where dense stands of *Acropora* collapsed. Most other reefs visited in the region also had declining cover, although the magnitude of the disturbance was less severe and varied considerably among locations. In 2011, coral cover continued to decline or stayed unchanged at most reefs, the clear exception was at 2m depth at Double Cone Is where cover increased due to the survival and growth of coral fragments produced during Cyclone Ului. By 2012 cover showed some recovery from recent pressures increasing slightly at some reefs. We interpret the tendency for low rates of cover increase to be a consequence of environmental stress resulting from increased supply of sediments and any absorbed contaminants due to a prolonged period of higher than median flows in this and adjacent regions (Table 5).

Regionally, cover has been consistently low in the Burdekin Region since surveys began in 2005 (Figure 6). From past monitoring studies (Sweatman *et al.* 2007, Done *et al.* 2007) it is clear that reefs in this region have had minimal recovery since being severely impacted by bleaching in 1998. Although disturbances have been relatively minor, the rate of cover increase has been slow and regional cover has remained consistently low. The recent decline observed in Figure 6 is due mostly to a loss of cover caused by Cyclone Yasi at some reefs: most notably at Orpheus Is East (see section 3.2.4) There were also slight declines considered to have occurred during sub-cyclonic storms in 2009 (Pandora Reef, and Lady Elliot Reef) and 2010 (Pelorus Is & Orpheus Is West). Flooding of the Burdekin River and local streams in 2008, 2009 and 2011 (Table 5) have likely also contributed to slight declines or at least limited recovery of 2m sites at Middle Reef and Geoffrey Bay. There was little recovery of coral cover between surveys in 2011 and 2012.

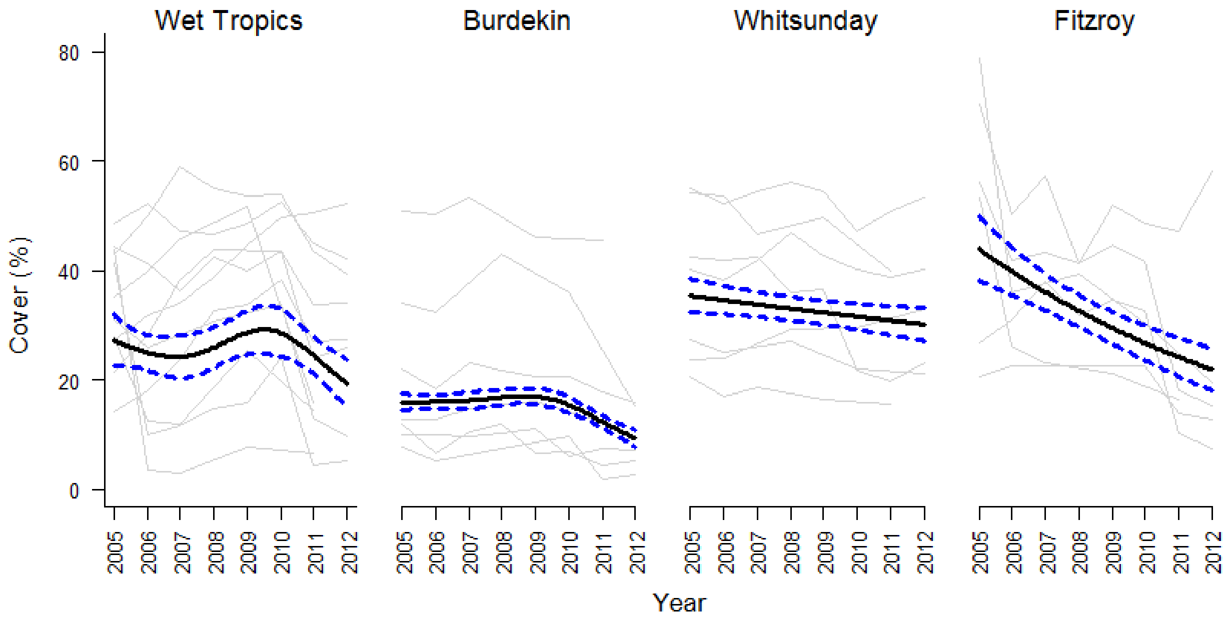


Figure 6: Regional trends in hard coral cover. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.3 Cover of soft corals

The average cover of soft corals was generally stable over the period 2005-2010 with cover typically low on most surveyed reefs (Figure 7). In 2011, declines were evident at some Wet Tropics and Burdekin regions reefs caused by physical removal of colonies during Cyclone Yasi. In the Fitzroy Region record flooding of the Fitzroy River killed almost all soft corals at or above 2m depth on reefs inshore of Great Keppel Is and also caused declines at deeper depths. Previous disturbances to soft coral communities include: a sharp decline on one reef (Barren Island) in the Fitzroy Region in 2008 and again in 2010 as the result of two separate storms (section 3.2.6) and similar reductions in 2006 at reefs in the Wet Tropics and Burdekin Regions exposed to Cyclone Larry (sections 3.2.2-4). Between 2011 and 2012 the cover of soft corals remained largely unchanged at all reefs.

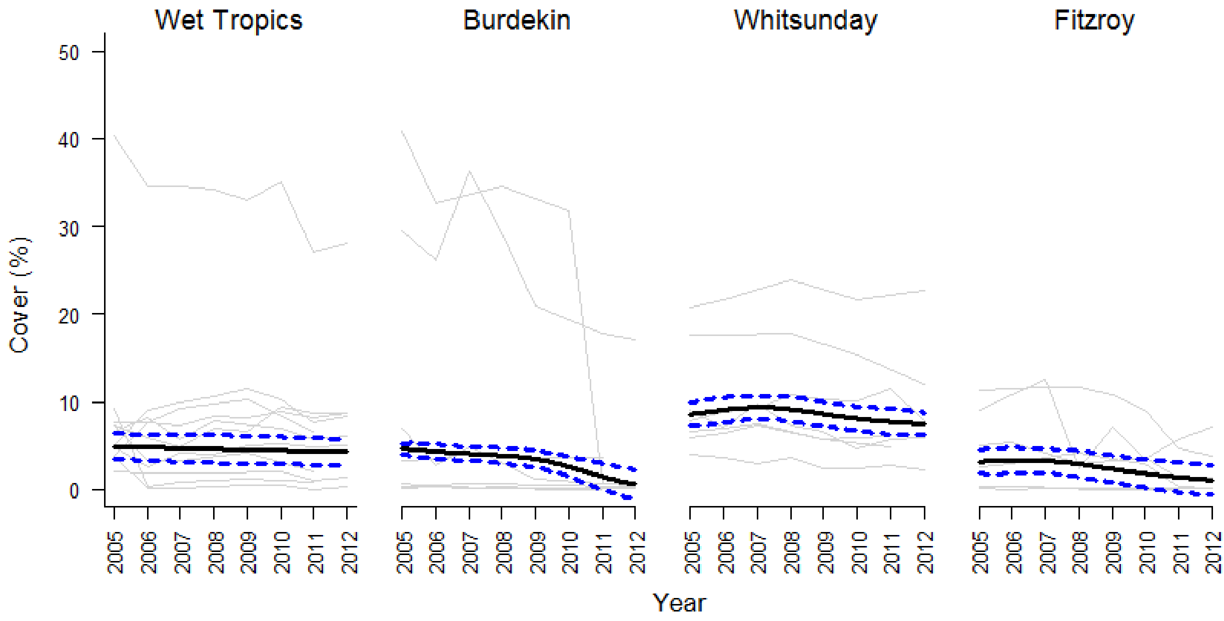


Figure 7: Regional trends in soft coral cover. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.4 Cover of macroalgae

The cover of macroalgae can be highly variable through time compared to that of corals, due to the short life spans of individual thalli, seasonally changing biomass and the potential for high growth rates. Inter-annual variations in cover at individual reefs can be seen in the light grey lines of Figure 8. In addition, macroalgae are consistently absent or in very low abundance at some reefs, which can make it difficult to detect consistent regional level trends, as rapid changes in cover on some reefs are weighed against consistently low, and so invariant, abundance at others. Despite these problems the following trends in the cover of macroalgae are evident.

In the Wet Tropics Region, Cyclone Larry temporarily removed algae from some reefs in the Herbert Tully sub-region resulting in a slight regional reduction in cover. In the period 2007 to 2009/10 cover tended to increase as algae re-established and occupied space made available as a result of reduced coral cover post Cyclone Larry. In addition, red algae tended to increase amongst fine branching and sub-massive corals on some reefs in the Johnstone Russell-Mulgrave and Daintree sub-regions. In 2011 Cyclone Yasi caused a short term reduction in cover on reefs in the southern part of this region with cover re-establishing or exceeding pre cyclone levels in 2012.

In 2012, the cover of macroalgae in the Burdekin Region increased from the low levels observed in 2011. Of the reefs at which moderate to high cover of macroalgae have been observed, brown algae have been the main component of the community at Geoffrey Bay, Pandora Reef and Havannah Is. Cover at these reefs was high though variable over the period 2005-2008 and then declined. Declines in cover at Pandora reefs are considered to have resulted from the physical removal of algae due to a storm event in 2009 and the Cyclone Yasi in 2011. At Havannah Is the cover has followed a similar pattern as Pandora with low estimates of cover in 2009 compared with previous years and then very low cover in 2011. In contrast to Pandora, however, physical damage to the coral communities at Havannah Is was not obvious and so the reduction in cover of macroalgae here may represent a successional trend away from high macroalgal cover at this reef. At Lady Elliot Reef, cover of macroalgae has been consistently high; the macroalgal community here is a mixture of brown (*Dictyota* sp.) and red (*Hypnea* sp.) that form a thick blanket over a rubble substratum at 2m.

On the Mackay Whitsunday Region reefs macroalgae are only common at two of the reefs surveyed. At neither of these reefs have there been substantial changes in cover.

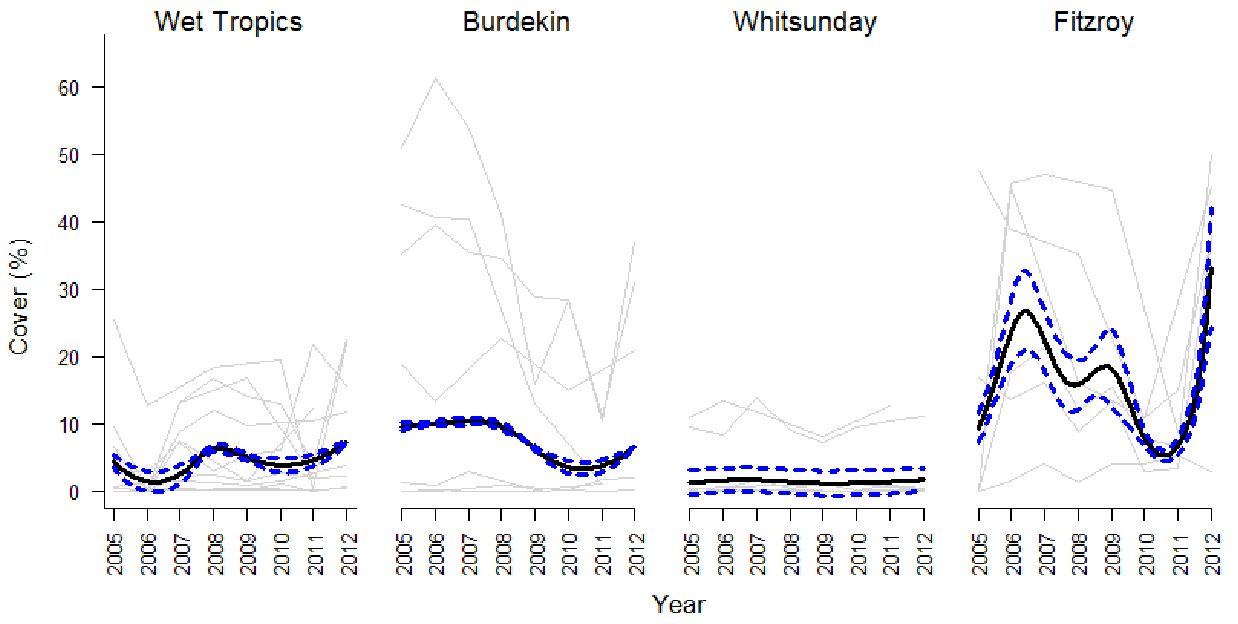


Figure 8: Regional trends in macroalgae cover. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

In the Fitzroy Region, communities of macroalgae differ between the mixed assemblages found at Peak Is and Pelican Is and those dominated by the brown alga *Lobophora variegata* on the reefs further offshore. The regional-level increase between 2005 and 2007 was due to the rapid colonisation by *L. variegata* of coral skeletons after coral bleaching mortality in early 2006 (Diaz-Pulido *et al.* 2009). Subsequent declines in macroalgal cover reflect both a decrease in cover of *L. variegata* on offshore reefs along with a slight decrease in the cover of the mixed communities at Peak Is and Pelican Is. Interestingly, decreases in cover of macroalgae in both 2008 and 2010 were observed coinciding with major floods of the Fitzroy River. However, minor storm disturbances also occurred in these years making it unclear as to which of these disturbances exerted the greatest influence on macroalgal cover. In 2011, cover again declined on most reefs, and again this decline followed major flooding of the Fitzroy River. In 2012 cover increased dramatically on some reefs as macro algae rebounded from temporary disturbance and additionally colonised space made available by the loss of corals.

3.2.5 Density of juvenile hard coral colonies

The density of juvenile hard coral colonies has declined over the period 2005 to 2012 in all regions except for the Fitzroy Region where densities have remained low but stable (Figure 9). Comparing mean densities of juvenile colonies on reefs sampled in 2005 and 2012 shows that the largest decline has occurred in the Wet Tropics Region. There appear to be two causes of the decrease in densities of juvenile colonies in the Wet Tropic Region. Firstly, a number of reefs were impacted by Cyclone Yasi. At these reefs similar reductions occurred in 2006 as the result of Cyclone Larry, however, over the period 2007-1010 juvenile densities increased again as corals recruited onto the exposed substratum to begin the process of recovery. Future monitoring results will show if the recovery after Cyclone Yasi will follow a similar trajectory. It should be noted, however, that a high proportion of the corals recruiting onto the reefs disturbed by both Cyclone Larry and Cyclone Yasi were of the genus *Turbinaria*, a genus not common in the community prior to disturbance. Secondly, and more worrying, is a general decline in juvenile numbers on most reefs that were not impacted by either Cyclone Larry or Cyclone Yasi.

In the Burdekin Region, juvenile densities have declined marginally over the 2005-2012 period, though juvenile densities at individual reefs have been variable. Declines on most reefs in 2011were attributed to the impact of Cyclone Yasi. In 2012 the density of juveniles had increased most notably at Lady Elliot Reef where for the first time high numbers of juveniles of the Genus *Acropora* were observed.

In the Mackay Whitsunday Region, the density of juvenile hard corals remains low after steadily declining from 2005 until 2010. The only acute disturbance that affected the reefs in this region was Cyclone Ului in 2010; however, with the exception of a slight decrease in juvenile density at Daydream Is, the majority of declines do not coincide with this event and remain unexplained other than that they coincide with a period of increasing mean turbidity.

The mean juvenile density in the Fitzroy Region has been stable over the past seven years. This however, masks clear reductions in the density of juvenile colonies at Pelican and Peak Islands in 2011, caused by exposure to flood waters, and concurrent increases in densities at Barren Is and North Keppel Is.

The numbers of juvenile colonies recorded by this study are the result of settlement and survival over the preceding two to four years. Several acute disturbances are likely to have caused lower density of juvenile colonies on those reefs directly exposed: Cyclone Larry in 2006, Cyclone Ului in 2010, Cyclone Yasi in 2011, a local thermal bleaching event in Keppel Bay in 2006, and exposure of shallow water communities to low salinity flood waters in Keppel Bay 2011. In addition to these acute events, declines in the density of juvenile colonies correspond with increasing levels of fine sediments and turbidity that are likely to be a consequence of four years of higher than median discharges from adjacent catchments (Table 5, Sections 3.1.1 and 3.1.2). These high flows were also correlated with increased levels of disease in adult corals (Appendix 3). Early life stages of corals are generally perceived as being more susceptible than adults to environmental degradation (as reviewed by Fabricius 2005), and it is entirely plausible that observed declines in juvenile densities are a direct response to increased runoff.

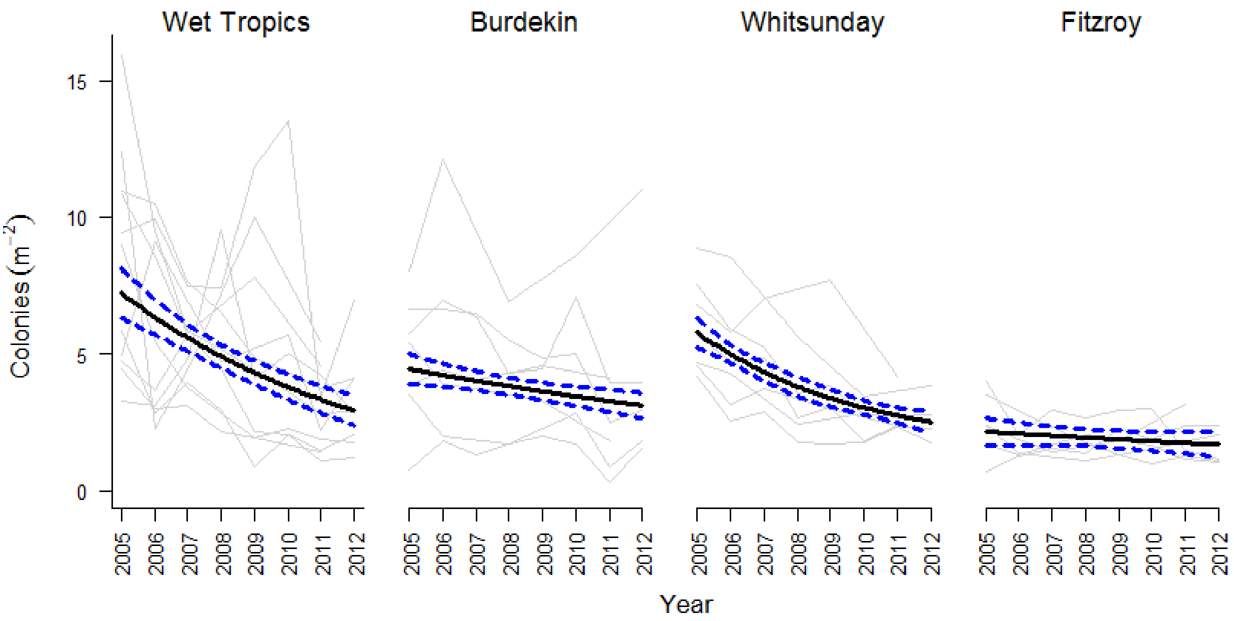


Figure 9: Regional trends in juvenile hard coral density. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.6 Richness of hard coral genera

A possible result of environmental degradation is the loss of diversity as susceptible taxa are not replaced after mortality events. Over the period 2005-2010 there was no evidence that this is occurring with stable or increasing richness in all regions (Figure 10). In 2011, richness declined in three regions, largely as a result of severe reductions in coral cover on reefs impacted by Cyclone Yasi (Wet Tropics and Burdekin regions) and flooding (Fitzroy Region). In such cases it is not unexpected that genera represented by just a few individuals would no longer be observed. In 2012 richness had increased slightly at many of those reefs disturbed in 2011 (grey lines in Figure 10).

A further point to note is that richness of coral genera, as reported here, is a relatively coarse measure of diversity as the number of species within genera varies widely. This is especially relevant when considering richness on turbid water reefs; a number of species found preferentially in turbid waters are from genera that include few or even single species, in contrast the genus *Acropora* which is more common on the slightly clearer water reefs includes 10's of species. The result is that genus richness may be higher in turbid waters but that this result can potentially mask the reverse pattern for species richness. The consistent differentiation of coral species from photo transects is not possible.

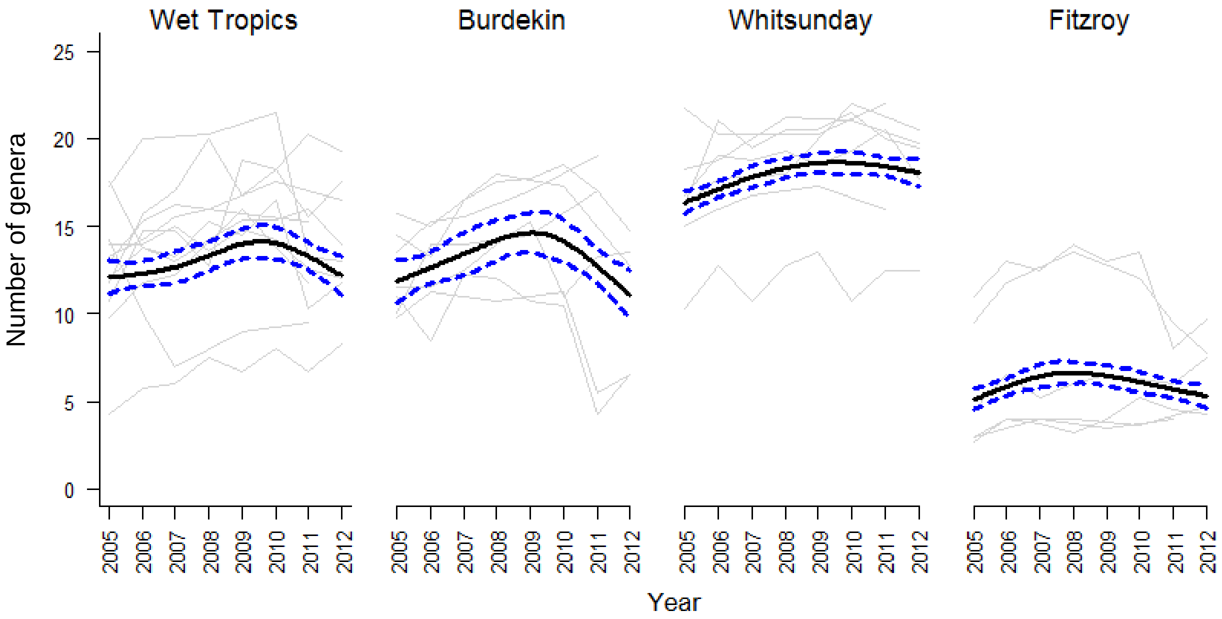


Figure 10: Regional trends in hard coral richness. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.7 Richness of juvenile (<10cm) hard coral colonies

Estimates of the richness of juvenile hard corals from 2005 and 2006 are not directly comparable to later observations due to a doubling of the transect area for surveys from 2007 onwards. Because of this, we only present patterns in richness from 2007 to 2012(Figure 11).

In all regions there has been a decline in the average number of genera represented by juvenile-sized colonies. These declines tend to mirror similar declines in the abundance of juvenile colonies (Figure 9) and coincided with a shift from relatively dry to wetter than average years in adjacent catchments (Table 5). In the Wet Tropics and Burdekin Regions the passages of tropical cyclones Yasi and Tasha reduced juvenile abundance on several reefs as evidenced by steep declines between 2010 and 2011. In all regions with the exception of the Wet Tropics Region richness stabilised or showed slight recovery in 2012.

As noted above for genus richness of adult hard corals, genus richness of juvenile corals is a coarse assessment of diversity, but again, consistent identification to species is not considered possible. Mostly, variation among years is due to the observation, or not, of individuals of rare genera. However, consistent declines are emerging and they appear to coincide with an extended period of wetter than average years, suggesting a degree of sensitivity of juveniles of some genera to an increased exposure to catchment runoff. In the Wet Tropics and Burdekin regions, however, the severe disturbances due to Tropical Cyclones, Larry (2006) and Yasi (2011) clearly confound any influence of runoff at exposed reefs.

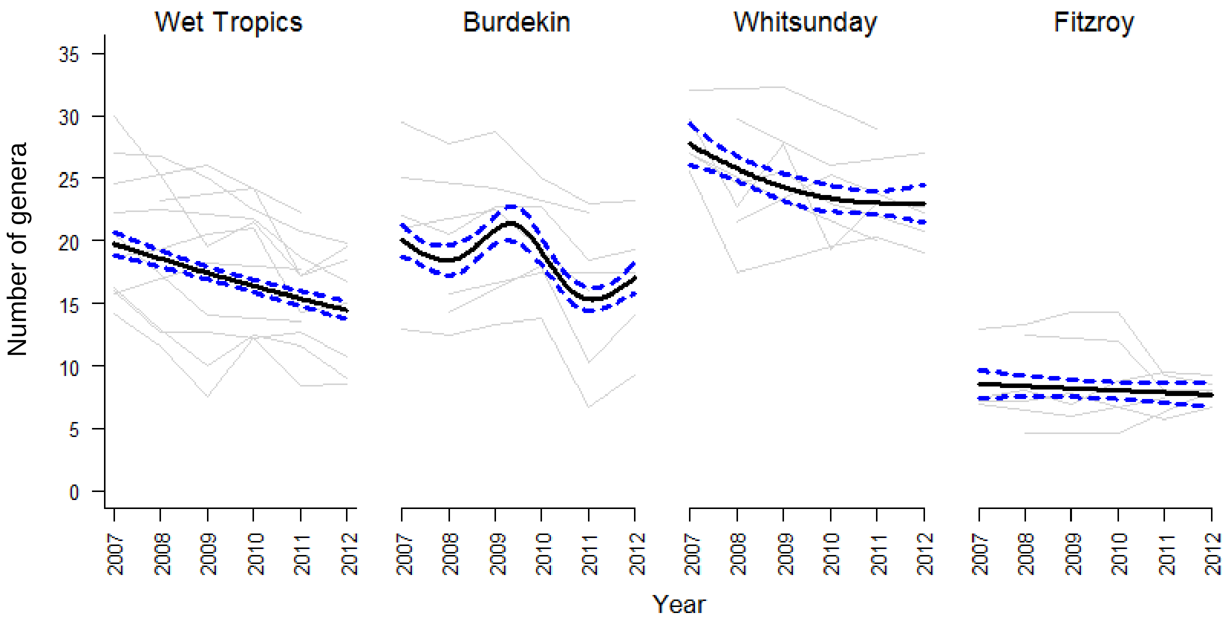


Figure 11: Regional trends in juvenile hard coral richness. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.8 Hard coral recruitment measured by settlement tiles

The settlement tile deployment and recovery of 2011/2012 represents the seventh recruitment season sampled by the MMP. For all regions and sampling years, settlement of coral larvae to tiles is highly variable (Figure 12), with average annual spat counts per reef ranging from 867 to 2140. Coral settlement to tiles is overwhelmingly dominated by the broadcast spawning Acroporidae. While not ecologically dominant in the adult coral community at all reefs, the family Acroporidae make up 80%, on average, of the spat settled to tiles. Other identifiable, but much less common, spat include the families Poritidae, Pocilloporidae and Fungiidae (see Figures 22, 31, 36, 41 in the regional report sections). It must be acknowledged, however, that the deployment of tiles specifically targets the peak spawning period of broadcast spawning species, and as such, brooding taxa such as *Pocillopora* will be under represented. Additionally, as coral larvae respond to chemical cues from the biofilms associated with the settlement substrate it is entirely plausible that the biofilms developing on tiles create a biased settlement substrate.

Given the observed high variability of spat counts, a number of environmental variables that potentially promote or suppress coral settlement of Acroporidae were explored (Thompson *et al.* 2012). In addition to the observed inter-annual variability, the variables that showed significant relationships with larval settlement were (i) the local cover of adult Acroporidae colonies, (ii) turbidity during the recruitment period and (iii) the composition of local sediments.

There was an overall decline in recruitment of 43% between 2010 and 2011. This continues a general decrease from 2007, punctuated by isolated recruitment pulses (Fitzroy Is and Daydream Is 2007, Pandora Reef 2010, Figure 12). The 2011 recruitment season had the lowest number of settled corals of the study so far, averaging 867 spat per reef. While the cause of this drop in spat numbers at individual reefs is unclear, the major contributing factors are likely to include a decline in adult coral cover, an increase in turbidity, and an increase in fine sediments. Loss of brood stock from reefs impacted by Cyclone Yasi (Wet Tropics and Burdekin regions), and brood stock affected by floodwaters (Fitzroy Region) are the drivers determining reduced larval supply in these regions in 2011 (Figure 12). In the Whitsundays there have been no appreciable impacts of cyclones or floodwaters to the adult brood stock in the 2011 – 2012 spawning season. However, the continued decline in recruitment observed over the past two years reflects the flood plumes of early 2011 and subsequent poor conditions that affect settlement of planulae. The accumulation of fine sediment on the settlement tiles has been observed consistently in this region. Turbidity, too, is a strong contributing factor here, and, for 2011 and 2012, annual turbidity levels were at or above average at core reefs (Figure 34). In addition, the vacant space created by Cyclone Yasi and extreme flood plumes in 2011 has enabled the establishment and rapid growth of macroalgae in all regions (Figure 8). Macroalgae have been observed to suppress fecundity (Foster *et al*. 2008) and interfere with the process of settlement, metamorphosis, and post-recruitment survival; both physically and chemically (Birrell *et al*. 2005, 2008a, Vermeij *et al.* 2009). While the adult communities are still recovering, the supply of coral larvae will continue to be reduced, and recruitment will depend on those that survive among the macroalgae. The loss of brood stock, rise of macroalgae, and seasonal turbidity in combination serves to slow the process of coral recovery and undermine reef resilience. Monitoring the supply of coral larvae and the survivorship of recruits is critical to estimate the resilience of reef communities that encounter repeated disturbances (Hughes *et al*. 2010). The current diminishing trends in reef resilience, especially for regions with low adult populations and low recruitment (e.g. Burdekin Region), should be viewed with concern.

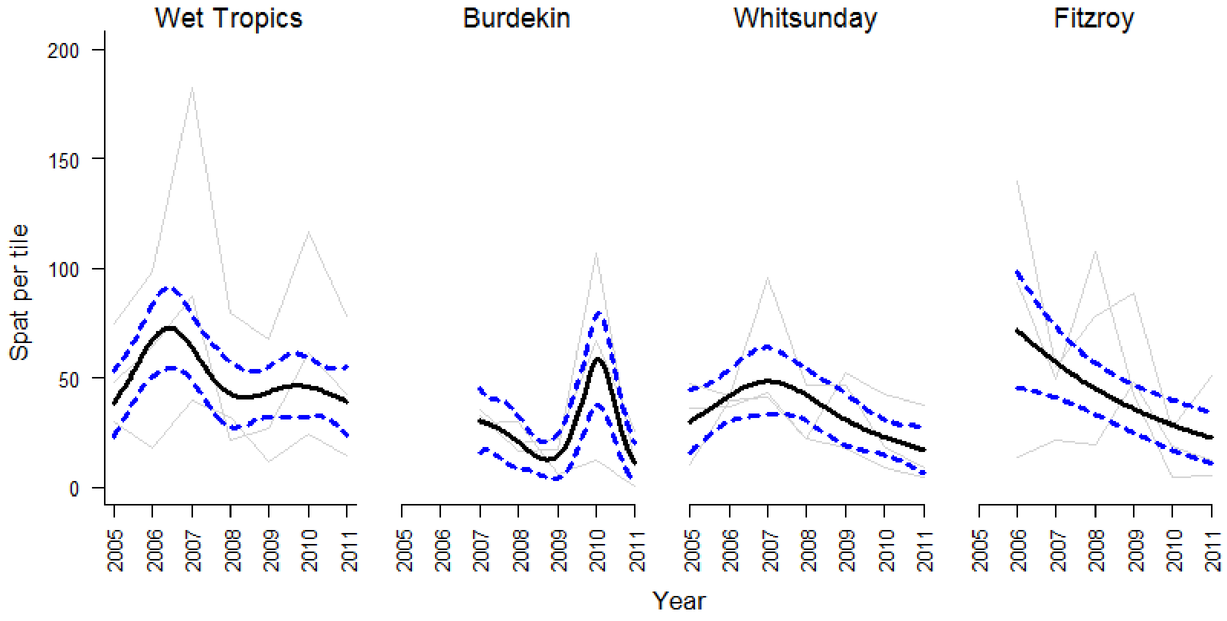


Figure 12: Regional trends in coral settlement. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.2.9 Foraminiferal assemblages

Sediment samples for foraminiferal analysis have been collected eight times from most of the 14 core reefs; however, only samples from 2005 and 2006 (as part of a MTSRF-funded research project) and 2007, 2010, 2011 and 2012 (as part of the MMP) have been analysed for the density and composition of foraminiferal assemblages. Sediment samples from 2008 and 2009 were appropriately stored at AIMS for potential future analysis. The density of several heterotrophic taxa clearly increased in 2012, most likely in response to improved food conditions. However, methods we applied thus far to estimate densities do not provide reliable estimates at the very high densities currently present. Detailed analyses of these would require more effort and thus increased funding. Thus, this year we focus on the FORAM index in this report.

The FORAM index over all monitoring years was relatively similar the Wet Tropics, Burdekin and Fitzroy regions, but distinctly lower in the Mackay Whitsunday Region (Figure 13). However, since the baseline assessments in 2005 and 2006, the FORAM index has consistently declined in all regions. The decline is somewhat less pronounced in the Fitzroy region.

It appears likely that higher relative abundances of heterotrophic species (expressed as lower FORAM index), as observed in the Mackay Whitsunday Region, reflect increased food availability as a result of higher concentrations of organic carbon and nitrogen in the sediments (see section 3.1.1), which is most likely an effect of the recent extreme flood events. Both organic carbon and nitrogen content in sediments, in addition to grain-size, explained a significant amount of variation in the distribution of these species (Uthicke *et al.* 2010). Experimental work supported this and demonstrated that the growth of symbiont-bearing species is limited under high nutrient loads and that heterotrophic species are generally more abundant at sites with higher sediment organic carbon (Uthicke and Nobes 2008, Uthicke and Altenrath 2010, Reymond *et al*. 2011). These conditions will on the one hand provide more food for heterotrophic organisms, but increased nutrients and decreased light may also disadvantage symbiont-bearing foraminifera

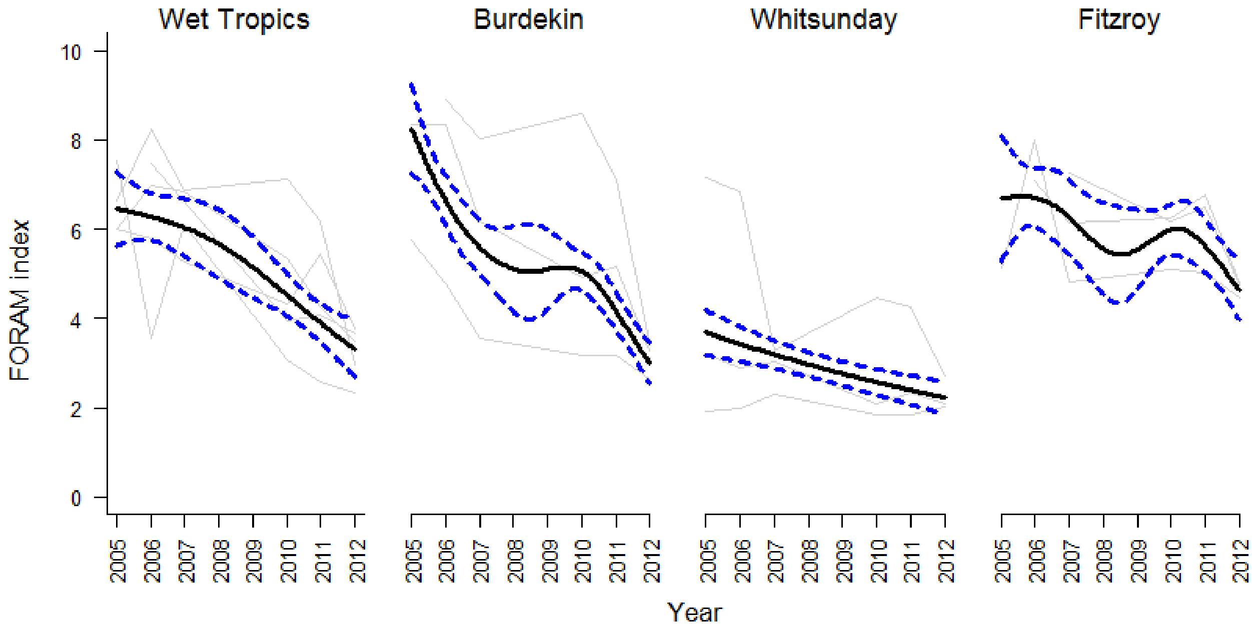


Figure 13: Regional trends in the FORAM index. Bold black curve represents predicted regional trend bounded by blue dashed lines depicting the 95% confidence intervals of that trend (see section 2.6 for analysis detail). Grey lines show observed trends for each reef.

3.3 Description of coral and foraminifera communities on survey reefs in each region

3.3.1 Wet Tropics Region: Barron Daintree sub-region

Two reefs, Snapper Is North and Snapper Is South are sampled annually in this sub-region (Figure 14). These reefs have been monitored by Sea Research since 1995 (Ayling and Ayling 2005). These historical observations demonstrate the resilience of these communities with periods of recovery following observed disturbances (Sweatman *et al.* 2007, Table A1-5). This propensity to recover is evident in the observations presented here with coral cover increasing over the period 2005 to 2007 at all locations (Figure 15). Since 2007, however, changes in coral cover have been more variable with cover on the northern and deeper southern reefs not increasing at rates previously observed.

Google Earth 2010

Figure 13: Reef Rescue MMP inshore coral reef monitoring sites: Barron Daintree sub-region, Wet Tropics Region.

The reefs in this sub-region are subject to discharge from the Daintree and, to a lesser extent, the Mossman and Barron rivers. Snapper Is is 4km from the mouth of the Daintree River. Prior to surveys in 2005, corals at 2m sites of Snapper Is South suffered high rates of mortality as a result of freshwater inundation during floods of the Daintree River in 1996 and then again in 2004 (Ayling and Ayling 2005). While not monitored at that time, anecdotal evidence suggests the deeper 5m sites were below the impact of these flood events. The coral communities at Snapper Is North were less impacted by these floods, though they did suffer substantial reductions in cover caused by coral bleaching in 1998 and then Cyclone Rona in 1999 (Ayling and Ayling 2005). Over the period 2005 to 2012, annual discharge for both the Daintree and Barron rivers has been at, or slightly above, median levels in most years with major floods of the Barron River in 2008 and again in 2011 when the Daintree River also flooded. The 2011 floods were the highest flows recorded for both rivers over the last ten years (Table 5).

From 2005 to 2012, the only acute disturbance to have impacted these reefs was a storm event (possibly associated with Cyclone Hamish in March 2009) that caused physical damage to corals at Snapper Is North. It is likely that this disturbance caused the slight reduction in cover of hard coral, soft coral and macroalgae observed in early 2009. While the combined cover of hard and soft corals was still high following the set-back in 2009 there has been little evidence of recovery of the hard coral community resulting in the continued negative assessment of the “change in hard coral cover” indicator (Table 7). By late 2009 at 2m depth, the cover of soft corals (largely *Clavularia*) and macroalgae had recovered (Figure 15). By 2010, hard coral cover had begun to recover at 2m, but continued to decline at 5m depth where reductions in the cover of the families Poritidae (genus *Goniopora*) and Acroporidae accounted for the majority of the change (Figure 16).

The 2011 and 2012 surveys identify a persistent increase in the cover of macroalgae at both, the 2m and 5m sites at Snapper Is North. This increase coincides with declines in coral cover (Figure 15). The algal community is predominantly composed of red algae (Table A1-8), a group that has been shown to inhibit coral growth by both direct shading and also by causing changes to the chemical microenvironment of the surrounding water (Hauri *et al.* 2010). This increase of algae has resulted in the downgrading of assessments for this indicator to negative at both 2m and 5m, and has likely contributed to the decline of cover at 5m to below the 50% threshold and a lower density of juvenile hard corals, leading to a downgrading of the indicators for “coral cover” to neutral and “juvenile density” to negative (Table 7).

Additional to the effects the algal community may have on coral cover, scuba search surveys observed increased prevalence of coral disease in both 2010 and 2011, which is considered to be a likely contributor to the decline in coral cover. In 2010 there was a high incidence of Brown Band and Skeletal Eroding Band disease and it is likely that these diseases were the primary agent in reducing the Acroporidae cover from 34% to 27% at this site. In 2011 disease was still prevalent and would have contributed to declines in coral cover in both 2011 and 2012.

In 2012 an active outbreak (as per Engelhardt *et al.* 1997) of crown-of-thorns starfish was recorded at Snapper Island. In November the density of starfish at 2m depth Snapper Is North was 173ha^{-1} (as estimated from scuba searches of monitoring transects) with individuals mostly in the 15-25cm size range. It is possible that changes in environmental condition caused by increased catchment runoff are linked to the increasing prevalence of disease and abundance of red algae. At a larger scale increased numbers of crown-of-thorns starfish in this region of the GBR have been linked to elevated nutrient supply delivered by major floods of rivers in the Wet Tropics (Fabricius *et al*. 2010).

In contrast to the sites on the northern side of the island, the coral communities at 2m depth on Snapper Is South continue to be assessed positively. Here, hard coral cover has increased steadily over the period 2005-2012 to reach current high levels. This increase reflects both the growth of colonies of the genus *Porites* that survived exposure to low salinity flood waters in 1996, and the re-establishment of *Acropora* colonies that suffered high rates of mortality (Ayling and Ayling 2005, Figure 16). In 2011, there was a slight decline in cover of *Acropora* consistent with further exposure to low salinity waters as a result of flooding of the Daintree River (Figure 16, Table 5), though this lost cover had recovered by 2012. Macroalgal cover has been consistently low (Figure 15) and juvenile coral densities were moderate to high, suggesting a high potential for recovery of the community after disturbance. The benthic community at 5m depth remains stable with the positive attributes of a high cover of corals and low cover of macroalgae balancing recent low rates of cover increase and very low densities of juvenile corals (Table 7, Figures 15 and 16).

Cause of differences in coral community condition between the northern and southern reefs of Snapper Is can be inferred from the sediments. Snapper Is North has above average levels of clay and silt-sized particles, organic carbon (Figure 15) and nitrogen (Table AI-1a-c). Conversely, inorganic carbon is low (Table AI-1d). In combination, these results suggest a low energy hydrodynamic setting that allows the accumulation of terrigenous sediment. The more exposed Snapper Is South has a lower proportion of clay and silt-sized sediments with higher inorganic carbon content, indicative of less accumulation of runoff derived contaminants. Turbidity at Snapper Is North (Figure 15) exceeds the Guidelines (GBRMPA 2010). This high turbidity is reflected in the marked compositional change in hard coral communities from Acroporidae and Poritidae (genus *Porites*) typical of high light environments at 2m to a more mixed community of lower light tolerant taxa at 5m including the families Agariciidae, Faviidae and Poritidae (genus *Goniopora*) (Figure 16). Although average chlorophyll concentrations do not exceed the Guidelines, concentrations recorded by an automated logger at Snapper North between May 2010 and June 2012 indicate high chlorophyll levels for sustained periods of time corresponding to peak river flows in the 2010/11 and 2011/12 wet seasons (Schaffelke *et al*. 2012). A positive correlation was identified between water column chlorophyll and cover of reef macroalgae implying that both may be limited by ambient nutrient availability (De’ath and Fabricius 2010).

Table 7: Benthic community condition: Barron Daintree sub-region, Wet Tropics Region. For each reef the overall condition score aggregates over the metrics excluding. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= ‘very poor’, orange= ’poor’, yellow= ‘moderate’, light green= ‘good’, dark green= ‘very good’. The average of the regional scores for each metric results in the overall condition assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density
Snapper Is North	2	- -	+	-	-	-
	5	- -	neutral	-	neutral	-
Snapper Is South	2	+++	+	+	+	neutral
	5	-	+	-	neutral	-
Sub-regional assessment		🟨	🟩	🟧	🟨	🟥

The overall condition rating for the reefs in the Barron Daintree sub-region was downgraded to “moderate” in 2011 and remained so in 2012 (Table 7). Slow rates of coral cover increase, low densities of juvenile corals and increased macroalgae cover all indicate a suppression of coral community resilience in recent years. These factors were offset by the continued high coral cover at these sites. Worrying were the high numbers of crown-of-thorns starfish present at Snapper Is North during surveys in 2012. Numbers of starfish were sufficient to classify the reef as having an “active outbreak”; it is expected that this outbreak will lead to substantially reduced coral cover over the next couple of years. The primary change from the baseline assessment presented in Thompson *et al.* (2010b) is the reduced score for “change in hard coral cover” from ‘good’ for observations over the period 2005-2009, to the current ‘poor’ for observations over the period 2008-2012 due to slow increases in coral cover at Snapper Is North and the 5m site at Snapper Is South. Contributing to these slow rates of cover increase were high incidence of disease in 2011and increased macroalgal cover both factors symptomatic of potential chronic environmental stress as indicated by high turbidity and accumulation of fine organically rich sediments (Figure 15).

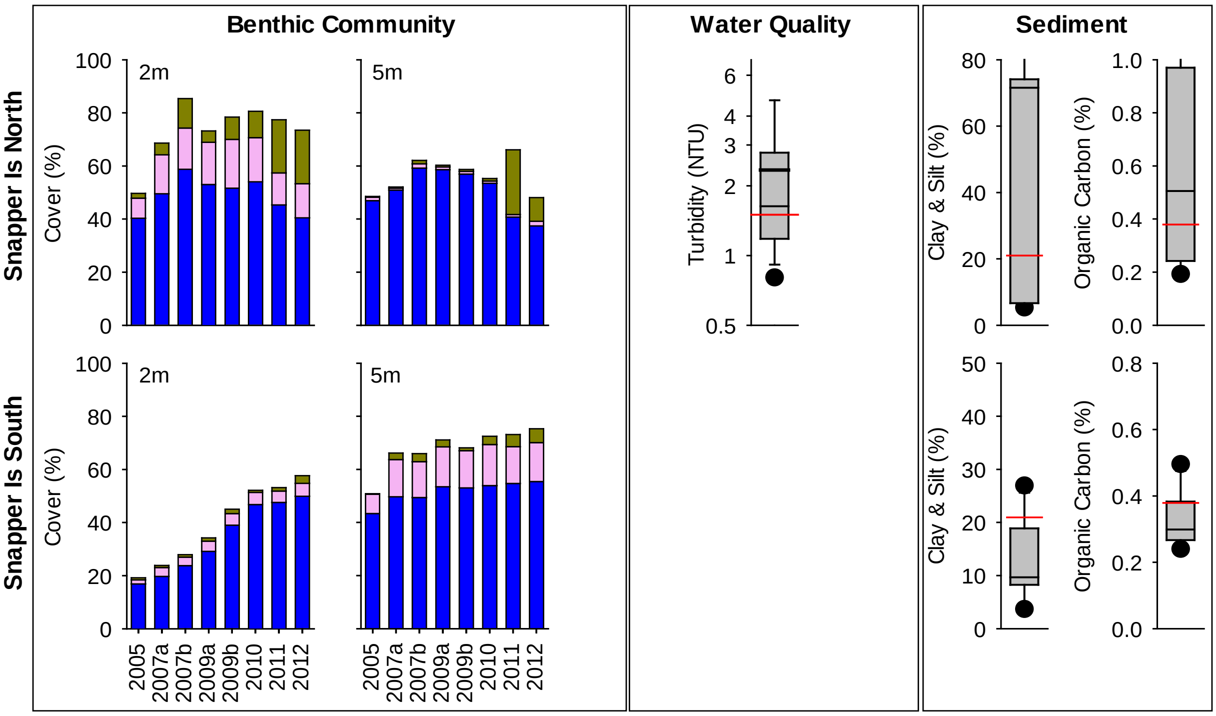


Figure 15: Cover of major benthic groups and levels of key environmental parameters: Barron Daintree sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box), mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guideline for turbidity (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

At Snapper Is North the FORAM index at both sites declined by nearly 50% from 2006 to 2012 to a value close to 4 (Figure 17). In the Caribbean, FORAM index values of between 2 and 4 reflect environmental conditions that are marginal for coral reef growth (Hallock *et al.* 2003). Interestingly, this result coincides with a period during which the rate of increase in coral cover was suppressed (Table 7), which adds weight to the notion that the environmental conditions experienced over the last three years may be causing a degree of chronic stress to benthic communities.

No assessment of condition based on the FORAM index was carried out, because there was only one year (2006) available during the baseline period, on which they assessment was based (see section 2.6.1).

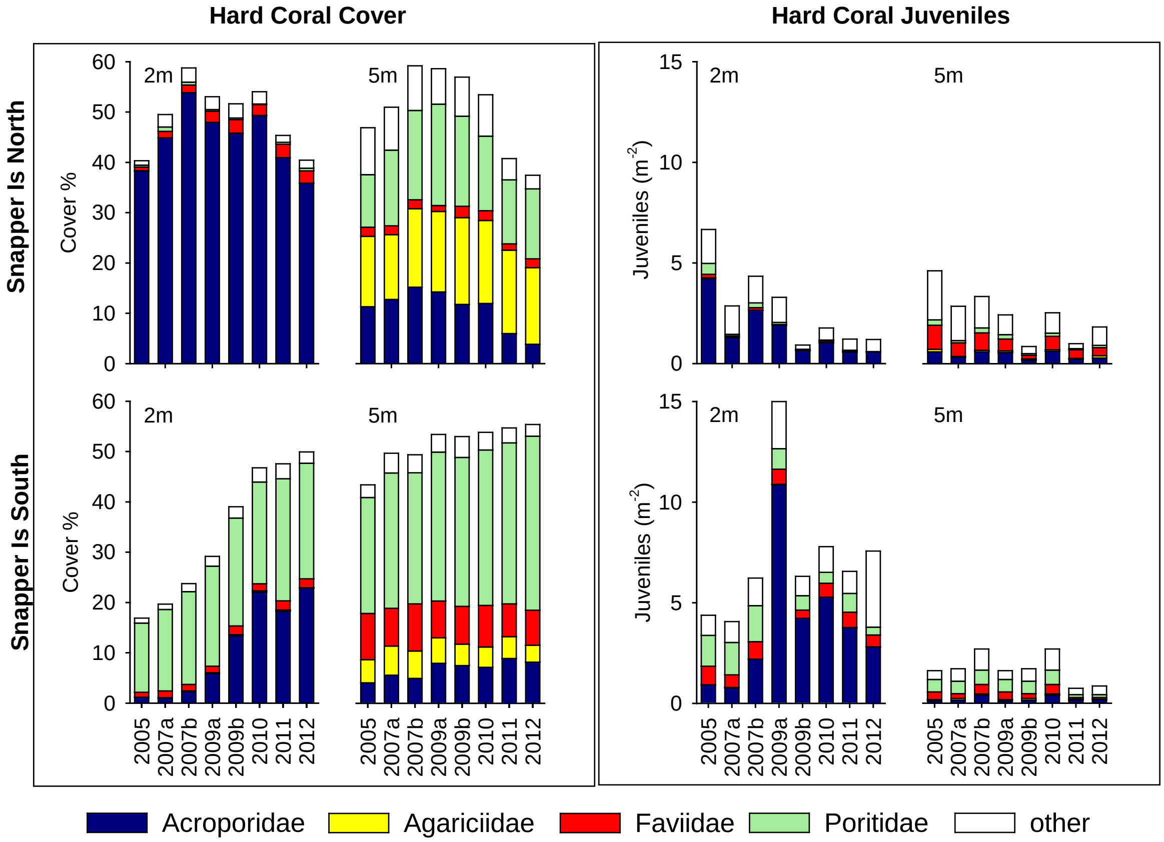


Figure 16: Composition of hard coral communities: Barron Daintree sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

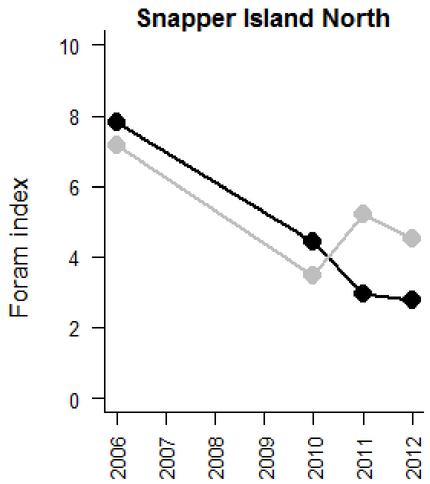


Figure 17: FORAM index: Barron Daintree sub-region, Wet Tropics Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

3.3.2 Wet Tropics Region: Johnstone Russell-Mulgrave sub-region

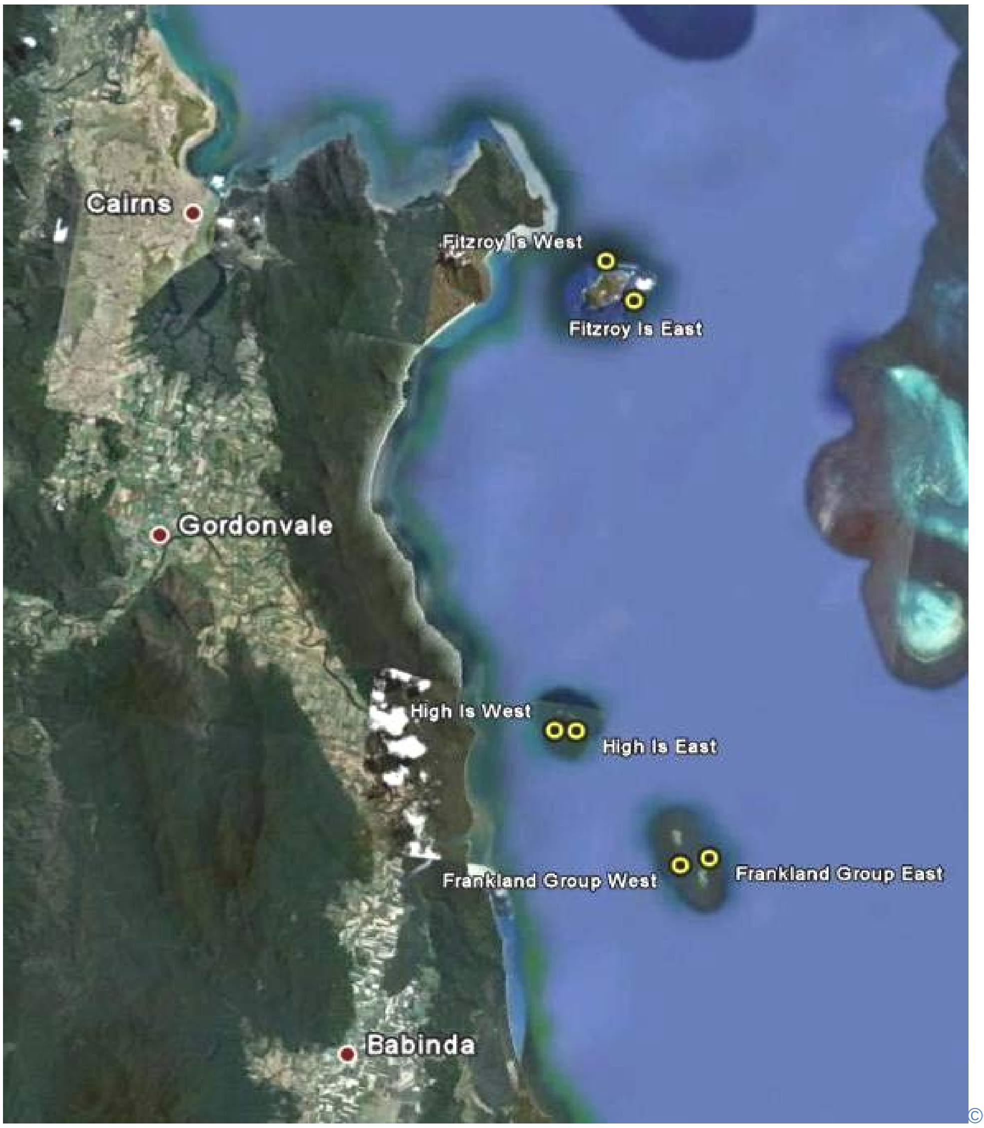


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Figure 18: Reef Rescue MMP inshore coral reef monitoring sites: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region

Prior to the commencement of MMP monitoring in 2005, surveys conducted by AIMS and Sea Research indicated that coral communities at Fitzroy Is and the Frankland Group were in a state of recovery following impacts attributed to crown-of-thorns starfish and coral bleaching (Sweatman *et al*. 2007, Ayling and Ayling 2005). Since 2005, Cyclone Larry (2006) and Cyclones Tasha and Yasi (2010/11) caused substantial reductions in coral cover at some reefs (Figure 19, Table A1-5). High levels of coral disease, exposure to freshwater at 2m depth High Is West in 2011, and high numbers of crown-of-thorns starfish at Fitzroy Is and Frankland Group West in 2012 have further compounded these impacts.

In 2012 the coral communities in this region were assessed to be in moderate condition based on levels of coral cover, the rate at which coral cover increases when not subject to acute disturbance, the density of juvenile colonies and the abundance of macroalgae (Table 8). However, these metrics vary between reefs and over time, and this variability allows a focus on environmental conditions that potentially limit community resilience in this region.

Reef aspect varies the exposure of corals to waves and hence to damage during cyclones; as can be seen in the higher proportion of coral lost in 2006 and 2011 on eastern compared to western reefs (Figure 19, Table A1-5). These differences in hydrodynamic settings along with proximity to rivers and coastal sediments also result in broadly different environmental conditions. For example, more sheltered locations are more prone to the accumulation of fine grained sediments (Wolanski *et al*. 2005), while turbidity levels closer to the coast reduce the light available for coral growth. Hard coral communities in this region fall into two broad categories, those with relatively high cover of the family Acroporidae on the more exposed eastern reefs and those with high abundance of the family Poritidae on the sheltered western reefs of High Is and Frankland Group (Figure 20).

Table 8: Benthic community condition: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. For each reef the overall condition score aggregates over the metrics excluding Settlement and FORAM index. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= 'very poor', orange= 'poor', yellow= 'moderate', light green= 'good', dark green= 'very good'. The average of the regional scores for metrics, excluding Settlement and FORAM index, result in the overall condition regional assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall Condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density		Settlement	FORAM index
Fitzroy Is East	2	-	neutral	-	+	-			
	5	-	neutral	-	+	-			
Frankland Group East	2	- - -	-	neutral	-	-			
	5	neutral	-	+	neutral	neutral			
Frankland Group West	2	neutral	+	neutral	neutral	-			
	5	- -	+	-	-	-		-	-
Fitzroy Is West	2	+	+	-	+	neutral			
	5	+	+	-	+	neutral		+	-
High Is East	2	- -	-	-	+	-			
	5	neutral	neutral	neutral	+	-			
High Is West	2	+	+	neutral	+	-			
	5	- -	-	-	+	-		neutral	-
Sub-regional assessment		🟨	🟨	🟧	🟩	🟥		🟨	🟥

Over the period 2005-2010 hard coral cover on most reefs increased during periods free from acute disturbance events at rates consistent with those predicted based on the relative proportions of fast growing Acroporidae to other slower growing species. These increases in cover resulted in generally neutral or positive assessments for the indicator "change in hard coral cover" until, and including 2010. In 2011, the rate of cover increase declined or cover decreased due to high incidence of coral disease at most reefs. In 2012, although the incidence of disease had declined and coral cover increased slightly at most 2m depths, continued declines, or lack of change at 5m depths contributed to the continued poor assessment for this indicator (Table 8). Reductions in coral cover attributed to cyclones and disease in 2011 resulted in a downgrading of the indicator

“Coral cover” from Very Good in 2010 to Moderate in 2011. This classification was maintained in 2012 due to little change in coral cover.

Of future concern is the presence of juvenile crown-of-thorns observed at Fitzroy Is and Frankland Group during 2012 surveys. At densities of 300 (Fitzroy Is West), 175 (Fitzroy Is East) and 75 (Frankland Group West), starfish per hectare these reefs are classified as having crown-of-thorns outbreaks (as per Engelhardt *et al.* 1997). In June/July 2012 the starfish were small (most <20cm diameter) and feeding within the understory of the coral community. However, it is almost certain that they will mature over the 2012/13 summer and cause marked reduction in coral cover over coming years.

Macroalgae can inhibit coral communities by altering physical, chemical and/or microbial conditions leading to reduced recruitment or fitness of corals (e.g. Birrell *et al*. 2008b, Morrow *et al*. 2011, Morrow *et al.* 2012, Vega Thurber *et al.* 2012). Regionally, the cover of macroalgae is low resulting in consistently good assessments of this indicator (Table 8). The exception is the Frankland Group where the cover of algae on the eastern reef has shown substantial variation through time. This variation appears to be partially linked to short term increases following cyclone disturbances (Figure19). On the western reef, red algae of the genera *Hypnea* and *Laurencia* form persistent mats amongst branching and sub-massive forms of the coral genus *Porites.* These mats are likely to be a primary cause of observed declines in cover at 5m depth (Figure 19).

Since 2006, the density of juvenile corals has been declining steadily across the region. Hence, the assessment for this metric remains ‘very poor’ in 2012 (Figure 20, Table 8). While speculative, the initial decline may mirror the increase in adult coral cover over the period 2005-2010, with high numbers of juveniles observed in earlier years taking advantage of available space that was occupied as corals grew. High levels of disease infecting adult corals in 2010-2011 along with high densities of crown-of-thorns starfish in 2012 may also have caused mortality of juvenile corals and explain low numbers in recent years.

The settlement of corals is highly variable from year to year with indications that this may be due to a combination of local broodstock and weather conditions during the few days prior to and during settlement (AIMS unpublished analysis). Despite this inter-annual variability, the relative settlement between the reefs remains consistent, with Fitzroy Is West recording higher settlement than High Is West which in turn has higher settlement than Frankland Group West (Figure 21). These relative differences in settlement are broadly reflected in the relative densities of juvenile colonies at these reefs (Figure 20).

In summary, the Acroporidae dominated coral communities have been repeatedly impacted by cyclones from which coral cover has shown clear recovery potential both through the recruitment and growth of colonies. However, these communities are susceptible to disease with peak levels of disease coinciding with peaks in discharge from nearby rivers (Thompson *et al.* 2012). The timing of disease outbreaks implies a potential link between coral condition and deviations from ambient environmental conditions occurring as a result of flood events. These communities are also susceptible to predation by crown-of-thorns starfish and the current high densities of these starfish pose a substantial risk to coral cover in the near future. Links between crown-of-thorns starfish and elevated nutrient levels resulting from flooding of Wet Tropics Rivers have been proposed (Fabricius *et al.* 2010). Given the severity of disturbance these starfish impart on the Great Barrier Reef in general (Osborne *et al*. 2011, De’ath *et al*. 2012), further research into the possibility of water quality in runoff as a driver of such outbreaks is justified.

In contrast, while the more sheltered reefs of High Is West and Frankland Group West have proven less susceptible to acute disturbance they have also shown limited recovery potential. In 2012, coral cover was lower than previously recorded on these reefs. At each reef and depth the reasons for recent declines differ though collectively point toward the influence of water quality rather than acute events. At 2m depth at High Is West coral cover had remained stable at high levels from 2005 to 2010. Observations of low salinity waters at our transect depths, coupled with bleached and dead colonies of susceptible species including *Acropora* and *Pocillopora* in January 2011 may explain the declines observed during surveys later that year. At 5m depth salinity is unlikely to have dropped to critical levels (Berkelmans *et al*. 2012). Rather increased sedimentation, as evidenced by an increase in the clay and silt component in sediment grain-size samples (Table A1-1), and associated turbidity that are likely to have contributed. At Frankland Group West the persistent cover of red algae appears to have chronically suppressed coral communities both by out-competing existing corals and limiting recruitment of juveniles.

Communities of foraminifera on the eastern sides of Islands in the Johnstone Russell-Mulgrave sub-region typically had high values of the FORAM index caused by high abundance of mixotrophic species (see previous reports). This combination of community attributes is typical of foraminiferal assemblages living under environmental conditions with low turbidity and limited accumulation of fine grained sediments (e.g., Renema *et al.* 2001). On the more sheltered western sides of the Islands where the core sites are located, fine sediments accumulate and sediments have higher concentrations of organic carbon. This lead to higher richness and relative abundance of heterotrophic species, leading to lower values of the FORAM index (Figure 23 in Thompson *et al*. 2012)

Considering values of the FORAM index over the period 2005-2007 as a baseline, there has been a decline in the relative abundance of symbiont-bearing species at both Frankland Group West and High Is West leading to a reduced FORAM index. This decline was confirmed in 2012, at which point Fitzroy Is also shows a sharp decline. All three reefs now have a ’very poor’ assessment of foraminiferal assemblage condition (Table 8).

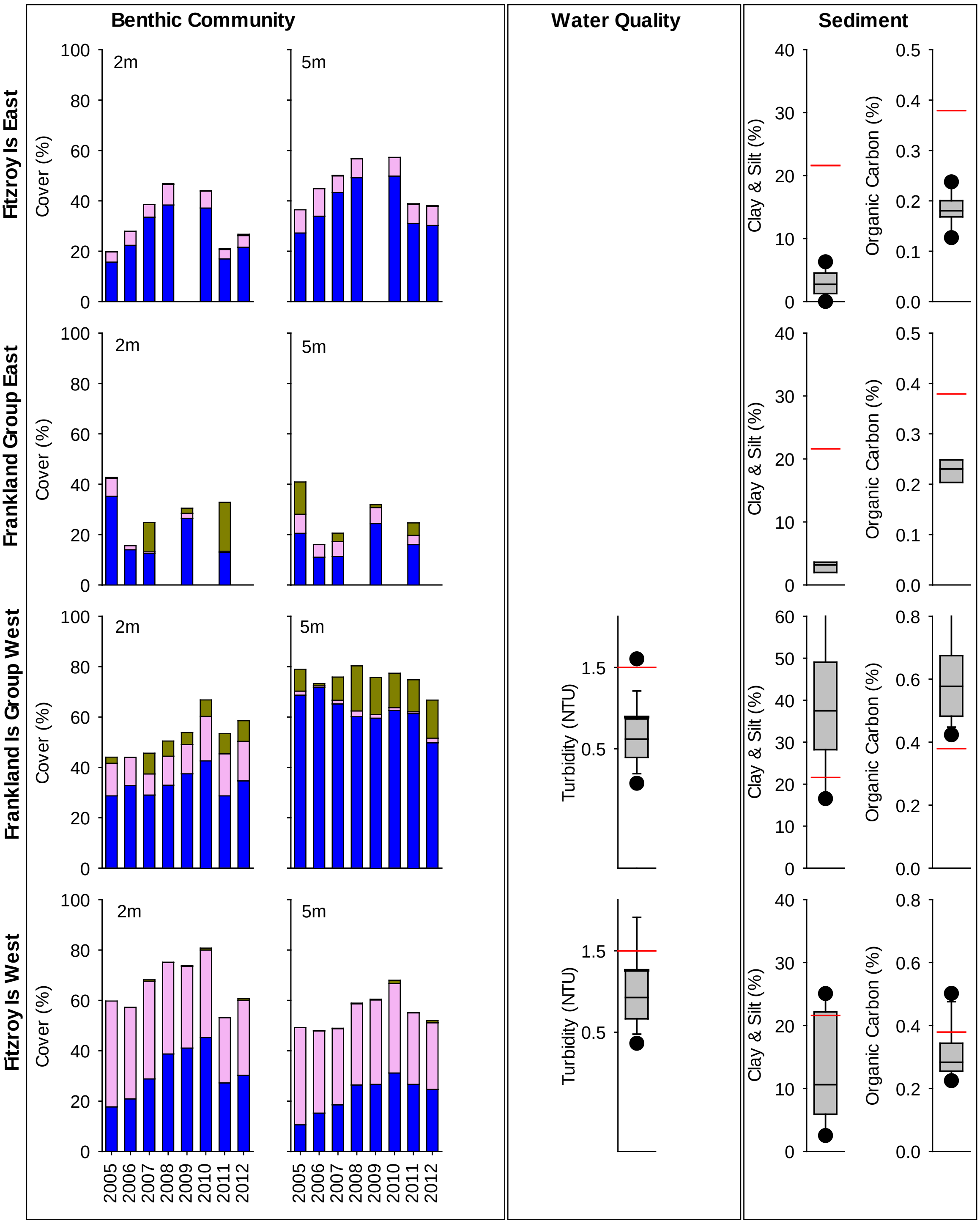

Figure 19: Cover of major benthic groups and levels of key environmental parameters: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box), mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guideline for turbidity (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

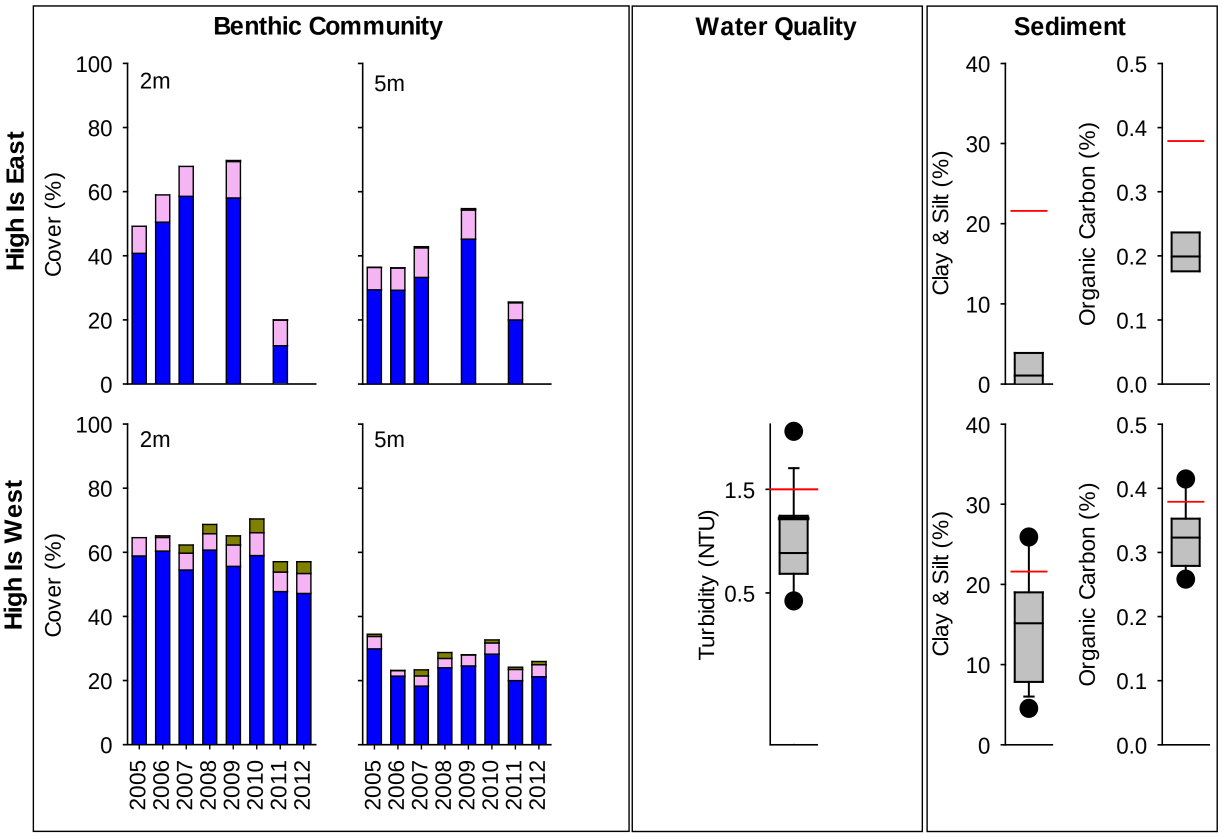

Figure 19: continued.

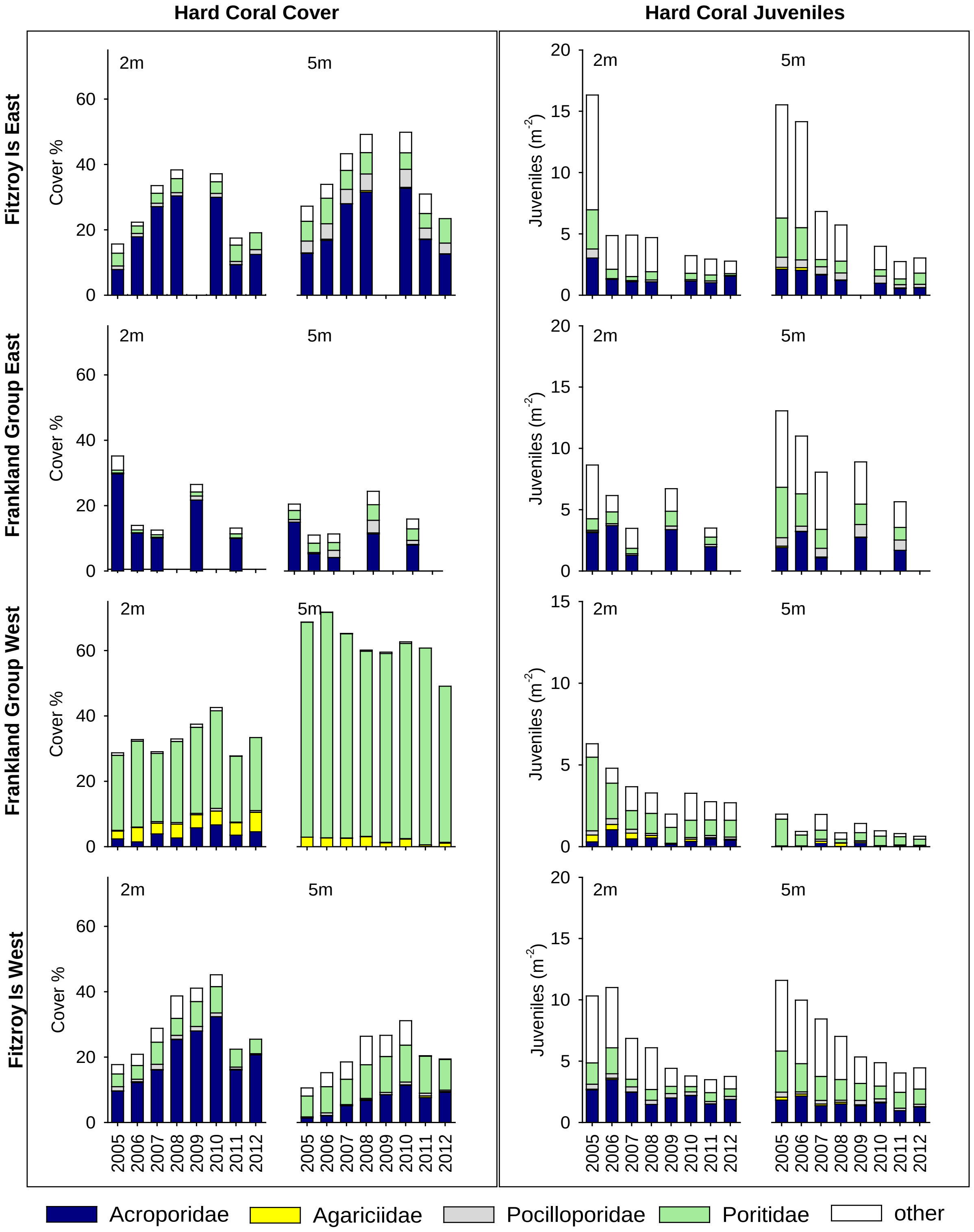

Figure 20: Composition of hard coral communities: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into ‘other’.

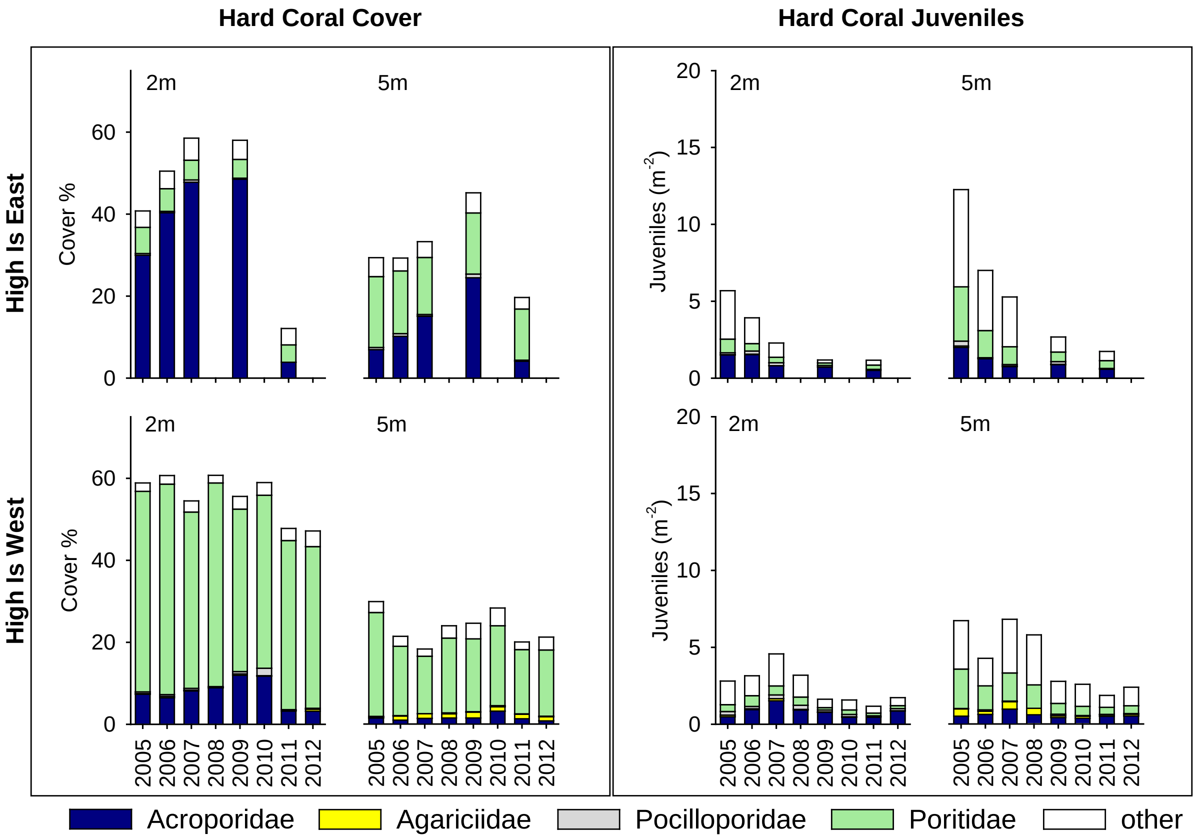

Figure 20: continued.

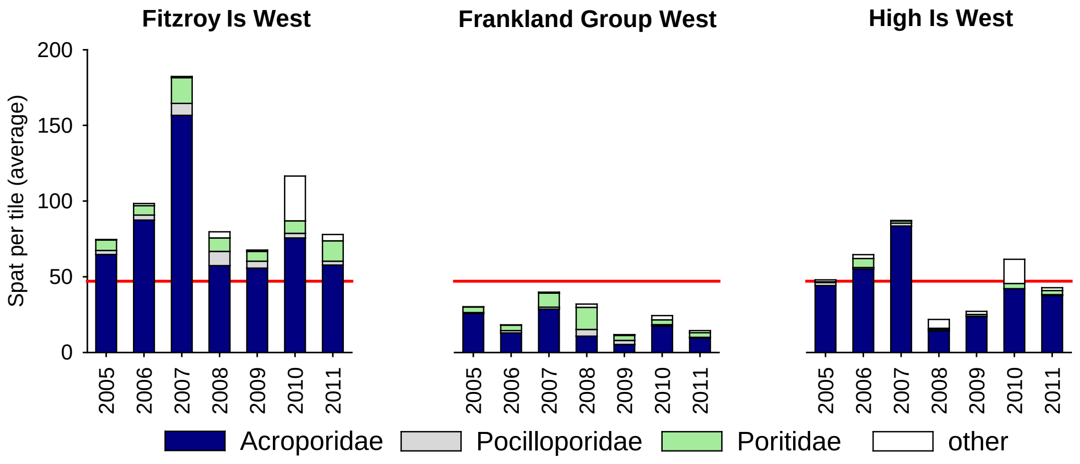

Figure 21: Coral settlement to tiles: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Data are from 5m tile deployments. Average values from all regions and years are indicated by red reference lines.

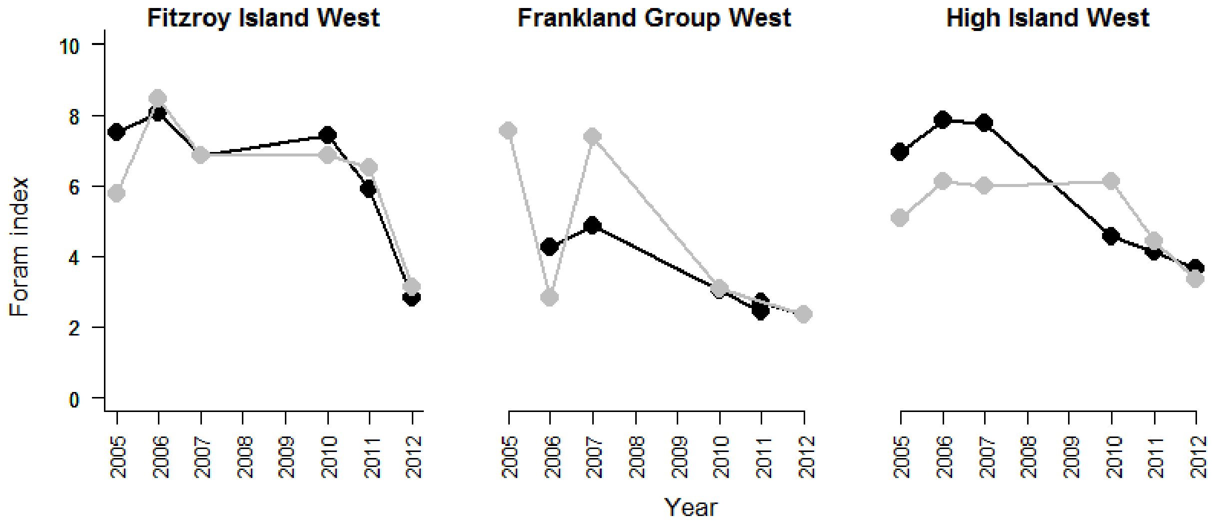

Figure 22: FORAM index in the Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

3.3.3 Wet Tropics Region: Herbert Tully sub-region

The past dynamics of the reefs in this region are largely unknown as no quantitative monitoring was undertaken prior to the MMP starting in 2005. However, the reefs were exposed to flood plumes 3 times between 1991 and 2001 (Devlin *et al.* 2001) and coral bleaching events in 1998 and 2002 (Wooldridge and Done 2004) (Table A1-5). Although not quantified, loss of coral cover as a result of thermal stress was likely to have been similar to levels recorded in the adjacent Johnstone Russell-Mulgrave sub-region. Since 2005 severe Cyclone Larry (2006) and severe Cyclone Yasi (2011) had significant impacts on coral communities (Figure 24, Table A1-5).

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Figure 23: Reef Rescue MMP inshore coral reef monitoring sites: Herbert Tully sub-region, Wet Tropics Region.

In 2012 the condition of coral communities in this region was “poor”. To a large extent this rating is influenced by the combined impacts of recent cyclones that have resulted in low coral cover on all reefs and lower densities of juvenile colonies (Table 9, Figures 24 and 25). Further influencing the assessment of condition was high cover of macroalgae on most reefs and a slow rate of recovery of coral cover between observations that do not span acute disturbance events.

Each of the metrics used to assess coral community condition are confounded by the scale of, and limited period of time since, impact of both Cyclone Larry and in particular Cyclone Yasi. For example, the very low cover of corals observed in 2012 is to be expected given that all reefs were impacted by at least one of the two cyclones. What is of importance is the rate at which coral communities recover from these impacts. As observations in 2012 are so soon following Cyclone Yasi it is useful to consider the observed state and dynamics of communities since 2005 to identify potential limitations to recovery.

Table 9: Benthic community condition: Herbert Tully sub-region, Wet Tropics Region. For each reef the overall condition score aggregates over the metrics excluding Settlement and FORAM index. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= 'very poor', orange= 'poor', yellow= 'moderate', light green= 'good', dark green= 'very good'. The average of the regional scores for metrics, excluding Settlement and FORAM index, result in the overall condition regional assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall Condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	FORAM index
North Barnard Group	2	-	-	neutral	+	-	
	5	neutral	-	neutral	+	neutral	
Dunk Is North	2	- - -	-	neutral	-	-	
	5	-	-	neutral	-	+	-
King Reef	2	- - -	-	neutral	-	-	
	5	- -	-	neutral	-	neutral	
Dunk Is South	2	- - - -	-	-	-	-	
	5	- -	-	-	neutral	neutral	
Sub-regional assessment		🟨	🟥	🟧	🟧	🟧	🟥

Prior to Cyclone Larry, coral cover was high on most reefs demonstrating that conditions leading up to 2005 had been conducive to the maintenance of these communities. The exceptions were King Reef and 2m depth at Dunk Is South with these locations supporting lower coral cover and comparatively high cover of macroalgae (Figure 24). Further, at Dunk Is South, the mixed community composition is indicative of high turbidity with high representation of corals typical of low light environments.

Following Cyclone Larry, rates of increase in coral cover were variable among reefs due to a combination of extent of disturbance and the coral and algal communities present. At North Barnard Is loss of coral was extreme and the subsequent recovery of coral cover was expectedly slow. While macroalgae cover increased at 2m, a strong pulse of coral recruitment was evident by 2009, by which time coral cover had begun to increase. At 5m depth macroalgal cover was not as high, coral cover showed some recovery and the density of juvenile corals was increasing in 2009. In summary, showed all positive signs of recovery potential were apparent at 5m depth. Similarly, at Dunk Is North there was clear recovery in coral cover along with increasing densities of juvenile corals prior to Cyclone Yasi with evidence that juvenile coral density was again increasing in 2012. However, it is expected that the recovery at this reef from cyclone Yasi will be slower as there were fewer surviving coral fragments from which cover can rapidly increase, and the cover of macroalgae observed in 2012 was higher than for any previous observation.

As Dunk Is South was not severely impacted by Cyclone Larry the potential for recovery from the impact of Cyclone Yasi is not clear. However, relatively low densities of juvenile corals, persistently high cover of macroalgae at 2m depth, and coral communities dominated by slower growing species all imply limited recovery potential. That coral cover continued to decline between surveys in 2011 and 2012 also implies a more chronic influence of either the cyclone or background environmental conditions on coral community condition at this location.

Projections for recovery at King Reef are poor. This year was the first survey of King reef following cyclone Yasi and it is clear that the already low coral cover was again further reduced. Coral cover has declined at both depths while the cover of macroalgae has increased further. High cover of fleshy macroalgae has been shown to decrease coral settlement (Diaz-Pulido *et al*. 2010), which is reflected in the continued decline in juvenile densities. Given the very low coral cover prior to Cyclone Larry, the lack of recovery prior to further loss during Cyclone Yasi, and the persistent cover of macroalgae, it is likely that the 2m sites in particular will remain a macroalgae dominated community for many years.

A further point of note is the disparity between the compositions of juvenile and adult communities particularly at Dunk Is North and the North Barnard Group where there is a disproportionally high density of juvenile Dendrophyliidae relative to the pre-disturbance adult community (Figure 25). Turbidity levels at Dunk Is North have been consistently high, with mean turbidity exceeding guidelines each year from 2005 to 2012 (Figure 24). At these levels of turbidity coral communities are known to undergo substantial change in relative abundances of the species represented (De'ath and Fabricius 2008, 2010). It is possible that the disparity observed is an indication that recent conditions have deteriorated sufficiently to be favouring species other than those previously present. Juveniles of the family Dendrophyliidae on these reefs are almost entirely of the genus *Turbinaria,* a group that can form high cover stands especially on turbid water reefs, though they can also suffer high mortality as they have a propensity to attach to lose substrata making them prone to toppling. Should there be a moderate survivorship of *Turbinaria,* it is possible that the adult community composition may shift on these reefs.

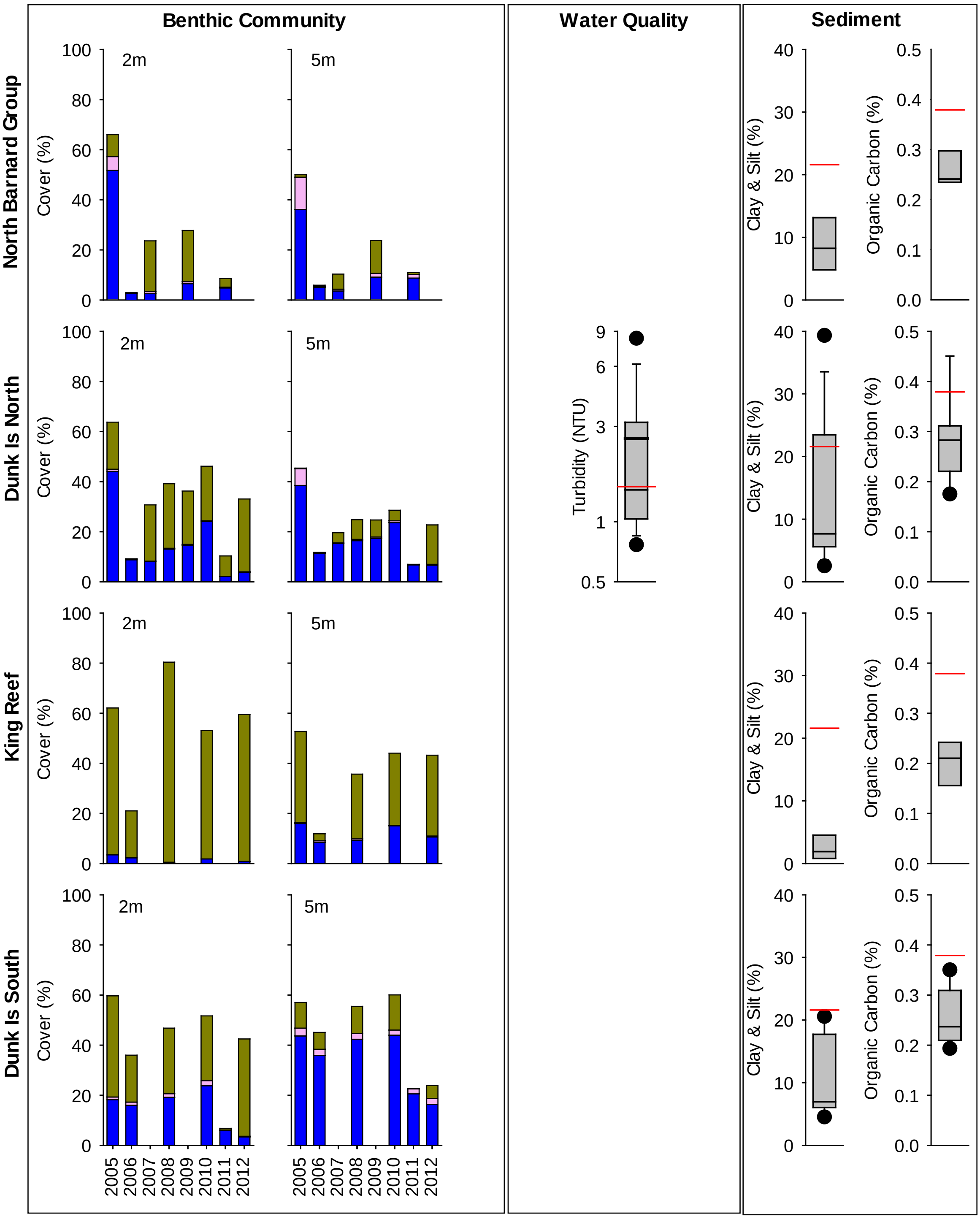

Figure 2414: Cover of major benthic groups and levels of key environmental parameters: Herbert Tully sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box, mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guideline for turbidity parameters (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

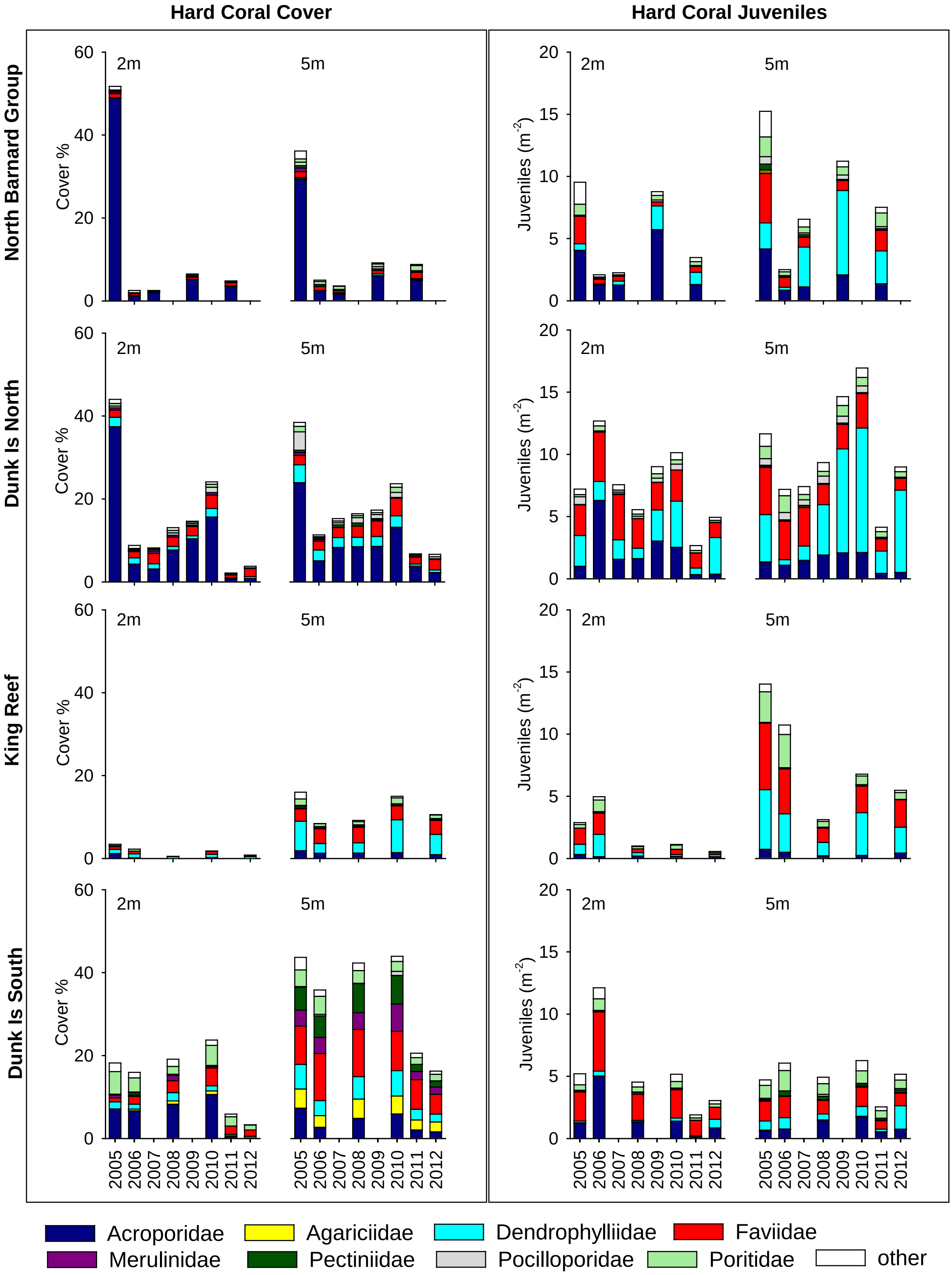

Figure 25: Composition of hard coral communities: Herbert Tully sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

Averaged over both sites the FORAM index at Dunk Is North was assessed to have declined in 2012 (Table 9). As indicated in Figure 26, this result is driven by a steep decline at Site 1, with the FORAM index at site 2 similar to that observed in 2005-2007.

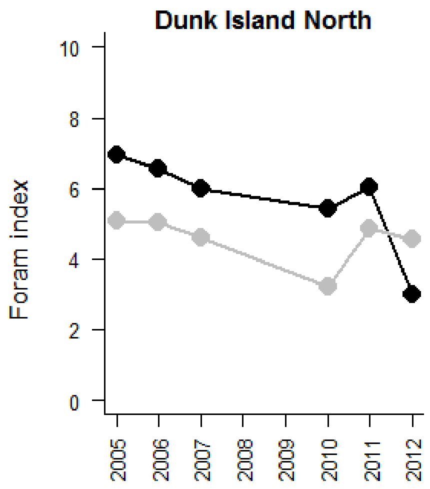

Figure 26: FORAM index in the Herbert Tully sub-region, Wet Tropics Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

3.3.4 Burdekin Region

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Figure 27: Reef Rescue MMP inshore coral reef monitoring sites: Burdekin Region.

Reefs in the Burdekin Region have been monitored since 1989 (AIMS, DERM, Sea Research), with bleaching and cyclones being identified as the principle disturbances to corals over that time (Ayling and Ayling 2005, Sweatman *et al.* 2007, Table A1-5). Temperature induced coral bleaching in 1998 had the largest impact from a single event, reducing coral cover on all reefs surveyed. Summer flood plumes extended to most reefs during the 90's (1994, 1997, 1998, Devlin *et al.* 2001), however no direct impacts in terms of loss of cover were reported (Ayling and Ayling 2005, Sweatman at al 2007). Following a series of drier wet seasons, seasonal flood plumes have returned with higher than median rainfall since 2008. The largest flood plume occurred during the 2010/11 wet season, when discharge from the Burdekin River exceeded the long term median by a factor of 5.8 (Table 5). This was accompanied by flood plumes from small local catchments that delivered low salinity waters more directly than the larger Burdekin River to the south. Cyclonic disturbances in 1990 (Cyclone Joy), 1997 (Cyclone Justin), 2000 (Cyclone Tessi), and 2006 (Cyclone Larry) have variously affected reefs in this region (Table A1-5). Most recently, Cyclone Yasi caused substantial loss of coral cover on some reefs, most notably Orpheus Is East where hard and soft corals were almost completely removed (Figure 28).

The cumulative influences of these past disturbance events along with underlining environmental conditions contribute to the “poor” condition of coral communities in this region in 2012. This continues several years of “poor” assessments, driven by low coral cover, underperforming coral growth, persistently high cover of macroalgae, and low densities of juvenile corals (Table 10). Which of these indicators of coral community condition are influencing condition assessments varies between reefs based largely on the interaction between past disturbance regimes and the local environmental conditions that have shaped coral community composition.

The composition of coral communities vary in response to environmental gradients, with water clarity and exposure to sedimentation widely acknowledged as key parameters. Within this region there is a shift from communities dominated by the families Acroporidae, Pocilloporidae and Poritidae (genus *Porites*) in clearer waters and in energetic hydrodynamic settings that preclude the accumulation of fine grained sediments, through to communities dominated by families such as Agariciidae, Oculinidae, Pectiniidae and Poritidae (Genus *Goniopora*) in more turbid and sheltered settings (Figures 28 and 29). In addition to selecting for different community types, the environmental setting of these reefs has also resulted in differential exposure to disturbances. The orientation of the reef differentially exposes corals to physical damage by cyclone drive waves, while differences in community composition result in differential impact of bleaching events as susceptibility to thermal stress varies among species (Baird and Marshall 2002). The generalisation is that communities dominated by Acroporidae have been most impacted by cyclones and bleaching events and in 2012 share very low coral cover. Conversely the relatively sheltered communities at 5m depth at Lady Elliot Is and at Middle Reef maintain moderate coral cover due to being sheltered from recent cyclones and having a high representation of species relatively resistant to thermal stress.

Compounding loss of coral cover is the almost ubiquitously low density of juvenile corals in this region (Table 10, Figure 29). The only reef in the region with consistently moderate to high densities of juvenile corals is Lady Elliot Reef at 2m depth where there have been unusually high densities of juvenile mushroom corals (Fungiidae) and a strong recruitment of *Turbinaria* in 2012 (Figure 29). In part it appears that low density of juveniles is a result of poor larvae supply with low and inconsistent settlement of coral spat (Figure 30), presumably due to regionally low coral cover and poor connectivity to broodstock farther afield (AIMS in-house modelling). The overall assessment for the density of juvenile hard corals remains ‘very poor’, while the drop in coral settlement from last year’s pulse sees this metric downgraded to ’very poor’ for 2012 (Table 10).

Low rates of coral cover increase during periods when no acute disturbances are recorded have been repeatedly observed in this region (Table 10, Thompson *et al.* 2011, 2012). In general, recovery has been slow or not occurred at; Pandora Reef, Geoffrey Bay, Orpheus Is East and Orpheus and Pelorus Islands West.

The ‘poor’ condition of coral reef communities in the Burdekin Region partly reflects the consequences of coral mortality during the mass bleaching events in the summers of 1998 and 2002 (Berkelmans *et al.* 2004, Sweatman *et al.* 2007) and then Cyclone Yasi in 2011. It appears that these events, and in particular the 1998 event, were of sufficient severity and spatial extent to substantially limit the supply of larvae and, hence, reduce the rate at which coral communities were able to recover (Done *et al.* 2007, Sweatman *et al*. 2007). Hydrodynamic modelling indicates limited connectivity between Halifax Bay and reefs further offshore (Luick *et al.* 2007, Connie 2.0), and so regionally reduced coral cover may partially explain the low settlement of coral larvae leading to low densities of juvenile colonies and poor rates of recovery of coral cover observed on most reefs in the Burdekin Region. In late 2010, we recorded a strong settlement pulse of *Acropora* spat that followed by a very gradual increase in cover of *Acropora* on some reefs. However, it is also possible that atypical currents provided greater connectivity to more distant broodstock in that year. Irrespective of the source of these larvae, their survival and progression into juvenile size classes is likely to have been reduced as a result of Cyclone Yasi, raising concern for the longer-term resilience of these communities (Done *et al.* 2007, Sweatman *et al.* 2007).

Possibly as a result of, but also potentially contributing to, the low rate of recovery, most benthic communities in this region have high cover of either macroalgae or soft corals (Figure 28). While Cyclone Yasi stripped both macroalgae and soft corals from more exposed reefs, there has been rapid regrowth of macroalgae over the 2011-2012 period at Geoffrey Bay, Lady Elliot Reef, and Pandora Reef. The assessment for macroalgae has been downgraded to 'moderate' for 2012 (Table 10). Macroalgae have been documented to suppress fecundity (Foster *et al*. 2008), reduce recruitment of hard corals (Birrell *et al*. 2008b, Diaz-Pulido 2010) and diminish the capacity of growth among local coral communities (Fabricius 2005), leading to protracted recovery from impacts. The delay in re-establishing is critical for coral communities exposed to a high frequency of disturbances and there is growing evidence for the active role of macroalgae in suppressing recovery through manipulation of microbial communities associated with corals (Morrow *et al*. 2012, Vega Thurbur *et al*. 2012). Similarly, occupation of space by soft corals effectively precludes the settlement of hard corals.

Recent palaeoecological evidence suggests that present-day coral assemblages in the Burdekin Region are the result of a shifted-baseline; from dominant arborescent *Acropora* to a remnant community of sparse *Acropora* and / or dominant non-*Acropora* species (Roff *et al.* 2013). An implied cause of this change is the sustained decline in water quality resulting from the expansion of agriculture in the catchment. Exposed to increased chronic stress the, once ubiquitous, suite of arborescent *Acropora* corals were no longer able to recover from recurring impacts of cyclones and floodwaters, suffering a systematic collapse between 1920 and 1955. In the context of Roff *et al*. 2013, the current *Acropora* assemblages on inshore reefs represent fragile communities exposed to poor water quality, with low resistance and resilience, and an uncertain future. This interpretation is supported by the observed relationship between the discharge of local rivers and levels of disease amongst the coral community (Thompson *et al.* 2012), both in this and other regions monitored under the MMP.

Table 10: Benthic community condition: Burdekin Region. For each reef the overall condition score aggregates over the metrics excluding Settlement and FORAM index. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= 'very poor', orange= 'poor', yellow= 'moderate', light green= 'good', dark green= 'very good'. The average of the regional scores for metrics, excluding Settlement and FORAM index, result in the overall condition regional assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall Condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density		Settlement	FORAM index
Orpheus Is East	2	neutral	-	+	+	-			
	5	-	-	neutral	+	-			
Pelorus Is & Orpheus	2	-	-	neutral	+	-			
	5	-	neutral	-	+	-		-	-
Havannah Is	2	- -	-	-	+	-			
	5	- -	-	-	+	-			
Pandora Reef	2	- - -	-	neutral	-	-			
	5	- - -	-	neutral	-	-		-	-
Lady Elliot Reef	2	- -	-	-	-	+			
	5	neutral	neutral	-	neutral	+			
Middle Reef		-	neutral	-	+	-			
Geoffrey Bay	2	- - - -	-	-	-	-			
	5	- - -	-	-	-	neutral		-	-
Regional assessment		🟧	🟥	🟧	🟨	🟥		🟥	🟥

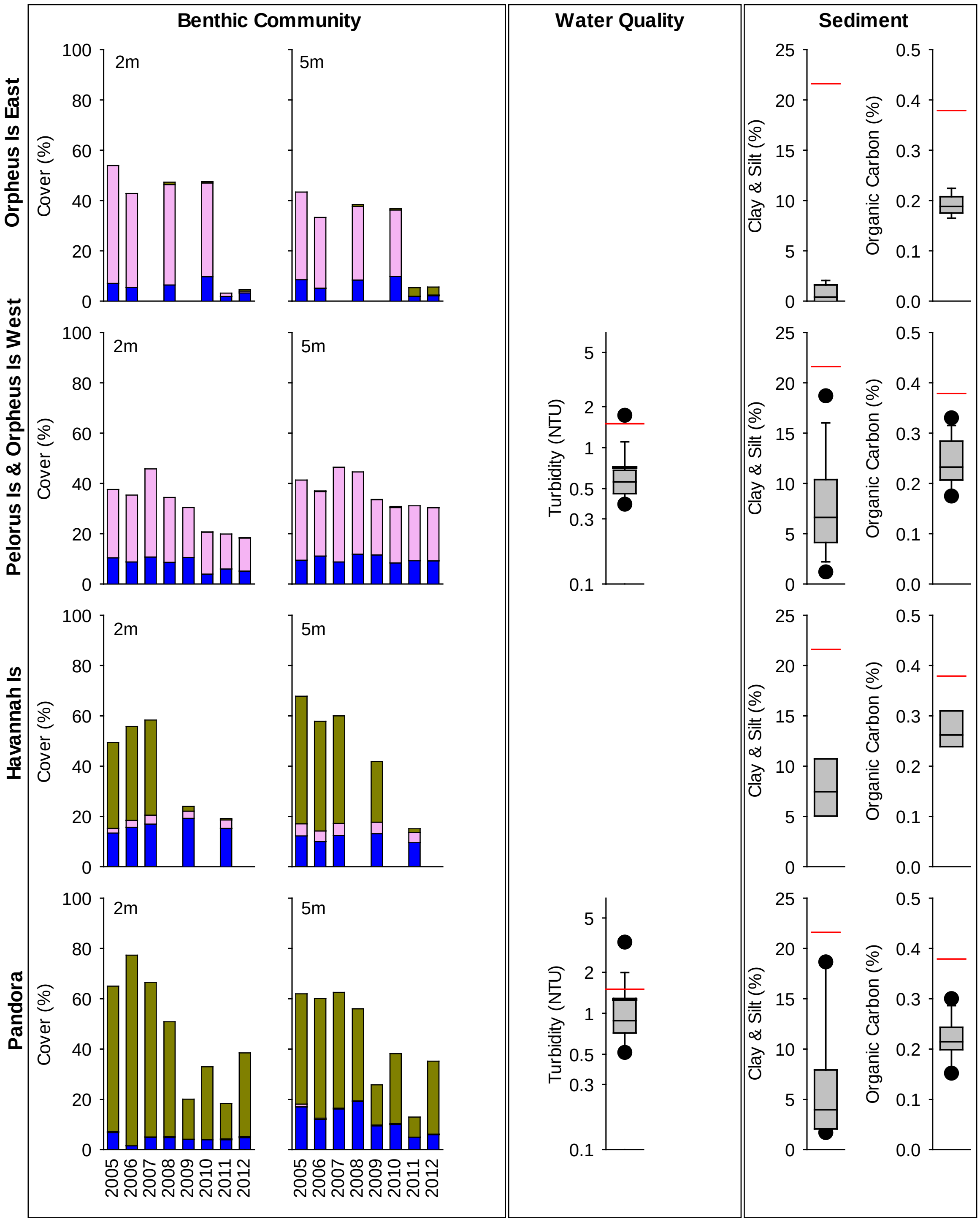

Figure 28: Cover of major benthic groups and levels of key environmental parameters: Burdekin Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box), mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guideline for turbidity parameters (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

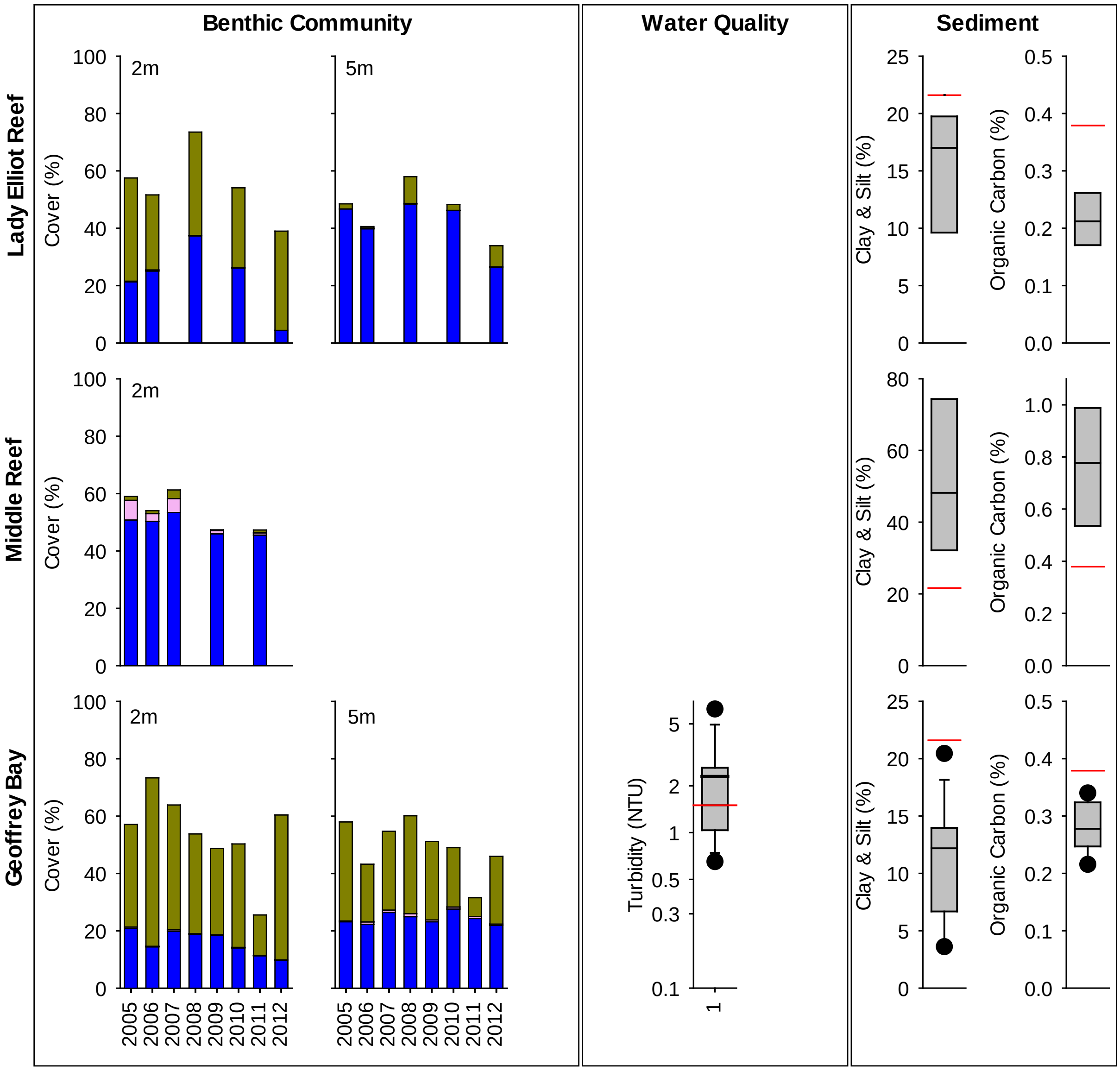

Figure 28: continued. Note different scales for sediment quality parameters at different reefs.

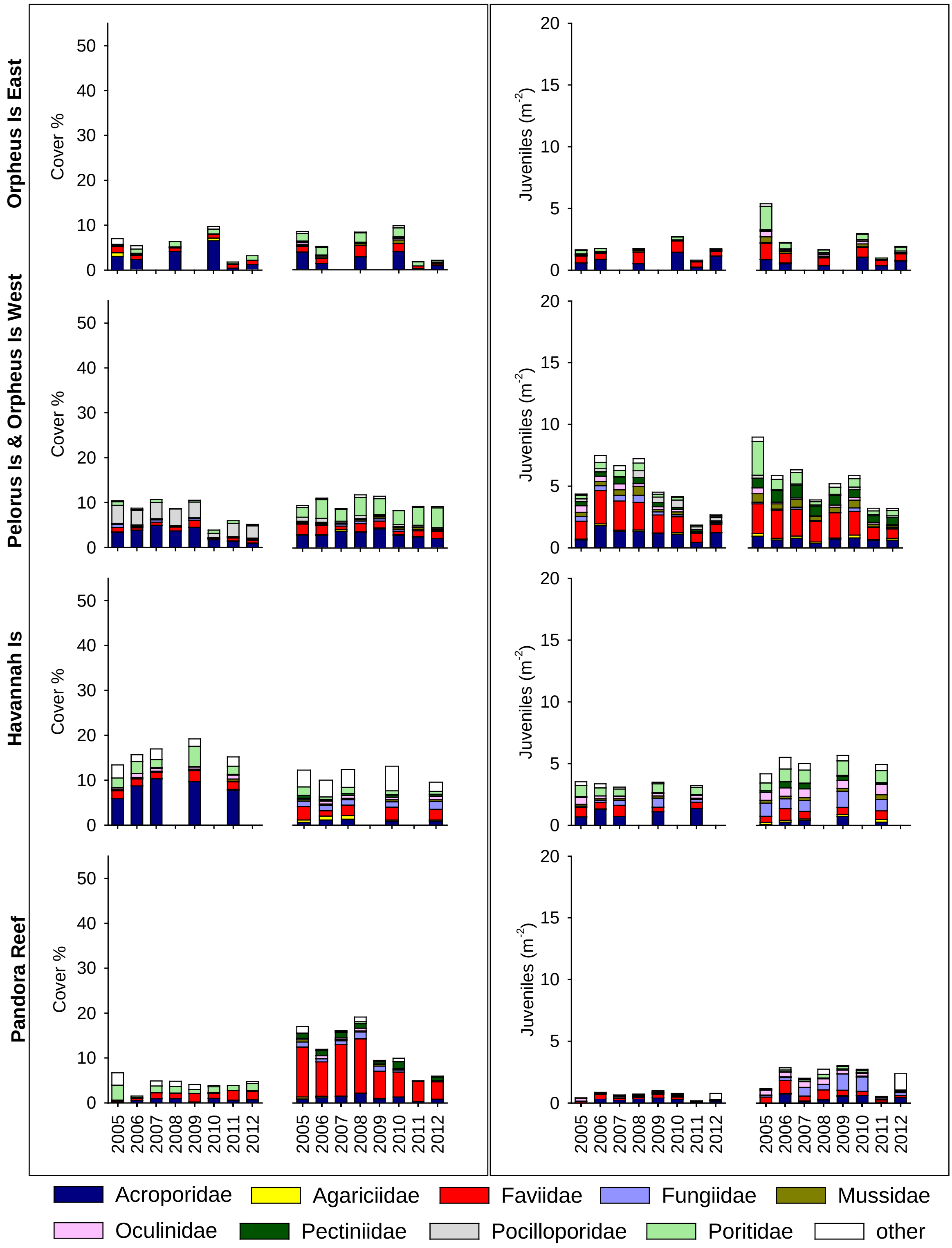

Figure 29: Composition of hard coral communities: Burdekin Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into ‘other’.

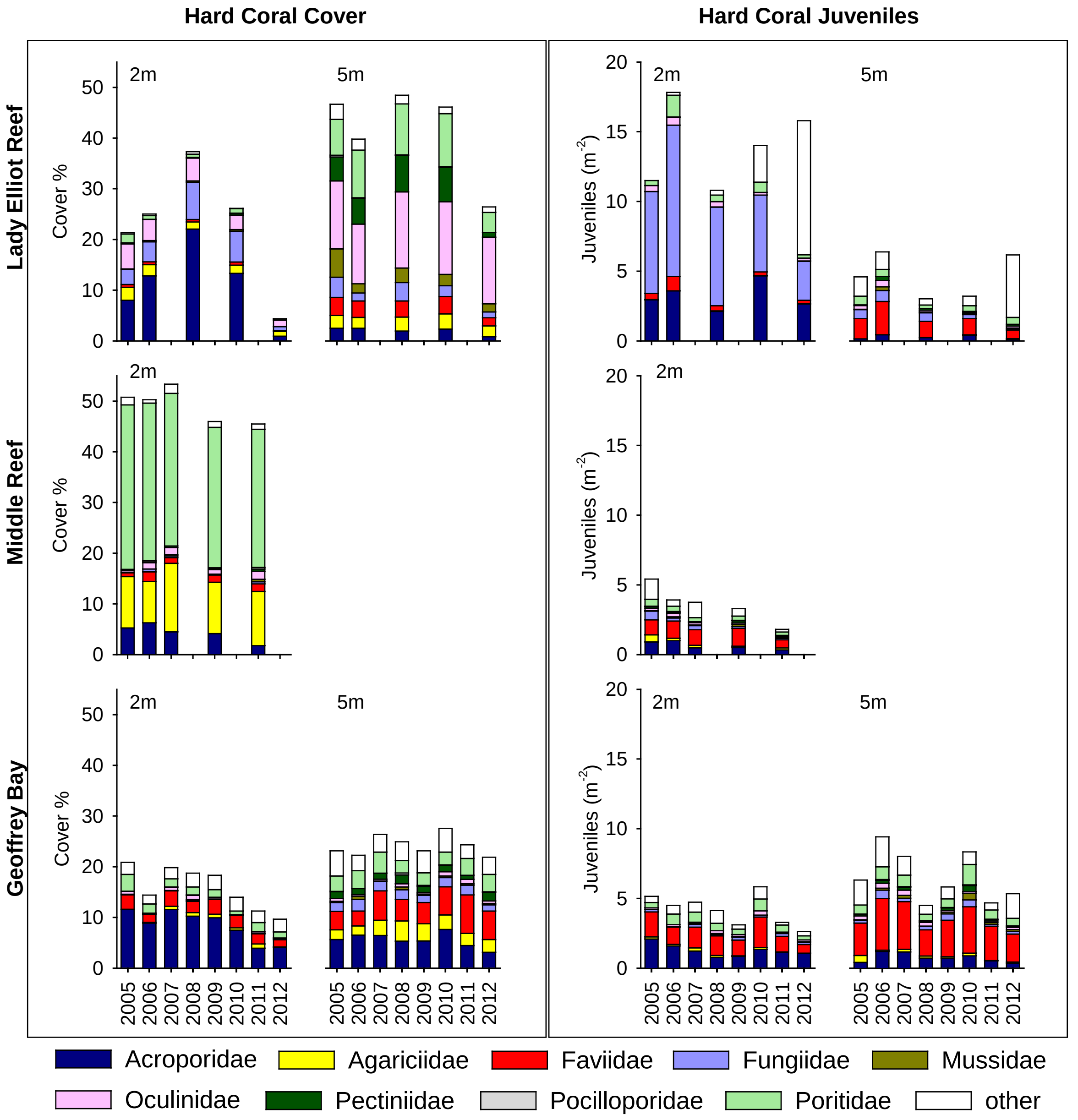

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Figure 29: Continued

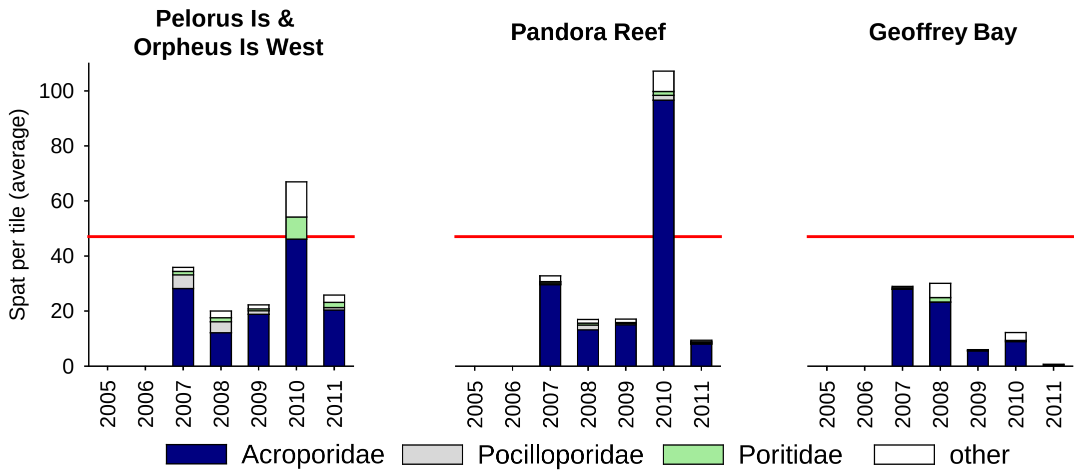

Figure 30: Coral settlement to tiles: Burdekin Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

The FORAM index on all three reefs of the Burdekin Region clearly declined since 2005 (Figure 31). Communities at Geoffrey Bay had consistently lower FORAM indices than other reefs, caused by a high relative abundance of heterotrophic species. Similar to other regions, we assume that this increase in heterotrophic species is driven by increased availability of food as indicated by higher organic content of the sediments, and also more fine grained sediment. The declines in FORAM index resulted in a negative condition rating of the communities of foraminifera on all three reefs (Table 10), and subsequently also for the entire region. Thus, foraminiferal assemblages indicate possible environmental stress in this region over recent years.

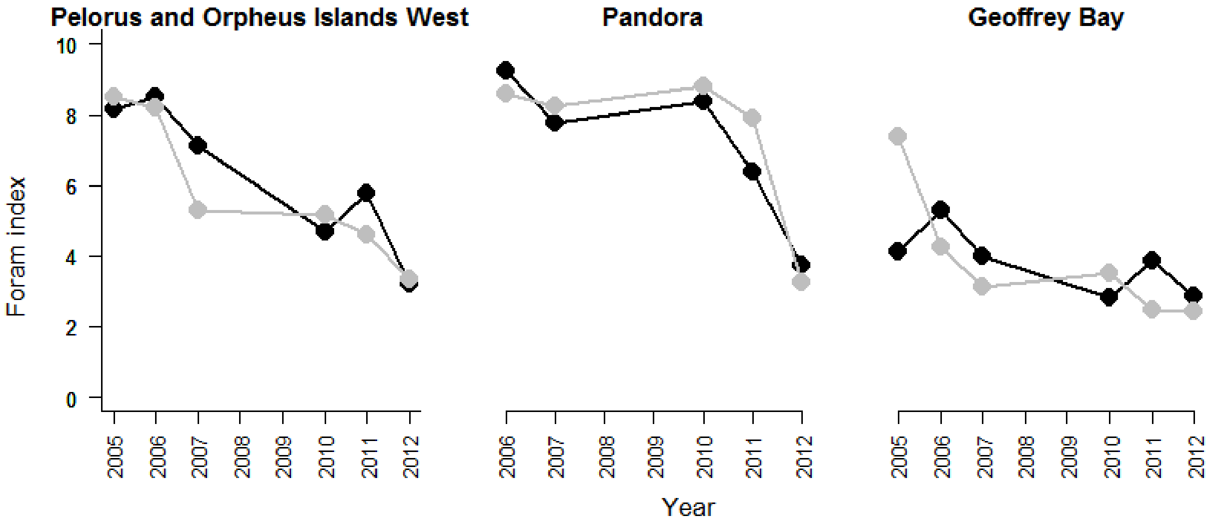

Figure 3115: FORAM index in the Burdekin Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

3.3.5 *Mackay Whitsunday Region*

There are limited historical time-series data available for the coral communities in this region (Sweatman *et al.* 2007). The largest widespread disturbances in recent history were coral bleaching events in 1998 and 2002, which most likely affected the reefs monitored by this program (Table A1-5). Observations from Dent Is and Daydream Is suggest an approximate 40% reduction in coral cover during 1998, while observations from AIMS LTMP monitoring sites at reefs in the outer Whitsunday Group record no obvious impact in 1998 and only marginal reductions in 2002 (Sweatman *et al.* 2007). Since 2005 there has been one known disturbance event, Cyclone Ului in 2010, the impacts of which were predominately restricted to Daydream and Double Cone Islands (Table A1-5).

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Figure 32: Reef Rescue MMP inshore coral reef monitoring sites: Mackay Whitsunday Region.

The overall condition of coral communities the Mackay Whitsunday Region in 2012 has remained “moderate” (Table 11, Figure 5). Positive aspects of the communities indicated by persistently low cover of macroalgae and moderate to high coral cover on most reefs balance the negative aspects of community condition of low and continued declines in the density of juvenile colonies and a lack of cover increase during periods free from acute disturbance. Although the lack of such disturbance has resulted in moderate to high cover of hard and soft corals in the region, gradual declines apparent since 2008 across the region indicate that environmental conditions are chronically impacting coral communities.

Table 11: Benthic community condition: Mackay Whitsunday Region. For each reef the overall condition score aggregates over the metrics excluding Settlement and FORAM index. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= ‘very poor’, orange= ’poor’, yellow= ‘moderate’, light green= ‘good’, dark green= ‘very good’. The average of the regional scores for metrics, excluding Settlement and FORAM index, result in the overall condition regional assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Double Cone Is	2	++	+	+	+	-		
	5	neutral	+	-	+	-	neutral	-
Daydream Is	2	-	neutral	-	+	-		
	5	neutral	neutral	-	+	neutral	-	-
Hook Is	2	-	neutral	-	+	-		
	5	-	neutral	-	+	-		
Dent Is	2	neutral	+	-	+	-		
	5	-	neutral	-	+	-		
Shute Is & Tancred Is	2	+++	+	neutral	+	+		
	5	+	neutral	-	+	+		
Pine Is	2	- - -	neutral	-	-	-		
	5	neutral	neutral	-	+	neutral	-	neutral
Seaforth Is	2	- - -	-	-	-	neutral		
	5	- -	-	-	neutral	neutral		
Regional assessment		🟨	🟨	🟥	🟩	🟧	🟥	🟥

Land use on the adjacent coast line is dominated by agriculture, primarily sugar cane cultivation. As such, reefs in the Mackay Whitsunday Region are considered to be at high risk from agricultural runoff (Brodie and Furnas 2001), supported by MMP flood monitoring which indicates high exposure to terrestrially derived material (Devlin *et al.* 2010). Collectively, the sediments on the reefs monitored in this region have the highest, and increasing, proportion of fine grained particles and nutrients, and the lowest levels of inorganic carbon (Figures 2, 33). The surrounding waters are nutrient-rich and highly turbid with mean chlorophyll and turbidity levels at or above the Guidelines (GBRMPA 2010) (Figure 33, Schaffelke *et al*. 2012). The combination of fine grained sediments and high turbidity, along with high rates of sedimentation (Appendix 3) and observations of substantial sediment deposits on substrata, corals and coral settlement tiles, indicates that coral communities in this region are exposed to the effects of sediments both directly through sedimentation and smothering and indirectly through light attenuation as a result of turbidity.

Reefs in the Whitsunday Islands are generally sheltered from wave action by the surrounding islands. This results in limited wave-driven re-suspension and, hence, limited transport of sediments away from the reefs, leading to the accumulation of fine sediments. Prior to the 2009 surveys, observations of sediments smothering live corals were rare and limited to occasional individuals. From 2009 onwards, accumulated sediments on living coral colonies have been a commonly observed cause of partial mortality and disease. The period over which this increase in sediment has been observed coincides with increased flows rivers in this and adjacent regions (Table 5). Although not supported by a direct causal link, these observations provide evidence that increased turbidity resulting from runoff (Fabricius *et al*. 2013a) is contributing to increased sediment deposits on the reefs in this region.

The sediment regime has clearly influenced the composition of coral communities in this region. The families Oculinidae, Pectiniidae, Agariciidae and Poritidae (genus *Goniopora*) are all found in relatively high abundance on some reefs (Figure 34) and are collectively considered sediment-tolerant taxa (Thompson *et al.* 2010a). Meanwhile most reefs have relatively low abundance of Acroporidae. Low abundance in the genus *Acropora* is a useful proxy for determining high sedimentation and turbidity, as many species of this genus favour high light environments (Thompson *et al.* 2010a). At the two reefs, Daydream Is and Dent Is where cover of Acroporidae is relatively high at the 5m depth, cover of this family has steadily declined in the period 2008-2011 (Figure 34). In the case of Daydream Is much of this loss can be attributed to the physical effects of Cyclone Ului. However the absence of such effects at Dent Island, and the continued decline at Daydream Is, indicate other factors influencing this trend. Levels of disease showed marked increases following 2010 and likely contribute to this decline. Higher incidence of disease showed a positive relationship to increases in discharge from local rivers, a pattern observed also in the other survey regions (Thompson *et al*. 2012). These findings supporting published studies which have shown a strong connection between physiochemical aspects of terrestrial runoff (e.g. sedimentation, enrichment with nutrients and organic carbon) and disease prevalence (Bruno *et al.* 2003, Haapkylä *et al.* 2011, Kaczmarsky and Richardson 2010). Surveys in 2012 showed levels of disease had decreased at Daydream Is coinciding with the first observed increase in hard coral cover at this site since 2009 (Figure 33).

Observed increase in hard coral cover was marginal across the region in 2012. Notable sites include: Shute and Tancred Islands and Double Cone Is (2m), Daydream Is and Pine Is (5m) (Figure 34). For both 5m sites this was the first time hard coral cover had increased since 2008. With the exception of Pine Island, increases were primarily driven by increased cover of family Acroporidae. At Pine Is increased cover in corals of the families Agariciidae and Pectinidae promoted this change. Continued declines or no change were evident at the remaining sites. In general changes in hard coral cover across the region have once again fallen short of those predicted for the types of coral communities at these reefs and thus the condition assessment for this indicator has remained ‘very poor’ (Table 11).

The cover of macroalgae has remained stable throughout the region. Only Pine Is and Seaforth Is maintain a significant macroalgal cover. These reefs are the closest to the rivers influencing the region and water quality data from Pine Is shows that mean chlorophyll concentration and turbidity consistently exceed Guidelines (Figure 33, Schaffelke *et al*. in review). Turbidity and chlorophyll concentrations are lower at Daydream Is albeit still exceed the GBRMPA Guidelines. However, macroalgal cover has not increased here in recent years despite the availability of substratum for colonisation following Cyclone Ului. The presence of Acroporids at this site suggests that light availability is not limiting here so it is not certain what has inhibited increased macroalgal cover. One possible explanation is grazing pressure from the high abundance of sea urchins observed at this site. Indeed the presence of herbivores has been shown to be of great importance in maintaining reefs in a coral dominated state and protecting reef resilience (Hughes *et al*. 2007).

The density of juvenile corals continued to decline across the region in 2012 ensuring the continued “poor” assessment for this metric (Table 11, Figure 34). This decline, along with recent very low settlement of larvae (Figure 35) may both be symptomatic of the cumulative influence of enhanced runoff over recent years (Table 5). High levels of disease amongst corals following major floods are evidence that environmental conditions are causing stress to adult corals in this region (Thompson *et al.* 2012). Stress during ontogenesis can reduce coral fecundity (Rinkevich and Loya 1987). At the same time increased sediment accumulation reduces larval settlement and survival (Babcock and Smith 2002, Birrell *et al*. 2005, Goh and Lee 2008).

Overall, the influence of prevailing environmental conditions such as high turbidity and increasing proportions of fine sediment on the coral communities in this region (particularly on juvenile survivorship) cannot be underestimated. Despite the still moderate to high coral cover on most reefs, the continued decline in juvenile abundance and lack of cover increase suggest a lack of resilience within the community and potential vulnerability to phase shifts should the region be impacted by a severe region-wide disturbance event such as coral bleaching.

Previous reports showed that the foraminiferal assemblages in the Mackay Whitsunday Region are distinct from those in other regions. The diversity of symbiont-bearing foraminifera was generally lower than in the regions further north (Thompson *et al.* 2012). In addition, the relative abundance of symbiont-bearing species was low resulting in generally lower regional FORAM indices.

Over the observation period (2005-2012) the composition of foraminiferal assemblages remained relatively stable at Daydream and Pine Is, and FORAM indices are on low levels (Figure 36).

The FORAM index on one site at Double Cone Is decreased markedly between 2006 and 2007. However, it becomes now apparent that there is a general trend of decline on both sites from 2005 to 2012, resulting in a negative condition ranking for that reef. The FORAM index at Daydream Is has remained more or less stable between 2010 and 2012 but is significantly lower than the 2005-07 baseline, resulting in a negative condition ranking for that reef in 2012. The FORAM index at Pine Is has not appreciably changed since 2005, giving again a neutral condition assessment for 2012. However, the FORAM index at that location has been at values close to the minimum possible (2, in case only heterotrophic taxa were present) since inception of this monitoring program. Thus values cannot decrease by much even if environmental conditions decrease.

A recent study of foraminiferal assemblage composition in sediment cores from the Whitsunday area showed that foraminiferal communities on the MMP survey reefs investigated in this area (Daydream and Double Cone Is, and also Dent Is in previous surveys) have remained stable over several thousand years prior to European settlement (Uthicke *et al.* 2012a). However, after European settlement, the taxonomic composition the foraminiferal assemblages changed on the three MMP reefs which are closer to the coast and subjected to agricultural runoff, while it remained stable on reefs more distant from the coast (Border Is and Deloraine Is). Therefore, the recently observed changes in the assemblage composition and FORAM index on the MMP reefs occurred in already altered assemblages; however, these changes have a high indicator value for the monitoring of marine water quality (Fabricius *et al.* 2012).

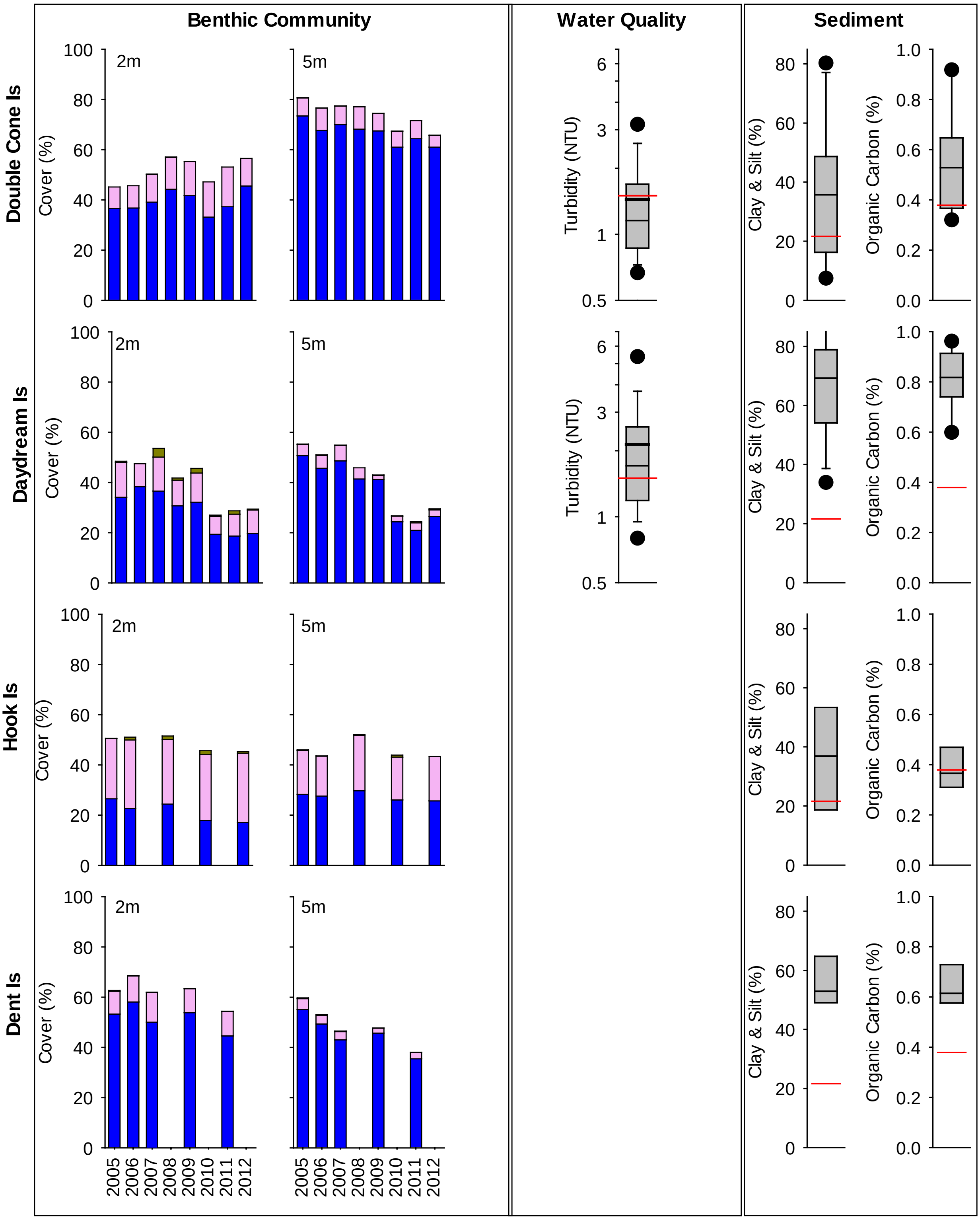
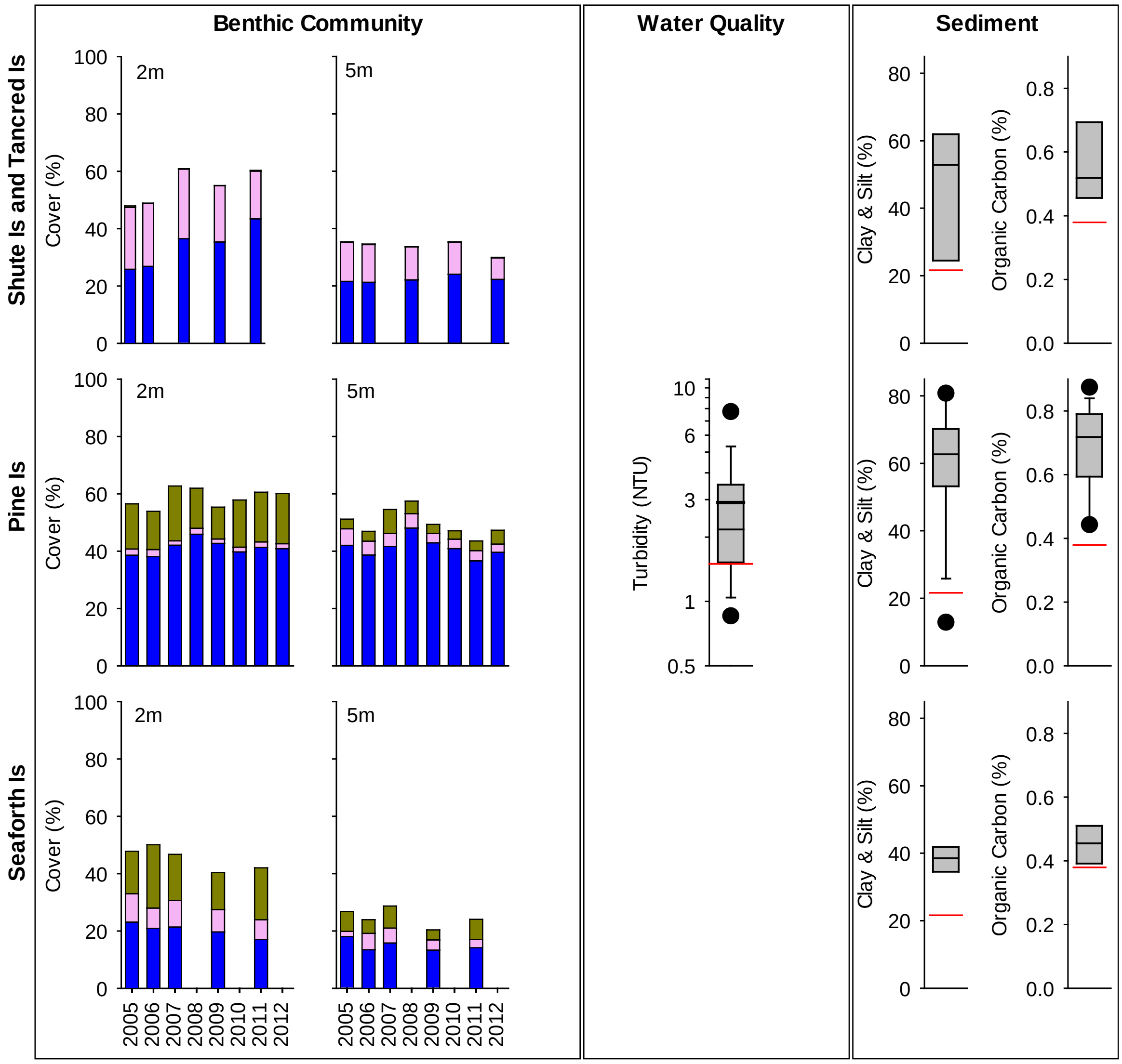


Figure 33: Cover of major benthic groups and levels of key environmental parameters: Mackay Whitsunday Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box), mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guideline for turbidity (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.



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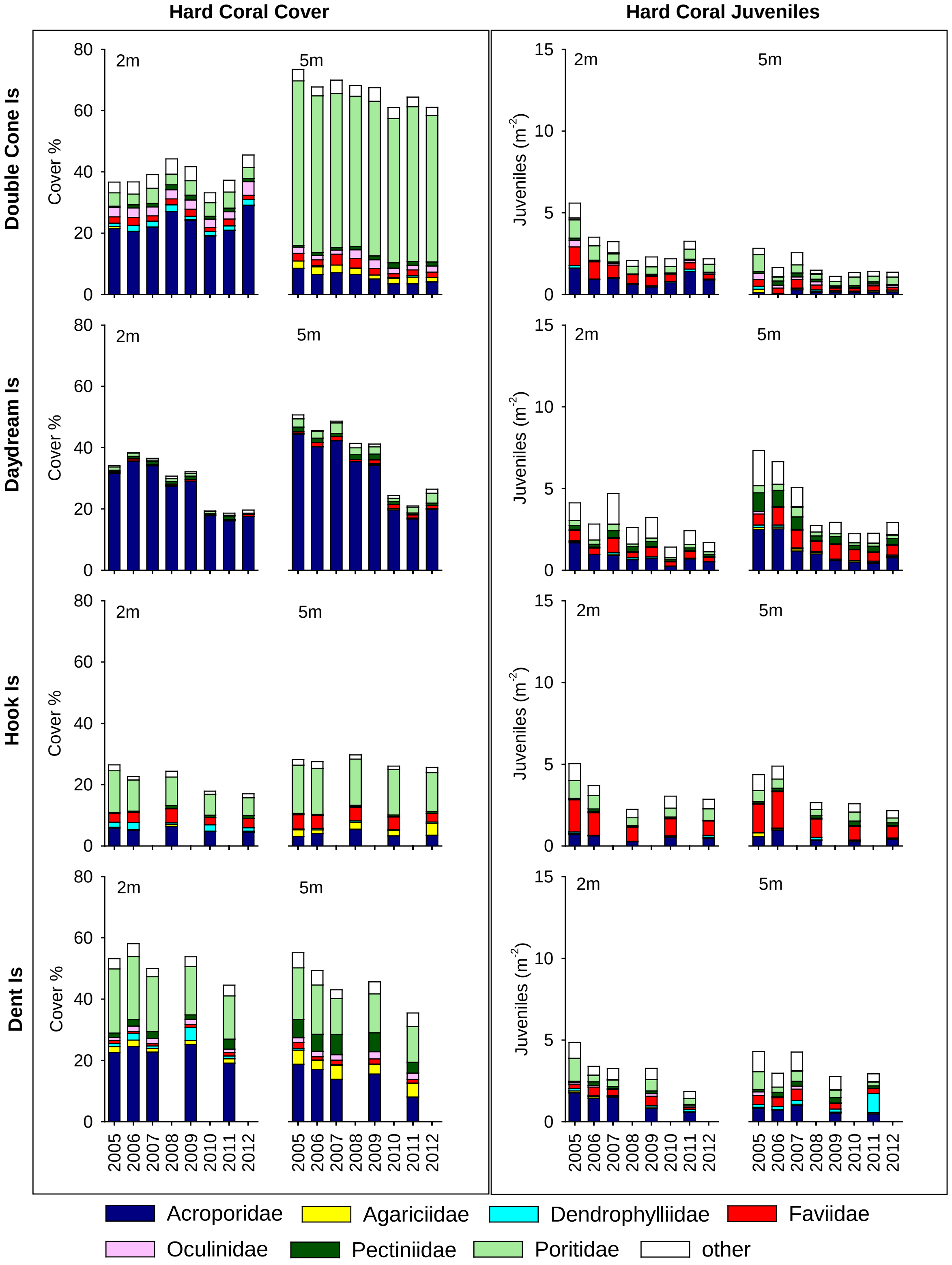
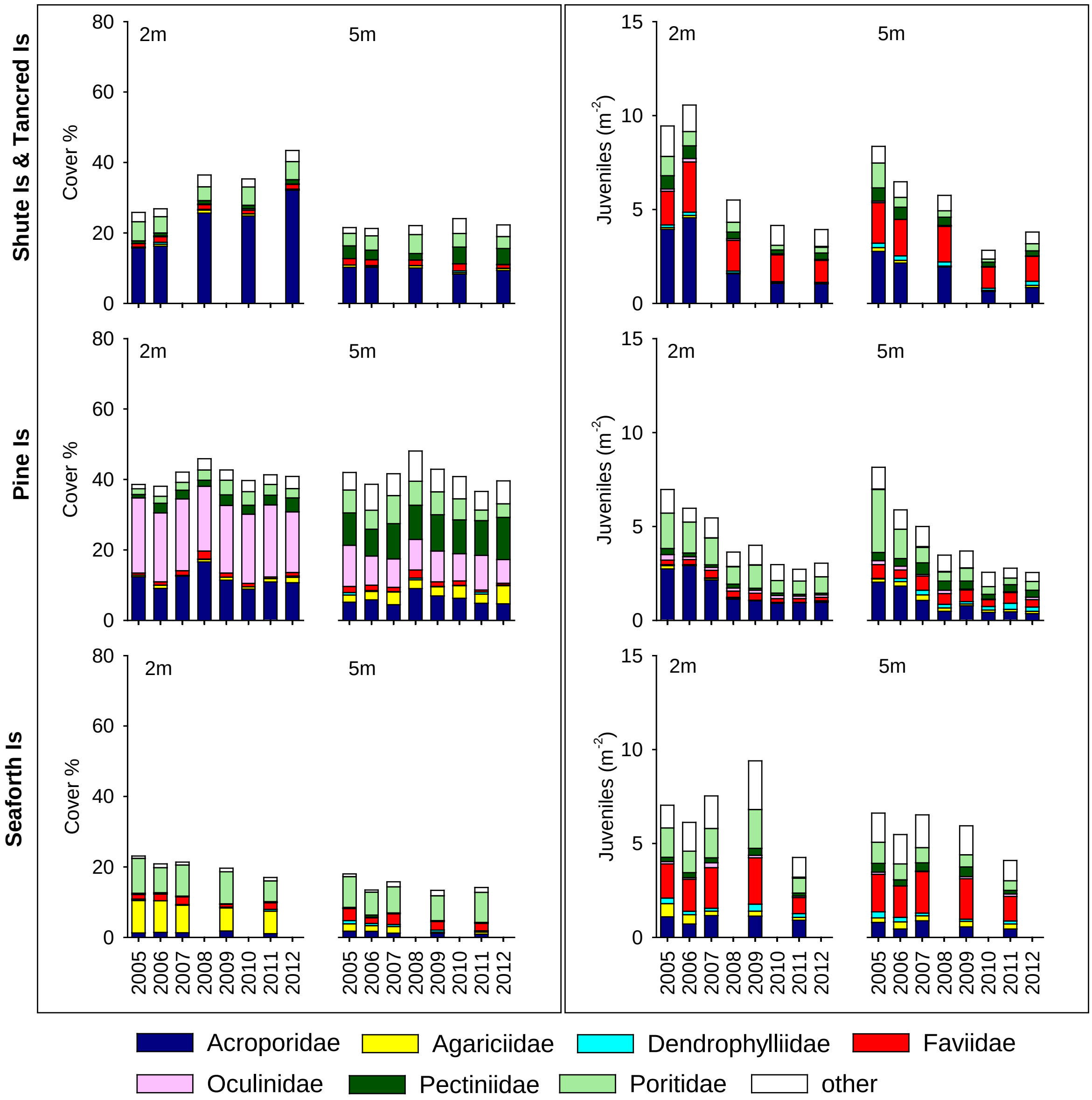


Figure 34: Composition of hard coral communities: Mackay Whitsunday Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.



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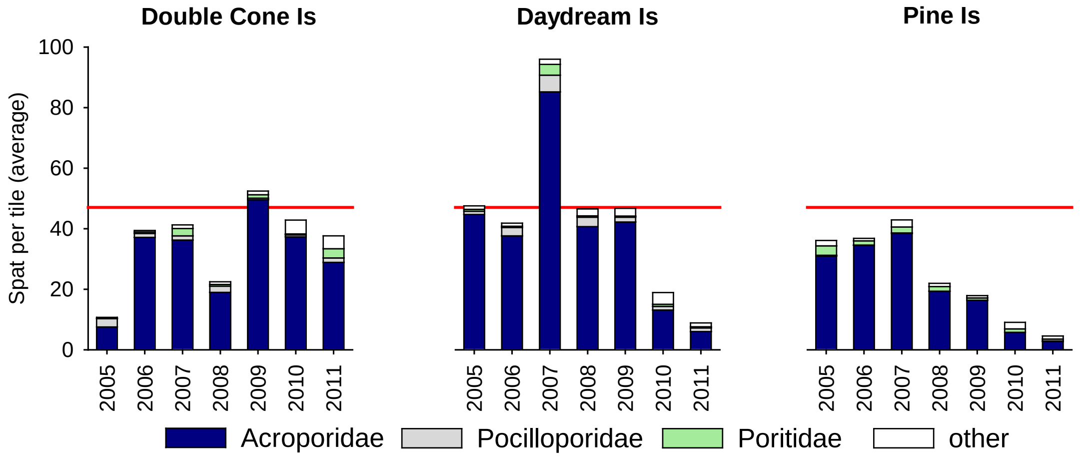

Figure 35: Coral settlement to tiles: Mackay Whitsunday Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

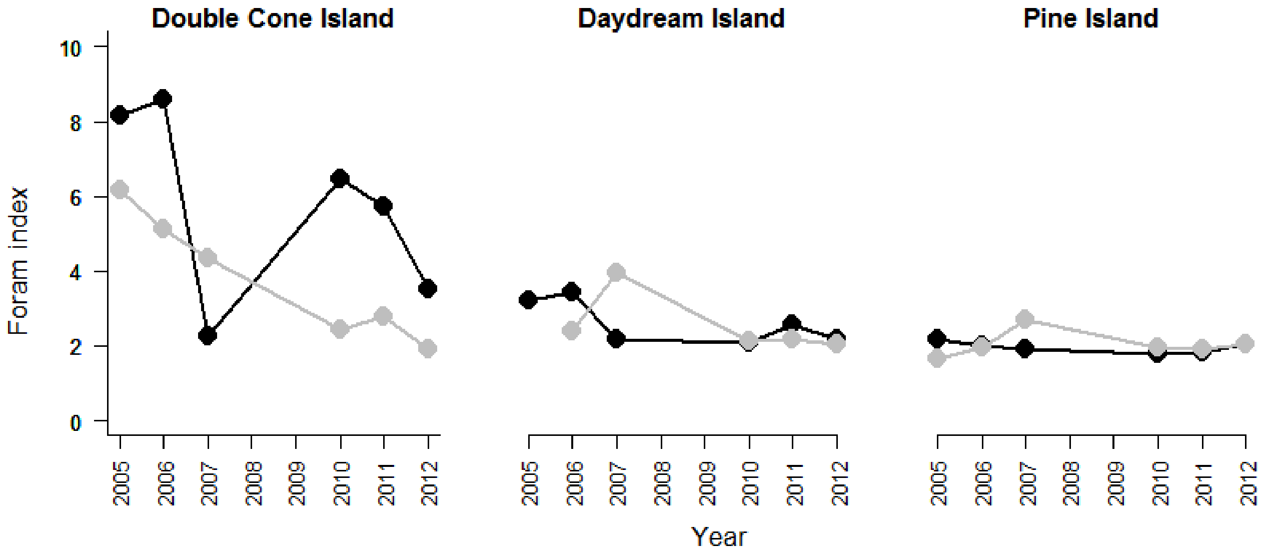

Figure 3616: FORAM index in the Mackay Whitsunday Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

3.3.6 Fitzroy Region

The Fitzroy NRM Region has the largest catchment area draining into the GBR. The climate is dry tropical with highly variable rainfall resulting in prolonged dry periods, followed by infrequent but major floods (Table 5). These floods have a profound impact on coral communities within Keppel Bay causing mortality to corals both as a direct result of inundation with low salinity water but also as a result of enhanced turbidity and nutrient availability. The exposure to critically low salinity is relative to the volume of the flood water entering the bay, the proximity of reefs to the river, the depth of corals (as low salinity flood plumes float over higher salinity seawater) and differences in tolerance among species (van Woesik 1991, Berkelmans *et al.* 2011, Devlin, *et al.* 2011). Relatively low proportions of fine-grained sediments at the reefs in this region (Figure 38) indicate that the hydrodynamic setting of these reefs is sufficiently energetic to prevent the long-term accumulation of fine-grained sediments. Hence, runoff is more likely to impact coral communities through increased turbidity and nutrient availability during, and in the months following, flood events (Devlin *et al.* 2011, Brando *et al.* 2011, Schaffelke *et al.* in review), rather than by smothering as a result of sedimentation. In addition to the periodic environmental gradient imposed by floods is a gradient in turbidity that decreases away from the coast and sheltered southern waters of Keppel Bay. In combination these flood driven and ambient water quality gradients determine the composition and dynamics of coral communities observed on the reefs monitored under the MMP.

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Figure 37: Reef Rescue MMP inshore coral reef monitoring sites: Fitzroy Region.

Of the six reefs monitored in this region (Figure 37) Peak Is and Pelican Is are situated in relatively turbid and nutrient-enriched waters compared to the waters surrounding the reefs further offshore; this is clearly evident in the differences in water column turbidity and chlorophyll (Figure 38, Schaffelke *et al*. in review). A direct result of this turbidity is the rapid attenuation of light reaching corals as depth increases. While generally high, turbidity at Pelican Is reached extremely high levels coinciding with flooding of the Fitzroy River (Schaffelke *et al*. in review). Median turbidity in the period following floods in 2008, 2010 and 2012 was at least 10 NTU; levels more than twice the suggested upper threshold beyond which corals may be severely light-limited (Cooper *et al.* 2007, 2008). The effect of light limitation results in a marked gradient in the composition of coral communities from a high proportion of the family Acroporidae, genus *Acropora* at 2m depth, to a mixed community at 5m (Figure 39). The communities at 5m depths at these reefs are unique among the reefs monitored under Reef Rescue MMP in having a high representation of the family Siderastreidae, genus *Psammocora,* and family Merulinidae, genus *Hydnophora*. These coral families are tolerant of the low light and high nutrient conditions found at these reefs (Figure 38). Although turbidity is not measured at Peak Is, the persistent low cover combined with very low juvenile density and a lack of substantial reef development suggest that the environmental conditions at this location are marginal for reef building corals. In contrast to the communities at Peak Is and Pelican Is, coral communities monitored on the reefs situated in the clear waters further from the coast and influence of the Fitzroy River are dominated by the family Acroporidae (mostly the branching species *Acropora intermedia* and *A. muricata*) at both 2m and 5m (Figure 39).

Prior to the beginning of monitoring under MMP in 2005, monitoring undertaken by the Queensland Parks and Wildlife Service from 1993 to 2003, identified reductions in coral cover at Halfway Is, Middle Is and North Keppel Is as a result of high seawater temperatures in 1998 and 2002 that were followed by rapid recovery (see Sweatman *et al.* 2007). Initial MMP surveys in 2005 documented moderate to high hard coral cover on all the *Acropora* dominated reefs confirming the resilience these communities had shown to prior bleaching events. Of note was that the resilience of coral communities observed between 1993 and 2005 coincided with a period during which there was no major flooding. In 2006 high temperatures again caused severe bleaching and loss of coral cover amongst the *Acropora* communities. It is the variable recovery and compounding of additional disturbances, including storms in 2008 and 2010 and flooding in 2008, 2010 and 2011 (Table A1-5) that have resulted in the current “very poor” condition assessment for reefs in this region (Table 12, Figure 5). Variable community responses following floods also help to identify areas where chronic suppression of coral communities as a result of poor water quality is implicated.

At each of the reefs dominated by branching *Acropora* (North Keppel Is, Middle Is, Humpy Is & Halfway Is and Barren Is) high temperatures in the summer of 2005/06 caused a marked reduction in coral cover, and an ensuing bloom of the brown macroalgae *Lobophora variegata* (Figure 38, see also Diaz-Pulido *et al.* 2009). The level of recovery of from this bleaching event is inversely related to the persistence of the macroalgal communities. At Barren Is, where mean chlorophyll concentration is below the Guidelines (Schaffelke *et al*. 2012), the bloom of *L. variegata* was less pronounced than at other reefs and recovery of coral cover was clearly evident in 2007. In 2012 coral cover had again increased despite additional losses in 2008 and 2010 attributed to a combination of storm damage and disease and then further disease in 2011. At the remaining reefs macroalgae cover has been persistently high and the rate of increase in coral cover low, or cover has continued to decline (Figure 38). It is likely that this lack of recovery is linked to flooding of the Fitzroy River. Exposure to fresh water during early 2011 occurred at 2m depths of Humpy and Halfway Islands resulting in coral mortality at these sites. Elsewhere it appeared salinity was not sufficiently reduced to kill the corals (Berkelmans *et al.* 2011, Devlin et al. 2011). Rather, a positive relationship between levels of disease and the magnitude of floods in the previous wet season, along with persistence of algal communities suggest a suppression of resilience during and following floods (Thompson *et al.* 2012). The reef showing the least recovery potential was North Keppel Is, where sediment sampling reveals a regionally high fraction of fine grain-sized particles and nutrient content indicating the potential for accumulation of, and higher exposure to, riverine materials (Figure 38, Table A1-2, A1-3). At both Middle Is and Humpy and Halfway Islands there were slight increases in cover at 2m depths through to 2009 followed by marked declines in 2011 attributed to exposure to low salinity. At 5m depths neither reef has shown any clear recovery potential with cover steadily declining to lowest recorded levels by 2012.

The dynamics of coral communities at Pelican Is and Peak Is differ from those offshore. The coral communities at Pelican Is and Peak Is were not strongly affected by the 2006 bleaching event and coral cover remained stable or increased over this period (Figure 38). Similarly, high macroalgae cover on these reefs is not only related to disturbance to the coral communities. Diverse algal communities were present when these reefs were first visited in 2004 (Sweatman *et al.* 2007) and are likely a natural component of the benthos in these more turbid and nutrient rich settings (Figure 38, Schaffelke *et al*. 2012). In 2008, coral cover and macroalgae cover declined at 2m depths at both reefs. These declines coincided with increased levels of disease concurrent with major flooding and physical damage attributed to storms. A decline of coral (at 2m) and macroalgae (2 and 5m) cover was noted in conjunction with yet another flooding event in 2010. In 2011 extreme flooding killed all but a few salinity resistant corals and temporarily reduced the cover of macroalgae at 2m depths. At 5m depth coral cover declined with a high incidence of disease recorded. Due to the higher abundance of the hyposaline tolerant coral genera *Psammocora* and *Cyphastrea* at 2m at Peak Is, the coral community at this reef was less affected by the flood than it was at Pelican Is, despite its closer proximity to the Fitzroy River. Osmotic stress did not kill corals at the 5m depth. In February 2011 almost all corals at 2m depth were dead, while those at 5m depth were alive but clearly stressed with large numbers of diseased and bleached colonies of both hard and soft coral observed. In 2012 corals had further declined at 5m presumably as the disease noted in 2011 continued to reduce coral cover while macroalgae increased (Figure 38).

The consistent pattern of high incidence of disease amongst coral communities following each of the recent floods supports the hypothesis of increased virulence by increased organic matter availability (Haapkylä *et al.* 2011). Reduction in light levels over extended periods of time as a result of higher turbidity from increasing concentrations of suspended sediments as well as dense plankton blooms, is another plausible explanation for reduced fitness of corals (Cooper *et al*. 2008).

Low and declining density of juvenile corals further contributes to the poor condition assessment for coral communities in this region (Table 12). Most notable are the extremely low densities at 2m depths at Peak Is and Pelican Is where almost all juveniles were killed by flood waters in 2011. At most other reefs juvenile densities have been consistently low following the loss of corals and increase in macroalgae in 2006. While Birrell *et al*. 2008b found that the presence *of L. variegata* promoted the settlement of on species of *Acropora* coral, this contradicts findings reported from the Caribbean (Kuffner *et al*. 2006) and the more general literature that indicate macroalgae suppress coral recruitment via a raft of physical and chemical mechanisms (e.g. Birrell *et al*. 2008a). Juvenile corals are also likely to be susceptible to the same chronic conditions that led to disease of larger colonies discussed above.

Settlement of coral spat to deployed settlement tiles in late 2010 and 2011 was lower than previously recorded at all reefs in this region (Figure 40). The reason for this very low settlement remains uncertain but was possibly influenced by the flooding of the Fitzroy River in 2010 and 2011. Fertilisation and early larval development in corals is severely compromised by exposure to salinities of between 28 and 30, especially when combined with elevated concentrations of suspended sediments or nutrients (Richmond 1993, Humphrey *et al.* 2008). For 2010, the majority of spawning in this region was predicted to have occurred approximately 5 nights after the full moon on the 21st November 2010. By the 4th of December, flood waters are clearly visible on satellite imagery extending at least as far offshore as Humpy Is (MODIS Aqua image courtesy NASA/GSFC, Rapid Response). Prior to this date cloud cover obscures the area, however, river discharge data do not suggest that flood waters would have preceded this date. That said, low temperatures in the month prior to spawning (Figure 4) may have delayed spawning until December in which case, spawned gametes would have floated directly into the flood plumes that covered the Region. Alternatively, or in addition, stress to corals during gametogenesis, as indicated by high incidence of disease in both mid-2010 and 2011, may have reduced fecundity of corals (Rinkevich and Loya 1987). At Pelican Is in particular, the loss of coral cover during the flooding of 2011 will have severely reduced local broodstock. Hence, the reduced settlement may be a direct reflection of a reduction in larval supply.

Table 12: Benthic community condition: Fitzroy Region. For each reef the overall condition score aggregates over the metrics excluding Settlement and FORAM index. Regional assessments for each metric convert three point categorical assessments into a five point scale consistent with reporting to the Paddock to Reef Program (see section 2.6.1 for more details): red= 'very poor', orange= 'poor', yellow= 'moderate', light green= 'good', dark green= 'very good'. The average of the regional scores for metrics, excluding Settlement and FORAM index, result in the overall condition regional assessment. Grey shading indicates sites/depths where metrics were not sampled.

Reef	Depth (m)	Overall condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Barren Is	2	+++	+	neutral	+	+		
	5	-	+	-	neutral	-	-	
North Keppel Is	2	- - -	-	-	neutral	-		
	5	- -	-	-	+	-		
Humpy Is & Halfway Is	2	- - - -	-	-	-	-		
	5	- - -	neutral	-	-	-	neutral	-
Middle Is	2	- - - -	-	-	-	-		
	5	- - - -	-	-	-	-		
Pelican Is	2	- - - -	-	-	-	-		
	5	- - -	-	-	neutral	-	-	neutral
Peak Is	2	- - - -	-	-	-	-		
	5	- - - -	-	-	-	-		
Regional assessment		🟥	🟧	🟥	🟧	🟥	🟥	🟧

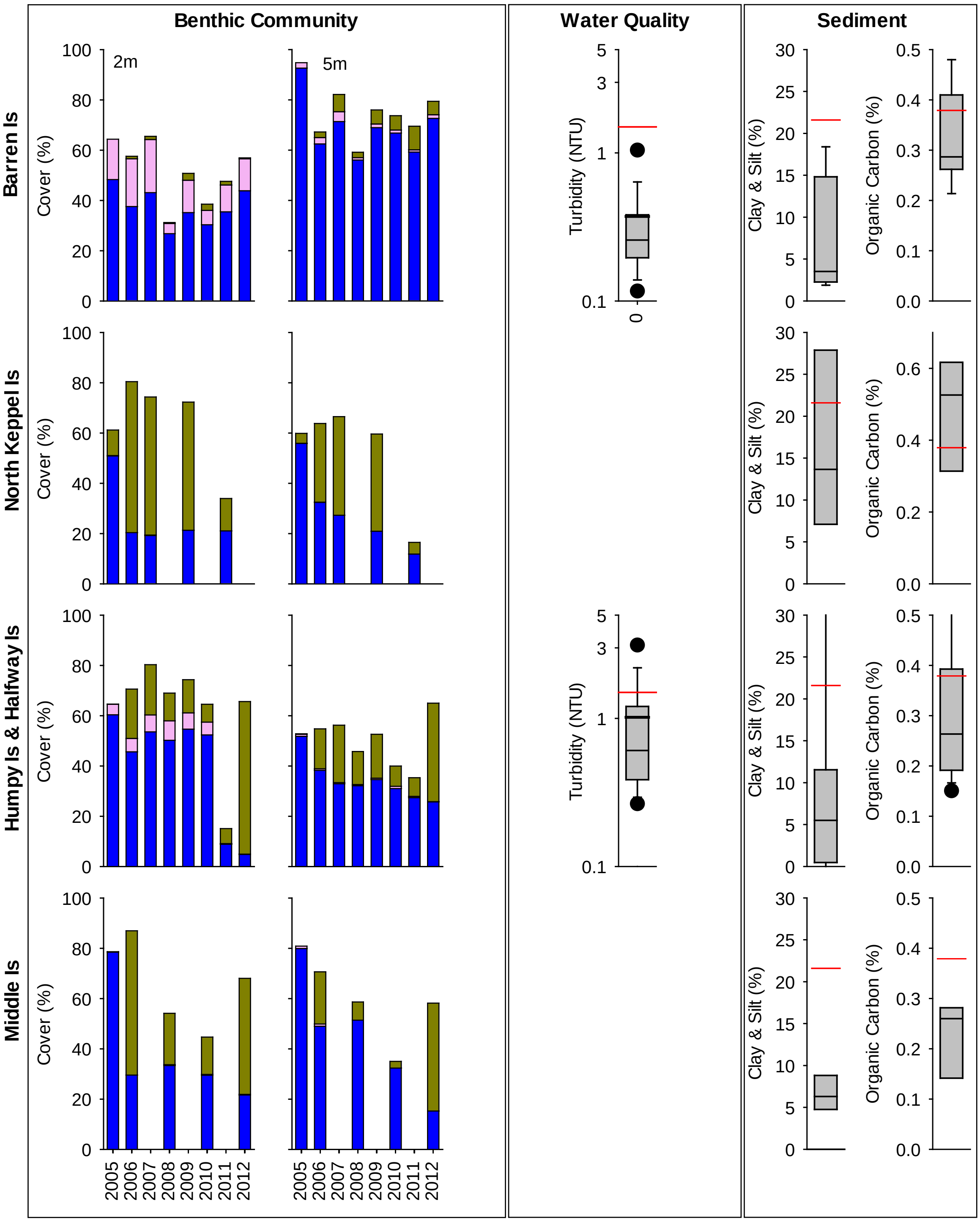

Figure 38: Cover of major benthic groups and levels of key environmental parameters: Fitzroy Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, i.e., median value (fine line within the grey box), mean value (heavy line, WQ only), and the ranges of the central 50% (grey box), 80% (whiskers), and 90% (black dots) of observations. Red reference lines indicate the Guidelines for turbidity (GBRMPA 2010), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

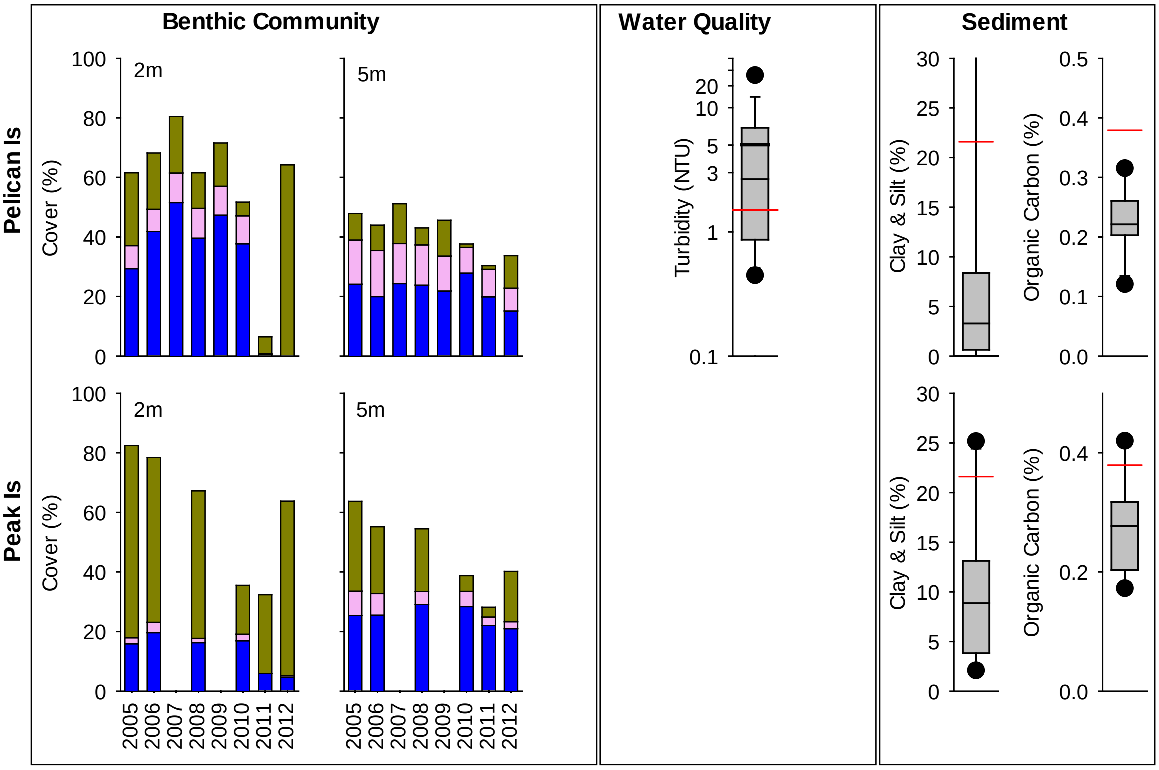

Figure 38: continued

In summary, the assessment of coral community condition for this region in 2012 declined to 'very poor', reflecting continued low densities of juvenile colonies, low rates of coral cover increase during periods free from acute disturbances, currently low coral cover as a result of multiple disturbances in recent years and a persistent cover of macroalgae at most reefs (Table 12). Generally, the coral communities in this region have shown limited recovery from the severe disturbance caused by coral bleaching in 2006. This assessment comes after a period of repeated flooding and contrasts recovery of coral cover following previous bleaching events, highlighting the detrimental influence of the combination of exposure to low salinity and increased turbidity. Light reduction as a result of turbidity, increased nutrient supply, as evidenced by higher levels of nitrogen in sediments (Figure 3, Table A1-3), along with lower salinity, are all mechanisms that reduce coral fitness or contribute to higher rates of disease in corals (e.g. Fabricius 2005, Voss and Richardson 2006, Haapkylä *et al.* 2011). With the eventual release from chronic pressures associated with repeated floods we may expect an improvement in coral community condition consistent with those observed in 2005, however at reefs such as Pelican 2m this improvement may be delayed if indications of a lack of connectivity to broodstock from which recovery can begin are confirmed by future observation.

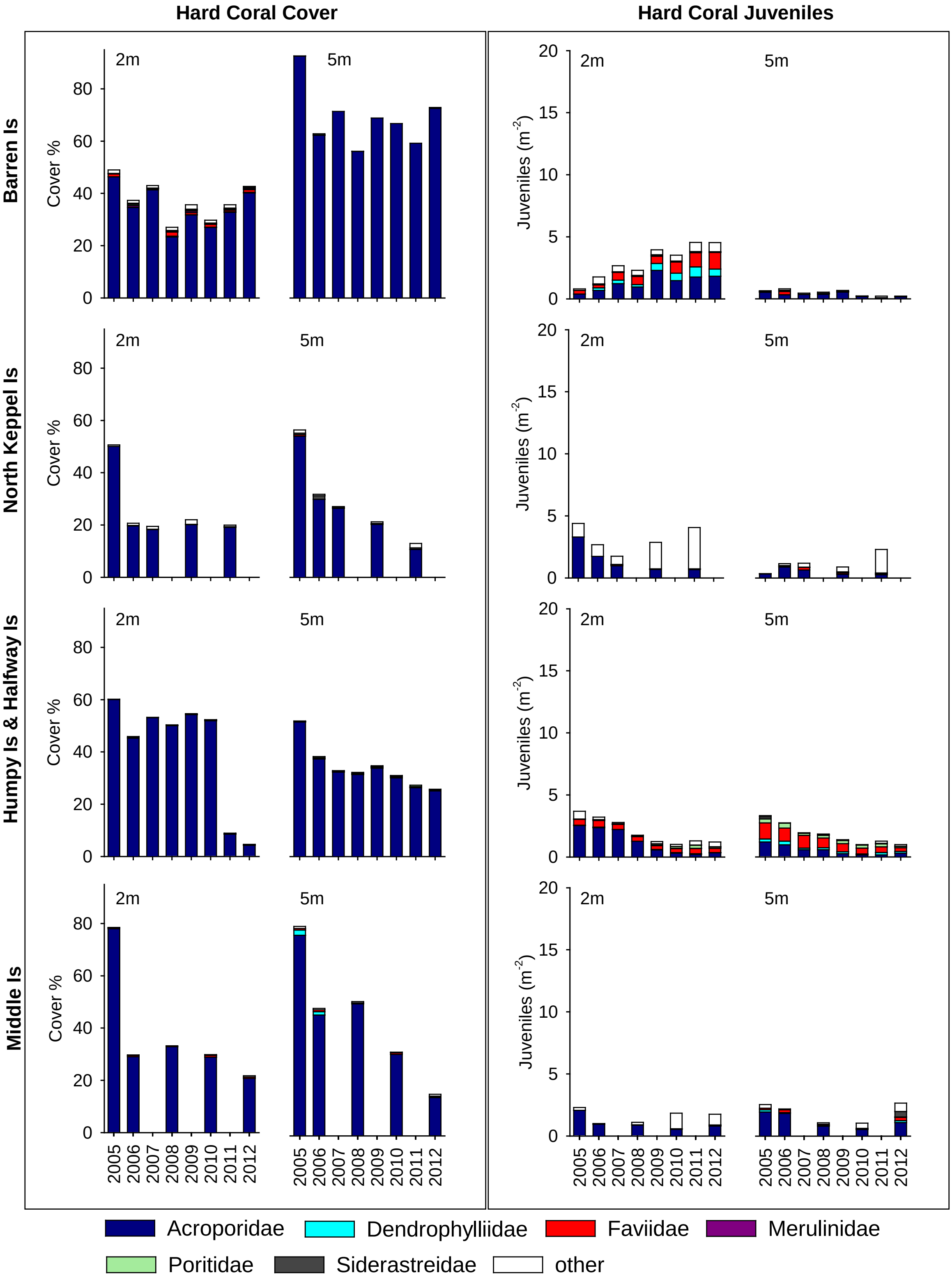

Figure 39: Composition of hard coral communities: Fitzroy Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

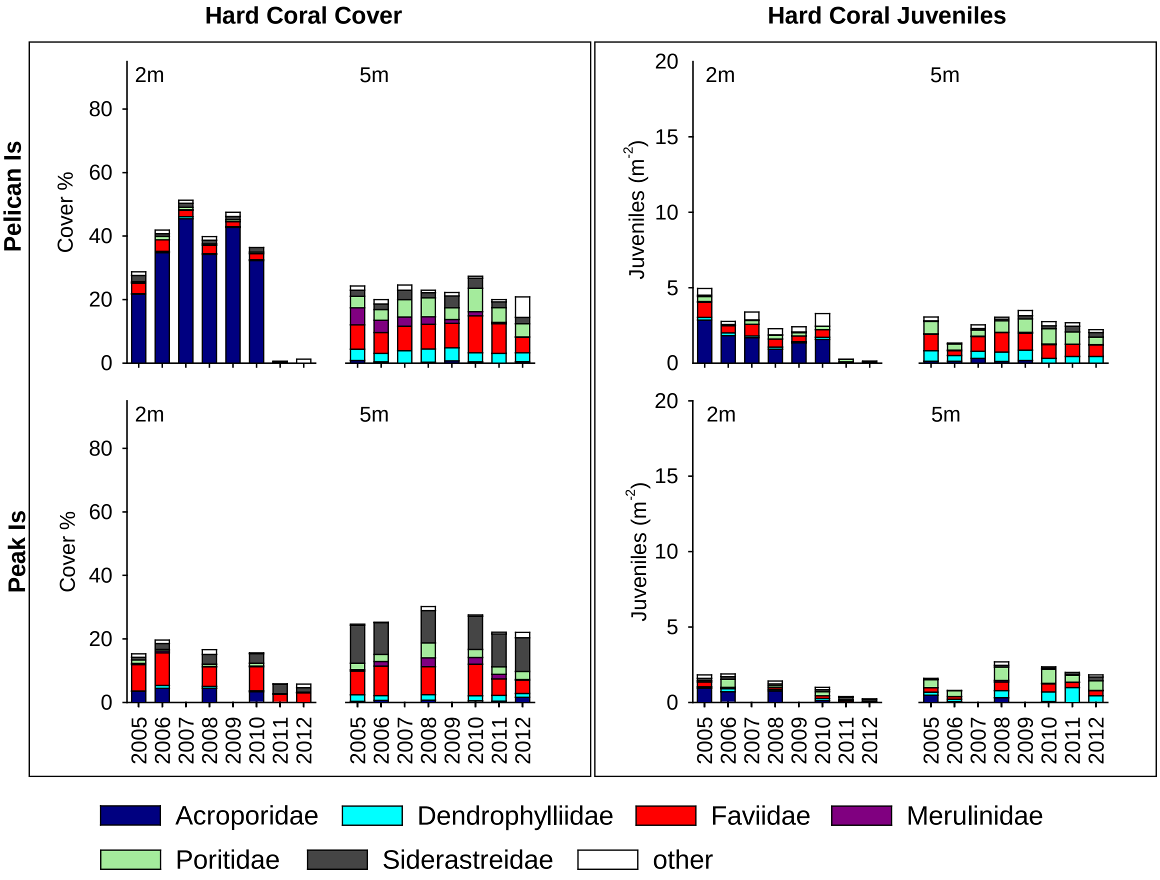

Figure 39: continued.

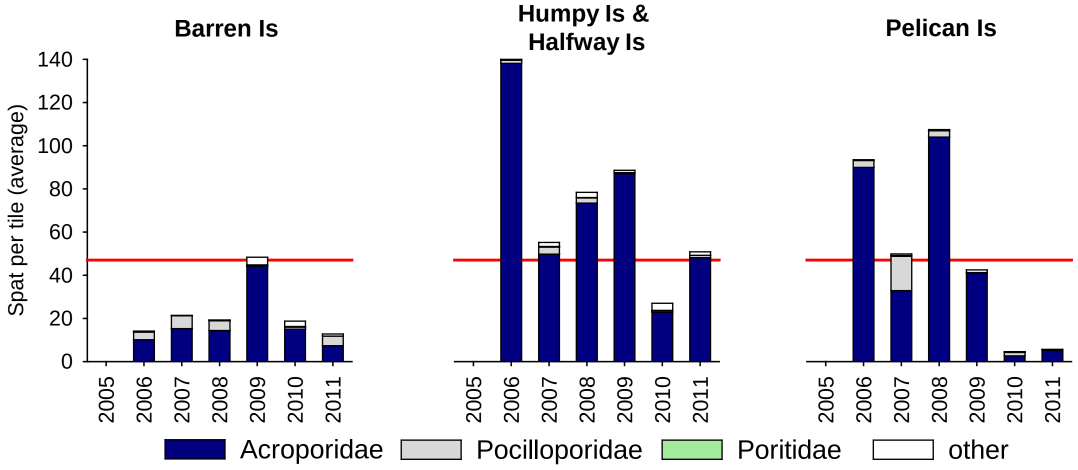

Figure 40: Coral settlement to tiles Fitzroy Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

FORAM indices are relatively different when comparing the two sites within Humpy and Halfway Islands and Pelican Is; only one site can be sampled at Barren Is due to the lack of sediments at the other site. The differences between sites are relatively stable over time and illustrate the sensitivity of the index to relatively minor changes in environmental conditions, and especially the grain size composition of the sediments (Uthicke *et al*. 2010).(Fig. 42). All stations show a slight decline with time over the sampling period. Humpy and Halfway Islands receive a negative ranking with Pelican Is ranked as 'neutral'. Barren Is was not ranked because of insufficient baseline data. In total, the rankings combine to a 'poor' score for the Fitzroy Region. Declines in the FORAM index in the Fitzroy region are relatively minor compared to other regions, though still imply a change in environmental conditions consistent with the observed increases in organic content and the proportion of clay and silt grainsized particles in sediments. As with other regions these changes are demonstrating that the sediment dynamics at inshore reefs respond to riverine inputs.

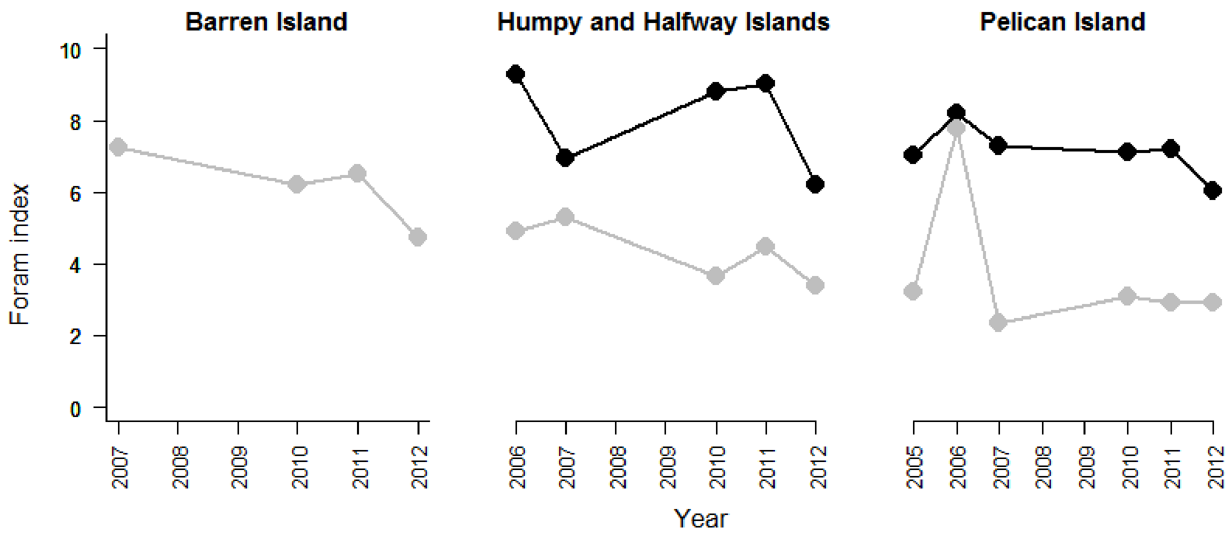

Figure 41: FORAM index in the Fitzroy Region. Separate profiles are presented for sites 1 (black) and site 2 (grey) to allow interpretation of consistency of trends in the FORAM index.

4. Conclusions

Local environmental conditions clearly influence the benthic communities found on coastal and inshore reefs of the GBR. Collectively, these reefs differ markedly from those found in clearer, offshore waters (e.g. Done 1982, Wismer *et al.* 2009, De'ath and Fabricius 2010). Within the inshore zone, coral reef communities vary along steep environmental gradients that occur with distance from the coast and from major rivers (van Woesik and Done 1997, van Woesik *et al.* 1999, Fabricius *et al.* 2005, De'ath and Fabricius 2008, Uthicke *et al.* 2010, Fabricius *et al.* 2012), but also within individual reefs in response to localised hydrodynamic conditions (Uthicke *et al.* 2010, Thompson *et al.* 2010a, Browne *et al*. 2010).

The general responses of coral reef communities to turbidity and nutrients are relatively well understood (e.g., Fabricius 2005, De'ath and Fabricius 2008, Philipp and Fabricius 2003, Thompson *et al.* 2010a, Uthicke *et al.* 2010). Simplistically, species that are tolerant to the environmental pressures at a given location are likely to be more abundant, compared to less-tolerant species (e.g., Stafford-Smith and Ormond 1992, Anthony and Fabricius 2000, Anthony and Connolly 2004, Anthony 2006). However, the processes shaping biological communities are complex and variable on a variety of spatial and temporal scales and they are likely to include interactions between various environmental factors, between species or taxonomic groups, the effects of past disturbances, and a degree of stochasticity in the demographic processes of individual species. As a result, substantially different communities may be present at any one time in very similar environmental settings. Conversely, species of corals may occur across a broad range of conditions due to their inherent physiological (Anthony and Fabricius 2000) and morphological (Anthony *et al.* 2005) plasticity.

Given the clear relationship between coral community composition and their environmental setting, it is expected that coral communities will be susceptible to deterioration of environmental conditions such as increases in the rates of sedimentation, levels of turbidity, nutrient concentrations or other pressures associated with anthropogenic activities in adjacent catchments or coastal zones. The premise underpinning Reef Plan and Reef Rescue is that contaminant loads delivered by rivers sufficiently alter the environmental conditions in inshore waters of the GBR to suppress ecological resilience.

While acute disturbance events must be considered as natural pressures influencing coral community dynamics, they highlight the importance of the resilience of communities to recover from such events during periods of non-disturbance. Our condition assessment of coral reef communities is based on the underlying assumption of this recovery. From 2005 to 2012 various acute disturbance events have affected the MMP survey reefs in the following regions (see Table A1-5 for a detailed description of reef level impacts):

- Tropical cyclones: TC Larry, 2006-Wet Tropics and Burdekin; TC Ului, 2010-Mackay Whitsunday; TC Yasi, 2011-Wet Tropics and Burdekin; TC Tasha, 2011-Wet Tropics;
- Severe storms: 2008-Fitzroy; 2009-Burdekin and Wet Tropics; 2010-Fitzroy.
- Severe freshwater floods: 2009, 2010, 2011-Burdekin; 2008-2011-Fitzroy.
- Coral bleaching: 2006-Fitzroy
- Crown-of-thorns seastar: 2012-Wet Tropics

Our monitoring of coral reef and foraminiferal communities has spanned a period of highly variable rainfall and runoff and, hence, created a natural experiment allowing the investigation of the following questions that are central to the rationale of Reef Plan:

1. How does variation in runoff alter environmental conditions at inshore reefs?

2. What is the ecological response of coral reef communities to these changed conditions?
3. What are the expected responses of coral reef communities in a future of potentially reduced runoff loads?

The explicit consideration of these questions allows the identification of areas of concern but also highlights key knowledge gaps limiting a more thorough understanding of the interactions between runoff and environmental and ecological conditions of GBR inshore reefs.

How does variation in runoff alter environmental conditions at near-shore reefs?

Gross levels of turbidity and sedimentation at a given location are largely driven by resuspension of accumulated sediment deposits (Larcombe *et al.* 1995, Larcombe *et al.* 2001). However, it is becoming increasingly apparent that the additional flux of fine sediment imported by rivers remains in the coastal zone for periods of months to years leading to chronically elevated turbidity and rates of sedimentation (Wolanski *et al.* 2007, Lambrechts *et al.* 2010, Fabricius *et al.* 2013a, Brodie *et al*. 2012). In the period 2007 to 2012, discharges from rivers in the Burdekin, Mackay Whitsunday and Fitzroy regions were at least twice the long-term median in at least four of the six years. In comparison, discharges in the period 2002 to 2006 were generally well below the long-term median. Our data support the argument that runoff is influencing environmental conditions in the near-shore GBR, as indicated by:

- Increases in mean turbidity at reef sites that correspond to increased river flow in all regions.
- Increases in the proportion of fine grained particles, nitrogen and organic carbon increased in all regions over the high flow period.
- The rate of sedimentation varying seasonally with peak levels observed during the wet season, corresponding to increased supply.

Despite the consistency of these observations there were discrepancies at some reefs and in some years. Most notable were consistently large increases in the proportion of fine grained particles, nitrogen and organic carbon in the sediments at the survey locations in 2012 despite lower river flows compared to 2011. The sediment sampling was added in 2006 to the MMP coral monitoring to provide additional site-specific environmental information. The results to date suggest that a more rigorous sampling strategy (e.g., more often than once per year, more replicates) should be considered to improve the detection and interpretation of changes in these parameters. Post-flood transport and transformation of fine sediments is poorly understood. One notable exception is Bainbridge *et al.* (2012) who describe the formation of large biologically-mediated flocs of fine grained particles as the mechanism by which fine sediments are transported substantial distances from rivers. Without knowledge of these processes the potential lags in sediment supply or indeed the catchments of origin will remain unknown. The very fine grained sediments and any adsorbed contaminants are most likely to reach reefs, and it is most pressing to understand the loads and fate of these constituents.

The turbidity data presented were not corrected for physical forcing by wave and tide-driven resuspension. In an earlier analysis of the MMP turbidity data using this correction, Fabricius *et al.* (2013) demonstrate consistent patterns of high turbidity in response to land runoff, with post-wet season decreases in turbidity as resuspendable material is winnowed out of the coastal zone over the dry season. This approach was not used in this report as the objective was to determine community response to variation in realised as opposed to standardised environmental conditions, but should be included in future analyses of the MMP turbidity data to increase the ability to identify and attribute long-term trends.

Our environmental data indicate that turbidity at the MMP survey reefs has increased, and this has led to an increased supply of fine sediment, and any adsorbed contaminants, to the substratum.

The actual conditions will vary at individual reefs in response to site-specific hydrodynamics. For example, high rates of sedimentation require a combination of a high supply of suspended particles, measurable as high turbidity, coupled with a low energy hydrodynamic setting that allows these particles to settle and accumulate (Wolanski *et al.* 2005). Such conditions only occur at some MMP reefs. Collectively, corals on reefs in the Mackay Whitsunday Region are subjected to high levels of turbidity, have sediments with high proportions of fine-grained particles, nutrients and non-carbonate material and are hence considered to be predisposed to the detrimental impacts of sedimentation; only Middle Reef in the Burdekin Region and Snapper Island North in the Wet Tropics Region share similar environmental conditions. However, declines in coral community condition have also occurred at reefs less exposed to the combination of turbidity and sedimentation, which suggests a response to other environmental factors such as increased nutrient availability.

What is the ecological response of coral reef communities to these changed conditions?

In all regions coral community condition has steadily declined, for two main reasons. Firstly, acute disturbances have variously impacted the majority of reefs (see above), resulting in decreases in overall coral cover. While these impacts *per se* do not constitute a loss of resilience, coral cover is included in our assessment of coral community resilience primarily as an indicator of the availability of broodstock for recovery after disturbances. Secondly, there are clear indications that the resilience of coral communities, i.e. the ability to recover from the acute disturbances has declined. Collectively, the resilience indicators of cover of macroalgae, juvenile density and rate of cover increase were either stable or declined on almost all reefs, as has have the number of coral larvae settling to tiles.

The broad range of coral community types on our survey reefs are indicative of the variety of environmental conditions experienced. We have observed declines in condition of coral communities across almost all these community types, over a wide range of ambient environmental conditions and at a large spatial scale, which is indicative of the sensitivity of coral communities to changes in their environmental setting. On one extreme are reefs in highly turbid and hydrodynamically protected settings where smothering of the substrate by fine sediment clearly limits coral settlement, coral disease is observed associated with sediment deposits on corals and only sediment-tolerant taxa persist. On the other extreme are reefs in relatively clear waters with high wave energy where fine sediments do not accumulate. These reefs typically support communities dominated by fast growing taxa such as *Acropora*, however even these communities show signs of coral disease and declines in the densities of juvenile corals after the extreme floods of the past few years, indicating a more general influence of water quality than simply turbidity. Intermediate between these extremes are reefs at which conditions are suitable for various macroalgal species, which are highly persistent despite occasional removal by storms. Macroalgae generally benefit from increased nutrient availability due to runoff (e.g. Schaffelke et al. 2005) and as coral competitors supress both coral growth and juvenile settlement or survival (e.g., McCook et al. 2001, Birrell et al. 2005, 2008). However, there are also corals species at all reefs that have tolerated both the recent acute disturbances and the chronic pressures associated with runoff of excess sediment and nutrients. The combination of acute and chronic pressures exerts selective pressure on coral reef communities leading, over time, to a dominance of the most tolerant species and a decline in diversity.

Particularly worrying is that declines in resilience of coral communities observed over recent years may be occurring within communities that have already changed in response to chronically altered conditions. Palaeoecological evidence suggests that such suppression of resilience to disturbance may have been occurring since as early as the 1920's. Roff *et al.* (2013) record a shift in coral communities at sites at Pelorus Island from dominance by large thicket-forming *Acropora* to a remnant community of sparse *Acropora* and/or dominant non-*Acropora* species; a result indicating that a species that had persisted for centuries was no longer able to recover from inevitable disturbance. The authors interpret this finding as evidence for a sustained decline in water quality resulting from the expansion of agriculture in the catchment. Future NERP-funded work by these researchers on more reefs, including some MMP survey reefs, will show whether the current condition of inshore coral communities might represent a “shifting baseline” (Hughes *et al*. 2011).

Similar to coral communities, the steady decline of the FORAM index on most reefs are consistent with a change to finer grained sediment and more nutrient-rich sediments. Recent studies on sediment cores and other historical foraminiferal communities highlighted that these communities were surprisingly persistent prior to anthropogenic disturbances starting ~150 years ago (Tager *et al.* 2010, Uthicke *et al.* 2012a). The recent changes in the foraminiferal assemblages of the inshore GBR reflect response patterns identified in experimental studies (Uthicke and Nobes 2008, Uthicke and Altenrath 2010, Reymond *et al*. 2011, Uthicke *et al.* 2012b) and support the assumption that the decline of coral reef ecosystem condition has been mainly due to increased turbidity and nutrient availability caused by the recent flood events. The changes in the foraminiferal assemblages also indicate that the negative trajectory of ecosystem health is widespread, e.g. covering a multitude of benthic organisms, including seagrasses (see McKenzie *et al.* (2012) for MMP seagrass monitoring, showing a continued decline in condition, also attributed to declining water quality due to the recent flood events).

What are the expected responses in a future of potentially reduced runoff loads?

We conclude that acute disturbances in combination with ensuing periods of elevated environmental stresses brought about by higher turbidity and accumulation of organic matter are the cause of observed declines in coral community condition. Clearly nothing can be done to prevent acute disturbances such as cyclones or flood-associated plumes of freshwater. However, what can be done is to reduce the sediment, nutrient and contaminant loads carried by rivers that both amplify the impacts of, and then suppress recovery from, such events. Recovery from acute disturbance requires the settlement and then survival and growth of juvenile corals to replace those that were killed. These early life history phases have been repeatedly shown to be particularly sensitive to the low light and high sedimentation conditions that result from an increased flux of fine sediments and their associated contaminants (see Fabricius 2011 for a synthesis). Our results extend the influence of runoff more generally, as we observed declines at reefs at which turbidity and sedimentation were unlikely to have caused the observed declines. Further, our observations of increased incidence of coral disease show that adult coral colonies are also negatively affected and provide evidence that elevated import of river-borne materials lead to changes in coral communities beyond those associated with underlying environmental gradients. Potential longer-term and wider-field consequences of extreme flood events for adult corals are also indicated by the relationship between high river flow and outbreaks of crown-of-thorns starfish (Fabricius *et al.* 2010); this coral predator is major agent of coral cover loss in the GBR (Osborne *et al.* 2011, De’ath *et al.* 2012).

The recognition of the significance of extreme events for shaping the condition of inshore coral reefs is important to inform the management strategies employed to limit downstream impacts of land runoff. The improvements in GBR catchment management implemented under Reef Plan and Reef Rescue are realistically expected to improve inshore marine water quality on two levels. Firstly, the reduction of event loads of sediments and nutrients, e.g. by improved erosion control measures or timing and method of chemical application, would reduce the extreme levels of light limitation, sedimentation and nutrient and chemical contaminant supply associated with flood events. Secondly, and likely an expected side effect of land management practices to reduce event loads, a general reduction would also reduce baseline loads of contaminants during lower flow periods. The reduced loads of contaminants in runoff would (i) reduce sub-lethal and lethal stresses to species living close to their environmental thresholds, (ii) increase the area of substratum suitable for coral settlement and survival, due to increased light penetration and reduced fine sediment flux, (iii) foster the maintenance of larger adult populations with positive feedbacks to a higher supply of larvae for recovery after acute events and (iv) reduce the fitness of space-competitors such as macroalgae. However, improvements in marine water quality and associated coral reef condition are likely to be slow and difficult to detect because of the highly variable baseline, lags in ecosystem responses and potentially long recovery periods (Brodie *et al*. 2012).

In addition to reducing the ability to recover from disturbance, degraded water quality increases the susceptibility of corals to disturbance. Evidence from recent research into the interactions between water quality and climate change suggests that the tolerance to heat stress of corals and foraminifera is reduced by exposure to contaminants including nutrients, herbicides and suspended particulate matter (Negri *et al*. 2011, Wiedenmann *et al*. 2013, Uthicke *et al*. 2012b, Fabricius *et al.* 2013b). As the frequency and severity of disturbance events are projected to increase as a result of climate change (Steffen *et al*. 2013), any increase in susceptibility to these disturbances as a result of local stressors may be catastrophic for GBR inshore communities. Increased susceptibility to, or frequency of, disturbance events will reduce the abundance of adult corals and so reduce the supply of coral larvae, further suppressing the ability of communities to recover.

The widespread decline in coral reef condition has clearly demonstrated the sensitivity of these communities to elevated loads of contaminants introduced by runoff. The effects were common in all regions, across environmental gradients and affecting a diversity of taxonomic groups, which makes the identification of individual areas most at risk to the effects of runoff a challenging task. Once pollutants reach the GBR lagoon, mixing and far-field transport makes it difficult to separate the effects of different catchment sources (but see Furnas *et al*. 2013). Because coral communities are the result of selection influenced by the local long-term environmental conditions their responses are expected to be site-specific and exposure-dependent. A recent risk assessment (Waterhouse *et al*. 2013) concluded that the risk of increased catchment pollutant loads differs between individual pollutants, catchments, and along cross-shelf gradients. The authors identify priority areas for management of degraded water quality: Wet Tropics for nitrogen management; Mackay Whitsunday and lower Burdekin for herbicide management; and Burdekin and Fitzroy for suspended sediment management. However, the assessment does not consider the rate of current adoption of management practices, their feasibility and effectiveness to improve water quality. Ultimately, the continued monitoring of inshore coral reef condition and resilience will enable us to detect improvements as land management practices progress towards the Reef Plan/Reef Rescue reduction targets.

Current knowledge gaps

Limiting the ability to more specifically identify contaminants or source areas of most concern are a lack of knowledge of the transport, accumulation and bio-geochemical transformation processes of nutrients, organic matter and herbicides in the GBR lagoon after flood events. The definition of zones of river influence for each catchment using hydrodynamic and pollution distribution models would allow the estimation of quantitative links between loads from individual catchments and marine concentrations of nutrients, fine sediments and herbicides. Such models are a focus of research within the broader eReefs initiative.

There is currently limited ability to describe the full range of environmental conditions experienced at individual reefs because of limited water quality sampling. Loggers can provide accurate estimates of turbidity but more consistent temporal and spatial data for all water quality variables, sediment fluxes, and agrichemical contamination are required.

To better interpret the coral reef monitoring data, we require a better understanding of the responses of key reef community components to cumulative impacts of repeated exposure to poor water quality associated with flood plumes, the cumulative impacts of multiple water quality pressures, and the responses to chronic low-level exposure to herbicides.

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Appendix 1: Detailed data tables

Table A1- 1: Clay and silt content of sediments. Values are the average proportion (%) of the sediment samples, by weight, with grain sizes < 0.063 mm.

Region	Catchment	Reef	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Barron Daintree	Cape Tribulation North	3.73						
		Cape Tribulation Middle	7.42						
		Cape Tribulation South	8.22						
		Snapper Is North	42.86		38.96	39.70	39.12	55.86	40.46
		Snapper Is South	8.73		7.25	7.28	17.70	23.62	11.15
	Johnstone Russell-Mulgrave	Fitzroy Is West	4.07	9.04	9.56	4.60	17.41	23.49	20.75
		Fitzroy Is East	4.77		0.57		5.22	2.45	1.65
		Frankland Group West	35.27	25.30	36.41	23.11	43.62	52.76	54.01
		Frankland Group East	17.85	3.12		3.26		3.21	
		High Is West	9.95	6.20	18.74	8.14	16.01	22.11	21.07
		High Is East	8.69	0.58		0		2.46	
	Herbert Tully	North Barnard Group	12.27	5.93		5.81		11.27	
		King	3.27		1.64		7.43		1.46
		Dunk Is North	5.03	6.65	14.86	5.85	20.36	18.80	23.56
		Dunk Is South	12.27		5.28		6.90	13.30	12.15
Burdekin	Burdekin	Pelorus and Orpheus Islands West	5.76	3.97	3.89	5.35	7.54	15.24	11.61
		Orpheus Is East	1.60		0		2.04	0.84	0.31
		Lady Elliot	14.50		12.57		16.38		18.59
		Pandora	3.43	2.36	2.98	1.85	6.58	7.95	18.36
		Havannah Is	7.62	7.45		2.99		11.42	
		Geoffrey Bay	13.16	9.76	7.97	4.12	13.84	10.77	18.15
		Middle Reef	80.48	54.92		30.0		49.42	
Mackay Whitsunday	Proserpine	Double Cone Is	14.12	34.59	28.52	33.33	60.17	52.62	32.14
		Hook Is	36.66		36.36		34.91		36.90
		Daydream Is	61.56	72.46	72.39	38.64	74.43	70.46	76.11
		Shute and Tancred Islands	38.07		25.60		63.77		57.42
		Dent Is	58.15	52.93		56.19		54.60	
		Pine Is	59.53	44.47	58.21	40.57	78.36	63.73	72.99
		Seaforth Is	36.43	41.37		37.39		36.85	
Fitzroy	Fitzroy	North Keppel Is	14.38	8.94		9.15		35.43	
		Barren Is	2.62	2.37	2.82	4.24	4.84	18.39	16.68
		Middle Is			4.69		12.93		7.68
		Humpy and Halfway Islands	3.26	3.14	5.74	5.45	14.94	6.66	21.29
		Pelican Is	2.42	2.55	0	1.69	5.59	5.44	8.20
		Peak Is	2.51		5.16		13.83	9.53	18.36

Table A1- 2: Organic carbon content of sediments. Values are the proportion (%) of the total sediment sample by weight.

Region	Catchment	Reef	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Barron Daintree	Cape Tribulation North	0.27						
		Cape Tribulation Middle	0.30						
		Cape Tribulation South	0.39						
		Snapper Is North	0.60		0.62	0.59	0.44	0.61	0.67
		Snapper Is South	0.28		0.40	0.36	0.28	0.33	0.27
	Johnstone Russell-Mulgrave	Fitzroy Is West	0.25	0.35	0.38	0.24	0.27	0.28	0.38
		Fitzroy Is East	0.20		0.18		0.22	0.15	0.18
		Frankland Group West	0.58	0.51	0.57	0.53	0.57	0.63	0.80
		Frankland Group East	0.23	0.23		0.22		0.25	
		High Is West	0.37	0.26	0.35	0.32	0.28	0.33	0.37
		High Is East	0.26	0.19		0.19		0.19	
	Herbert Tully	North Barnard Islands	0.28	0.27		0.25		0.23	
		King	0.18		0.20		0.21		0.22
		Dunk Is North	0.28	0.24	0.26	0.31	0.26	0.25	0.42
		Dunk Is South	0.31		0.23		0.21	0.24	0.29
Burdekin	Burdekin	Pelorus and Orpheus Islands West	0.23	0.19	0.20	0.26	0.22	0.29	0.32
		Orpheus Is East	0.22		0.17		0.20	0.19	0.18
		Lady Elliot	0.21		0.19		0.20		0.28
		Pandora	0.19	0.19	0.23	0.24	0.22	0.19	0.28
		Havannah Is	0.26	0.25		0.33		0.25	
		Geoffrey Bay	0.31	0.29	0.30	0.25	0.27	0.22	0.34
		Middle Reef	0.98	0.77		0.79		0.50	
Mackay Whitsunday	Proserpine	Double Cone Is	0.49	0.56	0.48	0.53	0.66	0.63	0.41
		Hook Is	0.37		0.43		0.37		0.64
		Daydream Is	0.62	0.79	0.88	0.88	0.76	0.90	0.87
		Shute and Tancred Islands	0.48		0.46		0.70		0.61
		Dent Is	0.65	0.67		0.70		0.56	
		Pine Is	0.76	0.66	0.75	0.66	0.79	0.64	0.60
		Seaforth Is	0.47	0.49		0.54		0.38	
Fitzroy	Fitzroy	North Keppel Is	0.21	0.48		0.56		0.58	
		Barren Is	0.26	0.28	0.25	0.33	0.34	0.48	0.48
		Middle Is			0.22		0.12		0.28
		Humpy and Halfway Islands	0.30	0.22	0.28	0.30	0.30	0.25	0.45
		Pelican Is	0.23	0.17	0.21	0.26	0.22	0.23	0.27
		Peak Is	0.23		0.25		0.28	0.23	0.38

Table A1- 3: Total nitrogen content of sediments. Values are the proportion of the total sediment sample by weight expressed as parts per hundred thousand.

Region	Catchment	Reef	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Barron Daintree	Cape Tribulation North	0.04						
		Cape Tribulation Middle	0.04						
		Cape Tribulation South	0.04						
		Snapper Is North	0.07		0.05	0.08	0.06	0.06	0.10
		Snapper Is South	0.01		0.04	0.05	0.04	0.05	0.05
	Johnstone Russell-Mulgrave	Fitzroy Is West	0.03	0.04	0.04	0.03	0.04	0.04	0.06
		Fitzroy Is East	0.02		0.02		0.03	0.02	0.04
		Frankland Islands West	0.08	0.08	0.07	0.08	0.08	0.08	0.12
		Frankland Islands East	0.02	0.03		0.03		0.04	
		High Is West	0.04	0.04	0.04	0.05	0.04	0.05	0.06
		High Is East	0.02	0.03		0.03		0.03	
	Herbert Tully	North Barnard Islands	0.04	0.03		0.04		0.03	
		King	0.03		0.02		0.03		0.04
		Dunk Is North	0.03	0.03	0.03	0.04	0.03	0.03	0.05
		Dunk Is South	0.03		0.03		0.03	0.04	0.04
Burdekin	Burdekin	Pelorus and Orpheus Islands West	0.03	0.03	0.03	0.03	0.03	0.04	0.06
		Orpheus Is East	0.02		0.03		0.03	0.03	0.03
		Lady Elliot	0.03		0.02		0.03		0.04
		Pandora	0.03	0.03	0.03	0.03	0.04	0.03	0.05
		Havannah Is	0.02	0.04		0.04		0.04	
		Geoffrey Bay	0.04	0.04	0.04	0.03	0.03	0.03	0.06
		Middle Reef	0.12	0.08		0.11		0.06	
Mackay Whitsunday	Proserpine	Double Cone Is	0.04	0.09	0.06	0.07	0.08	0.10	0.08
		Hook Is	0.05		0.06		0.05		0.12
		Daydream Is	0.09	0.10	0.10	0.12	0.09	0.11	0.10
		Shute and Tancred Islands	0.07		0.07		0.09		0.10
		Dent Is	0.08	0.09		0.09		0.07	
		Pine Is	0.09	0.09	0.09	0.08	0.08	0.08	0.09
		Seaforth Is	0.06	0.08		0.07		0.06	
Fitzroy	Fitzroy	North Keppel Is	0.03	0.05		0.08		0.08	
		Barren Is	0.04	0.05	0.05	0.04	0.05	0.07	0.09
		Middle Is			0.04		0.02		0.06
		Humpy and Halfway Islands	0.04	0.04	0.05	0.04	0.04	0.03	0.08
		Pelican Is	0.03	0.03	0.04	0.04	0.04	0.04	0.07
		Peak Is	0.03		0.05		0.04	0.03	0.07

Table A1- 4: Inorganic carbon content of sediments. Values are the proportion (%) of the total sediment sample by weight.

Region	Catchment	Reef	2006	2007	2008	2009	2010	2011	2012
Wet Tropics	Barron Daintree	Cape Tribulation North	7.87						
		Cape Tribulation Middle	8.53						
		Cape Tribulation South	8.21						
		Snapper Is North	6.99		5.98	6.98	7.70	5.82	6.73
		Snapper Is South	9.57		7.49	9.60	10.02	8.81	9.30
	Johnstone Russell-Mulgrave	Fitzroy Is West	9.80	9.47	9.35	10.26	9.93	8.86	8.89
		Fitzroy Is East	9.76		9.58		10.02	8.61	9.43
		Frankland Islands West	8.12	8.39	7.63	8.64	8.27	6.80	6.27
		Frankland Islands East	10.62	10.37		10.33		7.23	
		High Is West	9.45	9.91	8.90	9.77	10.12	8.94	8.89
		High Is East	10.09	10.58		10.76		10.20	
	Herbert Tully	North Barnard Islands	8.95	9.43		9.47		8.53	
		King	9.30		9.12		9.77		9.14
		Dunk Is North	8.47	8.65	7.15	8.64	8.74	7.29	7.17
		Dunk Is South	9.60		9.71		10.19	9.34	9.40
Burdekin	Burdekin	Pelorus and Orpheus Islands West	10.17	10.57	10.10	10.06	10.43	9.60	9.51
		Orpheus Is East	10.48		10.58		10.90	10.36	10.30
		Lady Elliot	3.82		5.08		5.42		5.11
		Pandora	10.56	10.55	10.27	10.41	10.63	9.80	9.31
		Havannah Is	10.19	10.11		10.22		8.28	
		Geoffrey Bay	7.88	8.40	8.36	9.17	9.27	3.93	7.98
		Middle Reef	2	4.70		4.75		6.56	
Mackay Whitsunday	Proserpine	Double Cone Is	9.31	7.49	7.61	7.25	6.62	9.80	8.34
		Hook Is	8.73		8.27		9.12		6.60
		Daydream Is	6.01	4.29	3.93	4.47	4.97	3.82	4.91
		Shute and Tancred Islands	7.58		7.59		5.69		6.47
		Dent Is	6.69	6.42		6.27		6.77	
		Pine Is	5.37	5.62	4.97	5.86	4.48	6.07	6.87
		Seaforth Is	8.40	7.79		7.82		8.23	
Fitzroy	Fitzroy	North Keppel Is	5.68	8.70		9.05		7.39	
		Barren Is	9.64	9.81	9.49	9.39	9.76	9.01	9.19
		Middle Is			3.74		1.93		3.66
		Humpy and Halfway Islands	8.68	8.76	8.73	8.86	8.68	7.94	8.20
		Pelican Is	8.03	7.42	8.21	7.80	9.38	7.61	7.51
		Peak Is	6.76		8.38		7.48	7.99	5.80

Table A1- 5: Known disturbances to coral communities at monitoring locations. For coral bleaching, decimal fractions indicate the probability of occurrence at this site (see table footnote). Percentages in brackets are the observed proportional loss of hard coral cover for a given disturbance at that reef.

Region	Catchment	Reef	Bleaching			Other recorded disturbances
			1998	2002	2006	
Wet Tropics	Barron Daintree	Snapper Is (North)	0.92 (19%)	0.95 (Nil)		Flood 1996 (20%), Cyclone Rona 1999 (74%), Storm , Mar 2009 (14% at 2m, 5% at 5m), Disease 2011 (16% at 2m, 24% at 5m), crown-of-thorns 2012 (10% at 2m, 8% at 5m)
		Snapper Is (South)	0.92 (Nil)	0.95 (Nil)		Flood 1996 (87%), Flood 2004 (32%)
	Johnstone Russell-Mulgrave	Fitzroy Is (East)	0.92	0.95		Cyclone Felicity 1989 (75% manta tow data), Disease 2011 (54% at 2m, 38% at 5m), crown-of-thorns 2012 (3% at 5m)
		Fitzroy Is (West)	0.92 (13%)	0.95 (15%)		Crown-of-thorns 1999-2000 (78%), Cyclone Hamish 2009 (stalled recovery trajectory), Disease 2011 (40% at 2m, 14% at 5m), crown-of-thorns 2012 (7% at 5m)
		Frankland Group (East)	0.92 (43%)	0.80 (Nil)		Unknown though likely crown-of-thorns 2000 (68%) Cyclone Larry 2006 (60% at 2m , 46% at 5m), Cyclone Tasha/Yasi 2011 (51% at 2 m, 35% at 5m)
		Frankland Group (West)	0.93 (44%)	0.80 (Nil)		Unknown though likely crown-of-thorns 2000 (35%) Cyclone Tasha/Yasi 2011 (33% at 2m)
		High Is (East)	0.93	0.80		Cyclone Tasha/Yasi 2011 (80% at 2m, 56% at 5m)
		High Is (West)	0.93	0.80		Cyclone Larry 2006 (25% at 5m), Flood/Bleaching 2011 (19% at 2m, 29% at 5m)
	Herbert Tully	North Barnard Group	0.93	0.80		Cyclone Larry 2006 (95% at 2m , 86% at 5m), Cyclone Yasi 2011 (26% at 2m)
		King Reef	0.93	0.85		Cyclone Larry 2006 (35% at 2m, 47% at 5m)
		Dunk Is (North)	0.93	0.80		Cyclone Larry 2006 (80% at 2m , 71% at 5m), Cyclone Yasi 2011 (91% at 2m, 71% at 5m)
		Dunk Is (South)	0.93	0.85		Cyclone Larry 2006 (12% at 2m , 18% at 5m), Cyclone Yasi 2011 (75% at 2m, 53% at 5m)

Note: As direct observations of impact were limited during the wide spread bleaching events of 1998 and 2002 tabulated values for these years are the estimated probability that each reef would have experienced a coral bleaching event as calculated using a Bayesian Network model (Wooldridge and Done 2004). The network model allows information about site-specific physical variables (e.g. water quality, mixing strength, thermal history, wave regime) to be combined with satellite-derived estimates of sea surface temperature (SST) in order to provide a probability (= strength of belief) that a given coral community in a given patch of ocean would have experienced a coral bleaching event. Higher probabilities indicate a greater strength of belief in both the likelihood of a bleaching event and the severity of that event. Where impact was observed the proportional reduction in coral cover is included. For all other disturbances listed the proportional reductions in cover are based on direct observation.

Table A1-5: continued.

Region	Catchment	Reef	Bleaching			Other recorded disturbances
			1998	2002	2006	
Burdekin	Burdekin	Orpheus Is (East)	0.93	0.80		Cyclone Larry 2006 (22% at 2m, 40% at 5m), Cyclone Yasi 2011 (81% at 2m, 82% at 5m)
		Orpheus & Pelorus Is (West)	0.92 (83%)	0.80		Unknown 1995-7 though possibly Cyclone Justin (32%) , Cyclone Larry 2006 (16% at 2m), Flood 2010 (63% at 2m, 27% at 5m)
		Lady Elliott Reef	0.93	0.85		
		Pandora Reef	0.93 (21%)	0.85 (2%)		Cyclone Tessie 2000 (9%), Cyclone Larry 2006 (78% at 2m, 30% at 5m), Storm 2009 (16% at 2m, 51% at 5m), Cyclone Yasi 2011 (50% at 5m)
		Havannah Is	0.93 (49%)	0.95 (21%)		Combination of Cyclone Tessie and Crown-of-thorns 1999-2001 (66%)
		Middle Reef	0.93 (4%)	0.95 (12%)		Cyclone Tessie 2000 (10%) , Flood/Beaching 2009 (14%),
		Geoffrey Bay	0.93 (24%)	0.95 (37%)		Cyclone Joy 1990 (13%), Bleaching 1993 (10%), Cyclone Tessie 2000 (18%), Cyclone Larry 2006 (31% at 2m, 4% at 5m), Flood/Bleaching 2009 (2% at 2m, 7% at 5m), Flood 2010 (24% at 2m) Cyclone Yasi and Flood/Bleaching 2011 (20% at 2m, 12% at 5m)
Mackay Whitsunday	Proserpine	Hook Is	0.57	1		Coral Bleaching Jan 2006, probable though not observed we did not visit region at time of event. Same for other reefs in region, Cyclone Ului 2010 (27% at 2m, 12% at 5m)
		Dent Is	0.57 (crest 32%)	0.95		Cyclone Ului 2010 most likely although reef not surveyed in that year (17% at 2m, 22% at 5m)
		Seaforth Is	0.57	0.95		
		Double Cone Is	0.57	1		Cyclone Ului 2010 (21% at 2m, 10% at 5m)
		Daydream Is	0.31 (crest 44%)	1		Cyclone Ului 2010 (40% at 2m, 41% at 5m)
		Shute Is & Tancred Is	0.57	1		Cyclone Ului 2010 (3% at 2m)
		Pine Is	0.31	1		Cyclone Ului 2010 (7% at 2m, 5% at 5m)
Fitzroy	Fitzroy	Barren Is	1	1	(22%, 2m) (33%, 5m)	Storm Feb 2008 (38% at 2m, 21% at 5m), Storm Feb 2010 plus disease (14% at 2m)
		North Keppel Is	1 (15%)	0.89 (36%)	(60%, 2m) (42% , 5m)	Storm Feb 2010 possible though not observed as site not surveyed that year. 2011 ongoing disease (44% at 5m) possibly associated with flood.
		Middle Is	1 (56%)	1 (Nil)	(62%, 2m) (39%, 5m)	Storm Feb 2010 plus disease (12% at 2m, 37% at 5m)
		Humpy & Halfway Is	1 (6%)	1 (26%)	(24%, 2m) (26%, 5m)	Flood 2008 (6% at 2m, 2% at 5m),Flood 2011 (83% at 2m, 12% at 5m)
		Pelican Is	1	1	17%, 5m	Flood /Storm 2008 (23% at 2m, 2% at 5m), Flood/Storm (20% at 2m), Flood 2011 (99%at 2m, 29% at 5m)
		Peak Is	1	1		Flood 2008 (17% at 2m), Flood 2011 (65% at 2m, 22% at 5m)

Table A1- 6: Composition of hard coral communities. Families (% cover) 2012.

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Wet Tropics	Barron Daintree	Snapper Is North	2	35.8527	0	0	0	2.4620	0.4599	0.2516	0.0417	0.2083	0.0000	0.4586	0.5422	0.1669	0
			5	3.8125	15.2673	0.0000	0	1.7500	0.6250	0.3125	0.0625	0.2500	0.7500	0.6875	13.8970	0.0000	0
		Snapper Is South	2	22.8750	0.0417	0.1250	0	1.7917	0.0417	0.0000	0.0000	1.0000	0.0000	0.8333	22.9583	0.2500	0
			5	8.1586	3.3550	0.3173	0	6.9712	0.5641	0.1883	0.2516	0.3762	0.0000	0.1875	34.5962	0.4375	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	20.7048	0.06289	0.0625	0	3.19575	0.125	0.25	0.625	0.56289	0	0.25	4.43789	0	0
			5	9.193003	0.25039	0	0	1.31289	0.6875	0.125	1	0.5	1.12578	0.4375	9.39386	0.5	0.125
		Fitzroy is East	2	12.4375	0	0	0	1.8125	0	0	0.25	0	0	1.5	5.125	0.4375	0
			5	12.56289	0.0625	0.0625	0	3.56446	0.0625	0.4375	0.5	1.25078	0.125	3.31328	7.44614	0.8125	0
		High Is West	2	3.189465	0.43867	0	0	1.81918	0.62617	0.31289	0.50196	0.25039	0.25157	0.25	39.4249	0.06289	0
			5	0.75	1.00157	0	0.25	2.25314	0.0625	0.06289	0.12539	0.125	0.12539	0.125	16.1497	0.0625	0.062893
		Frankland Group West	2	4.564873	5.93829	0	0	0.3125	0.37855	0	0.125	0.31368	0.0625	0.5	22.3389	0.125	0
			5	0.125	0.95541	0	0	0.125	0.31447	0	0.0625	0.12619	0.0625	0.25039	47.7417	0	0
	Herbert Tully	King	2	0.125	0	0.3125	0	0.3125	0	0	0	0	0	0	0.0625	0	0
			5	0.9375	0	4.875	0	3.375	0	0.125	0	0	0.1875	0.125	0.875	0	0
		Dunk Is North	2	0.8125	0	0.4375	0	2	0	0	0.0625	0.25	0	0	0.125	0.0625	0
			5	2.125791	0.125	0.625	0	2.56645	0.125	0	0.3125	0.125	0	0.125	0.5	0	0
		Dunk Is South	2	0.125	0.375	0.0625	0	1.5	0	0	0	0	0	0	1.1875	0.0625	0
			5	1.625393	2.37578	1.875	0	4.75589	0.25	1.8125	0.5	0	1.37657	0.06289	1.62578	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is	2	0.9375	0.0625	0	0	0.625	0.25	0	0.0625	0.0625	0.0625	2.75	0.1875	0.125	0
			5	2.125	0	0	0	1.5625	0.25	0	0.1875	0	0.125	0.25	4.4375	0.125	0.125
		Orpheus Is East	2	1.1875	0	0	0	1	0	0	0	0	0	0	1	0	0
			5	1	0.0625	0	0	0.375	0	0	0.1875	0	0	0.0625	0.375	0	0
		Lady Elliot	2	0.9375	0.9375	0.0625	0	0.125	0.8125	0	0	1.25	0	0	0.25	0	0
			5	0.8125	2.12932	0.3125	0.0625	1.62578	1.125	0.31289	1.62617	13.1419	0.93946	0	3.94300	0.3125	0
		Pandora	2	0.6875	0	0	0	1.875	0	0.25	0.1875	0	0	0	1.5625	0.1875	0
			5	0.8125	0	0	0	3.875	0.125	0.1875	0	0.125	0.8125	0	0	0	0
		Geoffrey Bay	2	4.112433	0.0625	1.99848	0	1.4375	0.23026	0.125	0.0625	0.05128	0	0	1.1875	0.375	0
			5	3.125	2.5	1	0.1875	5.625	1.25	2.1875	0.25	0.5	1.6875	0.125	3.4375	0	0

Table A1-6: Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Dendrophylliidae	Euphyyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Mackay Whitsunday	Proserpine	Double Cone Is	2	29.0466	0.0625	1.81906	0	1.42679	0.10363	2.24399	1.08434	4.46514	0.99368	0.21754	3.53303	0	0.51462
			5	4.078947	1.42580	0	0.3125	1.79717	0.05154	0.25	1.71711	1.98420	1.30085	0.21128	47.8283	0	0.05154
		Daydream Is	2	17.50815	0	0	0	0.69227	0.06369	0.06369	0.56767	0	0.37737	0.25477	0.0625	0	0.0625
			5	19.75	0.125	0.25	0	0.9375	0.125	0	0.75	0	0.875	0.4375	3.1875	0	0
		Hook Is	2	4.413044	0.37613	1.13542	0.15	3.00099	0.05263	0.15	0.16680	0	0.98293	0.73694	5.82937	0	0
			5	3.471554	3.92527	0.38547	0.0625	2.69911	0.1875	0	0.43988	0.125	0.57011	0.18988	12.7271	0.37817	0.43951
		Pine Is	2	10.697327	1.5	0.375	0.4375	1.00196	1.12657	1.18789	0.62578	17.2150	4.00275	0.06289	2.62775	0	0
			5	4.7091344	5.13405	0.1875	0.43946	0.50276	2.69182	0.125	3.19694	6.68868	12.0342	0	3.82312	0	0.06289
		Shute and Tancred Islands	2	32.13291	0.3125	0	0	1.375	0.3125	1.375	0.68829	0.0625	1.25079	0.6875	5.12579	0.0625	0
			5	9.314465	0.62578	0.0625	0.12539	0.9375	0.31328	0.125	2.06603	0.125	4.50825	0.6875	3.375	0	0
Fitzroy	Fitzroy	Middle Is	2	20.735312	0	0	0	0.51282	0.05263	0	0	0	0	0.29141	0	0	0
			5	14.639937	0	0	0	0.375	0	0	0	0	0	0.12578	0.125	0	0
		Barren Is	2	40.1875	0.3125	0.1875	0	1.0625	0	0.4375	0.0625	0	0	0.875	0.25	0.4375	0
			5	72.517080	0	0	0	0.0625	0	0	0	0	0	0	0	0	0
		Humpy Is and Halfway Is	2	4.2551100	0	0	0	0.25	0	0	0	0	0	0.1875	0.125	0	0
			5	25.097364	0	0.3125	0	0.1875	0	0	0	0	0	0	0.125	0	0
		Pelican Is	2	0.0625	0	0	0	0	0	0	0.0625	0	0	0	0	0	0
			5	0.4375	0	2.80492	0	4.91856	0	0.0625	0.1875	0	0.54924	0	4.1875	2	0
		Peak Is	2	0	0	0	0	3.00589	0	0.0625	0	0	0	0	0.18789	1.37775	0.0625
			5	1.625	0	1.1875	0	4.1875	0	0.1875	0.0625	0	0	0	2.5625	10.625	0.5

Table A1- 7: Composition of soft coral communities. Families (% cover) 2012.

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Wet Tropics	Barron Daintree	Snapper Is North	2	0.46	3.21	9.17	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.13	0.94	0.13	0.00	0.00	0.00	0.00	0.00	0.56
		Snapper Is South	2	2.71	0.67	0.00	0.00	0.00	1.46	0.00	0.00	0.00
			5	0.31	10.23	0.00	0.19	0.00	3.96	0.00	0.00	0.00
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	29.64	0.06	0.00	0.00	0.06	0.00	0.00	0.00	0.00
			5	26.38	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Fitzroy Is East	2	2.13	0.31	1.69	0.00	0.00	0.00	0.19	0.00	0.31
			5	2.75	3.88	0.63	0.00	0.00	0.06	0.25	0.00	0.00
		High Is West	2	3.44	0.00	0.00	0.00	0.00	2.82	0.00	0.00	0.00
			5	1.25	1.38	0.00	0.00	0.00	1.13	0.00	0.00	0.00
		Frankland Group West	2	8.13	0.00	7.33	0.00	0.00	0.19	0.00	0.00	0.00
			5	1.50	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
	Herbert Tully	North Barnard Group	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.31	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Dunk Is North	2	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.13	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00
		Dunk Is South	2	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	2.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	12.00	0.13	0.06	0.00	0.00	0.00	0.88	0.00	0.00
			5	15.94	3.25	0.19	0.06	0.31	0.00	1.25	0.00	0.00
		Orpheus Is East	2	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.25	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Lady Elliot	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Pandora Reef	2	0.25	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Geoffrey Bay	2	0.11	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.38	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A1-7: Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	7.29	3.55	0.00	0.00	0.00	0.00	0.00	0.10	0.00
			5	2.92	1.65	0.00	0.00	0.00	0.00	0.06	0.00	0.00
		Hook Is	2	24.94	2.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	16.40	1.19	0.00	0.00	0.06	0.00	0.00	0.00	0.00
		Daydream Is	2	9.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	2.56	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
		Shute and Tancred Is	2	14.84	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.88
			5	7.07	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00
		Pine Is	2	0.81	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.06
			5	2.01	0.44	0.00	0.00	0.00	0.00	0.25	0.00	0.00
Fitzroy	Fitzroy	Middle Is	2	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Barren Is	2	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.50
			5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
		Humpy Is and Halfway Is	2	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Pelican Is	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	5.80	0.00	0.00	0.06	0.81	0.00	0.13	0.00	0.13
		Peak Is	2	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.00	0.06
			5	1.38	0.00	0.00	0.00	0.69	0.00	0.06	0.00	0.00

Table A1- 8: Composition of macroalgal communities. Common genera and families (% cover) 2012. Presented are genera for which cover exceeded 0.5% on at least one reef, rare or unidentified genera are grouped to family. Taxa are arranged by family from left, to right by red algae (Rhodophyta), green algae (Chlorophyta) and brown algae (Phaeophyta).

Region	Catchment	Reef	Depth	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Rhodophyta	Other Rhodophyta	*Caulerpa*	*Halimeda*	Other Chlorophyta	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	Other Phaeophyta	Cyanobacteria	Unknown Family
Wet Tropics	Barron Daintree	Snapper Is North	2	5.09	0.08	3.34	3.88	7.14	0.00	0.04	0.08	2.46	0.04	0.00	0.00	0.00	1.54	0.00
			5	0.19	0.06	0.00	5.50	1.38	0.00	0.00	0.06	5.94	0.06	0.13	0.00	0.81	0.06	0.00
		Snapper Is South	2	0.00	0.00	1.29	2.50	0.67	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.19	1.33	2.39	3.53	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	0.00	0.19	0.06	0.25	0.25	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.00	0.63	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Fitzroy Is East	2	0.00	0.06	0.19	1.63	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
			5	0.00	0.13	0.00	1.06	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		High Is West	2	0.00	0.00	2.01	0.63	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.06	1.38	0.94	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06	0.00
		Frankland Group West	2	0.00	0.06	0.88	3.33	6.07	0.00	0.00	0.00	0.31	0.19	0.00	0.00	0.13	0.00	0.88
			5	0.00	0.00	0.00	7.21	14.12	0.00	0.19	0.38	0.13	0.00	0.00	0.06	0.00	0.00	0.32
	Herbert Tully	King Reef	2	0.00	0.00	0.00	0.50	8.13	0.00	0.00	0.81	1.25	2.13	1.06	41.31	2.88	0.00	0.81
			5	0.00	0.06	0.00	0.81	11.81	0.00	0.00	0.63	0.06	1.44	0.19	13.06	0.75	0.13	3.69
		Dunk Is North	2	0.00	0.00	0.00	1.44	2.50	0.06	0.00	1.63	4.88	4.13	1.25	8.19	3.75	0.06	1.56
			5	0.19	0.00	0.00	0.38	1.88	0.00	0.00	0.38	7.77	1.13	0.25	0.25	2.07	0.06	1.56
		Dunk Is South	2	0.00	0.00	0.00	0.63	3.06	0.00	0.00	1.38	0.94	2.88	1.44	14.25	13.00	0.06	0.44
			5	0.00	0.19	0.00	0.38	0.75	0.00	0.00	0.38	0.94	0.25	0.06	0.19	0.44	0.00	2.25
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06
			5	0.00	0.06	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Orpheus Is East	2	0.00	0.06	0.00	2.63	0.06	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.50	0.88	0.13
			5	0.00	0.00	0.06	3.13	0.06	0.00	0.00	0.00	0.00	0.06	0.25	0.00	0.63	0.06	0.13
		Lady Elliot Reef	2	0.00	0.31	12.13	1.25	7.31	0.06	0.00	0.00	10.00	0.00	0.31	0.00	1.00	0.00	3.44
			5	0.00	0.31	0.00	1.06	1.94	0.00	0.00	0.00	2.50	0.06	0.00	0.00	0.69	0.00	1.69
		Pandora Reef	2	0.13	0.00	0.50	1.00	1.81	0.00	0.00	1.31	6.44	2.94	6.50	3.81	4.69	0.00	5.25
			5	11.69	0.06	0.00	1.13	0.38	0.00	0.00	0.00	8.13	4.44	2.44	1.31	0.25	0.00	0.44
		Geoffrey Bay	2	0.00	0.17	0.06	1.17	1.02	0.00	0.00	0.00	9.76	16.11	0.50	14.12	7.44	0.00	1.16
			5	0.00	0.38	0.00	0.94	4.69	0.38	0.00	0.00	5.19	2.63	0.00	3.56	3.50	0.00	3.13

Table A1-8: Continued

Region	Catchment	Reef	Depth	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Rhodophyta	Other Rhodophyta	*Caulerpa*	*Halimeda*	Other Chlorophyta	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	Other Phaeophyta	Cyanobacteria	Unknown Family
Mackay Whitsunday	Proserpine	Double Cone Is	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00
		Hook Is	2	0.00	0.00	0.00	0.21	0.18	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Daydream Is	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00
		Shut and Tancred Is	2	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.06
			5	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.06
		Pine Is	2	0.00	0.38	0.06	1.69	4.32	0.00	0.06	0.06	0.00	6.45	0.00	5.07	0.56	0.00	0.56
			5	0.00	0.69	0.00	1.50	0.82	0.00	0.56	0.00	0.00	3.08	0.00	0.06	0.00	0.00	0.00
Fitzroy	Fitzroy	Middle Is	2	0.00	2.42	0.00	1.24	0.88	2.11	0.06	0.00	0.00	40.27	0.00	0.00	0.00	0.00	0.56
			5	0.00	2.26	0.00	0.00	2.88	0.00	0.00	0.00	0.00	34.55	0.00	0.13	0.38	0.00	2.88
		Barren Is	2	0.00	0.00	0.00	2.13	0.69	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00
			5	0.00	0.50	0.00	3.62	0.37	0.00	0.00	0.00	0.00	4.62	0.00	0.00	0.00	0.00	0.00
		Humpy Is and Halfway Is	2	1.88	0.94	0.25	1.00	7.15	0.31	0.00	0.06	1.56	48.55	0.13	0.13	0.06	0.00	0.06
			5	1.13	2.27	0.00	1.51	1.01	0.00	0.00	0.00	0.56	34.33	0.00	0.00	0.00	0.06	0.00
		Pelican Is	2	0.00	0.13	0.06	3.94	36.99	0.13	0.00	0.00	2.25	12.58	0.06	3.13	1.88	0.06	3.76
			5	0.00	0.25	0.00	0.44	6.67	0.00	0.00	0.00	0.56	2.00	0.00	0.81	0.44	0.00	0.06
		Peak Is	2	0.94	0.38	0.00	2.63	39.24	0.06	0.06	0.00	0.00	6.07	0.00	4.95	4.19	0.19	1.06
			5	0.00	0.56	0.00	0.81	15.56	0.06	0.13	0.00	0.00	0.13	0.00	0.19	0.13	0.00	0.06

Table A1- 9: Composition of juvenile hard coral communities. Families (count per 34m²) 2012

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Wet Tropics	Barron Daintree	Snapper Is North	2	19.67	0.33	0.00	0.00	0.00	0.33	10.33	0.33	0.00	1.00	0.00	1.67	0.00	1.00
			5	9.50	4.00	0.00	1.50	0.00	13.50	7.00	2.00	0.00	7.00	2.00	0.00	4.00	0.00
		Snapper Is South	2	95.33	0.00	0.00	0.00	0.00	20.00	3.00	0.00	0.33	3.00	0.00	10.67	13.33	0.67
			5	6.00	0.50	0.00	0.00	0.00	3.00	4.50	0.50	0.00	3.00	0.00	0.00	5.00	0.00
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	63.50	0.00	0.00	0.00	1.00	14.50	5.50	2.00	3.50	7.00	0.50	9.00	20.50	0.50
			5	43.00	1.00	0.00	1.50	0.00	14.00	14.50	0.50	10.00	13.50	4.00	6.50	42.00	1.00
		Fitzroy Is East	2	53.00	0.00	0.00	0.00	0.00	28.50	0.00	1.00	3.50	1.00	0.00	1.50	5.50	0.50
			5	20.50	0.50	0.00	0.50	0.50	19.00	4.00	3.00	6.00	8.00	0.50	9.00	31.00	0.50
		High Is West	2	29.00	0.50	0.00	1.50	0.00	6.50	1.00	1.00	3.00	3.50	1.00	5.00	6.50	0.00
			5	17.50	4.00	0.00	4.50	0.00	14.00	8.00	1.50	4.00	7.00	1.00	1.00	17.50	1.00
		Frankland Group West	2	13.50	2.00	0.00	0.50	0.00	3.00	16.00	1.00	4.00	8.00	1.00	4.50	35.00	2.50
			5	2.50	0.50	0.00	0.00	0.00	0.00	6.00	0.00	0.50	1.50	0.00	0.50	17.00	0.00
	Herbert Tully	North Banard Group	2	5.00	0.00	0.00	5.50	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50	0.00
			5	14.00	1.00	0.00	70.50	1.00	75.00	2.00	0.00	1.50	0.00	0.50	0.50	19.00	1.50
		Dunk Is North	2	12.50	0.00	0.00	100.00	0.00	41.00	0.50	0.50	1.00	1.50	0.00	0.50	5.00	5.50
			5	17.50	0.00	0.00	224.50	0.00	32.50	0.50	0.50	2.00	0.00	0.00	2.50	15.00	10.50
		Dunk Is South	2	29.00	0.00	0.00	23.50	0.00	33.00	0.00	0.00	1.00	6.00	0.00	0.00	9.00	2.00
			5	24.50	1.00	0.00	64.00	1.00	34.50	4.50	2.00	2.50	3.00	6.50	4.00	23.00	5.00
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	41.50	0.50	0.00	1.00	0.50	23.00	3.50	1.00	0.50	1.50	3.50	9.00	4.50	0.50
			5	21.50	4.50	0.00	2.50	0.50	26.00	3.00	0.50	5.50	3.00	21.00	4.00	14.50	0.50
		Orpheus Is East	2	39.00	0.00	0.00	0.50	0.00	13.00	0.00	0.50	2.00	0.00	0.00	1.00	2.50	0.50
			5	25.50	0.50	0.00	1.50	0.00	19.00	0.00	0.50	2.00	0.50	1.50	4.00	10.50	0.00
		Lady Elliot	2	90.00	0.50	1.00	321.50	0.00	8.50	95.00	0.00	1.00	7.00	0.00	0.00	8.00	4.50
			5	4.00	1.50	1.50	147.50	1.00	21.00	3.50	1.00	1.50	4.50	4.50	0.00	16.50	1.50
		Pandora Reef	2	5.50	0.00	0.00	17.00	0.00	0.50	0.00	0.00	0.50	0.50	0.00	0.50	1.50	0.00
			5	14.50	1.00	0.00	42.00	0.00	5.50	7.50	0.00	1.00	2.00	0.00	2.00	2.00	3.00
		Geoffrey Bay	2	35.50	1.00	0.00	7.00	0.50	21.00	5.50	1.50	1.50	4.50	0.00	0.00	10.00	1.00
			5	12.50	2.50	0.00	54.50	0.00	68.00	6.50	2.00	4.50	5.50	2.00	1.50	18.50	3.50

Table A1-9: Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	30.00	0.00	1.00	2.00	0.00	10.00	2.00	2.50	3.50	3.00	1.00	2.50	16.50	0.00
			5	5.50	3.50	0.00	0.00	0.50	6.00	3.00	2.50	3.50	3.50	2.50	0.50	15.00	0.00
		Hook Is	2	15.00	3.00	0.00	4.00	0.50	30.00	0.50	0.50	9.00	0.00	1.00	8.50	24.00	1.00
			5	13.00	2.00	0.00	1.50	2.00	23.50	0.00	1.00	9.00	2.00	6.00	3.50	10.00	0.00
		Daydream Is	2	17.50	0.00	0.00	0.00	0.50	9.00	3.50	3.00	10.50	1.50	5.00	1.50	5.50	0.00
			5	26.00	3.00	0.00	2.50	0.50	20.50	2.00	4.50	11.50	1.00	13.00	6.50	7.00	1.00
		Shute and Tancred Is	2	35.00	1.50	0.00	1.50	0.50	40.00	2.00	3.00	13.00	1.50	11.50	12.00	10.50	1.50
			5	28.50	4.00	0.00	7.50	1.00	45.00	3.00	3.00	11.50	0.50	9.50	2.50	13.00	0.00
		Pine Is	2	32.50	2.00	0.00	1.00	2.50	6.00	11.00	3.50	5.50	4.50	3.00	2.00	30.00	0.00
			5	12.00	4.50	0.00	7.50	1.50	13.50	3.50	1.50	9.50	4.50	12.50	0.00	16.00	0.00
Fitzroy	Fitzroy	Middle Is	2	27.00	0.00	0.00	0.00	0.00	1.00	21.00	0.50	0.00	0.00	0.00	8.50	1.00	0.50
			5	37.00	0.00	0.00	5.00	0.00	9.00	20.00	0.00	0.00	0.00	0.00	3.00	1.00	15.00
		Barren Is	2	62.00	0.50	0.00	19.50	0.00	45.50	0.00	0.00	0.50	0.00	0.00	24.00	1.00	1.00
			5	5.50	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	1.00	0.00	0.00
		Humpy Is and Halfway Is	2	11.50	0.00	0.00	0.50	0.00	11.50	2.00	0.00	0.00	0.00	0.00	11.00	3.50	1.00
			5	10.00	0.00	0.00	5.00	0.00	10.00	1.50	0.00	0.50	0.00	0.00	2.50	3.50	0.50
		Pelican Is	2	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00
			5	0.00	0.00	0.00	15.00	0.00	26.00	0.00	0.50	6.00	0.00	0.00	0.50	17.00	10.50
		Peak Is	2	0.00	0.00	0.00	1.50	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.50	4.00
			5	0.50	0.00	0.00	14.50	0.00	11.50	0.00	0.50	5.00	0.00	0.00	0.00	21.50	8.50

Table A1- 10: Composition of juvenile soft coral communities. Common families (count per 34m^2) 2012.

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Nephtheidae	Xeniidae
Wet Tropics	Barron Daintree	Snapper Is North	2	2	0	0	0	0
			5	1.5	0	1	0	0
		Snapper Is South	2	2	0	0	0	0
			5	3.5	0	0	0	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	36.5	0	0	0.5	0
			5	50.5	0	0	2	0
		Fitzroy Is East	2	20	1.5	5	2.5	25
			5	24	1.5	1.5	0.5	0
		High Is West	2	6.5	0	0	0	0
			5	12	0.5	0	0	0
		Frankland Group West	2	6	0	10.5	0	0
			5	3	0	0.5	0	0
	Herbert Tully	King Reef	2	0	0	0	0	0
			5	4	0	0	1	0.5
		Dunk Is North	2	10	0	0	0	0
			5	17.5	0	0	3	0
		Dunk Is South	2	2	1	0	0	0
			5	23.5	0.5	0	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	73.5	0	5.5	7.5	5
			5	77	0	1.5	240	0
		Orpheus Is East	2	10.5	0	0	0	0
			5	21	0	0	0	0
		Lady Elliot	2	0	0	0	1	0
			5	4	0	0	1	0
		Pandora	2	7	0	1.5	0.5	0
			5	3.5	0	0.5	1	0
		Geoffrey Bay	2	13	0.5	0	0	0
			5	17.5	0	0	0.5	0
Mackay Whitsunday	Proserpine	Double Cone Is	2	44	1.5	0	0	1
			5	34	0.5	0	1.5	0
		Hook Is	2	96.5	2	0	4	0.5
			5	153.	0.5	0	0	0
		Daydream Is	2	82.5	0.5	0	1	4
			5	68.5	0	0	0	0
		Shut and Tancred Is	2	86	0	0	2	0.5
			5	137.	0	0	3.5	0
		Pine Is	2	8.5	3	0	0	2.5
			5	17	1.5	0	0	0
Fitzroy	Fitzroy	Middle Is	2	0.5	0	0	0	0
			5	8	0	0	3	0
		Barren Is	2	1	0	0	0	160
			5	0	0	0	0	420
		Humpy Is and Halfway Is	2	3	0	0	0.5	2.5
			5	1	0	0	0	4
		Pelican Is	2	0	2	0	2.5	0
			5	33	0	3.5	16	12.5
		Peak Is	2	0	0	0	5.5	0.5
			5	30	0	0.5	37.5	9

Table A1- 11: FORAM index baseline values. Values represent the average and standard deviation of the FORAM index for core reefs sampled more than once over the period 2005-2007.

Region	Reef	Baseline FORAM index	Standard Deviation of baseline
Wet Tropics	Fitzroy Is West	7.26	0.87
	High Is West	6.63	0.53
	Frankland Islands West	5.74	2.02
	Dunk Is North	5.70	0.38
Burdekin	Pelorus and Orpheus Islands West	7.62	1.24
	Pandora	8.47	0.63
	Geoffrey Bay	4.70	1.10
Proserpine	Double Cone Is	5.77	2.15
	Daydream Is	3.06	0.15
	Pine Is	2.07	0.21
Fitzroy	Barren Is		
	Humpy and Halfway Islands	6.63	0.68
	Pelican Is	5.98	1.75

Appendix 2: QAQC Information

Photo point intercept transects. The QA/QC for the estimation of cover of benthic communities has two components. The sampling strategy which uses permanently marked transects ensures estimates are derived from the same area of substratum each year to minimise possible sampling error. The second component is to ensure the consistency of identification of community components from digital photo images, and to achieve this, all points are double-checked by a single observer on completion of analysis each year. This double-checking has now been done for all digital still photograph images in the database reported in this document. All hard corals, soft corals and macroalgae were identified to at least genus level where image quality allowed. Other benthic groups were also checked and consistency in differentiation achieved.

Juvenile coral belt transects. Two observers collected juvenile coral count data in 2012. Data from Snapper Is was supplied by Sea Research. The Sea Research observer, Tony Ayling, is the most experienced individual in Australia in surveying the benthic communities of inshore coral reefs. Like the AIMS observers, his taxonomic skills are complete at genus level and he used the same field protocols, pre-printed datasheets and data entry programs as AIMS observers. Prior to commencement of surveys observer standardisation for Tony Ayling included detailed discussion and demonstration of methodologies with the AIMS team. While we are confident that limited bias was introduced as a result of his participation as the focus of the program is for temporal comparisons any bias between Tony Ayling and AIMS observers will not manifest in temporal comparisons at Snapper Is. All other reefs were surveyed by experienced AIMS staff that have previously undergone training in the technique sufficient to ensure its standardised application. To ensure no drift occurs between observers informal comparative counts were undertaken along short sections of transect and count and size class information compared and discrepancies discussed with direct reference to the colony in question. As most dives included two of the experienced aims staff uncertainties in identification were typically discussed *in situ* or that evening with reference to photographs taken of problem individuals. It must be acknowledged however that for some of the smallest size class <2cm identification to genus is impossible in the field, though for the most part this is the case for relatively rare taxa for which reference to nearby larger individuals cannot be made.

Settlement plate spat counts. It is the stated QA/QC aim that hard coral recruits (spat) on retrieved settlement tiles were to be counted and identified using a stereo dissecting microscope with identification to the highest practicable taxonomic resolution and between observer errors (spat overlooked) should not exceed 10%. Identification of the various taxa of spat was achieved on the basis of experience and reference to a photographic archive spat. To examine the percentage of spat overlooked a second observer examined 55 tiles selected at random from four different reefs. As spat are marked during counting to avoid double counts, spat missed by the first observer are easily identified (not marked). This comparison revealed 254 missed spat compared to 3102 recorded, an error rate of 8.1%. This is within the stated QA/QC goal of 10%.

Appendix 3: Patterns in sediment accumulation and river discharge

Sedimentation processes in the inshore GBR are an important determinant of the environmental conditions for coral reefs. It is widely agreed that sediment loads entering the Great Barrier Reef (GBR) lagoon have increased since European settlement (Brodie *et al.* 2003, Kroon *et al.* 2012). The level to which increased loads contribute to high background levels of fine sediments in coastal deposits with flow-on effects of increased turbidity and rates of sedimentation on coral reefs remains a topic of debate. It has been argued that concentrations of suspended fine sediment are not supply-limited in the GBR lagoon as the mass of sediment held in suspension by wind driven waves and currents is several orders of magnitude greater than that introduced by the largest flood plumes (Larcombe and Woolfe 1999, Webster and Ford 2010). In contrast, Lambrechts *et al*. (2010) developed a model which suggests that reducing sediment input from the Burdekin river catchment would reduce turbidity in Cleveland Bay by half in a short period of time (170 days) following the cessation of flooding. Similar evidence is provided by Fabricius *et al*. (2013a) in which data from MMP *in situ* turbidity loggers over three years indicated a significant effect of river flow on turbidity at any given wave height, wave period and tidal range.

Over the course of 2011-2012, sediment traps were deployed at each of the core MMP reefs to assess if sediment deposition increased at times of high river flow. At each reef, three 400mm long and 100mm diameter cylinders were attached to separate star pickets separated by 25m at a height of approximately 450mm above the sea floor at a depth of 5m below lowest astronomical tide. Traps were deployed for periods ranging from 30-160 days.

On retrieval, wet sediments were transferred into plastic containers and frozen. Samples were wet sieved to separate into four grain size classes, based on the Wentworth scale; >1000µm, >250 µm, >63 µm, and <63 µm. Sieved samples were washed with freshwater to remove salt content before being oven dried at 75^0C and weighed allowing the calculation of average daily deposition over the time of each deployment for the four grain size categories.

The use of sediment traps has been much debated for the purpose of measuring sediment accumulation rates on coral reefs (e.g. Browne *et al.* 2012, Thomas and Ridd 2004) and the application of data collected (Storlazzi *et al*. 2011). At this stage we do not use the data as a direct estimate of the rate of sediment deposition on the substrate affecting the benthic community. Rather, we are interested in the relative rates of sedimentation gained from the standardised deployments of the traps both spatially (between reefs) and through time against which any relationship with river flow can be assessed.

Traps were first deployed in the 2010-2011 wet season, however due to adverse diving conditions at the time traps were not deployed in the Fitzroy Region. For the traps that were deployed, detection of the effects of river discharge was confounded by the occurrence of Cyclone Yasi. The effects of the storm resulted in significantly higher total weights of sediment and a disproportional amount of larger grain-size fractions most notably in the Burdekin and Wet Tropics regions where the storm had the greatest impact (Figure A3-1).

A consistent relationship was identified between river flow and sediment accumulation in the Whitsundays region. At all three reefs in the region the quantity of the clay/silt fraction (<63 µm) was highest during the periods coinciding with high river flow and subsided over the following dry season (Figure A3-1). Over the same period little variation in the >63 µm fraction was observed, suggesting that increased accumulation was not the result of wind or current-driven resuspension. With the exception of Double Cone Is, daily accumulation rates were also consistently higher than the water quality guideline value set for sedimentation (GBRMPA 2010).

These results support the reported vulnerability of the Whitsunday reefs to agricultural runoff (Brodie and Furnas 2001, Devlin *et al*. 2010). The sheltered nature of the reefs in this region limits wave-driven resuspension which in turn leads to less advection of fine sediments away from these reefs. As such, deliveries of sediments into the region from terrestrial runoff result in the accumulation of fine sediments onto the Whitsunday reefs.

For the reefs in the other regions sampled the relationship between sedimentation and river flow was only apparent at those reefs closest to the river mouth, in particular High Island in the Wet Tropics Region and Geoffrey Bay in the Burdekin Region. Across all regions there was an obvious decrease in total sediment accumulation across the gradient away from the river mouth; however it is likely that depth influences confound this information and cannot be attributed solely to effects of inputs from rivers.

Overall the relationship between river flow and sediment accumulation in the regions other than the Mackay Whitsunday Region appears to be weak based on the data collected. Indeed it is apparent that resuspension of fine sediments is a major factor in the accumulation rates seen in our traps. However, we suggest that the amount of material available for resuspension is increased by river inputs and as such the winnowing of this material prolongs the effects of flood plumes long after the acute event (Wolanski *et al.* 2007).

Recent studies have argued that fine sediments delivered into the GBR lagoon have residence times far greater than water (weeks to months) and in fact could be in the order of decades to centuries (Brodie *et al.* 2012). This extended residence time results in an accumulation of material being deposited over time (where hydrodynamic regimes permit) which is then available for repeated resuspension. Consequently, levels of sedimentation during the dry season are likely to be enhanced by the previous wet season(s). This fact is likely to be a main contributor to the high levels of sedimentation observed in the Whitsundays region where conditions promote accumulation with limited advection away from the reefs, thus the re-supply of terrigenous sediments every wet season has resulted in considerable deposits of fine sediment, more than in any other region we sampled.

This study was conducted to fit within the field schedule for the MMP and as a result was necessarily coarse in terms of duration of trap deployments. Further studies of the sedimentation regimes of inshore reefs aimed at better quantification of the relative contributions of weather driven resuspension of accumulated deposits and runoff derived sediments would benefit from a more targeted sampling design with more frequent sampling to allow matching between observed rates of deposition with weather conditions but also perhaps longer duration to across years of differing rainfall. Furthermore, techniques employed for the tracing of sediment sources (e.g. Reusser and Bierman 2010, Takesue 2009, Douglas *et al.* 2008) would provide valuable information. This would in turn be beneficial for targeted management at the catchment or sub-catchment scale to reduce sediment loads entering the Great Barrier Reef lagoon.

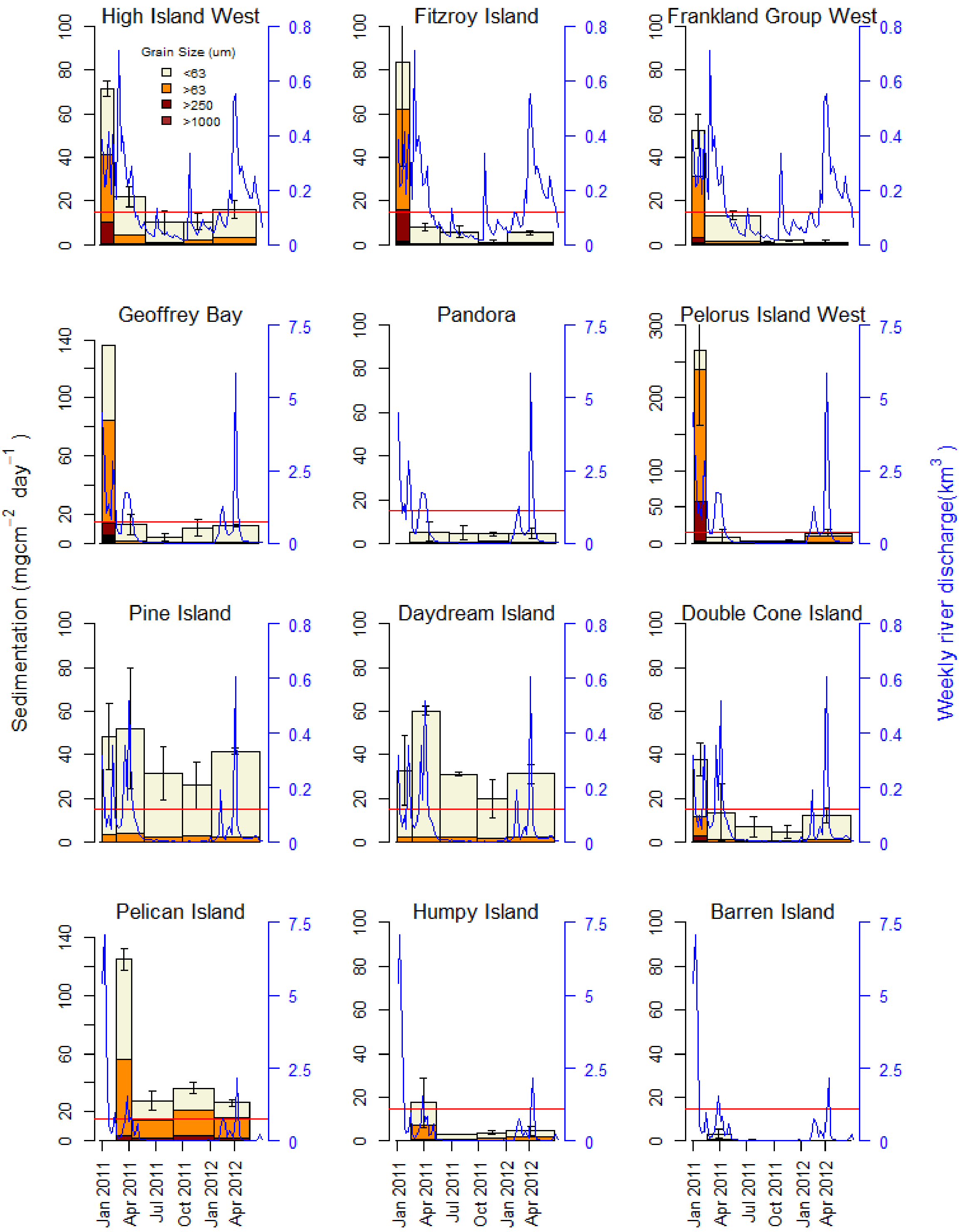

Figure A3- 1: Daily sedimentation rates (mg cm^{-2} day^{-1}). Blue line indicates weekly river discharge (km^{3}), red line is the GBRMPA guideline for sedimentation, width of bars indicate deployment period.

Appendix 4: Scientific publications and presentations arising from the Programme 2012

Publications

Thompson A, Costello P, Davidson J, Logan M, Schaffelke B, Takahashi M, Uthicke S (2012) Reef Rescue Marine Monitoring Program. Final report of AIMS activities 2011 – Inshore coral reef monitoring 2011. Report for Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville.

Fabricius KE, Cooper TF, Humphrey C, Uthicke S, De'ath G, Davidson J, LeGrand H, Thompson A, Schaffelke B (2012) A bioindicator system for water quality on inshore coral reefs of the Great Barrier Reef. Marine Pollution Bulletin 65(4-9):320-332

Presentations:

Oral presentation entitled: “Runoff impacts coral communities in nearshore waters of the GBR” by Angus Thompson*, Britta Schaffelke Paul Costello and Johnston Davidson. International Coral Reef Symposium, Cairns, July 2011

Oral presentation entitled: “Assessing the effectiveness of water quality management of the Great Barrier Reef” by Katherine Martin*, Chris Chinn, Britta Schaffelke, Karen Kennedy, Len McKenzie, Michelle Waycott, Vittorio Brando, Angus Thompson, Michelle Devlin. International Coral Reef Symposium, Cairns, July 2011

Oral presentation entitled “Great Barrier Reef health - status and drivers” by B Schaffelke. Reef Rescue Forum, Brisbane, September 2012.

Oral presentation entitled: “Water quality in the Great Barrier Reef-monitoring mapping and assessing compliance of status” by Schaffelke B, Brando V, Devlin M. Invited seminar at SEWPAC, Canberra, October 2012.