Reef Rescue Marine Monitoring Program

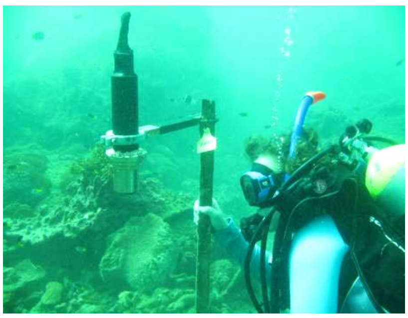
Final Report of AIMS Activities 2010
Project 3.7.1b Inshore Coral Reef Monitoring

Angus Thompson,
Johnston Davidson, Sven Uthicke,
Britta Schaffelke, Frances Patel, Hugh Sweatman

PRODUCED FOR
Reef and Rainforest Research Centre

Australian Government | Australian Institute of Marine Science

Townsville
February 2011



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

This report should be cited as:
Thompson A, Davidson J, Uthicke S, Schaffelke B, Patel F, Sweatman H (2011) Reef Rescue Marine Monitoring Program. Report of AIMS Activities – Inshore coral reef monitoring 2010. Report for Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville. (122 pp.).

Contents

List of Figures and Tables

Executive Summary

- The coral reef monitoring component of the Reef Rescue Marine Monitoring Program (MMP) undertaken in 2010 was a continuation of activities under previous arrangements from 2005 to 2009. 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 24 inshore reef locations in four Natural Resource Management 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 sixth inshore coral reef survey under MMP allows for updated assessments of the overall condition of the inshore coral reef communities. In summary, the overall regional estimates of condition were unchanged from our previous assessment of 2009 data. Within NRM regions, however, assessments of some coral community attributes did vary compared to those previously presented. Our assessments of coral reef community condition in 2010 are as follows:
- The reefs in Barron Daintree and Johnstone Russell-Mulgrave sub-regions of the Wet Tropics Region had the highest regional estimate of coral reef community condition. The condition of these coral communities was assessed as 'good' as a result of high coral cover, which has tended to increase rapidly during periods free from acute disturbance. The density of juvenile colonies was, however, variable among reefs, despite relatively high numbers of coral larvae settling to tiles in the Johnstone Russell- Mulgrave sub-region. The cover of macroalgae was low on most reefs. Levels of chlorophyll and turbidity at the three core reefs in the Johnstone Russell-Mulgrave sub-region were generally below water quality guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009, hereafter 'the Guidelines'), while water turbidity at the one core reef in the Barron Daintree sub-region was highly variable and on average exceeded the Guidelines.
  In contrast to the above sub-regions, the condition of coral communities on reefs in the Herbert Tully sub-region was again rated as 'poor'. This 'poor' assessment reflects the still very low coral cover values resulting from mortality caused by Cyclone Larry in 2006. This is to be expected given the severity of the impact. The observed moderate rates of increase in coral cover and moderately high densities of juvenile colonies show that recovery from this event is underway. The water turbidity at the one core reef in the Herbert Tully Sub-region was consistently high, with mean values exceeding the Guidelines, while mean chlorophyll concentrations were below the guidelines.
- In 2010, the condition of coral reef communities in the Burdekin Region was again rated as 'poor'. The lack of recovery of coral cover here is of real concern as there have been no obvious disturbances since coral bleaching impacted reefs in 2002.

Settlement of spat to tiles and numbers of juvenile colonies continued to be low. Regionally low coral cover may be limiting the availability of coral larvae and so explain the observed low density of juvenile corals. The rate of coral cover increase was low, which, in combination with persistently high cover of macroalgae at some reefs, is reflected in the 'poor' condition assessment of these coral reef communities. Water quality at the three core reefs in this region is characterised by high chlorophyll a values that on average are at or above the Guidelines, however with relatively low turbidity at some reefs, which implies some degree of eutrophication.

- Coral reef communities in the Mackay Whitsunday Region maintained a 'moderate' condition estimate in 2010 despite a substantial reduction in coral cover at Daydream Is caused by Cyclone Ului in early 2010. Regionally, a reduction in average coral cover attributed to Cyclone Ului and a continued decline in the density of juvenile colonies reduced assessment scores of these community attributes from 'good' to 'moderate' (coral cover) and from 'good' to 'poor' (density of juvenile corals). The rate of increase in coral cover when not impacted by disturbance events was slow and the settlement of coral larvae was also relatively low. In combination, these estimates raise concerns over the long-term resilience of local coral communities in this region. It is only the low cover of macroalgae on the reefs monitored that offset the 'poor' or 'very poor' scores for several of the coral-based community attributes.
  The sediment at these reefs had a high proportion of fine (silt and clay) particles, which increased after above-average wet seasons in 2007/08 and 2008/09. Water quality monitoring highlighted the high chlorophyll a and turbidity levels in this region with averages at the three core reefs near or above the Guideline levels.

- Coral reef communities in the Fitzroy Region also maintained a 'moderate' estimate of condition in 2010. While coral cover regionally maintained moderate levels, the rate of increase in cover over the period 2008-2010 was low and resulted in a downgrading of the assessment for this community attribute from 'moderate' in 2009 to 'poor' in 2010. In contrast, there was a general decline in the cover of macroalgae between 2009 and 2010, changing the assessment of macroalgae cover from 'poor' to 'good'. There has been an ongoing discrepancy 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. It is possible that the chronic influence of increased turbidity and nutrient levels resulting from the major floods of the Fitzroy River in both 2008 and 2010 may be temporarily influencing the resilience of coral community in this region.
  The three core reefs in the Fitzroy region are located along distinct cross-shelf gradient, which is reflected in the water quality measured at these sites. The outermost site had mean turbidity and chlorophyll values below the guidelines, the middle site had mean chlorophyll concentrations above the guidelines and the

innermost site had both turbidity and chlorophyll exceeding the guidelines. Major flooding occurring in early 2011 is expected to further disturb the coral communities in this region. This is of particular concern given an ongoing discrepancy between high rates of coral larvae settling to tiles and low densities of juvenile corals. The implied low survival of early life stage corals is a potential bottleneck for the recovery of coral communities following severe disturbance.

- The composition of benthic foraminiferal assemblages showed distinct regional patterns which reflected differences in water and sediment quality. Changes in the community structure have occurred since 2007, and a newly introduced condition assessment system based on baseline data from the first sampling periods indicated strong declines in the FORAM index (an indicator of water quality based on the relative proportions of symbiont-bearing, opportunistic and heterotrophic species groups) for several reefs; the FORAM index also consistently declined in all regions. As for coral 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.
- The present assessment of coral reef communities continues to highlight areas of the GBR where certain aspects of coral communities appear to be under stress and identifies likely causal environmental factors. The monitored coral reef communities are subject not only to direct impacts, such as cyclones, disease, bleaching, and flooding, but are also under the continual influence of coastal processes that determine water quality. It is emerging that variation in environmental conditions between years, particularly with respect to the magnitude of the wet season, is sufficient to significantly alter the dynamics of coral reef communities on inshore reefs. In the Mackay Whitsunday Region, high levels of fine grained sediments disproportionately expose coral communities to turbidity and sedimentation with indications that this is affecting coral growth and recruitment. Similarly in the Fitzroy Region, repeat flooding of the Fitzroy River appears to have been sufficient to suppress the growth of corals in recent years. In the Burdekin Region, coral communities are struggling to recover from severe disturbance in 1998 associated with high temperatures. If proposed links between elevated pollutant loads and susceptibility to thermal bleaching events prove true, this will have serious consequences for inshore reefs into the future. However, should changes in land management practices in the GBR catchments under the Reef Plan and Reef Rescue lead to decreased loads of sediments and nutrients to GBR coastal and inshore waters, we expect to be able to detect associated positive changes in coral reef communities in the longer term.

Introduction to the Program

The Reef Rescue Marine Monitoring Program (MMP), formerly known as the Reef Water Quality Protection Plan Marine Monitoring Programme, was designed and developed by the Great Barrier Reef Marine Park Authority (GBRMPA) and is now funded under the Australian Government's Reef Rescue initiative. In 2009 the Program was integrated into the Marine Tropical Sciences Research Facility (MTSRF) and has been managed by the Reef and Rainforest Research Centre (RRRC). The program forms an integral part of the Paddock to Reef Integrated Monitoring, Modeling 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. The Paddock to Reef Program produces an annual report card and technical report, presenting monitoring information about land management practice, catchment condition indicators, catchment loads and marine indicators. The MMP contributes assessments and information to both of these products.

The Australian Institute of Marine Science (AIMS) and the RRRC entered into a co-investment contract in November 2010 to provide inshore coral reef monitoring activities under the MMP for 2010.

The AIMS monitoring activities in the current contract period of the MMP are largely an extension of activities established under previous arrangements from 2005 to 2009.

This Report presents the results of AIMS coral reef monitoring activities from May to November 2010, with inclusion of data from previous monitoring years since the MMP began in 2005.

Results from the sub-program "Inshore Marine Water Quality Monitoring" are reported separately (Schaffelke *et al.* 2010), however, relevant water quality data are included in the present report to allow interpretation of water quality effects on coral reef condition.

Inshore Coral Reef Monitoring

1. Introduction

Coral reef communities occur in a wide range of environmental settings and vary in their composition in response to environmental conditions such as light availability, sedimentation and hydrodynamics (e.g. Done 1983, 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 waters and generally experience higher water turbidity than reefs further offshore, mainly due to sediment resuspension and episodic flood events. However, reefs adjacent to the developed coast of the central and southern GBR are exposed to land runoff carrying excess amounts of fine sediments and nutrients that have increased since European settlement (Kroon *et al.* 2010); 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 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 now predominantly funded by the Australian Government's Reef Rescue initiative. The MMP is now an integral part of this monitoring. 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 should, with time, also lead to improved water quality in the coastal and inshore GBR. 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 (Death and Fabricius 2010, Thompson et al 2010a,b), it is logical to expect that coral reef communities will change in response to improved land management practices.

The MMP coral monitoring task firstly provides a baseline of the condition at the start of Reef Plan and then documents changes in environmental and biological parameters during the implementation of Reef Plan initiatives. Given the expected small and incremental changes in land run off and the large natural variability in environmental conditions and biological communities, the detection of clear trends will almost certainly require long-term data sets to resolve any responses in marine ecosystems. A second and more immediate use of monitoring data is to provide observational data that can help parameterise ecological models that link environmental drivers to the dynamics of biological communities and may predict the spatial and temporal scale of expected changes before they can be empirically measured.

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 nearshore 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 *et al.* 2008, Diaz-Pulido *et al.* 2009). Laboratory and field studies show that elevated concentrations of nutrients, agrichemicals, and turbidity, can effect one or more of; gametogenesis, fertilisation, planulation, egg size, and embryonic development in corals (reviewed by Fabricius 2005). 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 along environmental gradients can also disproportionately 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, either by feeding on ingested particles and organisms or 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 an artefact of growth form) or active (such as mucous 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 chlorophyll *a* concentrations in the water column, indicating higher nutrient availability

(De'ath and Fabricius 2010). High macroalgal abundance may further suppress reef resilience (e.g., Hughes *et al.* 2007, 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) . The result is that the combination of environmental parameters at a given location will disproportionately favour some species and thus influence community composition. 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 composition of the community (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 to adapt to suit 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 changes in environmental conditions may be delayed until a severe disturbance resets the community (through mortality of the relic community components) and the following recruitment would reflect the current conditions.

In recognition of this, 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 extensively tested at AIMS (see e.g. Uthicke and Nobes 2008, Nobes *et al.* 2008, Uthicke *et al.* 2010, Uthicke and Altenrath 2010). After discussions at the 2008 MMP Synthesis Workshop it was decided by the GBRMPA for cost efficiency to collect samples of foraminifera from core reefs every year but to analyse the community composition only every other year, with the option to later analyse samples of the intervening years if a significant change was observed (and if funding was available). However, foraminifera samples collected in 2009 were not analysed because of funding deficiencies in that year. This report includes the temporal profiles of key attributes of the foraminiferal communities from all reefs where samples have been analysed up to date, i.e. samples collected in 2005 and 2006 under a MTRSF-funded research project and in 2007 and 2010 as part of the MMP. 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, was calculated for each reef. A decline in the FORAM index occurs when there is a reduction in the relative abundance of symbiont bearing species compared to heterotrophic species, which indicates a reduction in light and/or and increase in nutrient availability at a site.

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.*, 2010) 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. Water temperature is continuously monitored at all locations to allow the identification of bleaching events. Assessments of the grain size distribution and nutrient content of sediments were added to the routine coral reef monitoring in 2007/08 from which the hydrodynamic setting of the communities can be inferred and changes in the accumulation of fine sediments and or nutrients documented. The MMP water quality monitoring sites (see separate report, Schaffelke *et al.* 2010) are matched to the core coral reef monitoring locations, which are monitored annually. We are currently exploring the use of MMP remote sensing data to obtain water quality information for the two-yearly monitored cycle reef sites.

In order to quantify inshore coral reef community condition in relation 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 related to water quality and disturbances;
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 drivers 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 sixth annual survey of coral reef sites under the MMP (undertaken in the period from May 2010 to November 2010; hereafter called “2010”) and provides summaries of the monitored suite of community variables over the period 2005 to 2010. The assessment of the condition of reef communities presented in this report provides an overview of the relative condition of the benthic communities in 2010. We again emphasise that this assessment protocol is still developing. As our understanding of the dynamics and drivers of coral communities in inshore waters evolves through ongoing monitoring, and development and validation of ecosystem models, it is anticipated that the assessment protocol will be further refined.

2. Methods

In the following an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the AIMS methods used in the MMP, including quality assurance and quality control procedures, are available in a separate report prepared in May 2009 and updated in May 2010 (Reef & Rainforest Research Centre Ltd 2010).

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 to specific catchments, or groups of catchments (Region), and to disturbance events. Within each Region, reefs are selected along a gradient in 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 the 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 is stratified by depth. Within each site and depth, fine scale spatial variability is accounted for by the use of five replicate transects. Reefs within each region are designated as either 'core' or 'cycle' reefs. At core reefs all benthic community sampling methods are conducted annually, however, at cycle reefs sampling is undertaken every other year and coral recruitment estimates are 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.

Where well-developed reefs existed on more than one aspect of an Is, 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 reefs selected 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.

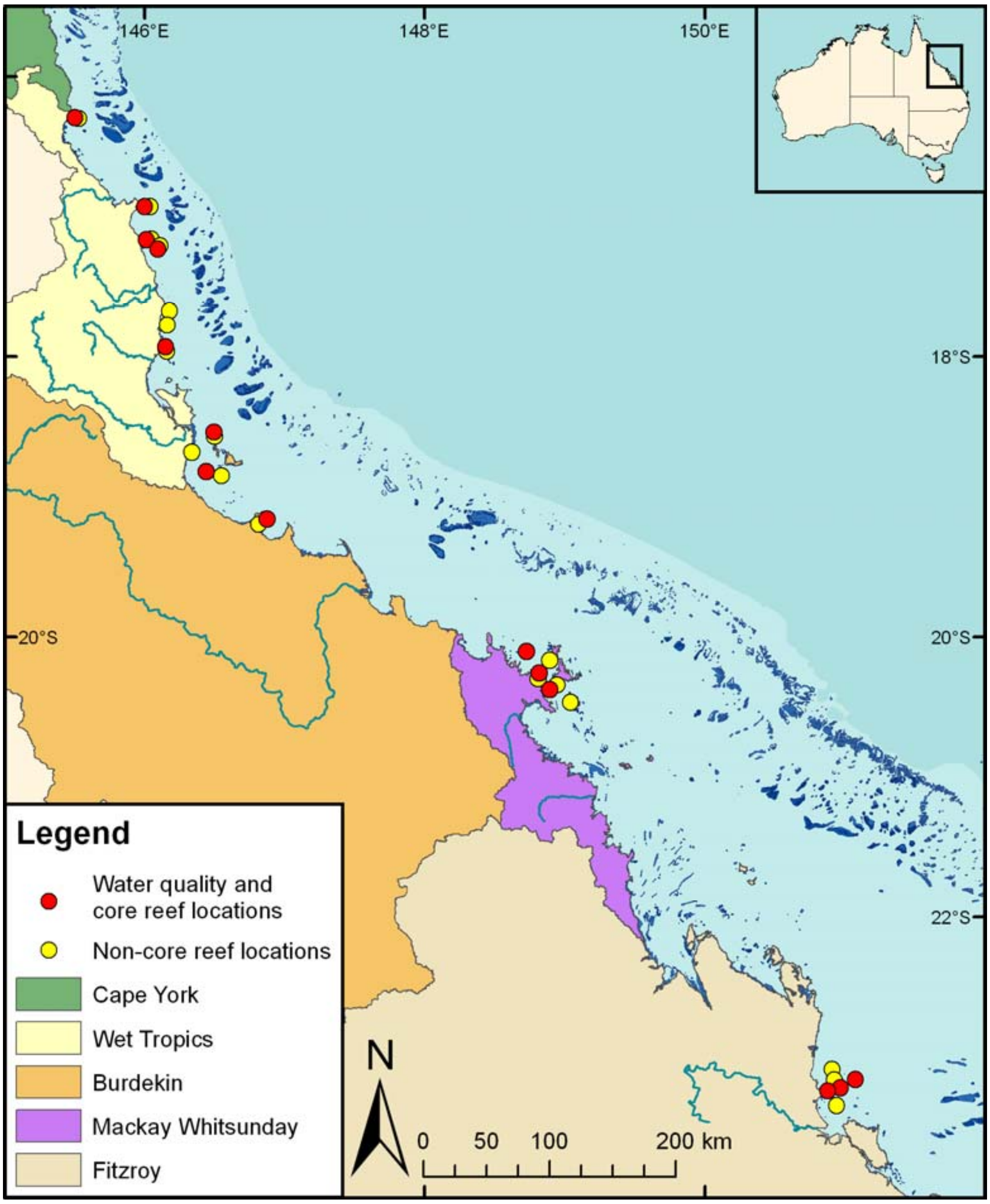


Figure 1 Sampling locations of the Reef Rescue MMP inshore coral monitoring. Core reef locations have annual coral reef benthos surveys, coral settlement assessments and regular water quality monitoring. Exceptions are Snapper Is and Dunk Is North (water quality monitoring, annual coral surveys, but no coral settlement). Cycle reef locations have benthos surveys every two years and no water quality monitoring. See Table 2.1 for the list of surveys completed in 2010. Region boundaries are represented by coloured catchment areas and the black line for marine boundaries.

Table 1 Coral reef sampling in 2005 to 2010. Coral reef monitoring completed (✓), 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
Wet Tropics	Barron Daintree	Cape Tribulation (North)	✓	✓				
		Cape Tribulation (Middle)	✓	✓				
		Cape Tribulation (South)	✓	✓				
		Snapper Is North	✓	✓	✓	✓	✓	✓
		Snapper Is South	✓	✓	✓	✓	✓	✓
	Johnstone Russell-Mulgrave	Fitzroy Is West	✓T	✓T	✓T	✓T	✓T	✓T
		Fitzroy Is East	✓T	✓T	✓T	✓		✓
		High Is West	✓T	✓T	✓T	✓T	✓T	✓T
		High Is East	✓T	✓T	✓T		✓	
		Frankland Group West	✓T	✓T	✓T	✓T	✓T	✓T
		Frankland Group East	✓T	✓T	✓T		✓	
	Herbert Tully	North Barnard Group	✓	✓	✓		✓	
		King Reef	✓	✓		✓		✓
		Dunk Is North	✓	✓	✓	✓	✓	✓
		Dunk Is South	✓	✓		✓		✓
Burdekin	Herbert	Pelorus Is & Orpheus Is West	✓	✓	✓T	✓T	✓T	✓T
		Orpheus Is East	✓	✓		✓		✓
	Burdekin	Lady Elliot reef	✓	✓		✓		✓
		Pandora Reef	✓	✓	✓T	✓T	✓T	✓T
		Havannah Is	✓	✓	✓		✓	
		Middle Reef	✓	✓	✓		✓	
		Geoffrey Bay	✓	✓	✓T	✓T	✓T	✓T
Mackay Whitsunday	Proserpine	Double Cone Is	✓T	✓T	✓T	✓T	✓T	✓T
		Hook Is	✓	✓		✓		✓
		Daydream Is	✓T	✓T	✓T	✓T	✓T	✓T
		Shute & Tancred Islands	✓	✓		✓		✓
		Dent Is	✓	✓	✓		✓	
		Pine Is	✓T	✓T	✓T	✓T	✓T	✓T
		Seaforth Is	✓	✓	✓		✓	
Fitzroy	Fitzroy	North Keppel Is	✓	✓	✓		✓	
		Middle Is	✓	✓		✓		✓
		Barren Is	✓	✓T	✓T	✓	✓T	✓T
		Humpy & Halfway Islands	✓	✓T	✓T	✓T	✓T	✓T
		Pelican Is	✓	✓T	✓T	✓T	✓T	✓T
		Peak Is	✓	✓		✓		✓

2.2 *Field survey methods*

2.2.1 Site marking

At each selected reef, sites were 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 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. 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 cover of the substratum of major benthic habitat components.	Approximately 25cm belt along upslope side of transect form 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 the 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 at the 5m sites.	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 follows 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. Estimation of cover of benthic community components was derived from the identification of the benthos lying beneath five points overlaid onto these images. In all 32 images are 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 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 within 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 on 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 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 estimate the number of juvenile colonies that result from the settlement and subsequent survival and growth of coral larvae rather than small coral colonies 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 as declines in coral condition due to these agents must be carefully considered as covariates in analyses of trends associated with changes in water quality in response to Reef Plan outcomes. 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. In 2010 tiles were deployed to all reefs prior to the full moon on the 23rd October 2010 (Table 3). This allowed a period of at least 3 weeks for tiles to condition before any settlement was expected. It is envisaged that these tiles be retrieved in late December 2010 to early January 2011 and so capture larvae settling following spawning after the full moons in October and November [Note: the retrieval, analysis and reporting will be part of the next MMP coral monitoring contract].

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 10-20mm 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, tagged with the 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 6 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 (not *Isopora*), Acroporidae (*Isopora*), 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.

Region	Catchment	Coral monitoring locations	Coral settlement tile deployment
Wet Tropics	Johnstone Russell-Mulgrave	Fitzroy Is West	08-Oct-10
		High Is West	09-Oct-10
		Frankland Group West	06-Oct-10
Burdekin	Burdekin	Geoffrey Bay	04-Oct-10
		Pandora Reef	05-Oct-10
		Orpheus Is & Pelorus Is West	05-Oct-10
Mackay Whitsunday	Proserpine	Double Cone Is	02-Oct-10
		Daydream Is	02-Oct-10
		Pine Is	01-Oct-10
Fitzroy	Fitzroy	Pelican Is	30-Sep-2010
		Humpy Is & Halfway Is	30-Sep-2010
		Barren Is	30-Sep-2010

Foraminiferal abundance and community composition from sediment samples

The density and composition of foraminiferal assemblages were estimated from a subset of the surface sediment samples collected from 14 coral monitoring sites (see section 2.3). Sediments were washed with freshwater over a 63 µm sieve to remove small particles. After drying (>24 h, 60°C), haphazard subsamples (ca. 2 g) 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 which showed no sign of ageing were considered. 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 dry weight of the sediment and the foraminifera was determined to calculate foraminiferal densities per gram sediment. These density values were used to calculate the FORAM index.

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 is 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 availability of inorganic and 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 calculates 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 = $10P_s + P_o + 2P_h$

2.3 Sediment quality monitoring

Sediment samples were collected from all reefs visited during 2010 (Table 1) 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 six 20-40mm deep 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. This represents the top centimetre of surface sediment. This sediment was transferred to labelled sample jars, yielding a pooled sediment sample per site. Another four cores were collected in the same way to yield a pooled sample per site 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 hotel freezers on the night of collection and then ultimately transferred to a freezer at AIMS for storage 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 Geoscience Australia and the size fractions were chosen to maintain continuity with the analysis provided in previous years by the School of Earth Sciences, James Cook University.

Total carbon (carbonate carbon + 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 carbonate carbon component was assumed to be $CaCO_3$ and was calculated as the difference between total carbon and organic carbon values. In purely reef-derived sediments the carbonate carbon component will be very close to 12% 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 are deployed at, or in close proximity to, all locations at both 2m and 5m depths and routinely exchanged at the time of the coral surveys (i.e. every 12 or 24 months). Two types of temperature loggers have been used for the sea surface temperature logger program. The first type was the Odyssey temperature loggers (http://www.odysseydatarecording.com/), these have now been superseded by the 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 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 is undertaken using WETLabs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors. The 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.* 2010).

The Eco FLNTUSB Combination instruments are deployed year round and perform simultaneous *in situ* measurements of chlorophyll fluorescence, turbidity and temperature at ten minute intervals. 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. The instrument measures as range of chlorophyll pigments, not just chlorophyll *a*, and in the following the instrument data are referred to as "chlorophyll", in contrast to data from the direct water sampling which measures specifically "chlorophyll *a*". 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 2009, 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. At this stage, with a maximum of six observations over five years the formal analysis of trends is unlikely to reveal more than the visual assessment of data plots. As such presentation of results is limited to plots of key community attributes through time. We are, however, working toward the development of appropriate statistical tools to more fully interrogate the temporal dynamics of coral communities and how these relate to environmental conditions.

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 the key community variables monitored, in terms of their support toward a broad concept of resilience. This represents a minor refinement to the assessments of condition presented previously in Schaffelke *et al.* (2009) though is consistent with assessments presented in Thompson *et al.* (2010b).

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. For hard coral communities, a high cover can be interpreted as an indication of resilience as the corals are clearly coping with the ambient environmental conditions. Also, high cover equates to a large broodstock, a necessary link to recruitment. Low cover, however, may result from a recent acute disturbance that has reduced coral cover and so may not be a direct reflection of the community's resilience to the underlying environmental conditions. For this reason we considered coral cover in our assessment in two ways; (i) as a static measure of cover where more is better (see above) and (ii) using the observed rate of change in cover over the last three years as a direct measure of recovery potential. The measure of recovery potential is possible because rates of recovery for inshore reefs on the Great Barrier Reef have been modelled (Thompson and Dolman 2010), allowing estimations of expected increases in cover for communities of varying composition and levels of cover. 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 rate for the 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 exceed 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.

The cover of macroalgae can be highly variable due to a combination of rapid growth rates, seasonality and short life spans of individual thalli. This variability in macroalgal cover precludes a reasonable estimation of change from past monitoring data, and assessments were simply based on a categorisation based on the level of cover in combination with any obvious trends from the previous year.

The density of juvenile corals and settlement of coral larvae to tiles are relatively new additions to monitoring studies on the GBR. Both these measures are linked to recovery potential by indicating the survival of larvae (implicit in coral settling to tiles) and settled juvenile colonies. At present, the data are too sparse and too variable between years to allow for a confident determination as to whether observed levels of recruitment are indicative of a resilient system. For these reasons we can only assess these measures in relative terms among reefs. As both these measures vary between years at any given reef our best estimates on which to rank reefs was the mean level observed to date. The number of juvenile colonies observed along fixed area transects may 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 on to which corals are unlikely to settle. To create a comparative estimate of juvenile colonies between reefs, the numbers of recruits per m^2 were converted to standardised recruit densities per m^2 of 'available substratum' by considering only the proportion of the substratum that was occupied by algae, and hence potentially available to coral recruitment. For both, the number of larvae settling to tiles, and the density of juvenile colonies, three assessment categories were defined, representing the upper, lower and central thirds of the data.

The decision rules for categorization of coral reef community attributes, as described above, are summarized in Table 4. For each reef a categorical assessment was made for each community attribute and the condition of the reef was determined by aggregation across these categories. To aggregate the condition assessment to a sub-regional or regional level, the assessments for each attribute were converted to numerical scores whereby: positive = 2, neutral = 1, and negative = 0. The attribute scores were added for each (sub-) region and then converted into an overall proportional score relative to the maximum possible score by dividing this sum by the number of assessments x 2 (i.e. the maximum rating that could be achieved if all assessments returned a positive score = 2) and multiplying by 100 (to convert into a percentage scale). The average of these regional attribute scores gave the overall (sub-) regional assessment rating. The proportional scores were expressed on a five point scale and converted to a colour scheme for reporting whereby:

- 0%-20% is assessed as 'very poor' and coloured red
- >20%-40% equates to 'poor' and coloured orange
- >40%-60% equates to 'moderate' and coloured yellow
- >60%-80% equates to 'good', and coloured light green
- >80% is assessed as 'very good' and coloured dark green.

Table 4 Threshold values for the assessment of coral reef condition and resilience

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 (coral cover change)	+	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) > 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) - between 7 and 13 juvenile colonies per m^2 of available substratum (5m depth)
	-	< 7juvenile 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

An assessment of Foraminiferal assemblages was included for the first time in this report. At this stage we are considering the foraminiferal assemblages separately from the coral community attributes 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. From these initial observations values of the FORAM index (sensu Hallock *et al.* 2003) were calculated for each reef (Table A1-8). Current 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 lower than the 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 are presented in two sections. In the first section the temporal profiles of the various community attributes and environmental variables are presented at the scale of regions. This is 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, the discussion of results focuses on the comparison of trends between 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) and Thompson *et al.* (2010a).

The second section provides detailed reef-level data for each region, or in the case of the Wet Tropics Region, sub-regions based on major catchments. These reef-level estimates were then aggregated to form the regional and sub-regional assessments presented in Section 1 of the results.

3.1 GBR-wide summary of changes in environmental variables and benthic communities between 2009 and 2010 with reference to changes since 2005

3.1.1 Sediment quality

This section provides an overview of sediment data collected from all coral monitoring sites (detailed results in Appendix Table A1-1). The grain size and nutrient content of sediments have demonstrated links to coral community composition (Fabricius 2005, Fabricius *et al.* 2005). 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 including: preventing settlement of coral larvae (Babcock and Smith 2002, Baird *et al.* 2003, Fabricius *et al.*, 2003, Birrell *et al* 2005), 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). Nutrient content in sediments is an indication of the availability of nutrients in the system which in turn can promote the growth of potential space-competitors to corals such as macroalgae and filter feeding organisms (Fabricius 2005).

The Burdekin and Fitzroy regions are both characterised by having large catchments dominated by single river systems with relatively large, flood-dominated (Bureau of Meteorology, electronic resource) discharges into the coastal receiving waters (Table 5). Further, both regions have an open coastline with monitored core reefs at a greater distance from the river source than in other regions. The land use in both regions is predominately pasture for cattle grazing (Brodie *et al.* 2003, Australian Natural Resource Atlas (electronic resource)). The sediments of core reefs in both regions had broadly similar values of clay and silt, nitrogen, organic and inorganic carbon from 2006 to 2010 (Figure 2). In combination, relatively low proportions of clay and silt sized particles and high proportions of inorganic carbon (reefal in origin) in sediment samples indicate limited accumulation of terrestrially derived sediments at the core reefs. This lack of accumulation of fine sediments is likely due to the frequent re-suspension of sediments by wind waves and subsequent advection of fine sediments away from reefs by coastal waves. In the Burdekin Region there has been no evidence of an increase in the nutrient content of the sediments despite substantial flooding of the Burdekin in 2008 and 2009. As nutrients tend to sorb to fine sediments (Furnas 2003) the hydrodynamic setting of the core reefs that effectively limits the accumulation of fine sediments may act to buffer any short term changes in nutrient supply. Further, the survey reefs are located a considerable distance (>100 km by sea) from the mouth of the Burdekin River. Over the time taken for flood waters to travel this distance (several days) most dissolved nutrients would have been taken up by biological communities or settled to the sea bed (Furnas 2003). Such settlement of nutrients in close proximity to the river is likely responsible for the marked increase in nitrogen content of the Fitzroy Region (where core reefs are within 50km of the Fitzroy river mouth) sediments in 2008 and 2010 following major flood events of the Fitzroy River (Figure 2).

Catchments in the Wet Tropics and Mackay Whitsunday regions are relatively small and compressed by coastal mountain ranges. At greater than 1000 mm $y^{-1,}$ average rainfall is 2-3 times higher in these catchments than for the Burdekin or Fitzroy Regions. Both regions have several rivers flowing into the inshore waters. These river systems are relatively small and meander through soils primarily cultivated for crops, with high carbon and nitrogen content (Australian Natural Resource Atlas, electronic resource). The reef sediments analysed in the Mackay Whitsunday Region have the highest proportion of fine grained particles, nitrogen and organic carbon and the lowest levels of inorganic carbon (Figure 2). In combination, and considering the high turbidity in this region, these results indicate that reefs in this region have a much greater exposure to pressures associated with high sedimentation and nutrient levels than reefs in other regions. This is supported by field observations of substantially greater accumulation of sediments to coral settlement tiles deployed in this region compared to other regions, which provide direct evidence of the difficulty facing coral larvae attempting to settle to substrata on these reefs. There is also a relationship between changes in sediment composition and annual fluctuations in river flow. In the Mackay Whitsunday Region, river discharge in the period 2001/02 to 2005/06 was substantially lower than discharge from 2006/07 to 2009/10 (Table 5). Over this recent period of high flows the proportion of sediments of marine origin (inorganic carbon) declined while nitrogen and organic carbon content and the proportion of fine grained particles in the sediment increased (Figure 2). Data from the Wet Tropics Region are more variable with moderate proportions of clay & silt sized particles and sediment nutrients. Moderate though variable levels of fine grained particles could indicate a variable hydrodynamic setting with periods of sediment accumulation punctuated by re-suspension events.

Our analysis of grain-size distribution (see Methods) identified a higher proportion of fine clay/silt particles across all samples in 2010 (Figure 2). These changes may indicate real increases in some regions due to increased river output (e.g. Wet Tropics, Fitzroy Regions) or the redistribution of existing sediments caused by physical disturbance (e.g. Mackay Whitsunday Region due to Cyclone Ului). However, the increases in silt content were not accompanied by large changes associated with the nutrient content and we assume that most of the changes in silt content described in Figure 2 are the result of a change in delivery (see section 2.3). Future monitoring years will show whether the changes persist.

In summary, while the sediment composition varies among sites and between years the last five years of monitoring has established a range of regional values to support a baseline against which future changes can be assessed.

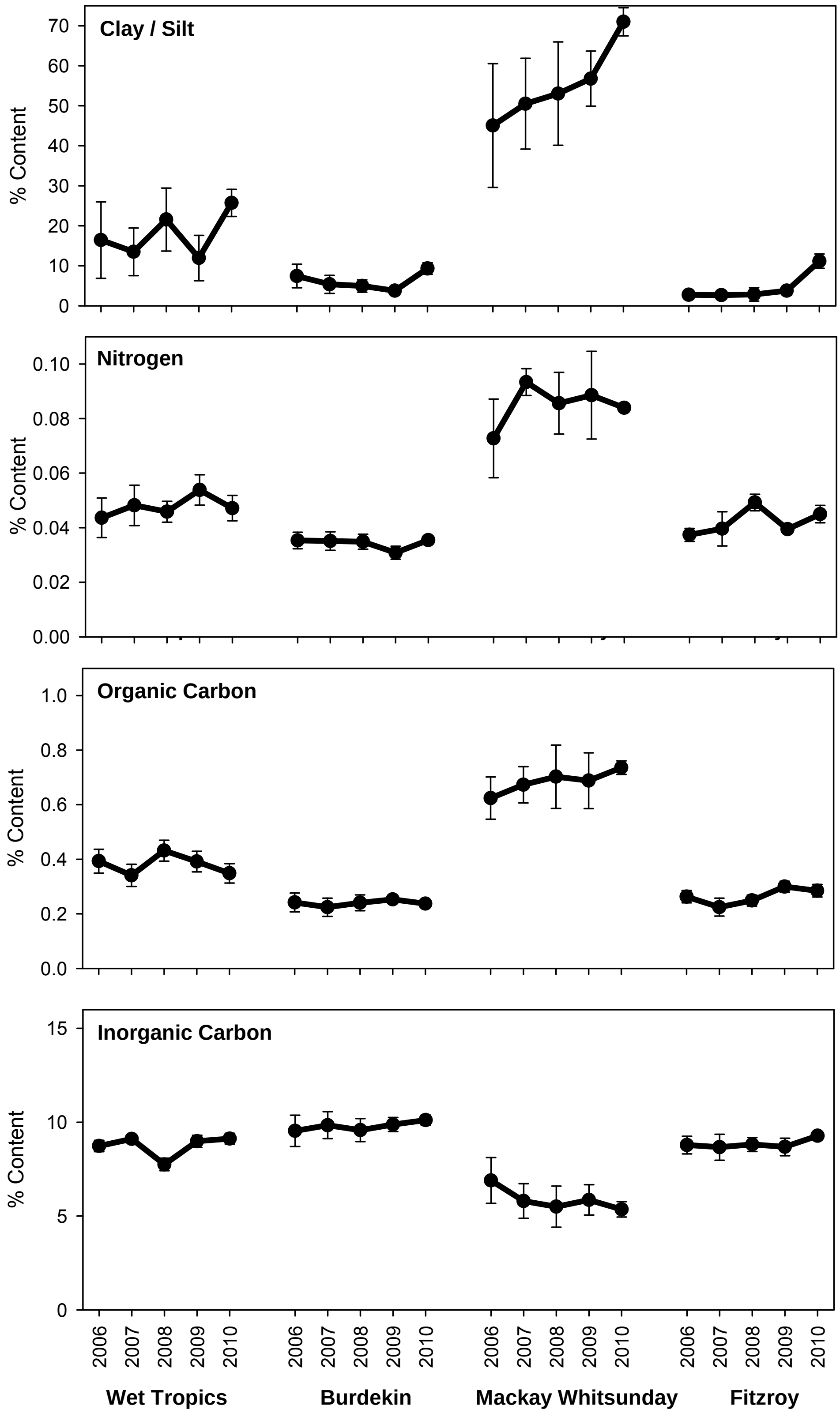


Figure 2 Reefal sediment composition. Average proportion of sediment consisting of; clay and silt sized grains, nitrogen, organic carbon, and inorganic carbon for each region (+/- standard error). Only reefs sampled in all years were included to ensure consistency among means.

Table 5 Annual freshwater discharge for the major GBR Catchment rivers. 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. Colours highlight those years for which flow exceeded the median by 50-100% (yellow), 100-200% (light orange), 200-300% (dark orange), and more than 300% (red). Missing values represent years for which >15% of daily flow estimates were not available, where as an * indicates that between 5% and 15% of daily observations were missing. Discharge estimates for 2010 only include data up to the 10th of June 2010.

Region	River	Median discharge (ML)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Wet Tropics	Daintree	727,872	1.4*		0.2	2.0	0.7	1.7	1.0	1.2		1.5
	Barron	689,957	1.2	0.2	0.2	1.4	0.6	1.1	0.6	2.3	1.1	0.7
	Mulgrave	751,149		0.2	0.4	1.5		1.2	1.0	1.2	0.9	0.7
	Russell	1,193,577	1.0	0.4	0.5	1.1	0.8	1.1	1.1	0.9	0.9	0.8
	North Johnstone	1,746,102	1.2	0.4	0.5	1.3	0.8	1.2	1.2	1.1	1.1	0.8
	South Johnstone	820,304	1.0*	0.4	0.4		0.7	1.2	1.1	1.0	1.2	0.7
	Tully	3,074,666	1.2	0.4	0.5	1.1	0.7	1.2	1.3	1.0	1.2	0.7
	Herbert	3,067,947	1.5	0.3	0.2	1.1	0.4	1.3	1.3	1.1	3.1	0.9
Burdekin	Burdekin	5,982,681	1.5	0.7	0.3	0.3	0.7	0.4	1.6	4.6	5.0	1.3
Mackay Whitsunday	Proserpine	17,140	0.8	1.2	1.1	0.6	1.4	1.2	2.6	4.5	3.8	2.7
	O'Connell	145,351	1.0	0.6	0.2*		0.5	0.6	1.2	1.6	1.1	1.4
	Pioneer	671,839							1.3	2.0	1.4	1.9
Fitzroy	Fitzroy	2,827,222	1.1	0.2			0.3*	0.2	0.4	4.3	0.7	3.8

3.1.2 Sea temperature monitoring

Sea temperature data are reported for the period of June 2005 to June 2010 (Figure 3). 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 aseasonally high temperatures have been shown to cause stress to corals that may increase susceptibility to disease (e.g. Bruno *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 3). In the Fitzroy Region these high summer temperatures resulted in widespread bleaching and subsequent loss of coral on most of the reefs included in this study. There were also slight declines in coral cover over this period on reefs in the Burdekin and Mackay Whitsunday Regions. These reefs were visited in December 2005 when no bleaching was evident; if temperature stress was responsible for the slight declines in coral cover in this region they would most likely have occurred in late January and February as was the case in the Fitzroy Region (Diaz-Pulido *et al.* 2009). In the Burdekin Region, reefs at Magnetic Is were visited frequently over this period of high temperature with no bleaching observed (Ray Berkelmans pers. comm.). Deviations above the long-term averages in the period April 2006 to June 2010 have been relatively minor and or short lived and have not caused observable mortality of corals in any regions. Temperatures in November and December 2008 in the Burdekin and Mackay Whitsunday Regions were aseasonally high, however, they were reduced by heavy rainfall in the following months. Coral bleaching did occur in early 2009 but was most likely due to exposure to low salinity (as observed by van Woesik *et al.* 1995) with bleached corals rarely observed more than 0.5m below lowest astronomical tides. The bleaching of corals in very shallow waters did not affect coral cover along the fixed transects monitored by this program as they were in slightly deeper water. The exception were reefs in Cleveland Bay area of the Burdekin Region where low salinity penetrated to several meters causing stress and mortality among corals at 2m locations at both Geoffrey Bay and Middle Reef.

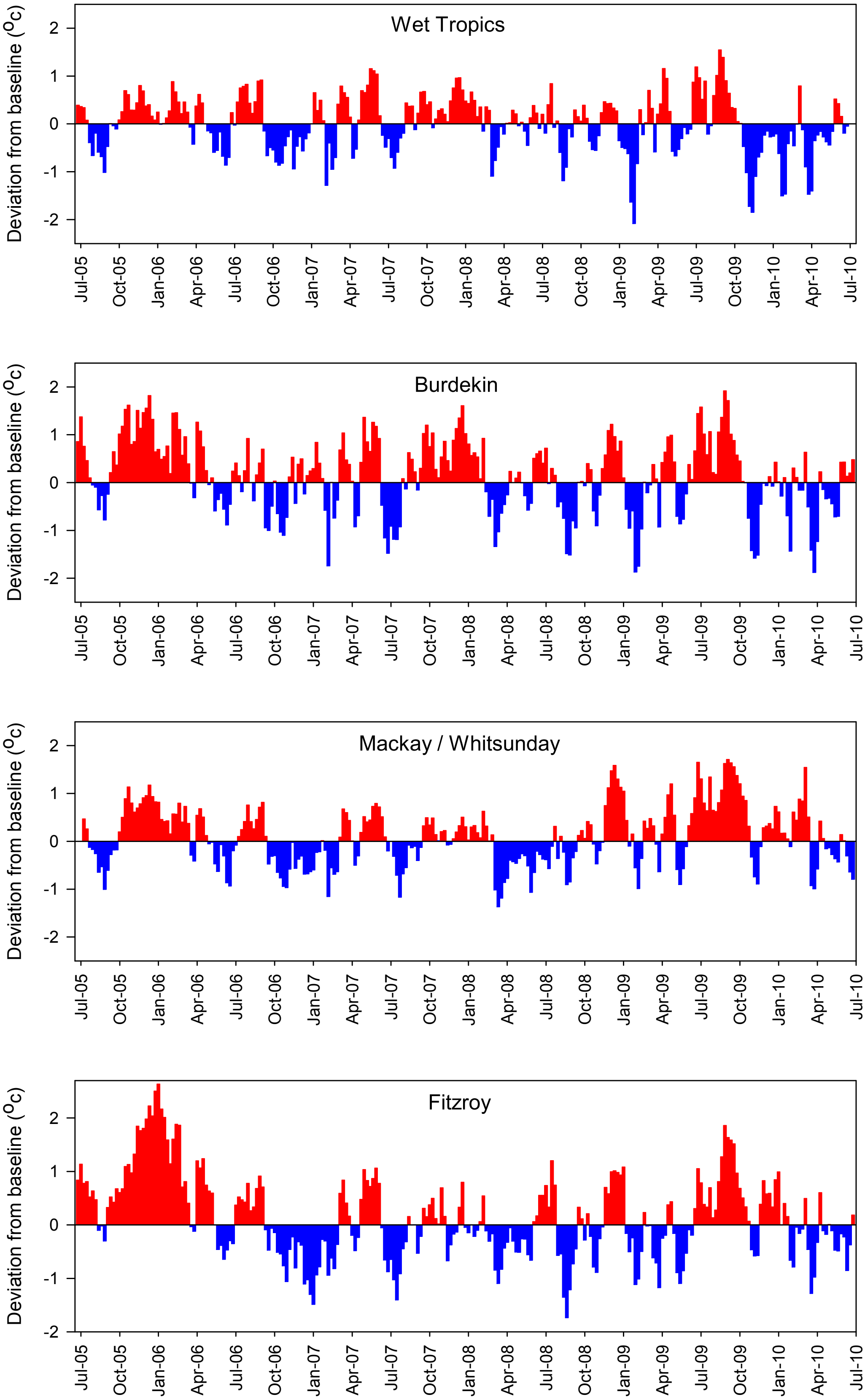


Figure 3 Sea temperature monitoring 2005 to 2010. Data presented are weekly deviations from regional climatology (based on records from July 1999 to June 2008).

3.1.3 Condition of inshore coral reef communities

The assessment of coral reef community condition rates coral reef communities based on a combination of their current condition (cover of corals and macroalgae) and their recovery potential (rate of coral cover increase, density of juvenile corals and settlement of spat). 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 demonstrated supply of larvae and survival of juveniles.

The assessment of condition was first undertaken for observations between 2005 and 2009 and presented in Thompson *et al.* (2010b). This second assessment (Table 6) updates the first assessment by including observations for coral and macroalgal communities observed in 2010. In addition, the first assessment based estimates of the attribute "coral cover change" on the years 2005 – 2009 while this second assessment only considers the changes in cover over the period 2008 – 2010. This change to the most recent three years represents a shift from the baseline assessment reported in Thompson *et al.* (2010b). Focusing on the change in cover over the last three years allows the assessment to stay current. It should also be noted that as the first assessment included coral settlement data from the summer of 2009/10, and this report precedes the assessment of settlement for 2010/11, no new settlement data are included here. Regional estimates of condition (Table 6) were derived by aggregating reef level condition scores within each region and sub-region (see section 3.2). The current regional estimates of condition and deviations from our last assessment are as follows:

- The reefs in Barron Daintree and Johnstone Russell-Mulgrave sub-regions of the Wet Tropics Region had the highest regional estimate of coral reef community condition. The condition of these coral communities was assessed as 'good' as a result of high coral cover, which has tended to increase rapidly during periods free from acute disturbance. The density of juvenile colonies was, however, variable among reefs, despite relatively high numbers of coral larvae settling to tiles in the Johnstone Russell- Mulgrave sub-region. The cover of macroalgae was low on most reefs.
  In contrast to the above sub-regions, the condition of coral communities on reefs in the Herbert Tully sub-region was again rated as 'poor'. This 'poor' assessment reflects the still very low coral cover values resulting from mortality caused by Cyclone Larry in 2006. This is to be expected given the severity of the impact. The observed moderate rates of increase in coral cover and moderately high densities of juvenile colonies show that recovery from this event is underway.
- In 2010, the condition of coral reef communities in the Burdekin Region was again rated as 'poor'. The lack of recovery of coral cover here is of real concern as there have been no obvious disturbances since coral bleaching impacted reefs in 2002. Settlement of spat to tiles and numbers of juvenile colonies continued to be low. Regionally low coral cover may be limiting the availability of coral larvae and so explain the observed low density of juvenile corals. The rate of coral cover increase was low, which, in combination with persistently high cover of macroalgae at some reefs, is reflected in the 'poor' condition assessment of these coral reef communities.
- Coral reef communities in the Mackay Whitsunday Region maintained a 'moderate' condition estimate in 2010 despite a substantial reduction in coral cover at Daydream Is caused by Cyclone Ului in early 2010. Regionally, a reduction in average coral cover attributed to Cyclone Ului and

a continued decline in the density of juvenile colonies reduced assessment scores of these community attributes from 'good' to 'moderate' (coral cover) and from 'good' to 'poor' (density of juvenile corals). The rate of increase in coral cover when not impacted by disturbance events was slow and the settlement of coral larvae was also relatively low. In combination, these estimates raise concerns over the long-term resilience of local coral communities in this region. It is only the low cover of macroalgae on the reefs monitored that offset the 'poor' or 'very poor' scores for several of the coral-based community attributes.

- Coral reef communities in the Fitzroy Region also maintained a 'moderate' estimate of condition in 2010. While coral cover regionally maintained moderate levels, the rate of increase in cover over the period 2008-2010 was low and resulted in a downgrading of the assessment for this community attribute from 'moderate' in 2009 to 'poor' in 2010. In contrast, there was a general decline in the cover of macroalgae between 2009 and 2010, changing the assessment of macroalgae cover from 'poor' to 'good'. There has been an ongoing discrepancy 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. It is possible that the chronic influence of increased turbidity and nutrient levels resulting from the major floods of the Fitzroy River in both 2008 and 2010 may be temporarily influencing the resilience of coral community in this region.

Table 6 Regional and sub-regional estimates of coral community condition. The overall condition aggregates assessments of five indicators, coral cover, coral cover change, macroalgal cover, juvenile hard coral density and settlement of coral larvae. The regional estimates of these indicators are, in turn, derived from the aggregation of assessments from the reefs within each region (Section 3.2). The FORAM index assessments are included as a separate indicator of current environmental conditions and do not influence the "Overall Condition" assessment for each region. The colour scheme is consistent with reporting to the Paddock to Reef Program and fits the three category assessments at reef level to a five point scale (see Section 2.6.1). Colours reflect the relative condition of reef communities: red= very poor, orange= poor, yellow= moderate, light green= good, dark green= very good. Grey shading indicates regions where indicators were not sampled or assessed.

Region	Sub region	Overall Status	Coral Cover	Coral Cover Change	Macroalgae Cover	Coral Juveniles	Coral Settlement	FORAM index
Wet Tropics	Barron Daintree	light green	dark green	orange	light green	yellow	grey	grey
	Johnstone Russell-Mulgrave	light green	dark green	light green	dark green	yellow	light green	red
	Herbert Tully	orange	red	yellow	red	light green	grey	red
Wet Tropic (Regional)		light green	light green	yellow	light green	yellow	light green	red
Burdekin		orange	orange	orange	yellow	yellow	red	red
Mackay Whitsunday		yellow	yellow	red	dark green	orange	orange	orange
Fitzroy		yellow	yellow	orange	light green	red	light green	yellow

FORAM index values observed in 2010 where consistently below those observed over the period 2005-2007. 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. As it stands 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 2010 that favours heterotrophic species.

At present, the uniform, abundance-based criteria for the assessment of coral cover, macroalgae cover, juvenile density and settlement do not differentiate between reefs with different community composition. However, it is well documented that both susceptibility to disturbance and environmental condition, and also growth and mortality rates, vary among coral taxa (see e.g., Sweatman *et al.* 2007). Thompson and Dolman (2010) use GBR inshore reef community data to model expected growth rates (increases in cover) based on broad differences in community composition. This analysis forms the basis of the condition estimates for the "coral cover change" assessment presented here (Table 6). As the time series extends it is expected that the estimation of condition will evolve to incorporate consideration of community composition into other condition indicators. For example, lower numbers of juvenile colonies in a community dominated by large colonies of relatively resilient taxa (*Porites* for example) may be adequate to replace colonies lost to mortality, whereas far greater levels of recruitment may be required to maintain a *status quo* if more susceptible taxa (*Acropora* for example) suffered high mortality. At this point insufficient data exist for us to derive individual expectations for these community attributes for the principal community types found on inshore reefs. The current assessment provides a relative assessment among reefs and may point toward reefs that are at most risk of decline.

Cover of hard corals

Overall cover of hard corals was stable at 36 % on the reefs surveyed in both 2009 and 2010. The substantial decline in cover on the core reefs in the Mackay Whitsunday Region attributed to damage caused by Cyclone Ului in combination with lesser declines in the Burdekin and Fitzroy regions balanced the cover increases on reefs in the Wet Tropics Region, where coral communities continued to recover from past disturbance events (Figure 4).

The most dramatic change in hard coral cover in the period 2009 to 2010 was attributed to the passage of Cyclone Ului through the Whitsunday Islands. This event was the primary cause of the observed decline in hard coral cover in 2010 in that region (Figure 4). The cyclone passed almost directly over the monitoring sites at Daydream Is, and resulted in reductions in cover from 32% to 19% at 2m depth and 41% to 24% at 5m depth (see Figure 33) where thickets 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. Prior to 2010 coral cover in the Mackay Whitsunday Region remained relatively stable or in some cases declined. We interpret this lack of growth as evidence of chronic stress rather than this impact of any particular disturbance event.

In the Wet Tropics Region the cover of hard corals is generally high and/or in the process of recovering from past disturbance events, for example, Cyclone Larry in 2006, flooding in 2004. The largest increases in cover over the period 2009-2010 were at 2m depth at Snapper Is South, where the cover of Acroporidae continued to recover from declines attributed to flooding in 2004, and at Fitzroy Is West, where the cover of Acroporidae continued to recover from crown-of-thorns starfish feeding activity in 2000. Increases in cover of Acroporidae were less common at 5m depths but were evident at Fitzroy Is West. At High Is East and Frankland Group East communities have a high abundance of the family Poritidae and cover of this family also increased to 2010. Recovery of hard coral cover following declines attributed to Cyclone Larry was evident at all locations in the Herbert Tully sub-region. It was only at 5m depth of Snapper Is North where cover declined marginally between 2009 and 2010.

In both the Burdekin and Fitzroy regions average coral cover on the core reefs declined slightly in 2010. In the Burdekin Region cover has been consistently low since surveys began in 2005. 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 lack of recovery suggests a lack of resilience of the coral communities in this region. In the Fitzroy Region several of the reefs have communities with a high cover of branching *Acropora* that have repeatedly shown the potential for rapid increases in cover following disturbances (see the jagged profile of cover in Figure 4, Figure 38, and also Diaz-Pulido *et al.* 2009). In the period 2009-2010, the slight decline observed on core reefs could be due to a combination of minor impacts of storm events at 2m at both Barren Is and Pelican Is along with mortality caused by disease. The prevalence of disease noted on these reefs in 2010 may imply chronic environmental stress as a result of repeated flooding of the Fitzroy River in 2008 and 2010; this premise is consistent with observed declines in coral cover in the Mackay Whitsunday Region in 2009 that were preceded by severe flooding earlier that year.

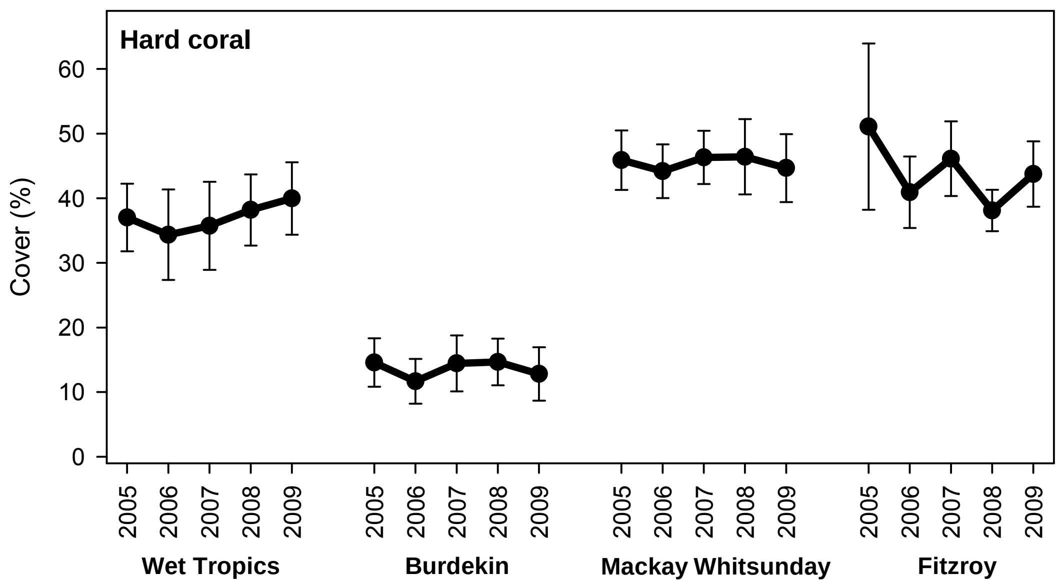


Figure 4 Regional change in hard coral cover. Average cover on core reefs for each region (+/- standard error). For each region only reefs sampled in all years were included to ensure consistency among annual averages.

Cover of soft corals

The average cover of soft corals has been stable on core reefs between 2005 and 2010 in both the Wet Tropics and Mackay Whitsunday regions (Figure 5). In the Fitzroy Region the slight decline in cover observed in 2008 was the result of storm damage at Barren Is. By 2009, this soft coral cover had largely recovered prior to further storm damage in 2010. In the Burdekin Region the decrease in the regional average reflects the soft coral cover at just one location, Pelorus Is & Orpheus Is West, with cover elsewhere being very low. Little can be concluded from the relatively small fluctuations in cover at this reef as the taxa present have colonies that are highly retractile and so observed changes in cover may simply reflect the degree of extension of colonies at the time of sampling.

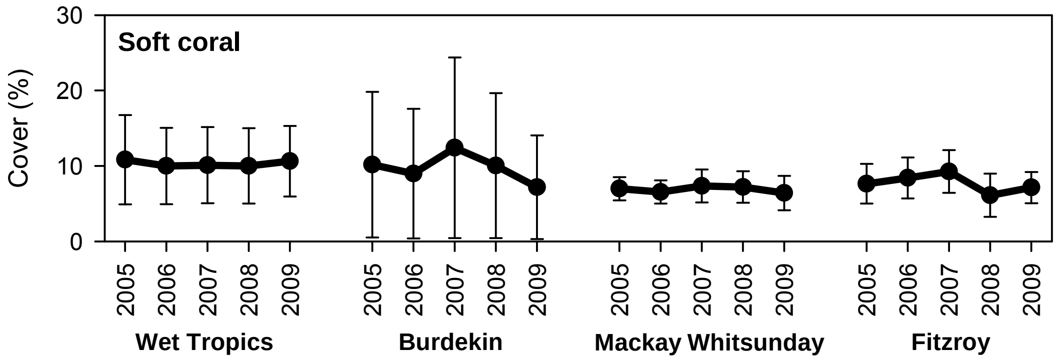


Figure 5 Regional change in soft coral cover. Average cover on reefs for each region (+/- standard error). For each region only reefs sampled in all years were included to ensure consistency among annual averages.

Cover of macroalgae

The cover of macroalgae can be more variable through time compared to that of corals, due to the short life spans of individual thalli, seasonality, and the potential for high growth rates. Despite this potential for variability in cover the overall mean cover of macroalgae on core reefs did not change between 2009 and 2010. This overall lack of change, however, masks the variable profiles of algae cover at the regional level (Figure 6) and also at individual reefs within each region.

In the Wet Tropics Region, macroalgae cover continued to be low on reefs in the Barron Daintree and Johnstone Russell-Mulgrave sub-regions and when present is typically comprised of red algae colonising coral rubble and spaces between coral branches. In 2010 the cover of these algae was within the range observed in previous years. In the Herbert Tully sub-region brown algae were more common and followed a general trajectory of moderate cover in 2005, a reduction in 2006 directly after the passage of Cyclone Larry followed by a subsequent rapid increase to the relatively high cover maintained through to 2010.

In the Burdekin Region, brown algae have had consistently high cover at both Geoffrey Bay and Pandora Reef for the period 2005 to 2008. In 2009, cover at Pandora Reef was reduced following storm damage, but increased again in 2010. It is this substantial fluctuation in cover at Pandora Reef that is evident in the dip in regional cover in 2009 (Figure 6). On the cycle reefs, a similar reduction in macroalgae cover in 2009 was observed at Havannah Is though evidence of storm damage was not obvious at this reef. Macroalgae cover has also been consistently high at Lady Elliot Reef where a mixture of brown (*Dictyota* sp) and red (*Hypnea* sp) form a thick blanket over the rubble substratum at 2m. It is highly likely that the high cover of macroalgae at these reefs is limiting the rate at which coral cover increases.

On the Mackay Whitsunday Region core reefs macroalgae were only common at Pine Is. The regional average cover largely reflects the variability in the cover of brown algae (mostly *Sargassum* sp) at this reef. Seaforth Is is the only other location monitored in this region at which macroalgae cover has exceeded 5% of the substratum. The reef was last monitored in 2009 when macroalgae cover had declined relative to previous years.

In the Fitzroy Region, communities of macroalgae differ between the mixed assemblages found at Peak and Pelican Islands and those dominated by the brown algae *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). Decreases in average macroalgal cover to 2008 reflect both a decrease of *L.. variegata* on the offshore reefs along with slight decrease in the cover of the mixed community at Pelican Is. In 2009, macroalgal cover at each reef monitored had returned to levels similar to those reached in 2007. In 2010 cover had decreased again. Interestingly, decreases in cover of macroalgae in both 2008 and 2010 were observed after major floods of the Fitzroy River, but also localised storm events. However, it is unclear as to which of these disturbances exerted the greatest influence on macroalgal cover.

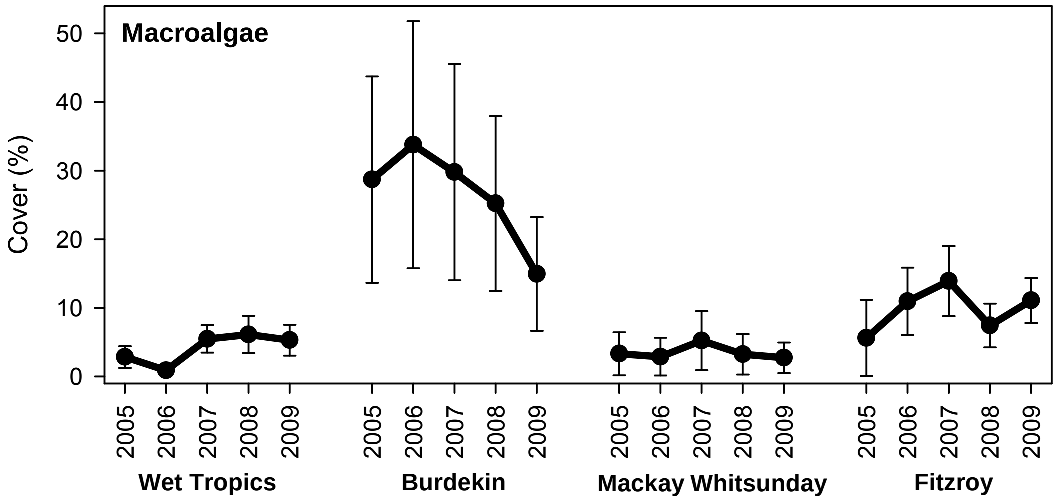


Figure 6 Regional cover of macroalgae. Average on reefs for each region (+/- standard error). For each region only reefs sampled in all years were included to ensure consistency among annual averages.

Density of juvenile hard coral colonies

On the core reefs the average density of juvenile hard coral colonies decreased annually from 5.2 m^{-2} in 2005 to a low of 3.5 m^{-2} in 2009, which remained stable at 3.7 m^{-2} in 2010. The decrease through to 2009 was distinct in the Wet Tropics, Burdekin and Mackay Whitsunday regions but less pronounced in the Fitzroy where the density of recruits has been consistently low (Figure 7). In the Mackay Whitsunday Region, the density of juvenile hard corals continued to decrease in 2010 as the effect of Cyclone Ului compounded previous declines. By 2010 the density of juvenile colonies in the Mackay Whitsunday Region was only 36% of that observed in 2005. In contrast, densities of juvenile colonies increased in both the Wet Tropics and Burdekin regions in 2010, although these increases were not consistent across the core reefs within each region. In the Burdekin Region, the increase was due to higher numbers of juvenile colonies at Geoffrey Bay (Figure 28) while in the Wet Tropics Region juvenile densities at Dunk Is North continue to increase from low values following Cyclone Larry (Figure 24). There was also a slight increase in the density of juvenile colonies relative to those observed in 2009 at Snapper Is North in the Wet Tropics Region(Figure 15) are primarily driving the observed patterns.

While speculative, possible explanations for the above mentioned decreases in the density of juvenile colonies include a combination of response to disturbance events and variation in river flows. Numbers of juvenile colonies are the result of settlement and survival over the preceding three years. Cyclone Larry and associated flooding in 2006 (Wet Tropics Region), Cyclone Ului in 2010 (Mackay Whitsunday Region) and bleaching of corals in Keppel Bay in 2006 (Fitzroy Region) were events that are likely to have caused the lower density of juvenile colonies recorded in the following years. Disturbances directly reduce broodstock as well as causing sub-lethal stress to corals that may influence reproductive success in following seasons. Decreases in the density of juvenile corals also corresponded to high river flow data: in each region flows were above median levels over the period of declining density of juvenile colonies. With the exception of the Burdekin Region, where density of recruits was highest in 2006, all regions showed highest density of colonies in 2005. River flow data (Table 5) show that the major catchments in the Wet Tropics Region had below median flows in three of the four years preceding sampling in 2005 and flows in 2004 that did not greatly exceed the median. The Burdekin River had below median flows for the six years preceding sampling in 2006. While the O'Connell and Pioneer rivers, which are influencing the Mackay Whitsunday Region, had near median flows in the five years preceding 2006 sampling and below or near median flows in the smaller Proserpine River over this same period. The Fitzroy River had below median flows in five of the six years preceding sampling in 2007, with near median flow in 2003. Flooding of the Burdekin, Pioneer and Fitzroy Rivers in 2008, the Burdekin River again in 2009 and the Fitzroy River again in 2010 greatly exceeded median flow. It is plausible that increased flux of fine sediments associated with these wetter years contributed to the decline in juvenile densities as the repeated re-suspension of fine material would repeatedly reduce light availability at the reef surface and sedimentation requires energy from the corals for active sediment removal. Future analyses of Reef Rescue MMP data will focus on assessing the evidence for the influence of environmental conditions such as water clarity on the replenishment of coral populations.

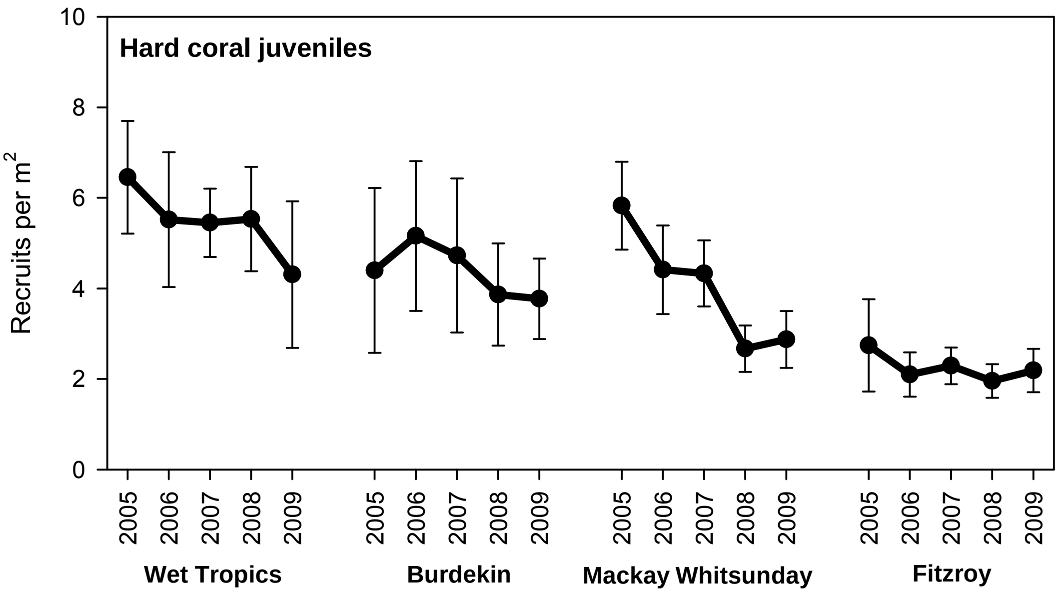


Figure 7 Regional density of juvenile hard coral colonies. Average on reefs within each region (+/- standard error). For each region only reefs sampled in all years were included to ensure consistency among annual averages.

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, the average number of hard coral genera recorded on photo transects on the core reefs remained relatively stable (Figure 8). At the genus-level there is no evidence for a loss of diversity. However, this result cannot be used to infer any changes in diversity at the species level. Genera with a large number of species, such as *Acropora*, may show changes in richness that cannot be resolved from the data available. Further, the generally higher generic richness post 2005 was potentially an artefact of a change in sampling technique from 2006 onwards, when there was a shift from still video frames to digital still photographs. This shift improved image quality and hence the ability for taxonomic identification. One possible point of concern was a slight decline of richness in the Burdekin Region in 2010: here the lower richness was due to the declines in the number of genera observed at both Pandora Reef and Pelorus Is & Orpheus Is West. At both these locations coral cover was very low, and in the case of Pelorus Is & Orpheus Is West, decreased in 2010. In such cases it is not unexpected that genera represented by just a few individuals would no longer be observed.

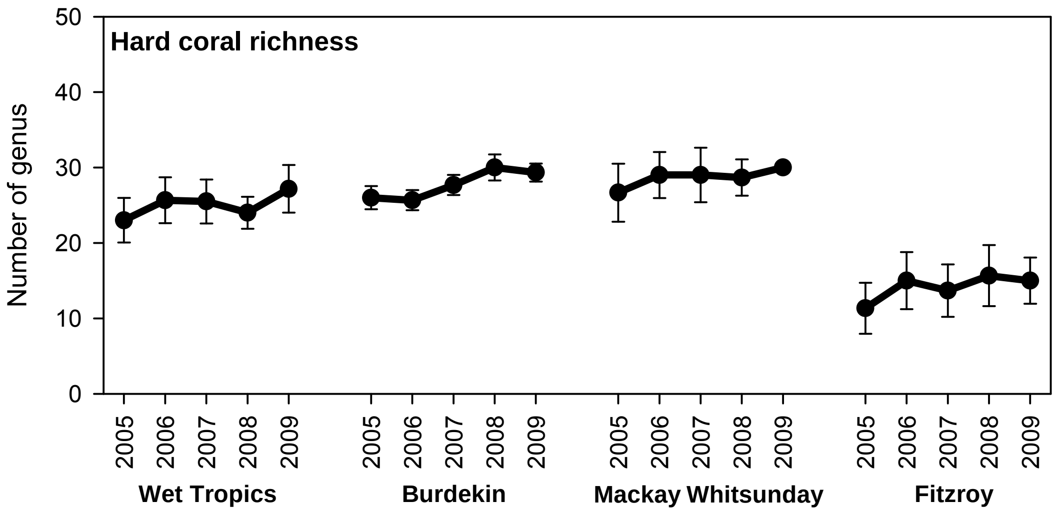


Figure 8 Regional hard coral genus richness. Average number of genera per reef observed on photo transects for each region (+/- standard error). For each region only reefs sampled in all years were included to ensure consistency among annual averages.

Richness of juvenile (<10cm) hard coral colonies

Estimates of the richness of juvenile hard corals from 2005 and 2006 are not directly comparable to those from 2007 to 2010 due to a doubling of the transect area in the latter. Increasing the area of transects likely resulted in increased richness as individuals of rare genera are more likely to occur and be counted. Hence, the observed increase in richness from 2006 to 2007 in all regions is interpreted as a sampling artefact (Figure 9).

There was a substantial decline in the number of genera represented by juvenile sized hard coral colonies in the Mackay Whitsunday Region in 2008 (Figure 9), corresponding to a decline in numbers of juveniles in this region (Figure 7). The genera missing in 2008 varied among reefs; the most consistent omissions were the genera *Coeloseris, Ctenactis, Physogyra*, *Plesiastrea* and *Pseudosiderastrea* each of which were observed in low abundances (1-3 individuals) on two of the three core reefs in 2007 and were not recorded in 2008. Both the density and richness of juvenile hard coral have been more or less stable from 2008 to 2010.

In the Wet Tropics, Burdekin and Fitzroy regions the richness of hard coral juveniles remained relatively stable from 2007 to 2010. In the Wet Tropics Region, four of the five core reefs had their highest recorded richness in 2007. Since then, the profiles of richness at each reef varied but the regional estimates were stable from 2008-2010. In the Burdekin Region a slight decline in richness in 2010 was due to a decline at Pelorus Is & Orpheus Is West from 42 genera in 2009 to 35 in 2010; this decline was not observed elsewhere and is most likely the result of an acute but unidentified impact that caused a reduction in coral cover at this reef.

In summary, there are no obvious indications of declining diversity of juvenile corals. It must be noted, however, that generic richness is a very coarse assessment of diversity as observations of single individuals of a genus count for the same as genera that include many individuals and/or species. Mostly, variation among years is due largely to the observation, or not, of individuals of rare genera.

It is intended to investigate the use of more sensitive measures of diversity that take relative abundance of genera into consideration for future reporting of this important facet of coral community resilience.

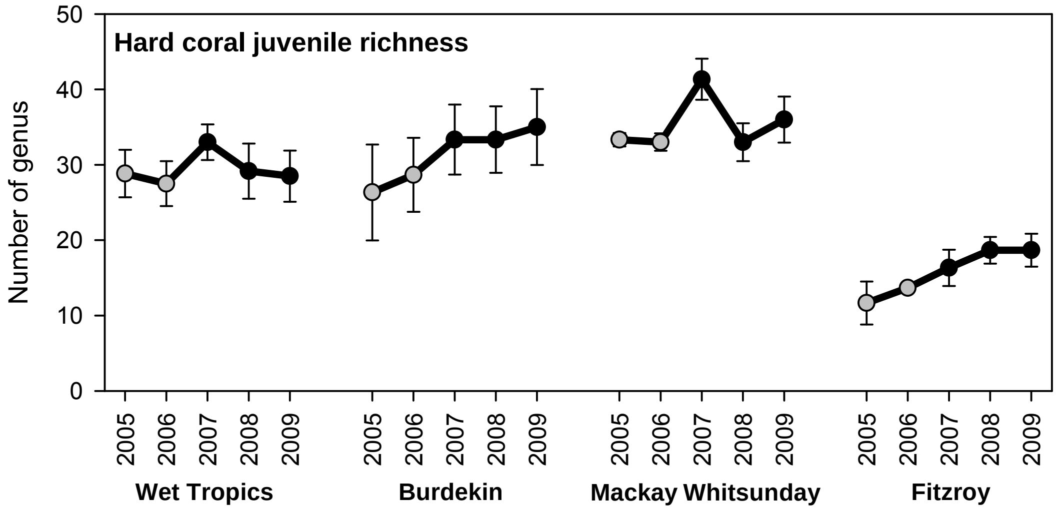


Figure 9 Regional change in juvenile hard coral genus richness. Average number genera per reef represented by colonies < 10cm in diameter observed during transect searches for juvenile colonies (+/- standard error). Note that data from 2005 and 2006 (grey dots) are not directly comparable to later years (black dots) due to a doubling in transect area searched. For each region only reefs sampled in all years were included to ensure consistency among annual averages.

Hard coral recruitment measured by settlement tiles

At a regional level, fluctuations in the settlement of coral larvae between 2006 and 2009 (2010 data not yet available) followed a similar pattern in three of the four regions (Wet Tropics, Burdekin, Mackay Whitsunday), with a distinct peak in settlement rate in 2007, followed by a return to lower levels (Figure 10). This pattern was reversed in the Fitzroy Region, with a drop in settlement in 2007. Unexpectedly the highest settlement in the Fitzroy Region was in 2006, in the reproductive season directly following a major bleaching event that saw a high proportion of adult corals bleached white (Jones *et al.* 2008) and a marked reduction in coral cover (Figures 30, 31). Bleaching of corals is assumed to reduce per colony fecundity in the following season (Ward *et al.* 2002, Baird and Marshall 2002), so the increase in the Fitzroy Region in 2006 may either reflect the absence of this effect, and/or a compensatory high survival of larval and/or post settlement stages.

Relative to previous observations, settlement in 2009 was low in both the Wet Tropics and Burdekin regions and similar to past observations in both the Mackay Whitsunday and Fitzroy regions.

The settlement of coral larvae to tiles is dominated by the family Acroporidae and it is the highly variable settlement of this family, both between years and among reefs, that leads to the observed patterns of settlement. Large pulses and inter-annual changes in Acroporidae settlement occurred in regions with high cover of adult Acroporidae that act as broodstock. While general patterns of recruitment at particular reefs may be linked to the local availability of larvae, the majority of temporal variability in regional settlement remains largely unexplained. This is not unexpected given settlement is the end result of population fecundity, fertilisation, larval mortality and larval transport. Each of these steps in the lead up to settlement may vary in response to environmental conditions at various spatial and temporal scales and lead to patchiness in larval availability at time of settlement (e.g. Hughes *et al.* 2001 and references therein). Hydrodynamics are a key factor to influence larval availability in the inshore environment, and the variation of local wind conditions and the influence of large-scale currents (Brinkman *et al.* 2001) are likely to cause substantial variability in larval transport between years. In addition, wind conditions are a primary cause of turbidity in inshore waters (Larcombe *et al.* 1995) with high turbidity shown to be detrimental to survival of coral larvae (as reviewed by Fabricius 2005). Lastly, settlement surfaces can be smothered by fine sediment which, again, may be linked to the combination of locally variable turbidity and wind driven re-suspension over the settlement period. .

In combination, this can result in particularly high recruitment at individual reefs in individual years, for example Fitzroy Is East in the Wet Tropics Region (Figure 20) and Daydream Is in the Mackay Whitsunday Region (Figure 34) in 2007. Conversely, low regional broodstock, as in the Burdekin Region, and/or unfavourable currents or weather, can result in particularly low settlement (e.g. Geoffrey Bay in 2009, Figure 29). In the fifth year of this study, the settlement of coral larvae to tiles is recognised as being highly variable within and among reefs within each region. However, there is evidence of a range within which settlement fluctuates in each region (Figure 10). The consistently lower settlement in the Burdekin Region is compared to the other three regions.

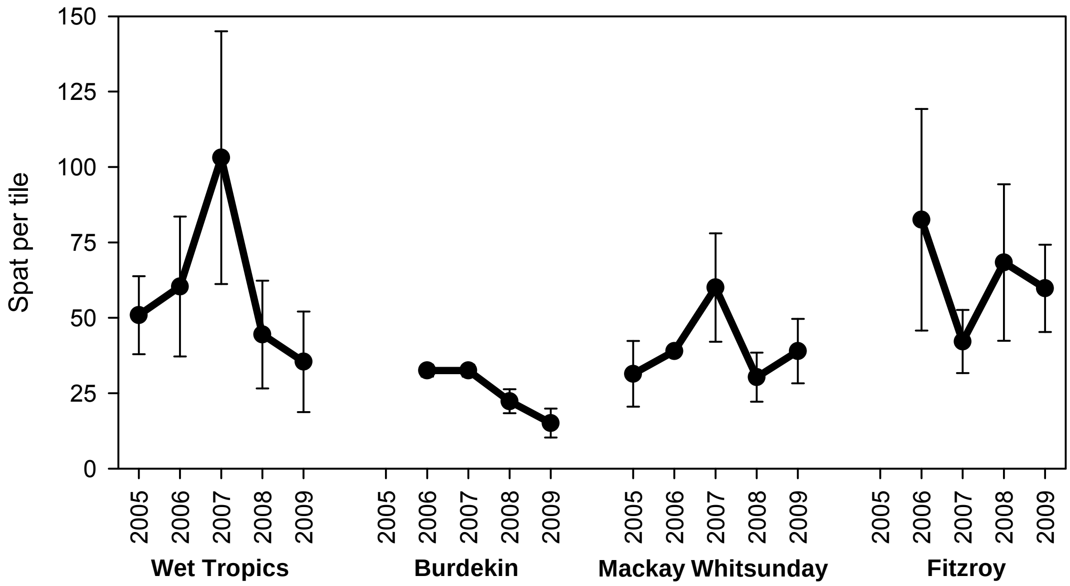


Figure 10 Regional coral settlement. Average number of hard coral spat per tile on core reefs in each region. Settlement tiles were deployed only at 5m depth.

Foraminiferal assemblages

Sediment samples have been collected six 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 and 2010 (as part of 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.

Foraminiferal densities in all sectors fluctuated but are usually between 200 and 400 individuals per g sediment (Figure 11). One exception was in the Mackay Whitsunday Region where densities in 2010 had doubled compared to 2007. This increase reflects a drastic increase in the density of heterotrophic species at both Daydream Is and Pine Is (Figure 35).

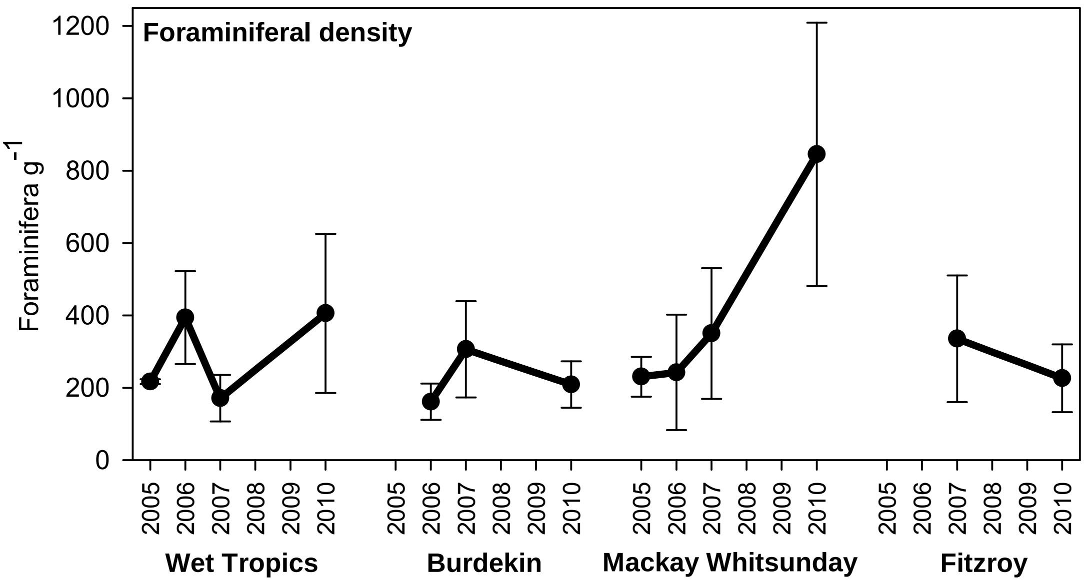


Figure 11 Regional density of benthic foraminifera. Average density (+/- standard error) in sediments from core reefs in each region.

The FORAM index was relatively similar among the Wet Tropics, Burdekin and Fitzroy regions, but distinctly lower in the Mackay Whitsunday Region (Figure 12). The FORAM index has declined in all regions, with the exception of the Fitzroy Region, however this region was only sampled twice. It appears likely that higher density and relative abundance of heterotrophic species, as observed in the Mackay Whitsunday Region, reflect the higher food availability as a result of higher concentrations of organic carbon and nitrogen in the sediments, possibly an effect of recent flood events. Both organic carbon and nitrogen, in addition to grain size parameters explained a significant amount of variation in the distribution of these species (Uthicke *et al.* 2010). The temporal trend for an increase in density of heterotrophic species and hence decline in FORAM index observed in the Mackay Whitsunday Region is also related to these increases in organic carbon and nitrogen concentrations in sediments (Figure 2). In experimental work we have demonstrated that growth of symbiont-bearing species is hampered under high nutrient loads and that heterotrophic species are generally more abundant where organic carbon levels are higher (Uthicke and Nobes 2008, Uthicke and Altenrath 2010). However, declines in the Burdekin and Wet Tropics regions are not supported by obvious changes in the nutrient composition of sediments.

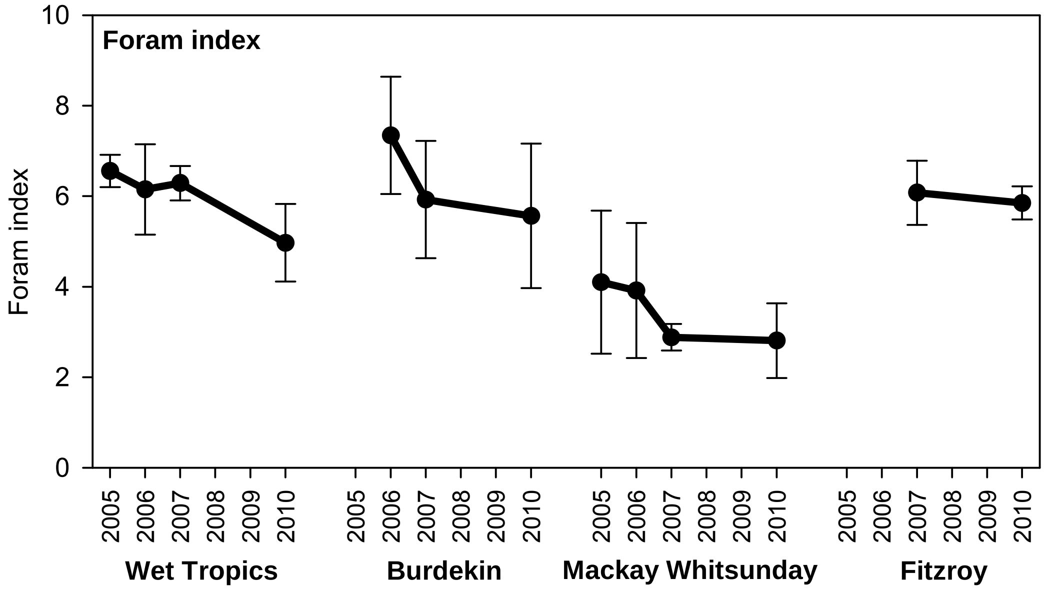


Figure 12 Regional FORAM index. Average (+/- standard error) values for the FORAM index from core reefs in each region.

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

3.2.1 Wet Tropics Region: Barron Daintree sub-region

Two reefs, Snapper Is North and Snapper Is South are sampled annually in this sub-region (Figure 13). These reefs have been monitored by Sea Research since 1995. These historical observations show that while the benthic communities have experienced several disturbances (Table A1-2), they have shown resilience, with coral cover tending to increase in inter-disturbance periods (Ayling and Ayling 2005). 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 14). Since 2007, however, changes in coral cover have been more variable with cover on the northern 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 area are subject to outflows from the Daintree River 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, 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 2010 annual flows for both the Daintree and Barron rivers have been slightly above median levels in all years other than 2007, with a major flood of the Barron River in 2008 (Table 5).

From 2005 to 2010, the only disturbance that 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. By late 2009 at 2m depth the cover of soft corals (largely *Clavularia*) and macroalgae had recovered (Figure 14). 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 15). The recovery of coral cover at 2m depth has been variable between sites with the eastern-most site (site 3) showing rapid increase in cover; here the genus *Acropora* has steadily increased from 5% in 2005 to 40% in 2010. In contrast, the more sheltered western-most site (site 1) reached a maximum cover of *Acropora* in 2007 (66%) from which point cover has steadily declined to the 36% observed in 2010. Scuba search surveys observed disease, which may be the primary cause of this decline. At the same time, however, a mixed community of red macroalgae continued to increase at this site (Figure 14, Table A1-5). The presence of red macroalgae has been shown to inhibit coral growth by both direct shading and causing changes to the chemical microenvironment of the surrounding water (Hauri et. al. 2010). These reductions in cover during periods free from acute disturbance result in negative assessments for the rate of change in coral cover at both depths (Table 8).

In the absence of disturbance, the cover of hard coral, and to a lesser extent soft coral, increased steadily at Snapper Is South. Prior to the impact of flooding in 1996 the coral community at 2m was dominated by *Acropora* (Ayling and Ayling 2005) with this genus disproportionately affected by the flood leaving a community dominated by *Porites*. Since MMP surveys began in 2005, coral cover at 2m has rapidly increased (Figure 14). Initially the increase in cover was due mostly to the growth of surviving *Porites* colonies but *Acropora* cover rapidly increased after new recruitment (see family level cover and density of juvenile Acroporidae, Figure 15). Many of the strong cohort of Acroporidae juveniles observed in April 2009 exceeded the diameter size limit for juveniles (<10 cm) by November 2009, accounting for the decline in juvenile density (Figure 15). In 2010, the high coral cover, rapid rate of coral cover increase, high numbers of juvenile corals and low macroalgae cover all contributed to the positive condition assessment for the 2m community (Table 8). At 5m depth, the increase cover has been slower, although still within the model predicted range for the mix of families present (Table 8). The density of juvenile colonies has been consistently low (Figure 15); however, the relatively high coral cover may be limiting space for recruitment. Overall the high coral cover, low cover of macroalgae and moderate rate of cover increase resulted in a positive assessment of the coral community at 5m depth at Snapper Is South.

Sediments at Snapper Is North had above average levels of clay and silt sized particles, organic carbon (Figure 14) and nitrogen (Table AI-1a-c). Conversely, inorganic carbon was 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 had a lower proportion of fine sediments with higher inorganic carbon content, which indicated that sediments at this site were mainly reef-derived and fine sediments and organic matter did not accumulate. Turbidity at Snapper Is North (Figure 14) exceeds the Guidelines (GBRMPA 2009). High turbidity causes rapid attenuation of light in the water column, which results in a steep environmental gradient with increasing water depth, but also will result in high rates of sedimentation in low energy settings, such as the 5m depth sites. This high turbidity is reflected in the marked compositional difference between hard coral communities at 2m and 5m depth (Figure 15). Chlorophyll *a* concentrations were only marginally below the Guidelines (Figure 14). A significant positive correlation was identified between water column chlorophyll *a* and cover of reef macroalgae implying that both may be limited by ambient nutrient availability (De'ath and Fabricius 2010). Considering the levels of water quality and sediment parameters measured, it is possible that both the higher incidence of disease and macroalgae cover (at 2m) in coral communities at Snapper Is North, may be symptomatic of environmental conditions.

The overall condition rating for the reefs in the Barron Daintree sub-region remains 'good' (Table 7). It is the continued high coral cover at all locations and low cover of macroalgae, and moderate to high densities of hard coral juveniles at most locations that primarily influence this assessment. 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 2008-2010 due to the lower than expected increases in coral cover at Snapper Is North.

Table 7 Benthic community condition: Barron Daintree sub-region, Wet Tropics Region. Overall condition score is aggregated over five indicators; regional scores for each indicator convert the 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 FORAM index was not assessed due to the lack of baseline data. Grey shading indicates sites/depths where indicators were not sampled.

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

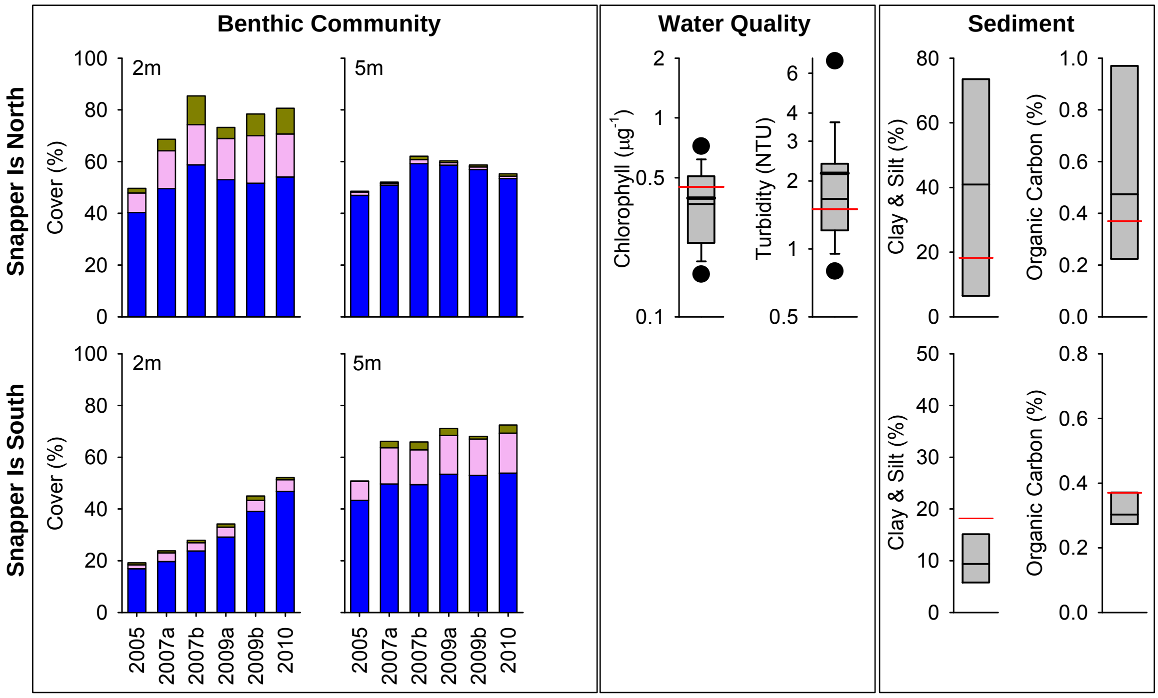


Figure 14 Cover of major benthic groups and levels of key environmental parameters: Barron Daintree sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution 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 Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

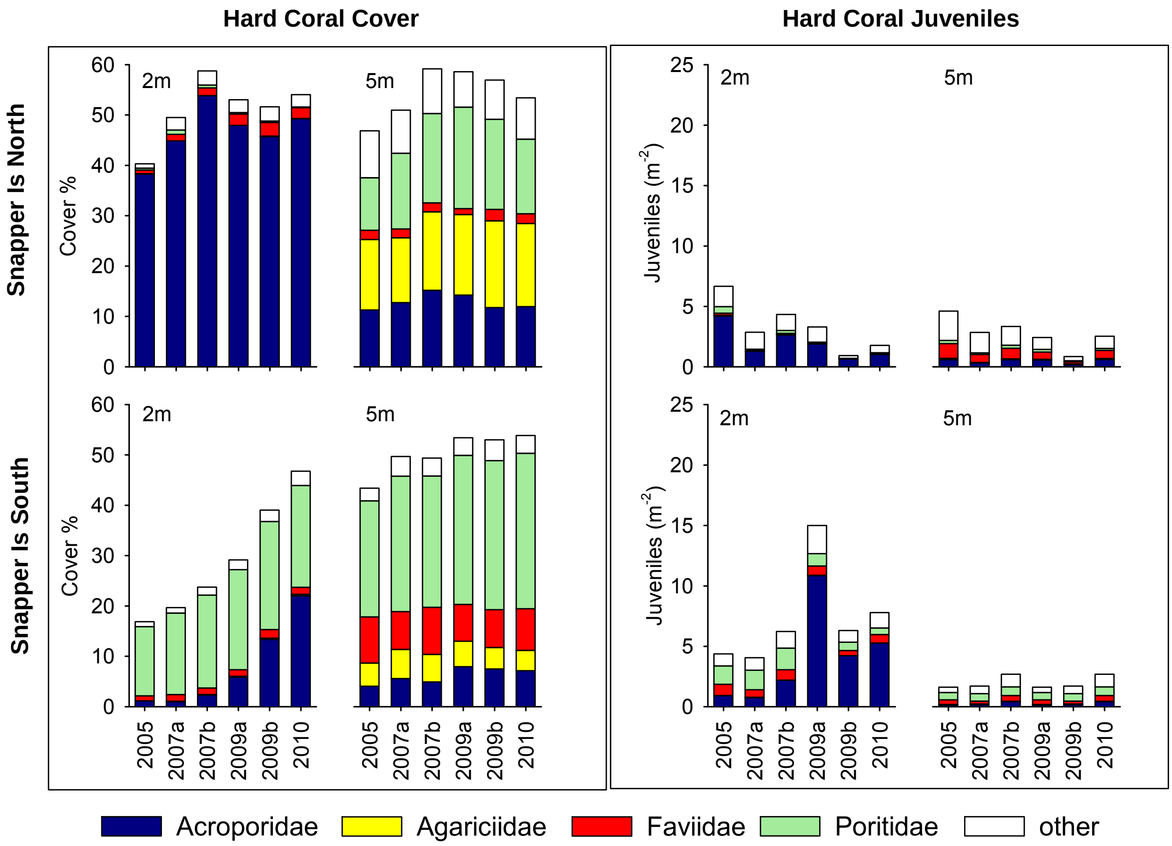


Figure 15 Composition of hard coral communities: Barron Daintree sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m² of available substratum, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

Foraminiferal samples from the Barron Daintree sub-region are only available from two locations at Snapper Is, and only on Snapper Is North are these available for two points in time. At Snapper Is North the richness of foraminifera increased between 2007 and 2010 (Figure 16). This is mainly due to an increase in the number of heterotrophic species, which have also increased in abundance. This change (a higher proportion of heterotrophic individuals) has lead to a strong decline in the FORAM index to a value close to 4 in 2010. 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 3 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 (2007) available during the baseline period, on which they assessment was based (see section 2.6.1).

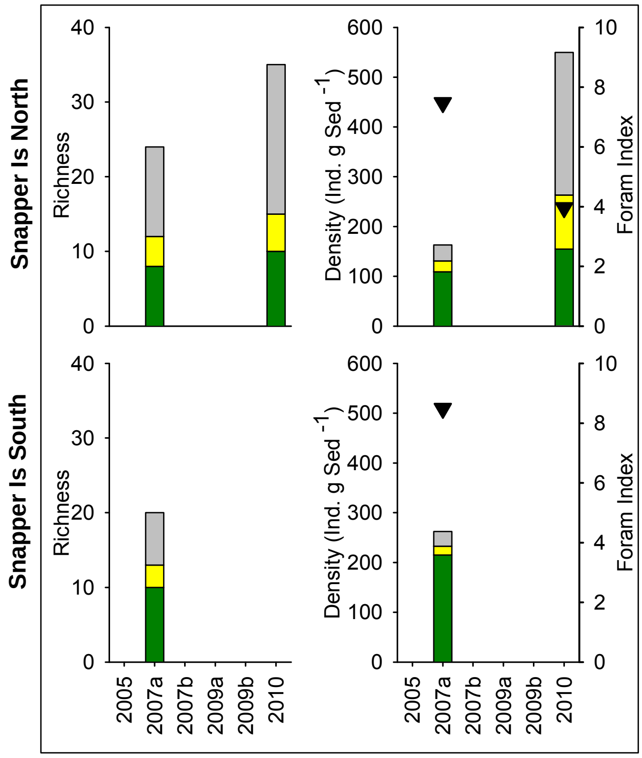


Figure 16 Composition of foraminiferal assemblages: Barron Daintree sub-region, Wet Tropics Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

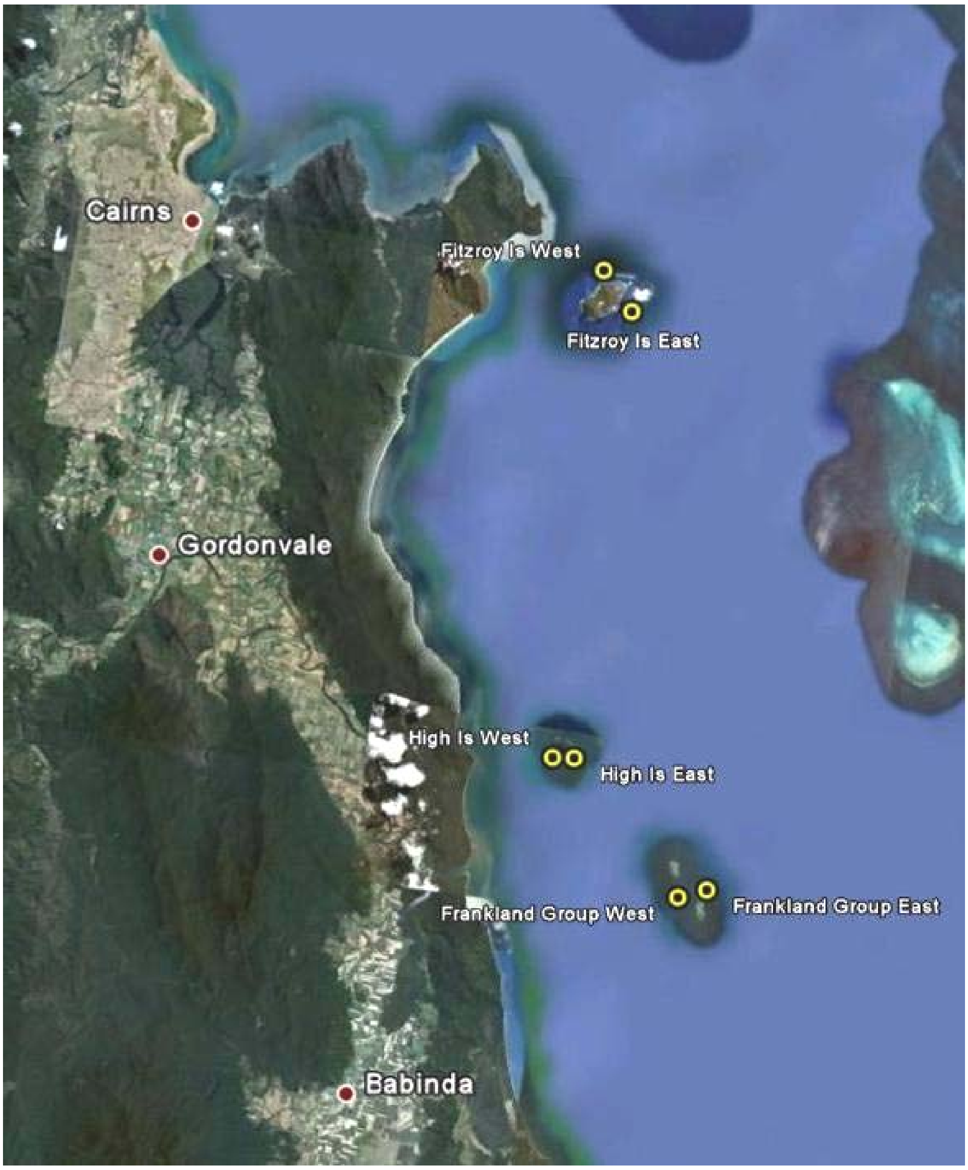
3.2.2 Wet Tropics Region: Johnstone Russell-Mulgrave sub-region

Of the reefs surveyed in this sub-region (Figure 17), those at the Frankland Group and Fitzroy Is have been monitored regularly since 1995 (Ayling and Ayling 2005) and 1992 (Sweatman *et al.* 2005), respectively. These monitoring programs, along with observations from Reef Rescue MMP, have documented four major disturbances that resulted in substantial reductions in coral cover on reefs in this region; coral bleaching in 1998 and 2002, crown-of-thorns starfish (COTS) outbreak in 1999-2000, and Cyclone Larry in 2006 (Table A1-2). In 1998, coral bleaching affected all coral communities on the target reefs in this region. Of the reefs for which long-term information exists, the eastern reefs of the Frankland Group suffered the greatest coral mortality in 1998 with a 44% decrease in hard coral cover followed closely by the western reefs where cover decreased by 43% (Ayling & Ayling 2005). Fitzroy Is and the Frankland Group both suffered a major reduction in coral cover due to COTS in the period 1999-2000: western reef slope communities at Fitzroy Is lost 78% of their hard coral (Sweatman *et al.* 2007) and the eastern reef communities of the Frankland Group lost 68% (Ayling & Ayling 2005). Bleaching in 2002 was less severe than in 1998, but still affected most coral communities in some way (Table A1-2). Freshwater plumes associated with major flooding were recorded at most reefs in 1994, 1995, 1996, 1997 and 1999 (Devlin *et al.* 2001, Devlin and Brodie 2005); however, observations from the time suggest there were no marked impacts on coral cover directly attributable to these events at the depths monitored by the MMP. It is possible that coral communities in water shallower than 2m may have suffered some mortality during these flood events. Observations from these reefs in February 2009, immediately following flooding of the Russell-Mulgrave River, strongly suggested that freshwater had impacted shallow reef flat communities at some locations (AIMS unpublished data). At the same time, physical damage to corals at Fitzroy Is West was also noticed and attributed to Cyclone Hamish. Longer-term trajectories of coral cover at Fitzroy Is and the Frankland Group are presented in Sweatman *et al.* (2007), and show periods of recovery up to 2005 following these multiple disturbance events.

There were no substantial disturbances affecting coral reefs in the Wet Tropics Region in 2010, and coral communities appeared to have been growing steadily from 2007 (see Table A1-2 for disturbance data, and Figures 15 and 16), resulting in the highest benthic community condition score among all surveyed regions (Table 8). Of the annual river flows in the Johnstone Russell-Mulgrave sub-region in 2010 (Table 5), only the Russell River was above the long-term median, the result of protracted higher flows rather than a distinct peak flood event.

The reefs in this sub-region are regularly subjected to outflows from the Johnstone and the Russell-Mulgrave rivers. Although these rivers pass through catchments with intense agricultural development, the majority of reefs surveyed have sediments with moderately low proportion of clay and silt, organic carbon and nitrogen (Figure 18 and Table AI-1a-c) indicating low residence or low accumulation of sediment components derived from the rivers. The exception is the Frankland Group West site, lying directly east of the Russell-Mulgrave River outflow that continues to have higher than average levels of clay and silt, organic carbon and nitrogen. The accumulation of fine sediments has been restricted to pockets and gullies formed between large coral colonies. It is likely the complex topography and sheltered nature of the site reduces the resuspension of these sediments.

The general lack of sediment accumulation on coral settlement tiles deployed at this reef, along with low turbidity suggest that, although fine sediments do accumulate at this reef, the import and movement of these sediments is very low.



©Google Earth 2010

Figure 17 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Johnstone Russell-Mulgrave sub-region, Wet Tropics Region.

Within this sub-region, turbidity levels and chlorophyll *a* concentrations are below the Guidelines (GBRMPA 2009, Figure 18). The regionally low cover of macroalgae (Figure 6) is consistent with the observed low levels of these key water quality variables. The low cover of macroalgae at these sites adds to the positive assessment of condition at most reefs (Table 8). In addition, the broad similarities in community composition between 2m and 5m depths (Figure 19) are consistent with a low turbidity environment; light climate is generally acknowledged as a strong determinant of coral community composition and the rate of change in light climate with depth is proportional to turbidity.

Despite the history of disturbance described above, coral cover is high on most reefs in this region, with an overall increase in both hard and soft corals since 2006 (Figure 18). The hard coral communities fall into two broad categories, those with a high proportion of the family Acroporidae and those with a high proportion of the family Poritidae (Figure 19). The family Acroporidae is typically fragile and susceptible to disturbance events such as Cyclone Larry in 2006 but also has the capacity to recover quickly given its high growth rate relative to most other corals (e.g. Frankland Group East). The family Poritidae typically has a slower growth rate. The combination of moderate to high cover and rates of increase that were consistent with, or above expectations (based on model predicted rates on increase), added to the positive assessment of coral community condition for most reefs. The exception was Frankland Group West (5m depth); where, although consistently high, coral cover has not shown clear increases despite a lack of acute disturbances (Figure 18). It is possible that in this *Porites*-dominated community cover has reached an upper limit for such a community.

At most risk from damage by ex-Cyclone Olga was Fitzroy Is East, however, no evidence of storm damage was observed although there were patches of disease that may be associated with stress from physical force. Disease outbreaks following storm damage have been noted in other coral communities (Sweatman *et al.* 2008) and may also explain the disease outbreaks following Cyclone Larry in 2006 at Frankland Group West and High Is West in 2007.

The resilience in coral cover within this sub-region seems to have been underpinned by the generally high level of coral recruitment to settlement tiles (Figure 20) and high density of juvenile colonies. The only reef at which the observed levels of these early life stages did not match this assessment of resilience is the western Frankland Group reef where both settlement of coral larvae and the density of coral juveniles are distinctly lower than at other reefs within the region (Table 8; Figures 19, 20). However, of concern is the overall trend of diminishing juvenile numbers at both depths across the sub-region (Figure 19), leading to the current negative assessments for several locations for these indicators (Table 8). The trend of diminishing juvenile numbers is repeated in the other regions in the survey (Figure 7) and represents a significant concern for the future resilience of coral communities in the inshore GBR as the capacity to recover from future widespread impacts (bleaching, disease, storms, predation) appears to be decreasing as the frequency of impacts is predicted to increase (Steffen 2009).

At Frankland Group West 2m, previous monitoring data indicate the community included a high proportion of the genus *Acropora* prior to the influence of bleaching and COTS in the late 1990's (Ayling and Ayling 2005). This component of the community has failed to recover despite a lack of subsequent disturbance. The very low settlement of Acroporidae larvae (Figure 20) may explain this lack of recovery, but the reasons for the low settlement are unclear. Plausible, though speculative explanations may include local currents that could isolate the sites from the regionally available larval pool, or larvae actively avoiding settlement into a community dominated by branching *Porites*. Potentially corroborating these explanations is that, of all reefs monitored, this reef has had the highest proportion of larvae settling from the families Poritidae and Pocilloporidae. The Pocilloporidae and some Poritidae are known to brood larvae and so hydrodynamic factors excluding transport of Acroporidae larvae from other locations may equally act to retain locally brooded or spawned larvae. Also, the settlement of Poritidae larvae may be less limited by the presence of mature con-specifics than larvae of other taxa.

Macroalgal assemblages in the Johnstone Russell-Mulgrave sub-region mainly comprise red fleshy algae at High Is West and the Frankland Islands (East and West) (Figure 18 and Table A1-5). Particularly at Frankland Group West, the expected coral growth may be restricted due to the colonisation of spaces between branches of *Porites cylindrica* and *Porites rus* by red macroalgae, which may indicate environmental conditions that favour these particular macroalgae (e.g. pockets of sediment supporting higher localised nutrients), rather than any acute disturbance event. There were no extensive areas of brown macroalgae (*Sargassum* sp, *Lobophora* sp) in the sub-region, which is consistent with lower values of water column chlorophyll (a proxy for nutrient availability, Figure 18).

Table 8 Benthic community condition: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Overall condition score is aggregated over five indicators; regional scores for each indicator convert the 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. FORAM index scores are included as a separate column and are not included in the overall regional assessment score. Grey shading indicates sites/depths where indicators 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	neutral	+	-	+	
	5	+++	+	neutral	+	neutral	+	
Frankland Group East	2	+	neutral	neutral	+	neutral	neutral	
	5	+++	neutral	neutral	+	+	+	
Frankland Group West	2	+	+	+	neutral	neutral	-	
	5	- -	+	-	neutral	-	-	-
Fitzroy Is West	2	+++++	+	+	+	+	+	
	5	+++++	+	+	+	+	+	neutral
High Is East	2	+	+	neutral	+	-	neutral	
	5	+++	+	neutral	+	neutral	+	
High Is West	2	+	+	neutral	+	-	neutral	
	5	+	neutral	+	+	-	neutral	-
Sub-regional assessment								

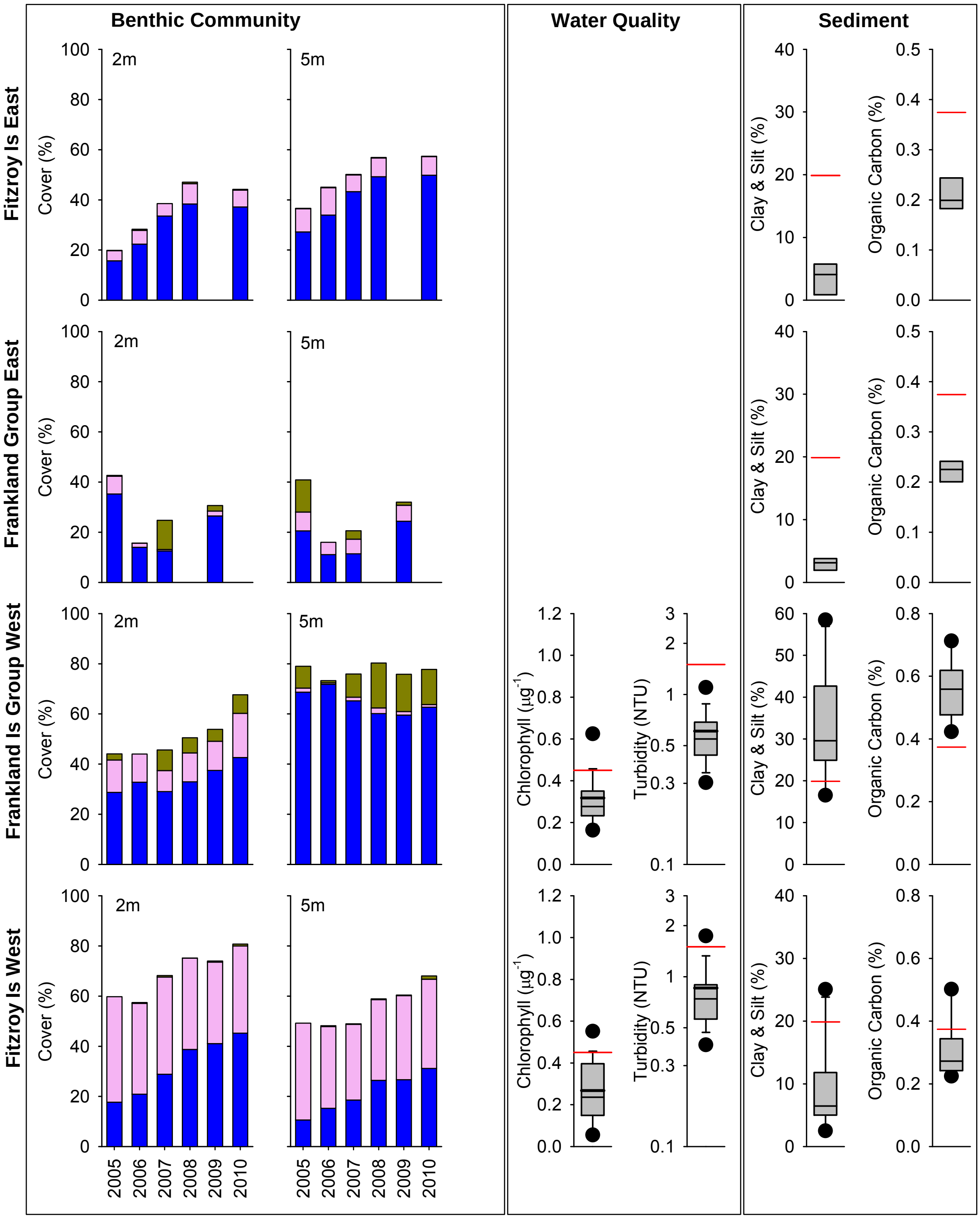


Figure 18. Cover of major benthic groups and levels of key environmental parameters: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent 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 Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

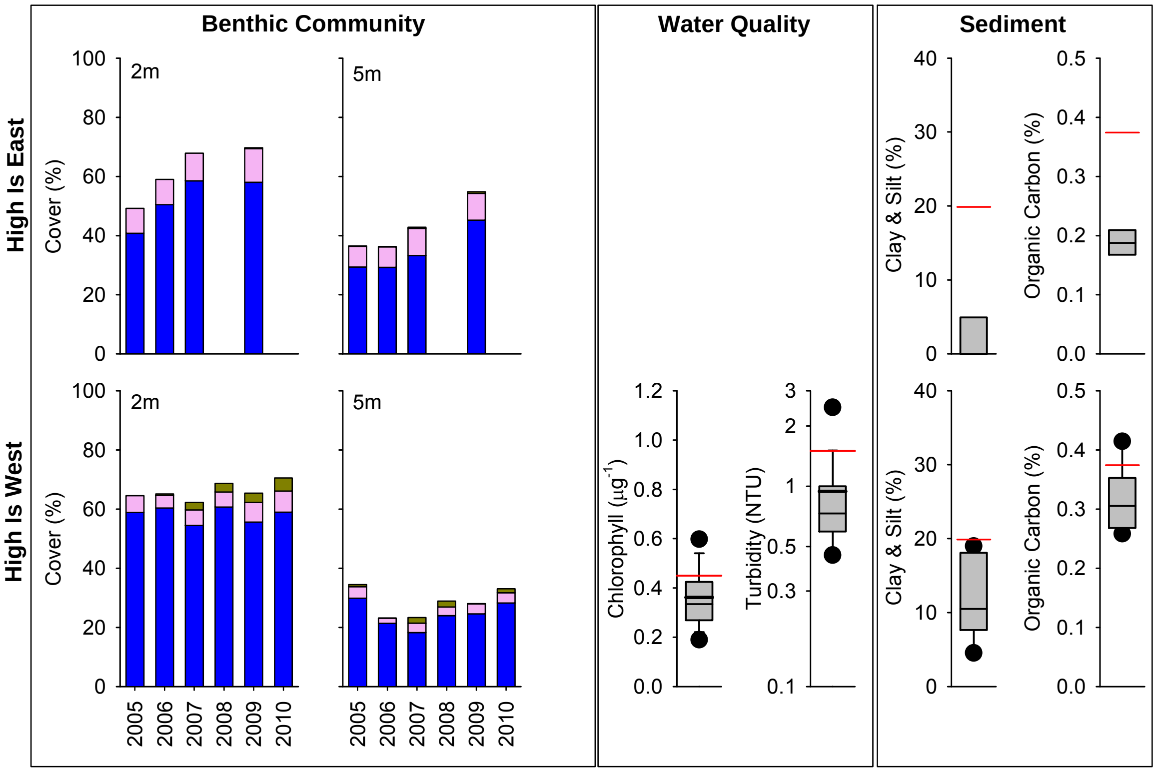


Figure 18 continued.

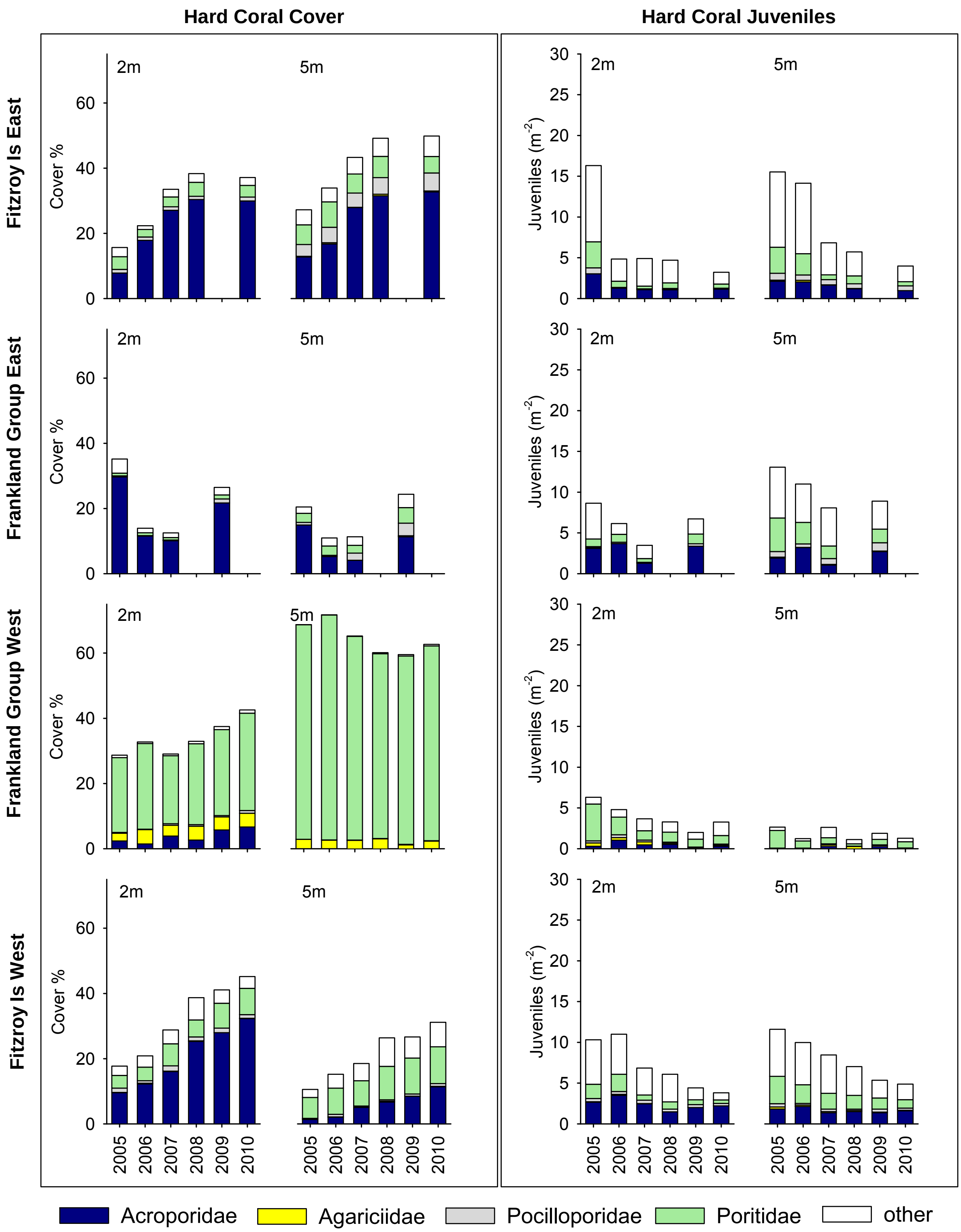


Figure 19 Composition of hard coral communities: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2 of available substratum, of dominant families within the region (see legend for colour coding). Only families for 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'.

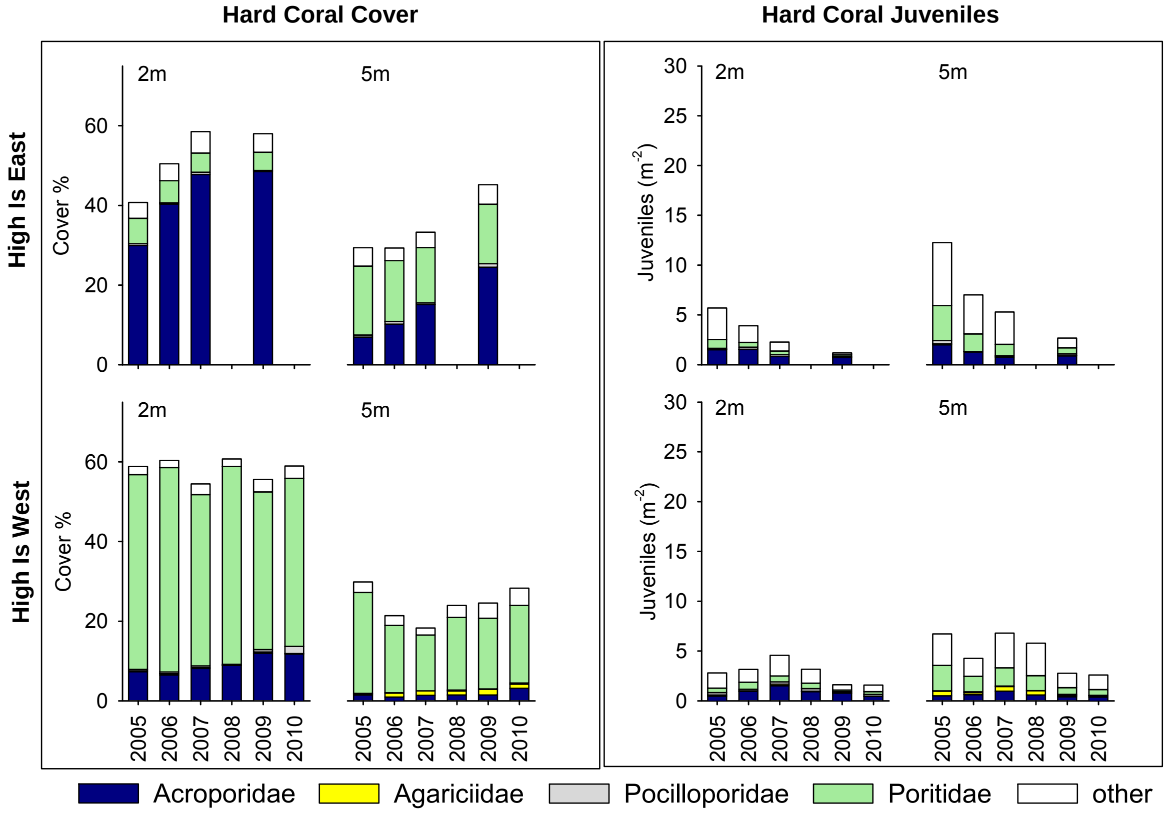


Figure 19 continued.

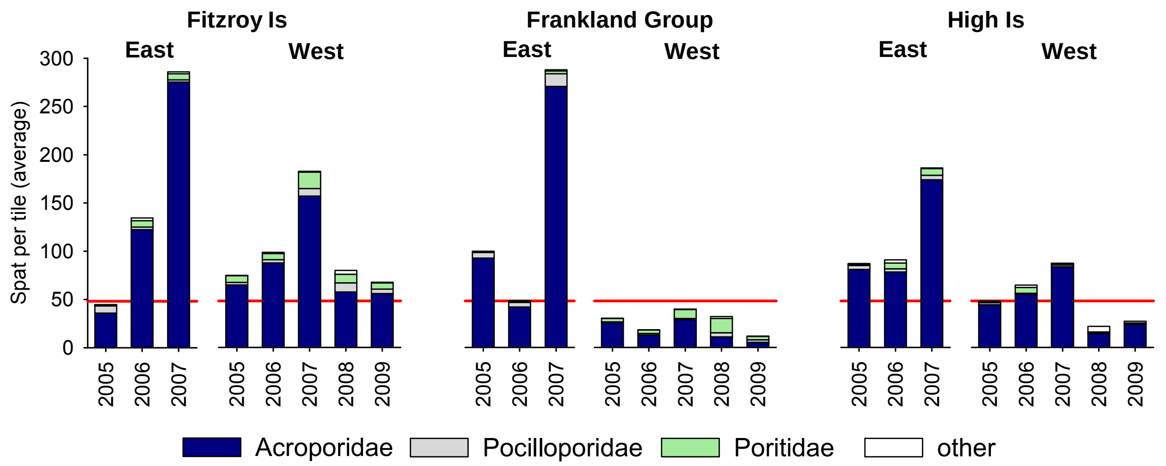


Figure 20 Coral settlement to tiles: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Data are from 5m tile deployments. Average values from all reefs and regions over all years are indicated by red reference lines.

Communities of foraminifera on the eastern sides of Islands in the Johnstone Russell-Mulgrave sub-region typically had low richness and abundance of heterotrophic species leading to high values of the FORAM index. 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 fine sediments accumulate and sediments have higher concentrations of organic carbon (Figure 18), the richness and relative abundance of heterotrophic species is higher leading to lower values of the FORAM index (Figure 21). In 2010, the density of foraminifera was low at both High Is West and Fitzroy Is West which was in stark contrast to the very high density at Frankland Is West. At the latter location, the abundance of heterotrophic species was highly variable through time. This variability remains unexplained.

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 Is West and High Is West leading to the reduced FORAM index and subsequently a 'very poor' assessment of foraminiferal assemblage condition in 2010 (Table 8).

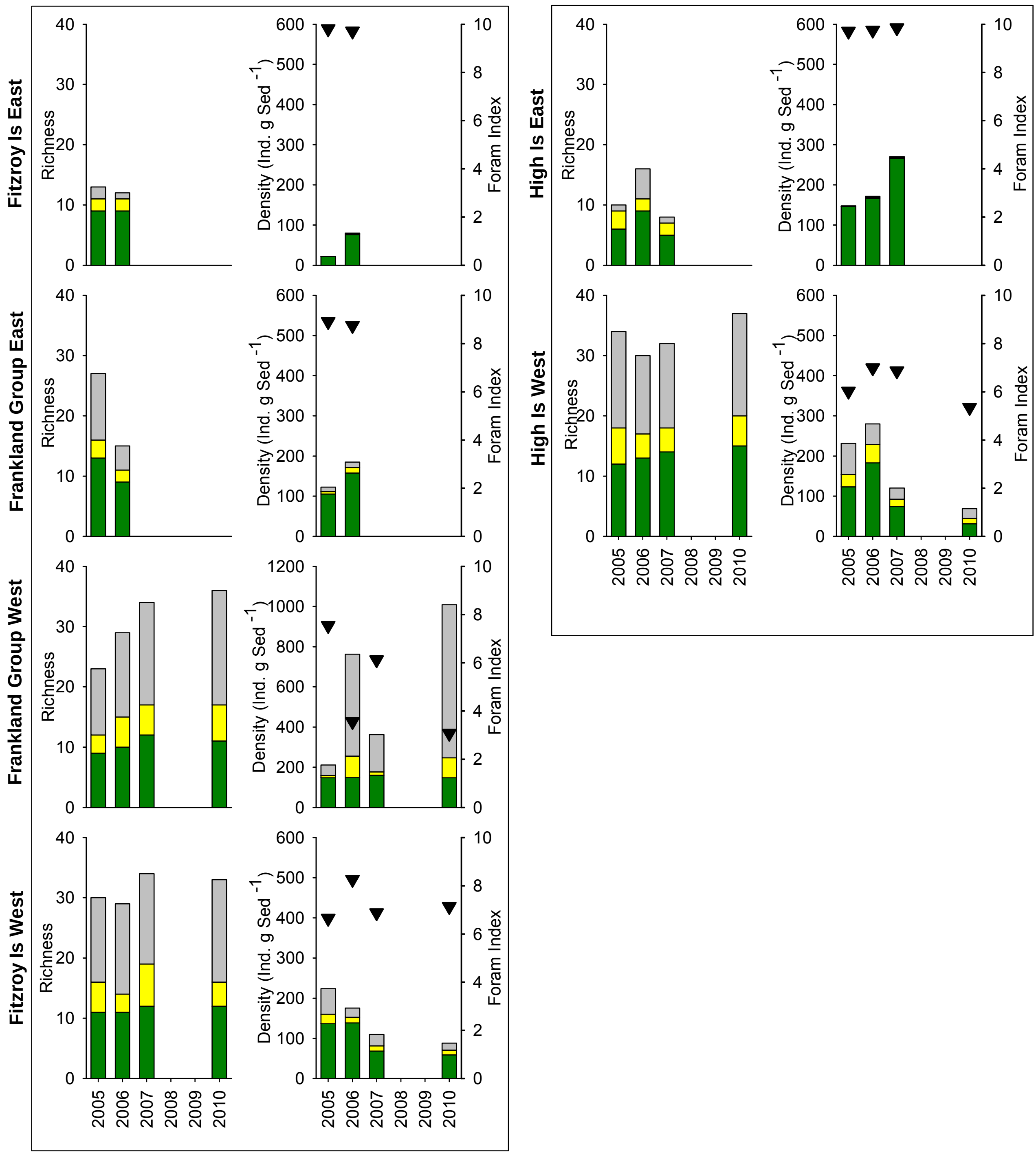


Figure 21 Composition of foraminiferal assemblages: Johnstone Russell-Mulgrave sub-region, Wet Tropics Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

3.2.3 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. Flood plume observations by Devlin *et al.* (2001) show that these reefs were subject to flood events on at least three occasions between 1991 and 2001 (Table A1-2); however, the impacts on the benthic communities are unknown. Recent modelling work (Wooldridge and Done 2004) indicates that hard coral communities in this sub-region were likely to have been impacted by coral bleaching in 1998 and 2002 (Table A1-2). Reductions in hard coral cover similar to those observed by Ayling and Ayling (2005) at the Frankland Is Group in 1998 (43%) may also have occurred in the Herbert Tully sub-region.

The reefs in this sub-region are exposed to the outflow from the Herbert and Tully Rivers, with Dunk Is only 10km from the Tully River mouth (Figure 22). Both the Tully and Herbert Rivers produced significant flood plumes in 2009, but there was no major flooding in 2010 (see Table 5). The levels of fine sediment and organic carbon in the reefal sediments are low compared to the average from all regions (Figure 23). Turbidity levels at Dunk Is North are consistently high with mean turbidity from 2007 – 2010 exceeding the Guidelines (GBRMPA 2009), above which coral reef communities undergo substantial changes (De'ath and Fabricius 2008, 2010) (Figure 23). In combination, the sediment and turbidity data suggest a process of frequent re-suspension rather than accumulation of sediments at the sites sampled. The mean chlorophyll concentration was below the Guidelines (Figure 23).

In March 2006, Cyclone Larry severely impacted the coral communities at the North Barnard Group and Dunk Is North, resulting in a substantial reduction in the cover of hard and soft corals and also macroalgae (Figure 23). King Reef was also affected; however, as coral cover was already very low, the disturbance was most evident in the removal of macroalgae (Figure 23). The reduction of macroalgae observed directly following Cyclone Larry was short-lived with cover rapidly increasing to similar or higher levels than observed prior to the cyclone in subsequent surveys (Figure 23). The high macroalgae cover at most reefs in this sub-region during 2009-2010 resulted in predominantly negative assessment of coral community condition for this indicator (Table 9). There was also a slight decline in the cover of hard corals at 5m depth at Dunk Is South consistent with the timing of Cyclone Larry. Mortality here was considered to have been the result of high turbidity and sedimentation with many corals suffering partial mortality by smothering and bleaching rather than the physical damage, as was observed at the more exposed sites.

Coral cover increased at these reefs in period 2009-2010 at rates consistent with expectations based on predicted rates of increase for nearshore communities at all locations except King Reef (2m) where coral cover in 2010 was still very low (Table 9). Overall, the level of coral cover was still below 25% on most reefs in the sub-region leading to a negative assessment of condition based on the level of cover present for all reefs other than the 5m depth at Dunk Is South (Table 9).

The density of juvenile colonies at most reefs in this sub-region were moderate to high resulting in the overall positive assessment of this condition indicator (Table 9). The obvious exception was at 2m depth at King Reef where, the density of juvenile colonies has been consistently low since surveys began in 2005 (Figure 24). At most reefs there is a disjunction between the composition of the juvenile and adult coral communities (Figure 24). At the North Barnard Group, King Reef, and Dunk

Is North, juvenile communities had high representation of the families Dendrophylliidae and Faviidae compared to the adult communities that tended to include a high proportion of the family Acroporidae (Figure 24). Within the family Faviidae, a number of species are either small or have slow growth rates and so it is not clear whether high densities of such taxa are likely to lead to substantial increases in the cover of these families. Juveniles of the family Dendrophylliidae 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.

©Google Earth 2010

Figure 22 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Herbert Tully sub-region, Wet Tropics Region.

In contrast, the adult community at Dunk Is South (5m) is comprised of a relatively diverse suite of taxa tolerant to high turbidity conditions but these taxa are less well represented within the juvenile community. It is possible that lower juvenile densities of such taxa would be required to sustain viable populations if, like the adults, juveniles were tolerant of the local environmental conditions. However, as we do not know the relative rates of mortality for juvenile colonies of various taxa under differing environmental conditions this explanation is purely speculative. There were no settlement tiles deployed in this sub-region to capture data on spat recruitment.

The overall condition rating for reefs in this sub-region was 'poor', primarily due to low cover of corals and high cover of macroalgae (Table 9) at most locations. The recovery of coral communities from Cyclone Larry at both Dunk Is North and the North Barnard Group is clearly the result of the rapid growth of Acroporidae colonies, and, given the relatively high densities of juvenile colonies, these reefs are likely to reach higher adult coral cover soon. For Dunk Is South, where diversity at both depths is highest among this sub-region, the cover of Acroporidae is relatively low and the community comprised of a suite of slower growing corals thus reducing the capacity for rapid change in cover. Strong recruitment of a diverse range of corals suggests the resilience of the coral community at 5m depth especially. Projections for recovery at King Reef are not as positive. Prior to Cyclone Larry coral cover was already low (especially at 2m), macroalgae cover (predominately *Sargassum* spp.) was very high and juvenile densities also relatively low. Fleshy macroalgae have been shown to reduce coral settlement (Diaz-Pulido *et al.* 2010) and so while corals have been observed to overgrow macroalgae over wide areas (Done *et al.* 2007) there is a prior requirement for strong recruitment of corals; a feature of the community not yet observed at the 2m depth of King Reef.

Unfortunately we have detailed water quality data only for Dunk Is North and are unable to draw any conclusions about the environmental conditions at the other three locations. Limited water sampling at King Reef during the first two years of the MMP (2005-06) did however show high suspended solid and chlorophyll *a* concentrations, indicating that the condition of the coral community may be limited by environmental conditions (see Thompson *et al.* 2010a).

Table 9 Benthic community condition: Herbert Tully sub-region, Wet Tropics Region. Overall condition score is aggregated over four indicators; regional scores for each indicator convert the 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. FORAM index scores are included as a separate column and are not included in the overall regional assessment score. Grey shading indicates sites/depths where indicators 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	-	+	
Dunk Is North	2	-	-	neutral	-	+	
	5	+	-	neutral	+	+	-
King Reef	2	- - - -	-	-	-	-	
	5	- -	-	neutral	-	neutral	
Dunk Is South	2	-	neutral	neutral	-	neutral	
	5	neutral	neutral	neutral	-	+	
Sub-regional assessment							

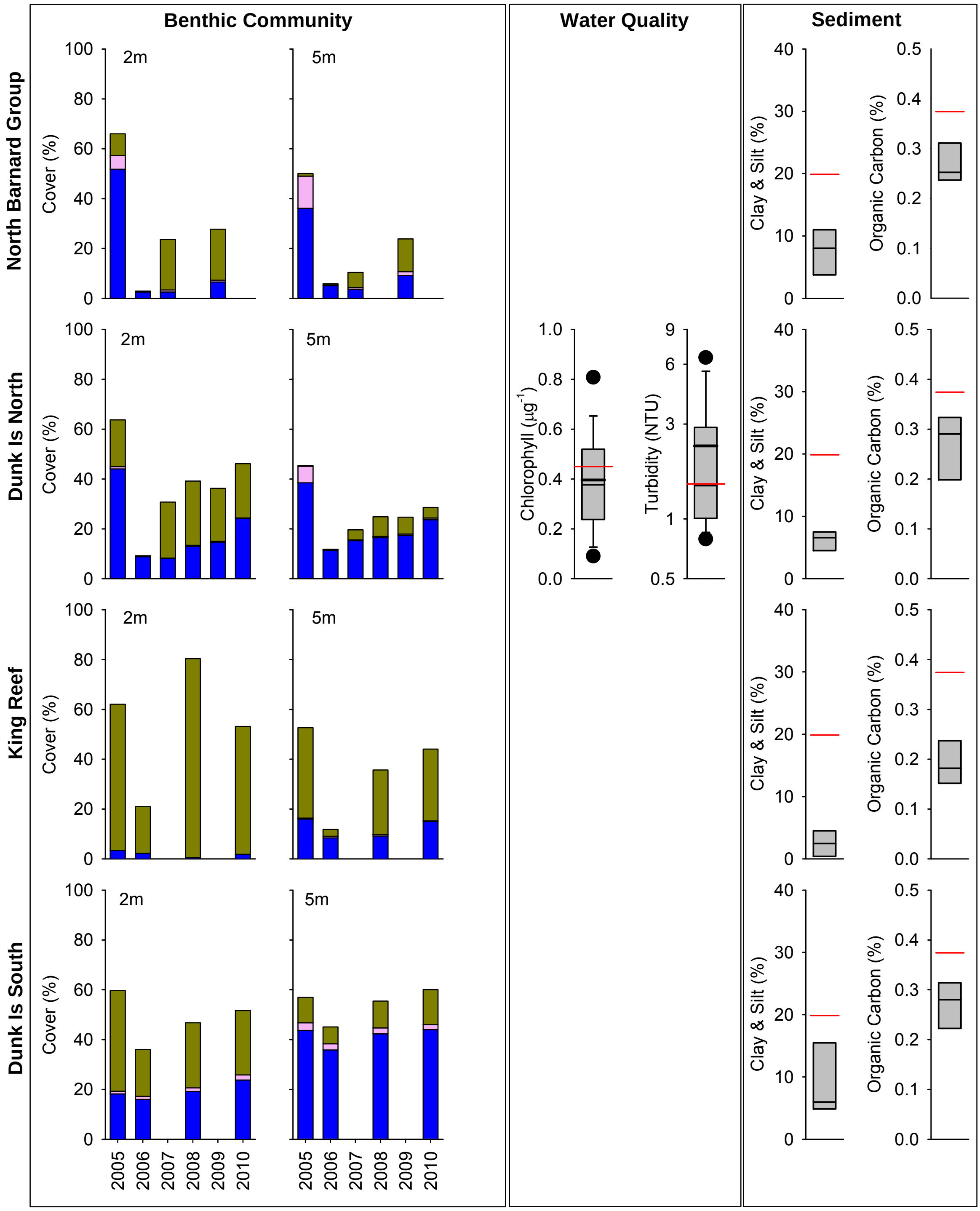


Figure 23 Cover of major benthic groups and levels of key environmental parameters: Herbert Tully sub-region, Wet Tropics Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution 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 Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

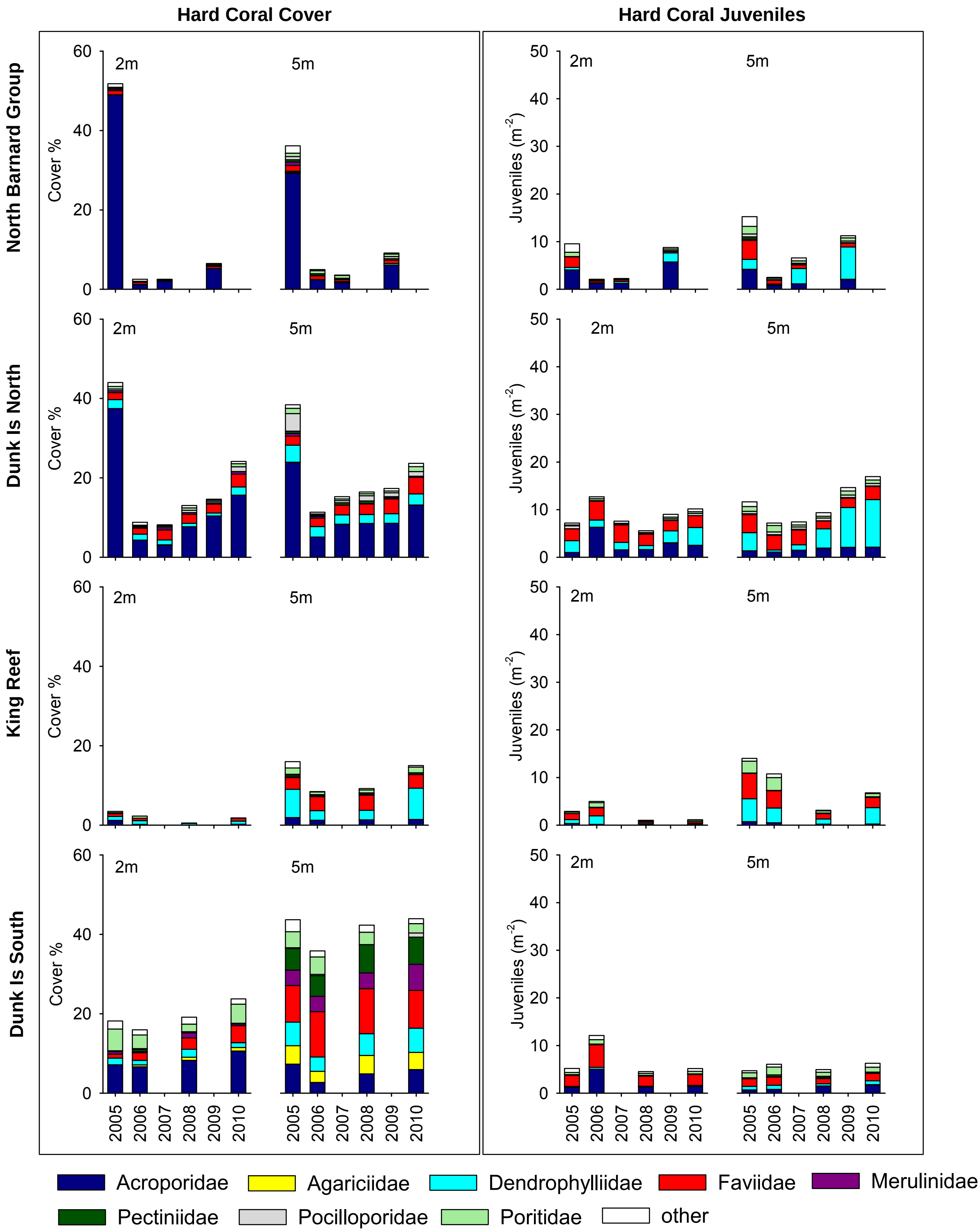


Figure 24 Composition of hard coral communities: Herbert Tully sub-region, Wet Tropics Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m² of available substratum, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

Richness and density of foraminifera were determined for four reefs of the Herbert Tully sub-region, Wet Tropics Region. The FORAM index of the only reef sampled in 2010 (Dunk Is North) indicated a slight but steady decline since 2005 (Figure 25). The value of the FORAM index in 2010 at Dunk Is North was more than one SD lower that the average during the initial three surveys resulting in the negative rating (Table 9). This reflected a disproportionate increase the density of heterotrophic species and corresponds to higher levels of nitrogen in the sediments in 2009 and 2010 than in previous years (Table A1-1c), likely associated with flood-related inputs. The FORAM index on all other reefs was high (> 8) in the earlier monitoring years due to low densities of heterotrophic species.

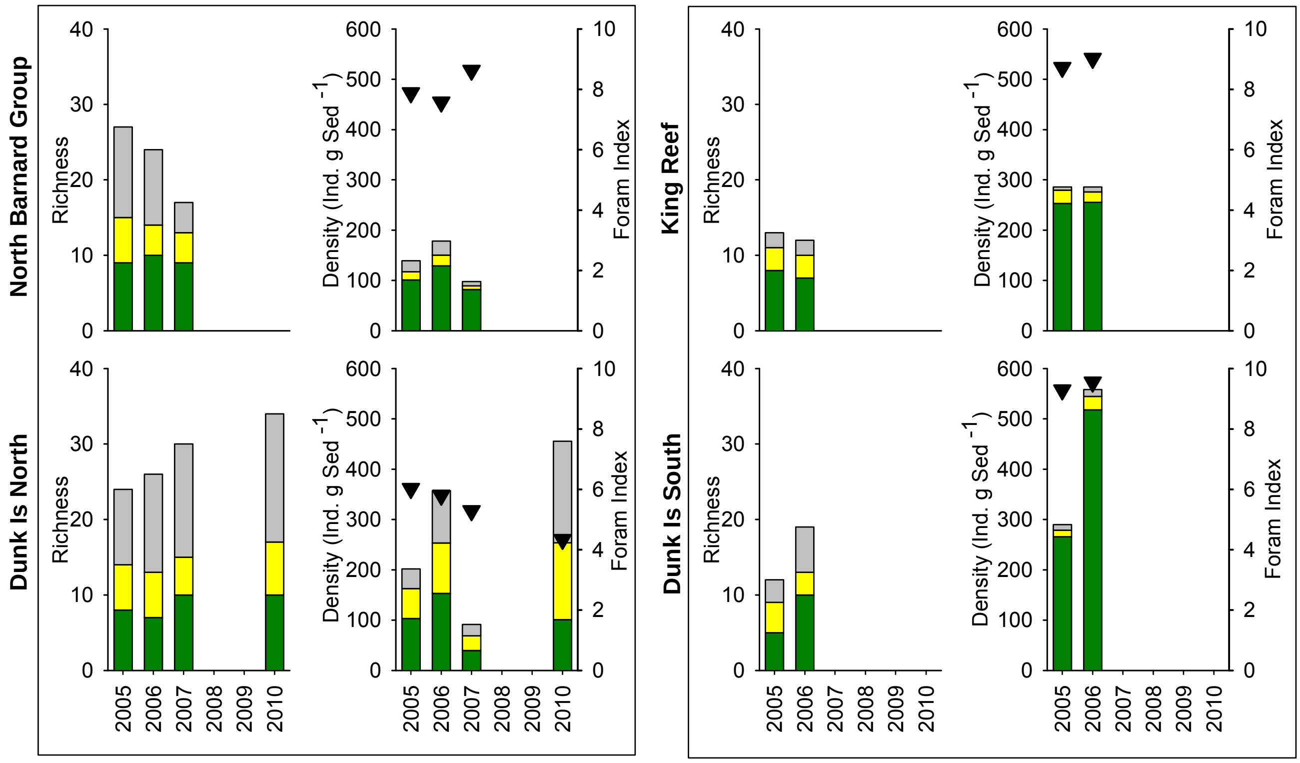


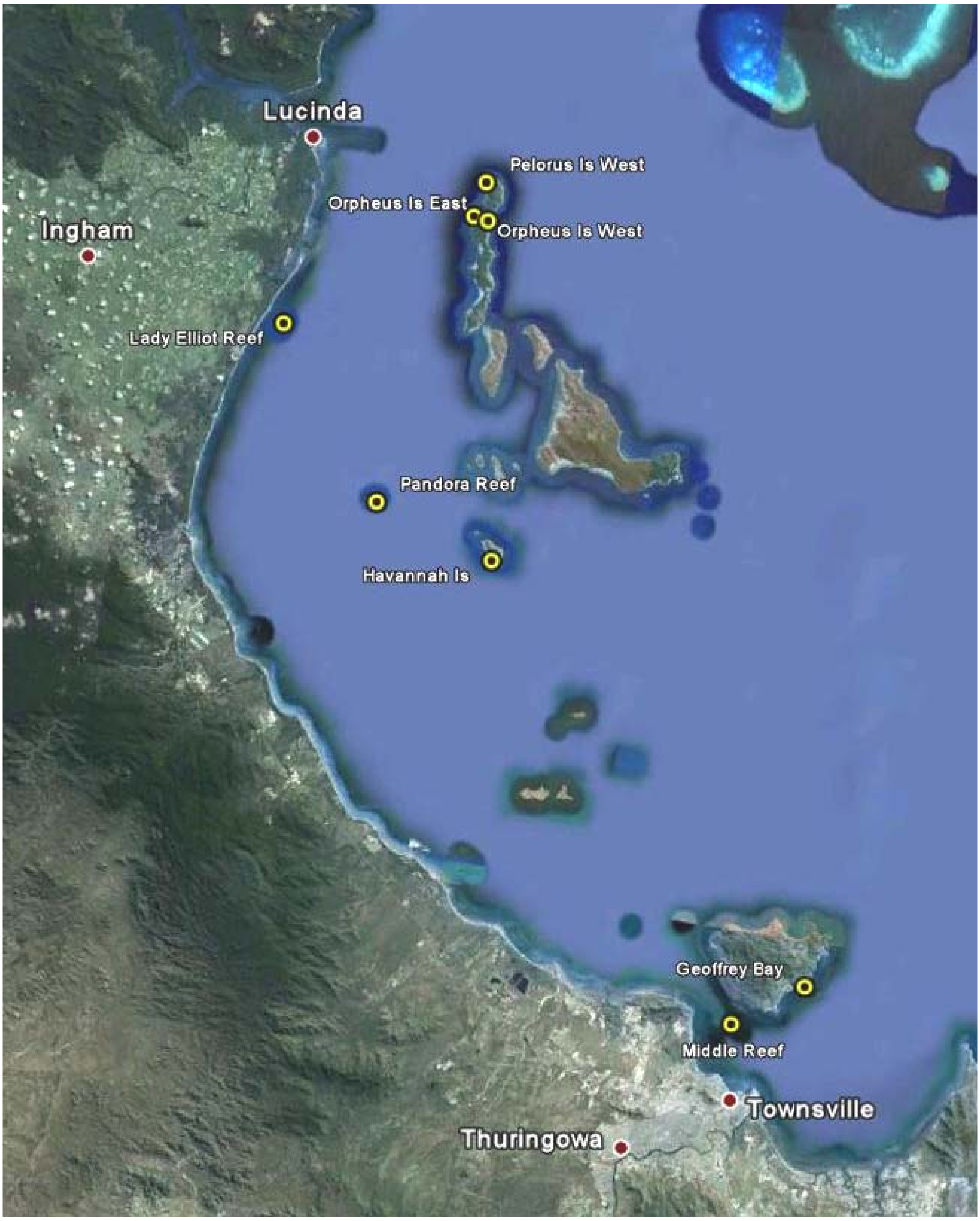
Figure 25 Composition of foraminiferal assemblages: Herbert Tully sub-region, Wet Tropics Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

3.2.4 Burdekin Region

Reefs in the Burdekin Region have been monitored since 1989 by AIMS, the now Department of Environment and Resource Management and Sea Research under a variety of projects. The resulting time-series reveal the intense and frequent nature of disturbance to some reefs (Ayling and Ayling 2005, Sweatman *et al.* 2007, Table A1-2). The largest disturbance since monitoring began was the mass coral bleaching event in 1998. This event affected all coral communities on the target reefs in this region (Table A1-2). In 2002, bleaching was less severe than in1998 but still affected the majority of coral communities (Table A1-2). Cyclonic disturbances in 1990 (Cyclone Joy), 1996 (Cyclone Justin) and 2000 (Cyclone Tessi) impacted some reefs, and a large decrease in coral cover attributed to Cyclone Tessi at Havannah Is may also include the effects of elevated numbers of crown-of-thorns starfish in the same year. During the period 1991-1999 flood plumes extended to most reefs in 1994, 1997 and 1998 (Devlin *et al.* 2001). However no direct effects on coral communities (loss of cover) were observed (Ayling and Ayling 2005, Sweatman *et al.* 2007). Recovery following these disturbances has generally been slow; particularly when cover was reduced to very low levels as occurred on most reefs monitored in Halifax Bay as a result of bleaching in 1998 and 2002 (Done et al. 2007; Sweatman *et al.* 2007). The loss of coral cover following these bleaching events, particularly of corals in the family Acroporidae, is likely to still influence the low settlement rates of coral larvae observed in this region (Figure 29). Low larval supply is also reflected in the low densities of juvenile colonies on most reefs.

Over the period 2007 to 2010 the coral communities at Orpheus Is East, Havannah Is, and at 5m at Pandora Reef were the only ones in the region to increase at a rate consistent with model based expectations given their community composition and based on modelled predicted change (Thompson and Dolman 2010). At Orpheus Is East at both 2m and 5m this reflects increasing cover of the family Acroporidae (Figure 28). At Pandora Reef, the family Faviidae (genus *Echinopora*) was steadily increasing prior to a storm driven reduction in 2009. Elsewhere coral cover has remained relatively stable, mostly at low levels, with several reefs showing slight declines that cannot be ascribed to obvious disturbance events. Such declines are likely to be indicative of chronic stress to the corals that increases their susceptibility to disease and competition with other benthos such as macroalgae and soft corals.

High macroalgal cover is a common transient state following disturbance to coral reefs (e.g. Done 1999), as algae rapidly occupy available substratum. Persistent macroalgal communities, however, can be indicative of environmental conditions such as high water column chlorophyll concentrations, which in turn indicate high nutrient availability that may benefit macroalgae (De'ath and Fabricius 2010) or changed grazing pressure by local herbivores (e.g. Cheal *et al.* 2010). Once established, high cover of fleshy macroalgae is detrimental to coral community resilience and suppresses hard coral recovery by competing with various life stages of corals and by various mechanisms, for example (Kuffner *et al.* 2006; Birrell *et al.* 2008; Diaz-Pulido *et al.* 2009, 2010; Hauri et al. 2010). The cover of macroalgae in the Burdekin Region is generally high but very variable between reefs (Figure 27). Pandora Reef, Havannah Is, and Geoffrey Bay (Magnetic Is) all have high cover of brown macroalgae (comprised for example, of the genera *Sargassum*, *Dictyota*, *Padina* and *Lobophora*) while at Lady Elliot Reef (2m) there is a mixture of red (predominantly *Hypnea*) and brown (predominantly *Dictyota*) macroalgae (Appendix Table A1-5). Cover of macroalgae at other locations has been consistently low (Figure 27).



©Google Earth 2010

Figure 26 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Burdekin Region.

At most sites, macroalgae cover has remained constant over the period 2005-2010, which is consistent with regionally high chlorophyll concentrations that often exceeded the Guidelines (GBRMPA 2009, Figure 27). At both Pandora Reef and Havannah Is, cover was markedly lower in 2009 compared to previous years. At Pandora, this reduction was almost certainly a result of physical removal of macroalgae during rough conditions in early 2009, as indicated by substantial physical damage to the substratum observed in January 2009 when coral settlement tiles were retrieved. By

2010 the cover of macroalgae had again increased at this reef. Havannah Is was not revisited in 2010 and so we cannot yet ascertain whether a similar rebound in macroalgal cover has occurred there. The sustained high macroalgal cover at Havannah Is was recently interpreted as a persistent coral-algal phase shift attributed to a lack of herbivorous fish compared to other reefs where algal blooms following disturbance were short lived (Cheal *et al.* 2010). The local fish assemblage has been unable to control the abundant macroalgae, which in turn has prevented the recovery of hard coral cover. It will be informative to continue monitoring the interplay between algal and coral communities at this site.

Macroalgae are rare at Orpheus Is East and Pelorus Is & Orpheus Is West where turbidity is low. Macroalgae are also rare at Middle Reef where the reef community consists of extensive coral colonies interspersed with gaps of fine silt sediment, leaving few areas vacant for macroalgal colonisation. Low macroalgal cover results in a positive condition assessment at these sites.

The abundance and diversity of hard coral juveniles at many reefs in the Burdekin Region reflects the adult community (Figure 28). In general, where cover of adult corals is low, juvenile colonies are sparse. While juveniles of the fast growing Acroporidae are present at most reefs, they are generally very uncommon. Juvenile communities at many reefs have high proportions of either small (e.g. Fungiidae at Lady Elliot Reef) or slow growing (e.g. Faviidae) families that would not be expected to promote rapid increases in cover. In 2010, there was a very slight increase in the density of juvenile colonies at three of the five reefs monitored (Figure 28) resulting in juvenile densities regionally being assessed as 'moderate' (Table 10), which is an improvement from the 'poor' categorisation in 2009.

Recruitment of coral larvae to settlement tiles in the Burdekin Region is well below the overall average among regions (Figure 29) and results in a 'very poor' assessment score for this indicator (Table 10). Acroporidae are the dominant recruits among all core reefs, with a strong presence of Pocilloporidae at Pelorus Is & Orpheus Is West, most likely recruiting from the local adult population (Figure 28). Settlement data showed a steady regional decline among core reefs, predominantly due to a steep decline of 80% at Geoffrey Bay in 2009. Low levels of recruitment are likely the result of regionally low abundance of adult colonies in combination with hydrodynamic conditions that may isolate reefs within the region from broodstock further afield. While large inter-annual fluctuations in larval settlement are not unusual, continued low annual recruitment emphasises the Burdekin Region's diminished capacity for maintaining coral community resilience.

The major input of sediments to this region comes from the Burdekin River, the single largest source of fine sediment for the GBR lagoon system (Furnas 2003). The discharge from the Burdekin River has been above the long term median each year since 2006/07, with major flood events in 2008 and 2009 (Table 5). Despite this large input, the reefs in the Burdekin Region have sediments with below average clay and silt, organic carbon and nitrogen components (Table AI-1a-c) indicating low residence or accumulation of sediment. The exception is Middle Reef where sites are sheltered from wind-driven waves and the ensuing re-suspension, thus promoting the accumulation of finer grained sediments with higher levels of organic carbon and nitrogen (Figure 27, Table AI-1a-c). The proportions of the clay and silt fraction in the sediments at the sampling locations in this region have not increased after the two flood events. This is not surprising as grain size composition is more likely related to local hydrodynamic conditions rather than differences in sediment supply (Larcombe *et al.* 1995). However, a fine sediment budget indicated that Cleveland Bay is accumulating fine sediment during the wet season which is only partially exported during the trade wind-dominated dry season, except for years when cyclonic winds lead to a net export (Lambrechts *et al.* 2010). Sediment accumulation was apparent at Middle Reef (see above), but not at Geoffrey Bay. The latter site, however, has regular high turbidity events. In combination, the sediment and turbidity data suggest a process of frequent re-suspension rather than accumulation of sediments at the Geoffrey Bay site.

Table 10 Benthic community condition: Burdekin Region. Overall condition score is aggregated over five indicators; regional scores for each indicator convert the 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. FORAM index scores are included as a separate column and are not included in the overall regional assessment score. Grey shading indicates sites/depths where indicators 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	neutral	neutral	+	-		
	5	neutral	neutral	neutral	+	-		
Pelorus Is & Orpheus Is West	2	neutral	-	-	+	+		
	5	-	neutral	-	+	neutral	-	-
Havannah Is	2	-	-	neutral	+	-		
	5	-	-	+	-	neutral		
Pandora Reef	2	- - - -	-	-	-	-		
	5	- - - -	-	neutral	-	-	-	neutral
Lady Elliot Reef	2	-	neutral	-	-	+		
	5	neutral	neutral	-	+	neutral		
Middle Reef		+	neutral	-	+	+		
Geoffrey Bay	2	- - -	-	-	-	neutral		
	5	- -	neutral	-	-	+	-	-
Regional assessment		(orange)	(orange)	(orange)	(yellow)	(yellow)	(red)	(red)

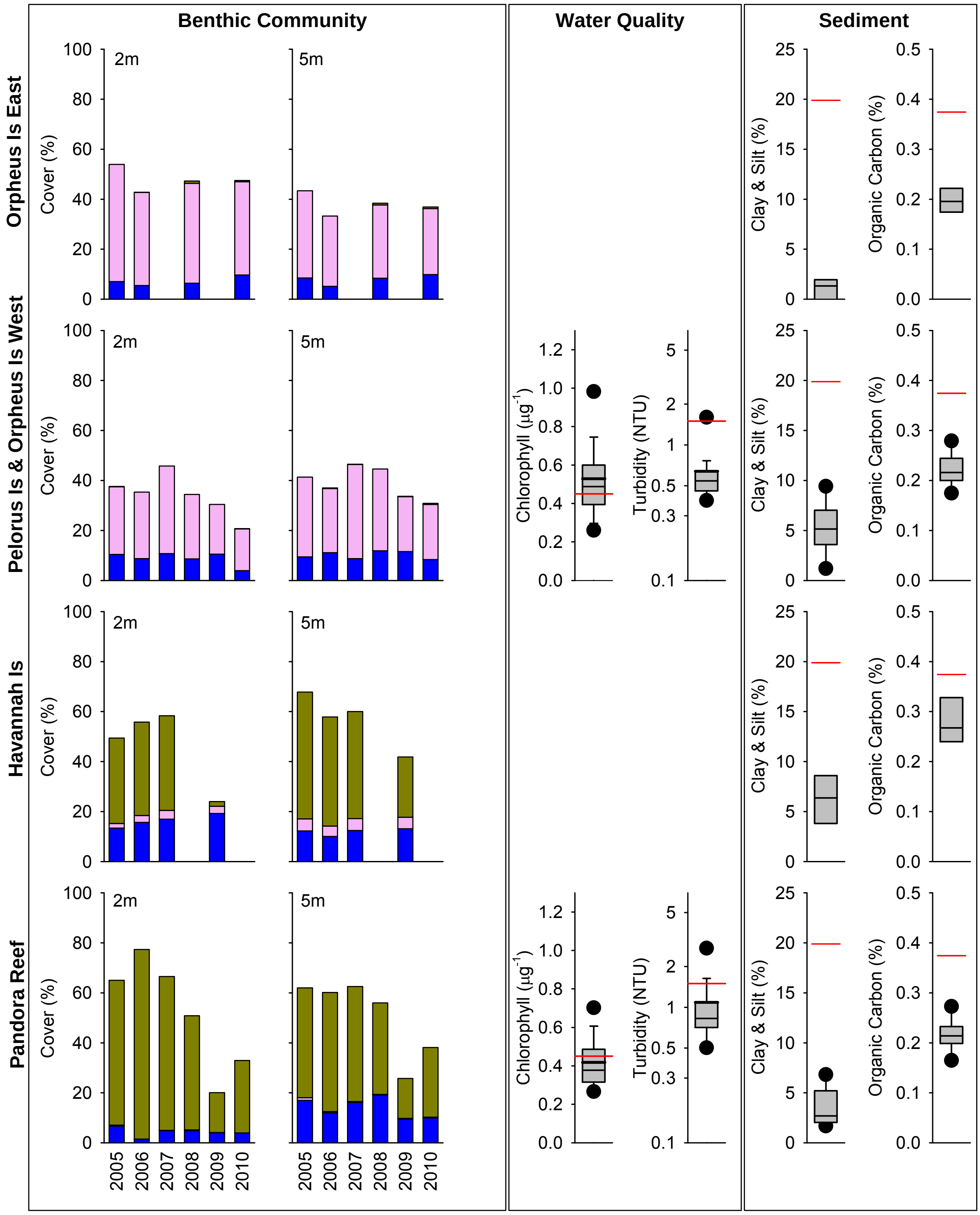


Figure 27 Cover of major benthic groups and levels of key environmental parameters: Burdekin Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to 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 Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters..

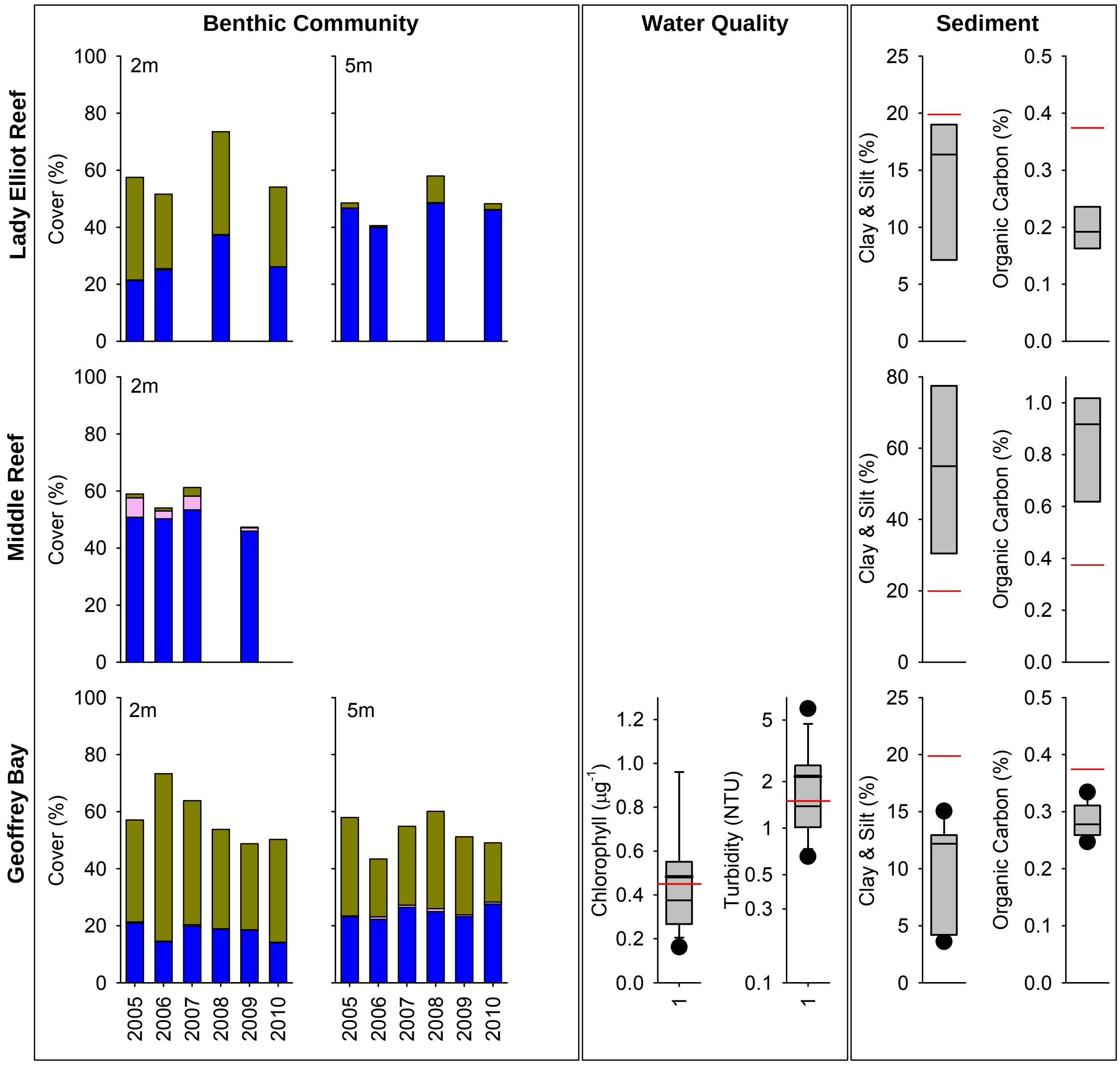


Figure 27 continued. Note different scales for sediment quality parameters at different reefs.

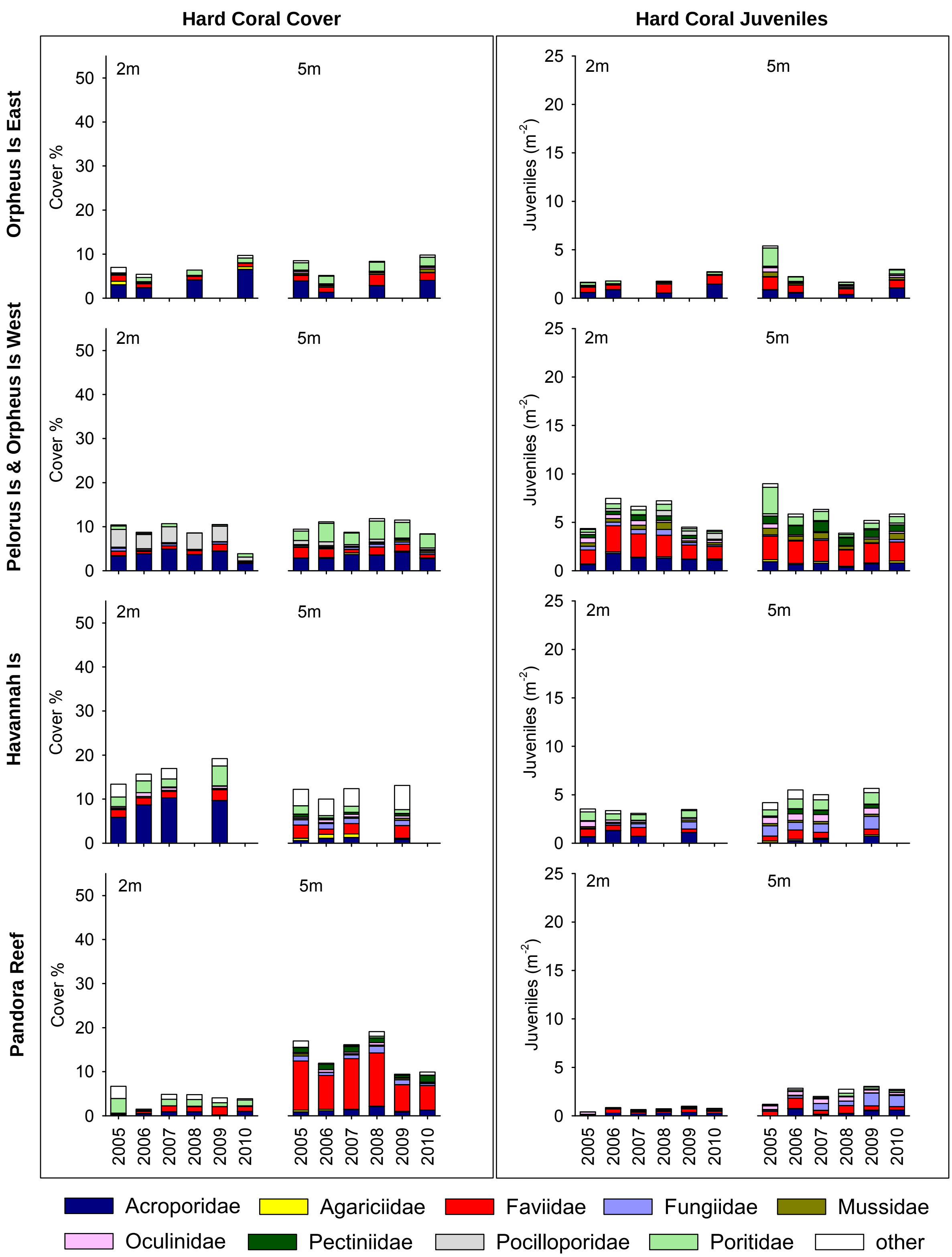


Figure 28 Composition of hard coral communities: Burdekin Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2 of available substratum, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

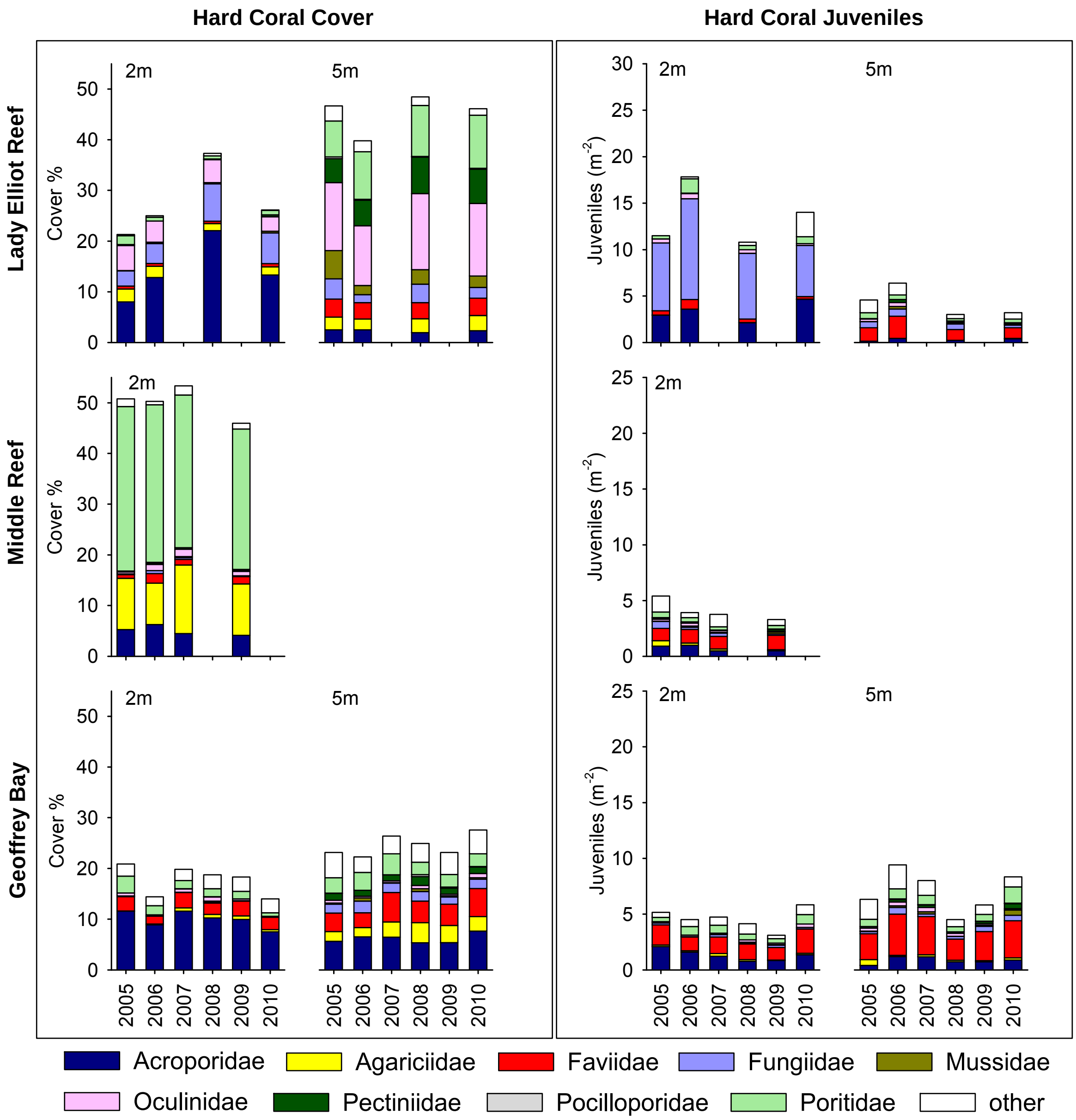


Figure 28 continued.

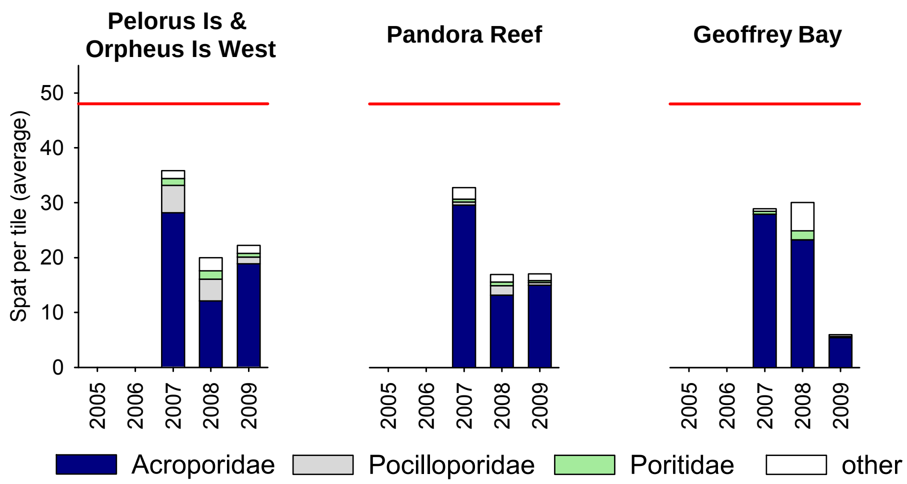


Figure 29 Coral settlement to tiles: Burdekin Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

Compared to the other regions the density and richness of foraminifera and values of the FORAM index in the Burdekin Region were more variable amongst reefs and times (Figure 30). Communities at Geoffrey Bay and Middle reefs had consistently lower FORAM indices than other reefs, caused by a high relative abundance of heterotrophic species. In addition, the proportion of heterotrophs at Geoffrey Bay has increased over time reducing the FORAM index to values below 4 in 2010. Values of the FORAM index also declined at Pelorus Is & and Orpheus Is West. These declines resulted in a negative condition rating of the communities of foraminifera of those reefs (Table 10). Thus, foraminiferal assemblages indicate possible environmental stress in this region over recent years, similar to the coral communities. The foraminifera communities at Pandora Reef remained stable.

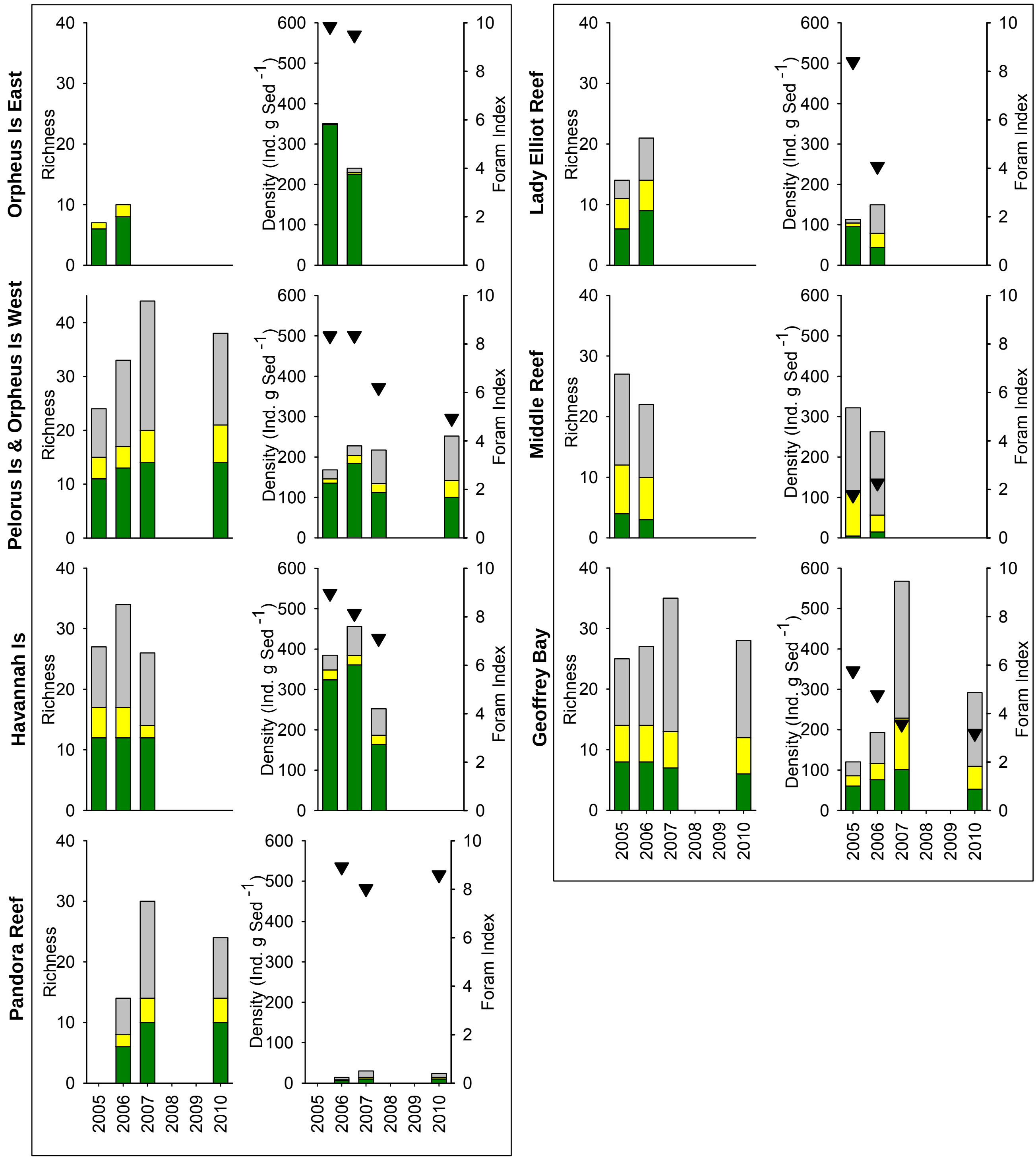


Figure 30 Composition of foraminiferal assemblages: Burdekin Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

3.2.5 Mackay Whitsunday Region

The main sources of sediments and other land-derived material to the Mackay Whitsunday Region are the Proserpine and O'Connell rivers. These catchments have both heavy rainfall and land-use that is dominated by agriculture, such as sugar cane cultivation on the coastal plains. The reefs in this area 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, 32). The surrounding waters are nutrient-rich and highly turbid with mean chlorophyll *a* and turbidity levels at or above the Guidelines (GBRMPA 2009) at the three core reefs (Figure 32). The combination of fine grained sediments and high turbidity, along with observations of high sediment loads to 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 turbidity reducing light levels reaching the benthos.

Reefs in the Whitsunday Islands are generally sheltered from wave action by the surrounding Islands. This results in limited wave-driven re-suspension and limited transport of sediments away from the reefs leading to the accumulation of fine sediments on the fringing reefs. The main agent of dispersal for fine sediments in this region is strong tidal action (Schaffelke et al 2010), which, with a tide range that can exceed 4m, is much higher than other inshore areas of the GBR. The selection for sediment tolerant corals is obvious in this region, with relatively low cover of the family Acroporidae on most reefs. 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 Daydream Is and Dent Is, where cover of Acroporidae is relatively high at 5m depth, the family is represented by just a few species of *Acropora* with branching growth forms or the genus *Montipora*. The families Oculinidae, Pectiniidae and Agariciidae and Poritidae (genus *Goniopora*) are all found in relatively high abundance on some reefs (Figure 32) and are collectively considered sediment-tolerant taxa (Thompson *et al.* 2010a). Tolerance of hard corals to sedimentation is usually due to two mechanisms, low sediment retention due to colony morphology, or the capacity to actively remove sediments from their surface, e.g. by mucus sloughing (Stafford-Smith & Ormond 1992). Prior to the 2009 surveys, observations of sediment smothering of live corals were rare and limited to occasional individuals, although corals that succumbed to smothering would be rapidly buried and difficult to detect in the annual surveys. In 2010, sediment loads to living corals were especially high at 5m depths. The proportion of substratum classified as 'silt' in photo-transects was higher in 2010 than in any prior survey at the 5m depths at three of the five reefs visited in 2010; a result corresponding to higher than median flows in adjacent catchments over recent years(Table 5), but also the recent passage of Cyclone Ului.

There are limited historical time-series data available for the coral communities for most of the survey locations 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 severely affected all reefs monitored by this program (Table A1-2). Observations from Dent Is and Daydream Is imply an approximately 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). River flows in the region have consistently exceeded long term medians for over the past four successive years (Table 5). Importantly, only the Pioneer River flooded during the 2009/2010 wet season, as a result of the passing of an unusually deep monsoon trough that included the remnant systems of ex-Cyclone Olga and ex-Cyclone Neville. While there were no acute disturbances to the reefs in this region between 2005 and 2009 in March 2010 Cyclone Ului crossed the region. The passage of Cyclone Ului resulted in physical damage to reef structures and short-term peak levels in water quality indicators (see Schaffelke et al. 2010).

©Google Earth 2009

Figure 31 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Mackay Whitsunday Region.

Cyclone Ului crossed almost directly over Daydream Is and wind speeds in excess of 100kts were reported from several locations. Not surprisingly, the reef at Daydream Is was hit hard, with a 40% loss of hard coral cover at both depths. Losses were mostly due to the reduction in cover of fragile branching *Acropora* spp. but also included the families Pectiniidae and Poritidae (Figure 33). Physical damage, however, appeared limited to the collapse of large stands of branching *Acropora* spp. and an influx of fine sediment, and only minor structural damage in places along the reef slope. Double Cone Is also showed evidence of physical damage, losing 20% cover at 2m and 10% cover at 5m in the form of overturned massive colonies and broken branching corals. At Hook Is there were some overturned coral colonies along the more exposed section of the site, but no extensive damage. A minor amount of disease (including white syndrome) was noted at Daydream 5m in 2010, and it will be of interest to track the development of any disease outbreak following this amount physical damage given that there still remains an Acroporidae dominated community on the slopes and reef flat. No appreciable impact was reported for soft corals and no damage was observed at Pine Is. However, instruments at this location recorded extremely high levels of turbidity for a week following Cyclone Ului which can easily stress corals (Cooper et al 2007, 2008). In comparisons with the widespread damage caused by Cyclone Larry that crossed inshore reefs of the Herbert Tully sub-region in 2006 (Table A1-2), the impact of Cyclone Ului was limited to the cyclone track. The height of the surrounding continental Islands sheltered the west-facing fringing reefs from high winds, and the confined nature of the Whitsunday Islands, combined with the quick passage of the cyclone, prevented any appreciable build-up of destructive waves from impacting upon most of these reefs. In contrast, for the east-facing coastal communities around Airlie Beach it was the worst storm in 40 years, with waves of 6m reported.

While Cyclone Ului had an effect on Daydream Is coral reef communities, the lack of any widespread disturbance to the region since at least 1998 explains the moderate to high cover of hard and soft corals in 2010 (Figure 32). The survey reefs in the Mackay Whitsunday Region are characterised by coral taxa tolerant to the frequent turbid conditions found at these reefs, particularly at Shute & Tancred, Hook, Double Cone, and Pine Islands. Of concern, however, is that hard coral cover across the region has not increased at the rate expected for the types of coral communities at these sites, resulting in the 'very poor' condition assessment for this indicator (Table 11).

The cover of macroalgae has remained consistently low on all reefs with the exception of the 2m depths at Pine Is and Seaforth Is. Shallow macroalgae communities at Pine Is (mainly *Sargassum* spp. and *Lobophora* spp.) remained stable in spite of the proximity to the path of Cyclone Ului. Both Pine Is and Seaforth Is are the reefs closest to the rivers influencing this region and water quality data from Pine Is shows that mean chlorophyll concentration and turbidity exceeded the Guidelines (Figure 32). Mean chlorophyll concentration and turbidity at Daydream Is also exceeded the Guidelines, and there is the potential for macroalgal cover to increase on this reef, colonising substratum that has become available after coral mortality following Cyclone Ului.

The average density of juvenile hard coral colonies was moderate to low on most reefs (Table 11, Figure 33) and there have been general declines in juvenile populations across all reefs to 2010. The extent to which the declining juvenile population can support coral community resilience is of concern. Juvenile and adult coral community composition were broadly similar, which indicates that it is likely that communities similar to those in place now will persist in the future. Notable exceptions include: the lack of Oculinidae juveniles at Pine Is, the decline of adult Pectiniidae at

Daydream Is, and the generally higher representation of Faviidae in the juvenile communities. The unusually high cover of adult Oculinidae (genus *Galaxea*) at Pine Is resulted from the presence of a large stand of unusually large individuals at site 2. Such a stand of *Galaxea* is unique amongst the reefs visited under Reef Rescue MMP and little can be inferred from this observation. The family Pectiniidae includes some species that tolerate high sedimentation and turbidity; the presence of this family in the juvenile community at Daydream Is is consistent with the high turbidity and fine grained sediments at this reef (Figure 32). Conversely, the genus *Acropora* is not typically common in such turbid settings (Thompson *et al.* 2010a) and so the high density juveniles and the high adult cover at Daydream Is are unusual. Relatively high proportions of Faviidae in the juvenile communities compared with their representation as adult cover are not uncommon and reflect relatively slow growth of some species, a tendency toward small colony size in others, as well as a tendency for colonies to settle in the under-storey of other taxa and therefore not observable by the photo point intercept sampling method used to quantify coral cover.

Settlement of coral larvae in the Mackay Whitsunday Region continued to be close to or slightly below the overall average settlement for all regions, with only Double Cone Is exceeding the regional average in 2009 (Figure 34). As in other regions, the recruits on the settlement tiles were consistently dominated by the family Acroporidae. Settlement at Pine Is and Double Cone Is was variable over the five years of recruitment monitoring, with records punctuated by occasional high or low estimates in some years. In contrast, Daydream Is had the highest and most consistent settlement rates in this region in all years except for 2009 (Figure 34). This higher settlement corresponds to marginally higher densities of juvenile colonies of the family Acroporidae at Daydream Is compared to either Pine Is or Double Cone Is (Figure 33). In general, the high variability of settlement between reefs and years remains unexplained; however, it likely reflects the combination of stochastic events such as weather and currents combining to produce variability in larval supply at a given reef.

For the most part, coral communities in the Mackay Whitsunday Region returned neutral or negative assessments of condition due to the mostly low rates of cover increase, the declining density of juvenile corals, and the moderate to low settlement of larvae (Table 11). This was offset to some degree by the generally high cover of corals and the low cover of macroalgae. Only the sites at Shute & Tancred Islands and the 2m depth communities at Dent Is returned overall positive assessments. At both these reefs, higher rates of juvenile density increase and overall coral cover (Figures 27, 28) contributed to this positive result. Overall, the influence of prevailing environmental conditions, such as high turbidity and increasing proportions of fine sediment, upon the coral communities in this region (particularly on juvenile survivorship) cannot be underestimated. Despite the general higher adult coral cover, there is a concern that continued decline in juvenile survivorship will lower the resilience of the coral communities and increase their vulnerability to phase shifts following widespread impacts such as bleaching, disease and cyclones.

Table 11 Benthic community condition: Mackay Whitsunday Region. Overall condition score is aggregated over five indicators; regional scores for each indicator convert the 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'. FORAM index scores are included as a separate column and are not included in the overall regional assessment score. Grey shading indicates sites/depths where indicators 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	- -	neutral	-	+	-	-	
	5	neutral	+	-	+	-	neutral	neutral
Daydream Is	2	- -	neutral	-	+	-	-	
	5	-	neutral	-	+	-	neutral	-
Hook Is	2	neutral	neutral	neutral	+	-	N/A	
	5	neutral	neutral	-	+	neutral	N/A	
Dent Is	2	+++	+	neutral	+	+	N/A	
	5	-	neutral	-	+	-	N/A	
Shute Is & Tancred Is	2	+++	+	neutral	+	+	N/A	
	5	+	neutral	-	+	+	N/A	
Pine Is	2	- - - -	neutral	-	-	-	-	
	5	-	neutral	-	+	-	neutral	neutral
Seaforth Is	2	neutral	neutral	-	neutral	+	N/A	
	5	neutral	-	-	+	+	N/A	
Regional assessment								

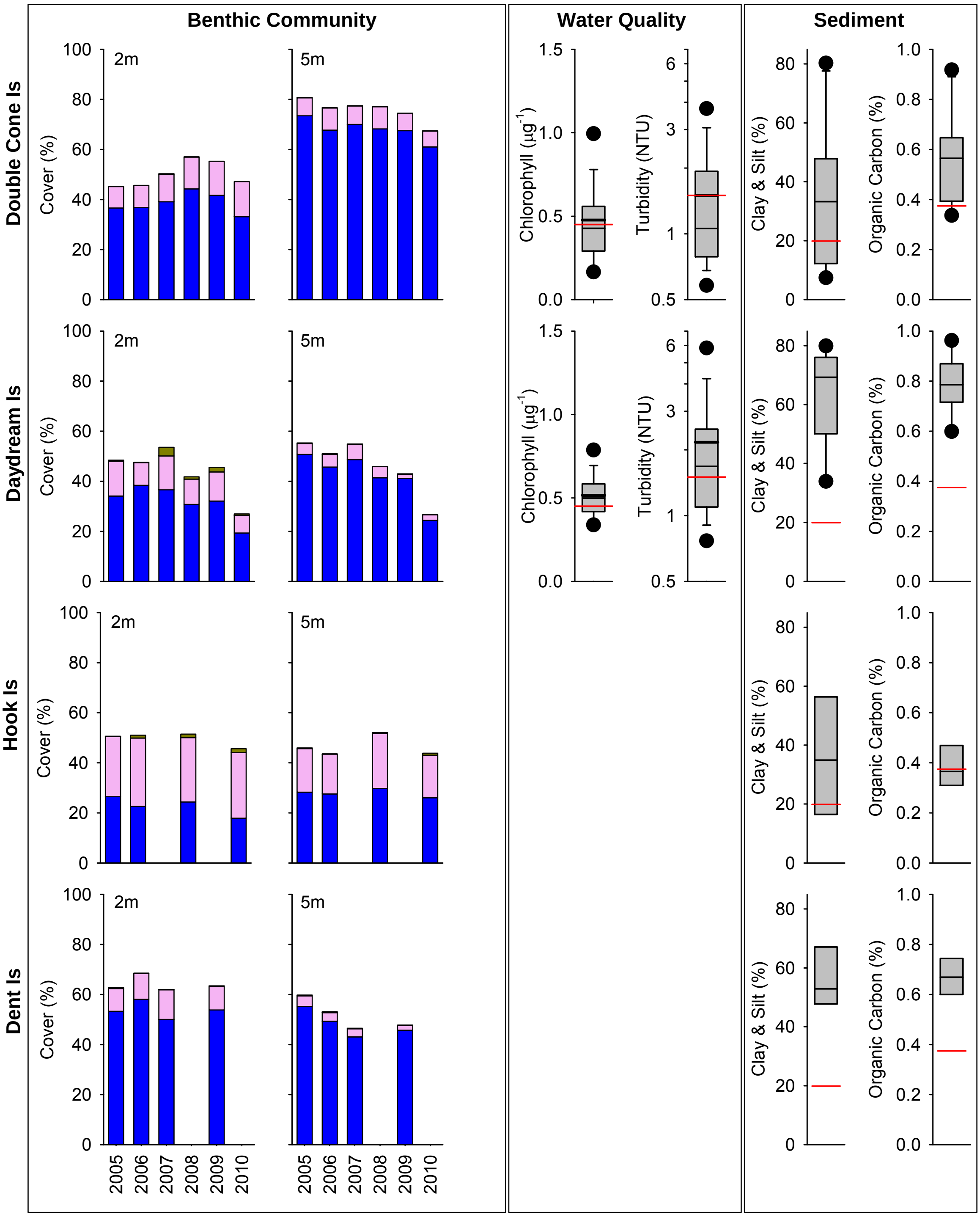


Figure 32 Cover of major benthic groups and levels of key environmental parameters: Mackay Whitsunday Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations 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 Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

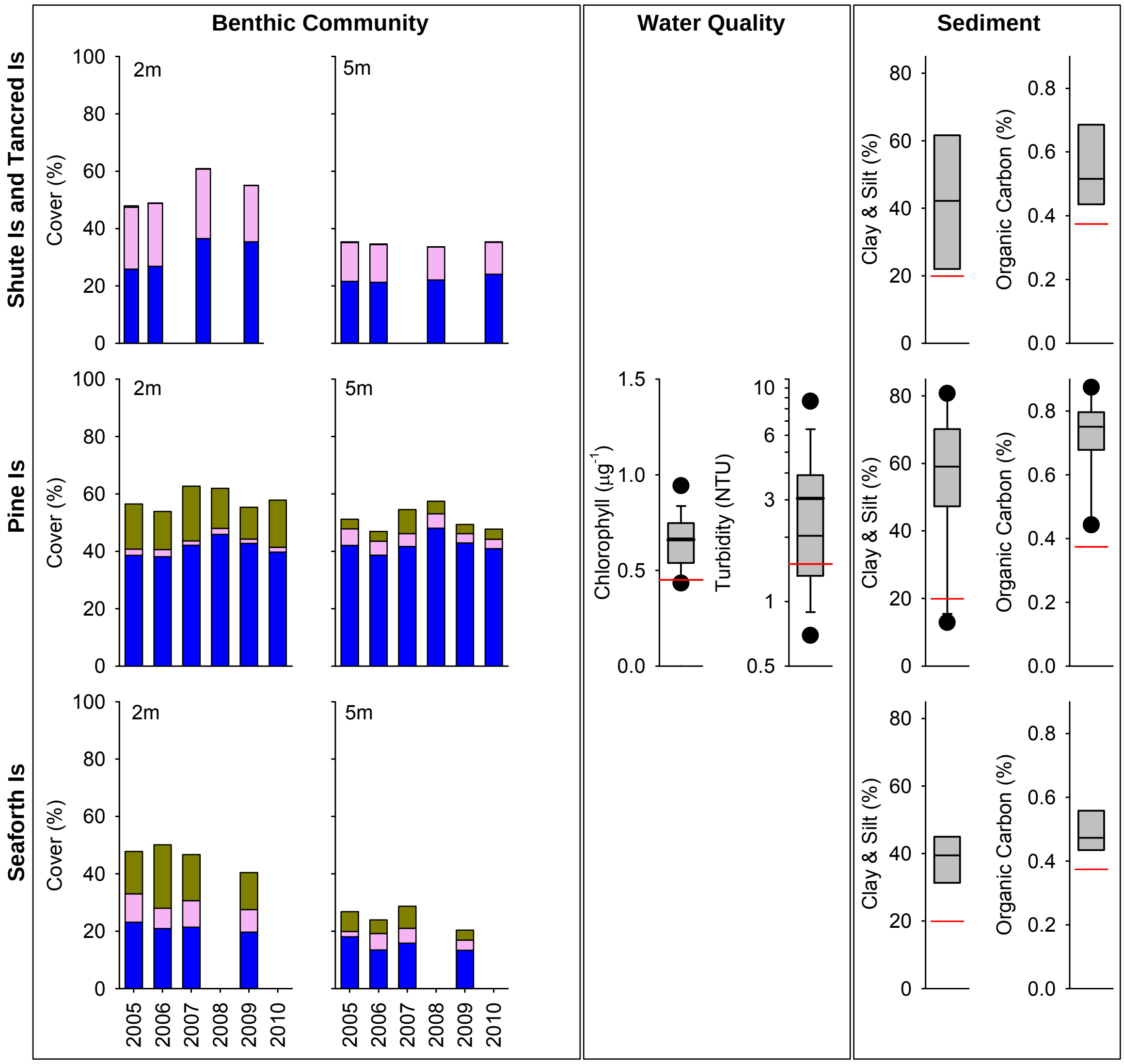


Figure 32 continued.

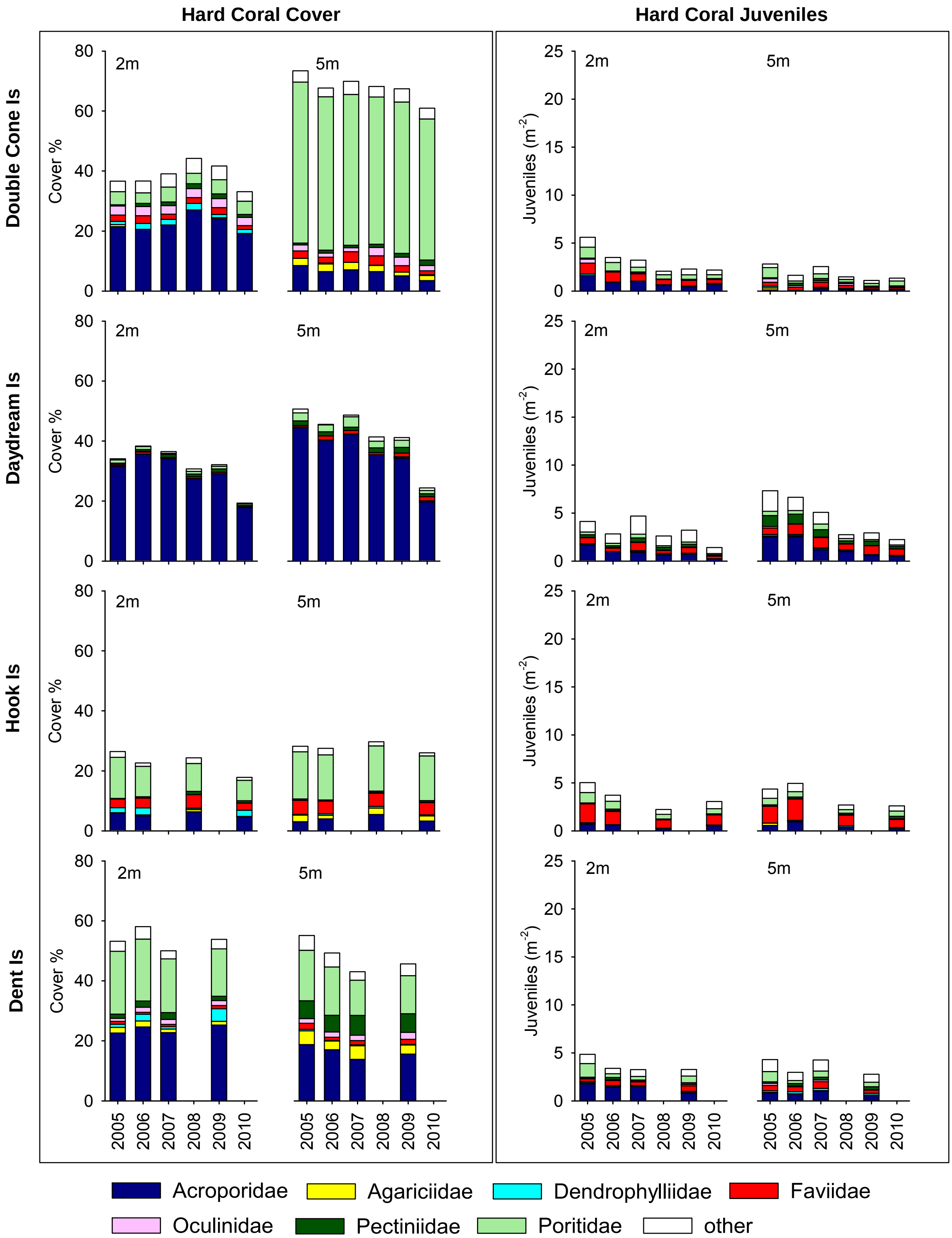


Figure 33 Composition of hard coral communities: Mackay Whitsunday Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m² of available substratum, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

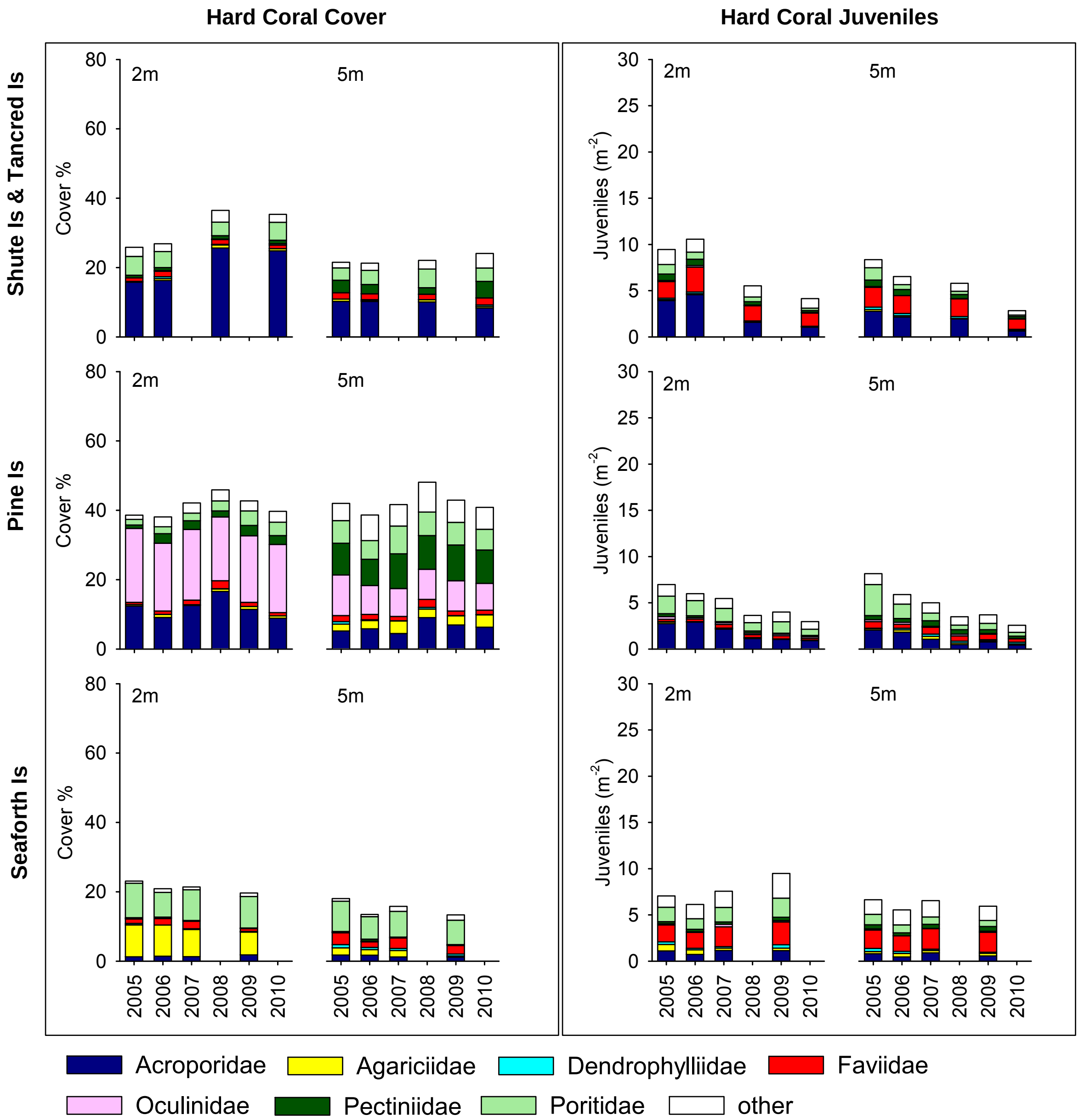


Figure 33 continued

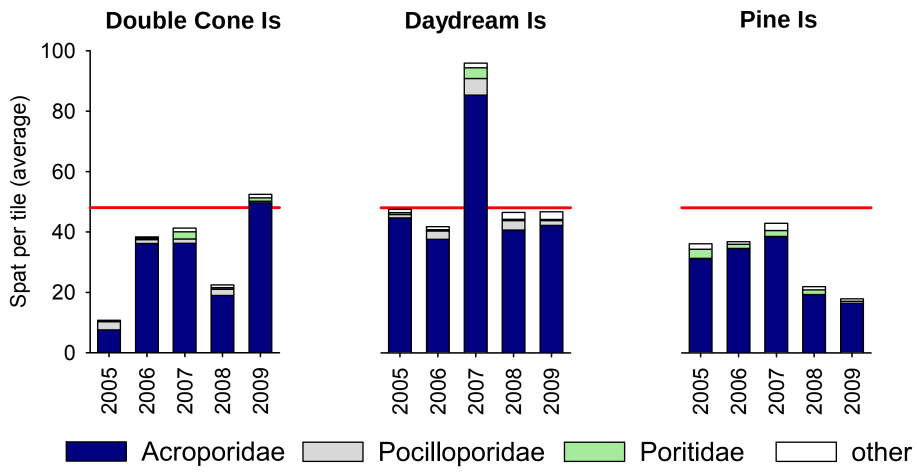


Figure 34 Coral settlement to tiles: Mackay Whitsunday Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

Foraminiferal communities in the Mackay Whitsunday Region are distinct from those in other regions. The diversity of symbiont bearing foraminifera is generally lower than in the regions further north. In addition, also the relative abundance of symbiont bearing species was low in that region resulting in generally lower FORAM indices (Figure 12). Over the period 2005-2007 the density, richness and composition of foraminiferal assemblages remained relatively stable on most reefs (Figure 35). On Dent Is, the richness (mainly of symbiont bearing species) decreased from 2005 to 2007. Although richness remained stable at Daydream Is, the density of heterotrophic species nearly tripled between 2007 and 2010, reaching the highest densities observed in these surveys. Similarly, the densities of heterotrophic foraminifera on Pine Is have also sharply increased in 2010. The FORAM index on Double Cone Is strongly decreased after 2006. However, due to the high variance in the first three years that decrease was within one SD of the initial (baseline) average. A similar decrease on Daydream Is resulted in a negative condition ranking for that reef (Table 11). The amount of organic carbon in the sediments was relatively high in 2010 compared to earlier years on most reefs (Table A1-1b) which may explain the increase in the density of heterotrophic species on some reefs. Whether the impact of Cyclone Ului also contributed to the exceptionally high numbers of heterotrophic foraminifera on Daydream Is is currently unknown.

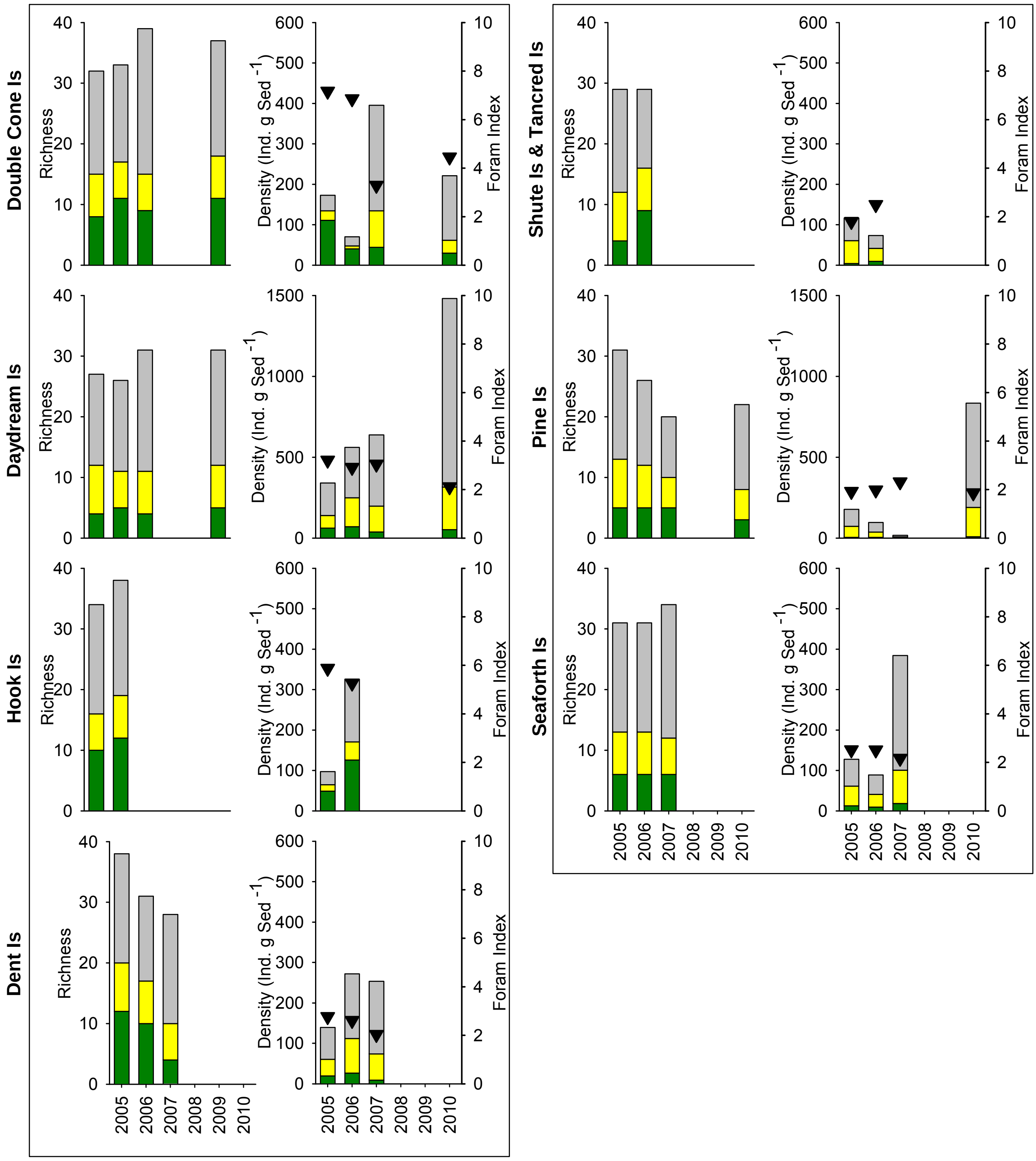


Figure 35 Composition of foraminiferal assemblages: Mackay Whitsunday Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

3.2.6 Fitzroy Region

The primary catchment of the Fitzroy Region is the Fitzroy River. The Fitzroy River catchment is one of two large, dry tropical, catchments that drain into the GBR, the other being the Burdekin. Land use in the catchment is predominantly cattle grazing (Brodie *et al.* 2003). The annual flow from the Fitzroy River is highly variable with long periods of low flow punctuated by flood events. These flood events reduce salinity around the reefs in Keppel Bay and so can have a substantial impact on shallow water communities. Historical observations document that flooding of the Fitzroy River in January 1991 caused up to 85% mortality of corals in depths down to 1.5m at Humpy Is, Halfway Is and Middle Is, with reduced salinity implicated as the cause of this mortality (van Woesik 1991). In addition to the immediate impact of reduced salinity, flooding also results in periods of extremely high turbidity, and higher than normal levels of water column chlorophyll (likely the result of nutrient enrichment) especially around the reefs closest to the river mouth (Schaffelke *et al.* 2010). Relatively low proportions of fine grained sediments at the reefs in this region (Figure 37) indicate that the hydrodynamic setting of these reefs is sufficiently energetic to prevent the accumulation of fine grained sediments. Hence, direct influences of river borne sediments are more likely to impact coral communities through their contribution to turbidity during events rather than smothering as a result of sedimentation.

In addition to the impacts associated with flood events, monitoring of coral cover by the Queensland Parks and Wildlife Service (spanning 1993-2003, see Sweatman *et al.* 2007) and then Reef Plan (2005-2010) identify coral bleaching in 1998, 2002 and 2006 and storm events in 2008 and 2010 as causing marked reductions in coral cover in this region (Table A1-2).

The six reefs monitored in this region (Figure 36) span a strong gradient in water quality. The reefs at 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 *a* (Figure 37). 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 in February and March in both 2008 and 2010 coinciding with flooding of the Fitzroy River (Schaffelke et al 2010). At these times median turbidity 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 shift in the composition of the coral community from a high proportion of the family Acroporidae, genus *Acropora* at 2m depth, to a mixed community at 5m (Figure 38). 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 37). 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 may be beyond the limits that can support a true coral reef community. In contrast to the communities at Peak Is and Pelican Is, coral communities monitored on the reefs further away 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 38), which are indicators for clear water.

Over the period 2005-2010, coral communities in this region have been impacted by a severe coral bleaching event in 2006 (Diaz-Pulido *et al.* 2009, Table A1-2), and a combination of floods of the Fitzroy River and storms in both 2008 and 2010 (Table A1-2). The proximity to the Fitzroy River, differences in community composition, and subtle differences in the directional aspect of the reefs largely explain the variable impacts of these disturbances across the reefs monitored.

Figure 36 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Fitzroy Region.

The most severe disturbance occurred in early 2006 when abnormally high water temperatures (Figure 3) caused widespread coral bleaching. At each of the reefs dominated by branching *Acropora* (North Keppel Is, Middle Is, Humpy Is & Halfway Is and Barren Is) this event caused a marked reduction in coral cover, and an ensuing bloom of the brown macroalgae *Lobophora variegata* (Figure 3, see also Diaz-Pulido *et al.* 2009). At Barren Is, where mean chlorophyll concentration was below the Guidelines (Figure 37) the bloom of *L. variegata* was less pronounced than at other reefs and some recovery of coral cover was clearly evident in 2007. There was also some recovery at Humpy Is & Halfway Is at 2m depth. However, there was no recovery in coral cover at North Keppel Is where the *L. variegata* was highly abundant or at 5m at Humpy Is & Halfway Is. Interestingly, of the reefs monitored in this region, sediments at North Keppel Is had the highest concentrations of nitrogen and organic carbon with mean levels higher than the average for all reefs monitored under Reef Plan (Figure 37, Table A1-1(b, c)), while mean water column chlorophyll concentration at Humpy Is & Halfway Is exceed the Guidelines; these observations are consistent with a link between persistence and extent of the algal blooms and local nutrient enrichment.

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 37). Similarly high macroalgae cover on these reefs is not related to disturbance to the coral communities in 2006 as diverse algal communities were present when these reefs were first visited in 2004 (Sweatman *et al.* 2007). Cover of macroalgae on these inshore reefs did, however, decline in 2010 (Figure 37). It remains uncertain however, as to whether this reduction in macroalgae might reflect a short term response to physical removal during recent storms and/or low light conditions over the recent flood event or a more general longer term decline, future monitoring will help to clarify this issue.

In early 2008 a monsoon low over the adjacent catchment resulted in a large flood of the Fitzroy River and also bought strong winds from the north over Keppel Bay. At Barren Is physical damage to the coral consistent with exposure to high waves was evident during surveys in late April and obviously contributed to reductions in coral cover. Some physical damage to corals was also observed at 2m at both Peak Is and Pelican Is, although dead corals that had not been physically disturbed were also present, which indicates that observed declines were likely influenced by both storm damage and exposure to the Fitzroy River flood plume. Coral cover at Middle Is had increased marginally in 2008 from levels observed in 2006 while the cover of macroalgae decreased, indicating some recovery from the 2006 bleaching event. Higher levels of disease were recorded at 5m depths on each reef surveyed in 2008 with the exception of Barren Is; this observation is interpreted as an indication of chronic stress to the corals as a result of exposure to either higher than background turbidity or nutrients following flooding of the Fitzroy River. Light reduction as a result of turbidity, increased nutrient supply (as evidenced by higher levels of nitrogen in sediments (Figure 2, Table A1-1(c)), or lower salinity are all possible mechanisms that may reduce coral fitness or contribute to higher rates of disease in corals (e.g. Fabricius 2005, Voss & Richardson 2006, Haapkylä *et al.* 2011).

No major disturbances occurred in the year leading up to surveys in 2009 and coral cover tended to increase at most reefs. The clear exception was North Keppel Is where coral cover remained low and macroalgae cover high. Cover also declined slightly at Pelican Is 5m; mostly likely due to ongoing mortality from the high levels of disease noted in 2008.

In 2010, at all reefs where the coral community includes a high proportion of the family Acroporidae the cover of this family declined (Figure 38). Surveys for coral disease in 2010 noted a high incidence of disease amongst the Acroporidae that almost certainly contributed to these declines. In early 2010 reefs were again impacted variously by winds from the north and flooding of the Fitzroy River. Again, the high incidence of coral disease in this region followed flooding of the Fitzroy River further reinforcing the proposed link between flooding of the Fitzroy River and chronic stress leading to disease amongst the coral community. Moreover, flood impacts were superimposed over storm damage, with corals at Middle Is and 2m at Barron Is showing obvious physical damage.

In summary, the assessment of coral community condition for the region in 2010 as 'moderate' (Table 12) primarily reflects high rates of larval settlement and recent reductions in macroalgae. These positive aspects of the community offset the negative attributes of low densities of juvenile colonies and low rates of coral cover increase in recent years. In general terms the coral communities in this region have shown limited capacity to recover from the severe disturbance caused by coral bleaching in 2006. However, it is likely that two major floods of the Fitzroy River are influencing the observed suppression of resilience. With the eventual release from chronic pressures associated with repeated floods we may expect an improvement in coral community condition in this region.

Table 12 Benthic community condition: Fitzroy Region. Overall condition score is aggregated over five indicators; regional scores for each indicator convert the 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'. FORAM index scores are included as a separate column and are not included in the overall regional assessment score. Grey shading indicates sites/depths where indicators 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	neutral	+	-	-	
	5	neutral	+	+	neutral	-	-	
North Keppel Is	2	- - - -	-	-	-	-		
	5	- - - -	-	-	-	-		
Humpy Is & Halfway Is	2	+	+	-	+	-	+	
	5	neutral	neutral	-	+	-	+	neutral
Middle Is	2	-	neutral	neutral	neutral	-		
	5	-	neutral	-	+	-		
Pelican Is	2	++	neutral	neutral	+	neutral	+	
	5	++	neutral	neutral	+	neutral	+	neutral
Peak Is	2	- - - -	-	-	-	-		
	5	+	neutral	neutral	+	neutral		
Regional assessment								

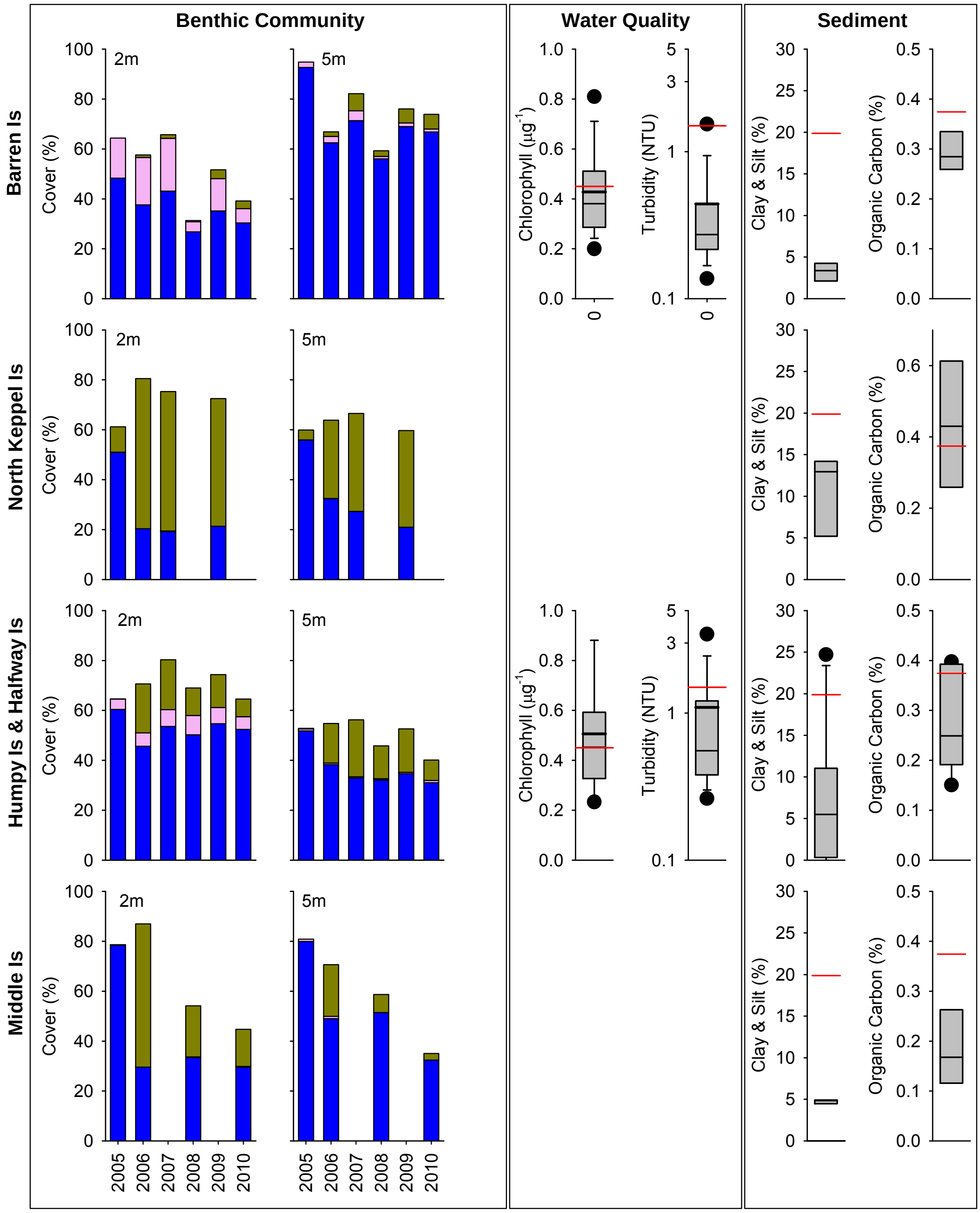


Figure 37 Cover of major benthic groups and levels of key environmental parameters: Fitzroy Region. Stacked bars represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Box plots for both water and sediment quality represent the distribution of all observations to date, 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 water quality parameters (GBRMPA 2009), and the overall mean across all Reef Rescue MMP reefs for sediment parameters.

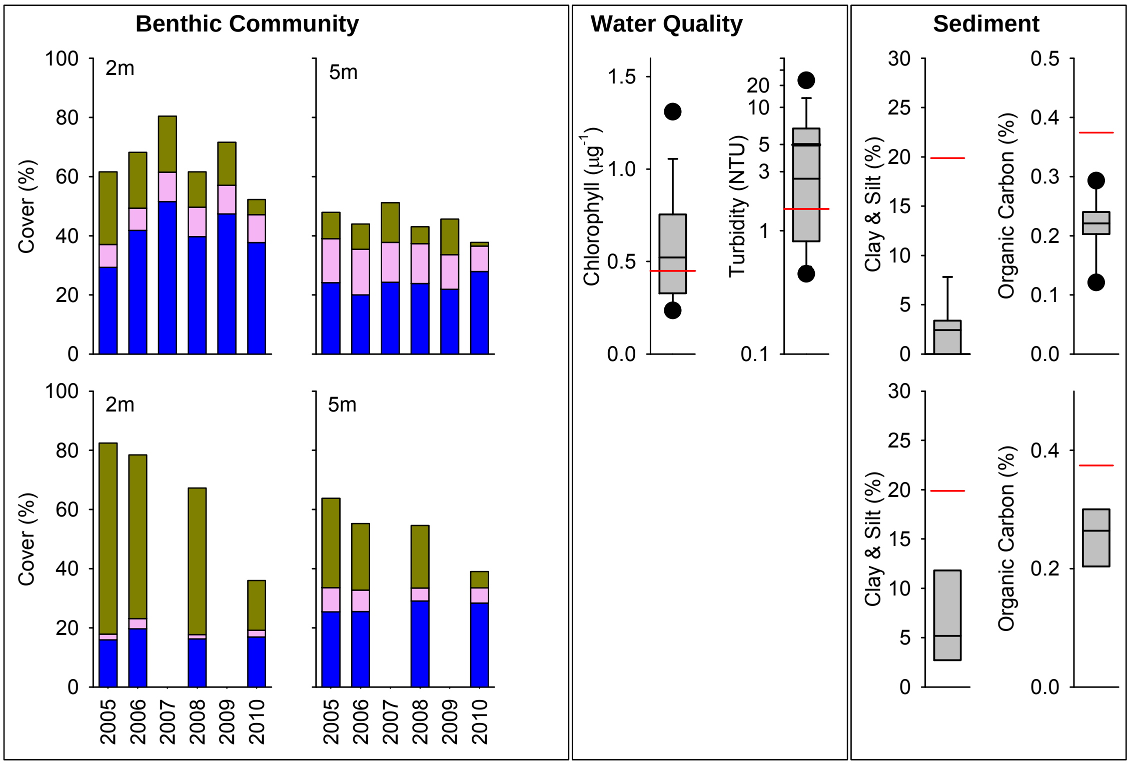


Figure 37 continued

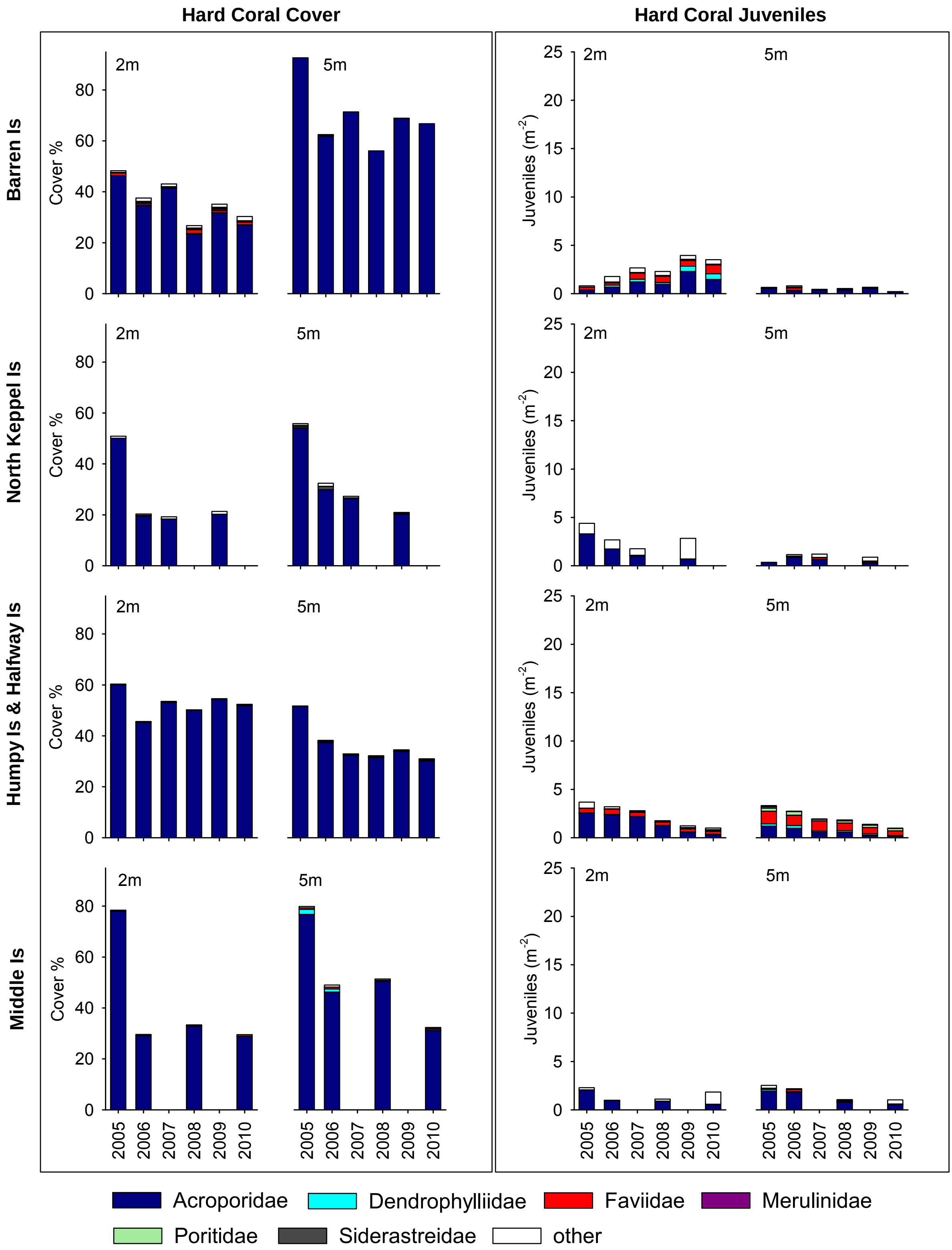


Figure 38 Composition of hard coral communities: Fitzroy Region. Stacked bars represent cumulative cover, or density of juvenile colonies per m^2 of available substratum, of dominant families within the region (see legend for colour coding). Only families for which cover exceeded 4% cover on at least one reef at one depth in one year were differentiated, all other families were aggregated into 'other'.

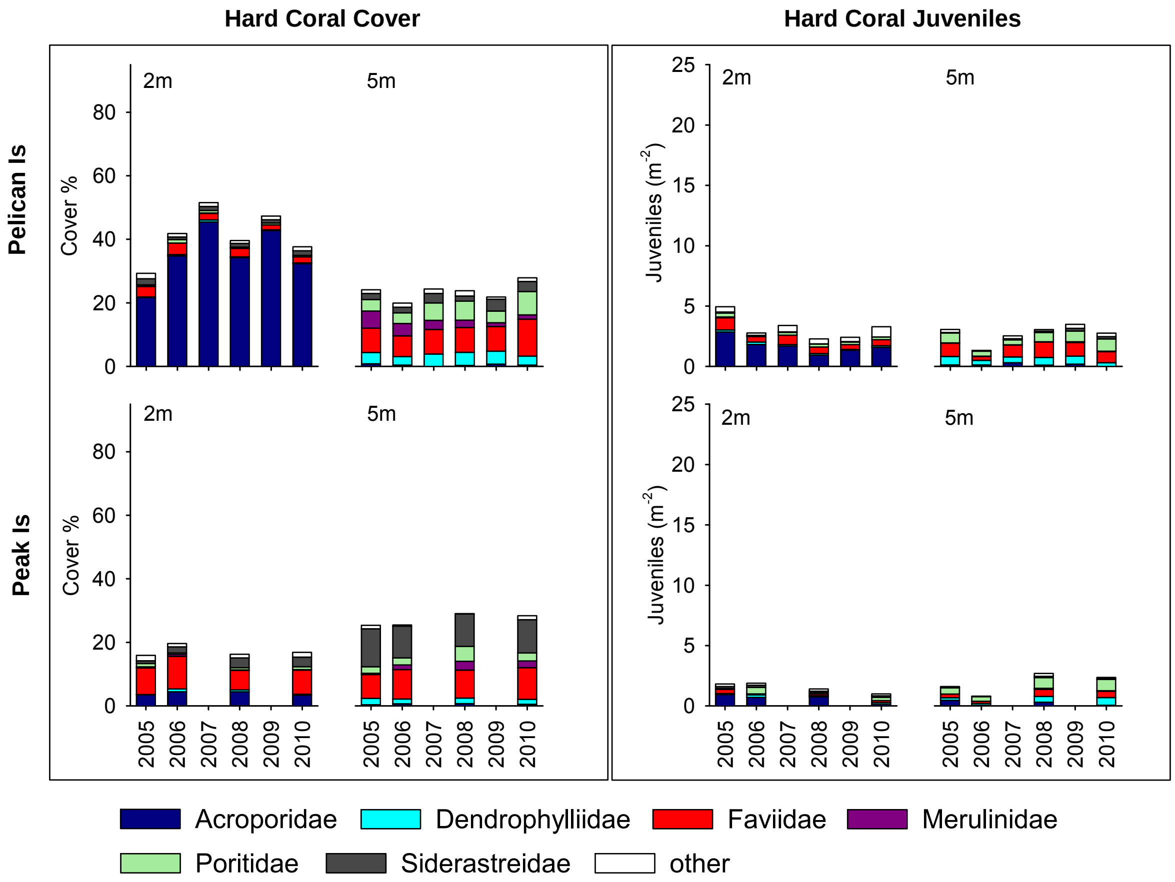


Figure 38 continued.

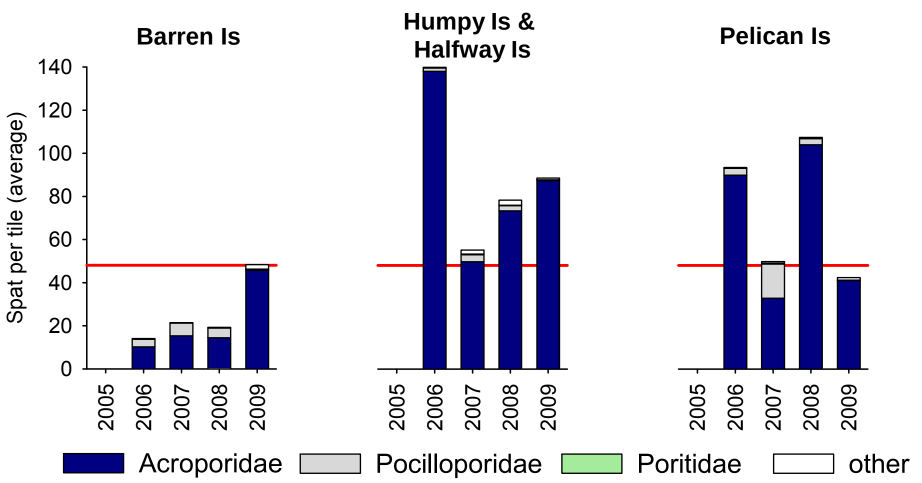


Figure 39 Coral settlement to tiles Fitzroy Region. Data are from 5m tile deployments. Average values from all reefs and regions sampled in each year are indicated by red reference lines.

The strong environmental gradient between Pelican Is and Peak Is and then the islands further offshore as evidenced by differences in coral community composition (Figure 38) are also evident in the foraminifera with low densities on the nearshore reefs, and a very low richness at Peak Is (Figure 40). Reasonable temporal data is only available from Humpy Is & Halfway Is and Pelican Is. At both these locations the richness of foraminifera in 2010 was similar to that observed over the period 2005-2007; however, the densities in 2010 were the lowest recorded (Figure 40). Interestingly at both reefs the declines were consistent across both heterotrophic and symbiont-bearing groups. In the period between 2007 and 2010 the two major floods of the Fitzroy River are likely implicated in the reduction of foraminiferal density. A case exists for the analysis of stored samples to pinpoint the timing of these declines. The values of the FORAM index remained unchanged leading to the neutral ranking of foraminiferal assemblages in this region (Table 12) despite substantial declines in density. The FORAM index at Barren Is was not included in the condition assessment because there were only data for one year of the baseline period (see 2.6.1).

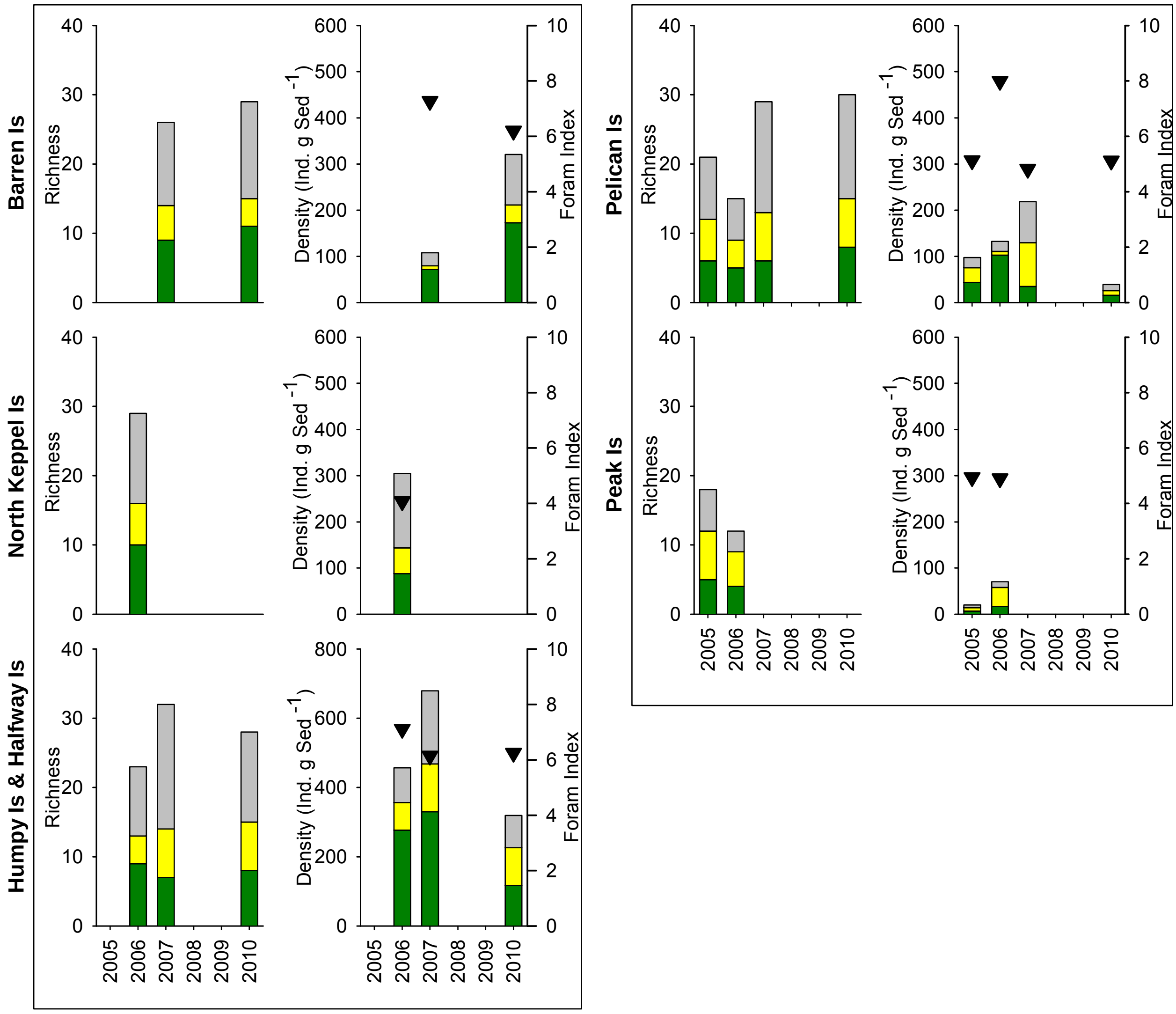


Figure 40 Composition of foraminiferal assemblages: Fitzroy Region. Bars are the cumulative richness (number of species), or density of individual trophic groups per gram of sediment. Groups as used to calculate the FORAM index are separated by colours (green = symbiont bearing foraminifera, yellow = opportunistic foraminifera, grey = heterotrophic foraminifera. The FORAM index value is indicated by a triangle.

4. Conclusions

Scientists and managers have realised that the continued management of regional and local pressures such as nutrient runoff and overfishing is vital to provide corals and reef organisms with the maximum resilience to cope with global stressors such as climate change (Bellwood *et al.* 2004, Marshall and Johnson 2007, Carpenter *et al.* 2008, Mora 2008). The management of water quality remains an essential requirement to ensure the long-term protection and resilience of the coastal and inshore reefs of the GBR. The MMP supports the effective management of water quality in the inshore GBR by monitoring changes in the inshore marine environment that will gauge the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan and Reef Rescue initiative to improve water quality entering the GBR. In addition, the MMP will deliver long-term condition assessments and detailed descriptions of GBR inshore coral reef ecosystems, which is essential information for reef managers.

Local environmental conditions clearly influence the benthic communities found on coastal and inshore reefs of the GBR. These reefs differ markedly from those found in clearer, offshore waters (e.g. Done 1982, Wismer *et al.* 2009, Death 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, Thompson *et al.* 2010a). Given the clear relationship between coral community composition and their environmental setting, coral communities will be susceptible to deterioration in environmental conditions such as increases in the rates of sedimentation, levels of turbidity, nutrient concentrations or other pressures associated with anthropogenic activities in the connected catchments or coastal zones. Conversely, if improvements under Reef Plan and Reef Rescue lead to better water quality in the inshore GBR, coral communities may change over time to reflect the improved environmental conditions (De'ath and Fabricius 2008, 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, 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 & 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, past disturbance regimes 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, gradually changing environmental conditions may allow existing colonies to adapt, due to the inherent physiological (Anthony and Fabricius 2000) and morphological (Anthony *et al.* 2005) plasticity of corals. Colonies may then persist in conditions unlike those into which they recruited, forming relic communities. In combination, the above considerations may obscure the relationship between community composition and environmental conditions, which makes it difficult to assess condition and resilience of GBR inshore coral reef communities based on their composition alone. For the above reasons, our protocol for assessing the condition of coral communities considers their potential to recover from disturbance events. This assessment compares observed levels of various community attributes with levels expected for a resilient community. The underlying assumption is that a healthy community will show resilience to disturbances by recovering lost cover through the recruitment and growth of new colonies or the re-growth of surviving colonies and fragments. Basing our assessments on indicators of recovery potential removes the considerable shortcomings and ambiguities associated with assessing coral community condition based on composition and/or percentage cover alone. Importantly, it provides for communities that vary across naturally occurring environmental gradients to be considered within a uniform framework.

This most recent application of our assessment protocol (a baseline assessment was presented in Thompson *et al.* 2010b) indicates that reefs in the Burdekin Region remained in 'very poor' condition and show the least capacity to recover from disturbance events (Table 6). In this region, coral cover remained low, and was increasing at a very slow rate, some reefs had a very high cover of macroalgae, and settlement of coral larvae was very low. A slight increase in the number of juvenile corals observed in 2010 has, however, improved the assessment of juvenile density from 'poor' to 'moderate' compared to the baseline assessment for data collected in 2009. The 'poor' condition of coral reef communities in the Burdekin Region in part 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). One GBR inshore reef (Pandora Reef, located in Halifax Bay) was studied since 1981 and showed initially high resilience to disturbances despite proximity to land runoff (Done *et al.* 2007). However, it appears that this resilience has been reduced over the last decade because certain reef zones have not recovered at all, which has been interpreted as a result of reduced availability of larvae (ibid). Hydrodynamic modelling indicates that over a period of 1-2 weeks (which is generally long enough for coral larvae to settle) particles released in Halifax Bay stay within the bay with some movement to the north or south depending on the prevailing winds, however, they do not move to reefs further offshore (Luick *et al.* 2007). This indicates that larvae originating in Halifax Bay will predominantly settle within the bay. That water is not leaving the bay logically implies water is not entering the bay suggesting limited scope for supply of larvae from reefs further off shore. The mortality of a high proportion of adult corals in the Burdekin Region during the 1998 bleaching event resulted in a substantial reduction in local larval supply, leading to low juvenile densities and limited rate of recovery, as observed in the MMP surveys. Perhaps of more concern is the low rate at which coral cover increases when these reefs are not under the influence of acute disturbance events. The rate at which coral cover increases, while influenced by recruitment, is primarily related to the growth rate of the existing coral colonies. The implication is that recovery is stalled not only as a result of limited replenishment of new colonies, but also as a result of suppression of coral growth rates. Environmental conditions, such as the high turbidity and chlorophyll *a* concentrations observed at some of the reefs, may be influencing the growth rate of existing colonies as well as adding to post settlement mortality of the spat that settle.

The condition of coral communities in the Burdekin Region highlights a key issue facing inshore coral reefs in general. That the Burdekin reefs show little evidence of recovery after 10 years illustrates the long-term effects that severe disturbances can have on coral communities. While the interactions between water quality and climate change are poorly understood, and require urgent experimental investigation, evidence is accumulating that suggests corals tolerance to heat stress is reduced by exposure to contaminants including nutrients, herbicides and suspended particulate matter (Wooldridge 2009, Negri *et al.* 2011, Cseke and Fabricius *et al.* in prep.). With frequency and severity of disturbance events projected to increase in response to continuing rise in greenhouse gases

(Hoegh-Guldberg et al 2007, Steffen 2009) any increase in susceptibility as a result of local stressors may be catastrophic for GBR inshore communities.

While the overall assessment of coral communities in the Mackay Whitsunday Region continues to be 'moderate', there are three aspects of the community dynamics that are cause for concern. Despite moderate to high coral cover and low levels of macroalgae, the rate of coral cover increase is low, settlement of coral larvae is low and there has been a substantial decline in the density of juvenile colonies. We interpret both the declines in numbers of juvenile corals and suppressed growth rates of existing colonies as responses to regional environmental stress, based on the high levels of turbidity, chlorophyll *a* and the fine grained, nutrient rich sediments on reefs in this region. Benthic community composition has been shown to respond to the proportion of fine grained components in sediments (silt and clay sized particles) (Thompson *et al.* 2010a), which have noticeably increased on reefs in the Mackay Whitsunday Region since 2005 (Figure 2). This increase in fine grained sediment particles corresponds to changes in the flows of the nearest rivers (Proserpine, O'Connell and Pioneer rivers). River flows were below long-term medians for several years prior to 2005, and since 2006 were substantially higher than the median flow. Further evidence that increased runoff from the catchments have led to observed changes in the environmental conditions on the nearby reefs is that the proportion of the substratum categorised as "silt" has generally increased (Table A1-9). As turbidity is largely a function of wave and tidal re-suspension (Larcombe *et al.* 1995), the increase in silt levels would lead to higher resuspension under given conditions and so increase the flux of particles between turbidity and sedimentation. Both turbidity and sedimentation have the potential to stress corals by reducing light availability for photosynthesis, with sedimentation also incurring an energy cost when active removal is required. Both these processes are likely to have influenced the lower than expected rate that coral cover increased over the period of higher than median river flows in the Mackay Whitsunday Region. Similarly, as juvenile corals are generally more susceptible to turbidity and sedimentation than adult colonies (Fabricius *et al.* 2003, Fabricius 2005) the observed declines in juvenile density are also likely linked to the increased supply of sediments. Declining densities of juvenile colonies may reflect reduced survivorship of settled individuals and/or a reduction in the number of larvae settling to the reef. While the number of coral larvae that settled to tiles show no clear pattern, on average settlement is lower in the Mackay Whitsunday Region than either the Wet Tropics Region or Fitzroy Region (Figure 10). Although not quantified, it was repeatedly observed that settlement tiles deployed in this region accumulate substantially thicker covering of silt than those deployed in other regions. Settlement of larvae is enhanced by chemical cues arising from the biological characteristics of the settlement substratum (e.g. bio-films, Negri *et al.* 2002). A thick layer of sediments will limit settlement both chemically and physically, by precluding the development of appealing bio-films and by not providing a suitably stable substratum for attachment (Birrell *et al.* 2005). Accumulation of sediments on tiles almost certainly influences settlement rates but, importantly, also mirrors the accumulation of sediments to the reefal substratum. Given the high turbidity and hydrodynamics that promote the accumulation of fine grained sediments in the region it will be interesting to monitor the recovery of coral communities at Daydream Is following damage caused by Cyclone Ului in early 2010.

The pattern of higher river flows in recent years coinciding with lower juvenile coral densities is consistent across regions. However, clear changes in sediment composition have not been observed in other regions. This is not unexpected, given, the typically larger grain sizes of sediments in other regions relative to those on Mackay Whitsunday Region reefs; an observation that suggest local hydrodynamic conditions preclude accumulation of fine grained material. However, this does not preclude periodic sedimentation during calm or low tidal flow periods. It has been shown that fine sediment imported by flood events remains in the coastal zone for long after an event, leading to recurring high turbidity as a result of re-suspension (Wolanski *et al.* 2008, Lambrechts *et al.* 2010). As the time series of high intensity, instrument-derived, water quality measurements at MMP core reefs extends, more detailed analyses of the relationship between water quality, especially turbidity, and river flow will be possible. In addition to the observed coincidence of declining juvenile densities and above median river flows, is the observation that the rate which coral cover increased also declined. In both the Burdekin and Fitzroy regions the average rate of coral cover increases over the period 2007-2010 was lower than the baseline rate averaged over the years 2005-2009. Declines in measures of coral community condition that to coincide with periods of high river discharge warrant continued research efforts into both the identification and subsequent fate of river-borne contaminants that are influencing coral community condition.

Monitoring of reef communities since 2005 has improved our understanding of the functioning of inshore communities. An important step forward is that we now do not expect all communities to be the same; rather, we acknowledge that community composition will vary depending on their position along a multidimensional environmental gradient, and their exposure to past disturbance events. With these factors in mind our approach has been to develop an assessment protocol focusing on the recovery potential over time of a community rather than present condition alone. This is work in progress. For the community variables we measure, still too few data exist to factor into our assessments the various expectations for communities in different habitats or stages of recovery. For example, we have been able to use a body of past monitoring data from inshore reefs to create growth models for hard coral communities that incorporate differences in community composition and initial coral cover (derived from Thompson and Dolman 2010). However, we have not been able to similarly conceptualise and predict other aspects important to the resilience of coral reef communities. For example, we need to define the number of coral larvae settling to tiles and the density of juvenile colonies that would be sufficient to sustain a coral community in the long term, or a resilience threshold for the cover of macroalgae beyond which coral recovery is impeded. At present our assessment can only compare relative levels of these key variables. It is intended that we continue to improve our protocol for coral reef condition assessments. Central to this improvement will be a greater capacity to estimate critical values of community and environmental variables that promote community resilience as time series develop and additional environmental data streams become available (e.g., estimates of chlorophyll, turbidity from satellite remote sensing).

The condition assessment of the foraminiferal assemblage suggested here may need updating in the future as our understanding of the dynamics of these communities improves. Generally however, the FORAM index is considered a useful indicator of environmental conditions (Uthicke and Nobes 2008, Hallock *et al.* 2003). In the Caribbean reefs FORAM index values below 2 are considered to represent locations having '*stress conditions unsuitable for reef growth*', values between 2 and 4 are considered marginal and values above that as '*environment conducive to reef growth*' (Hallock *et al.* 2003). Broadly speaking, these ranges may also apply to the GBR (Uthicke and Nobes 2008), however, they are not necessarily a trend indicator, nor do they account for the possibility that low values may be caused by recent disturbances rather than the 'natural' state of the system. To identify changes in the water quality in inshore areas of the GBR we therefore propose the use of a baseline observation of the FORAM index against which future estimates of the FORAM index (from that reef) can be compared. In general, condition scores for individual reefs usually matched assessments based on the other benthic community indicators, but with a tendency for the foraminiferal assemblage to yield lower scores. It is possible that this difference may reflect the potential for a more rapid response by foraminifera. However, several reefs in clear decline could not satisfactorily be identified with this indicator because values in the first surveys, from which the baseline was estimated, had high variance; such observations suggest some fine tuning of baselines may be required especially where communities sampled for baseline may have been influenced by recent disturbance. The FORAM index, foraminiferal densities, and richness to date have shown interpretable trends when considered in conjunction with changes in environmental parameters suggesting that foraminifera are adequately representing changes in environmental condition on inshore GBR reefs (Uthicke *et al.* 2010). Similar to coral communities, the steady decline of the FORAM index and rapid increases of heterotrophic species densities on some reefs appear to reflect higher sediment and nutrient inputs to the inshore areas facilitated by strong wet seasons in recent years.

The present assessment of coral reef communities continues to highlight areas of the GBR where certain aspects of coral communities appear to be under stress and identifies likely causal environmental factors. For the reefs monitored under MMP it has been shown that the particulate components of marine water quality (suspended sediment and particulate nutrients and carbon) are the most important drivers of inshore coral reef communities (Thompson *et al.* 2010a, Uthicke *et al.* 2010). In the Mackay Whitsunday Region, high levels of fine grained sediments disproportionately expose coral communities to turbidity and sedimentation with indications that this is affecting coral growth and recruitment. Similarly in the Fitzroy Region, repeat flooding of the Fitzroy River appears to have been sufficient to suppress the growth of corals in recent years (Table 6). In the Burdekin Region, coral communities are struggling to recover from severe disturbance in 1998 associated with high temperatures. If proposed links between elevated pollutant loads and susceptibility to thermal bleaching events prove true, this will have serious consequences for inshore reefs into the future. However, should changes in land management practices in the GBR catchments under the Reef Plan and Reef Rescue lead to decreased loads of sediments and nutrients to GBR coastal and inshore waters, we expect to be able to detect associated positive changes in coral reef communities in the longer term.

Acknowledgments

We thank Aaron Anderson, Joe Gioffre Charlotte Johansson, Shawn Smith, Marcus Stowar and Kate Osborne for valuable field assistance. We also thank Terry Done, Johanna Johnson and Katherine Martin for their detailed reviews of the manuscript

5. References

Australian Institute of Marine Science (electronic resource) http://www.aims.gov.au/docs/research/climate-change/coral-bleaching/bleaching-events.html Accessed 12/4/2010

Anon. (2003) Reef Water Quality Protection Plan for catchments adjacent to the Great Barrier Reef World Heritage Area. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 43 pp

Anon. (2009) Reef Water Quality Protection Plan 2009. For the Great Barrier Reef World Heritage Area and adjacent catchments. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 30 pp

Anon. (2010) Paddock to Reef Integrated Monitoring, Modelling and Reporting Program Design (DRAFT). Version 12 February 2010. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 93p

Anthony KRN (1999) Coral suspension feeding on fine particulate matter. Journal of Experimental Marine Biology and Ecology 232:85-106

Anthony KRN (2006) Enhanced energy status of corals on coastal, high-turbidity reefs. Marine Ecology Progress Series 319:111-116

Anthony KRN, Connolly SR (2004) Environmental limits to growth: physiological niche boundaries of corals along turbidity-light gradients. Oceologia 141:373-384

Anthony KRN, Fabricius KE (2000) Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity. Journal of Experimental Marine Biology and Ecology 252:221-253

Anthony KRN, Hoogenboom MO, Connolly SR (2005) Adaptive variation in coral geometry and the optimization of internal colony light climates. Functional Ecology 19:17-26

Australian Natural Resource Atlas (electronic resource),
http://www.anra.gov.au/topics/land/carbon/qld/basin-burdekin-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-fitzroy-river-qld.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-barron-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-mulgrave-russell-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-johnstone-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-tully-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-herbert-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-proserpine-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-oconnell-river.html
http://www.anra.gov.au/topics/land/carbon/qld/basin-pioneer-river.html
(Accessed 20/4/2010)

Ayling A M, Ayling A L (2005) The dynamics of Cairns and Central section fringing reefs: 2005 Unpublished report submitted to the Great Barrier Reef Marine Park Authority, Townsville

Babcock RC, Smith L (2002) Effects of sedimentation on coral settlement and survivorship. In: Kasim Moosa, M.K., Soemodihardjo, S., Nontji, A., Soegiarto, A., Romimohtarto, K., Sukarno, Suharsono (Eds.) Proceedings of the Ninth International Coral Reef Symposium, Bali, Indonesia, October 23–27, 2000. Ministry of Environment, the Indonesian Institute of Sciences and the International Society for Reef Studies, pp. 245–248

Baird AH, Marshall PA (2002) Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef. Marine Ecology Progress Series 237:133-141

Baird AH, Babcock RC, Mundy CP (2003) Habitat selection by larvae influences the depth distribution of six common coral species. Marine Ecology Progress Series 252:289-293

Bellwood DR, Hughes TP, Folke C, Nystrom M (2004) Confronting the coral reef crisis. Nature 429:827-833

Berkelmans R (2002) Time-integrated thermal bleaching thresholds of reefs and their variation on the Great Barrier Reef. Marine Ecology Progress Series 229:73-82

Berkelmans R, De'ath G, Kininmonth S, Skirving WJ (2004) A comparison of the 1998 and 2002 coral bleaching events on the Great /barrier Reef: spatial correlation, patterns, and predictions. Coral Reefs 23:74-83

Birrell CL, McCook LJ, Willis BL (2005) Effects of algal turfs and sediment on coral settlement. Marine Pollution Bulletin 51:408-414

Birrell CL, McCook LJ, Willis BL, Diaz-Pulido GA (2008) Effects of benthic algae on the replenishments of corals and the implications for the resilience of coral reefs. Oceanography and Marine Biology: An Annual Review 46: 25-64

Brinkman R., Wolanski E., Deleersnijder E., McAllister F., Skirving W. (2001) Oceanic inflow from the Coral Sea into the Great barrier Reef. Estuarine, Coastal and Shelf Science 54:655-668

Brodie J, Furnas M (2001) Status of nutrient and sediment inputs from Great Barrier Reef catchments and impacts on the Reef Proceedings of the 2nd National Conference on Aquatic Environments: Sustaining Our Aquatic Environments – Implementing Solutions, Townsville

Brodie JE, McKergow LA, Prosser IP, Furnas MJ, Hughes AO, Hunter H (2003) Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area., James Cook University, Townsville

Brodie J, Binney J, Fabricius K, Gordon I, Hoegh-Guldberg O, Hunter H, O'Reagain P, Pearson R, Quirk M, Thorburn P, Waterhouse J, Webster I, Wilkinson S (2008) Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet). Published by the Reef Water Quality Protection Plan Secretariat, Brisbane

Bruno JF, Sweatman H, Precht WF, Selig ER, Schutte VGW (2009) Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. Ecology 90:1478-1484

Bruno JF, Selig ER, Casey KS, Page CA, Willis BL (2007) Thermal stress and coral cover as drivers of coral disease outbreaks. PLoS Biol 5(6): e124. doi 10.1371/journal.pbio50124

Bureau of Meteorology (electronic resource) http://www.bom.gov.au/hydro/flood/qld/brochures/burdekin/burdekin.shtml and http://www.bom.gov.au/hydro/flood/qld/brochures/fitzroy/fitzroy.shtml. Accessed 10/4/2010

Carpenter KE, Abrar M, Aeby G, Aronson RB, Banks S, Bruckner A, Chiriboga A, Cortés J, Delbeek C, DeVantier L, Edgar GJ, Edwards AJ, Fenner D, Guzmán HM, Hoeksema BW, Hodgson G, Johan O, Licuanan WY, Livingstone SR, Lovell ER, Moore JA, Obura DO, Ochavillo D, Polidoro BA, Precht WF, Quibilan MC, Reboton C, Richards ZT, Rogers AD, Sanciangco J, Sheppard A, Sheppard C, Smith J, Stuart S, Turak E, Veron JEN, Wallace C, Weil E, Wood E (2008) One-third of reef building corals face elevated extinction risk from climate change and local impacts. Science 321:560-563

Cheal AJ, Macneil MA, Cripps E, Emslie M, Jonker M, Schaffelke B, Sweatman H (2010) Coral-macroalgal phase shifts or reef resilience: links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs: DOI 10.1007/s00338-010-0661-y

Cooper TF, Uthicke S, Humphrey C, Fabricius KE (2007) Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Region, central Great Barrier Reef. Estuarine, Coastal and Shelf Science 74:458-470

Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE (2008) Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. Marine and Freshwater Research 59:703-716

De'ath G, Fabricius KE (2008) Water Quality of the Great Barrier Reef: Distributions, Effects on Reef Biota and Trigger Values for the Protection of Ecosystem Health. Research Publication No. 89. Great Barrier Marine Park Authority, Townsville

De'ath G, Fabricius K (2010) Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecological Applications 20:840-850

Dennis B, Taper ML (1994) Density dependence in time series observations of natural populations: estimation and testing. Ecological Monographs 64:205-224

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

Devlin MJ, Waterhouse J, Taylor J, Brodie J (2001) Flood Plumes in the Great Barrier Reef: Spatial and Temporal Patterns in Composition and Distribution. Research Publication No. 68. Great Barrier Reef Marine Park Authority, Townsville

Devlin MJ, McKinna L, Harkness P (2010) Reef Rescue marine Monitoring Program: Terrestrial runoff in the Great Barrier Reef (3.7.2b). Flood Plume Monitoring for 2009/10 Annual Report. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville. 138 pp.

Diaz-Pulido G, McCook LJ, Dove S, Berkelmans R, Roff G, Kline DI, Weeks S, Evans RD, Williamson DH, Hoegh-Guldberg O, (2009) Doom and Boom on a Resilient Reef: Climate Change, Algal Overgrowth and Coral Recovery. PLoS ONE 4(4): e5239. doi:10.1371/journal.pone05239

Diaz-Pulido G, Harii S, McCook LJ, Hoegh-Guldberg O (2010) The impact of benthic algae on the settlement of a reef-building coral. Coral Reefs 29: 203-208

Done TJ (1982) Patterns in the distribution of coral communities across the central Great Barrier Reef. Coral Reefs 1:95-107

Done TJ (1983) Coral zonation, it's nature and significance. In Barnes DJ (ed) Perspectives on coral reefs. Australian Institute of Marine Science, Townsville

Done TJ (1999) Coral Community Adaptability to Environmental Change at the Scales of Regions, Reefs and Reef Zones. American Zoologist 39:66-

Done T, Turak E, Wakeford M, DeVantier L, McDonald A and Fisk D (2007) Decadal changes in turbid-water coral communities at Pandora Reef: loss of resilience or too soon to tell? Coral reefs 26:789–805

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. Marine Pollution Bulletin 50:125-146

Fabricius KE, Death G (2001) Biodiversity on the Great Barrier Reef: Large-scale patterns and turbidity-related local loss of soft coral taxa. In Wolanski E (ed) Biological-Physical Links: Oceanographic processes on the Great Barrier Reef. CRC Press, Boca Raton

Fabricius KE, De'ath G (2004) Identifying ecological change and its causes: A case study on coral reefs. Ecological Applications 14:1448-1465

Fabricius KE, Wolanski E (2000) Rapid smothering of coral reef organisms by muddy marine snow. Estuarine, Costal and Shelf Science 50:115-120

Fabricius KE, Wild C, Wolanski E, Abele D (2003) Effects of transparent exopolymer particles and muddy terrigenous sediments on survival of hard coral recruits. Estuarine, Costal and Shelf Science 57:613-621

Fabricius KE, Death G, McCook L, Turak E, Williams DMcB (2005) Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef. Marine Pollution Bulletin 51:384-396

Falkowski PG, Jokiel PL, Kinzie RA (1990) Irradiance and corals. In Dubinsky Z (ed) Ecosystems of the world 25: Coral Reefs. Elsevier, New York, pp 89-107

Furnas M (2003) Catchments and corals : terrestrial runoff to the Great Barrier Reef. Australian Institute of Marine Science. Townsville

Great Barrier Reef Marine Park Authority (2009) Water Quality Guidelines for the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, Townsville

Haapkylä J, Unsworth R, Flavell M, Bourne D, Schaffelke B, Willis BL (2011) Seasonal rainfall and runoff promote coral disease on an inshore reef of the Great Barrier Reef, Australia. PLoS One. 6(2): e16893. doi:10.1371/journal.pone.0016893

Hallock P (1981) Algal Symbiosis: a mathematical analysis. Marine Biology 62: 249–155.

Hallock P, Lidz BH, Cockey-Burkhard EM, Donnelly KB (2003) Foraminifera as bioindicators in coral reef assessment and monitoring: the FORAM index. Environmental Monitoring and Assessment 81: 221-238

Harrison PL, Wallace CC (1990) Reproduction, dispersal and recruitment of Scleractinian corals. In Dubinsky Z (ed) Ecosystems of the world 25: Coral Reefs. Elsevier, New York, pp 133-202

Hauri C, Fabricius K, Schaffelke B, Humphrey C (2010) Chemical and physical environmental conditions underneath mat- and canopy-forming macroalgae, and the effects on understory corals. PLoS ONE 5(9): e12685. doi:10.1371/journal.pone.0012685

Hoegh-Guldberg O, Mumby PJ, Hooten AJ (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1742

Hughes TP, Baird AH, Dinsdale EA, Motschaniwsky NA, Pratchett MS, Tanner JE, Willis BL (2001) Supply-side ecology works both ways: the link between benthic adults, fecundity, and larval recruits. Ecology 81:2241-2249

Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschaniwskyj N, Pratchett MS, Steneck RS, Willis B (2007) Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change. Current Biology 17:360-365

Ives AR, Dennis B, Cottingham KL, Carpenter SR (2003) Estimating community stability and ecological interactions from time series data. Ecological Monographs 73:301-330

Jones AM, Berkelmans R, van Oppen MJH, Mieog JC, Sinclair W (2008) A community shift in the symbionts of a scleractinian coral following a natural bleaching event: field evidence of acclimatization. Proceedings Royal Society London, Series B: Biological Sciences 275: 1359–1365

Jonker M, Johns K, Osborne, K. (2008) Surveys of benthic reef communities using underwater digital photography and counts of juvenile corals. Long-term Monitoring of the Great Barrier Reef, Standard Operational Procedure Number 10, Australian Institute of Marine Science, Townsville

Kroon F, Kuhnert K, Henderson B, Henderson A, Turner R, Huggins R, Wilkinson S, Abbott B, Brodie J, Joo M (2010) Baseline pollutant loads tot eh Great Barrier Reef. CSIRO: Water for a Healthy Country Flagship Report Series.

Kuffner IB, Walters LJ, Becerro MA, Paul VJ, Ritson-Williams R, Beach KS (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Marine Ecology Progress Series 323:107-117

Lambrechts J, Humphrey C, McKinna L, Gourge O, Fabricius KE, Mehta AJ, Lewis S, Wolanski E (2010) Importance of wave-induced liquefaction in the fine sediment budget of Cleveland Bay, Great Barrier Reef. Estuarine, Coastal and Shelf Science 89:154-162

Larcombe P, Ridd PV, Prytz A, Wilson B (1995) Factors controlling suspended sediment on inner-shelf coral reefs. Townsville, Australia. Coral Reefs 14:163-171

Luick JL, Mason L, Hardy T, Furnas MJ (2007) Circulation in the Great Barrier Reef Lagoon using numerical tracers and in situ data. Continental Shelf Research 27:757-778

Marshall PA, Johnson JE (2007) The Great Barrier Reef and climate change: vulnerability and management implications. In: Johnson JE, Marshall PA (eds) Climate change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Australia, p 774-801

McCook LJ, Jompa J, Diaz-Pulido G (2001) Competition between corals and algae on coral reefs: a review of evidence and mechanisms. Coral Reefs 19: 400-417

Miller IR, Jonker M, Coleman G (2009) Crown-of-thorns starfish and coral surveys using the manta tow and SCUBA Search techniques. Long-term Monitoring of the Great Barrier Reef Standard Operational Procedure Number 9, Edition 3. Australian Institute of Marine Science, Townsville

Mora C (2008) A Clear human footprint in the coral reefs of the Caribbean. Proceedings of the Royal Society B 275:767-773

Negri AP, Webster NS, Hill RT, Heyward AJ (2002) Metamorphosis of broadcast spawning corals in response to bacteria isolated from crustose algae. Marine Ecology Progress Series. 223:121-131

Negri AP, Flores F, Röthig T, Uthicke S (2011) Herbicides increase the vulnerability of corals to rising sea surface temperature. Limnology and Oceanography. 56:471-485

Nobes K, Uthicke S (2008) Benthic Foraminifera of the Great Barrier Reef: A guide to species potentially useful as Water Quality Indicators. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (44pp.). available at: http://www.rrrc.org.au/publications/downloads/371-AIMS-Nobes-et-al-2008-Benthic-Foraminifera-of-the-GBR.pdf

Reef & Rainforest Research Centre Ltd (2010) *Reef Rescue Marine Monitoring Program: Quality Assurance/Quality Control Methods and Procedures Manual.* Report prepared for the Great Barrier Reef Marine Park Authority. Reef & Rainforest Research Centre Ltd, Cairns

Renema W, Hoeksema BW, Van Hinte JE (2001) Larger benthic Foraminifera and their distribution patterns on the Spermonde shelf, South Sulawesi. Zoologische Verhandelingen 334: 115-150.

Rogers CS (1990) Responses of coral reefs and reef organisms to sedimentation. Marine Ecology progress Series 62:185-202

Schaffelke B, Thompson A, Carleton J, Cripps E, Davidson J, Doyle J, Furnas M, Gunn K, Neale S, Skuza M, Uthicke S, Wright M, Zagorskis I (2008) Water Quality and Ecosystem Monitoring Final Report for 2007/2008. Australian Institute of Marine Science, Townsville. http://www.gbrmpa.gov.au/corp_site/info_services/science_management/marine_monitoring_program

Schaffelke B, Thompson A, Carleton J, Davidson J, Doyle J, Furnas M, Gunn K, Skuza M, Wright M, Zagorskis I (2009) Reef Rescue Marine Monitoring Program-Final Report of AIMS Activities 2008/2009. Australian Institute of Marine Science, Townsville. http://www.gbrmpa.gov.au/corp_site/info_services/science_management/marine_monitoring_program

Schaffelke B, Carleton J, Doyle J, Furnas M, Gunn K, Skuza M, Wright M, Zagorskis I (2010) Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities – Inshore water quality monitoring 2009/10. Australian Institute of Marine Science, Townsville. http://www.gbrmpa.gov.au/corp_site/info_services/science_management/marine_monitoring_program

Smith LD (2008) Resilience of coral communities on an isolated system of reefs following catastrophic mass-bleaching. Coral Reefs 27:197-205

Stafford-Smith MG, Ormond RFG (1992) Sediment-rejection Mechanisms of 42 Species of Australian Scleractinian Corals. Australian Journal of Marine and Freshwater Research 43:683-705

Steffen W (2009) Climate change 2009: faster change and more serious risks. Report to the Australian Government, Department of Climate Change

Sweatman H, Burgess S, Cheal AJ, Coleman G, Delean S, Emslie M, Miller I, Osborne K, McDonald A, Thompson A (2005) Long-term monitoring of the Great Barrier Reef. Status Report No.7. CD-Rom. Australian Institute of Marine Science, Townsville

Sweatman H, Thompson A, Delean S, Davidson J, Neale S (2007) Status of inshore reefs of the Great Barrier Reef 2004. Australian Institute of Marine Science, Townsville

Thompson A, Dolman A (2010) Coral bleaching: one disturbance too many for inshore reefs of the Great Barrier Reef. Coral Reefs 29:637-648

Thompson A, Schaffelke B, De'ath G, Cripps E, Sweatman H (2010)a Water Quality and Ecosystem Monitoring Programme-Reef Water Quality Protection Plan. Synthesis and spatial analysis of inshore monitoring data 2005-08. Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville

Thompson A, Davidson J, Schaffelke B, Sweatman H (2010)b Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities – Inshore coral reef monitoring 2009/10. Report for Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville.

Todd PA (2008) Morphological plasticity in Scleractinian corals. Biological Reviews 83:315-337

Uthicke S, Altenrath C (2010) Water column nutrients control growth and C : N ratios of symbiont-bearing benthic foraminifera on the Great Barrier Reef, Australia. Limnology and Oceanography 55: 1681-1669

Uthicke S, Nobes K (2008) Benthic foraminifera as ecological indicators for water quality on the Great Barrier Reef. Estuarine, Costal and Shelf Science 78:763-773

Uthicke S, Thompson A, Schaffelke B (2010) Effectiveness of benthic foraminiferal and coral assemblages as water quality indicators on inshore reefs of the Great Barrier Reef, Australia. Coral Reefs 29:209-225

van Woesik R (1991) Immediate Impact of the January 1991 floods on the Coral Assemblages of the Keppel Islands. Research Publication No. 23. Great Barrier Reef Marine Park Authority, Townsville

van Woesik R, Done TJ (1997) Coral communities and reef growth in the southern Great Barrier Reef. Coral Reefs 16:103-115

van Woesik R, De Vantier LM, Glazebrook JS (1995) effects of Cyclone Joy on nearshore coral communities of the Great Barrier Reef. Marine Ecology Progress Series 128:261-270 van Woesik R, Tomascik T, Blake S (1999) Coral assemblages and physico-chemical characteristics of the Whitsunday Islands: evidence of recent community changes. Marine and Freshwater Research 50:427-440

Voss JD, Richardson LL (2006) Nutrient enrichment enhances black band disease progression in corals. Coral Reefs 25: 569-576

Wakeford M, Done T, Johnson C (2008) Decadal trends in a coral community and evidence of changed disturbance regime. Coral Reefs 27:1-13

Ward S, Harrison P, Hoegh-Guldberg O (2002) Coral bleaching reduces reproduction of scleractinian corals and increases susceptibility to future stress. In: Moosa MK, Soemodihardjo S, Soegiarto A, Romimohtarto K, Nontji A, Suharsono S (eds) Proc. 9th International Coral Reef Symposium 2:1123-1128

Wismer S, Hoey AS, Bellwood DR (2009) Cross-shelf benthic community structure on the Great Barrier Reef: relationships between macroalgal cover and herbivore biomass. Marine Ecology Progress Series 376:45-54

Wolanski E, Fabricius KE, Cooper TF, Humphrey C (2008) Wet season fine sediment dynamics on the inner shelf of the Great Barrier Reef. Estuarine, Coastal and Shelf Science 77:755-762

Wooldridge S, Done T (2004) Learning to predict large-scale coral bleaching from past events: A Bayesian approach using remotely sensed data, in-situ data, and environmental proxies. Coral Reefs 23: 96–108

Wooldridge SA (2009) Water quality and coral bleaching thresholds: formalising the linkage for the inshore reefs of the Great Barrier Reef (Australia). Marine Pollution Bulletin 58:745-751

Appendix 1: Detailed data tables

Tables A1-1a-d Sediment analysis results for reefs sampled between 2006 and 2010.

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

Region	Catchment	Reef	2006	2007	2008	2009	2010
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
		Snapper Is South	8.73		7.25	7.28	17.70
	Johnstone Russell-Mulgrave	Fitzroy Is West	4.07	9.04	9.56	4.60	17.41
		Fitzroy Is East	4.77		0.57		5.22
		High Is West	9.95	6.20	18.74	8.14	16.01
		High Is East	8.69	0.58		0	
		Frankland Islands West	35.27	25.30	36.41	23.11	43.62
		Frankland Islands East	17.85	3.12		3.26	
	Herbert Tully	North Barnard Islands	12.27	5.93		5.81	
		King	3.27		1.64		7.43
		Dunk Is North	5.03	6.65	14.86	5.85	20.36
		Dunk Is South	12.27		5.28		6.90
Burdekin	Burdekin	Pelorus and Orpheus Islands West	5.76	3.97	3.89	5.35	7.54
		Orpheus Is East	1.60		0		2.04
		Lady Elliot	14.50		12.57		16.38
		Pandora	3.43	2.36	2.98	1.85	6.58
		Havannah Is	7.62	7.45		2.99	
		Geoffrey Bay	13.16	9.76	7.97	4.12	13.84
		Middle Reef	80.48	54.92		30.0	
Mackay Whitsunday	Proserpine	Double Cone Is	14.12	34.59	28.52	33.33	60.17
		Hook Is	36.66		36.36		34.91
		Daydream Is	61.56	72.46	72.39	38.64	74.43
		Shute and Tancred Islands	38.07		25.60		63.77
		Dent Is	58.15	52.93		56.19	
		Pine Is	59.53	44.47	58.21	40.57	78.36
		Seaforth Is	36.43	41.37		37.39	
Fitzroy	Fitzroy	North Keppel Is	14.38	8.94		9.15	
		Barren Is	2.62	2.37	2.82	4.24	4.84
		Middle Is			4.69		12.93
		Humpy and Halfway Islands	3.26	3.14	5.74	5.45	14.94
		Pelican Is	2.42	2.55	0	1.69	5.59
		Peak Is	2.51		5.16		13.83

Table AI-1(b) Organic carbon content of sediments. Values are the proportion (%) of the total sediment sample by weight.

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

Table AI-1(c) Total nitrogen content of sediments. Values are the proportion of the total sediment sample by weight expressed as parts per thousand.

Region	Catchment	Reef	2006	2007	2008	2009	2010
Wet Tropics	Barron Daintree	Cape Tribulation Nth NORTH	38.8				
		Cape Tribulation Mid MIDDLE	39.2				
		Cape Tribulation Sth SOUTH	41.6				
		Snapper Is North	67.9		50.8	79.1	55.7
		Snapper Is South	14.6		44.6	45.7	36.7
	Johnstone Russell-Mulgrave	Fitzroy Is West	25.6	41.6	36.7	31.0	36.4
		Fitzroy Is East	21.1		24.0		31.6
		Frankland Group West	82.0	81.4	70.0	78.7	77.9
		Frankland Group East	20.3	33.5		33.6	
		High Is West	42.9	38.1	43.6	46.8	40.1
		High Is East	18.0	30.3		25.6	
	Herbert Tully	North Barnard Group	37.4	32.3		37.7	
		King	28.1		22.5		29.9
		Dunk Is North	28.8	31.6	29.3	41.6	34.2
		Dunk Is South	33.4		33.1		26.6
Burdekin	Burdekin	Pelorus and Orpheus Islands West	34.5	30.9	31.2	34.6	34.7
		Orpheus Is East	18.4		28.2		30.7
		Lady Elliot	31.8		20.9		26.6
		Pandora	30.4	32.5	33.2	26.5	36.7
		Havannah Is	23.4	37.0		36.4	
		Geoffrey Bay	40.9	41.9	40.3	31.4	34.8
		Middle Reef	115.7	75.6		108.6	
Mackay Whitsunday	Proserpine	Double Cone Is	43.9	92.0	64.0	67.7	80.5
		Hook Is	46.6		57.4		53.4
		Daydream Is	86.0	102.5	102.2	120.1	88.3
		Dent Is	79.2	88.6		87.2	
		Shute and Tancred Islands	66.3		72.0		92.1
		Pine Is	88.3	85.6	90.6	77.8	82.9
		Seaforth Is	57.5	75.0		65.7	
Fitzroy	Fitzroy	North Keppel Is	30.0	52.8		76.4	
		Barren Is	38.3	52.0	51.2	41.4	54.7
		Middle Is			36.5		15.3
		Humpy and Halfway Islands	41.0	35.2	53.2	36.9	42.3
		Pelican Is	32.9	31.6	43.3	40.1	37.9
		Peak Is	34.6		51.9		41.9

Table AI-1 (d) Inorganic carbon content of sediments. Values are the proportion (%) of the total sediment sample by weight.

Region	Catchment	Reef	2006	2007	2008	2009	2010
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
		Snapper Is South	9.57		7.49	9.60	10.02
	Johnstone Russell-Mulgrave	Fitzroy Is West	9.80	9.47	9.35	10.26	9.93
		Fitzroy Is East	9.76		9.58		10.02
		High Is West	9.45	9.91	8.90	9.77	10.12
		High Is East	10.09	10.58		10.76	
		Frankland Islands West	8.12	8.39	7.63	8.64	8.27
		Frankland Islands East	10.62	10.37		10.33	
	Herbert Tully	North Barnard Islands	8.95	9.43		9.47	
		King	9.30		9.12		9.77
		Dunk Is North	8.47	8.65	7.15	8.64	8.74
		Dunk Is South	9.60		9.71		10.19
Burdekin	Burdekin	Pelorus and Orpheus Islands West	10.17	10.57	10.10	10.06	10.43
		Orpheus Is East	10.48		10.58		10.90
		Lady Elliot	3.82		5.08		5.42
		Pandora	10.56	10.55	10.27	10.41	10.63
		Havannah Is	10.19	10.11		10.22	
		Geoffrey Bay	7.88	8.40	8.36	9.17	9.27
		Middle Reef	2	4.70		4.75	
Mackay Whitsunday	Proserpine	Double Cone Is	9.31	7.49	7.61	7.25	6.62
		Hook Is	8.73		8.27		9.12
		Daydream Is	6.01	4.29	3.93	4.47	4.97
		Shute and Tancred Islands	7.58		7.59		5.69
		Dent Is	6.69	6.42		6.27	
		Pine Is	5.37	5.62	4.97	5.86	4.48
		Seaforth Is	8.40	7.79		7.82	
Fitzroy	Fitzroy	North Keppel Is	5.68	8.70		9.05	
		Barren Is	9.64	9.81	9.49	9.39	9.76
		Middle Is			3.74		1.93
		Humpy and Halfway Islands	8.68	8.76	8.73	8.86	8.68
		Pelican Is	8.03	7.42	8.21	7.80	9.38
		Peak Is	6.76		8.38		7.48

Table A1-2 Known disturbances to coral communities at Reef Rescue 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 1998	Bleaching 2002	Other recorded disturbances
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)
		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 (75% manta tow data)
		Fitzroy Is (West)	0.92 (13%)	0.95 (15%)	Crown-of-thorns 1999-2000 (78%), Cyclone Hamish 2009 (stalled recovery trajectory)
		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)
		Frankland Group (West)	0.93 (44%)	0.80 (Nil)	Unknown though likely crown-of-thorns 2000 (35%)
		High Is (East)	0.93	0.80	
		High Is (West)	0.93	0.80	Cyclone Larry 2006 (25% at 5m)
	Herbert Tully	North Barnard Group	0.93	0.80	Cyclone Larry 2006 (95% at 2m , 86% at 5m)
		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)
		Dunk Is (South)	0.93	0.85	Cyclone Larry 2006 (12% at 2m , 18% 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 A1-2 continued.

Region	Catchment	Reef	Bleaching 1998	Bleaching 2002	Bleaching 2006	Other recorded disturbances
Burdekin	Burdekin	Orpheus Is (East)	0.93	0.80		Cyclone Larry 2006 (22% at 2m, 40% 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)
		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)
		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)
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		
		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)	
		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),
		Pelican Is	1	1	17%, 5m	Flood /Storm 2008 (23% at 2m, 2% at 5m), Flood/Storm (20% at 2m)
		Peak Is	1	1		Flood 2008 (17% at 2m)

Table A1-3 Composition of coral reef communities - hard coral families (% cover) 2010

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Wet Tropics	Barron Daintree	Snapper Is North	2	49.28	0.04	0.04	0	0	2.17	0.54	0.21	0.08	0.54	0	0.50	0.13	0.50	0
			5	11.94	16.50	0	0	0	1.94	1	1.56	0.06	0.31	2.75	2.44	14.81	0	0.13
		Snapper Is South	2	22.06	0.25	0	0.13	0	1.42	0.21	0	0.04	1.04	0	1.04	20.22	0.33	0.04
			5	7.13	4.06	0	0.25	0	8.27	1.13	0.19	0.25	0.38	0.13	0.06	30.90	1.13	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	32.31	0.06	0	0	0	1.50	0.13	0.19	0.69	1.13	0	1.13	8.06	0	0
			5	11.38	0.13	0	0.06	0.13	2.25	0.81	0.31	1.63	1.56	0.50	0.88	11.25	0.25	0
		Fitzroy is East	2	29.94	0	0	0	0	2.19	0	0	0.13	0	0	1.19	3.56	0.13	0
			5	32.69	0.31	0	0.13	0.06	3.63	0.19	0.56	0.50	0.88	0.06	5.50	5.06	0.25	0
		High Is West	2	11.75	0.06	0	0	0	1.50	0.63	0.06	0.38	0.31	0.25	1.81	42.19	0	0
			5	3.13	1.06	0	0	0.31	1.88	0.69	0.06	0.19	0.81	0.38	0.25	19.50	0	0
		Frankland Group West	2	6.63	4.25	0	0	0	0.19	0.31	0.06	0.13	0.31	0	0.81	29.88	0	0
			5	0.13	2.19	0	0	0	0.19	0.19	0	0	0.06	0	0.13	59.75	0	0
	Herbert Tully	King Reef	2	0.38	0	0	0.63	0	0.69	0	0	0	0	0	0	0.06	0.06	0
			5	1.44	0	0.06	7.88	0	3.38	0	0.13	0.25	0	0.38	0	1.44	0.06	0
		Dunk Is North	2	15.63	0	0	2.06	0.06	3.25	0	0.63	0.06	0.06	0	1.25	0.75	0.31	0.06
			5	13.04	0.13	0	2.77	0.06	4.21	0	0.06	0.56	0.06	0.19	1.19	1.25	0.06	0.06
		Dunk Is South	2	10.63	0.88	0	1.19	0.06	4.31	0	0.44	0.19	0.81	0	0.19	4.81	0.25	0
			5	5.94	4.31	0.06	6.13	0	9.50	0.44	6.56	0.50	0.25	6.88	1	2.38	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	1.69	0	0	0	0	0.25	0.06	0	0.19	0.06	0	0.88	0.75	0	0
			5	2.81	0.13	0	0	0	0.75	0.38	0	0.44	0	0.31	0.38	3.13	0.06	0
		Orpheus Is East	2	6.56	0.56	0	0	0	0.81	0	0	0.06	0.06	0	0	1.06	0.56	0
			5	4.06	0	0	0.13	0	1.75	0	0.38	0.81	0.38	0.06	0.25	2	0	0
		Lady Elliot Reef	2	13.31	1.63	0	0.06	0	0.63	6.06	0	0.31	2.88	0.38	0	0.88	0	0
			5	2.31	3	0	0.13	0.06	3.44	2.13	1	2.25	14.31	6.75	0.19	10.44	0.13	0
		Pandora	2	1	0	0	0	0	1.13	0.06	0	0	0.06	0	0	1.31	0.31	0
			5	1.31	0	0	0	0	5.56	0.44	0.69	0.13	0.19	1.56	0	0.06	0	0
		Geoffrey Bay	2	7.50	0.44	0	1.81	0	2.44	0	0.56	0	0.19	0	0	0.69	0.38	0
			5	7.63	2.88	0	2.19	0.06	5.56	1.81	2.38	0.31	0.81	1.31	0.06	2.50	0	0.06

Table A1-3 Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Mackay Whitsunday	Proserpine	Double Cone Is	2	19.06	0.19	0	1.31	0	1.25	0.25	1.56	1.25	2.75	0.94	0.06	4.44	0.06	0
			5	3.50	1.69	0	0.25	0.31	1.31	0.13	0.50	2.56	1.81	1.75	0.13	47.06	0	0
		Hook Is	2	4.63	0.19	0	2.07	0.06	2.38	0.13	0.13	0.19	0.06	0.69	0.38	6.83	0	0.13
			5	3.25	1.75	0	0.31	0	4.13	0.13	0	0.56	0.13	0.50	0.06	14.89	0	0.31
		Daydream Is	2	17.81	0	0	0	0	0.25	0.06	0	0.06	0	0.50	0.13	0.50	0	0
			5	19.70	0.38	0	0	0.06	1.38	0.19	0	0.38	0	0.94	0.19	1.07	0	0.06
		Shute Is & Tancred Is	2	24.84	0.56	0	0	0	1.06	0.56	0.06	1.25	0.38	1	0.38	5.19	0	0.06
			5	8.32	0.44	0	0.44	0.13	2.01	0.44	0.44	1.70	0.06	4.69	1.19	3.88	0	0.31
		Pine Is	2	8.88	0.63	0	0	0.44	1	0.94	0.94	0.63	19.63	2.56	0.06	3.88	0.06	0.06
			5	6.25	3.56	0	0.13	0.63	1.25	2.63	0.44	2.44	7.75	9.56	0.06	6	0	0.13
Fitzroy	Fitzroy	Middle Is	2	28.88	0	0	0	0	0.63	0	0	0	0	0	0	0	0	0
			5	31.13	0	0	0	0	0.63	0	0	0	0	0	0.50	0	0.13	0
		Barren Is	2	27	0.25	0	0.06	0	1.06	0	0.31	0.56	0	0	0.88	0	0.19	0
			5	66.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Humpy Is and Halfway Is	2	51.88	0	0	0	0	0.25	0	0	0	0	0	0.19	0.06	0	0
			5	30.06	0	0	0.19	0	0.38	0	0	0.13	0	0	0	0.19	0.06	0
		Pelican Is	2	32.31	0	0	0.25	0	1.94	0	0	0.19	0	0.06	1.06	0.44	1.44	0
			5	0.38	0	0	2.88	0	11.63	0	1.31	0.81	0	0.06	0.25	7.38	3.19	0
		Peak Is	2	3.38	0	0	0.25	0	7.63	0	0.19	0.50	0	0	1	0.88	3.06	0
			5	0.50	0	0	1.56	0	10	0	2.06	0	0	0.69	0.56	2.56	10.44	0

Table A1-4 Composition of coral reef communities - common soft coral families (% cover) 2010

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Wet Tropics	Barron Daintree	Snapper Is North	2	0.54	2.71	13.38	0	0	0	0	0	0
			5	0.31	0.44	0.06	0	0	0.06	0	0	0
		Snapper Is South	2	2.46	0.50	0	0	0	1.54	0	0.04	0
			5	0.50	9.50	0	0.13	0	5.38	0	0	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	34.56	0.13	0	0	0.06	0	0	0	0
			5	35.56	0	0	0	0	0	0	0	0
		Fitzroy Is East	2	2.63	0.50	2.31	0	0	0	0.19	0	1.06
			5	4.75	2.31	0.25	0	0	0	0.06	0	0
		High Is West	2	3.81	0	0	0	0	3.31	0	0	0
			5	1.38	1.06	0	0	0	1	0	0	0
		Frankland Group West	2	7.31	0	9.88	0	0	0.19	0.31	0	0
			5	1	0	0.06	0	0	0	0	0	0
	Herbert Tully	King Reef	2	0	0	0	0	0	0	0	0	0
			5	0.06	0.13	0	0	0	0	0	0	0
		Dunk Is North	2	0.13	0.06	0.06	0	0	0	0	0	0
			5	0.19	0	0	0.06	0.44	0	0	0	0
		Dunk Is South	2	0.13	1.94	0	0	0	0	0	0	0
			5	0.13	1.94	0	0	0	0	0	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	15.88	0.13	0.38	0	0	0	0.38	0	0.06
			5	18.88	2	0.44	0	0.13	0	0.56	0	0
		Orpheus Is East	2	36.94	0	0.31	0	0	0	0	0	0
			5	25.69	0.13	0.06	0	0	0.06	0	0	0.50
		Lady Elliot Reef	2	0	0	0	0	0	0	0	0	0
			5	0.06	0	0	0	0	0	0	0	0
		Pandora	2	0	0	0	0	0	0	0	0	0
			5	0.19	0	0.13	0	0	0	0	0	0
		Geoffrey Bay	2	0	0.19	0	0	0	0	0	0	0
			5	0.44	0.25	0	0.06	0	0	0	0	0

Table A1-4 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	8.31	5.69	0	0	0	0	0	0	0
			5	3.81	2.50	0	0	0	0	0	0	0
		Hook Is	2	22.30	3.50	0	0	0	0	0.19	0.13	0.06
			5	15.64	1.31	0	0	0.06	0	0	0	0
		Daydream Is	2	7.06	0	0	0	0	0	0	0	0
			5	2.07	0	0	0	0	0	0.13	0	0
		Shute Is & Tancred Is	2	19.04	0	0	0	0	0	0.31	0	0.25
			5	10.28	0.31	0	0	0	0	0.56	0	0
		Pine Is	2	0.44	1.25	0	0	0	0	0	0	0
			5	3.06	0.19	0	0	0	0	0.06	0	0
Fitzroy	Fitzroy	Middle Is	2	0.31	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0
		Barren Is	2	0.81	0.06	0	0	0	0	0	0	4.88
			5	0	0	0	0	0	0	0	0	1.25
		Humpy Is and Halfway Is	2	0.19	0	0	0	0	0	0	0	4.88
			5	0.88	0	0	0	0	0	0	0	0
		Pelican Is	2	8.88	0	0	0	0	0	0.31	0.06	0.13
			5	7.44	0	0	0.06	0.56	0	0.25	0.13	0.19
		Peak Is	2	1.75	0	0	0	0.19	0	0.13	0.13	0.06
			5	3.56	0	0	0.06	0.94	0	0.25	0	0.31

Table A1-5 Composition of coral reef communities - common macroalgae genera and families (% cover) 2010. 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	Unknown Family
Wet Tropics	Barron Daintree	Snapper Is North	2	2.04	0.04	2.13	2.50	3.13	0	0	0.13	0	0	0	0	0	0
			5	0	0	0	0.06	0.38	0	0	0	0.44	0.06	0	0	0	0
		Snapper Is South	2	0	0	0.04	0.04	0.25	0	0	0.50	0	0	0	0	0	0
			5	0	0	0.94	0.06	2.01	0	0	0	0	0	0	0	0.06	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	0	0.25	0.06	0.06	0.19	0	0.13	0.13	0	0	0	0	0	0
			5	0	0.38	0	0.13	0.63	0	0.19	0.06	0	0	0	0	0	0
		Fitzroy Is East	2	0	0.06	0	0.06	0.25	0	0	0	0	0	0	0	0	0
			5	0	0	0	0.06	0.13	0	0	0	0	0	0	0	0	0
		High Is West	2	0	0	0.69	0	3.75	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	1.31	0	0	0.06	0	0	0	0	0	0
		Frankland Group West	2	0	0.75	1.06	0	5	0	0	0	0.13	0	0	0	0	0.38
			5	0	0.31	0	0.38	12.56	0.06	0.56	0	0	0	0	0	0.06	0.13
	Herbert Tully	King Reef		0	0.19	0	1.06	2.75	0	0	0.81	0.94	1.25	0.06	42.44	0.50	1.31
				0	0.19	0	0.88	8.06	0	0	0.06	0	0.56	0	18.13	0.19	0.81
		Dunk Is North	2	0	0.06	0	0.50	3	0	0.06	0.56	3.56	1.94	0.06	11.88	0	0.13
			5	0	0.19	0	0	0.56	0	0	0.06	1.31	0.88	0	0.75	0.38	0.06
		Dunk Is South	2	0	0.06	0.19	0.56	2.69	0	0	0.38	0.94	10	1.31	9.06	0.38	0.25
			5	0	0.25	0	0	0.88	0	0	0	0.06	12.56	0.13	0.13	0.06	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06
			5	0	0	0	0	0.19	0	0	0.13	0	0.06	0	0	0	0.06
		Orpheus Is East	2	0	0.06	0	0	0.38	0	0	0.06	0	0	0	0	0	0
			5	0	0	0	0	0.31	0	0	0.25	0	0.06	0	0	0	0
		Lady Elliot Reef	2	0	0.25	15.7	0	8.38	0.31	0	0	1.94	0	0	0	0.06	1.25
			5	0	0.25	0	0	0.56	0	0	0	1.25	0	0	0	0	0
		Pandora Reef	2	0.44	0	0	0	1.50	0	0	0	1.81	9.75	0.94	13.19	0.25	1.19
			5	1	0.06	0	0	0.31	0	0	0.13	12.44	10.75	1	2.06	0.06	0.06
		Geoffrey Bay	2	0	0.13	0.38	0.06	2.50	0.06	0	0.06	9.19	13.31	0.13	10.06	0.13	0.06
			5	0	1.19	0	0.06	1	0.19	0	0	6.69	2.13	0.06	9.25	0.19	0

Table A1-5 Continued

Region	Catchment	Reef	Depth	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Rhodophyta	Other Rhodophyta	*Caulerpa*	*Halimeda*	Other Chlorophyta	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	Other Phaeophyta	Unknown Family
Mackay Whitsunday	Proserpine	Double Cone Is	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
		Hook Is	2	0	0	0.13	0	0	0	0	1.44	0	0	0	0	0	0
			5	0	0.06	0	0	0	0	0	0.63	0	0.13	0	0	0	0
		Daydream Is	2	0	0	0	0	0	0	0	0	0	0.56	0	0	0	0
			5	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
		Shute Is & Tancred Is	2	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0.06
		Pine Is	2	0	0.69	0	0	0.81	0	0.06	0	0	4	0	10.88	0	0
			5	0	0.56	0	0	0.81	0	0.13	0.13	0	1.88	0	0	0	0.06
Fitzroy	Fitzroy	Middle Is	2	0	5.19	0	0	0.31	0	0	0	0	9.44	0	0	0	0
			5	0	1.38	0	0	0	0	0	0	0	1.25	0	0	0	0
		Barren Is	2	0	0.31	0	0	0.69	0	0	0	0	2.06	0	0	0	0
			5	0	0.56	0	0	0.25	0	0	0	0	5.06	0	0	0	0
		Humpy Is and Halfway Is	2	0	1.25	0	0	0.63	0	0	0	0	5.06	0	0	0	0.19
			5	0	3.63	0	0	0.44	0	0	0.06	0.13	3.63	0	0	0	0.38
		Pelican Is	2	0	0.81	0	1.19	0.88	0	0	0.06	0.13	1.44	0.13	0.44	0	0.13
			5	0	0.31	0	0.19	0.50	0	0	0	0	0.19	0	0	0	0.06
		Peak Is	2	0	0.13	0	1.44	10.56	0	0.38	0.75	0	1.94	0.25	0.75	0.13	0.56
			5	0	0.31	0	0.44	3	0	0.94	0.19	0.13	0.06	0	0	0.06	0.38

Table A1-6 Composition of juvenile hard coral communities - common families (count per 34m^2) 2010

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Wet Tropics	Barron Daintree	Snapper Is North	2	35	0.3	0	0	0	2.7	13.3	0.3	0	1.7	0	1	1.7	4
			5	21	2.5	1	3	0	22.5	9	2.5	0.5	8	2.5	8	5.5	0
		Snapper Is South	2	179.3	0	0	0.7	0	23.7	6	0	0.7	8.7	0	24.3	18.3	3
			5	9	1	0	0	0	4	4.5	2	0.5	4	1	0	3	1.5
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	74.5	0.5	0	0	0.5	13.5	5.5	2.5	2.5	4.5	0.5	10	14.5	0
			5	54	2.5	0.5	1.5	2.5	13	20.5	4	6.5	12.5	3.5	9	35.5	0
		Fitzroy Is East	2	39	0	0	0.5	0.5	40.5	0	1.5	3.5	1	0	4	17.5	1.5
			5	33	0	0	1.5	1	27.5	6.5	2	12.5	11	1	20	17.5	2
		High Is West	2	15.5	0.5	0	2.5	0	8.5	3.5	1	2.5	2	1	5.5	10	1
			5	12.5	4	0	5	0	19.5	5.5	1.5	4	10	3	2	20	0.5
		Frankland Group West	2	11	4.5	0	0	0.5	5.5	27.5	1.5	1	16.5	1	3.5	36	2.5
			5	2.5	0.5	0	0	0.5	0	10	0	1	3.5	0	0	26	0
	Herbert Tully	King Reef	2	6	0	0	5	0	13.5	0	0.5	0	0.5	0	0	11.5	1.5
			5	8.5	0	0	116.5	1.5	73	2	0.5	1	0	3.5	0	23.5	0.5
		Dunk Is North	2	86	0	0	126	0.5	85.5	0.5	0	3.5	3.5	0	15.5	12	11.5
			5	71.5	0.5	0	340	1.5	94	0.5	2	1	5	0.5	18.5	23.5	17.5
		Dunk Is South	2	47.5	0	0	8.5	0.5	77.5	1.5	3.5	4	9.5	0.5	0.5	18	4
			5	57.5	3	0	27	0	53	8.5	3	7	7.5	6	1	34.5	5
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	37.5	4	0	1.5	0	44	5.5	1	8	7.5	4.5	20.5	6.5	1
			5	27.5	7.5	0.5	2	0	65.5	9.5	1.5	21.5	7	22	7	23	4.5
		Orpheus Is East	2	49	0.5	0	0	0	31	0	0.5	1	1.5	0	0.5	8	0.5
			5	36	0	0.5	0.5	0	27	1.5	1	8	7	1	4.5	14	0
		Lady Elliot Reef	2	158.5	0.5	0.5	86	0	9	187.5	2	0	6.5	0	0	25	1
			5	13.5	1.5	0	19.5	0	39	10	1.5	2	3	3	0	13.5	2.5
		Pandora Reef	2	10.5	0	0	0.5	0	5.5	1.5	0.5	0	1	0.5	1	4	1
			5	21	0	0	2.5	0	11	39.5	1	2.5	7.5	1	0.5	6	0
		Geoffrey Bay	2	46	4.5	0	22	0	74	4.5	1.5	0.5	10	0	0	29	6.5
			5	30	6.5	0.5	19	1	113	17	7.5	16	4	15	1.5	50	2.5

Table A1-6 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	24	0	0	3	0.5	14	3.5	4	5	2.5	1	3	13.5	0
			5	4.5	1.5	0	1	2.5	5	2	2	2	3	3.5	1	17.5	0
		Hook Is	2	18	1	0.5	2	2	35.5	2	0.5	11	1	2.5	9	18.5	0.5
			5	8.5	2.5	0	1	1.5	28.5	0.5	1	12	2	9	2	19	0.5
		Daydream Is	2	8.5	0	0	0	0	9	4	3.5	11	0.5	4	3.5	4	0
			5	17	3	0	0	0.5	23	3	4	10	0.5	8.5	1	5	0.5
		Shute Is and Tancred Is	2	36	1	0	2.5	1	48.5	5.5	3	16	1.5	7	10.5	8.5	0
			5	21.5	2	0	4	0.5	38	5	2	7	1	8	1.5	5.5	0
		Pine Is	2	31	1	1	0.5	0.5	7	13.5	2	8.5	5.5	4.5	3.5	22.5	0
			5	14.5	4	0	6.5	3	12.5	8	2.5	12.5	1	8.5	0	14	0
Fitzroy	Fitzroy	Middle Is	2	18	0	0	0	0	1	40.5	0	0	0	0	2.5	0.5	0
			5	18	0	0	1	0	0	12	0	0	0	0	2	0	2
		Barren Is	2	50	0.5	0	20	0	31	0.5	0	0	0	0	15	0	2.5
			5	6	0	0	0	0	0	0	0	0	0	0	1	0	0.5
		Humpy Is and Halfway Is	2	10.5	0	0	1.5	0	10.5	1.5	1.5	1.5	0	0	3	4.5	0
			5	5.5	0	0	2.5	0	16	1	0	0.5	0	0	0	8	0
		Pelican Is	2	53.5	0	0	4.5	0.5	17.5	0	0	23.5	0	0	4.5	7.5	0
			5	0	0	0	10.5	0	31	0	1.5	8.5	0	0.5	0.5	34.5	6.5
		Peak Is	2	4	0	0	5	0	6	0	0	5	0	0	0.5	9	4.5
			5	2	0	0	21.5	0	18	0	1.5	3	0	0	0	31.5	2.5

Table A1-7 Composition of juvenile soft coral communities - common families (count per 34m²) 2010

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Nephtheidae	Xeniidae
Wet Tropics	Barron Daintree	Snapper Is North	2	0.3	0	0	0	0
			5	1	2	0	0	0
		Snapper Is South	2	5.7	0	0	0	0
			5	1	0.5	0	0	0
	Johnstone Russell-Mulgrave	Fitzroy Is West	2	69	2	0	1.5	0
			5	67.5	0.5	0	0	0.5
		Fitzroy Is East	2	28	2	8.5	2	52
			5	26	3.5	0.5	1	1
		High Is West	2	14.5	0	0	0	0
			5	14	2.5	0	0.5	0
		Frankland Group West	2	13	0	19	1.5	2
			5	2	0	4	0	0
	Herbert Tully	King Reef	2	0	0	0	0	0
			5	6.5	1.5	0	1	0
		Dunk Is North	2	23	0.5	0	0	0
			5	21.5	0	0	0.5	0.5
		Dunk Is South	2	4	6.5	2.5	0	0
			5	13	3.5	0.5	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	72	6.5	9.5	9.5	2.5
			5	74	5	2	194	1
		Orpheus Is East	2	23	1.5	0.5	0	0
			5	43.5	2	1	0.5	18.5
		Lady Elliot Reef	2	0	0	0	0	0
			5	2	0	0	0	0.5
		Pandora	2	0.5	0	2	0	0
			5	1.5	0	5	0	0
		Geoffrey Bay	2	6.5	6.5	3	0	0
			5	25.5	1	0	0	0.5

Table A1-7 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Nephtheidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	27.5	3.5	0	0	1
			5	37.5	3	0	0	0
		Hook Is	2	104.5	7	0	1.5	0
			5	154	3	0	0	0
		Daydream Is	2	61.5	1	0	0	0
			5	41	0	0	0	0
		Shute Is and Tancred Is	2	117.5	0.5	0	1.5	0.5
			5	99	0	0	1.5	0.5
		Pine Is	2	10	3	0	0	0
			5	14.5	2	0	0	0
Fitzroy	Fitzroy	Middle Is	2	0	0	0	0	0
			5	4	0	0	0	0
		Barren Is	2	1.5	0	0	0	1039
			5	0	0	0	0	220
		Humpy Is and Halfway Is	2	5.5	0	0	0.5	278
			5	2	0	0	0	3
		Pelican Is	2	24.5	0	0	14	28.5
			5	35.5	0	0	20	23.5
		Peak Is	2	40.5	0	0	7	8.5
			5	40	0	0	16	23

Table AI-8 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

Table AI-9 Percent cover of Silt for reefs in the Mackay Whitsunday region. Values are the average cover from 5m transects in each year.

Reef	2005	2006	2007	2008	2009	2010
Daydream Is	12.1	8.8	12.8	20.6	23.3	26.3
Dent Is	6.1	11.0	6.3		8.3	
Double Cone Is	0.8	1.1	0.6	2.1	6.1	5.0
Hook Is	9.8	8.6		9.5		16.7
Pine Is	10.9	11.3	4.6	7.3	31.9	18.1
Seaforth Is	24.0	37.8	30.8		42.3	
Humpy and Halfway Islands	25.4	14.8		42.3		44.8
Shute Is & Tancred Is	12.1	8.8	12.8	20.6	23.3	26.3

Appendix 2: QAQC Information

Validation of benthic community assessments

Photo point intercept transects. The QA/QC for the estimation of percent cover of benthic communities has two components. The sampling strategy that 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. Three observers collected juvenile coral count data in 2010. 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 has 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%. To verify that we met that standard, one experienced observer undertook the counts in 2009/10. 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 28 tiles selected at random from 7 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 52 missed spat compared to 1862 recorded, an error rate of 2.8%. This is well within the stated QA/QC goal of 10%.

Appendix 3: List of Scientific Publications arising from the Programme 2010

Uthicke S, Thompson A, Schaffelke B (2010) Effectiveness of benthic foraminiferal and coral assemblages as water quality indicators on inshore reefs of the Great Barrier Reef, Australia. Coral Reefs. 29:209-225

Thompson A, Dolman A (2010) Coral Bleaching: one disturbance too many for near-shore reefs of the Great Barrier Reef. Coral Reefs.

Reef Rescue Marine Monitoring Program 2009/10 Milestone Report. Project 3.7.8 Milestone 01 April 2010, 5 p.

Reef Rescue Marine Monitoring Program 2009/10 Milestone Report. Project 3.7.1b Milestone 01 April 2010, 4 p.

Reef & Rainforest Research Centre Ltd (2010) Reef Rescue Marine Monitoring Program: Quality Assurance/Quality Control Methods and Procedures. Manual. Report prepared for the Great Barrier Reef Marine Park Authority. Reef & Rainforest Research Centre Ltd, Cairns

Schaffelke B (2010) Reef Rescue Marine Monitoring Program. Methods and Quality Assurance/Quality Control Procedures. Appendix A: Detailed AIMS Manuals and Standard Operational Procedures. Report to Reef & Rainforest Research Centre. Australian Institute of Marine Science, Townsville.177 pp.

Thompson A, Schaffelke B, De'ath G, Cripps E, Sweatman H (2010)a Water Quality and Ecosystem Monitoring Programme-Reef Water Quality Protection Plan. Synthesis and spatial analysis of inshore monitoring data 2005-08. Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville

Thompson A, Davidson J, Schaffelke B, Sweatman H (2010)b Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities – Inshore coral reef monitoring 2009/10. Report for Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville.